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The analysis of trash bin design preferences and the effect of setting condition on waste collection performance and waste segregation behaviors

Doctor Dissertation

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Transdisciplinary Graduate School of Science and Engineering

Tokyo Institute of Technology

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1. Introduction

1.1 Solid waste management situation

1.1.1 Worldwide issue

In 2050, municipal solid waste (MSW) generation will increase up to 3 times according to World Bank's prediction (Kaza et al., 2018). The effective waste management is become the solution to handle with the increasing of MSW. Organic waste is the majority of MSW, it is about 56% of a total MSW. Waste collection is the initial waste management process and the major operational solid waste management cost. The collection rate in high-income countries are near 100%. However, the collection rate is decreasing due to the lower income. Low-income countries are able to collect of MSW about 39%. 23% of worldwide waste generation is generated by East Asia and Pacific region (including Thailand and Japan), it is the highest waste generation region. This study focused the improvement of MSW management in Thailand and Japan. The detail of solid waste management situation in these countries will be explained in following section.

1.1.2 Japan issue

In Japan, main strategy of municipal solid waste (MSW) management is promoting 3R (reduce, reuse, and recycle) (Ministry of the Environment, Japan, 2016). Japan is categorized as a high-income country in East Asia and Pacific region. The waste collection rate close to 100%. MSW generation per capita in one day in Japan decreased from 1.089 kg/person/day in 2004 to 0.942 kg/person/day in 2016. Recycling rate increased from 5.3% in 1990 to 20% in 2016. 70.8 weight percent (wt%) of MSW is combustible wastes (Chifari et al., 2017) and packaging wastes (food packaging and other plastic containers) is the highest volume-based percentage of MSW (60 volume percent (v/v%) and 20 wt%). Under the Containers and Packaging Recycling Act, consumers are responsible for separating these packaging wastes from the other solid wastes and dispose of these materials to designated collection containers such as appropriate trash bins and collection site (The Japan Container and Recycling Association, 2020). The number of waste separation categories in Japan is up to 25 (Matsumoto, 2011). Waste separation at sources is effective for waste recycles. Recycling is sometimes made cheaper when limited capacity of landfills is available (Kaza et al., 2018). However, the quality of waste separation is still not sufficient. Sometimes, the other wastes are mixed and further separation process is necessary for waste recycles. The improvement of waste separation in Japan could make an effective waste management.

1.1.3 Thailand issue

Municipal solid waste (MSW) generation all over the world is predicted to increase up three times by 2050 (Kaza et al., 2018). Thailand is categorized as an upper middle-income country in East Asia and Pacific region. Waste generation rate in Thailand is 1.15 kg/person/day (Ministry of Natural Resources and Environment, Thailand, 2019), which is greater than the global average of waste generation rate (0.74 kg/person/day) and that in East Asia and Pacific region (0.56 kg/person/day) (Kaza et al., 2018). In Thailand, recycling rate of MSW is still 9%, which is lower than the global average rate (13.5%) (Kaza et al., 2018). Low recycling rate strongly related to poor waste sorting. Waste sorting is correlated with the economic situation of countries, in which sorting rate is usually higher in higher income countries (Minelgaitė and Liobikienė, 2019). Not only waste sorting but also waste treatment and disposal in Thailand are still not good enough. Pollution Control Department (PCD) of Thailand reported that 27% of collected MSW was improperly dumped or treated by open burning (Ministry of Natural Resources and Environment, Thailand, 2019). High waste generation rate with low separation efficiency in Thailand should be improved for better waste management.

1.2 Trash bin

In general, waste collection and first waste sorting are done using trash bins. The most of recyclers first became aware of recycling schemes through seeing trash bins (McDonald and Ball, 1998). If waste segregation can be improved by trash bins with better design and/or appropriate setting, it is promising because high performance of waste separation at source can reduce cost and time consumption in recycling processes (Gundupalli et al., 2017) and increase the quality of waste composting (Matter et al., 2013). In addition, source separation also increase the efficiencies and reduce the emissions of other processes in waste management such as incineration, digestion, and landfilling (Havukainen et al., 2017; Liamsanguan and Gheewala, 2008). Furthermore, waste recycling also reduce cost of resource material (Bohm et al., 2010). Trash bins or trash containers are commonly used tools for waste collection. Although trash bins seem to be important and/or effective for in-situ waste separation, the impacts of trash bins on waste collection and waste separation have been still uncertain. Researches on trash bins are very limited in contrast to their importance in waste collection and separation. Some researches investigated trash bins in term of the number, design, and setting location of bins. Easy access to trash bins can improve sorting efficiency of compostable and recyclable wastes in high-density residential buildings (DiGiacomo et al., 2018) as well as waste segregation performance in academic buildings (Ludwig et al., 1998). O'Connor et al also reported that the location of trash bin impacted waste separation efficiency (O'Connor et al., 2010). When trash bins for various waste types (more than one type of bin) were commingled, it increased waste separation efficiency by about 180% compared with a single trash bin case (Andrews et al., 2013). On the other hand, increasing number of trash bins for the same waste type might not encourage consumers to separate wastes (O'Connor et al., 2010). Trash bin design is also influential to encourage waste separation. For example, insert slot of trash bins specifically designed for recyclable wastes increased separation performance (Duffy and Verges, 2009) and inhibited recycling contamination (Jiang et al., 2019). In contrast, new design of trash might encourage consumers to separate wastes in some cases (O'Connor et al., 2010). The visual prompts like signage on trash bins can also improve separation efficiency (Miller et al., 2016). Physical design of trash bins is also related to waste disposal behavior. The design of waste disposal signage influenced to judge waste classification, icons/picture improved waste sorting performance (Wu et al., 2018). Moreover, the visual prompts (additional sign over trash bin such as “PET Bottles Here!!”) is effective on waste separation efficiency (Miller et al., 2016). When visual prompts were designed appropriately, it increased separation rate compared with simple signs (Hussong-Christian, 2016). The messages in visual prompts also gave the effect on waste separation. Weak or provocative arguments made people change their waste separation behavior permanently (Werner et al., 2009). The waste disposal slot design also increases waste separation efficiency (Duffy and Verges, 2009). An inappropriate color and/or shape of trash bin caused lack of willingness to participate and low recycling rate (Tonglet et al., 2004). The appropriate bin should be designed with the public participation. The public participation has strong correlation with the waste classification accuracy (Li et al., 2019). When the distance between house and waste collection place increased, it contributed to lower waste generation (Erfani et al., 2017). The distance from walking path to trash bins gave significantly impact on waste collection rate. Our previous research suggested that the increase of distance between trash bins and walking path decreased waste collection rate (Leeabai et al., 2019). In addition, the distance also gave the impact to increase waste separation about 40% when trash bins were placed near consumers (Struk, 2017). The set of trash bin preference was investigated focusing on different types of waste bins (packages, plastic, aluminum, glass, glass bottles, and papers) and designs (color, shape, slot position, and setting style). The most preferred multi-bins were colorful rectangular bins with front position including packages, plastic, and paper bins (Keramitsoglou and Tsagarakis, 2018). The arrangement of trash bins might also be related to waste disposal behavior. In previous works of the authors' group (Jiang et al. 2017), psychological preferences of trash bin arrangement were scaled by web questionnaires using pairwise comparison method with Thurstone's law of comparative judgement (Thurstone, 1927). The survey suggests that people prefer to separate general waste trash bins (combustible wastes/incombustible wastes) and recyclable waste trash bins (PET bottles/cans). When combustible waste trash bin was set on the left side, it had higher preference score than others. Furthermore, a pair of general waste trash bins in the middle had lower preference score than those set on the left side. When trash bins of combustible waste and incombustible were separated by the other bin, preference score was usually lower.

1.3 Waste segregation behaviors

Human behavior is strongly dependent on many influential aspects. Human behaviors could be changed by dependent factors such as social demographics, attitudes, subject norms, education, perception, and perceived behavioral control. In general, the theory of planned behavior model was used to interpret human behavior (Ajzen, 1991) as shown in Figure 1-1. Waste segregation behavior is also one of human behavior. The models based different gender were developed to support specific recycling behavior for both male and female (Oztekin et al., 2017). Waste segregation behavior could be changed by its influential factors. Related people like friends and/or parents give the impact on waste separation behavior (Zhang et al., 2017). If related people do waste segregation, the person might follow them to separate of his/her wastes. This neighborhood effects may cause behavioral contagion (Crociata et al., 2016). The visual prompts affected waste littering in social space (Liu and Sibley, 2004). Inconvenience situation is also influential factors for people to reject waste separation. According to questionnaire-based study, five minutes walking made people reject to carry waste for disposal (González-Torre and Adenso-Díaz, 2005). The most inconvenience factor is the understanding in waste classification (Lee et al., 2017). In addition, Saito found that color preferences give impacts on human behaviors (Saito, 2015). Law and regulations are also external factors that increase recycling rate (Iyer and Kashyap, 2007). The acceptance of legal norms is the most general reason for recycling in some areas (Miafodzyeva and Brandt, 2013), but they appear less influential in the others (Hage et al., 2009). The influential factors are different in various region (Stoeva and Alriksson, 2017). It could be noted that the best option for solid waste management must be investigated in the target area.

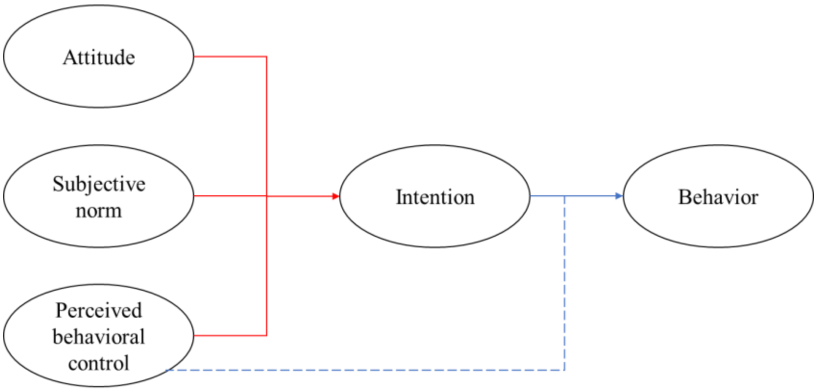


Figure 1-1 The model of the Theory of Planned Behavior (Ajzen, 1991)

Trash bin is also strongly related with waste segregation behavior, it is one of the influential factors to the behavior. The terrible or environmentally offensive colored bin was given one of the main reasons for non-participation in waste separation (McDonald and Oates, 2003). Adding number of another type of waste to separate is not the barrier to reject waste separation (Byrne and O'Regan, 2014).

1.4 Analysis tools

1.4.1 Psychological preference

Psychological preference is the choice that people choosing by their decision (Kahneman and Tversky, 1982). There are no right or wrong preferences, it just what the person prefer. The survey questionnaires are used to evaluate respondent's preference. In general, there are many ways to design the questionnaires to get the data. Sometimes, it is very hard to decide the preferred choice with too many choices in the questionnaires sheet. It is easier to select the object that you prefer with two choices (A or B). In this study, pairwise comparison tests were used to be analysis tool to justify preference score. The preference scores were scaled by field or web questionnaires using pairwise comparison method with Thurstone's law of comparative judgement (Thurstone, 1927) or Scheffé's method (Scheffé, 1952) with Nakaya's variation (Nakaya, 1970).

1.4.2 Monitoring measurement

In case of on-site experiments, trash bins were set based on psychological preferences or designed conditions. The monitoring measurements were collecting data from trash bins. The data were recorded wight and/or number each waste type in the bin. Recorded data is used to calculate capture rate, contamination rate, and effective capture rate. These results are shown waste collection performance and segregation efficiencies.

1.4.3 Statistical analysis

The statistical tests are the analysis tools to distinguish the different of monitoring results. The different of monitoring results indicate the effects of experimental conditions and error terms. The statistical tests include Shapiro-Wilk test, Welch's t-test, one-way or multi-ways ANOVA, and Mann-Whitney U test. Shapiro-Wilk test is used to check Gaussian normality of all dataset. When all data followed the normality, Welch's t-test or ANOVA were used to identify the different of results. On the other hand, when the data did not follow the normality, Mann-Whitney U test was used.

1.5 Research objectives

1.5.1 Improvement of trash bin collection performance

As mentioned before about the setting condition of trash bin give the impact on waste separation efficiency. Convenient setting location of trash bins can improve sorting performance in high-density residential buildings (DiGiacomo et al., 2018) and academic buildings (Ludwig et al., 1998; O'Connor et al., 2010). It means long distance to trash bin influence people reject waste separation (González-Torre and Adenso-Díaz, 2005). On the other hand, the increase of distance between trash bin and consumer can decrease waste collection rate of trash bin (Erfani et al., 2017). Scaling distance is important for disposing. In other word, nearer trash bins are easily to disposed, meanwhile a lot of garbage will also be thrown. At the same time, the cost of waste collection trip also increased due to higher waste collection rate. So, choosing appropriate distance should be concerned to induce an effective separation. The various distance between consumer and trash bin were tested to find out the appropriate distance to trash bin. In addition, inconvenient setting condition by separated setting of trash bins might decrease waste separation willingness. Thus, the separated setting of trash bins was tested to compare the results with background setting condition.

In previous works of the authors' group (Jiang et al. 2017), psychological preferences of trash bin arrangement deepened on the type of position. The arrangements were significantly different in term of preference scores. When trash bins were set with high arrangement preference, it might encourage people to do waste separation.

The authors also focused on color of trash bins because the color can be an inducing factor to a behavior. The color can facilitate object recognition (Clarke and Ludington, 2018), and the color also give an effect on the noticeability (Kruijff et al., 2018). Moreover, the color perception gives an impact on human psychological functions such as the memory and decision performance (Elliot and Maier, 2014). The color can be associated with the types of waste, so the appropriate color might improve waste sorting efficiency. The color inference in visual communication was used to find out the meaning of colors in a recycling behavior (Schloss et al., 2018). The terrible or environmentally offensive colored bin was also given one of the main reasons for non-participation in recycling program (McDonald and Oates, 2003). On the other hand, bright yellow bin covers can improve the capture rate of food waste (Lin et al., 2016). In addition, the color preference is significant factor for recycling bin selection (Kalatzi et al., 2015). The survey questionnaires were used to find out the candidate colors for on-site experiments.

The effects of distance to trash bin, trash bin arrangement, trash bin color on waste collection rate, capture rate, contamination rate, and the effective capture rate were investigated.

1.5.2 Design of trash bin on psychological preference

The majority of people is continuously changing from younger people (less than 40 years old in 1950) to be elder people (over 60 years old in 2100). That means a lot of design will focus on the users mostly older than 60 years old in the future. Total number of Japanese people is declining since 2010. Meanwhile, the population ratio of elderly people has been increased. The old-age population (65 years old or above) of Japan has been vastly increased from 5.1% of the total population in 1945 to 26.0% in 2013 (Kobayashi, 2015). Thus, new designs focused on average physical ability of the elder people are become considered. Universal Design could be one of solution to tackle people's physical difficulties (Keates et al., 2000). The seven principles of universal design are including equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical efforts, and size/space for approach and use. Eyes problem is become the main problem for older people, older people usually face with low vision problem. Low vision caused lower quality of life (Wolffsohn and Cochrane, 2000). To make the universal design of trash bins, eyes diseases are considered as one indicator. The increase of age is related to visual acuity (VA), diabetic retinopathy (DR), and macular degeneration (MD) (Clemons et al., 2003; Ryan and MARGRAIN, 2008). Even retinitis pigmentosa RP is not a directly age-related disease, but the onset rate of RP is dramatically increased by age (Tsujikawa et al., 2008). This study is focusing on design trash bins to support VA, DR, MD, and RP

The trash bin designs in this study are including PET bottle bin with 2-dimensional shapes (2D) and combustible waste bin with 3-dimensional shapes (3D). The designed bins are including various designing parameters. The designing parameters are shape of bin, slot position, labeling signage, and visibility. In each experiment, trash bins were designed with 3 different designing parameters. In addition, focusing eyes diseases are treated with various treatment degree in PET bottle bin experiment to find out the appropriate universal design to support people in the future.

1.5.3 Perceptive classification on waste mixtures

Although people have a good attitude towards waste separation, the separation of waste might be incorrect if they do not understand what kind of their garbage. Therefore, the understanding of waste classification is still be inconvenience factor for waste segregation (Lee et al., 2017). The monitoring results in previous research showed combustible waste trash bin contain high amount of incorrectly disposed. For the reason, this study investigates on combustible waste understanding in Japan. If we could find groups of respondents which misunderstand in waste classification, the guidance of waste classification should be provided for them. It will be useful for waste management policies to encourage to target waste consumers who are misunderstanding in waste classification. Because law and regulations are influential external factors to increase recycling behavior (Iyer and Kashyap, 2007) and influence moral norm (Hage et al., 2009).

1.6 Thesis structure

Chapter 1: *Introduction*

This Chapter is the summarized the literature reviews about the effects of trash bins on waste segregation behaviors. This research proposes the improvement of waste collection performance and segregation behaviors with trash bins. This study not only focused on the improvement of waste management in developed country like Japan but also developing country like Thailand. In different regions, the specific results of the study will be useful to develop waste management. The analysis methods included survey and on-site experiments. Firstly, survey questionnaires data were collected to evaluate the psychological preference. The psychological preferences were evaluated by pairwise comparison. The results of survey questionnaires were used to provide the preferred designed object. High preference score means the designed object is high preferred for the respondents. Secondly, collected wastes in trash bins were calculated to identify waste collection, capture rate, contamination rate, and effective capture rate. The results were analyzed by statistical tests to distinguish real waste separation effects and experimental errors. The comparison between survey results and on-site experiment results show the effects of preference scores on real separation efficiencies.

Chapter 2: *The effect of trash bin setting conditions*

In Chapter 2, the distance to trash bins along walking path gave no significant effects on waste collection and separation performances. On the other hand, the increase of distance out of walking path significantly decreased waste collection. The increase of 4 m and 8 m distance decreased total amount of waste collection about 10.9% and 30%, respectively. In contrast, the distance gave no significant effect on separation efficiencies. Threshold distance that can affect waste disposal behaviors might exist between 8 and 410 m. Separated setting of combustible waste and PET bottle trash bins in the opposite side of the original position (3 m distance) significantly decreased capture rates of these wastes while contamination rates of trash bins in the original position were significantly increased. The results suggested that appropriate distance to trash bin can reduce cost on waste transportations and multi-process of waste disposal should be avoided.

Chapter 3: *The effect of trash bin arrangements*

In Chapter 3, the preference of trash bin arrangement gave no significant effect on waste collection and the others excluding capture rate of can. It might be interpreted focusing not on arrangement preference but on setting positions of trash bins. Cans were correctly disposed to can trash bin when can trash bin was set in the middle position. On the other hand, some of cans were incorrectly disposed to glass bottle trash bin in the middle position when can trash bin was moved to the left position. It is the same with glass bottle. When glass bottle trash bin was set in the middle position, capture rate of glass bottles was higher than that in the right position although the differences were not regarded as significant. Persons might prefer to drop recyclable wastes (cans and glass bottles) to a trash in the middle position rather than in the left/right position.

Chapter 4: *The effect of trash bin colors*

In Chapter 4, it was found that yellow bin is the most commonly preferred bin. The lowest preferred color combination performed the highest waste separation efficiencies. However, color combination preference gave no impact on waste collection. The effective capture rate linearly decreased with increase of total waste collection. The contamination rate increased with increase of proportional of the other wastes. The effective capture rate had significant correlations with the noticeability for all types of wastes. Trash bins with less noticeable color combinations would require larger attention to be found. It might contribute to waste separation encouragement. It could be noted that too low noticeability of trash bin might make people could not find the bins. It suggests that trash bins should be set with appropriate noticeability to motivate people separate of their waste. In addition, behavioral mechanism of participants was found. PET bottle is the easiest waste for correct disposal while PET bottle bin is the most easily contaminated.

Chapter 5: *The design analysis of trash bin*

In Chapter 5, two types of bins were investigated including PET bottle bin with 2-dimensional shapes (2D) and combustible waste bin with 3-dimensional shapes (3D). The preferences of PET bottle bin designs were checked with various degree of visual diseases including Visual Acuity (VA), Diabetic Retinopathy (DR), Macular Degeneration (MD), and Retinitis Pigmentosa (RP). The results showed that the illustrated label designs were more preferred than letter label designs. In the addition, all treatments increased the preference of illustrated label design. The preference scores of slot position and shape were depended on type and degree of visual diseases. In case of combustible waste bin design, the results showed respondents prefer slope slot, top slot, and front slot, respectively and they also prefer visibility trash bin rather than invisibility one. In addition, respondents do not prefer trash bin with lid attached. Appropriate trash bin design will be helpful to support elderly society in the near future. These results can be used for trash bin design guidance.

Chapter 6: *The perceptive classification of waste mixtures*

In Chapter 6, the perceptive of waste classification was also checked. According to the previous monitoring results, it was found that some waste types easily contaminated in the inappropriate bin. This study focuses on perceptive classification of combustible and incombustible waste. The result showed respondents are quite good understanding in waste classification with arranged score from higher to lower combustible waste composition. Food wastes gave the impact on the perception of respondents as combustible waste. In addition, plastic wastes are more perceptive as combustible waste than the other incombustible wastes. Female is more understanding in classification of commingled wastes than male. Younger people can classify combustible wastes from plastic wastes clearer than older people. It will be useful for waste management policies to encourage to target waste consumers who are misunderstanding in waste classification.

Chapter 7: *Overall conclusion and recommendations*

In Chapter 7, the conclusions in all chapters were summarized with the recommendations. The results showed that the distance to trash bin can decrease waste collection rate and the separated trash bins setting decreased waste separation performance. The appropriate distance to trash bins can determine amount of waste collection for planned waste shifting systems. Setting of trash bin at one side is recommended. In addition, recyclable bins are recommended to place in the middle position of the arrangement. The colors of trash bins affect separation performance with their noticeability in the setting location. Trash bin should be set with the appropriate noticeability to make the effective waste separation. According to the effects of color and noticeability of trash bin, the designs of trash bin are related to the segregation behavior of consumers. Trash bins should be designed to support the target consumers. Illustrated label is recommend for trash bin design. Bottles or cylinder shape are very useful designed shapes for PET bottle bin. Slope slot position, visibility, and avoided lid attachment are recommended for combustible waste bin. The perceptive classification of wastes should be one of the considered factors to develop waste segregation behaviors. The guidance for easily misunderstanding wastes should be provided to the citizen. The education of waste sorting guidance should serve to older people. It could be noted that on-site experiment participants in the studies, demographic properties are very biased because they are mainly students. Biased demographic properties might give non-negligible impact on the results. Our experimental results risky generalized something according to the results.

1.7 Publication

1.7.1 The effects of setting conditions of trash bins on waste collection performance and waste separation behaviors; distance from walking path, separated setting, and arrangements

(Published in Waste management, WM-18-3174, edition 94 (2019) page 58-67)

Abstract

This study investigated the effects of setting conditions of trash bins on waste collection, separation efficiency, and incorrect disposal. Tested trash bins are for combustible wastes, PET bottles, cans, and glass bottles. Monitoring results were analyzed by statistical tests to distinguish real effects and experimental errors. The distance to trash bins along walking path gave no significant effects on waste collection and the others. On the other hand, when the distance was out of walking path, its increase significantly decreased waste collection of combustible wastes. In contrast, the distance gave no significant effect on separation efficiency and foreign waste percentage. It was suggested that threshold distance that affects waste disposal behaviors is between 8 and 410 m. When trash bins were set separately, it affected the motivation of waste separations. Separated setting of combustible waste and PET bottle trash bins in the opposite side of the original position significantly decreased separation efficiencies of these wastes. Because no significant effect was found on separation efficiency of other wastes whose trash bins were set in the original position, additional 3 m distance to the opposite side might exceed the threshold distance and have caused low separation efficiencies. The preference of trash bin arrangement gave no significant effect on waste collection and the others excluding separation efficiency of can. These results suggest that appropriate location of trash bins can improve waste collection and waste separation. It might be useful for waste management in public areas with high population density like shopping mall.

Keywords: trash bin, setting condition, waste collection, separation efficiency, incorrect disposal

1.7.2 The effects of color preference and noticeability of trash bins on waste collection performance and waste sorting behaviors

(Submitted to Waste management journal)

Abstract

This study investigated design effect of trash bins on waste collection, capture rate, contamination rate, and effective capture rate in Thailand, in particular focusing on color preference and perceptive easiness of finding a trash bin (noticeability). Trash bins to separately collect compostable waste, recyclable waste, and PET bottle were tested. Perceptive preferences of three primary colors (red, blue, and yellow), four blended primary colors, and three achromatic colors were evaluated by survey questionnaires with sample size of 889 respondents. It was found that yellow bin was the most commonly preferred regardless of waste type. The results of waste collection experiments in three locations for 15 weeks were analyzed by statistical methods. It suggested that trash bins with the lowest preferred colors performed the highest waste separation efficiencies. On the other hand, color preference gave no significant impact on waste collection. PET bottles were the easiest waste for correct disposal compared with other wastes while PET bottle bin was more easily contaminated than the other trash bins. The effective capture rate had a significantly negative correlation with noticeability. Large necessary attention to find less noticeable trash bins might have helped participants recognize correct waste disposal. It is concluded that location, body color, and noticeability of trash bins can affect waste collection and separation performances. In particular, affections to human recognition through appropriate design and setting of trash bins might enable efficient collection of more segregated wastes.

Keywords: waste sorting, trash bin, color preference, noticeability, pairwise comparison

2. The effect of trash bin setting condition

2.1 Background

As mentioned in Chapter 1, trash bin was investigated in term of setting conditions. In this study, the experiments were conducted at Fukuoka University, Japan. Waste separation categories in Japan is up to 25 types of wastes (Matsumoto, 2011). However, the quality of waste separation is still not sufficient. Further separation process is necessary for waste recycles. Waste separation at source can improve the efficiency of recycling process (Gundupalli et al., 2017). The appropriate location of trash bins at convenient site for consumers increased separation efficiency (Ludwig et al., 1998). According to questionnaire-based study, five minutes walking made people reject to carry waste for disposal (González-Torre and Adenso-Díaz, 2005). When the distance between house and waste collection place increased, it contributed to lower waste generation (Erfani et al., 2017). In addition, the distance also gave the impact to increase waste separation about 40% when trash bins were placed near consumers (Struk, 2017).

In this Chapter, the authors investigated the effects of setting conditions of trash bins on waste collection, capture rate, and incorrect disposal to wrong trash bins. Setting conditions include the distance to trash bins along or out of walking path and separated setting. The results of this study might be useful for waste management to find out the appropriate setting conditions in the public areas.

2.2 Methodology

2.2.1 On-site experiments

The tested setting conditions of trash bins in this study are the various distance to trash bins along walking path, the various distance out of walking path, and separated setting of trash bins with 3 m distance. On-site experiments were conducted in two buildings at Fukuoka

University, Japan from 2015 to 2017. The target persons of this experimental campaign included students, staffs, and visitors in the buildings. The numbers of total students and staffs in Fukuoka University were 22,318 persons with 63% male and 37% female. The tested trash bins in this study are for combustible wastes, PET bottles, cans, and glass bottles. Wastes collected by trash bins were monitored and recorded every day in the weekdays. Five days data were summarized as weekly monitoring data and used for statistical analysis. The monitored data were the weight of collected wastes (combustible wastes, PET bottles, cans, and glass bottles). The number of collected wastes were also recorded except for combustible wastes. Therefore, weight- and number-based waste collection data were finally created. Daily waste generation rates (g/person/day) were significantly different during weekdays, but the seasons and university's activities hardly affect waste generation in significance (Edjabou et al., 2015). For the reason, weekly data were used in this experiment to avoid the effect of weekdays.

In this study, the capture rate of certain waste was defined as the weight percentage of the waste correctly disposed to the target trash bin in the total waste collected by all trash bins, as shown in Eq. (1). Therefore, the capture rate indicates the ratio of correct disposal of target waste to appropriate bin.

$$\textit{Capture rate} = \frac{\textit{The weight}\ \text{of correctly}\ \textit{disposed waste in the trash bin}}{\textit{The weight of waste collected in all trash bins}} \times 100\% \tag{1}$$

The weight percentage of foreign wastes contamination was also analyzed in this study, as shown in Eq. (2). It is the percentage of incorrectly disposed wastes in the total wastes collected by a target trash bin. The contamination rate indicates how much wastes was segregated correctly focusing on a target trash bin, not waste itself. The purposes of experimental campaign are summarized in Table 2-1.

$$Contamination\ rate = \frac{The\ weight\ of\ incorrectly\ disposed\ waste\ in\ the\ trash\ bin}{The\ weight\ of\ total\ waste\ collected\ in\ the\ trash\ bin} \times 100\% \qquad (2)$$

2.2.2 Effect of the distance to trash bins along walking path

The experiments were conducted at 4th floor of Building A in Fukuoka University, Japan from October to December in 2015. It examined the impact of trash bins located along walking path with different distance. The setting condition of trash bins are illustrated in Figure 2-1. After the persons entered 4th floor of the building by escalator, they walked along the corridor to classroom entrance or stair. The trash bins were set along this walking path. Under condition 1A, trash bins were placed in the right side of walking persons near the escalator. Under condition 2A, trash bins were replaced 8 m far from the original position. Both condition 1A and 2A were repeated 4 times in an alternate manner for a week per time.

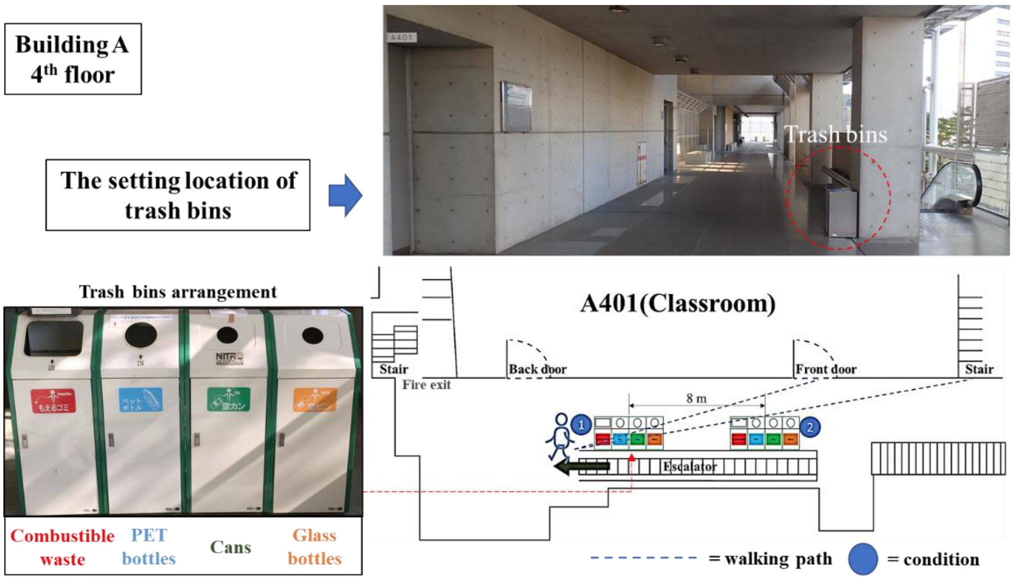


Figure 2-1 Trash bins placement conditions at 4th floor of Building A

Table 2-1 Summary of the experiment conditions

Condition	Purpose	Detail	Location	Period
1A	The impact of trash bins location along walking path	Trash bins were placed on right hand side of the people who arrive 4th floor by escalator.	Building A	2 months (autumn to winter, 2015)
2A	(see figure 2-1)	Trash bins were replaced 8 m far from original position.		
1B	The impact of trash bins location out of	Trash bins was placed nearby consumers. (original position)	Building B	2 months (autumn to winter, 2015), 5 months (summer to autumn 2016).
2B	walking path.	4 m far from original position.		5 months (summer to autumn 2016).
3B	(see figure 2-2)	8 m far from original position.		2 months (autumn to winter, 2015), 5 months (summer to autumn 2016).
1C	The impact of separated trash bins	From left to right, combustible, PET, can, and glass on one side. (original)	Building B	6 months (summer to autumn, 2017)
2C	(D: 3 m) (see figure 2-2 and	Cans and glass on one side. Combustible and PET on the other side.		
3C	2-3)	Combustible, cans, glass on one side. PET on the other side.		

2.2.3 Effect of the distance to trash bins out of walking path

The experiments were conducted at 2nd and 3rd floor of Building B. There are two experimental periods. The 1st experimental campaign was conducted from October to December in 2015. The 2nd experiment was conducted from June to December in 2016. It examined the impact of trash bins located out of walking path with different distance. Setting condition of trash bins are illustrated in Figure 2-2. In this experiment, trash bins were set in the original position near stair (condition 1B). They were replaced 4 m or 8 m far from the original position under condition 2B and 3B, respectively. Under condition 2B and 3B, persons had to walk away from the walking path to dispose of their wastes. In 2015, two-week experiments under condition 1B and 3B were conducted. After that, one-week experiments under both conditions were repeated 2 times in an alternate manner. In 2016, one-week experiments under condition 1B, 2B, and 3B were repeated 5 times in an alternate manner.

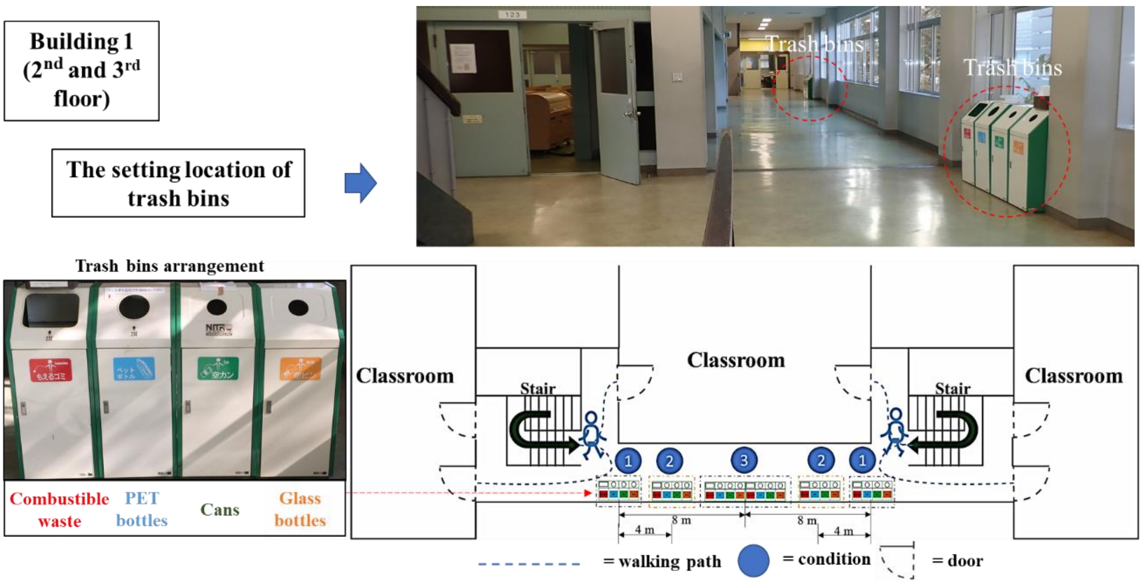


Figure 2-2 Trash bins placement conditions at 2nd and 3rd floor of Building B

2.2.4 Effect of separated setting of trash bins

Experiments were conducted at 2nd and 3rd floor of Building B from May to December in 2017. It examined the effect of separated setting of trash bins. Three types of trash bin setting condition were tested. It is illustrated in Fig. 2-3. Condition 1C is the control condition. All trash bins were set together in the original position. Under condition 2C, trash bins of combustible wastes and PET bottles were set separately in the opposite side from the original position. There is 3 m distance between both sides. Therefore, if persons wanted to dispose of PET bottles and glass bottle, they needed to walk 3 m from one side to the other for correct disposal. Under condition 3C, only PET bottle trash bin was set separately in the opposite side. The other trash bins were located in the original position. one-week experiments under condition 1C, 2C, and 3C were repeated 4 times in an alternate manner.

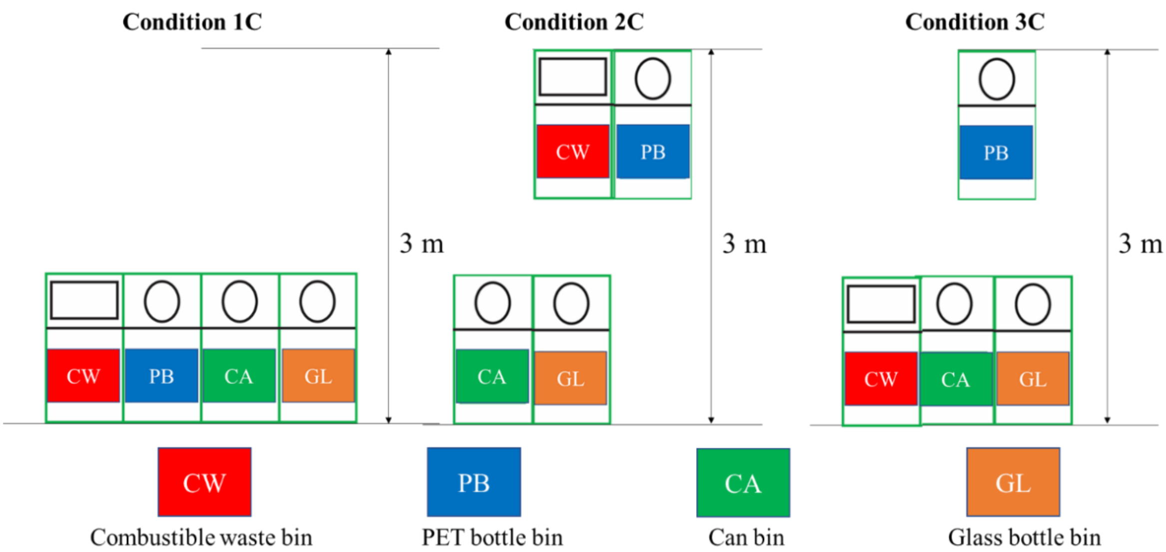


Figure 2-3 Detail of trash bins condition 1C 2C and 3C at 2nd and 3rd floor of Building B

2.2.5 Statistical tests to identify effects of trash bin setting conditions

Gaussian normality of all dataset (waste collection, separation efficiency, and contamination rate) was checked using Shapiro-Wilk test to select parametric and non-parametric test. Significance level was 5%. The results of normality test were summarized in

Table S2-1. When all data followed the normality, Welch's t-test or one-way ANOVA with significance level of 5% was used to identify significant differences between experimental conditions. When some of data did not follow the normality, Mann-Whitney U test was used. Significance level (5%) was treated by Bonferroni correction when necessary. When statistical test suggested rejection of null hypothesis which assumes no difference among dataset, the difference would be always described "significant" or "significantly" in following sections.

2.3 Results and discussions

2.3.1 The impact of trash bin location along walking path (Condition A)

The impact of the 8 m distance along walking path on waste collection, capture rate, and contamination rate were evaluated by the comparison between control condition (1A) and the other (2A). The monitoring results are shown in Figure 2-4. The waste collections based on the weight under both conditions were not significantly different (see Fig. 2A). Waste collection based on the number also shows insignificant differences (see Fig. 2B). The increase of the distance along walking path also did not affect the capture rate (see Fig. 2C). In addition, it also gave no significant impact on the contamination rate for each trash bin (see Fig. 2D). The capture rate of cans and glass bottles were apparently increased and decreased by 8 m increase of the distance, respectively. The contamination rates of cans trash bin and glass bottles trash bin also show large differences between the two conditions (see Fig. 2C and 2D). However, the statistical test results suggest that capture rates and the contamination rates were not significantly different. Although low collection rates of cans and glass bottles should be considered, it is concluded that 8 m distance along walking path gave no significant impact on waste collections and capture rates of any wastes. It also did not significantly change the contamination rate of any types of trash bins. The results showed the same trend with other studies that distance of trash bins from the consumers gave no effect on both waste collection and capture rate (O'Connor et al., 2010). In addition, 8 m distance is in the range of appropriate distance for recycling behavior (Heathcote et al., 2010) that 80% respondents admitted to walk with their wastes.

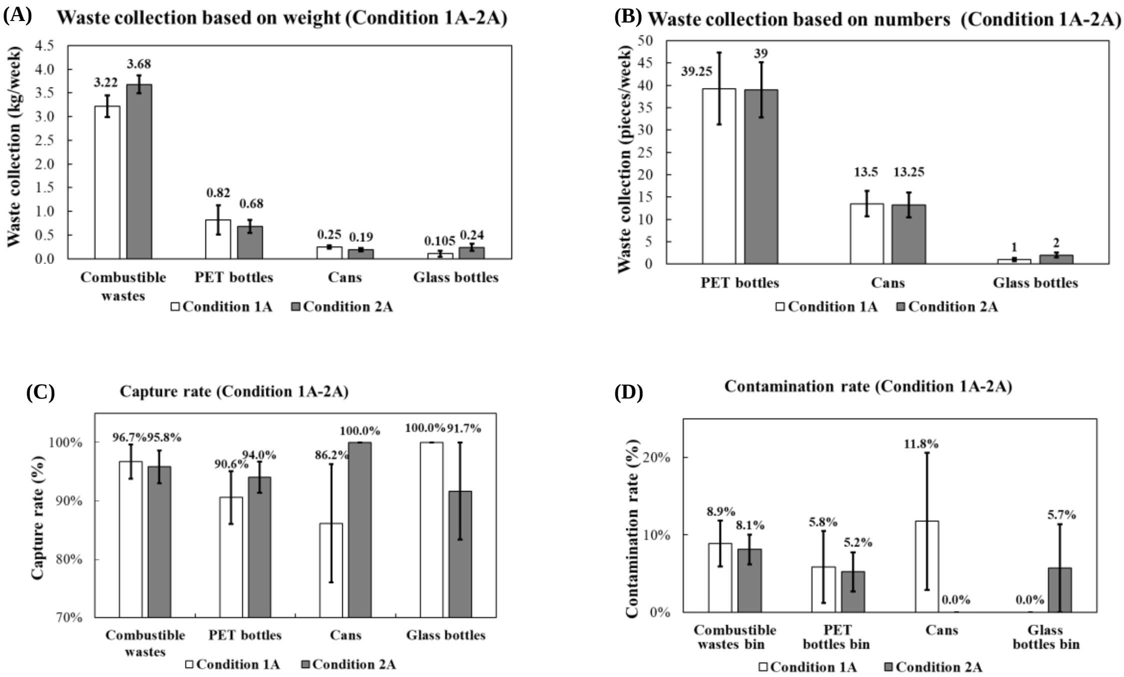


Figure 2-4 The results of trash bins location along walking path (Condition 1A-2A)

2.3.2 The impact of trash bins location out of walking path (Condition B)

The monitoring results of trash bin location out of walking path are shown in Figure 2-5 to 2-6. Waste collections of all type of wastes apparently decreased with the increase of the distance in both year 2015 (see Figure 2-5A to 2-5B) and 2016 (see Figure 2-6A to 2-6B) experiments. In 2015, however, the statistical test suggests that 8 m distance gave no significant impact on waste collections of any types of wastes possibly owing to limited data. On the other hand, statistical test (ANOVA) using year 2016 experiment results suggests that the increase of the distance significantly decreased waste collections of combustible wastes (16.1% for 4 m and 30.8% for 8 m, $p = 0.0403$) and cans (19% for 4 m and 33.1% for 8 m, $p = 0.0478$). It should be noted that waste collection data of combustible wastes in 2016 under condition 1B does not follow the normality (see Supplementary Table 2-1). However, Mann-Whitney U test also suggests that 8 m distance decreased waste collection of combustible wastes significantly ($p = 0.0090$). When data of both year experiments are summarized, the statistical test (ANOVA) suggests that distance increase causes significant decrease of overall waste collection ($p = 0.0325$). The increase of 4 m distance decreased total amount of waste collection about 10.9%. The increase of 8 m distance decreased total amount of waste collection about 30%. When waste collections were measured based the number of wastes, however, the distance increase gave no significant impact on overall waste collection.

In 2015, waste separation efficiency of all types of wastes were apparently decreased by the increase of the distance (see Figure 2-5C). However, only the capture rate of PET bottles was significantly decreased by about 1.91% with the increase of the distance ($p = 0.0264$). The contamination rates of all trash bins were apparently increased by increasing distance in 2015 (see Figure 2-5D). However, contamination rates of only combustible waste bin were regarded significant difference (about 790% by 8 m distance, $p = 0.0456$).

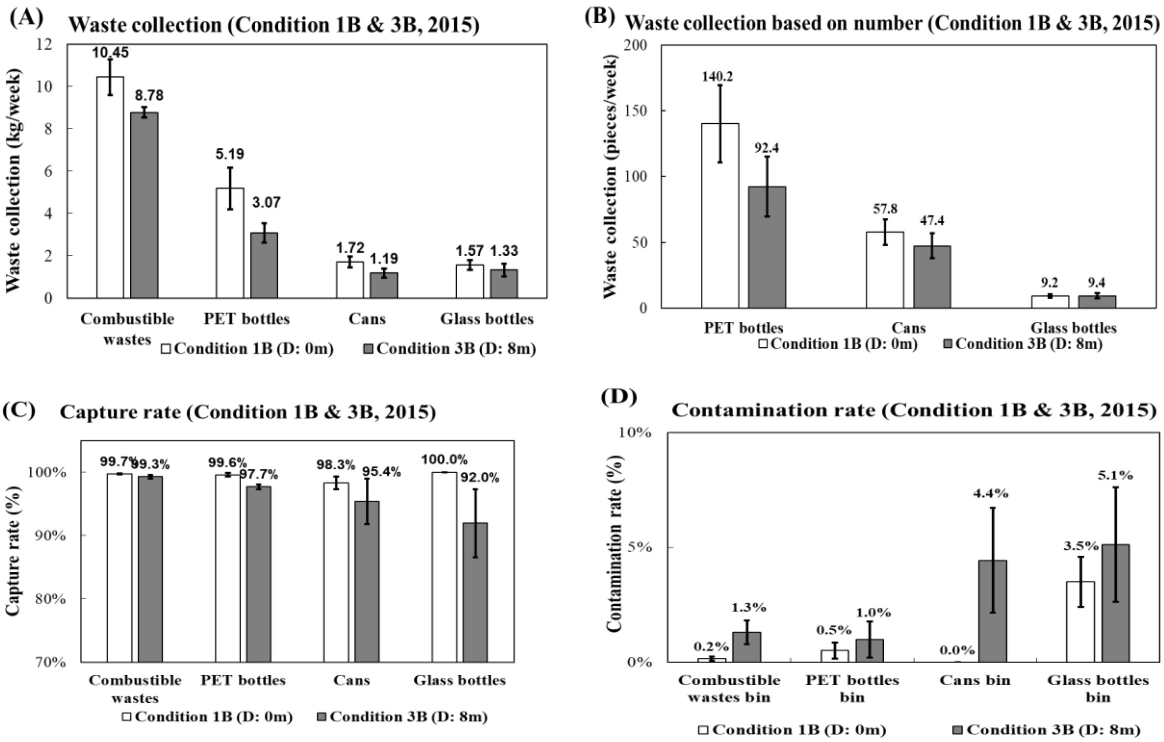


Figure 2-5 The results of trash bins location out of walking path (Condition 1B and 3B, 2015)

After repeated experiment in 2016, however, the results did not show any significant differences of the capture rate for all type of wastes (see Figure 2-6C). Therefore, it is concluded that significant impact of distance increase on capture rate was not verified for any types of wastes in this study. The results also did not show any significant difference of contamination rates for all type of trash bins (see Figure 2-6D). Therefore, as the same with capture rate, this study concluded no significant impact of the distance increase on contamination rates for all types of trash bins. 8 m distance is still so short that it does not change human behaviors of waste separation and correct disposal to trash bins. However, longer distance might change human behaviors. González-Torre and Adenso-Díaz (2005) reported that 5 minutes walking made people reject to separate their wastes. When 136.7 cm/s walk speed is used (Bohannon, 1997), threshold distance that can affect waste separation and correct disposal behaviors will exist between 8 and 410 m. Furthermore, Struk (2017) also reported the reduction of waste separation from 10.6% at curbsides site collection to 7.7% at drop-off sites.

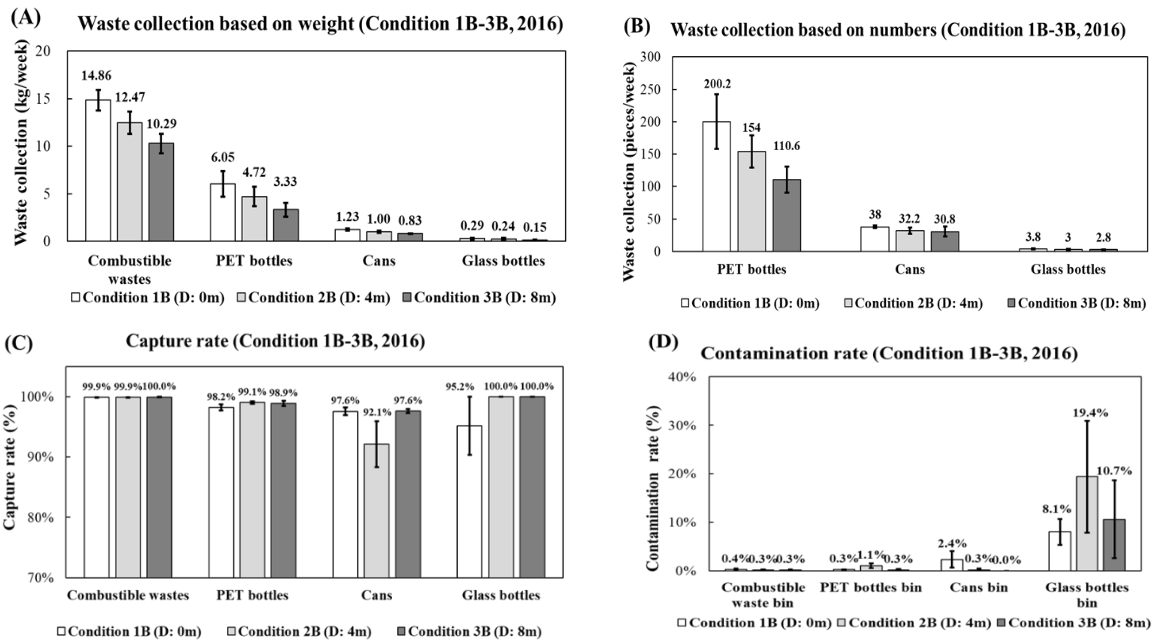


Figure 2-6 The results of trash bins location out of walking path (Condition 1B - 3B, 2016)

The results of waste collection showed the amount of all collected waste decreased linearly with the increase distance (R^2 = 0.975, see Figure 2-7A). Furthermore, with the increase of walking distance, waste collection of combustible wastes (R^2 = 0.794), PET bottles (R^2 = 0.979), and cans (R^2 = 0.741) were decreased linearly (see Figure 2-7B to 2-7D). Due to the low glass bottles collection rates in 2016, it could not find linear correlation with walking distance (R^2 = 0.0695, see Figure 2-7E). The results show that waste collection was decreased refer to increased distances. The total waste collection was decreased about 10.9% by the increment of 4 m distance and 30% by the increment of 8 m distance as described earlier. It is similar with the previous research (Erfani et al., 2017) with 12.5% reduction of waste with the increasing of distance.

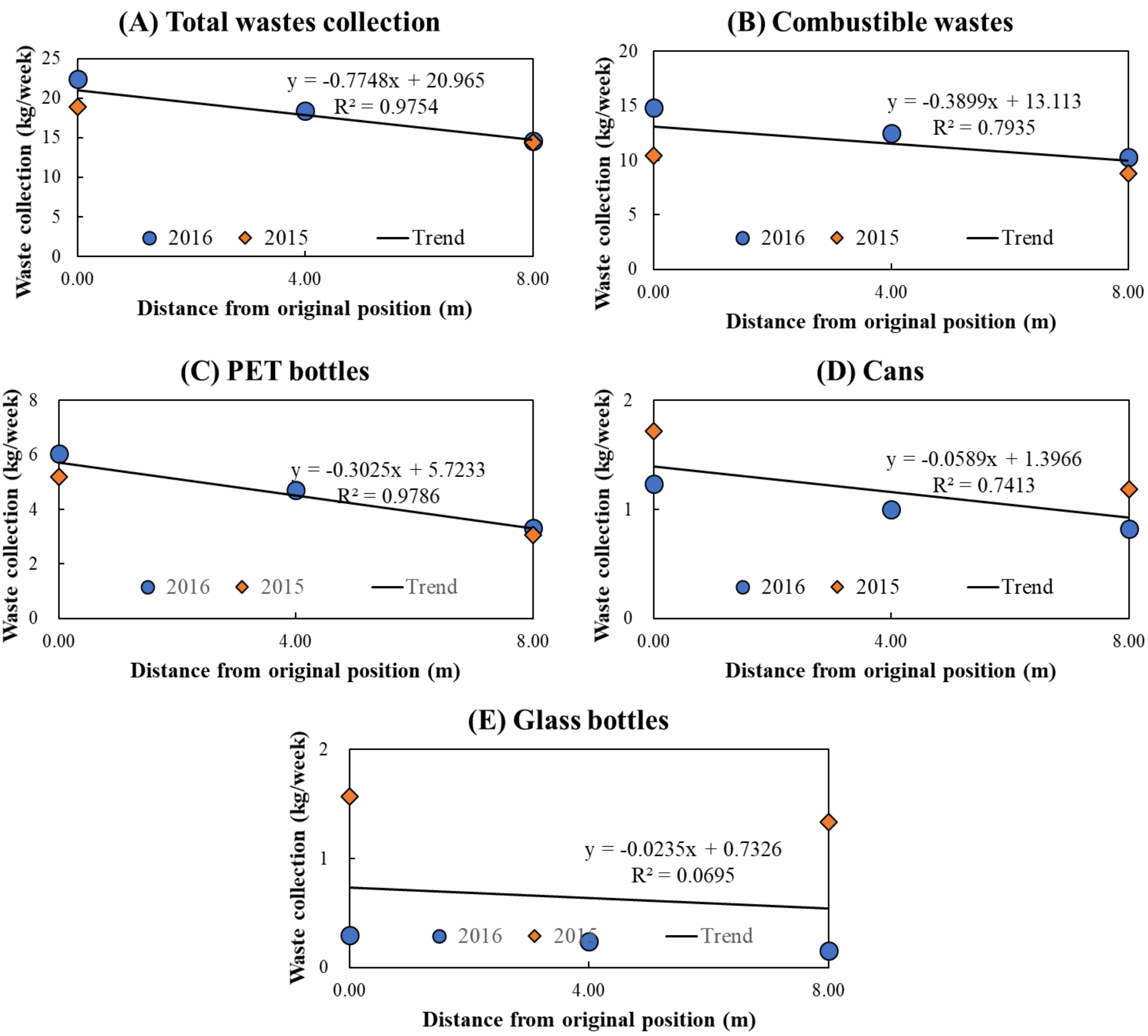


Figure 2-7 Relationship between waste collection and distance

2.3.3 The impact of separated trash bins (Condition 1C-3C)

The impact of separated setting of trash bins on waste collection, capture rate, and contamination rate were evaluated by the comparison between control condition (1C) and the others (2C and 3C). The monitoring results of separated trash bins are shown in Figure 2-8. The monitoring results show that waste collection under control condition and the others are similar (see Figure 2-8A and 2-8B). The statistical test also suggests that waste collections based on both the weight and the number are not significantly changed by separated setting of trash bins for all type of wastes. On the other hand, the separated trash bins affected the motivation of separating wastes (see Figure 2-8C). When combustible waste and PET bottle trash bins were set separately in the opposite side of the original position, capture rates of combustible wastes and PET bottles were significantly decreased (7.35%, $p = 5.98\times10^{-5}$ for combustible wastes and 9.21%, $p = 7.88\times10^{-4}$ for PET bottles). On the other hand, the separated bins did not affect the capture rates of cans and glass bottles whose trash bins were still in the original position. When PET bottle trash bin was set alone in the other side, the capture rate of PET bottles was significantly decreased (21.4%, $p = 0.00918$). On the other hand, the capture rates of other three wastes were not affected significantly. The separated setting of trash bins also gave some significant impacts on the contamination rate for trash bins in the original side (see Figure 2-8D). Under condition 2C in which combustible waste and PET bottle trash bins were separately set, contamination rates of cans and glass bottle trash bins were highly increased. It means that combustible wastes and PET bottles were mixed in these trash bins in the original position. Some persons disliked further 3 m walking to the opposite side in order to dispose of combustible wastes and/or PET bottles. The statistical test also suggests that the separated setting significantly increased contamination rates of can trash bin (210%, $p = 0.00355$) and glass bottle trash bin (268%, $p = 0.00749$). Under condition 3C in which only PET bottle trash bin was set separately, contamination rates of three trash bins (combustible wastes, cans, and glass bottles) in the original position were also increased. It means that PET bottles were mixed in three trash bins in the original side. However, statistical test results suggest that significant increase of contamination rate is found only for glass bottle trash bin (269%, $p = 8.18 \times 10^{-5}$).

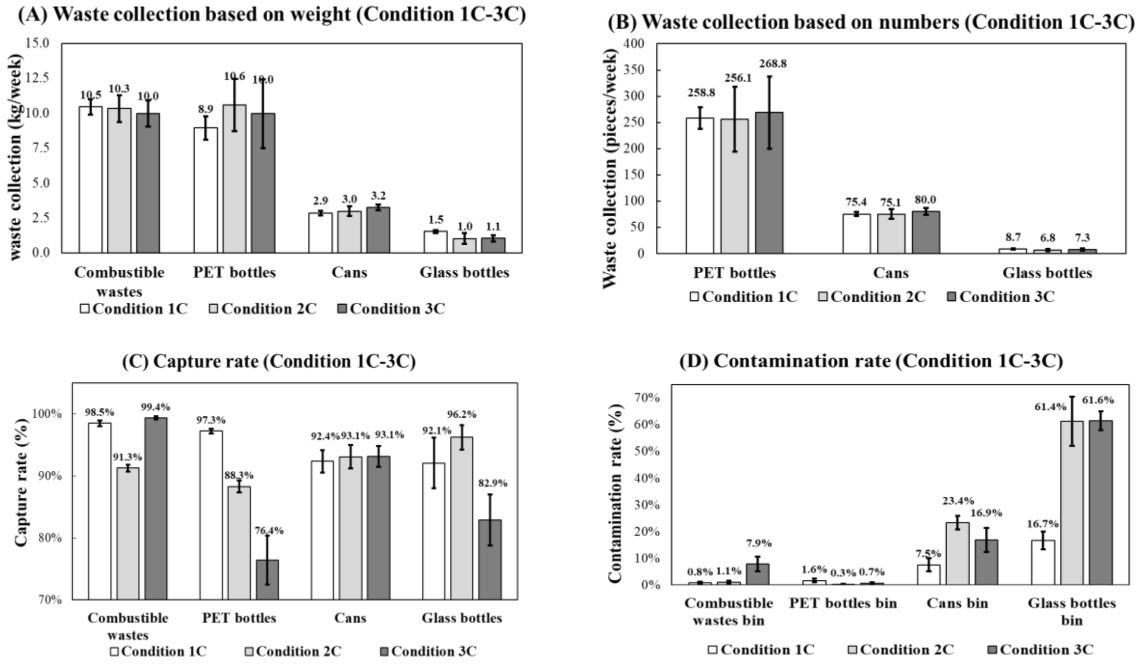


Figure 2-8 The results of separated trash bins (Condition 1C-3C)

In this section, it is concluded that some persons disliked further 3 m walking to the other side in order to dispose of some wastes correctly (combustible wastes and PET bottles in this case). The separated setting of trash bins in the opposite side from the original position significantly decreased capture rate of target wastes (combustible wastes and PET bottles). They were mixed in incorrect category trash bins (can and glass bottle trash bins) in the original position. On the other hand, the separated setting did not significantly affect capture rates of wastes for which their trash bins were set in the original position. In the previous section 2.3.2, threshold distance that can affect waste separation and correct disposal behaviors was suggested as 8 to 410 m. Additional 3 m distance to the opposite side after 8 m walking to the original position of trash bins might exceed the threshold distance and have caused low separation efficiencies. The multiple processes of waste separation might make people feel inconvenient. The results confirmed inconvenient in disposal process reduce waste separation efficiency (Lee et al., 2017; Schultz et al., 1995).

2.4 Summary

The total amount of collected waste including combustible wastes, PET bottles, cans, and glass bottles under all conditions are displayed in Figure 2-9A. The overall capture rate and the contamination rate for all types of trash bins under all conditions are also displayed in Figure 2-9B and Figure 2-9C, respectively. The results show that the relocation of trash bins along the walking path (condition 1A to 2A) did not significantly affect the amount of all collected waste, the capture rate, and the contamination rate. In the case of the distances away from walking path (condition 1B to 3B), it was found that the increase of the distance decreased the waste collection significantly as described in section 2.3.2. However, the increase of the distance did not affect to the capture rate and the contamination rate. On the other hand, separated setting of trash bins (condition 1C to 3C) decreased the capture rate and increased the contamination rate significantly as described in section 2.3.3. However, it did not affect the waste collection.

However, it should be noted that careful attentions are still necessary to reach generalized conclusion based on the outcomes obtained in this study. The results of this study were done at the university building. Some impacts of gender, age, education, social and cultural community with public areas might be bias of the results in public areas. For example, gender of people gave the impact on waste separation behavior (Oztekin et al., 2017; Zhang et al., 2017). The education in perceptive of waste classification is also one of the most inconvenient factor on waste separation (Lee et al., 2017). In terms of waste management strategy, waste collection system designed on basis of the characteristics of local wastes is also a promising approach (de Vega et al., 2008).

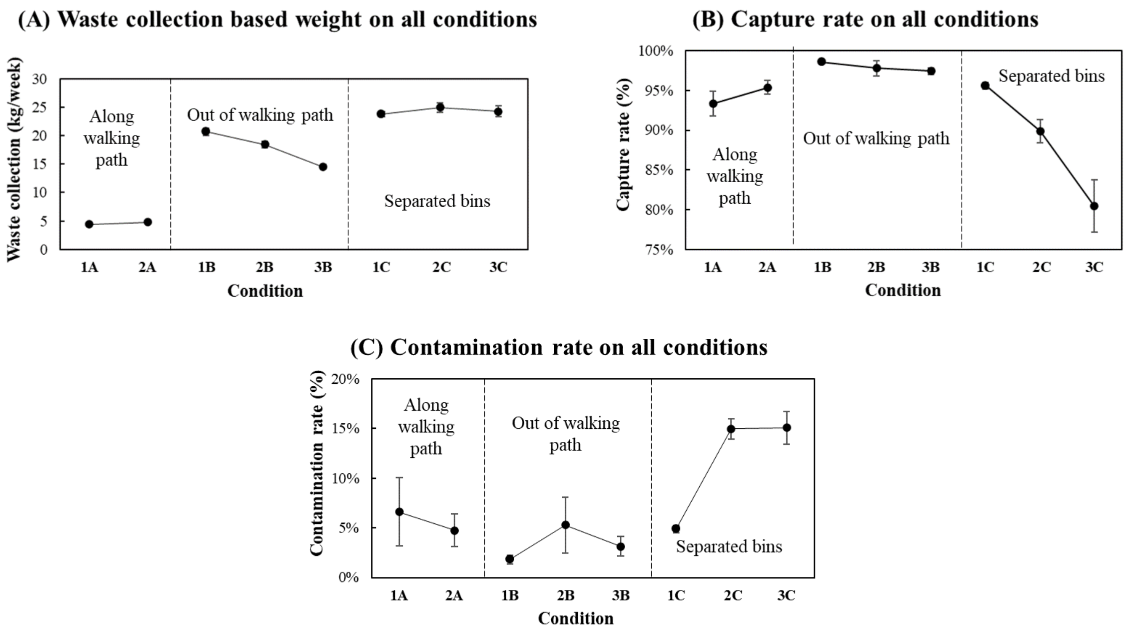


Figure 2-9 The results summary of bin setting conditions

2.5 Conclusion

This study investigated the effects of setting conditions of trash bins on waste collection, capture rate, and incorrect disposal. Tested trash bins are for combustible wastes, PET bottles, cans, and glass bottles. Monitoring results were analyzed by statistical tests to distinguish real effects and experimental errors. The distance to trash bins along walking path gave no significant effects on waste collection and the others. On the other hand, when the distance was out of walking path, its increase significantly decreased weight-based waste collection of combustible wastes. The decrease of waste collection was linear to the distance increase. In contrast, the distance gave no significant effect on capture rate and contamination rate. Threshold distance that can affect waste disposal behaviors might exist between 8 and 410 m. When trash bins were set separately, it affected the motivation of waste separations. Separated setting of combustible waste and PET bottle trash bins in the opposite side of the original position significantly decreased capture rates of these wastes. Because no significant effect was found on capture rate of other wastes whose trash bins were set in the original position, additional 3 m distance to the opposite side might exceed the threshold distance and have caused low separation efficiencies. These results suggest that appropriate location of trash bins can improve waste collection and waste separation. It might be useful to improve waste management in public areas with high population density like shopping mall and airports. A psychological model-based approach is recommended for further study, in particular psychological processes between preference and behavior.

3. The effect of trash bin arrangement

3.1 Background

As mentioned in Chapter 1, the set of trash bin preference was investigated focusing on different types of waste bins (packages, plastic, aluminum, glass, glass bottles, and papers) and designs (color, shape, slot position, and setting style). The most preferred multi-bins were colorful rectangular bins with front position including packages, plastic, and paper bins (Keramitsoglou and Tsagarakis, 2018). Moreover, the set of trash bins (more than one bin) increased waste separation efficiency from single bin about 1.80 times (Andrews et al., 2013). The arrangement of trash bins might also be related to waste disposal behavior. In previous works of the authors' group (Jiang et al. 2017), psychological preferences of trash bin arrangement were scaled by web questionnaires using pairwise comparison method with Thurstone's law of comparative judgement (Thurstone, 1927).

In this questionnaire, two illustrations of different trash bin arrangements were presented to the respondents and asked to select better arrangement if they separately drop wastes to the bins (see Figure 3-1). The survey suggests that people prefer to separate general waste trash bins (combustible wastes/incombustible wastes) and recyclable waste trash bins (PET bottles/cans). When combustible waste trash bin was set on the left side, it had higher preference score than others. Furthermore, a pair of general waste trash bins in the middle had lower preference score than those set on the left side. When trash bins of combustible waste and incombustible were separated by the other bin, preference score was usually lower. It could be noted that the respondents in this survey are in Japan to avoid the error by country because the on-site experiment was also conducted in Japan.

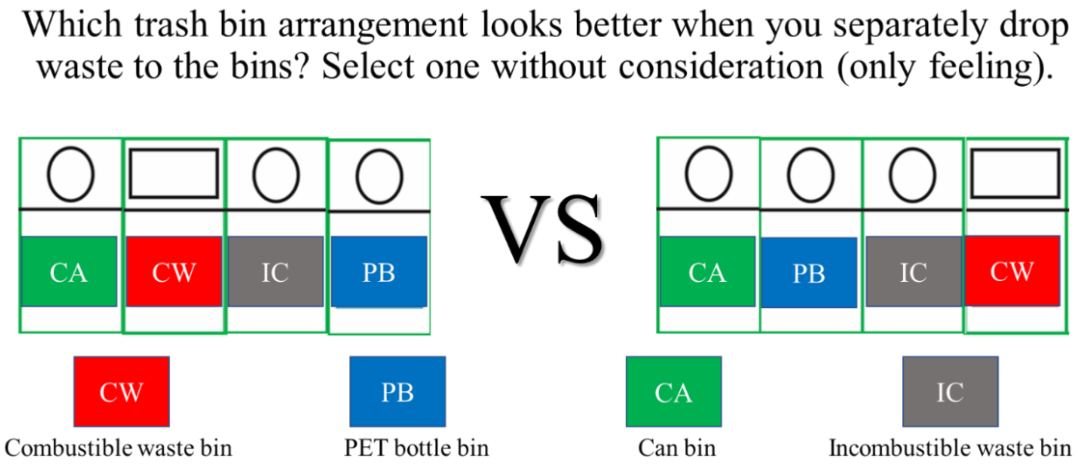


Figure 3-1 The questions in the applied questionnaire

In this Chapter, the authors investigated the effects of arrangement of trash bins on waste collection, capture rate, and incorrect disposal to wrong trash bins. The results of this study might be useful for waste management to find out the appropriate setting conditions in the public areas.

3.2 Methodology

3.2.1 On-site experiments

In this study, trash bins were set with different arrangements. On-site experiments were conducted in the building at Fukuoka University, Japan in 2017. Persons of this experimental campaign included students, staffs, and visitors in the buildings. The numbers of total students and staffs in Fukuoka University were 22,318 persons with 63% male and 37% female. Trash bins tested in this study were for combustible wastes, PET bottles, cans, and glass bottles. Wastes collected by trash bins were monitored and recorded every day in the weekdays. 5 days data were summarized as weekly monitoring data and used for statistical analysis. The monitored data were the weight of collected wastes (combustible wastes, PET bottles, cans, and glass bottles)., the number of collected wastes were also recorded except for combustible wastes. Therefore, weight- and number-based waste collection data were finally created. Daily waste generation rates (g/person/day) were significantly different during weekdays, but seasons and university's activities hardly affect waste generation in significance (Edjabou et al., 2015). For the reason, weekly data were used in this experiment to avoid the effect of weekdays.

In this study, capture rate of certain waste was defined as the weight percentage of the waste correctly disposed to the target trash bin in the total waste collected by all trash bins, as shown in Eq. (1). Therefore, the capture rate indicates the ratio of correct disposal of target waste.

$$\textit{Capture rate} = \frac{\textit{The weight of correctly disposed waste in the trash bin}}{\textit{The weight of waste collected in all trash bins}} \times 100\% \tag{1}$$

The weight percentage of foreign wastes contamination was also analyzed in this study, as shown in Eq. (2). It is the percentage of incorrectly disposed wastes in the total wastes collected by a target trash bin. The contamination rate indicates how much wastes was segregated correctly focusing on a target trash bin, not waste itself.

$$\textit{Contamination rate} = \frac{\textit{The weight of incorrectly disposed waste in the trash bin}}{\textit{The weight of total waste collected in the trash bin}} \times 100\% \tag{2}$$

3.2.2 Effect of trash bin arrangement

Experiments were conducted at 2nd and 3rd floor of Building B from May to December in 2017. Three types of trash bin arrangement were tested based on preference score of trash bin arrangement. However, it should be noted that trash bins placed in Building B were different with the arrangement preference survey (Jiang et al. 2017). Instead of incombustible waste trash bin, glass bottle trash bin was used in on-site experiments. When three target arrangement was designed based on arrangement preference scores, the authors changed incombustible waste trash bin in the previous survey to glass bottles trash bin in on-site experiment. In arrangement 1, the arrangement of four trash bins was combustible wastes, PET bottles, cans, and glass bottles from the left side to the right. In arrangement 2, the arrangement was cans, PET bottles, glass bottles, and combustible wastes from the left. In arrangement 3, the arrangement was cans, combustible wastes, glass bottles, and PET bottles from the left. Tested arrangements of trash bins are shown in Figure 3-2. one-week experiments in arrangement 1, 2, and 3 were repeated 4 times in an alternate manner.

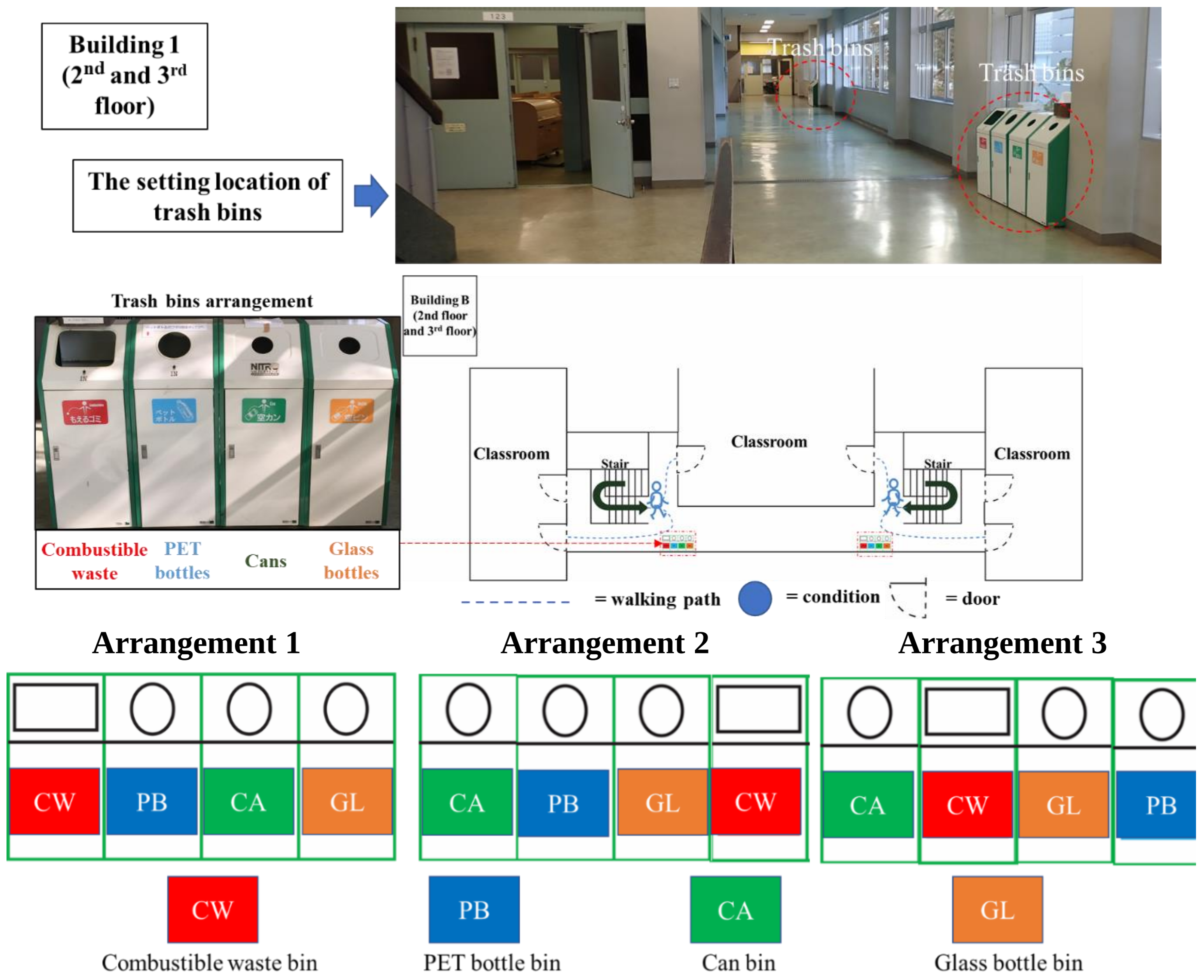


Figure 3-2 Trash bins placement arrangements at 2nd and 3rd floor of Building B

3.2.3 Statistical tests to identify effects of trash bin setting conditions

Gaussian normality of all dataset (waste collection, capture rate, and contamination rate) was checked using Shapiro-Wilk test to select parametric and non-parametric test. Significance level was 5%. The results of normality test were summarized in Table S3-1. When all data followed the normality, Welch's t-test or one-way ANOVA with significance level of 5% was used to identify significant differences between experimental conditions. When some of data did not follow the normality, Mann-Whitney U test was used. Significance level (5%) was treated by Bonferroni correction when necessary. When statistical test suggested rejection of null hypothesis which assumes no difference among dataset, the difference would be always described "significant" or "significantly" in following sections.

3.3 Results and discussions

3.3.1 Preference score of tested trash bins

The results were compared with the arrangement preference of previous study. Preference score of 24 arrangements of four trash bins are shown in Figure 3-3. In Figure 3-3 higher score means higher preference. The arrangement preference score of arrangement 1 is 0.356 ± 0.025. It is the highest in this experiment. The arrangement preference score of arrangement 2 is 0.309 ± 0.031, which is a little bit lower than that of arrangement 1. The arrangement preference score of arrangement 3 is -0.172 ± 0.035, which is much lower than those of arrangement 1 and 2.

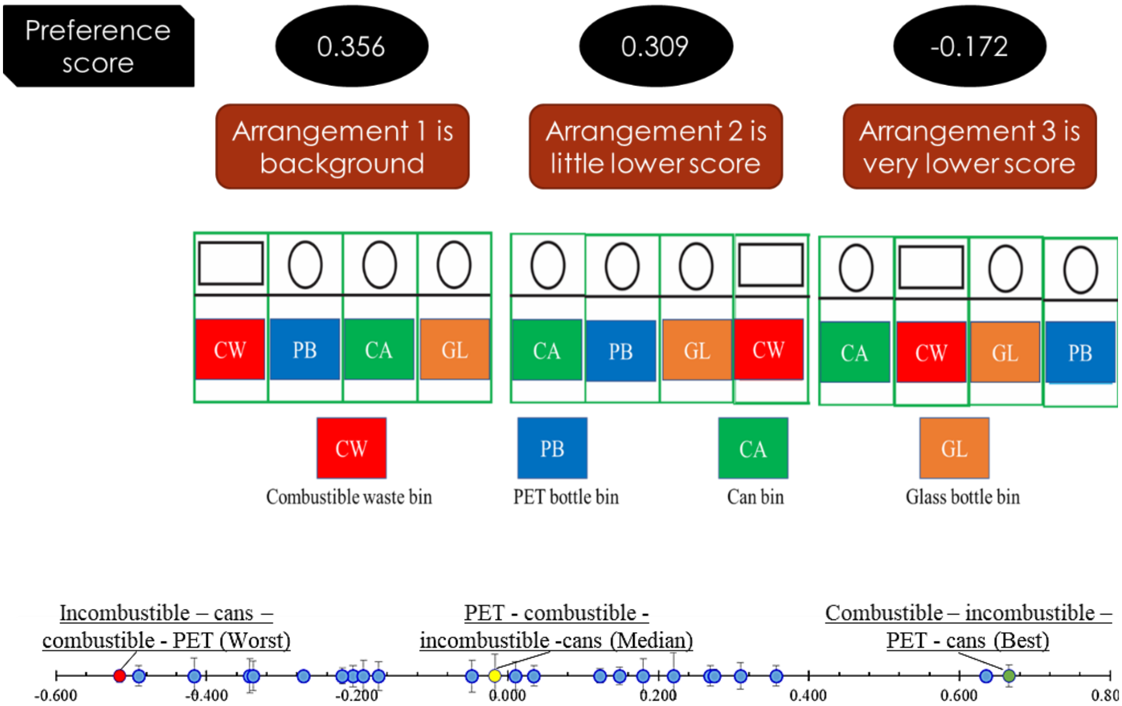


Figure 3-3 Scaled preferences of trash bin arrangement

3.3.2 The impact of trash bin arrangement

The monitoring results are shown in Figure 3-4. The arrangement preference did not significantly affect waste collection for all types of wastes (see Figure 3-4A). Waste collection based on the number also shows no significant difference (see Figure 3-4B). The statistical test also suggests that low arrangement preference did not significantly affect both the capture rates and contamination rates excluding one case (see Figure 3-4C and 3-4D). Only capture rate of cans was regarded as significant decrease ($p = 0.0396$) when lower preference of trash bin arrangement. The capture rate of cans was decreased about 7.72% with a little bit lower preference score. In addition, it was decreased about 10.60% with much lower preference score. Contamination rates of glass bottle trash bin are clearly higher at lower arrangement preference case (14.23% for a little bit lower score and 111.61% for much lower score). However, it was not regarded as significant change by Mann-Whitney U test ($p = 0.0180$; slightly higher than corrected significance level $\alpha = 0.0167$) owing to limited data. According to further analysis of collected waste, it was verified that some of cans were incorrectly disposed to glass bottle trash bin when preference of trash bin arrangement decreased. It explains decreasing trend of capture rates of cans shown in Figure 3-4C and increasing trend of contamination rate of glass bottle trash bin shown in Figure 3-4D. It might be interpreted focusing not on arrangement preference but on setting positions of can/glass bottle trash bins. At the time, can trash bin was set in the middle position (arrangement 1), cans were correctly disposed to can trash bin. After can trash bin was moved to the left position (arrangement 2 and 3), some of cans were incorrectly disposed to glass bottle trash bin set in the middle position. It is the same with glass bottle. When glass bottle trash bin was set in the middle position (arrangement 2 and 3), capture rate of glass bottles was higher than that in the right position (arrangement 1) although the differences were not regarded as significant. Persons might prefer to drop recyclable wastes (cans and glass bottles) to a trash in the middle position rather than in the left/right position. The combination of multi-bins has different preferences (Keramitsoglou and Tsagarakis, 2018) and gave different waste separation efficiencies (Andrews et al., 2013). On the other hand, although the arrangement of trash bins also had different preferences, it gave no significant impact on waste capture rate. The relation between psychological preferences and human behaviors has been still a challenging work. Ajzen (1991) proposed the Theory of Planned Behavior in which behavior was predicted by psychological model variables (intention, attitude, subjective norm, and perceived behavioral control). Psychological preference can be included in attitude. In this sense, preferences of trash bin arrangement might have given no impact on intention and thus no contribution to waste separation behavior was found in this study. However, careful discussion might be still necessary. Stoeva and Alriksson (2017) applied an extended psychological model to evaluate the influence of recycling programs on waste separation behavior. They reported clearly different contributions of psychological factors to waste separation behavior between two groups. They proposed that different experiences and/or participations in waste separation and diverse social pressures to act in an appropriate manner might have caused different impacts on behavior. After waste collection experiments in different scenes, psychological preference of trash bin arrangement might also give different contribution to waste separation behavior. A psychological model-based approach is recommended for further study.

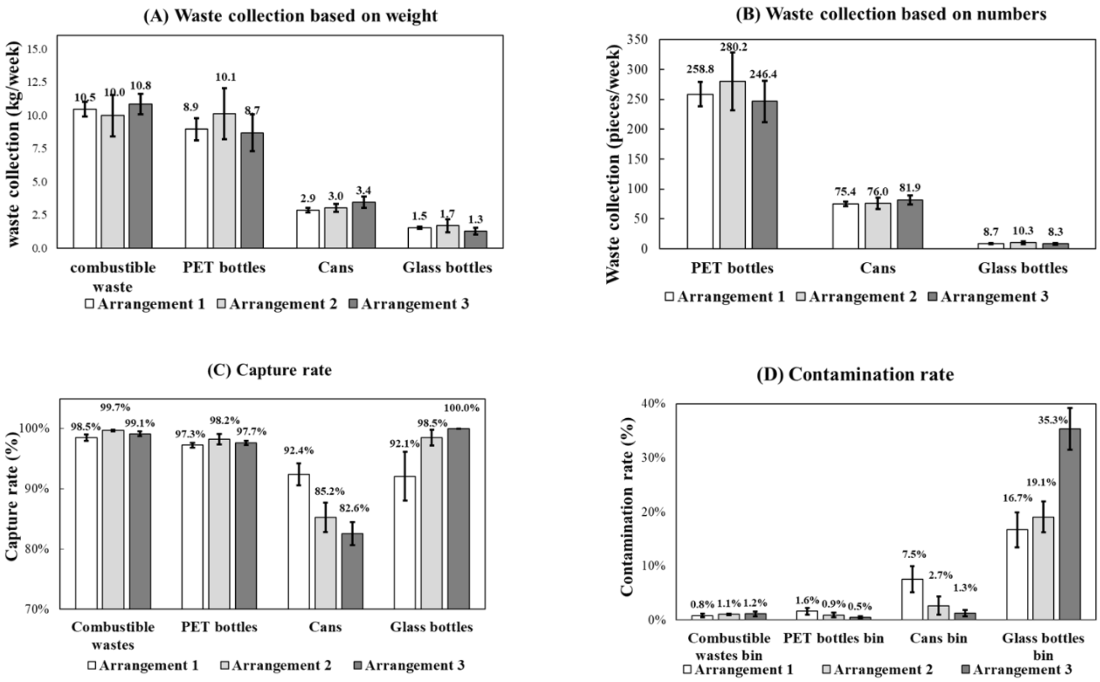


Figure 3-4 The results of arrangement preference

3.4 Summary

The comparisons of results among arrangements are shown in Figure 3-5. The preference of trash bin arrangement did not affect the waste collection. On the other hand, better preference of trash bin arrangement significantly increased the capture rate of cans and decreased the percentage of foreign wastes for glass bottles trash bin as described in section 3.3.2. However, it should be noted that careful attentions are still necessary to reach generalized conclusion based on the outcomes obtained in this study. The results of this study were done at the university building. Some impacts of gender, age, education, social and cultural community with public areas might be bias of the results in public areas. For example, gender of people gave the impact on waste separation behavior (Oztekin et al., 2017; Zhang et al., 2017). The education in perceptive of waste classification is also one of the most inconvenient factor on waste separation (Lee et al., 2017). In terms of waste management strategy, waste collection system designed on basis of the characteristics of local wastes is also a promising approach (de Vega et al., 2008).

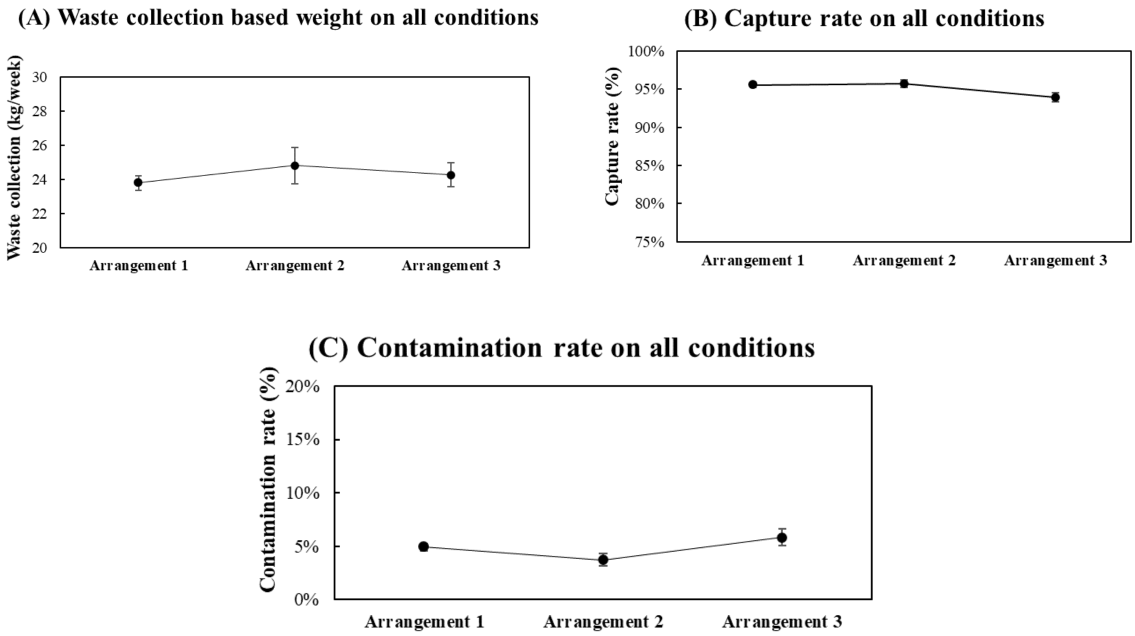


Figure 3-5 The results summary of bin arrangements

3.5 Conclusion

This study investigated the effects of arrangements of trash bins on waste collection, capture rate, and incorrect disposal. The tested trash bins are for combustible wastes, PET bottles, cans, and glass bottles. The monitoring results were analyzed by statistical tests to distinguish real effects and experimental errors. The preference of trash bin arrangement gave no significant effect on waste collection and the others excluding one case. Only the capture rate of can was decreased significantly with the decrease of the arrangement preference. These results suggest that the appropriate position of trash bins can improve waste separation performance. It might be useful to improve waste management in public areas with high population density such as shopping malls and airports. A psychological model-based approach is recommended for further study, in particular psychological processes between preference and behavior.

4. The effect of trash bin color

4.1 Background

In this study, the authors focused on color of trash bins because the color can be an inducing factor to a behavior. The color can facilitate object recognition (Clarke and Ludington, 2018), and the color also give an effect on the noticeability (Kruijff et al., 2018). Moreover, the color perception gives an impact on human psychological functions such as the memory and decision performance (Elliot and Maier, 2014). The color can be associated with the types of waste, so the appropriate color might improve waste sorting efficiency. The color inference in visual communication was used to find out the meaning of colors in a recycling behavior (Schloss et al., 2018). The terrible or environmentally offensive colored bin was also given one of the main reasons for non-participation in recycling program (McDonald and Oates, 2003). On the other hand, bright yellow bin covers can improve the capture rate of food waste (Lin et al., 2016). In addition, the color preference is significant factor for recycling bin selection (Kalatzi et al., 2015). This study includes both public participation survey and on-site experiment. The survey questionnaires were used to find out the candidate colors for on-site experiments. The effects of trash bin color and their noticeability on waste collection rate, capture rate, contamination rate, and the effective capture rate were investigated based on the candidate colors. It could be noted that the respondents in this survey are consumers in on-site experiment to avoid the error by different group of persons

4.2 Methodology

4.2.1 Survey questionnaires

4.2.1.1 Sample size and analysis methods

In the questionnaires, two illustrations of different objects (bin color, bin color combination, or bin combination in various locations, respectively) were presented to the respondents and asked to select better object if they separately drop waste to the bins or notice the bin combination (see Figure 4-1). The questionnaires were included both Thai and English languages. Persons of this survey campaign included students and staffs in the Faculty of Engineering at Kasetsart University, Thailand. The number of total students and staffs were 6,954 persons with 67% of male and 33% of female. The sufficient of sample size was calculated with the assumption of finite population for Faculty of Engineering (exactly 6954 persons), 90% of confidential level, and 7% of margin error in Eq (1). Z score is calculated by the inverse normal cumulative distribution for a given probability value ($1 - \alpha/2$, where α is 10% significant level). The Z scores of ± 1.645 are the critical Z-scores for a 90% confidence interval. The sufficient simple size were 136 samples. The data were analyzed by pairwise comparison method with Scheffé's approach (Scheffé, 1952). The analysis method will be described in the following section.

It could be noted that most statistical theory is based on an underlying infinite population. However, survey sampling theory is built on a basis of sampling from a finite population. In the general margin of finite population sampling, the samples of size (n′) is considered from a finite population of size (N), there is a population with N persons.

$$n' = \frac{\frac{z^2 \times p(1-p)}{\varepsilon^2}}{1+\frac{z^2 \times p(1-p)}{\varepsilon^2 N}} \tag{1}$$

where n′ is the sample size, z is the z score (based on confidence level), p is the probability (usually 50% or 0.5), ε is the margin error, and N is the population (6954 persons).

4.2.1.2 Pairwise comparison (Scheffé's method)

Pairwise comparison is the method to evaluate the preference of respondents. Scheffé's method is one of the analysis tools to justify the better objects in term of pairwise comparison.

This method provides the selectable choices with vary odd numbers grading. In this study, the questionnaires were scaled 5-grading system (see Figure 4-2).

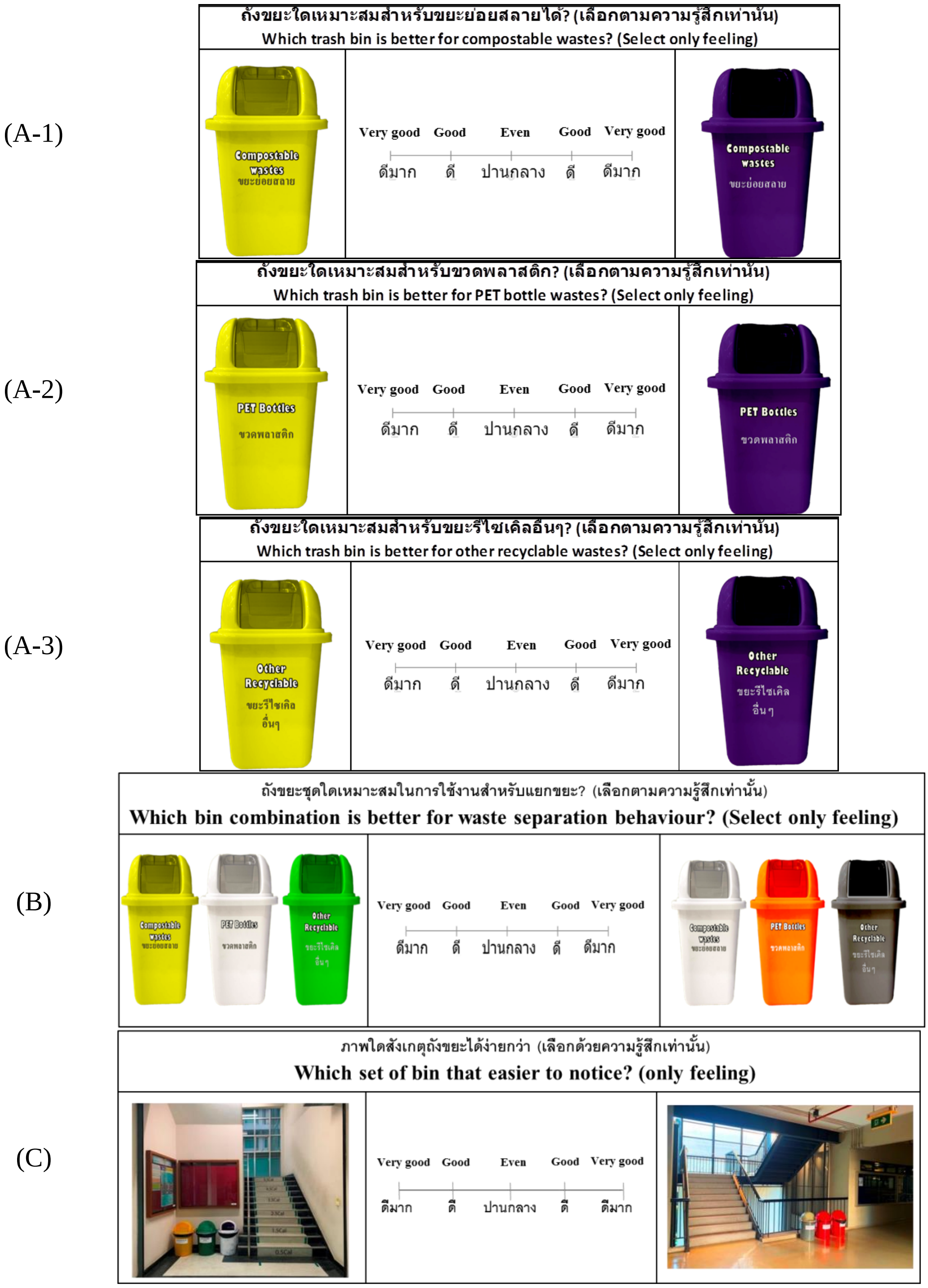


Figure 4-1 The example of survey questionnaires.

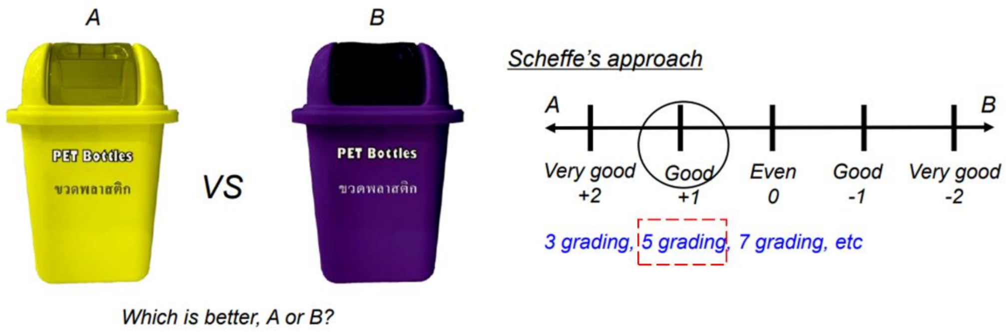


Figure 4-2 Comparison of selectable options for Scheffé's method

The 5-grading system is multiple selection from +2 to -2 in integer number. This means the comparison between design A and B are able to select five options including **+2**: A is extremely preferred, **+1**: A is preferred, **0**: A and B are equally preferred, **-1**: B is preferred, **-2**: B is extremely preferred. There are generally four types for Scheffé's method as shown in Table 4-1. Scheffé's method with Nakaya's variation were used to evaluate all pairs comparison by panelist excluded an order effect (Nakaya, 1970).

Table 4-1 Four types of Scheffé's Method

	Comparison by a panelist (only one pair)	**Comparison by a panelist (all pairs)**
Order effect Included	*Original*	Ura's variation
Order effect Excluded	Haga's variation	***Nakaya's variation***

The preference degrees with Scheffé's method have a certain number of design and questionnaire with the preference scale bar. For example, assume four designs to compare as shown in Figure 4-3.

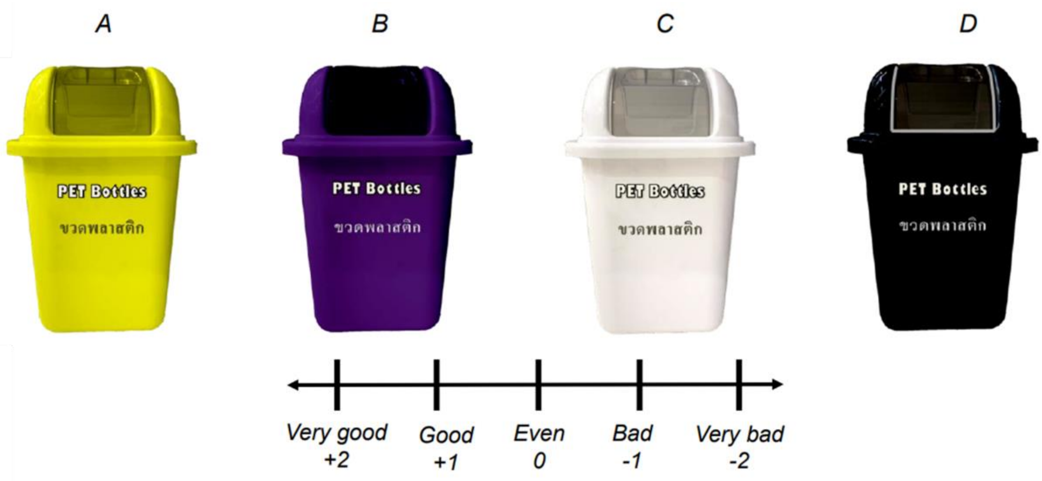


Figure 4-3 An example of Scheffé's method with four designs

The number of all pairs is 6 questions for respondents for 4 objects in Eq (2). The questionnaires can be prepared with 6 pairs to let respondents mark to the bar as their selections (see Figure 4-4).

$$The\ number\ of\ all\ pairs = {}_{M}C_2 = \frac{M!}{2!(M-2)!} = \frac{1}{2}M(M-1) \tag{2}$$

where M is the number of objects.

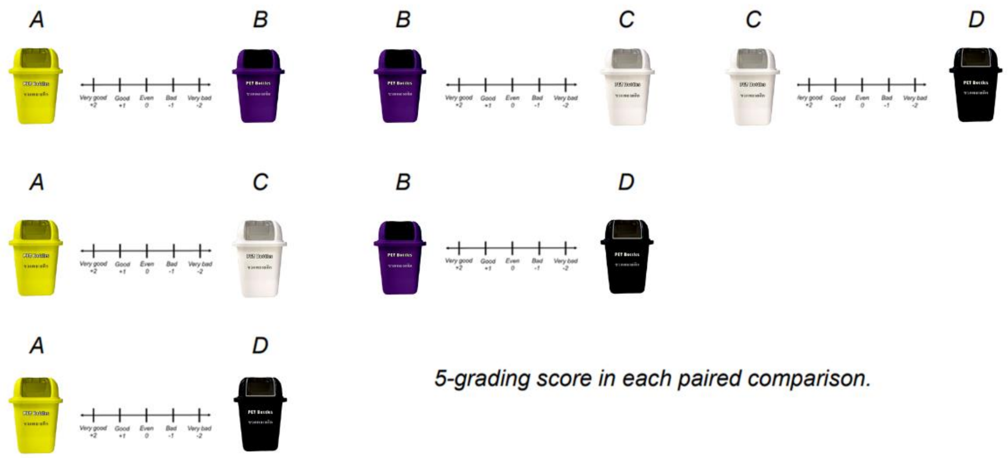


Figure 4-4 An example of 5-grading pairwise comparison with four designs

Scheffé proposed a new model consisting of main effect, combination effect, order effect, and error terms based on not psychological physics models but multi-way ANOVA model (Scheffé (1952), Inoue (2012)). According to ANOVA technique, it is possible to statistically test the significance of main effect difference among two designs, which is preferred difference in this study case, using *yardstick (Y)* calculated based on the studentized range distribution. Nakaya simplified Scheffé's model to let order effect be negligible (Nakaya (1970)). The preference score of design X compared with design Y, given by person m, is showed in Eq. (3). The analysis method will be described in the following section.

$$Z_{x,y,m} = \left(A_x - A_y\right) + \left(\alpha_{x,m} - \alpha_{y,m}\right) + Y_{x,y} + \varepsilon_{x,y,m} \tag{3}$$

where x and y are the component number of the objects, m is participant identification number, $Z_{x,y,m}$ is the preference score of design X in the paired comparison between design X and Y given by participant m, A_x is preference score of design X, $A_x - A_y$ is the difference of average preference between design X and Y, $\alpha_{x,m} - \alpha_{y,m}$ is the personal difference from average preference of design X for person m, $Y_{x,y}$ is the combination effect of design X and Y preference score, and $\varepsilon_{x,y,m}$ is an error term of paired comparison between design X and Y for participant m.

The example of four designs as A, B, C, and D, the score of design A for person m is calculated by the summation of three equations below.

$$Z_{A,B,m} = (A_A - A_B) + \left(\alpha_{A,m} - \alpha_{B,m}\right) + \Upsilon_{A,B} + \mathcal{E}_{A,B,m}$$

$$Z_{A,C,m} = (A_A - A_C) + \left(\alpha_{A,m} - \alpha_{C,m}\right) + \Upsilon_{A,C} + \mathcal{E}_{A,C,m}$$

$$Z_{A,D,m} = (A_A - A_D) + \left(\alpha_{A,m} - \alpha_{D,m}\right) + \Upsilon_{A,D} + \mathcal{E}_{A,D,m}$$

Since $\sum_{X=A}^{D} A_X = 0$, $\sum_{X=A}^{D} \alpha_{X,m} = 0$, $\sum_{X=A}^{D} \Upsilon_{A,X} = 0$, and $\sum_{X=A}^{D} \mathcal{E}_{A,X,m} = 0$.

A summation of preference score could write down this equation. This is the preference score of design A compared with all designs (including comparing with design A) for person m.

$$\sum_{X=A}^{D} Z_{A,X,m} = 4A_A + 4\alpha_{A,m}$$

In case of the design A preference score by all respondents from person 1 to person N. The preference score should be calculated one by one and then summation needed after the calculation as below.

$$\sum_{m=1}^{N} \sum_{X=A}^{D} Z_{A,X,m} = \sum_{m=1}^{N} 4A_A + \sum_{m=1}^{N} 4\alpha_{A,N} = 4 \cdot N \cdot A_A$$

Because $\sum_{k=1}^{N} 4\alpha_{A,N} = 0$. Therefore, A_A can be arranged as below.

$$A_A = \frac{1}{4 \cdot N} \sum_{m=1}^{N} \sum_{X=A}^{D} Z_{m,X,k}$$

Then $\alpha_{A,m}$ can be arranged using A_A into the **summation of preference score** equation.

$$\alpha_{A,m} = \frac{1}{4} \sum_{X=A}^{D} Z_{A,X,m} - \frac{1}{4 \cdot N} \sum_{m=1}^{N} \sum_{X=A}^{D} Z_{A,X,m}$$

Use m from 1 to N in Eq (3) for design A compare with B to calculate $\Upsilon_{A,B}$.

Person 1, Design A and B $\quad Z_{A,B,1} = (A_A - A_B) + (\alpha_{A,1} - \alpha_{B,N}) + \Upsilon_{A,B} + \mathcal{E}_{A,B,1}$

Person 2, Design A and B $\quad Z_{A,B,2} = (A_A - A_B) + (\alpha_{A,2} - \alpha_{B,N}) + \Upsilon_{A,B} + \mathcal{E}_{A,B,2}$

…

Person N, Design A and B $$Z_{A,B,N} = (A_A - A_B) + \left(\alpha_{A,N} - \alpha_{B,N}\right) + \Upsilon_{A,B} + \mathcal{E}_{A,B,N}$$

Since $\sum_{k=1}^{N} \alpha_{A,m} = 0$ and $\sum_{k=1}^{N} \mathcal{E}_{A,B,m} = 0$. **A summation of preference score for person N equations** is following.

$$\sum_{m=1}^{N} Z_{A,B,m} = N(A_A - A_B) + N\Upsilon_{A,B}$$

Arrange the equation to find A_A and A_B.

$$A_A = \frac{1}{4 \cdot N} \sum_{m=1}^{N} \sum_{X=A}^{D} Z_{A,X,m}$$

$$A_B = \frac{1}{4 \cdot N} \sum_{m=1}^{N} \sum_{X=A}^{D} Z_{B,X,m}$$

Then substitute A_A and A_B into **the summation of preference score for person N equations**.

$$\sum_{k=1}^{N} Z_{A,B,k} = N(\frac{1}{4 \cdot N} \sum_{k=1}^{N} \sum_{X=A}^{D} Z_{A,X,k} - \frac{1}{4 \cdot N} \sum_{k=1}^{N} \sum_{X=A}^{D} Z_{B,X,k}) + N\Upsilon_{A,B}$$

Therefore, $\Upsilon_{A,B}$ can be calculated as below:

$$\Upsilon_{A,B} = \frac{1}{N} \sum_{m=1}^{N} Z_{A,B,m} - \left(\frac{1}{4 \cdot N} \sum_{m=1}^{N} \sum_{X=A}^{D} Z_{A,X,m} - \frac{1}{4 \cdot N} \sum_{m=1}^{N} \sum_{X=A}^{D} Z_{B,X,m} \right)$$

The number of designs as M, and the number of questionnaire participants as N. The equation can be arranged the terms as a list below:

- $Z_{i,j,m}$: score of design X_i against design X_j, which given by person m
- A_i: average preference degree of design X_i

$A_i = \frac{1}{MN} \sum_{m=1}^{N} \sum_{j=1}^{M} Z_{i,j,m}$

- $\alpha_{i,m}$: personal difference from the average preference of design X_i for person m

$$\alpha_{i,m} = \frac{1}{M}\sum_{j=1}^{M} Z_{i,j,m} - \frac{1}{MN}\sum_{m=1}^{N}\sum_{j=1}^{M} Z_{i,j,m}$$

- $\Upsilon_{i,j}$: combination effect of design X_i and X_j

$$\Upsilon_{i,j} = \frac{1}{N}\sum_{m=1}^{N} Z_{i,j,m} - \left(\frac{1}{MN}\sum_{m=1}^{N} \sum_{j=1}^{M} Z_{i,j,m} - \frac{1}{MN}\sum_{m=1}^{N}\sum_{j=1}^{M} Z_{i,j,m}\right)$$

In addition, a table for sum of squares for ANOVA (Analysis of Variance) has been developed in Table 4-2.

Table 4-2 ANOVA table of Scheffé's method: sum of squares and degree of freedom

Factor	Formula	Degree of freedom
Square sum of average preference	$S_A = \frac{1}{MN}\sum_{i=1}^{M}\left(\sum_{m=1}^{N}\sum_{j=1}^{M} Z_{i,j,m}\right)^2$	$df_A = M - 1$
Square sum of the interaction (Average Preference × Personal Difference)	$S_{A\alpha} = \frac{1}{M}\sum_{m=1}^{N}\sum_{i=1}^{M}\left(\sum_{j=1}^{M} Z_{i,j,m}\right)^2 - S_A$	$df_{A\alpha} = (M-1)(N-1)$
Square sum of combination factor	$S_\Upsilon \frac{1}{N}\sum_{i=1}^{M-1}\sum_{j>i}^{M}\left(\sum_{m=1}^{N} Z_{i,j,m}\right)^2 - S_A$	$df_\Upsilon = \frac{1}{2}(M-1)(N-2)$
Square sum of error	$S_{Error} = S_T - S_A - S_{A\alpha} - S_\Upsilon$	$df_{Error} = \frac{1}{2}(M-1)(M-2)(N-1)$
Total sum of square	$S_T \sum_{m=1}^{N}\sum_{i=1}^{M-1}\sum_{j>i}^{M} Z_{i,j,m}{}^2$	$df_T = \frac{1}{2}NM(M-1)$

Moreover, the unbiased variances and the statistic F values for average preference, the interaction, and combination effect can be calculated (see Table 4-3).

Table 4-3 ANOVA table of Scheffé's method: unbiased variance and statistic F

Factor	Square Sum	Degree of Freedom	Unbiased Variance	Statistic F
Average preference	S_A	df_A	$U_A = \frac{S_A}{M-1}$	$\frac{U_A}{U_{Error}}$
Interaction (Average Preference × Personal Difference)	$S_{A\alpha}$	$df_{A\alpha}$	$U_{Aa} = \frac{S_A}{(M-1)(N-1)}$	$\frac{U_{Aa}}{U_{Error}}$
Combination effect	S_γ	df_γ	$U_\gamma = \frac{S_\gamma}{\frac{1}{2}(M-1)(N-2)}$	$\frac{U_\gamma}{U_{Error}}$
Error	S_{Error}	df_{Error}	$U_{Error} = \frac{S_{Error}}{\frac{1}{2}(M-1)(M-2)(N-1)}$	
Total	S_T	df_T		

When average preference is significant (p-value of statistic F is lower than certain significance level), check confidence interval of preference degree between each pair with a 'Yardstick (Y)' in Eq (4).

$$Y = q_{(M,df,\alpha)}\sqrt{\frac{U_{Error}}{MN}} \tag{4}$$

where $q_{(M,df,\alpha)}$ is a studentised range, df is a degree of freedom of 'Error' in the ANOVA table, and α is a significance level.

After the calculation of the Yardstick, the confidence interval between preference degree of design X_i and design X_j. The lower and upper values of confidential interval show as below.

$$lower\ confidence\ interval = X_i - X_j - Y$$

$$Upper\ confidence\ interval = X_i - X_j + Y$$

If the confidence interval includes 0, then the difference between design X_i and design X_j is not significant.

4.2.1.3 The color preference of trash bins

This study tested 10 bin colors to find out the most, median, and the worst preferred colors for three types of waste bin including compostable waste bin, PET bottle bin and recyclable wastes bin. 10 colors were three primary colors (red, blue, and green), four blended primary colors (brown, yellow, pueple, and orange), and three achromatic colors (white, gray, and black) (see Figure 4-5). The survey questionnaires included 1) compostable waste bin color preference, 2) PET bottle bin color preference, and 3) recyclable waste bin color preference. 45 pairs of the questions were asked respondents in each survey sheet. Survey questionnaires for individual color preference were collected from 2nd to 9th August 2019 at Kasetsart University. The survey questionnaires consisted of 442 respondents for three surveys. The examples of these questionnaires are shown in Figure 4-1A. The most, median, and the worst preferred colors for each bin type were used to make nine color combinations. The color combinations were used for the survey to find out color combination preferences. Questionnaire data for color combination preference was collected from 13th December 2019 to 17th January 2020 at Kasetsart University, Thailand. The survey questionnaires consisted of 151 respondents. The example of these questionnaires is shown in Figure 4-1B.

Figure 4-5 Designed trash bins for survey questionnaires

4.2.1.4 The noticeability of trash bins

The noticeability of trash bins was investigated at three different locations using trash bins of most/median/worst preferred color combinations. Questionnaire data were collected from 13th December 2019 to 19th February 2020 at Kasetsart University, Thailand. The survey questionnaires consisted of 296 respondents. The example of these questionnaires is shown in Figure 4-1C.

4.2.2 On-site experiment

The color combinations of most, median, and the worst preferred color were used to make colored bins for on-site experiment. The experiments were conducted at three different locations from 20th August to 2nd December 2019. Persons of this experimental campaign included students, staffs, and visitors in the buildings. All buildings were placed in the Faculty of Engineering at Kasetsart University, Thailand. The number of persons was the same with the survey campaign. Tested trash bin in this study were for compostable waste, PET bottle, and recyclable waste. Wastes collected by trash bins were monitored and recorded once a week.

The monitored data was the weight of collected wastes. According to a previous work, daily waste generation rates (g/person/day) were non-negligible different during weekdays, but seasons and university's activities (such as examination period) did not significantly affect waste generation (Edjabou et al., 2015). Therefore, weekly data was used to avoid the effect of weekdays. Experiments were conducted at three different locations including building X, building Y, and building Z, as shown in Figure 4-6. All color combinations were repeated 5 times in an alternate manner for a week per time. Total 15 weeks of data were collected for each color combination.

In this study, the capture rate of certain waste was defined as the weight percentage of the waste correctly disposed to the target trash bin in the total waste collected by all trash bins, as shown in Eq. (5). Therefore, the capture rate indicates the difficulty level to find out the appropriate bin. High capture rate means that it is easy to find the appropriate bin for waste disposal.

$$\text{Capture rate} = \frac{\text{The weight of correctly disposed waste in the trash bin}}{\text{The weight of waste collected in all trash bins}} \times 100\% \tag{5}$$

The contamination rate was analyzed in this study, as shown in Eq. (6). It is the percentage of incorrectly disposed waste in the total waste collected by a target trash bin. The contamination rate indicates the difficulty level to misunderstand the appropriate bin. High contamination rate means that it is easy to misunderstand the appropriate bin.

$$\text{Contamination rate} = \frac{\text{The weight of incorrectly disposed waste in the trash bin}}{\text{The weight of total wastes collected in all trash bins}} \times 100\% \tag{6}$$

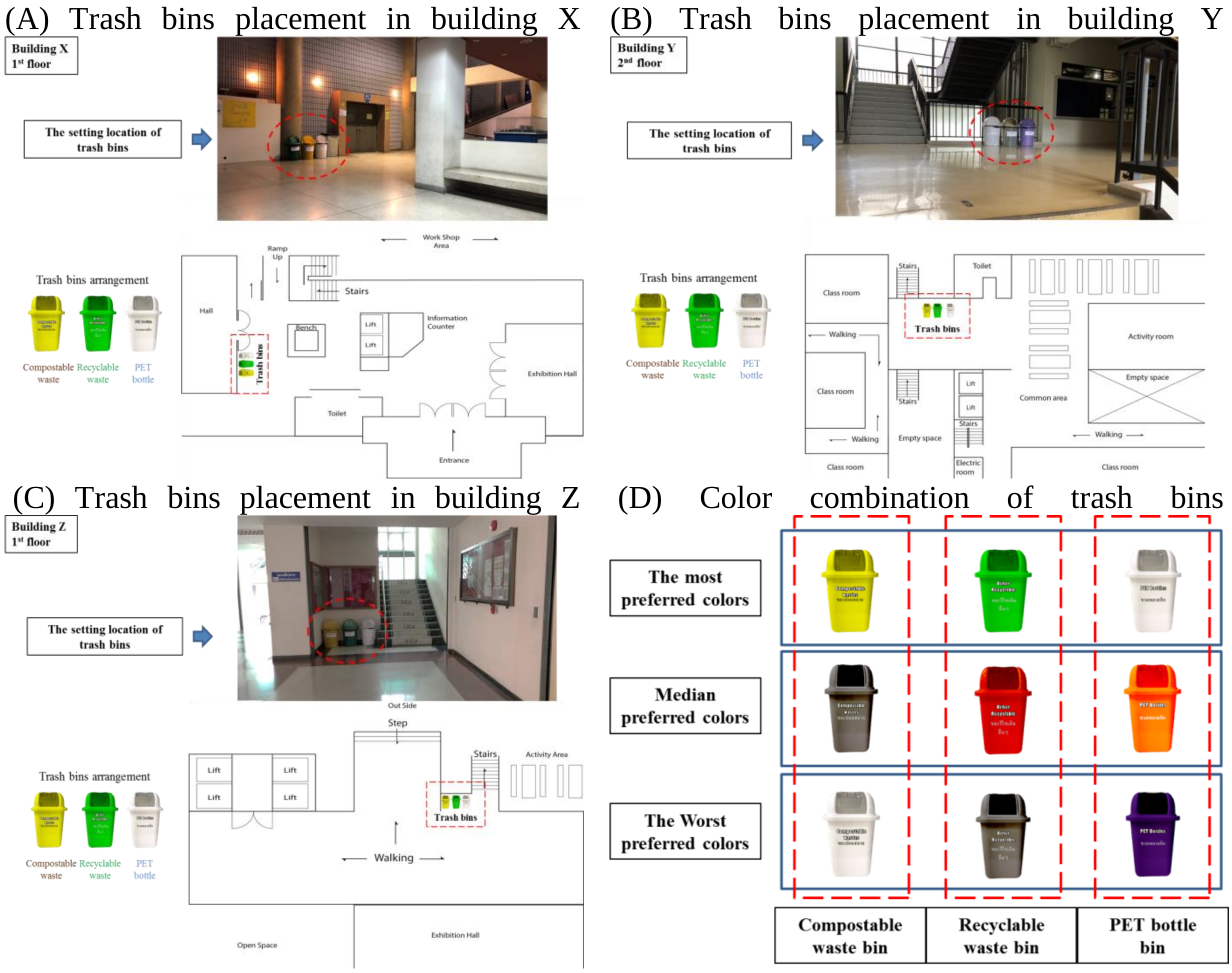


Figure 4-6 Trash bin setting in the on-site experiments.

The effective capture rate was also analyzed in this study, as shown in Eq. (7). It is the developed waste separation efficiency indicator. Sometimes the capture rate seems to be high while the contamination rate is also high, in fact it represented no waste sorting (Huang et al., 2018). The lower contamination rate is the closer the effective capture rate value with the capture rate.

$$\text{Effective capture rate} = \left(\frac{\text{proportion of other wastes} - \text{contamination rate}}{\text{proportion of other wastes}}\right) \times \text{Capture rate} \qquad (7)$$

where proportion of other wastes = the weight of the other wastes in all trash bins/the weight of total wastes collected in all trash bins

4.2.3 Statistical test to identify effects of waste collection and separation performance

Multi-way ANOVA and multiple comparisons test (Scheffé's method) with significant level of 5% were used to identify significant differences between experimental results. When statistical test suggested rejection of null hypothesis which assumes no difference between data set, the difference would be always described "significant" or "non-negligible" in following sections.

4.3 Results and discussions

4.3.1 Color preference of trash bins

The results of color preference for each bin type are shown in Figure 4-7. For compostable waste bin, yellow is the most preferred color (preference score (PS) = 0.321). Gray and white are the median and the worst preferred colors, respectively (PS = -0.00886 for gray, and -0.147 for white). For PET bottle bin, white and yellow are the most and the second preferred colors, respectively (PS = 0.172 for white, and 0.105 for yellow). However, the statistical test suggested that the difference of color preference between yellow and white were not significant at 5 % significance level. Orange and purple are the median and the worst preferred colors, respectively (PS = 0.0149 for orange, and -0.274 for purple). For recyclable waste bin, yellow and green are the most and second preferred colors (PS = 0.351 for yellow, and 0.242 for green). The statistical test also suggested that preferences of yellow and green were not significantly different. Red and gray are the median and the worst preferred colors, respectively (PS = -0.00240 for red, and -0.228 for gray).

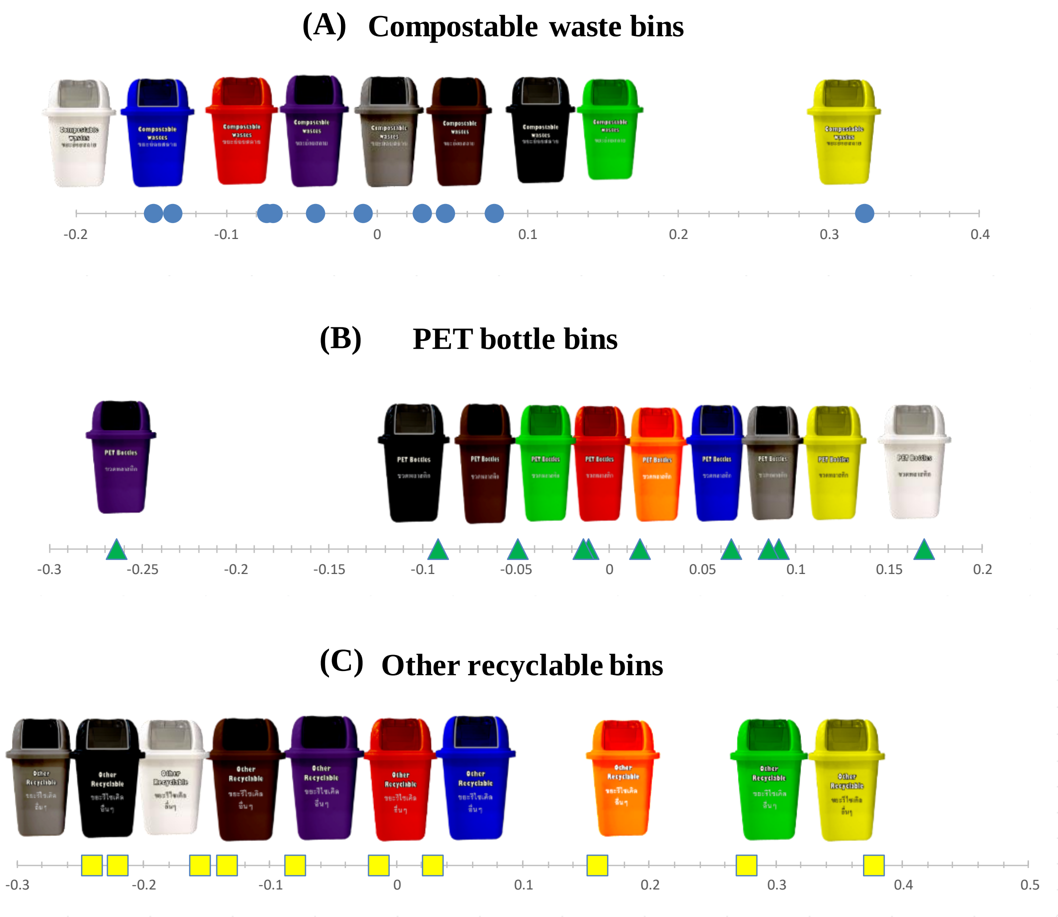


Figure 4-7 Bin color preference scores

In general, color preference is different in each region (Ou et al., 2004). In fact, other researchers in different countries found different results in the order of bin color selection. In the US, for example, brown, yellow, and red were the top, moderate, and the worst rated for compostable waste bin, respectively (Schloss et al., 2018). In Greece, preferred colors were hues of green and brown for compostable waste bin (Keramitsoglou and Tsagarakis, 2018). On the other hand, the type of wastes is still important for color preference. In a previous work of the authors' group (Dilinazi et al., 2018), it was found that white was the most preferred color for PET bottle bin in case of Japanese respondents. Moreover, Schloss et al. also reported that white bin was the top rank for plastic wastes (Schloss et al., 2018). Common preference of white color for plastic wastes might show that waste type perception is related to bin color selection. According to the survey in this study, yellow is the most commonly preferred color for all bin types. Furthermore, green is second preferred color for compostable waste bin and recyclable waste bin. In Thailand, yellow and green are usually used to label recyclable wastes and compostable wastes, respectively. In Greece, blue and green, which were used for recyclable waste bin, were top preferred colors for recyclable waste bin (Keramitsoglou and Tsagarakis, 2018). These results suggest that commonly used colors of public bins let respondents prefer the same color. In addition, personal color preference might be also important. It can let people tend to like objects labeled with the same preferred color (Schloss et al., 2013). Therefore, it is suggested that regionality, commonly used colors for public bins, and personal color preference should be taken into consideration when psychological mechanisms of bin color selection is analyzed. Figure 4-8 shows a color-coding systems designed based on the previous work (Schloss et al., 2018). The same color might be associated with multiple types of waste. In fact, many objects can be associated with the same color (Setlur and Stone, 2015). In this study, yellow is the most preferred color for both compostable waste bin and recyclable waste bin. Because there is no significant difference of color preference between yellow and green for recyclable waste bin, the authors assigned green to be the most preferred color instead of yellow for recyclable waste bin when the preferences of color combinations were tested.

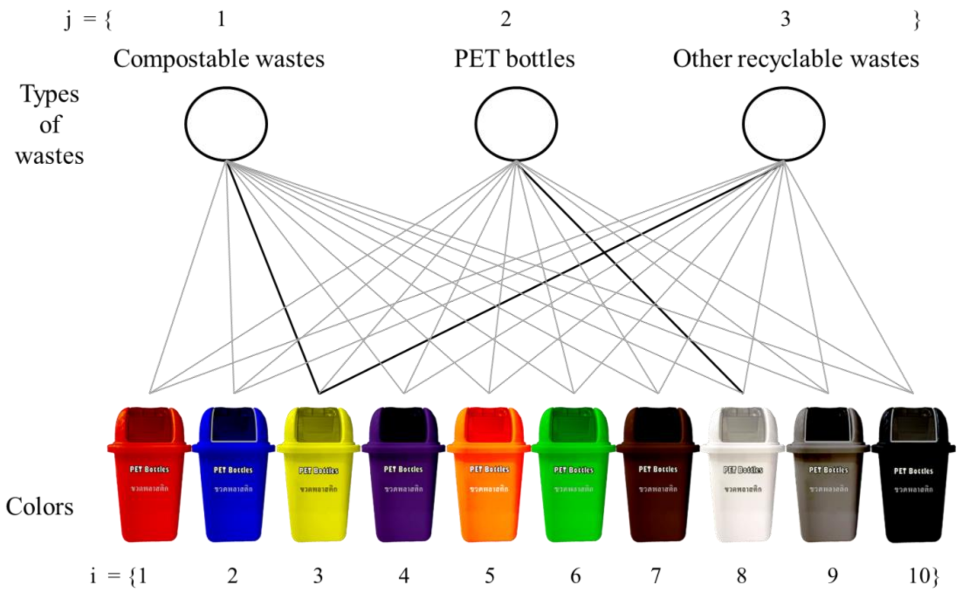


Figure 4-8 The color-coding system of trash bins.

The most, median, and the worst preferred colors for each bin type were used to make color combination. The arrangements of commingled trash bins from left to right side were compostable wastes bin, PET bottles bin, and recyclable wastes bin. Color combination A was the combination of the highest preferred colors. Therefore, yellow, white, and green were selected for compostable waste bin, PET bottle bin, and recyclable waste bin, respectively. Color combination E was the combination of median preferred colors. They were gray for compostable waste bin, orange for PET bottle bin, and red for recyclable waste bin, respectively. Color combination I was the combination of the lowest preferred colors. They were white for compostable waste bin, purple for PET bottle bin, and gray for recyclable waste bin, respectively. Other color combinations (B, C, D, F, and G) were combinations of the highest, median or the worst preferred colors. The results of color combination preferences are shown in Figure 4-9. Color combination A, G, and F were the best, median, and the worst preferred colors (0.655 for combination A, 0.0545 for combination G, and -0.620 for combination F, respectively). The combination of the highest preference colors (combination A) received top preference. The combinations of median and the lowest preferred colors (combination G, E, H, I, and F) were given lower preferences (fifth to ninth from the top). Figure 4-10 shows the comparison between color combination preferences and the average scores of individual color preferences. Strongly positive correlation was found ($r^2 = 0.828$). A t-test suggested that they were significantly correlated ($p = 0.000327$). According to multiple regression analysis, however, individual color preferences and error term were not satisfactory to predict color combination preference. Coefficients of these terms were not regarded significant at 5% significance level ($p = 0.16$ to 0.83, see Table S4-1). If individual color preference exactly reflects the preference of single association between color and waste type, these results are consistent with the global assignment hypothesis when people perform color assignment inference (Schloss et al., 2018) . It predicts that people consider not only the strength of single association between the waste and highly preferred color but also the relation strengths between all types of waste and colors within the scope of the color-cording system. In other words, they determine which assignments between colors and wastes optimize the color-waste associations of the entire set. Even when a color combination includes certain color specifically preferred for one type of waste, it might be less preferred than other color combinations including weakly associated colors. To predict color combination preference, the model should include not only individual color preference but also the optimization term of entire color-waste associations.

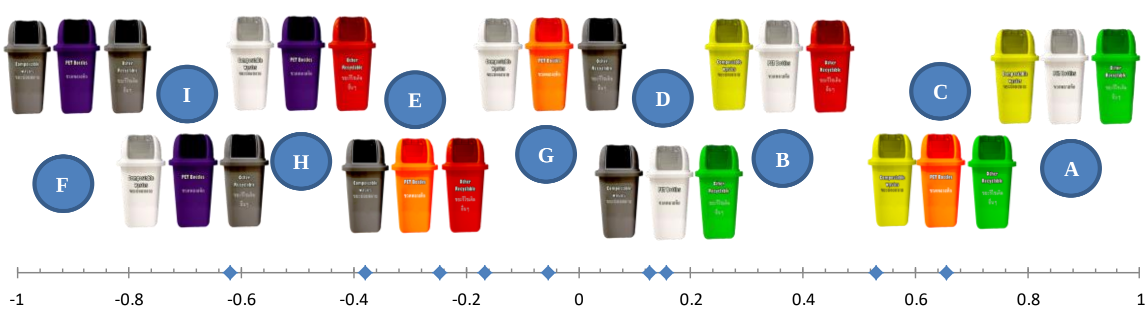


Figure 4-9 Color combination preference score

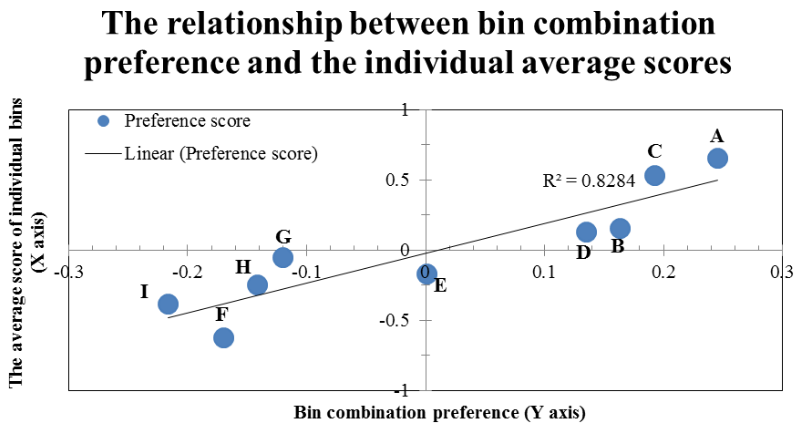


Figure 4-10 The relationship between combination preference and average score of individual bins

4.3.2 Experimental results of waste collection and waste separation efficiencies

4.3.2.1 Waste collection rate

The impacts of color combination preference on waste collection rate, capture rate, contamination rate, and effective capture rate were checked. The monitoring results are shown in Figure 4-11 and 4-12. Firstly, waste collection rates were analyzed by two-way analysis of the variance (ANOVA) focusing on color combination and the location where each type of trash bin was set. The significant differences of waste collection rates between the locations were found (p = 0.00123 for compostable waste, 0.00562 for PET bottle, and 0.00202 for recyclable waste, respectively). On the other hand, the collection rate had no significant difference between color combinations. It means that the examined locations affected waste collection while the color combination of trash bins gave no impact on it.

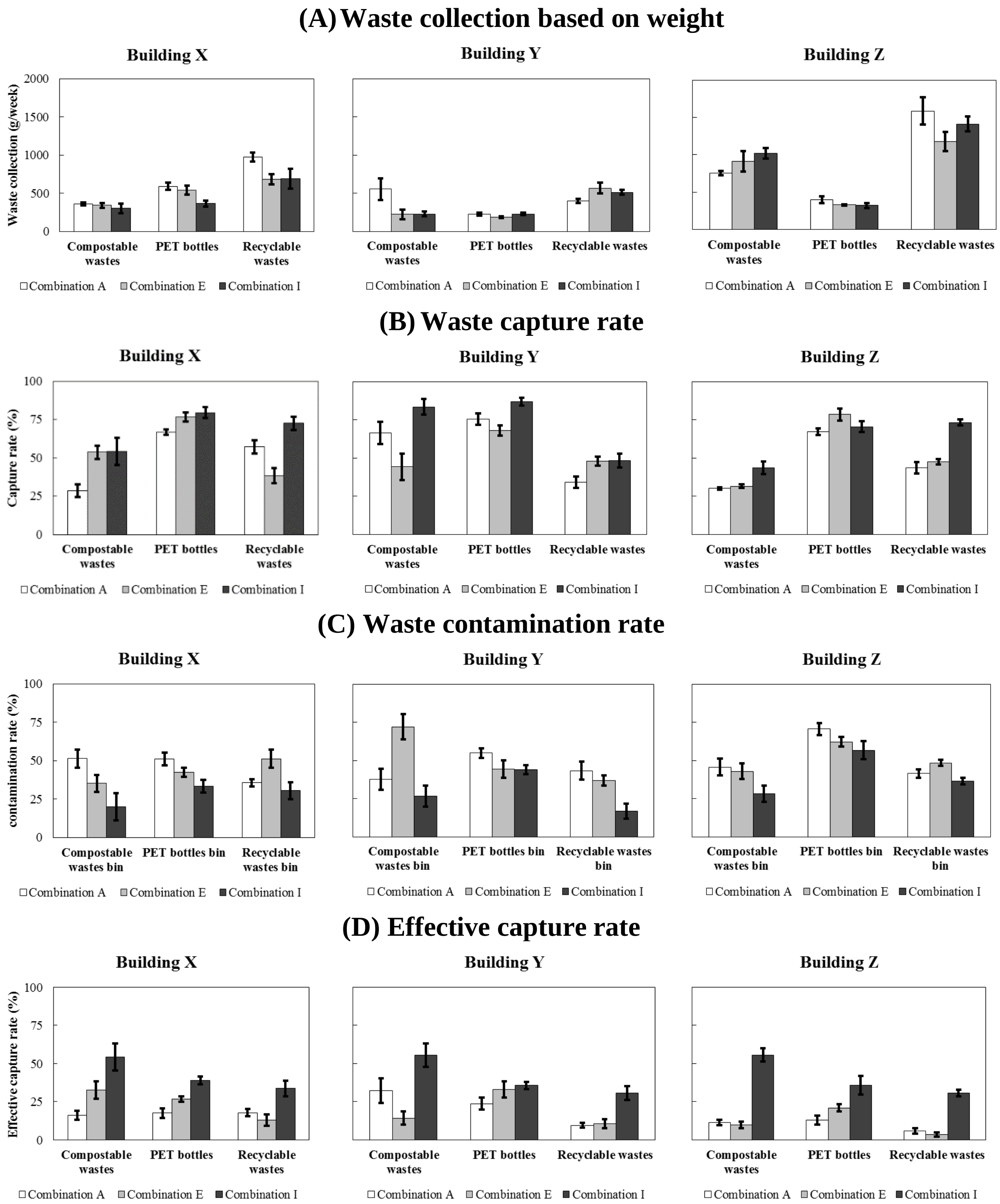


Figure 4-11 The results of collection and separation performances.

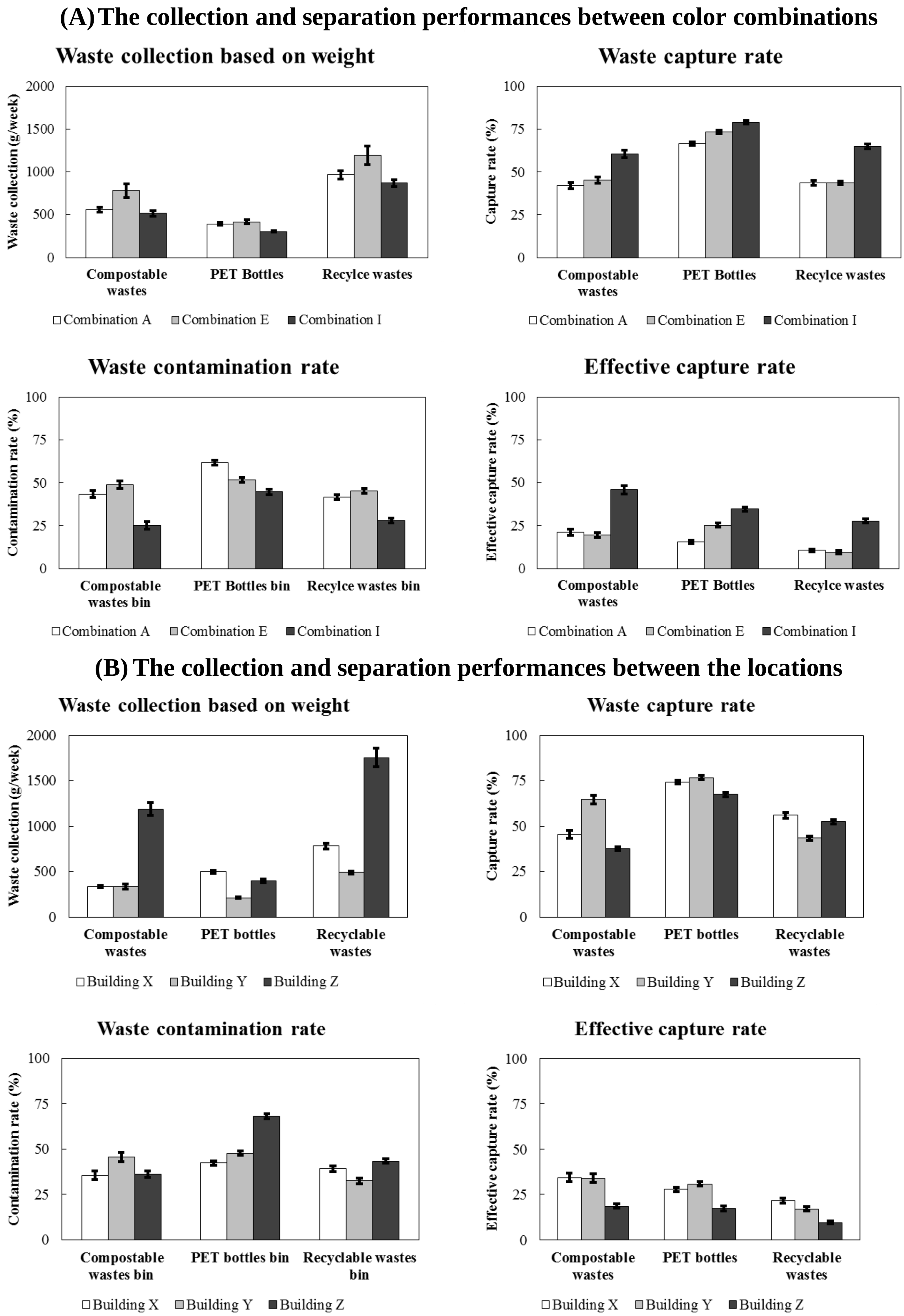


Figure 4-12 The experimental results of color combination (A) and locations (B).

4.3.2.2 Color combination preference vs waste separation efficiency

The waste separation efficiencies including the capture rate, the contamination rate, and the effective capture rate were analyzed by multi-way ANOVA and multiple comparison test focusing on color combination, location, and types of waste. The results were summarized in Table 4-4. The ANOVA test suggested that the color combination gave significant impacts on all waste separation efficiencies ($p = 0.00104$ for capture rate, 0.00471 for contamination rate, and 0.0000264 for effective capture rate, respectively). Furthermore, the multiple comparison test also suggested the capture rate under the conditions of color combination I was significantly higher than those under color combination A ($p = 0.00301$) and combination E ($p = 0.0103$). In addition, the effective capture rate under color combination I was also significantly higher than those under color combination A ($p = 0.000146$) and combination E ($p = 0.000704$). On the other hand, the contamination rate under the color combination I was significantly lower than those under color combination A ($p =0.0193$) and combination E ($p = 0.0153$). Although more preferred color combination was expected to contribute to better waste separation performance, the results were opposite. The lowest preferred color combination performed the highest waste separation efficiencies.

Table 4-4 The analysis results of multiple comparisons.

Factors	Tested value		Capture rate (%)				Contamination rate (%)				Effective capture rate (%)			
	Value 1	Value 2	Value 1	Value 2	% difference	p value	Value 1	Value 2	% difference	p value	Value 1	Value 2	% difference	p value
Color combination	A	E	52.17	54.04	No significance		47.94	48.41	No significance		16.27	18.26	No significance	
	A	I	52.17	68.07	53%	0.00301	47.94	32.55	76%	0.0193	16.27	36.15	152%	0.000146
	E	I	54.04	68.07	46%	0.0103	48.41	32.55	78%	0.0153	18.26	36.15	132%	0.000704
Location	X	Y	58.67	61.63			38.94	41.86			27.80	27.19	No significance	
	X	Z	58.67	53.98	No significance		38.94	48.09	No significance		27.80	15.68	111%	0.0317
	Y	Z	61.63	53.98			41.86	48.09			27.19	15.68	107%	0.0440
Types of waste	Compostable	PET bottle	48.41	74.39	85%	6.21×10^{-7}	39.98	51.06			28.24	26.51	No significance	
	Compostable	Recyclable	48.41	51.48	No significance		39.98	37.86	No significance		28.24	15.92	112%	0.0284
	PET bottle	Recyclable	74.39	51.48	73%	1.11×10^{-5}	51.06	37.86			26.51	15.92	No significance	
Building X	Compostable	PET bottle	45.55	74.38	96%	0.00178	35.47	42.27			34.33	27.64		
	Compostable	Recyclable	45.55	56.08	No significance		35.47	39.08	No interaction		34.33	21.42	No interaction	
	PET bottle	Recyclable	74.38	56.08			42.27	39.08			27.64	21.42		
Building Y	Compostable	PET bottle	64.66	76.77	No significance		45.46	47.72			33.91	30.77		
	Compostable	Recyclable	64.66	43.46	78%	0.0297	45.46	32.40	No interaction		33.91	16.90	No interaction	
	PET bottle	Recyclable	76.77	43.46	111%	0.000249	47.72	32.40			30.77	16.90		
Building Z	Compostable	PET bottle	35.02	72.03	138%	4.24×10^{-5}	39.00	63.18			16.47	21.13		
	Compostable	Recyclable	35.02	54.89	88%	0.0451	39.00	42.10	No interaction		16.47	9.45	No interaction	
	PET bottle	Recyclable	72.03	54.89	No significance		63.18	42.10			21.13	9.45		

4.3.2.3 Location of trash bins vs waste separation efficiency

The significant difference of effective capture rates in various locations were found ($p = 0.0129$). The multiple comparison test suggested that the effective capture rate in building Z was significantly lower than those in building X ($p = 0.0317$) and building Y ($p = 0.0440$). On the other hand, the location gave negligible impacts on capture rate and contamination rate. According to previous works, inconvenient condition weakened waste separation performance (Lee et al., 2017). On the other hand, the convenience of bin setting location improves waste separation efficiencies (DiGiacomo et al., 2018). They look inconsistent with the results of this study, in which the location did not significantly affect capture rate and contamination rate. In our previous work, however, distance to trash bins gave no significant impact on capture rate and contamination rate when within 8 meters (Leeabai et al., 2019). The distance in all tested locations might have been too short to differentiate the convenience of trash bin for waste separations.

4.3.2.4 Waste type vs waste separation efficiency

The ANOVA test suggested that capture rate, contamination rate, and effective capture rate between types of waste were significantly different ($p = 0.00621$ for capture rate, 0.0345 for contamination rate, and 0.0157 for effective capture rate, respectively). According to the multiple comparison test, however, the difference of the contamination rate between types of waste was slightly insignificant ($p = 0.0534$). The capture rate of PET bottle was significantly higher than those of compostable waste ($p = 6.21 \times 10^{-7}$) and recyclable waste ($p = 1.11 \times 10^{-5}$). Nevertheless, the effective capture rate of compostable waste was significantly higher than that of PET bottles ($p = 0.0284$). According to the results, it suggested that PET bottles were the easiest waste for correct disposal compared with other wastes while PET bottle bin was easier contaminated than the other bins. Hence, the effective capture rate of PET bottle was the lowest.

There was no finding on the interactions between color combinations, locations, and waste types, excluding the interaction between waste types and locations was found for capture rate ($p = 0.00622$). The capture rates were significantly different between waste types even in the same building. For example, the capture rate of PET bottle was significantly higher than that of compostable waste in both building X ($p = 0.00178$) and building Z ($p = 0.0000424$). The capture rate of PET bottle was also significantly higher than that of recyclable waste in building Y ($p = 0.000249$). On the other hand, the capture rate of compostable waste was significantly higher than that of recyclable waste in building Y ($p = 0.0297$), but significantly lower in building Z ($p = 0.0450$). This contradictory result seems to have been caused by interaction effect. It will be discussed in section 4.3.4.

4.3.2.5 Behavioral mechanisms of trash bin contamination

Figure 4-13A shows the comparison between the contamination rate of PET bottle bin and the proportion of other wastes (compostable waste and recyclable waste). Significantly positive correlation was found ($R^2 = 0.511$, $p = 1.72\times10^{-8}$). The contamination rate of recyclable waste bin was also significantly correlated with the proportion of other wastes (compostable waste and PET bottle) ($R^2 = 0.510$, $p = 1.783\times10^{-8}$, see Figure 4-13B). On the other hand, there was no significant correlation between the contamination rate of compostable waste bin and the proportion of other wastes (PET bottle and recyclable waste) (see Figure 4-13C). These results give some insights on how contamination happened for each trash bin. In the case of PET bottle bin, contamination rate was also significantly correlated with the proportion of only recyclable waste ($R^2 = 0.225$, $p = 0.000988$), but it was not with compostable waste. Persons in the experimental campaign might feel a little confusion to sort PET bottle and recyclable waste like plastic containers. The persons wrongly disposed of recyclable waste into PET bottle bin and it mainly caused the contamination of PET bottle bin. On the other hand, contamination rate of recyclable waste bin was significantly correlated with the proportion of compostable waste ($R^2 = 0.373$, $p = 8.59\times10^{-6}$), but not with PET bottle. It is reasonable because remaining foods in food packaging containers contaminated recyclable waste bin. Negligible correlation with PET bottle agrees with the behavioral mechanism proposed above. When people are confused to sort PET bottle and recyclable waste, they likely dispose of them together into PET bottle bin rather than recyclable waste bin. It results in small or ignorable correlation between the contamination rates of recyclable waste bin and PET bottle proportion. The contamination rate of compostable waste bin was not significantly correlated with the proportion of any wastes. It suggests that contamination by PET bottle or recyclable waste was random.

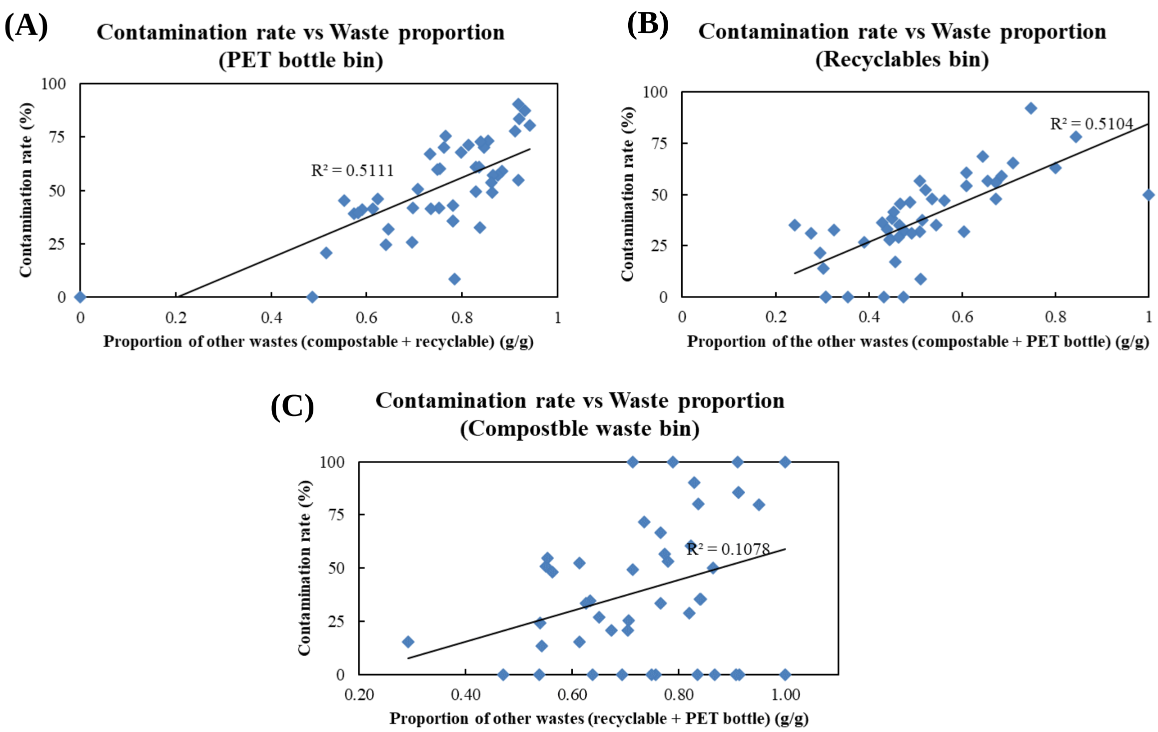


Figure 4-13 The results of the correlations between waste contamination rate in a target and waste proportion of inappropriate waste (A; PET bottle, B; recyclables waste, and C; compostable waste)

4.3.2.6 Effective capture rate vs waste collection rate

When waste collection rates were compared with effective capture rates, negative correlations were found for all types of wastes (see Figure 4-14). The effective capture rate of PET bottle linearly decreased with increase of total waste collection ($R^2 = 0.999$, see Figure 4-14). A t-test suggested that the effective capture rate of PET bottle and total waste collection is significantly correlated ($p = 0.0124$). However, the significant correlations between the effective capture rate of the other wastes and total waste collection were not found. It was caused by high effective capture rate of compostable waste and recyclable waste in building X. In building X, a lecturer who gave courses at the lecture hall of 1st floor encouraged students to separate their wastes. This educational encouragement might have contributed into higher effective capture rate (Sidique et al., 2010). In addition, noticeability of trash bins might also have contributed into higher effective capture rate in building X. It would be discussed in section 4.3.4.

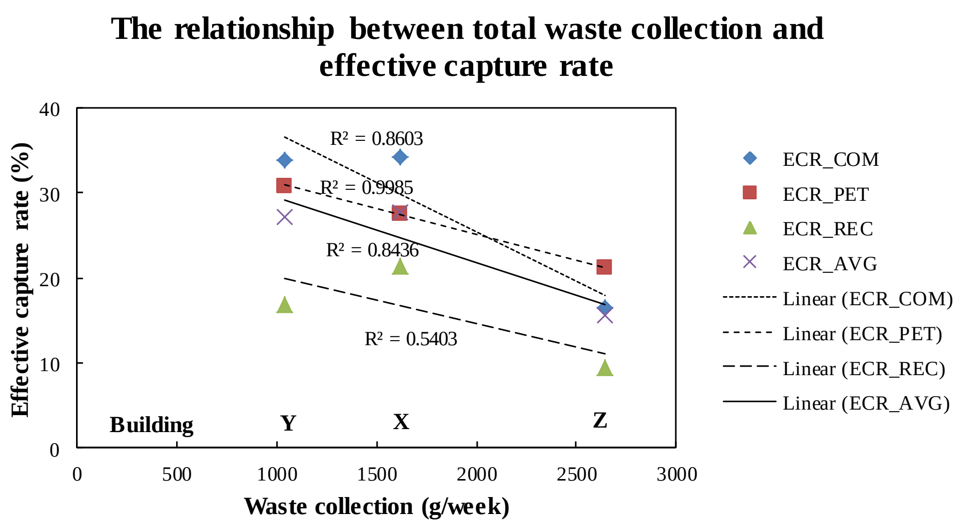


Figure 4-14 correlation between waste the effective capture rates and total waste collection

4.3.3 Noticeability of trash bins

Figure 4-15A shows that the noticeability (NA) of trash bins with different color combinations at different locations. In any locations, trash bins with the lowest preferred color combination (color combination I) had significantly lower noticeability than those of trash bins with the highest and median preferred color combination. On the other hand, the noticeability depended on the location when the highest and median preferred color combinations were tested. In building X, for example, the noticeability of trash bins with color combination A (NA = -0.162) and color combination E (NA = -0.124) were not significantly different. On the other hand, color combination A gave significantly lower noticeability than color combination I in building Y (NA = -0.00919 for color combination A, and 0.225 for color combination E), but significantly higher noticeability in building Z (NA = 0.581 for color combination A, and 0.448 for color combination E) at 0.1 % significance level. According to previous works, colors gave significant impacts on visual search time and the noticeability of objects (Bzostek and Wogalter, 1999; Einakian and Newman, 2019). In this study, the difference of bin color combinations also gave non-negligible impact on trash bin noticeability. Moreover, the environment affects the searching performance and the noticeability of objects (Kruijff et al., 2018). It could be noted that not only the color of trash bin but also the environment around the bins gave the impact on the noticeability of trash bins. Therefore, a polynomial model including color combination preference and the environment terms was tested to predict the noticeability of trash bins as described below.

$$NA=0.241PS+0.276EN \tag{8}$$

where NA is noticeability of trash bins, PS is color combination preference, and EN is environment effect. They are all unitless. The model successfully predicted the noticeability (see Figure 4-15B).

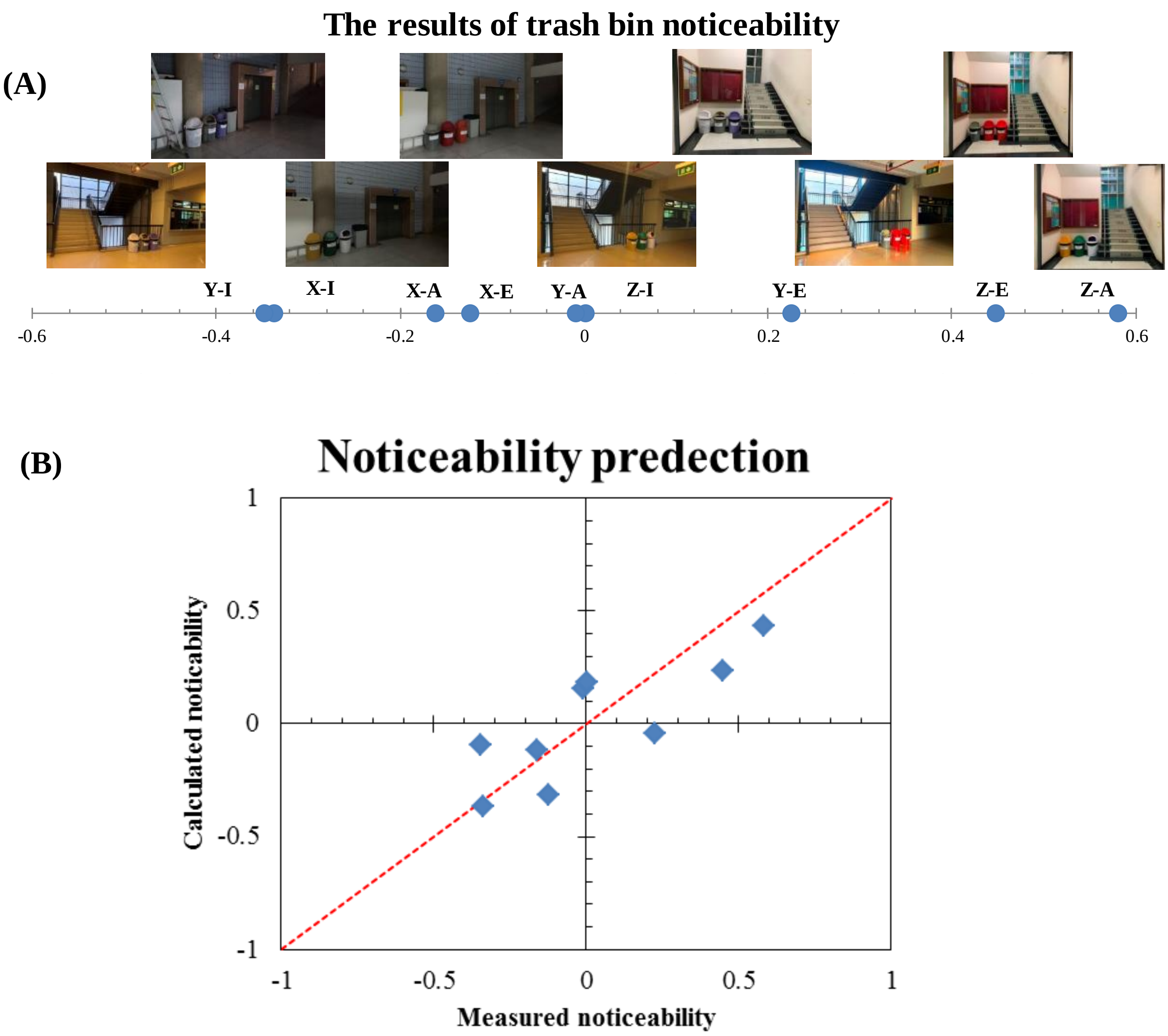


Figure 4-15 Noticeability of trash bins in different locations.

4.3.4 The impact of trash bin noticeability on waste separation efficiency

The waste separation efficiencies were compared with the noticeability of trash bins. Waste collections, capture rates, and contamination rates were not significantly correlated with the noticeability excluding two cases. Two exceptional cases were negative correlation between the capture rate of compostable waste and the noticeability (R^2 = 0.421, p = 0.0293) and positive correlation between the contamination rate of PET bottle and the noticeability (R^2 = 0.663, p = 0.00377). On the other hand, the effective capture rate had significant correlations with the noticeability for all types of wastes (see Fig. 4-16A to 4-16D). The results showed that the effective capture rates decreased with the increase of noticeability (R^2 = 0.700, p = 0.00247 for compostable waste, $R^2 = 0.430$, $p = 0.0275$ for PET bottle, and $R^2 = 0.740$, $p = 0.00147$ for recyclable waste). These results can be summarized that trash bins with lower noticeability performed higher waste separations. Noticeability is commonly associated with behavioral attention (Harley and Martin, 1999). Trash bins with less noticeable color combinations would require larger attention to be found. When people have strong motivation of waste disposal, it gives people sufficient attention to find trash bins even with low noticeability. Strong motivation for waste disposal and/or large attention to trash bins might contribute to waste separation encouragement. In fact, motivation is a key driver for the establishment of waste separation habit (Knickmeyer, 2019). According to the results, low noticeability of trash bin could improve the separation performance. However, if trash bins are too difficult to find, they could not collect wastes from waste disposer. Hence, too low noticeability of trash bin might let people improper dispose of their wastes on the ground. It suggests that trash bins should be set with appropriate noticeability to motivate people separate of their waste.

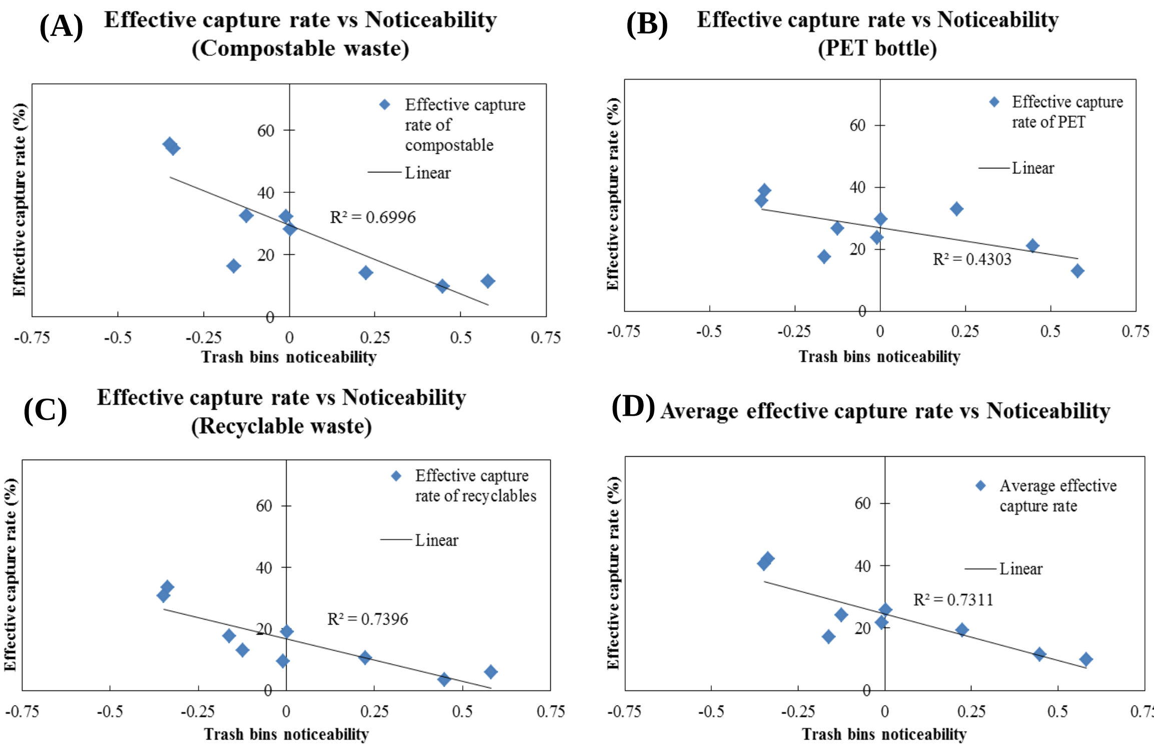


Figure 4-16 The correlation between effective capture rate of waste and noticeability of bins (A; compostable waste, B; PET bottle, C; recyclable waste, and E; average effective capture rate of all wastes).

The noticeability also explains insignificant correlations between total waste collection and the effective capture rates of compostable waste and recyclable waste in section 4.3.2.6 (see Figure 4-14). These insignificances were caused by higher effective capture rates in building X than those in building Y. Average noticeability of trash bins tested in building X were lower than that in building Y (-0.208 In building X and -0.0439 in building Y). According to Figure 4-16A and 4-16C, lower noticeability of trash bins results in higher effective capture rate.

In section 4.3.2.4, interaction effect between location and waste type was proposed to explain the contradictory result, in which the capture rate of compostable waste was significantly higher than that of recyclable waste in building Y but significantly lower in building Z. It might be also explained by the noticeability. Comparisons between the noticeability of trash bins and the capture rates of compostable waste and recyclable waste in building Y and Z are shown in Figure 4-17. The capture rates of compostable waste significantly decreased with increase of the noticeability ($p = 0.00425$). On the other hand, the capture rates of recyclable waste were constant regardless of the noticeability ($p = 0.376$). Different impacts of the noticeability on capture rates of these wastes seem to induce the interaction effect. As proposed in section 4.3.2.5, recyclable waste is likely disposed into PET bottle bin rather than recyclable waste bin when people are confused to sort PET bottle and recyclable waste. Even when people have strong motivation to dispose of recyclable waste, but they are confused for sorting, recyclable waste might be dropped into PET bottle bin together with PET bottle and thus it gives no impact on capture rate.

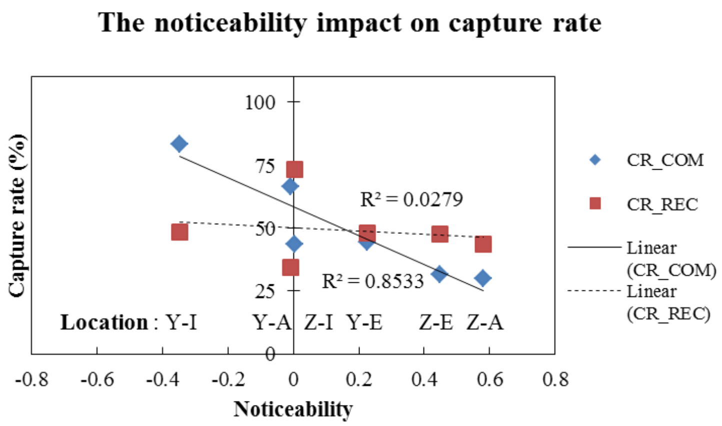


Figure 4-17 The impact of noticeability on capture rate

4.4 Conclusion

This study investigated the effects of color preference and noticeability of trash bins on waste collection, capture rate, contamination rate, and effective capture rate. The tested bins are for compostable waste, recyclable waste, and PET bottle. The experiments included field survey and on-site experiment. The survey questionnaires consisted of 889 respondents. The color preference and noticeability of trash bins were evaluated by pairwise comparison. It was found that yellow bin is the most commonly preferred bin. The on-site experiments were conducted with the combination of the most, median, and the worst color preference in three different locations. Monitoring results were analyzed by statistical tests to justify effects and experimental errors. The examined locations affected waste collection and effective capture rates. On the other hand, the location gave no impacts on capture rate and contamination rate. Waste collections were not significant difference with various color combinations. However, it was found that the lowest preferred color combination performed the highest waste separation efficiencies. Perceptive of waste classification gave the impact on segregation efficiencies. PET bottles were the easiest waste for correct disposal compared with other wastes while PET bottle bin was more easily contaminated than the other bins. People might feel a little confusion to sort PET bottle and recyclable waste like plastic containers. When people are confused to sort them, they likely dispose of them together into PET bottle bin rather than recyclable waste bin. The education might be needed to improve the understanding in the category of waste segregation. The effective capture rate had significant correlations with the noticeability for all types of wastes. Trash bins with less noticeable color combinations would require larger attention to be found. It might contribute to waste separation encouragement. On the other hand, if trash bins are too difficult to find, they hardly collect waste from waste disposer. Hence, too low noticeability of trash bin might let people improper dispose of their wastes on the ground. It suggests that trash bins should be set with appropriate noticeability to motivate people separate of their waste. The appropriate setting condition might be useful to improve waste management in public areas with high population density like shopping mall, school, official places and airports.

5. The design analysis of trash bin

5.1 Background

5.1.1 Trash bin design

AS mentioned in Chapter 1, design of trash bin gave significantly impact on waste segregation behavior. The terrible or environmentally offensive colored bin was given one of the main reasons for non-participation in waste separation (McDonald and Oates, 2003). Moreover, the monitoring results of Chapter 4 also confirmed that design of trash bin in term of bin color gave impacts on separation performances. Thus, appropriate design of trash bin affects the motivation of people to separate of their waste. Not only the psychological preference should be considered, but the physical usage of trash bin is also important in term of the design. Good trash bin design should support people utility such as the slot littering position, it should be set to make people feel convenient to dispose of their waste.

5.1.2 PET bottle bin design

Three different visual acuity (VA) conditions (clear, blurred, and heavily blurred) were applied on each design for the surveys. Clear condition means it was not applied with any treatments. This data will be the control condition. In addition, this study also investigated three more visual impairment such as diabetic retinopathy (DR), macular degeneration (MD), and retinitis pigmentosa (RP) in three severity condition (mild, moderate, and severe) for each impairment to uncover which design is the most preferred by people with these difficulties. Ageing society and sickliness of eyesight is now concerning in Japan as well as the other countries. The design attributes are basically shape, slot position, and label types for each bin. The purpose of this study was to understand design attributes preference. The preference might introduce segregation willingness for effective waste management in public areas. Eight PET bottle bin designs were tested. The collected data by web-questionnaires were scaled by pairwise comparison with Scheffé's method to calculate psychological preference.

5.1.3 Combustible waste bin design

The authors focused on design trash bin for the major of waste as combustible. This study designed a total of seven trash bin designs varying between the slot positions, visibility, and lid attachment. Designed trash bins are performed in three dimensional shapes (3D). This research included survey questionnaires and statistical analysis, which analyzed different designed trash bins to find out the best in terms of psychological preference.

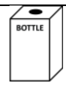
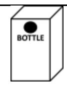
5.2 Methodology

5.2.1 Designed trash bin

The trash bin designs in this study are including PET bottle bin with 2-dimensional shapes (2D) and combustible waste bin with 3-dimensional shapes (3D). The designed bins are including various designing parameters. The designing parameters are shape of bin, slot position, labeling signage, and visibility. In each experiment, trash bins were designed with 3 different designing attributes.

Eight designed bins covered all various designing parameters for PET bottle bin as shown in Table 5-1. Trash bins in this experiment are varying shape, labeling signage, and slot position. Design A is cylinder shape with letter label and top slot position. Design B is cylinder shape with letter label and front slot position. Design C is cylinder shape with illustration (image) label and top slot position. Design D is box shape with letter label and top slot position. Design E is box shape with letter label and front slot position. Design F is box shape with illustrated label and top slot position. Design G is bottle shape with letter label and top slot position. Design G is bottle shape with letter label and front slot position.

Table 5-1 Sumarized designs of PET bottle bins

Design	A	B	C	D	E	F	G	H
Bin image								
Shape	*Cylinder*			*Square Box*			*Bottle*	
Label	*Letter*		*Image*	*Letter*		*Image*	*Letter*	
Slot position	*top*	*front*	*top*	*top*	*front*	*top*	*top*	*front*

For combustible bin designs, there are seven designed bins to identify the design preference (see Figure 5-2). Trash bins in this experiment are varying slot position, visibility, and lid attachment. Three different slot position are top (Design TB1, TB4, and TB7), slope (Design TB2 and TB5), and front (Design TB3 and TB6). Design TB1, TB2, TB3, and TB7 are designed with the visibility on body. Only design TB7 is attached lid.

Table 5-2 Sumarized designs of combustible waste bins

Design	TB1	TB2	TB3	TB4	TB5	TB6	TB7
Bin image							
Slot position	*Top*	*Slope*	*Front*	*Top*	*Slope*	*Front*	*Top*
Visibility	*Yes*			*No*			*Yes*
Lid adding	*No*						*Yes*

5.2.2 Survey questionnaires

5.2.2.1 Sample size and analysis methods

Pairwise comparison matrices are frequently applied in multi-criteria decision making (Bozóki, S. and J. Fülöp, 2016), preference analysis of trash bins is also the one of multi-criteria decision to find out the best among any designs. Binary pairwise comparison method was using to find out the best designed trash bin in statistical preference.

- PET bottle bin design

For visual impairment (VI), there are three VI degrees including clear, blurred (mild), and heavily blurred (severe) for VA, and mild, moderate, and severe for DR, MD, RP (see Figure 5-1). Clear impairment is perfectly clear image, all visual information is readable without any problems, it is the control. Mild impairment is mild treated, the visual information including shape of bins, letters, and images could be still readable but it could take some delay due to unclearness of the image. Moderate impairment is moderate treated, the visual information including shape of bins, letters, and images could be difficult to read. Severe impairment is extremely treated so that any information from the image is hard to understand without additional information. These simulated images were used for the questionnaires. In each questionnaire, there is 28 pairs of the question. The survey questionnaires were conducted from 19th December 2018 to 21st January 2019. Each of the questionnaire, we got 420 survey participants with balanced gender and balanced age from 20's to 60's with 10-years interval. Each psychometric analysis method applied with the all answers by pairwise comparison with Scheffé's method.

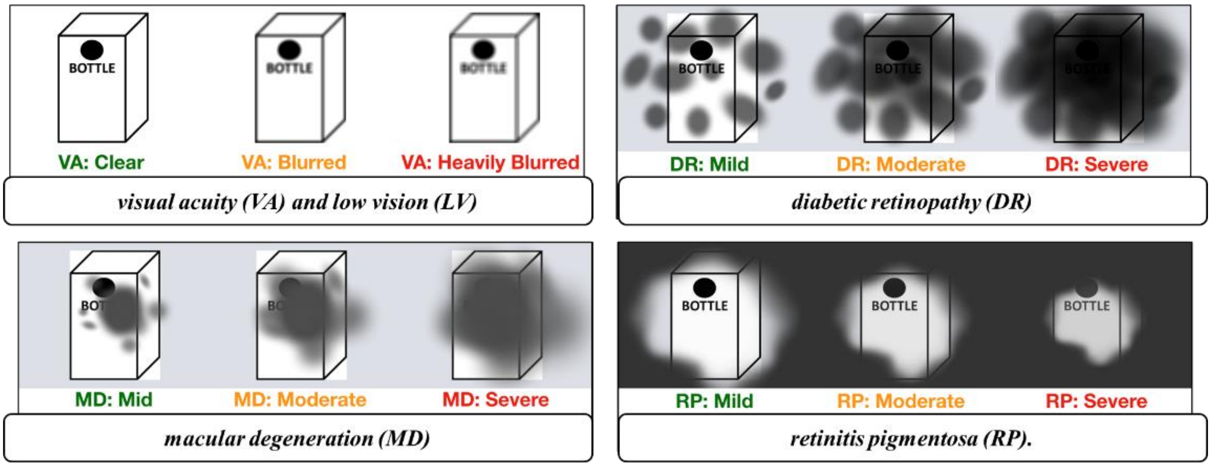


Figure 5-1 Treated trash bin to investigate visual diseases effects

- Combustible waste bin design

Seven design of trash bins provided 21 pair questions in one data set of web-survey. Psychological preferences of trash bin arrangement were scaled by web questionnaires using pairwise comparison method with Thurstone's law of comparative judgement. Web questionnaires were conducted in Mar. 2018 for 3,090 people. Therefore, a total of 3,090 data was collected in the study. Gender of respondents was balanced equally. The number of respondents was checked coefficient of agreement at significant level 5%, it is statically useful. The ages of respondents were from 20's to 60's and also balanced equally with 10-year interval.

5.2.2.2 Pairwise comparison (Scheffe's method)

As mentioned in Chapter 4, pairwise comparison with Scheffe's method is very useful psychometric analysis tool to justify human preference. In this Chapter, the questionnaires of PET bottle bin design were prepared for this method. The methodologies of this method were explained in section 4.2.1.2.

5.2.2.3 Pairwise comparison (Thurstone's method)

The Thurstone's method is well-known psychometric analyses for comparative judgement (Thurstone, 1927). For example, 3 objects (A, B, and C) are tested by pairwise comparison, the number of all comparisons is three (A vs B, A vs C, and B vs C). Same as Scheffé's method, pairwise comparison of N objects needs ${}_{N}C_{2}$ number of binary comparisons with yields ${}_{N}C_{2}$ number of selection ratio data. In the Thurstone's method, the people's answer data is expected 'A' or 'B' and that can be recorded as **+1 on A** or +**1 on B** to calculate. When respondent's personal preference on the design A and B is A < B; B is preferred than A: +(1) and A is preferred than B: +(0). From quantitative survey with the questionnaire, the preference distribution for each pair comparison can be plot. The comparison of design preference between design A and B and the difference of preference (A-B) were used for model selection and data conversion (see Figure 5-2).

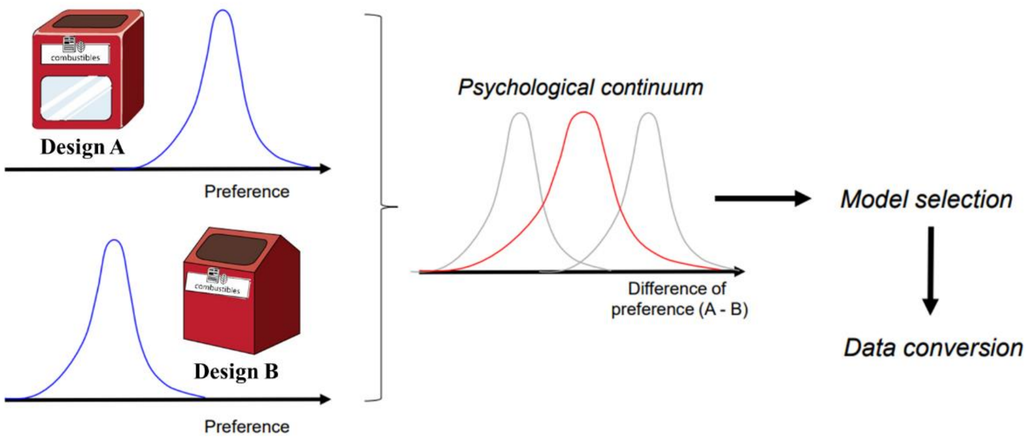


Figure 5-2 The preference distribution of design A and B

Selection ratio of design A and B were used to find out the difference of preference with the cumulative normal distribution in Eq. (1) (see Figure 5-3). More preferred design is showed as the positive number of the difference of preference. On the other hand, less preferred design is showed as the negative number.

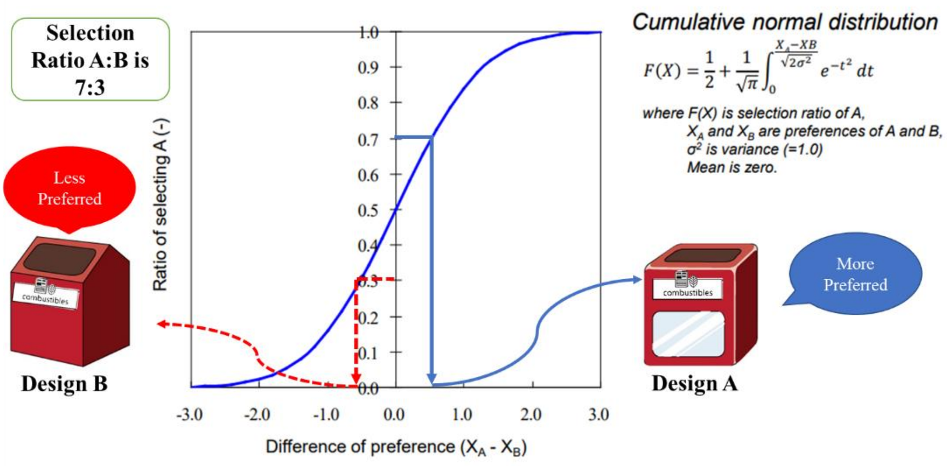


Figure 5-3 Thurstone’s Law of Comparative Judgement

$$F(X) = \frac{1}{2} + \frac{1}{\sqrt{x}}\int_0^{\frac{X_A-AB}{\sqrt{2\sigma^2}}} e^{-t^2}\,dt \tag{1}$$

where $F(X)$ is a selection ratio of A, X_A and X_B are preference scores of A and B. σ^2 is a variance, in this case $\sigma^2 = 1.0$, and the mean value is zero.

The preference of design A (X_A) is the average of all pairs difference of preferences compared with the other designs (see Figure 5-4).

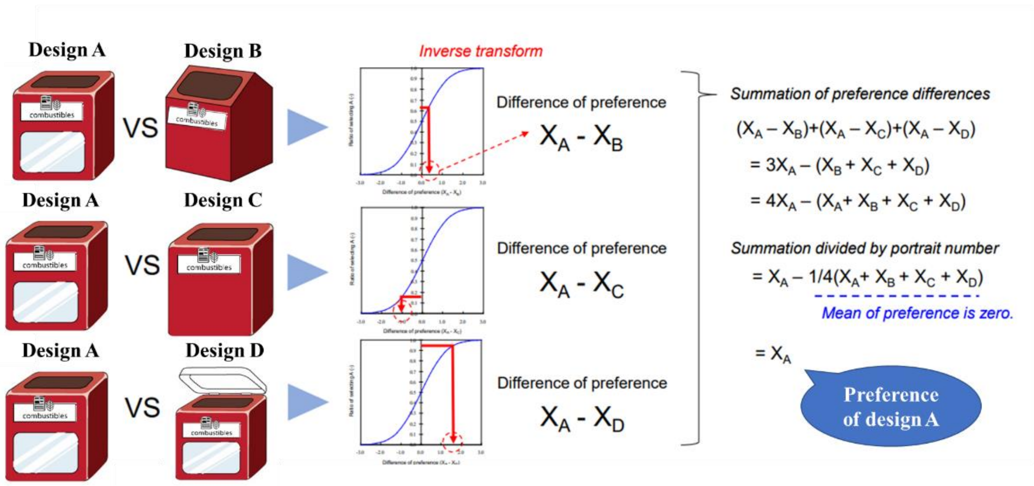


Figure 5-4 Comparison of all pairs enable preference estimation

The preference score of the other designs were calculated with the same method as design A. Finally, the preference score could be summarized in Table 5-3.

Table 5-3 An example of pairwise comparison with Thurstone's law result

Design	A	B	C	D	Score
A	-	$X_A - X_B$	$X_A - X_C$	$X_A - X_D$	X_A
B	$-(X_A - X_B)$	-	$X_B - X_C$	$X_B - X_D$	X_B
C	$-(X_A - X_C)$	$-(X_B - X_C)$	-	$X_C - X_D$	X_C
D	$-(X_A - X_D)$	$-(X_B - X_D)$	$-(X_C - X_D)$	-	X_D

Binomial's test was used to find out significant different between ranking of results at significant level 5%.

5.2.3 Statistical test

The statistical test is the analysis tool to distinguish the different of the results. A t-test and one/multi-way ANOVA are used to check the different of data groups with significant level 1% or 5%. In addition, the multiple comparison with Scheffe's method is used to justify the different between each data with significant level 1% or 5%.

5.3 Results and discussions

5.3.1 The preference score results of PET bottle bin design

The trash bin label designs categorized to two groups including letter label and illustration (image) label. The letter label designs are including design A, B, D, E, G, and H. So that, the image label designs are including design C and F. The results showed that preference scores of trash bins with illustrated label were significantly higher than the others in all cases as shown in Figure 5-5. The lowest preference score of illustrated labels was higher than the highest score in letter label side. According to the preference score results, the illustrated label is better design compared with letter label. The group of labels were separated by rank 2 and rank 3. Thus, the gap between rank 2 and rank 3 show the level of impact in any indicators such as treatment, age, and gender. The relative different is become the analysis tool to justify the level of impact. Relative different is the factor to evaluate the differential of the results set as shown in Eq. (2).

$$Relative\ different = \frac{Rank\ 2\ \text{-}Rank\ 3}{Rank\ 1\ \text{-}Rank\ 8} \tag{2}$$

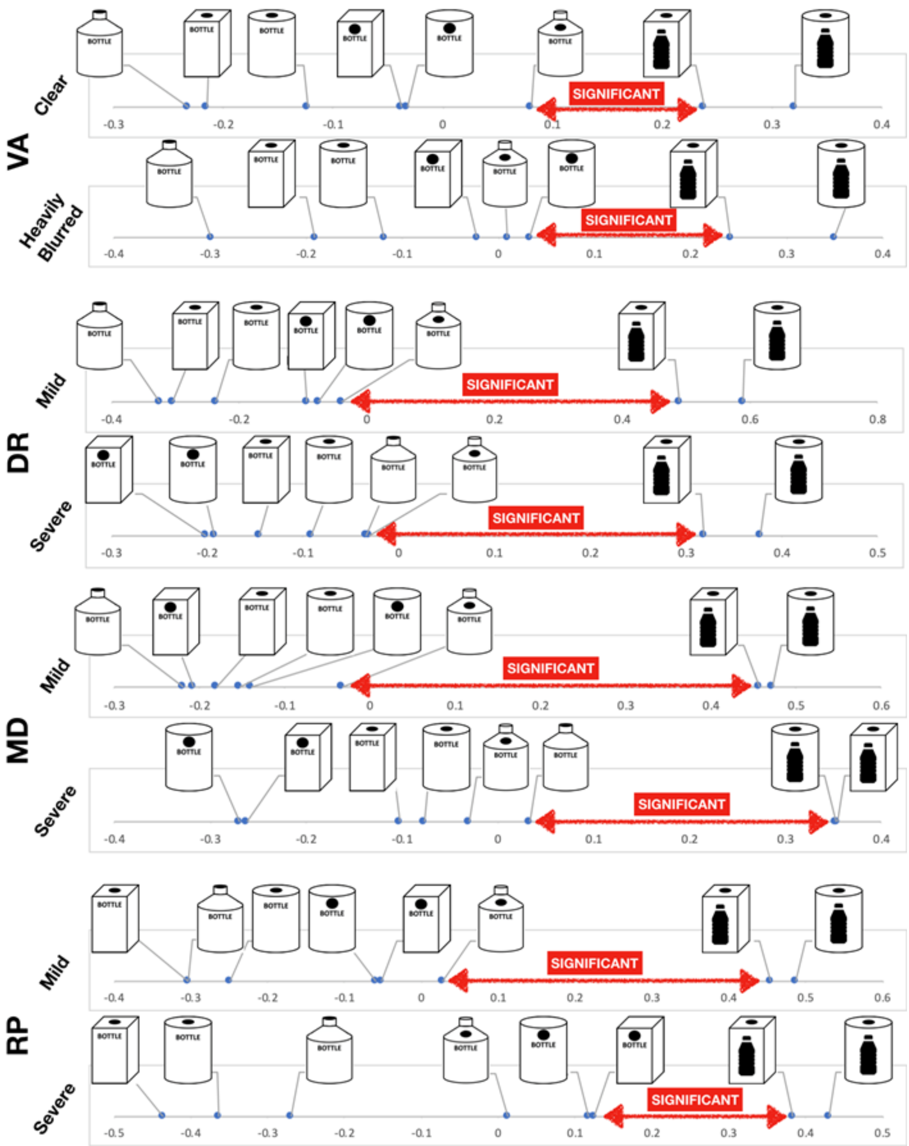


Figure 5-5 The preference scores of designed bins

From Figure 5-6A, the results show that trash bin with all treatments gave the impact to enlarge the relative different. The relative different of clear trash bins is 0.289, it is the reference value. For trash bins with VA treatment, relative differences were slightly increased by 15.3% for mild and 11.9% severe treatment (mild is 0.331 and severe is 0.320). For DR treatment, relative differences were greatly increased by 102% for mild, 93.3% for moderate, and 110% for severe (mild is 0.579, moderate is 0.553, and severe is 0.603). For MD treatment, relative differences were greatly increased by 146% for mild, 161% for moderate, and 79.6% for severe (mild is 0.706, moderate is 0.749, and severe is 0.514). For RP treatment, relative differences were greatly increased by 89.0% for mild, 48.91% for moderate, and 4.07% for severe (mild is 0.541, moderate is 0.426, and severe is 0.298). The results showed that VA treatment gave lowest level of impact compared with others. On the other hand, MD treatment gave highest impact for mild and moderate treatment degrees. However, the severe degree of MD was decreased the level of impact from mild and moderate. In addition, DR treatment gave similar level of impact for all treatment degrees. Moreover, the impact level of RP was decreasing when heavier treatment degree. It could be concluded that the illustrated label is very helpful for visually impaired people with four diseases, especially Diabetic Retinopathy, Macular Degeneration, and mild/moderate Retinitis Pigmentosa diseases.

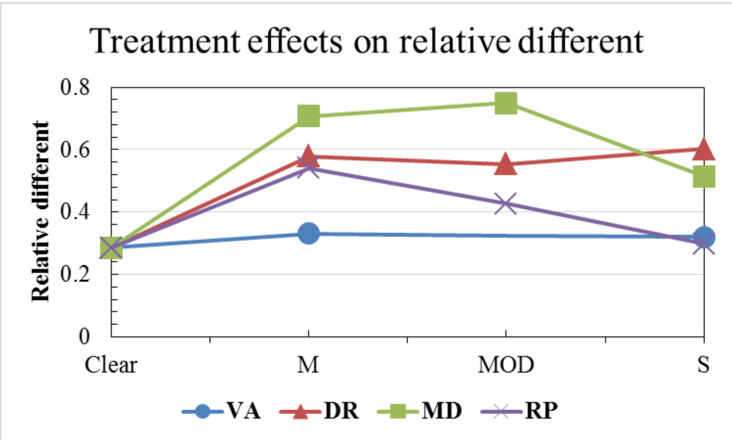


Figure 5-6 The relative different between image and letter label

Age of respondents affected impact level on label designs as shown in Figure 5-7. Based on overall data as the reference value, the relative different of 30s respondents was decreased by 79.5%, the others were increased. It meant the image label gave lowest impact level on 30s respondents. From Figure 5-7A, the results showed that VA treatment did not gave huge impact on the relative differences. However, the other three diseases gave high impact on the relative differences, especially 30s respondents as shown in Figure 5-7B to 5-7D. The relative differences of 30s respondents were increased by 780 to 1019% for DR, 772 to 1025% for MD, and 155 to 723% for RP.

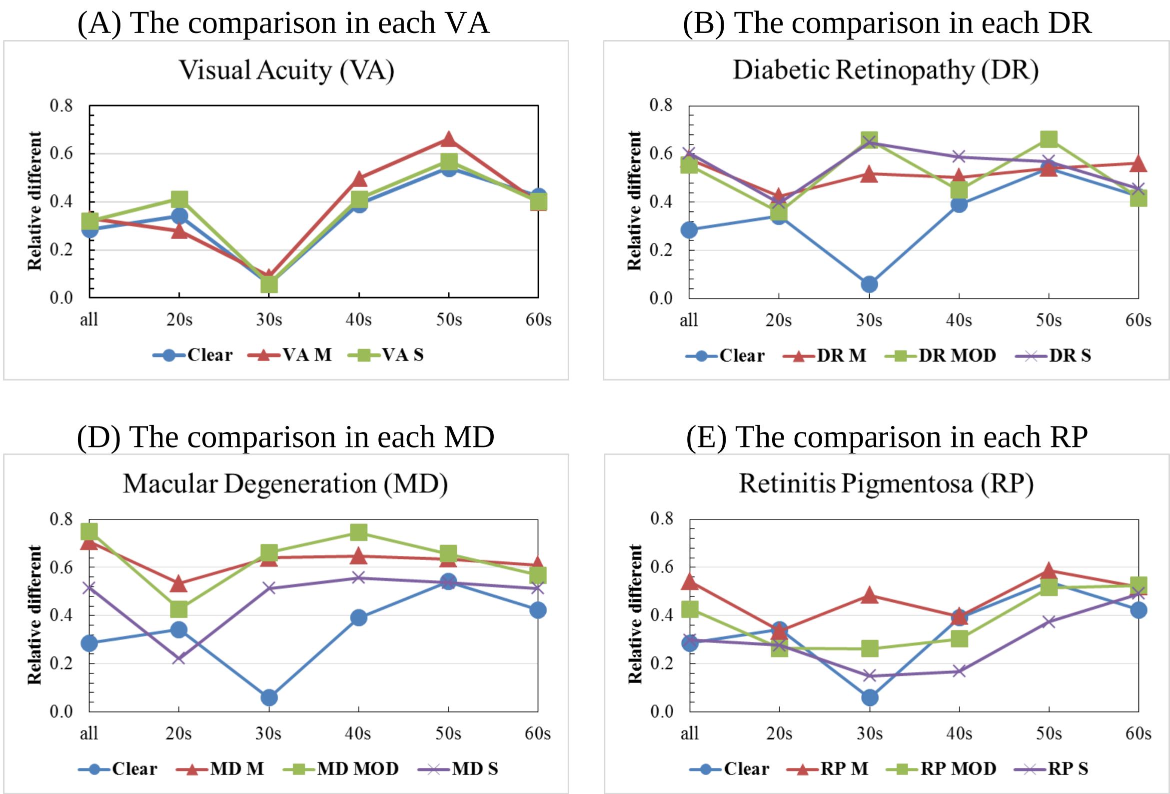


Figure 5-7 The relative different between image and letter label in various age

From Figure 5-8A and 5-8B, the results showed that the illustrated label designs were more preferred for male because the relative differences were higher than female. In the addition, all treatments increased the impact level of label preference for female except MD severe. VA treatments and RP severe decreased the impact level, but the others extremely increased the impact level.

(A) The comparison for male (B) The comparison for female

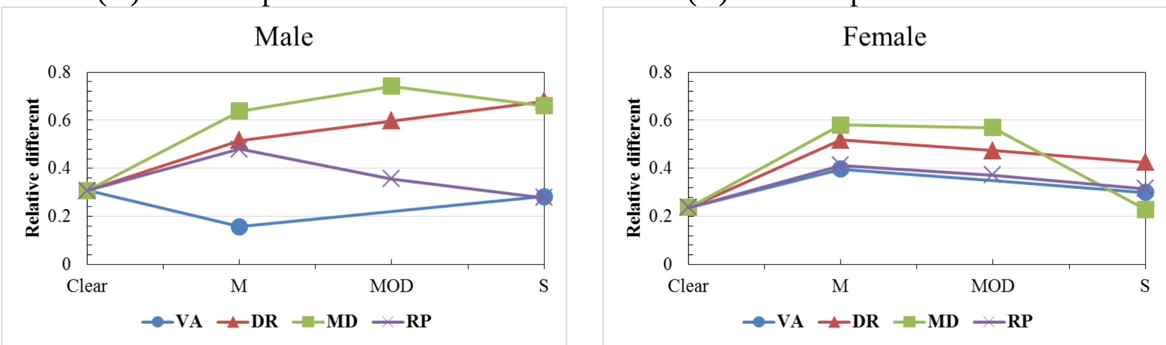


Figure 5-8 The relative different between image and letter label in each gender

5.3.2 The effects of shape and slot position on PET bottle bin design

From the previous section, the results showed that illustrated label is always higher preference scores than letter label in all cases. The analysis could be explaining the impact of various factors on selection preference. It could be noted that the impact of shape and slot position did not consider the design with image label. These sections were the analysis of bin shapes and bin slot positions. The shapes of trash bin were separated into three groups including cylinder, box, and bottle as shown in Figure 5-9. Six designs of trash bin were using for analyses the impact of shape with the same designed label. The cylinder shape was represented by design A and B. The box shape was represented by design D and E. The bottle shape was represented by design G and H.

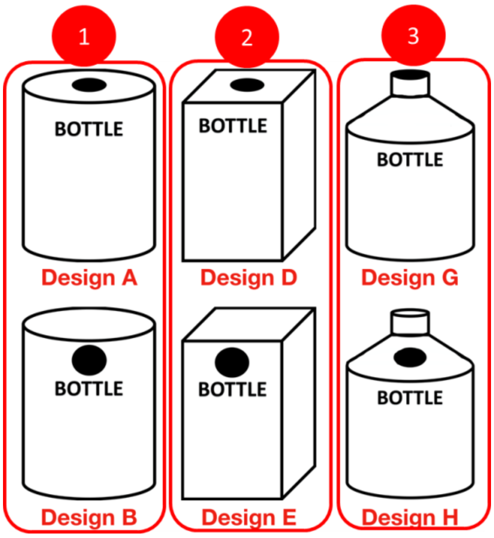


Figure 5-9 The classifications of trash bin based on shape

The slot positions of trash bin were separated into two groups including top and front slot position as shown in Figure 5-10. Six designs of trash bin were using for analyses the impact of slot position with the same designed label. The top slot position was represented by design A, D, and G. The front slot position was represented by design B, E, and H.

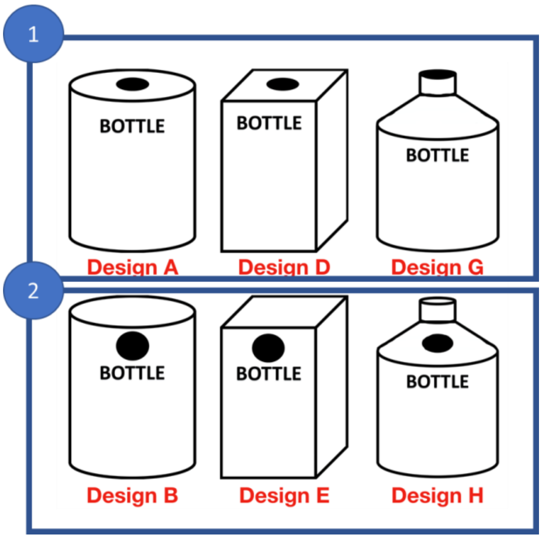


Figure 5-10 The classifications of trash bin based on slot position

From Figure 5-11, the ranking of bin designs was changed by the additional treatments. DR and MD treatments increased preference scores of top slot bin, so front slot bin preference scores were decreased by these treatments. On the other hand, RP treatment increased preference scores of front slot bin, so front slot bin preference scores were decreased.

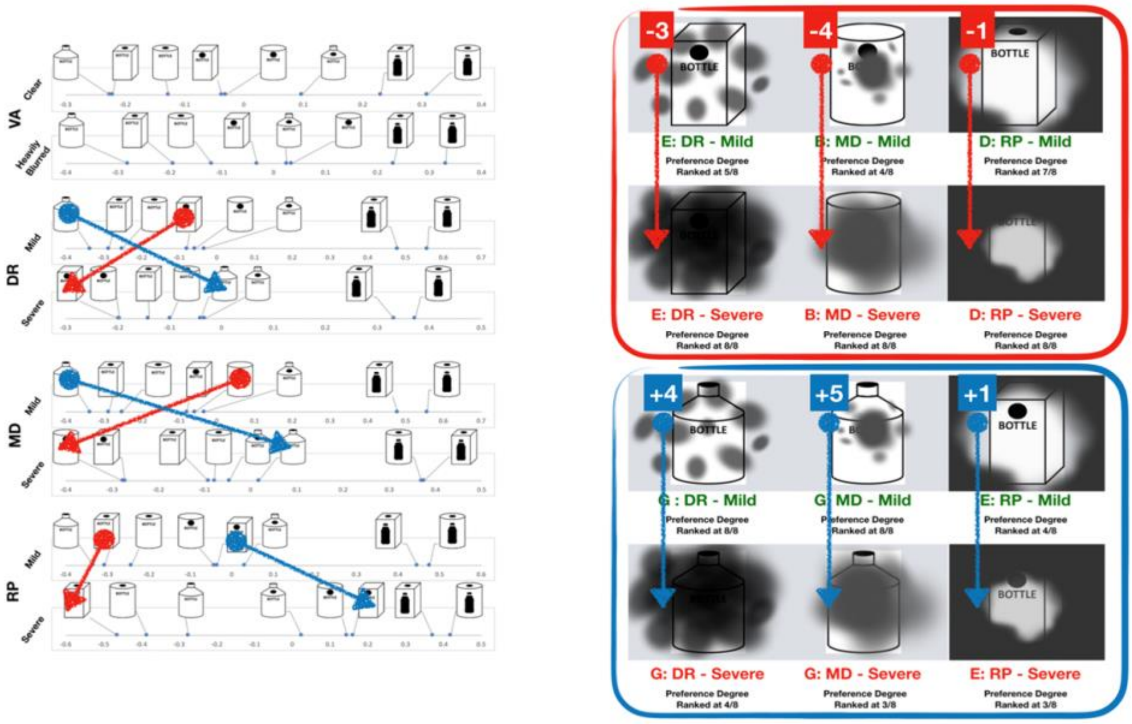


Figure 5-11 Treatment effects on designs preference ranking

The impact of shape and slot position depended on various factors including degrees of treatment, shape, and slot position. The statistical analyses using multi-way ANOVA are necessary. The summarized results using multi-way ANOVA has shown in Table 5-4. The difference between various factors could be explained by multiple comparison.

Table 5-4 The summary of ANOVA analysis

Factor	Clear	VA	DR	MD	RP
Degree	-	No sig.	**	**	**
Shape	No sig.	**	**	**	**
Slot	**	**	**	**	**
Degree * Shape	-	**	**	**	No sig.
Degree * Slot	-	No sig.	**	**	**
Shape * Slot	**	**	**	**	**
Degree * Shape * Slot	-	No sig.	No sig.	*	**
noted:	Significant level		**:1% sig. *:5% sig.		
	-	=	No data analysis		

The results without treatment showed that top and front slot position scores are significantly different ($p = 2.50 \times 10^{-6}$). However, it could not find that different between bin shapes. Furthermore, the interaction between shape and slot has shown the differential significance (p = 0.00185). The summarized interaction between shape and slot position is shown in Table 5-5. From the interaction, it was found that cylinder shape is the most preferred shape when slot position is placed on the top of trash bin. On the other hand, bottle shape is the most preferred shape when slot position is placed on the front of trash bin. In addition, front slot position is more preferred than top slot position regardless of any shapes.

Table 5-5 Interaction between shape and slot position on original design

Factor	**Clear**					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Shape * Slot	Top	Box	Cylinder	Cylinder>Box	27.30%	0.0355
		Box	Bottle	No significance		
		Cylinder	Bottle	Cylinder>Bottle	30.80%	0.0154
	Front	Box	Cylinder	No significance		
		Box	Bottle	Bottle>Box	272%	0.0106
		Cylinder	Bottle	Bottle>Cylinder	231%	0.0136
	Box	Top	Front	Front>Top	70.50%	0.000251
	Cylinder	Top	Front	Front>Top	58.80%	0.0128
	Bottle	Top	Front	Front>Top	206%	4.29×10^{-6}

- VA treatment

From Table 5-5, VA treatments gave no impact on the differential of average scores each treatment degree. However, the multi-way ANOVA suggests that the average scores among shapes of bin were significantly different ($p = 3.25 \times 10^{-7}$) and the average scores between slot positions of bin were significantly different ($p = 1.673 \times 10^{-16}$). Furthermore, ANOVA test also found the interaction between treatment degree and bin shapes (p = 0.0000313), and the interaction between bin shapes and slot positions ($p = 1.29 \times 10^{-9}$).

The summarized interaction treatment degree and bin shapes is shown in Table 5-6. The preference score of box shape was significantly increased by 19.90% from clear to mild (p = 0.0160). The preference score of bottle shape was significantly decreased by 31.90% from clear to mild ($p = 1.69\times10^{-4}$) and 31.20% from clear to severe ($p = 2.41\times10^{-4}$). On the other hand, the preference scores of cylinder shape were not significantly different in various VA treatment degree. Bottle shape is the most preferred shape without treatment following by cylinder, and box, respectively. The ranking of shape preference was significantly changed by VA treatment. Cylinder shape is the most preferred shape with VA treatments following by box, and bottle, respectively. It could be concluded that cylinder shape of PET bottle bin is the best option to support people with visual acuity eye disease. In addition, the preference scores of cylinder shape and bottle shape were not significantly different without treatment. It means that cylinder shape is not only best option to support consumer with visual acuity eye disease but also appropriate design for normal consumer.

Table 5-6 Interaction between degree of treatment and shape caused by VA treatments

Factor	**VA**					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Degree * Shape	Box	No	M	Mild>Clear	19.90%	0.016
		No	S	No significance		
		M	S	No significance		
	Cylinder	No	M	No significance		
		No	S	No significance		
		M	S	No significance		
	Bottle	No	M	Mild<Clear	31.90%	1.69×10^{-4}
		No	S	Severe<Clear	31.20%	2.41×10^{-4}
		M	S	No significance		
	No	Box	Cylinder	Cylinder>Box	24%	0.005
		Box	Bottle	Bottle>Box	24.80%	0.004
		Cylinder	Bottle	No significance		
	M	Box	Cylinder	Cylinder>Box	26.30%	0.0443
		Box	Bottle	Box>Bottle	27.20%	0.0005
		Cylinder	Bottle	Cylinder>Bottle	50%	4.02×10^{-6}
	S	Box	Cylinder	Cylinder>Box	42.30%	0.0005
		Box	Bottle	Box>Bottle	15.10%	0.0284
		Cylinder	Bottle	Cylinder>Bottle	54%	2.60×10^{-6}

The summarized interaction bin shapes and slot position is shown in Table 5-7. The results showed that VA treatments gave different impact on the preferences of bin shape for various slot position. The most preferred bin shape is cylinder when slot position is placed on top of trash bin. On the other hand, bottle shape is the most preferred shape when slot position is placed at front of trash bin. In addition, front slot position is more preferred than top slot position regardless of any shapes.

Table 5-7 Interaction between shape and slot caused by VA treatments

Factor	**VA**					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Shape * Slot	Top	Box	Cylinder	Cylinder>Box	19.60%	2.07×10^{-5}
		Box	Bottle	Box>Bottle	26.52%	6.35×10^{-7}
		Cylinder	Bottle	Cylinder>Bottle	43.84%	1.99×10^{-10}
	Front	Box	Cylinder	Cylinder>Box	221.67%	0.0485
		Box	Bottle	Bottle>Box	404.17%	0.0001
		Cylinder	Bottle	Bottle>Cylinder	128%	0.0332
	Box	Top	Front	Front>Top	88.63%	1.68×10^{-11}
	Cylinder	Top	Front	Front>Top	162.16%	1.08×10^{-9}
	Bottle	Top	Front	Front>Top	112%	9.70×10^{-16}

The comparison between trash bins without treatment and VA treatment is shown in Table 5-8. It could be concluded that respondents preferred cylinder shape with VA impairment. In addition, VA treatments increased front slot position preference because the different between top slot position preference and front slot position preference increased from 104% to 225%.

Table 5-8 The comparison between orginal design and VA treatment

Factor	**Comparison**		**Clear**			**VA**		
	Value 1	**Value 2**	**Cause**	**% different**	**p value**	**Cause**	**% different**	**p value**
Shape	Box	Cylinder	No significance			Cylinder>Box	70%	6.65×10^{-5}
	Box	Bottle				Box>Bottle	42%	5.53×10^{-5}
	Cylinder	Bottle				Cylinder>Bottle	104%	3.11×10^{-7}
Slot	Top	Front	Front>Top	104%	2.50×10^{-6}	Front>Top	225%	3.86×10^{-11}

- DR treatment

From Table 5-5, DR treatments significantly affected average preference scores with different treatment degree ($p = 0.0468$). In addition, the multi-way ANOVA suggests that the average scores of different shapes of bin were significantly different ($p = 3.55 \times 10^{-8}$) and the average scores of different slot positions of bin were also significantly different ($p = 1.84 \times 10^{-17}$). Furthermore, ANOVA test also found the interaction between treatment degree and bin shapes ($p = 3.30 \times 10^{-6}$), treatment degree and bin slot positions ($p = 4.30 \times 10^{-14}$), and bin shapes and slot positions ($p = 7.86 \times 10^{-10}$).

The summarized interaction treatment degree and bin shapes is shown in Table 5-9. The preference score of box and cylinder shape was significantly decreased with DR treatments. On the other hand, bottle shape was significantly more preferred with severe treated DR impairment. The results of multiple comparison test of shape in each degree of treatment level suggested the effect of DR treatment on slot position. Cylinder and bottle shapes were significantly more preferred than box shape without treatment ($p = 0.00956$ compared with cylinder and $p = 0.00773$ compared with bottle). After severe DR impairment was treated, bottle shape is the best design ($p = 4.40 \times 10^{-9}$ compared with box and $p = 4.45 \times 10^{-7}$ compared with cylinder). The results suggest that bottle shape is the best design to support people with severe DR impairment.

Table 5-9 Interaction between degree of treatment and shape caused by DR treatments

Factor	DR					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Degree * Shape	Box	No	M	M<No	22%	0.000499
		No	MOD	MOD<No	21%	0.00175
		No	S	S<No	16%	0.0286
		M	MOD	No significance		
		M	S	No significance		
		MOD	S	No significance		
	Cylinder	No	M	M<No	34%	0.000198
		No	MOD	MOD<No	25%	0.0147
		No	S	S<No	29%	0.00207
		M	MOD	No significance		
		M	S	No significance		
		MOD	S	No significance		
	Bottle	No	M	M<No	41%	2.41×10^{-6}
		No	MOD	MOD<No	35%	0.000108
		No	S	S>No	40%	0.0484
		M	MOD	No significance		
		M	S	S>M	70%	4.93×10^{-9}
		MOD	S	S>MOD	66%	1.28×10^{-7}
	No	Box	Cylinder	Box<Cylinder	24%	0.00956
		Box	Bottle	Box<Bottle	25%	0.00773
		Cylinder	Bottle	No significance		
	M	Box	Cylinder	Box<Cylinder	12%	0.0228
		Box	Bottle	No significance		
		Cylinder	Bottle	No significance		
	MOD	Box	Cylinder	Box<Cylinder	19%	0.00104
		Box	Bottle	No significance		
		Cylinder	Bottle	No significance		
	S	Box	Cylinder	No significance		
		Box	Bottle	Bottle>Box	69%	4.40×10^{-9}
		Cylinder	Bottle	Bottle>Cylinder	63%	4.45×10^{-7}

The summarized interaction treatment degree and slot position is shown in Table 5-10. Top slot position is lesser preferred when the treated trash bin with mild and moderate DR impairment. However, severe DR treatment significantly increased the preference in top slot position ($p = 2.97\times10^{-7}$ compared with clear, $p = 2.24\times10^{-13}$ compared with mild, and $p = 8.89\times10^{-11}$ compared with moderate). The preference score of front slot position was decreased with the increase of degrees of treatment. The results of multiple comparison test of slot position in each degree of treatment level suggested the effect of DR treatment on slot position. The preference score of front slot position were significantly higher than top slot position when no DR treatment ($p = 1.53\times10^{-14}$), mild DR treatment ($p = 1.09\times10^{-15}$), moderate DR treatment ($p = 8.76\times10^{-13}$). However, top slot position was more significantly preferred than front slot position when trash bin treated by severe DR impairment ($p = 0.000255$). It could be concluded that normal visual people and people with mild/moderate DR visual impairments are preferred trash bin which locate slot position at front of the body. However, the heavily DR visual impairment let people change their preference to top slot position trash bin because it is very hard to find the littering slot at front of trash bin.

Table 5-10 Interaction between degree of treatment and slot caused by DR treatments

Factor	DR					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Degree * Slot	Top	No	M	Mild<Clear	21%	2.97×10^{-7}
		No	MOD	Moderate<Clear	12%	0.00334
		No	S	Severe>Clear	35%	2.40×10^{-7}
		M	MOD	Moderate>Mild	9%	0.00491
		M	S	Severe>Mild	52%	2.24×10^{-13}
		MOD	S	Severe>Moderate	45%	8.89×10^{-11}
	Front	No	M	Mild<Clear	111%	2.94×10^{-5}
		No	MOD	Moderate<Clear	110%	5.01×10^{-6}
		No	S	Sever<Clear	105%	1.73×10^{-10}
		M	MOD	No significance		
		M	S	Sever<Mild	34%	5.28×10^{-5}
		MOD	S	Sever<Moderate	28%	0.000326
	No	Top	Front	Front>Top	208%	1.53×10^{-14}
	M	Top	Front	Front>Top	122%	1.09×10^{-15}
	MOD	Top	Front	Front>Top	101%	8.76×10^{-13}
	S	Top	Front	Front<Top	44%	0.000255

The summarized interaction shape and slot position is shown in Table 5-11. The results showed that DR treatments gave different impact on the preferences of bin shape for various slot position. The most preferred bin shape was cylinder when slot position is placed on top of trash bin. On the other hand, bottle shape was the most preferred shape when slot position is placed at front of trash bin. In addition, front slot position is more preferred than top slot position regardless of any shapes.

Table 5-11 Interaction between shape and slot caused by DR treatments

Factor	DR					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Shape * Slot	Top	Box	Cylinder	Cylinder>Box	18%	3.78×10^{-7}
		Box	Bottle	Bottle>Box	6%	0.349
		Cylinder	Bottle	Cylinder>Bottle	13%	1.16×10^{-5}
	Front	Box	Cylinder	No significance		
		Box	Bottle	Bottle>Cylinder	59%	1.55×10^{-9}
		Cylinder	Bottle	Bottle>Box	54%	2.78×10^{-8}
	Box	Top	Front	Front>Top	27%	1.54×10^{-11}
	Cylinder	Top	Front	Front>Top	17%	7.23×10^{-6}
	Bottle	Top	Front	Front>Top	72%	8.20×10^{-7}

The comparison between trash bins without treatment and DR treatment is shown in Table 5-12. It could be concluded that respondents preferred bottle shape with DR impairment. In addition, DR treatments increased top slot position preference. The average preference score of front slot position was higher than top slot position about 104%. However, after trash bins were treated with DR impairments, top slot position was more preferred than front slot position (72% difference).

Table 5-12 The comparison between orginal design and DR treatment

Factor	Comparison		Clear			DR		
	Value 1	**Value 2**	**Cause**	**% different**	**p value**	**Cause**	**% different**	**p value**
Shape	Box	Cylinder	No significance			Cylinder>Box	28%	1.23×10^{-5}
	Box	Bottle				Bottle>Box	41%	1.69×10^{-7}
	Cylinder	Bottle				Bottle>Cylinder	13%	0.0439
Slot	Top	Front	Front>Top	104%	2.50×10^{-6}	Top>Front	72%	5.76×10^{-13}

- MD treatment

From Table 5-5, MD treatments significantly affected average preference scores with different treatment degree ($p = 8.79 \times 10^{-7}$), bin shapes ($p = 2.29 \times 10^{-12}$), and bin slot positions ($p = 6.91 \times 10^{-6}$). Furthermore, ANOVA test also found the interaction between treatment degree and bin shapes ($p = 1.61 \times 10^{-7}$), degree and bin slot positions ($p = 2.80 \times 10^{-15}$), and bin shapes and slot positions ($p = 7.58 \times 10^{-11}$).

The summarized interaction treatment degree and shape is shown in Table 5-13. The preference score of box and cylinder shape was significantly decreased with MD treatments. On the other hand, bottle shape was significantly more preferred with severe treated MD impairment. The results of multiple comparison test of shape in each degree of treatment level suggested the effect of MD treatment on slot position. As mentioned in the analysis of DR treatment, cylinder and bottle shapes were significantly more preferred than box shape without treatment. When moderate or heavier MD impairments were treated, bottle shape is the most preferred design. The preference score of bottle shape was significantly greater than the score of cylinder shape ($p = 2.82 \times 10^{-5}$) and box shape ($p = 8.67 \times 10^{-6}$) when trash bins were treated by moderate MD treatment. In addition, the preference score of bottle shape was also significantly greater than the score of cylinder shape ($p = 1.56 \times 10^{-11}$) and box shape ($p = 4.57 \times 10^{-11}$) when trash bins were treated by severe MD treatment. The results suggest that bottle shape is the best design to support people with MD impairment.

Table 5-13 Interaction between degree of treatment and shape caused by MD treatments

Factor	MD					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Degree * Shape	Box	No	M	Clear>Mild	21%	0.00113
		No	MOD	No significance		
		No	S	Clear>Severe	18%	0.00681
		M	MOD	No significance		
		M	S	No significance		
		MOD	S	No significance		
	Cylinder	No	M	Clear>Mild	31%	0.000886
		No	MOD	Clear>Moderate	35%	7.87×10^{-5}
		No	S	Clear>Severe	38%	1.02×10^{-5}
		M	MOD	No significance		
		M	S	No significance		
		MOD	S	No significance		
	Bottle	No	M	Clear>Mild	25%	0.0184
		No	MOD	No significance		
		No	S	Severe>Mild	104%	0.000191
		M	MOD	Moderate>Mild	23%	0.0252
		M	S	Severe>Mild	103%	8.17×10^{-8}
		MOD	S	Severe>Moderate	104%	0.000135
	No	Box	Cylinder	Box<Cylinder	24%	0.0083
		Box	Bottle	Box<Bottle	25%	0.0067
		Cylinder	Bottle	No significance		
	M	Box	Cylinder	Box<Cylinder	14%	0.011
		Box	Bottle	Box<Bottle	21%	0.000353
		Cylinder	Bottle	No significance		
	MOD	Box	Cylinder	No significance		
		Box	Bottle	Box<Bottle	36%	8.67×10^{-6}
		Cylinder	Bottle	Cylinder<Bottle	34%	2.82×10^{-5}
	S	Box	Cylinder	No significance		
		Box	Bottle	Box<Bottle	102%	1.56×10^{-11}
		Cylinder	Bottle	Cylinder<Bottle	102%	4.57×10^{-11}

The summarized interaction treatment degree and slot position is shown in Table 5-14. The preference score of top slot position was increased with the increase of degrees of MD treatment. On the other hand, the preference score of front slot position was decreased with the increase of degrees of treatment. The results of multiple comparison test of slot position in each degree of treatment level suggested the effect of MD treatment on slot position. The preference score of front slot position were significantly higher than top slot position when no DR treatment ($p = 1.03\times10^{-14}$), and mild DR treatment ($p = 4.67\times10^{-5}$). However, there was no significant difference between different slot position when the bins were treated by moderate MD treatment. In addition, top slot position was significantly more preferred than front slot position when trash bin treated by severe MD impairment ($p = 1.49\times10^{-11}$). It could be concluded that normal visual people and people with mild DR visual impairments are preferred trash bin which locate slot position at front of the body. However, the heavily MD visual impairment let people change their preference to top slot position trash bin because it is very hard to find the littering slot at front of trash bin.

Table 5-14 Interaction between degree of treatment and slot caused by MD treatments

Factor	**MD**					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Degree * Slot	Top	No	M	No significance		
		No	MOD	Clear<Moderate	13%	0.0076
		No	S	Clear<Severe	59%	2.00×10^{-10}
		M	MOD	Mild<Moderate	12%	0.026
		M	S	Mild<Severe	58%	5.26×10^{-10}
		MOD	S	Moderate<Severe	50%	3.16×10^{-7}
	Front	No	M	Clear>Mild	106%	1.13×10^{-9}
		No	MOD	Clear>Moderate	106%	1.22×10^{-9}
		No	S	Clear>Severe	104%	3.47×10^{-13}
		M	MOD	No significance		
		M	S	Mild>Severe	19%	0.00033
		MOD	S	Moderate>Severe	20%	0.00029
	No	Front	Top	Front > Top	104%	1.03×10^{-14}
	M	Front	Top	Front > Top	19%	4.67×10^{-5}
	MOD	Front	Top	Front = Top	No significance	
	S	Front	Top	Top>Front	59%	1.49×10^{-11}

The summarized interaction shape and slot position is shown in Table 5-15. The results showed that MD treatments gave different impact on the preferences of bin shape for various slot position. The most preferred bin shape was bottle regardless of any slot position. Top slot position was more preferred than front slot position when trash bins were box or cylinder shape. On the other hand, front slot was more preferred than top slot position when trash bin was bottle shape.

Table 5-15 Interaction between degree of shape and slot caused by MD treatments

Factor	MD					
	Group of comparison	Value 1	Value 2	Cause	% different	p value
Shape * Slot	Top	Box	Cylinder	Cylinder>Box	10%	0.000936
		Box	Bottle	Bottle>Box	20%	0.0116
		Cylinder	Bottle	Bottle>Cylinder	10%	0.575
	Front	Box	Cylinder	No significance		
		Box	Bottle	Bottle>Box	73%	1.30×10^{-13}
		Cylinder	Bottle	Bottle>Cylinder	71%	7.39×10^{-13}
	Box	Top	Front	Top>Front	16%	0.959
	Cylinder	Top	Front	Top>Front	22%	0.00535
	Bottle	Top	Front	Front>Top	51%	2.73×10^{-12}

The comparison between trash bins without treatment and MD treatment is shown in Table 5-16. It could be concluded that respondents preferred bottle shape with MD impairment. In addition, MD treatments increased top slot position preference. The average preference score of front slot position was higher than top slot position about 104%. However, after trash bins were treated with MD impairments, top slot position was more preferred than front slot position (15% difference).

Table 5-16 The comparison between orginal design and MD treatment

Factor	Comparison		Clear			MD		
	Value 1	Value 2	Cause	% different	p value	Cause	% different	p value
Shape	Box	Cylinder	No significance			Cylinder>Box	12%	5.65×10^{-4}
	Box	Bottle				Bottle>Box	91%	5.48×10^{-14}
	Cylinder	Bottle				Bottle>Cylinder	81%	1.36×10^{-12}
Slot	Top	Front	Front>Top	104%	2.50×10^{-6}	Top>Front	15%	2.37×10^{-5}

- RP treatment

From Table 5-5, RP treatments significantly affected average preference scores with different treatment degree ($p = 7.12 \times 10^{-7}$), bin shapes ($p = 0.000263$), and bin slot positions ($p = 1.19 \times 10^{-26}$). Furthermore, ANOVA test also found the interaction between treatment degree and bin slot positions ($p = 1.51 \times 10^{-13}$), bin shapes and slot positions ($p = 0.0000663$).

The summarized interaction treatment degree and slot position is shown in Table 5-17. The preference score of both top and front slot position was decreased with the increase of degrees of treatment. It means RP treatments gave the impact to decrease the preference of letter label bins. The results of multiple comparison test of slot position in each degree of treatment level showed that front slot position was more preferred than top slot position with regardless any degrees of treatment. It could be concluded that normal visual people and people with RP visual impairments are preferred trash bin which locate slot position at front of the body.

Table 5-17 Interaction between degree of treatment and slot caused by RP treatments

Factor	RP					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Degree * Slot	Top	No	M	Clear>Mild	20%	5.49×10^{-7}
		No	MOD	Clear>Moderate	28%	8.71×10^{-11}
		No	S	Clear>Severe	30%	1.12×10^{-11}
		M	MOD	Mild>Moderate	9%	0.00131
		M	S	Mild>Severe	11%	6.06×10^{-5}
		MOD	S	No significance		
	Front	No	M	No significance		
		No	MOD	Clear>Moderate	88%	0.00105
		No	S	Clear>Severe	92%	7.84×10^{-6}
		M	MOD	Mild>Moderate	278%	2.04×10^{-6}
		M	S	Mild>Severe	200%	2.53×10^{-8}
		MOD	S	No significance		
	No	Front	Top	Front > Top	104%	1.73×10^{-14}
	M	Front	Top	Front > Top	82%	2.95×10^{-17}
	MOD	Front	Top	Front > Top	143%	9.85×10^{-22}
	S	Front	Top	Front > Top	163%	1.03×10^{-22}

The summarized interaction shape and slot position is shown in Table 5-18. The results showed that RP treatments gave different impact on the preferences of bin shape for various slot position. The most preferred bin shape was bottle when slot position is placed on top of trash bin. On the other hand, cylinder shape was the most preferred shape when slot position is placed at front of trash bin. In addition, front slot position is more preferred than top slot position regardless of any shapes.

Table 5-18 Interaction between shape and slot caused by RP treatments

Factor	RP					
	Group of comparison	**Value 1**	**Value 2**	**Cause**	**% different**	**p value**
Shape * Slot	Top	Box	Cylinder	Box>Cylinder	23%	4.08×10^{-6}
		Box	Bottle	Box>Bottle	11%	0.00751
		Cylinder	Bottle	No significance		
	Front	Box	Cylinder	No significance		
		Box	Bottle	No significance		
		Cylinder	Bottle	Bottle>Cylinder	90%	0.0261
	Box	Top	Front	Front>Top	127%	7.35×10^{-22}
	Cylinder	Top	Front	Front>Top	126%	1.77×10^{-19}
	Bottle	Top	Front	Front>Top	127%	1.58×10^{-21}

The comparison between trash bins without treatment and RP treatment is shown in Table 5-8. It could be concluded that respondents preferred cylinder or bottle shape with RP impairment. In addition, RP treatments increased front slot position preference because the different between top slot position preference and front slot position preference increased from 104% to 254%.

Table 5-19 The comparison between orginal design and RP treatment

Factor	Comparison		Clear			RP		
	Value 1	**Value 2**	**Cause**	**% different**	**p value**	**Cause**	**% different**	**p value**
Shape	Box	Cylinder	No significance			Cylinder>Box	17%	0.00330
	Box	Bottle				Bottle>Box	16%	0.00595
	Cylinder	Bottle				No significance		
Slot	Top	Front	Front>Top	104%	2.50×10^{-6}	Front>Top	254%	1.46×10^{-21}

5.3.3 The comparison of PET bottle bin design preference

The comparison results are shown in Table 5-20. Above 90% of preference scores were significantly different in order when trash bin images were introduced with clear. Only two pairs were not significantly different (B vs E and D vs G). There are the designs with same slot position. It could be confirmed the discussion in previous section that shape gave no impact on preference score. The ranking of preference scores was changed when treatments were added. However, the significances in order were getting lower. Design B and H were become not significant difference when VA/DR treatments were added. In addition, design C and F were not significantly different with MD/RP treatments. Therefore, the shapes of trash bin were not necessary in the universal design. It could be concluded that designed trash bins for appropriate use should have image label information and top slot position for support the visually impaired people.

5.3.4 The preference score results of combustible waste bin design

First at all, the result of coefficient of agreement showed P value is 0, which is meant statistically useful. After knowing that the data was statistically useful, then evaluate psychological preference using pairwise comparison.

From pairwise comparison, the results showed respondents prefer slope slot (TB2 and TB5), top slot (TB1 and TB4), and front slot (TB3 and TB6) respectively and they also prefer visibility trash bin (TB1 to TB3) rather than invisibility one (TB4 to TB6) of the same slot position design. Furthermore, respondents do not prefer trash bin with lid attached (TB7) (see Figure 5-12). From Binomial distribution test, there are not any single probability between ranking greater than 0.05, which is all of ranking are significantly different at significant level 5%. According to the distribution test, it was clearly shown that trash bin with lid attachment was significantly lower preferred than those bins without lid attachment. In addition, ANOVA test also suggested that the preference score of trash bins with various slot positions were significantly different ($p = 0.00180$). On the other hand, t-test suggested that the preference score of visible and invisible were not significantly different. Moreover, the authors also considered psychological preference on each gender and ages.

Table 5-20 The summary of differential preference between each design

Design	Clear	VA		DR			MD			RP		
		M	S	M	MOD	S	M	MOD	S	M	MOD	S
A-B	S	S	S	S	S	S	N	N	S	S	S	S
A-C	S	S	S	S	S	S	S	S	S	S	S	S
A-D	S	N	S	S	S	S	N	N	N	N	N	S
A-E	S	S	S	S	N	S	N	N	S	S	S	S
A-F	S	S	S	S	S	S	S	S	S	S	S	S
A-G	S	S	S	S	S	S	S	N	S	N	S	S
A-H	S	S	S	S	S	S	S	S	N	S	S	S
B-C	S	S	S	S	S	S	S	S	S	S	S	S
B-D	S	S	S	S	S	N	N	N	S	S	S	S
B-E	N	N	N	N	N	N	S	N	N	N	N	N
B-F	S	S	S	S	S	S	S	S	S	S	S	S
B-G	S	S	S	S	S	S	S	S	S	S	S	S
B-H	S	N	N	N	N	S	S	S	S	S	N	S
C-D	S	S	S	S	S	S	S	S	S	S	S	S
C-E	S	S	S	S	S	S	S	S	S	S	S	S
C-F	S	S	S	S	S	S	N	N	N	N	N	N
C-G	S	S	S	S	S	S	S	S	S	S	S	S
C-H	S	S	S	S	S	S	S	S	S	S	S	S
D-E	S	S	S	S	S	S	N	N	S	S	S	S
D-F	S	S	S	S	S	S	S	S	S	S	S	S
D-G	N	S	S	N	N	S	N	N	S	N	N	S
D-H	S	S	S	S	S	S	S	S	S	S	S	S
E-F	S	S	S	S	S	S	S	S	S	S	S	S
E-G	S	S	S	S	S	S	N	N	S	S	S	S
E-H	S	N	N	N	S	S	S	S	S	S	N	S
F-G	S	S	S	S	S	S	S	S	S	S	S	S
F-H	S	S	S	S	S	S	S	S	S	S	S	S
G-H	S	S	S	S	S	N	S	S	S	S	S	S

Note: **S** = significance **M** =Mild **S** =Severe
N = no significance **MOD** =Moderate

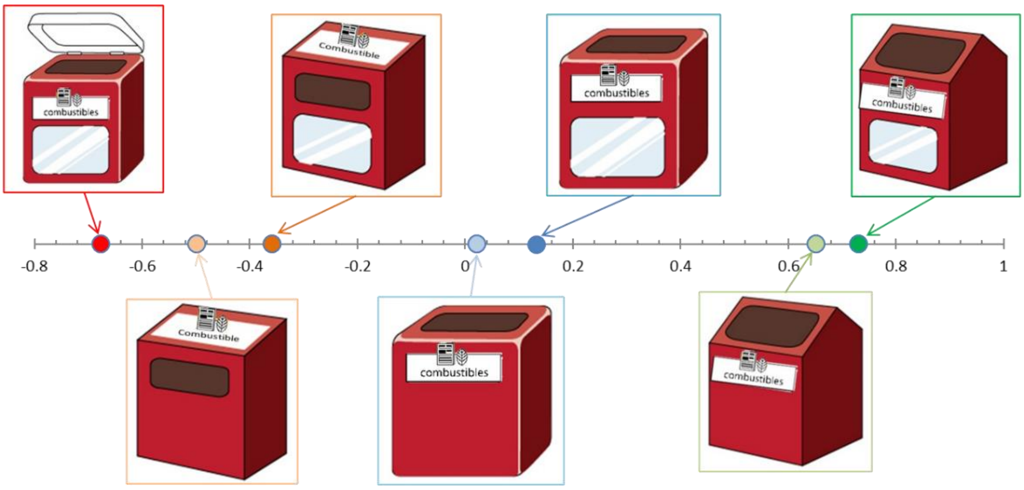


Figure 5-12 The preference score of combustible waste bin designs

5.3.5 Gender effect on combustible waste bin design

The results showed both of gender rankings were the same ranking of preference score as overall result (see Table 5-21). The statistical test suggested that there are not significant different between group for both genders (p = 0.5). The results suggested that design preference between male and female were the same. From Binomial distribution test, there are not any single probability between ranking greater than 0.05, which is all of ranking are significantly different at significant level 5%. The statistical tests also suggested the same results with overall analysis. According to the distribution test, it was clearly shown that trash bin with lid attachment was significantly lower preferred than those bins without lid attachment for both male and female. In addition, ANOVA test also suggested that the preference score of trash bins with various slot positions were significantly different for both male and female (p = 0.00282 for male and p = 0.00540 for female). On the other hand, t-test suggested that the preference score of visible and invisible were not significantly different for both male and female.

Table 5-21 The comparison of combustible waste bin design preference between each gender

Overall			Gender			
			Male		Female	
Rank	CODE	Z score	CODE	Z score	CODE	Z score
1	TB2	0.730	TB2	0.684	TB2	0.777
2	TB5	0.650	TB5	0.587	TB5	0.720
3	TB1	0.131	TB1	0.129	TB1	0.133
4	TB4	0.0219	TB4	0.0106	TB4	0.0351
5	TB3	-0.359	TB3	-0.324	TB3	-0.395
6	TB6	-0.498	TB6	-0.465	TB6	-0.535
7	TB7	-0.677	TB7	-0.621	TB7	-0.736

5.3.6 Age effect on combustible waste bin design

The results showed most of ages (20's to 50's) rankings were the same ranking of preference score as overall result (see Table 5-22). From Binomial distribution test, there are not any single probability between ranking greater than 0.05, which is all of ranking are significantly different at significant level 5%. The statistical tests also suggested the same results with overall analysis. According to the distribution test, it was clearly shown that trash bin with lid attachment was significantly lower preferred than those bins without lid attachment for all ages expect one case. Only 60's people prefer TB-07 rather than TB-06. However, there are not significant different between group for all ages. In addition, ANOVA test also suggested that the preference score of trash bins with various slot positions were significantly different for all ages ($p = 0.00183$ for 20's, $p = 0.000989$ for 30's, $p = 0.00151$ for 40's, $p = 0.00329$ for 50's, and $p = 0.00211$ for female, respectively). On the other hand, t-test suggested that the preference score of visible and invisible were not significantly different for all ages.

Table 5-22 The comparison of combustible waste bin design preference between each age

Overall			Age of respondents									
			20's		30's		40's		50's		60's	
Rank	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score	CODE	Z score
1	TB2	0.730	TB2	0.754	TB2	0.781	TB2	0.742	TB2	0.718	TB2	0.676
2	TB5	0.650	TB5	0.697	TB5	0.708	TB5	0.648	TB5	0.621	TB5	0.596
3	TB1	0.131	TB1	0.0500	TB1	0.0565	TB1	0.148	TB1	0.248	TB1	0.156
4	TB4	0.0220	TB4	-0.073	TB4	-0.029	TB4	0.0423	TB4	0.084	TB4	0.0991
5	TB3	-0.359	TB3	-0.233	TB3	-0.315	TB3	-0.387	TB3	-0.439	TB3	-0.422
6	TB6	-0.498	TB6	-0.357	TB6	-0.430	TB6	-0.510	TB6	-0.607	TB7	-0.497
7	TB7	-0.678	TB7	-0.838	TB7	-0.773	TB7	-0.683	TB7	-0.628	TB6	-0.609

5.4 Summary

- PET bottle bin design

The image label is more preferred design compared with letter label for any kind of visual impairments. Shape of trash bin is not specific for respondents without any treated visual impairments. Front slot position is more preferred than top slot position for normal visual people. For VA treatment, cylinder shape is the best option to support people with visual acuity eye disease. In addition, VA treatments increased front slot position preference. For DR treatment, the results suggest that bottle shape is the best design to support people with severe DR impairment. Heavily DR visual impairment let people change their preference to top slot position trash bin because it is very hard to find the littering slot at front of trash bin. For MD treatment, the results suggest that bottle shape is the best design to support people with MD impairment. Heavily MD visual impairment let people change their preference to top slot position trash bin because it is very hard to find the littering slot at front of trash bin. For RP treatment, people with RP visual impairments are preferred trash bin which locate slot position at front of the body. The summary of guidance is shown in Table 5-23.

- Combustible waste bin design

The results showed the best preference design was slope slot position with visibility and worst preference was trash bin with lid attachment. High preference score designs might encourage waste segregation. It could be concluded slot position, visibility, and lid attached affected to preference scores significantly. For 60's ages people, lid attachment was not impact to made them unlike it when compared with front slot position. Trash bin with lid attachment was not preference, it might be people do not want to touch the lid while dispose waste. The summary of guidance is shown in Table 5-23.

Table 5-23 Trash bins design guidance based on design preference

Designed trash bin	Treatment	Label	Slot position	Shape	Visibility	Lid attachment
PET bottle bin	Clear	Image	Front	No specific	-	
	VA		Front	Cylinder		
	DR		Top	Bottle		
	MD		Top	Bottle		
	RP		Front	Cylinder or Bottle		
Combustible waste bin	-	-	Slope	-	Yes	No

noted: - is no data

5.5 Conclusion

This study was designed on only two types of trash bins that using in Japan. In future, we are being able to continuous design on another type of trash bins to make waste management better. It was found the different between 2D and 3D design preference. Top slot position is more preferred than front slot position with 3D designed bin. On the other hand, top slot position is less preferred than front slot position with 2D designed bin. The dimension of designed objects gave significant impact on the respondent's decision. The design of trash bin should support the target consumer. For the label, it clearly showed that illustrated label is very preferred for respondents. The design of trash bin should include illustration of target waste to easily find out appropriate bin. The slot position design depended on the target of consumer. The research of consumer characteristic is necessary to make the appropriate trash bin design for them. The shape of PET bottle bin should be bottle or cylinder. The results suggest combustible waste bin should be visible to make consumer can see the wastes inside. Slope slot position is recommended for combustible waste bin. Slope slot position might helpful for people with Myasthenia Gravis (MG) problem. The lid attachment on top of trash bin is not recommended because it might me consumer feel inconvenient to dispose of their waste. This design guidance will be useful to design appropriate trash bins in public area. In addition, it will be design criteria for design trash bin in specific location for older people like nursing home.

6. Perceptive classification of waste mixture

6.1 Background

As mentioned in Chapter 1, municipal solid waste (MSW) is now becoming worldwide environmental issue due to higher waste generation year by year. The solution of the problem is good solid waste managements. The solid waste management processes are including waste generation, waste collection, waste recycling, waste treatment, and waste disposal. Waste generation is the initial process of waste management, so source segregation is one of the ways to improve waste management efficiency. However, not only the improving efficiency of waste management process that would be considered, but also the economical worth is necessary. The researchers found out waste source segregation impact to waste management service cost. Waste separation can reduce cost of waste management service by 26% (Chifari, Piano et al., 2017) and also reduce time consuming of waste sorting in MSW plant (Gundupalli, Hait et al., 2017). Although people have a good attitude towards waste separation, the separation of waste might be incorrect if they do not understand what kind of their garbage. Therefore, the understanding of waste classification is still be inconvenience factor for waste segregation (Lee, Choi, et al., 2017). According to the theory of planned behavior model (Ajzen, 1991), the human behavior was acted by the attitude, the subject norm, perceived behavioral control and the intention. The persons have good attitude in recycling and commit to the subject norm, they might have the intention to segregate their wastes. However, the incorrectly sorting action might be happened, if they misunderstand in waste separation categories.

Refer to monitoring results in previous chapters (Chapter 2,3, and 4), it was found that some waste types easily contaminated into an inappropriate bin. For example, recyclable wastes easily contaminated PET bottles in bin. It might be caused by the persons who dispose wastes were misunderstanding in waste classification.

The number of waste separation categories in Japan is up to 25 (Matsumoto, 2011). However, incorrectly disposed wastes are still detected in trash bins. Refer to trash bins in public space, there are four or five waste classifications including combustible waste, incombustible waste, PET bottles, cans, and glass bottles. However, in Japan, different administrative district has their own waste classification based on their waste management strategies. Plastic waste is categorized as combustible waste in some areas, but incombustible waste in others. The understanding of combustible waste classification become important factor to improve source segregation. In this study, the authors investigated the perceptive classification of combustible waste and incombustible waste focusing on plastic waste. According to monitoring results at our office in Suzukakedai campus, it also showed combustible waste trash bin contain high amount of incorrectly disposed (see figure. 6-1). For the reason, this study investigates on combustible waste understanding in Japan.

Figure 6-1 Waste composition in combustible waste trash bin.

6.2 Methodology

6.2.1 Survey questionnaires

This study designed six sets of waste composition following; 1) 100% combustible wastes (C100), 2) 80% combustible wastes and 20% plastic wastes (C80), 3) 50% combustible wastes and 50% plastic wastes (C50), 4) 20% combustible wastes and 80% plastic wastes (C20), 5) 100% plastic wastes (C0), and 6) 100% incombustible wastes exclude plastic (OT).

Each set of waste composition separated to three photos in different position of wastes. For example, three samples of 100% combustible wastes are C100-1, C100-2, and C100-3 (see Table 6-1). A total 18 samples were using in survey questionnaires and statistical analysis, which analyzed different waste compositions to find out the understanding of combustible waste.

Table 6-1 Waste composition for perceptive classificaition of waste mixture

Waste composition	**Position 1**	**Position 2**	**Position 3**
Combustible 100%	C100-1 	C100-2 	C100-3 
Combustible 80% Plastic 20%	C80-1 	C80-2 	C80-3 
Combustible 50% Plastic 50%	C50-1 	C50-2 	C50-3 
Combustible 20% Plastic 80%	C20-1 	C20-2 	C20-2 
Plastic 100%	C0-1 	C0-2 	C0-3 
Incombustible 100%	OT-1 	OT-2 	OT-3 

A pairwise comparison of 18 objects needs $_{18}C_2$ number of binary comparisons with yields $_{18}C_2$ number of selection ratio data. The number of binary comparisons is 153 questions. The understanding of combustible wastes was scaled by web questionnaires using pairwise comparison method with Thurstone's law of comparative judgement (Thurstone, 1927). Web questionnaires were conducted in Mar. 2018 for 3,090 people. Therefore, a total of 3,090 data was collected in the study. Gender of respondents was balanced equally. The ages of respondents were from 20's to 60's and also balanced equally with 10-year interval. The questionnaires for respondents are selecting one from two pictures. The question is "Which waste photo looks combustible waste? Select one without consideration (only feeling)".

Figure 6-2 An example of question to understand perceptive in waste classification

6.2.2 Pairwise comparison (Thurstone's method)

The method to justify the perceptive in waste classification is the same with preference score as mentioned in Chapter 5. The selection ratio data were transformed to the degree of combustible waste perception according to Thurston law of comparative judgment (see Figure 6-3). It is assumed that selection ratios correspond to the difference of psychological preference between two waste compositions presented to the respondents. In this study the psychological preference score (PS) means the degree of combustible waste perception (DP). If the respondents feel stronger percept object A as combustible waste than the other (object B), object A will be selected. Thurston law of comparative judgment suggests cumulative Gaussian normal distribution with the mean of 0 and the variation of 1 to describe the relation between selection ratio and the difference of perceptive in waste classification. When pairwise comparison of N objects is conducted, each object has N-1 data of selection ratio. Selection ratio data are converted by inverse transform of cumulative Gaussian normal distribution curve. Finally, the average of N-1 converted data represents the degree of combustible waste perception.

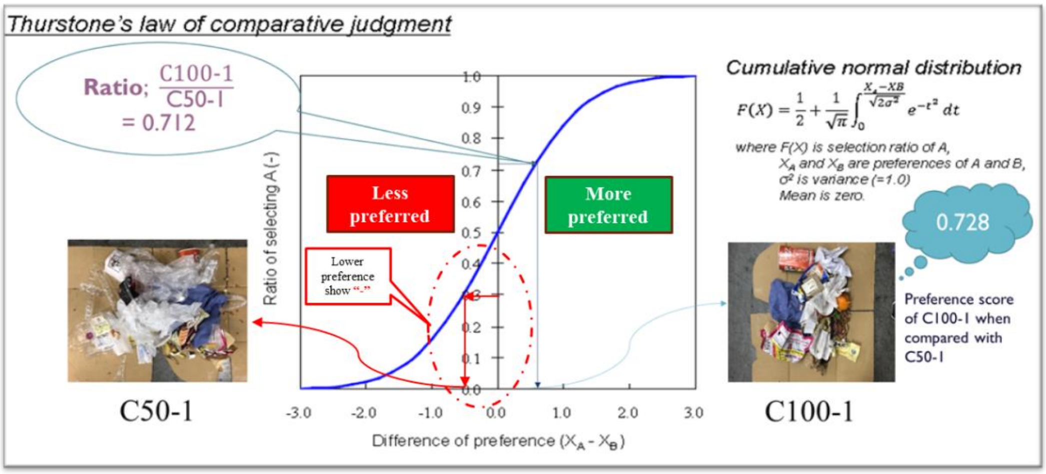


Figure 6-3 Pairwise comparison of waste perception

6.2.3 Statistical analysis

The data were tested by coefficient of agreement at significant level 5%. The results were evaluated between rank by Binomial's test at significant level 5%. In addition, the comparison each gender and ages 10-year interval were also scaled using pairwise comparison. The comparison of different among each waste composition was analyzed by ANOVA test with significant level 5%. A t-test was used to check the different between significant findings.

6.3 Results and discussions

6.3.1 General analysis

The data was analyzed using pairwise comparison with Thurstone's law of comparative judgement, which showed respondents understood in waste classification well. The ANOVA tests also suggested that the degree of combustible waste perception was significantly decreased with the decrease of combustible waste composition ($p = 4.26 \times 10^{-8}$). Only a few misunderstandings (C80-1 and C50-2) are found in the arrangement of score (see figure 2). The degree of combustible waste perception (DP) of C80-1 (0.449) was higher than DP of C100-3 (0.401). The different between DP of C100 and C80 were not found, it might be caused by the slightly higher score of C80-1. In addition, DP of C50-2 (0.380) was higher than DP of C80-2 (0.360) and C80-3 (0.248). The different between DP of C80 and C50 were not found, it might be caused by the slightly higher score of C50-2. The Furthermore, all of C0 (100% plastic wastes) are higher score than other incombustible wastes excluded plastic (OT). A t-test suggested that the average degree of combustible waste perception (DP) of C0 (-0.323) is significantly higher than the average DP of OT (-0.671) at 5% significant level ($p = 0.0105$). From the results, combustible wastes itself gave the most impact for respondent's selection. Similarly, plastic wastes are more impact than other incombustible wastes. P value was 0 for coefficient of agreement that meant statistically useful. Binomial distribution test at significant level 5%, all probabilities between ranking were significantly different. Hence, the ranking will not change in case of repeat experiment.

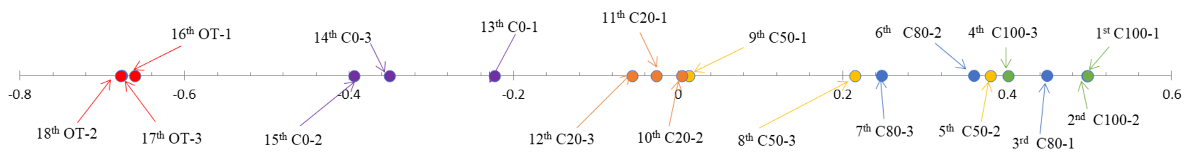
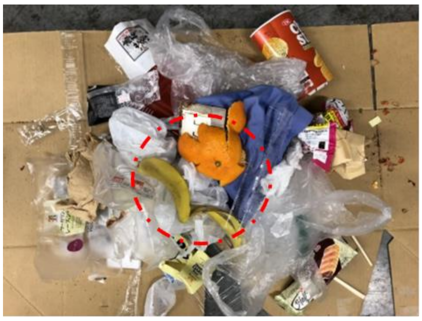


Figure 6-4 The summary of waste understanding with pairwise comparison

In the misunderstanding section, C80-1 and C50-2 had shown clearly outstanding food waste in those photos (see figure 6-5). Food waste might be effective to aware as combustible wastes. From the results, the respondents likely answered based on the middle area of photo. Due to C80-3 and C50-1, which showed plastic waste in the middle position, both objects were scaled as the lowest score among their own composition.



C50-2

C80-1

Figure 6-5 Photos of the waste that higher score than truly higher composition

In addition, the comparison of gender showed that perceptive classification scores for female are higher different than male. The ages analysis results showed perceptive classification scores of 60's respondents were disordered among C50 to C100 and C0 to C20.

6.3.2 The effects of gender on waste classification

The ANOVA tests suggested that the degree of combustible waste perception was significantly decreased with the decrease of combustible waste composition for both male and female ($p = 5.43 \times 10^{-8}$ for male and $p = 4.72 \times 10^{-7}$ for female). The gender of respondents showed that there is the different between male and female score distribution (see Figure 6-6). Higher gap between ranking means clearer understanding in waste classification. According to the results, women seems to be understanding in waste classification better than men. Waste classification understanding is one of the reasons that people reject to separate of their wastes (Lee et al., 2017). According to the results, women have better possibility to do waste segregation. It supports a previous work that suggests women is better in waste separation behavior (Zhang et al., 2017).

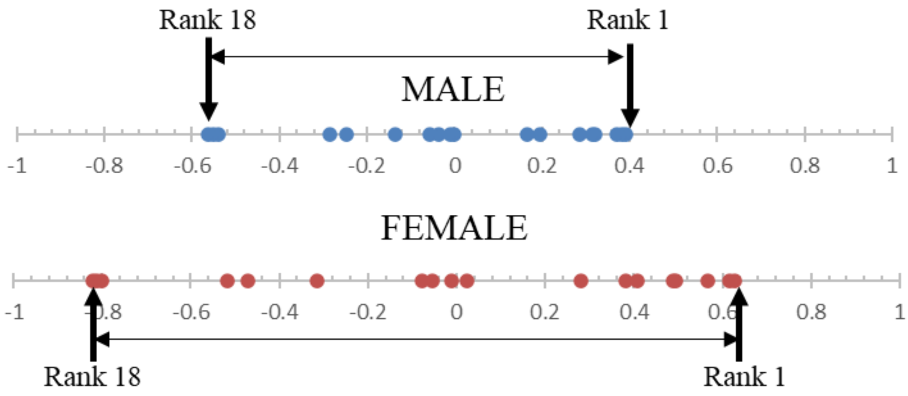


Figure 6-6 The different of gender in their waste perception

6.3.3 The effects of age on waste classification

The ANOVA tests suggested that the degree of combustible waste perception was significantly decreased with the decrease of combustible waste composition all ages expect 60's respondents ($p = 9.04 \times 10^{-7}$ for 20's, $p = 4.61 \times 10^{-7}$ for 30's, $p = 9.47 \times 10^{-8}$ for 40's, and $p = 8.57 \times 10^{-8}$ for 50's, respectively). For 60's respondents, ANOVA test also suggested that the DP of waste compositions were significantly different ($p = 9.02 \times 10^{-7}$). However, the average DP of C0 (-0.0571) is slightly higher than that of C20 (-0.0730). It could be noted that the perceptive classification of plastic waste as combustible waste should be considered for 60's respondents.

Combustible waste compositions from C20 to C100 have linear relationship with the degrees of combustible waste perception (Preference scores). The intercept vertical axis is the expectation of C0 ($C0_{cal}$). The gap between $C0_{cal}$ and actual preference score of C0 represents the perception level of combustible wastes separated from plastic wastes. The increase of different between $C0_{cal}$ and $C0_{actual}$ means the higher perception level of combustible wastes separated from plastic wastes.

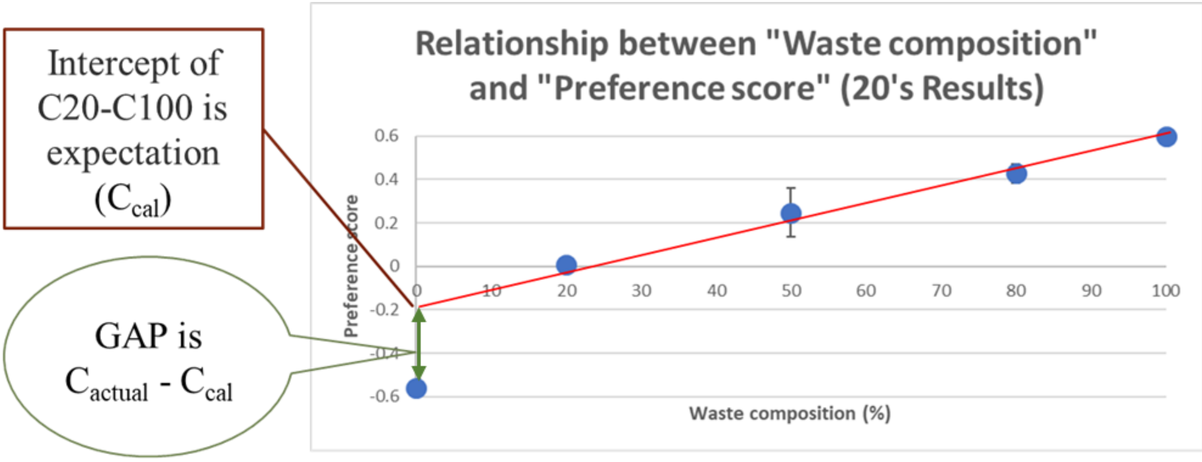


Figure 6-7 An example of differential between C0 calculation and actual

From Figure 6-8, the results showed that younger respondents were clearer distinguish combustible waste than older respondent. The increase of age of respondents significantly correlated with the perception level of combustible wastes separated from plastic wastes ($p = 0.000182$).

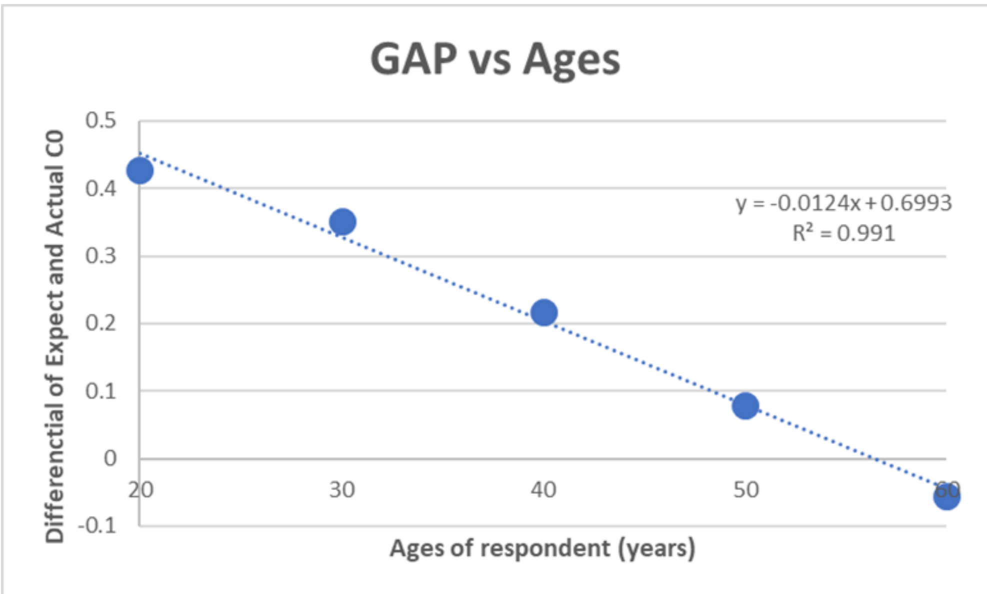


Figure 6-8 The differential between C0 calculation and actual

6.4 Summary

According to a previous work, misunderstanding in waste classification is one of the important factors for people to avoid separation process (Lee et al., 2017). The message of waste sorting guidance can improve the education in term of understanding in waste classification (Huang et al., 2018). It should be noted that waste sorting guide is necessary to improve the efficiency of waste sorting. Furthermore, this guidance could be including in the waste management policies in the target area. The regulation norm of the guidance would be improve the segregation behavior (Miafodzyeva and Brandt, 2013).

6.5 Conclusion

The authors concluded that the food waste seems to be impactable as combustible waste. In Japan, different administrative district has their own waste classification based on their waste management strategies. In some area of Japan, plastic waste counted in combustible waste. For the reason, plastic waste was not completely rejected from combustible waste. Thus, the difference between all compositions of combustible waste and other incombustible waste were greatly different. It might confirm that the respondents have a good understanding in waste classification. In addition, female respondents were better understanding in waste classification than male by the differential of each rank score. The 60’s respondents misunderstand in waste classification of combustible wastes. The policies of perceptive classification might be important. The guideline of waste sorting classification should be promoted to the target group. The classification of plastic waste should be more emphasized into order to achieve high segregation efficiency, because it is harder classified from combustible wastes than the others.

7. Overall conclusion and recommendations

According to the conclusions in the previous chapters, all results and discussions in this study have been summarized in this chapter.

In Chapter 1, it was mentioned waste management situations and important researches in this study. The studies of following chapters provided the improvements in waste management.

In Chapter 2, the results showed the effects of setting conditions of trash bins on waste collection performance and waste segregation behaviors. The setting conditions in Chapter 2 have been designed based on varying situations in the buildings. The experiments have been done at Fukuoka University, Japan.

In Chapter 3, design preference of setting condition based on survey questionnaires was concerned. The respondents in this survey are Japanese. Three different trash bin arrangements were monitored in the on-site experiment. The preference scores were used to identify the effect of arrangement preference on waste collection performance and waste segregation behaviors. The persons of this on-site experimental campaign are students, staffs, and visitors in the building at Fukuoka University, Japan.

In Chapter 4, the concept of trash bin design preference was continued. The trash bin colors were selected based on the results of color preferences in this chapter. It was found that the design of trash bin directly affects waste collection performance and waste segregation behaviors. Both survey and on-site experiments have been done at Kasetsart University, Thailand.

In Chapter 5, the authors studied more physical design preferences of trash bin to find out the appropriate trash bin design for the target waste. The preference scores were evaluated by public participation of Japanese respondents.

In Chapter 6, refer to the results of on-site experiments in previous chapters, the results showed that improperly segregation behaviors might be caused by the understanding in waste classification. Some waste types easily contaminated into an inappropriate trash bin. Thus, the authors focused on perceptive classification of combustible and incombustible waste from Japanese respondents. The results of this chapter provided easily misunderstanding wastes and target group of people who need the education in waste classification. It could improve waste segregation behaviors.

It could be carefully noted that participants and respondents are different in each chapter. The results may be useful in the specific areas because the culture, attitude, motivation, intention, education, and demographic property are different. For example, in Chapter 4, the significant findings were investigated by Thai participants and respondents. The findings might be different, if the study was investigated in Japan. The details of overall conclusion with recommendations are shown in following sections.

7.1 The improvement of waste collection performance

Setting conditions of trash bin gave the impact on waste collection performance and segregation behaviors. The increase of distance along walking path gave no impact on both collection rate and separation efficiencies. On the other hand, the distance to trash bin out of walking path can significantly decrease waste collection rate ($p = 0.0325$). The increase of 4 m and 8 m distance to trash bin decreased waste collection rate by 10.9% and 30%, respectively. However, the separation efficiencies were not significantly different with the increase of distances. The threshold distance that affects waste disposal behaviors is between 8 and 410 m. The separated trash bins setting decreased waste separation performance. According to the statistical test results in section 2.3.3, the contamination rate of trash bins at the original side significantly increased while the capture rate of trash bins at the opposite side significantly decreased. The participants need to walk 3 m to the opposite side, if they want to correct disposal. The multiple disposal process of waste sorting is considered as one of the inconvenient factors. Setting of trash bins at one side is recommended. The arrangement preference gave no impact on waste collection and segregation performances. However, the setting position of recyclable wastes bin affects waste separation efficiencies. The capture rate of cans was significantly increased when can bin was set in the middle position of the arrangement ($p = 0.0396$). In addition, the capture rate of glass bottles was also clearly increased when glass bottle bin was set in the middle position of the arrangement. Thus, the results suggested that recyclable wastes bins were more effective when those bins were set at the middle position of arrangement. The colors of trash bins affect separation performance with their noticeability in the setting location. Less noticeable trash bin cause larger attention and/or higher motivation to do waste separation. The effective capture rate significantly increased with the decrease of noticeability for all types of waste ($p = 0.00247$ for compostable waste, $p = 0.0275$ for PET bottle, and $p = 0.00147$ for recyclable waste). However, if trash bins were set with too low noticeability, consumers may not be able to find them. So, trash bin should be set with the appropriate noticeability to make the effective waste separation. It could be noted that on-site experiment participants in Fukuoka University and Kasetsart University, demographic properties are very biased because they are mainly students. Biased demographic properties might give non-negligible impact on the results. Our experimental results risky generalized something according to the results.

In addition, the number of bin types might be one remarkable factor that affect waste separation performance and segregation behaviors. The monitoring results of Chapter 2 and Chapter 3 represented the separation efficiencies of four bin types cases. The combination of four bin types includes combustible waste bin, PET bottle bin, can bin, and glass bottle bin, respectively. On the other hand, the monitoring results of Chapter 4 showed the separation efficiencies of three bin types. The combination of three bin types includes compostable waste bin, PET bottle bin, and recyclable waste bin. It was found that waste separation performances of four bin types were significantly better than those of three bin types as shown in Figure 7-1. The capture rate of four bin types was significantly higher than that of three bin types about 47.83% ($p = 2.99 \times 10^{-5}$). While, the contamination rate of four bin types was significantly lower than that of three bin types about 147.05% ($p = 3.74 \times 10^{-6}$). However, this comparison might contain experimental errors because the persons in the experimental campaigns were different. Higher separation efficiencies of four bin types might come from better segregation behaviors of Japanese participants compared to Thai participants. In addition, the difference of bin types in each combination might also give the effects on the results. The bins in four types combination might be let the consumers feel more convenient to do waste separation. In future researches, the authors recommended to do the on-site experiment with various number of bin types in the same location. It will be useful to provide appropriate number of bin types which set in the public areas.

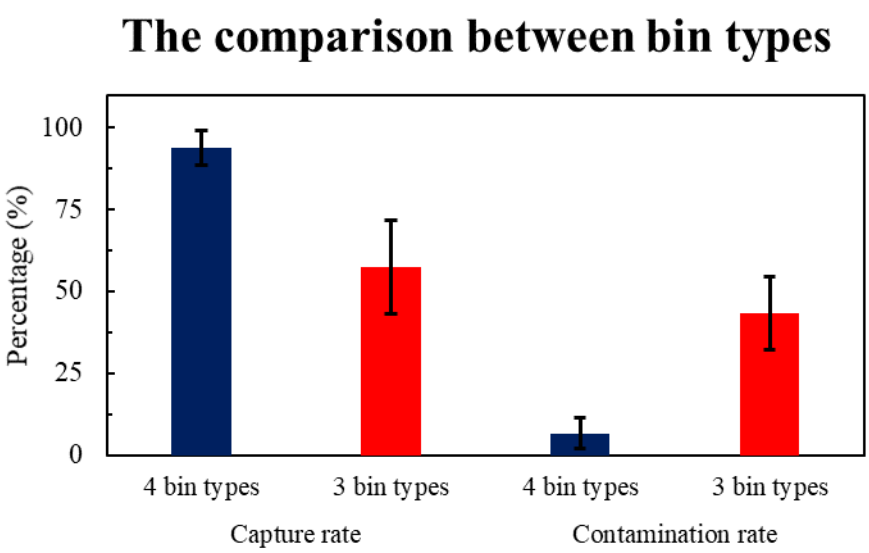


Figure 7-1 The comparison between 4 bin types and 3 bin types

According to monitoring results, it could be promoting the ideal setting condition as shown in Table 7-1. Firstly, trash bins can be set at 8 m distance away from walking path to reduce waste collection without negative effects on waste separation efficiencies. The longer distance (> 8m) to trash bins might be able to set, if it is confirmed in the future work. Appropriate distance to trash bin can make decent amount of waste to optimize waste transportation trips (Erfani et al., 2017). Secondly, separated setting of trash bins should be avoided because it will decrease waste separation performances. Hence, all types of trash bins should be set on one side. Thirdly, recyclable waste bins should be placed at the middle position of the arrangement. Fourthly, the noticeability of trash bins gave the impact on waste collection performance and separation efficiencies. Noticeability of trash bins can be designed by a polynomial model including color preference and location in section 4.3.3. Low noticeability of trash bin can increase waste separation performance with behavioral attention. However, too low noticeability of trash bin might let the persons improper dispose of their waste on the ground because they could not find trash bins. So, trash bins should be set with appropriate noticeability. Lastly, the comparison between number of bin types suggested that four types of trash bin have been performed better separation efficiencies than three types of trash bin. Nevertheless, the research to find out the appropriate number of bin types is the challenges in the future.

Table 7-1 The ideal setting condition of trash bin

Factors	**Distance to trash bins**	**Separated bin setting**	**Arrangement**	**Noticeability**		**Number of bin types**
Setting of trash bin	0 to 8 m	Avoided	Recyclable waste bins in the middle position	Appropriate color preference	Low noticeable in the location	4 types > 3 types
Remarks	It could be noted that on-site experiment participants in this study, demographic properties are very biased because they are mainly students.					

7.2 The recommended trash bin designs

According to the effect of trash bin color, the designs of trash bin are related to waste collection and segregation performances. Trash bins should be designed to support the target consumers. The dimension of designed objects (2D or 3D) in survey questionnaires gave significant impact on the respondent's decision (2D; Front > Top, $p = 2.50 \times 10^{-6}$ and 3D; Top > Front, $p = 0.00180$). According to the results in section 5.3.1, PET bottle bins with labelled PET bottle illustration were significantly more preferred than letter label in all cases. Hence, the design of trash bin should include illustration of target waste to easily find out appropriate bin. The slope slot position of combustible waste bin was the most significant preferred ($p = 0.00180$). Thus, slope slot position is recommended for combustible waste bin. However, the slot position design should be concerning on visual impairments of consumers. The preference score of front slot position was significantly higher than that of top slot position with treated VA and RP impairments ($p = 3.25 \times 10^{-7}$ for VA and $p = 1.19 \times 10^{-26}$ for RP). On the other hand, the preference score of top slot position was significantly higher than that of front slot position with treated DR and MD impairments ($p = 3.55 \times 10^{-8}$ for VA and $p = 6.91 \times 10^{-6}$ for RP). The shape of PET bottle bin should be bottle or cylinder. Cylinder shape is the most significantly preferred design with treated VA impairments ($p = 1.67 \times 10^{-16}$). While, bottle shape is the most significantly preferred design with treated DR and MD impairments ($p = 1.84 \times 10^{-17}$ for DR and $p = 2.29 \times 10^{-12}$ for MD). The results suggest combustible waste bin should be visible to make consumer can see the wastes inside. On the other hand, the lid attachment on top of trash bin is not recommended. This design guidance will be useful to design appropriate trash bins in public area.

The ideal trash bin designs are shown in Figure 7-2. PET bottle bin should illustrate the image of PET bottle to help the consumers easily find out appropriate bin. The slot position of PET bottle bin should be designed to support the target consumers. Top slot position is very helpful for the persons with DR and/or MD impairments. On the other hand, front slot position is appropriated for the persons with VA and/or RP impairments. Shape of PET bottle bin can be designed in bottle shape or cylinder shape. In case of combustible waste bin, slope slot position is the appropriate location for consumers. Furthermore, combustible waste bin should add transparent area in front of the bin to help consumer able to see the previous wastes inside. It could be noted that lid attachment of trash bin should be avoided for good usage.

PET bottles bins **Combustible waste bin**

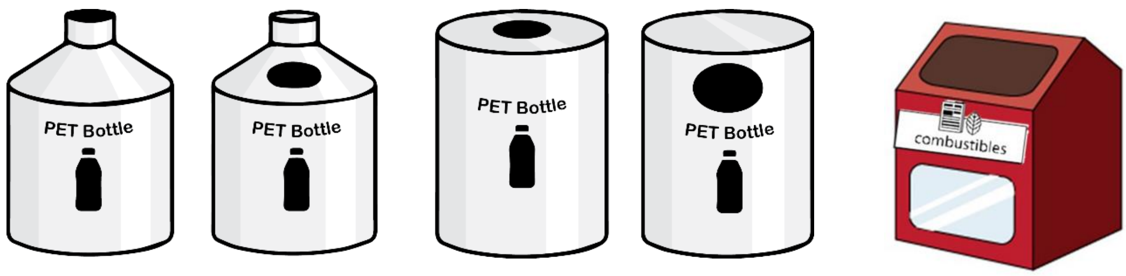


Figure 7-2 Recommended trash bin designs

In the future research, the authors planned to check the effects of design preference on real separation efficiencies. In this experiment, tested trash bins are exactly following designed bins in the survey questionnaires. Tested trash bins were made with similar size to public bins (Dimensional sizing: height = 60 cm, wide = 35.5 cm, and length = 40 cm). The finding of this study will explain the design preference benefit. If the design preference of trash bin positively correlates with the separation efficiencies, it means design preference is sufficient without on-site experiment. So, it will eliminate the cost of on-site experiment in the further studies.

Figure 7-3 The real trash bins based on survey experimental results

Moreover, the additional designed factors of trash bins will be considered in the future study. The designs of trash bin with the idea of 2 waste types in 1 bin have been illustrated in Figure 7-4A. The slot size is the influent factor for the study. For example, designed trash bins are for combustible waste (C) and plastic waste (P). The littering slots can be varying with different ratio such as C:P = 1:1, 1:1.5, and 1.5:1. In addition, the signages of trash bin are also challenging. Different signages for combustible waste bin were designed as shown in Figure 7-4B. The additional designed factors will be investigated by survey questionnaires and on-site experiments. The results of the study will show design preferences and its effects on waste collection performance and segregation behaviors.

(A) 2 wastes types in 1 bin **(B) Signage designs**

C:P is 1:1 **C:P is 1:1.5** **C:P is 1.5:1**

Figure 7-4 Additional designs for future studies

7.3 The improvement of segregation behaviors

According to the monitoring results in previous on-site experiments, the misunderstanding or confusion in some waste types strongly affects waste separation efficiencies. For example, the experiment in Thailand showed that PET bottle bin was contaminated recyclable wastes. The perceptive classification of wastes should be one of the considered factors to develop waste segregation behaviors. The perceptive classification of combustible waste and incombustible waste results showed that Japanese respondents are good in waste classification. The degree of combustible waste perception (DP) was significantly increased with the increase of combustible waste percentage in the composition ($p = 4.26 \times 10^{-8}$). However, plastic wastes are easily misunderstanding to be combustible waste because the classification categories of plastic waste in Japan are different in some areas. The DP of plastic wastes was significantly higher than that of the other incombustible waste ($p = 0.0105$). The results also showed that male or older people might misunderstand in waste classification. The guidance for easily misunderstanding wastes should be provided to the citizen (see Figure 7-5). The education of waste sorting guidance should serve to older people. Refer to a previous work, it was found that providing message of incorrectly disposed waste to the participant improve waste sorting performance (Luo et al., 2019). Hence, the providing of easily misunderstanding waste might improve waste segregation behaviors.

Figure 7-5 Easily misunderstanding waste in sorting guidance

According to the results in this study, the recommended trash bin designs with ideal setting conditions can integrate in the wider situation. For example, the larger area like big events generate high volume of wastes. The significant finding of this study will be useful to handle with large amount of wastes. The setting condition of trash bin can manage the predicted waste collection with effective separation performances. The appropriate design of trash bins may convince event's participants to do waste separation. Designed trash bins can be made as pattern form (see figure 7-6). It will be easy to install and uninstall for the temporary setting on the events. In addition, our results might be able to adapt the real policy of waste management. It means that the real policy can be written from our study perspective.

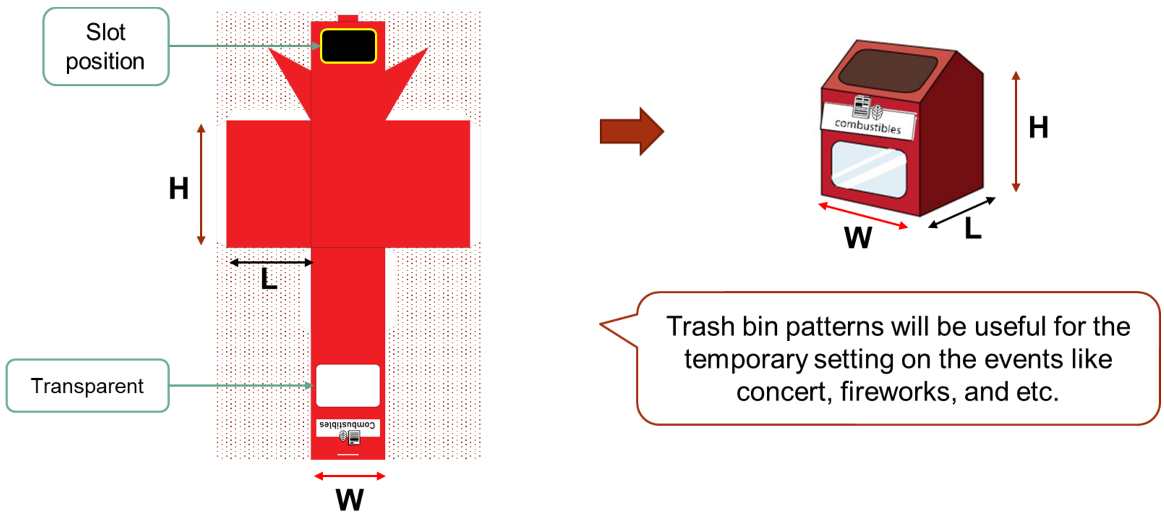


Figure 7-6 Trash bin patterns for temporary setting on the events

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Supplementary Table

Table S2-1 Gaussian normality of all condition dataset

Condition and type of waste			Waste collection by weight	Waste collection based on number	Separation efficiency	Foreign waste percentage
1A	Combustible wastes		*	No data	*	*
	PET bottles		*	*	not normality	not normality
	Cans		*	*	*	*
	Glass		*	*	not normality	not normality
	Total		*	-	-	-
2A	Combustible wastes		*	No data	*	*
	PET bottles		*	*	*	*
	Cans		*	*	not normality	not normality
	Glass		*	not normality	not normality	not normality
	Total		*	-	-	-
1B	2015	Combustible wastes	not normality	No data	not normality	not normality
		PET bottles	*	*	not normality	not normality
		Cans	*	*	not normality	not normality
		Glass	*	*	*	*
	2016	Combustible wastes	not normality	No data	*	*
		PET bottles	*	*	*	*
		Cans	*	*	*	not normality
		Glass	*	*	not normality	*
	2 years	Combustible wastes	*	No data	not normality	*
		PET bottles	*	*	*	not normality
		Cans	*	not normality	not normality	not normality
		Glass	*	*	not normality	*
		Total	not normality	-	-	-
2B	2015	Combustible wastes	*	No data	*	*
		PET bottles	*	*	*	*
		Cans	*	*	*	not normality
		Glass	*	*	not normality	not normality
		Total	*	-	-	-

Noted: * = normality accepted by Shapiro-Wilk test with 5% significant level
- = no data analysis

Table S2-1 Gaussian normality of all condition dataset (count.)

Condition and type of waste			Waste collection by weight	Waste collection based on number	Capture rate	Contamination rate
3B	2015	Combustible wastes	*	No data	*	*
		PET bottles	*	not normality	*	*
		Cans	*	*	not normality	*
		Glass	*	*	not normality	*
	2016	Combustible wastes	*	No data	not normality	*
		PET bottles	not normality	*	*	not normality
		Cans	*	not normality	*	not normality
		Glass	*	*	not normality	not normality
	2 years	Combustible wastes	*	No data	not normality	not normality
		PET bottles	*	not normality	not normality	not normality
		Cans	*	*	not normality	not normality
		Glass	*	*	not normality	not normality
		Total	*	-	-	-
1C	Combustible wastes		*	No data	*	*
	PET bottles		*	*	*	*
	Cans		*	*	*	*
	Glass		*	*	*	*
	Total		*	-	-	-
2C	Combustible wastes		*	No data	*	*
	PET bottles		*	*	*	*
	Cans		*	*	*	*
	Glass		*	*	*	*
	Total		*	-	-	-
3C	Combustible wastes		not normality	No data	*	*
	PET bottles		*	*	*	*
	Cans		*	not normality	*	*
	Glass		*	*	*	*
	Total		*	-	-	-

Noted: * = normality accepted by Shapiro-Wilk test with 5% significant level

- = no data analysis

Table S3-1 Gaussian normality of all arrangement dataset

Arrangement and type of waste		**Waste collection by weight**	**Waste collection based on number**	**Capture rate**	**Contamination rate**
1	Combustible wastes	*	No data	*	*
	PET bottles	*	*	*	*
	Cans	*	*	*	*
	Glass	*	*	*	*
	Total	*	-	-	-
2	Combustible wastes	*	No data	*	*
	PET bottles	*	*	not normality	*
	Cans	*	*	*	*
	Glass	*	*	not normality	not normality
	Total	*	-	-	-
3	Combustible wastes	*	No data	*	*
	PET bottles	*	*	*	*
	Cans	*	*	*	*
	Glass	not normality	*	not normality	*
	Total	*	-	-	-

Noted: * = normality accepted by Shapiro-Wilk test with 5% significant level
- = no data analysis

Table S4-1. Coefficients of the terms to predict color combination preference.

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1.141744417	0.380581472	8.259097121	0.02207549
Residual	5	0.230401379	0.046080276		
Total	8	1.372145796			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.017890671	0.080658092	-0.221808752	0.833237517	-0.225228896	0.189447555	-0.225228896	0.189447555
COM	0.601352937	0.514945203	1.167799863	0.295539699	-0.722355848	1.925061722	-0.722355848	1.925061722
PET	0.647214703	0.554333655	1.167554409	0.295630098	-0.777745321	2.072174727	-0.777745321	2.072174727
REC	0.876867292	0.538056035	1.629695115	0.164094715	-0.506249778	2.259984361	-0.506249778	2.259984361