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Quantitative Analysis of Material Flow of Used Mobile Phones in Japan

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Abstract

Since Japan is importing most of natural resources, reducing amount of material usage is an emerging problem. Plus, reducing environmental impact of product lifecycle is also important. This paper first, illustrated a material flow of used mobile phones with quantitative information. Then, a sensitivity analysis was applied to clarify important factors in reducing material consumption and environmental impact. Result showed that transportation length has a big influence on environmental impact. Thus, an efficient logistics can be a key in reducing environmental impact. The material flow showed that a big portion of used phones are stored in homes. To collect such stored mobile phones, official network called MRN (mobile phone network) is the best strategy in reducing material consumption and avoiding problems regarding outflow. Finally, the paper concluded that sensitivity analysis of material flow is a useful method in determining proper strategy of treatment of used products.

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Keywords: material flow, mobile phone, sensitivity analysis

1. Introduction

Since Japan is not a resource-rich country and is importing most of the necessary natural resources from overseas, utilizing resources stocked in products, so-called urban mine, is strongly focused. It is widely agreed that utilizing used products in some way is necessary for establishing sustainable society. Especially, the paper focuses on used mobile phones, since the critical metals and other metals that are potentially recovered from used mobile phones are larger than the amount contained in all the other small-sized e-waste [1]. However, as for electronic equipment such as mobile phones, not many people put their used products in a recycling bin. Although the number of used products is increasing, collection rates that means the numbers of actually recycled products divided by estimated numbers of products that reach end-of-life stage per year, are gradually decreasing [2]. Thus, one of the big problems regarding material recovery from used mobile phones is a low collection rate. Without a sufficient collection rate, social system to collect and recycle used products cannot be feasible. On the other hand, it often happens that used products are hibernated in personal homes and not recycled. Currently, more than 40% of used mobile phones per year is estimated to be hibernated. (Fig.1 [3]) To improve this situation, from April 2013, a legislation to promote recycling of WEEE (waste electrical and electronic equipment) has started to be enforced. However, the question is "what is the best strategy in managing used WEEE, especially mobile phones?" It is often said that product reuse is the best way to establish a sustainable society. But, in the case of mobile phones, some economic statistics suggest that such mobile phones for second-hand use are not for domestic markets. It has been reported [4] that such outflow of electronic products sometimes results in inadequate recycling processes and causes damage in environment. Therefore, we have to consider what is the best strategy to handle used mobile phones, in the aspects of resource consumption and environmental impact. In order to determine appropriate way to handle used mobile phones and establish resource efficient society, the first step should be the understanding of current situations of material flow of used products. Material flows are totally different depending on products, year, countries, etc. Thus, although there are some previous studies [5-9] focusing on the material flow of used electronics a new investigation is necessary for mobile phones in Japan. Therefore, the objective of this study is to investigate the current material flow of used mobile phones precisely and indicate the key factor in reducing environmental impact and promoting efficient use of resources. The paper tries to apply sensitivity analysis to know the effective strategy.

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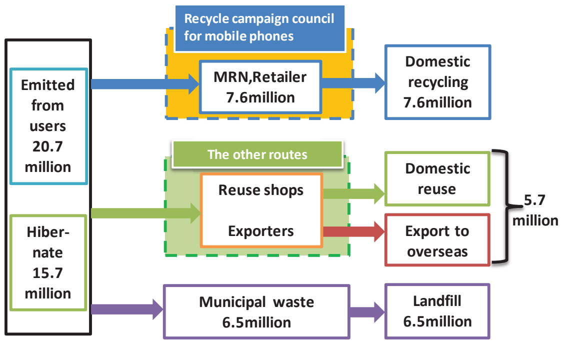

Fig.1 Basic material flow of used mobile phones

2. Investigation and illustration of the material flow

2.1. Increasing commodity of mobile phones

Mobile phones including both smartphones and feature phones are very common products in modern life. Number of mobile phones plus other personal communication devices has reached to more than 122% of the number of households. On the other hand, not many people put their used mobile phones into recycling bins. The collection rate of mobile phones has been around 20% and gradually decreasing (Fig.2). Previous survey [10] says that more than 200 million used mobile phones are hibernating in homes. Thus, it is evidently necessary to consider management strategy.

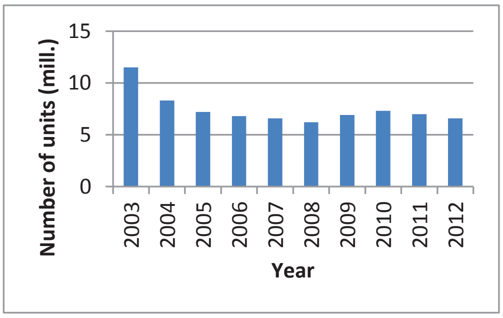

Fig. 2. Transition of collection rate of used mobile phones

2.2. Illustration of the material flow

Although Fig.1 shows the basic flow of used mobile phones in Japan, the flow is too abstract and it is insufficient to find out management strategy based on this figure. A more precise material flow is necessary. But, at least, the figure suggests that an official network to collect and recycle used mobile phones called MRN (Mobile phone Recycle Network [11]) is one of the key players. Then, the paper investigated available data from MRN, trade statistics and other statistical data. But, still some of the data were not available from open source and estimated based on assumptions. Basically, there are 4 choices for a used mobile phone. As shown in Fig.1, the choices are recycling by MRN, product reuse including export, municipal waste and hibernation. Plus, component reuse exists for a specific component. Considering all these factors and sub-flows which correspond to bypaths from a selection to another selection, material flow of used mobile phones can be illustrated as Fig.3. The figure still does not have quantitative information. So, the next step is to fill out amount of each flow. Also a variable is assigned to each major flow and sub-flow as it is indicated in the figure. Table 1 to 3 show the number of units of used mobile phones corresponding to the variable in the figure, as of 2011.

Table 1. Investigated amount of the flow

Variable	Corresponding flow	Number of units (10^4 units)
M.col	Collection by MRN	738
col1	Collection other than MRN	570
s,o	Second hand shop or online auction	120
loc	Disposed as municipal waste	654
los	Lost	13
bus	Sent out from MRN	738
rec2	Sent to recycling facilities	728
reu3	Sent to reuse from recycling facilities	10

Table 2. Estimated amount of the flow

Variable	Corresponding flow	Number of units (10^4 units)
tra	Transferred privately	15
mat	Material recycled	669

Table 3. Assumed amount of the flow

Variable	Corresponding flow	Number of units (10^4 units)
col2	Collected by e-commerce	2
hoa1	Hibernated after use	2211
hoa2	Hibernated after transferred	10
exp1	Exported after collected except by MRN	500
exp2	Exported after secondhand retailers or online auction	40
thr1	Disposed after hibernated	630
thr3	Disposed after secondhand retailers or online auction	20
dis3	Disposed after component reuse	2
thr2	Disposed after transferred	5
dis1	Not recyclable and disposed	78
reu1	Component reused after collected except by MRN	72
reu2	Component reused after collected by secondhand retailers or online auctions	60
reu4	Component reused	70
rec3	Sent to recycling facilities from component reuse companies	20

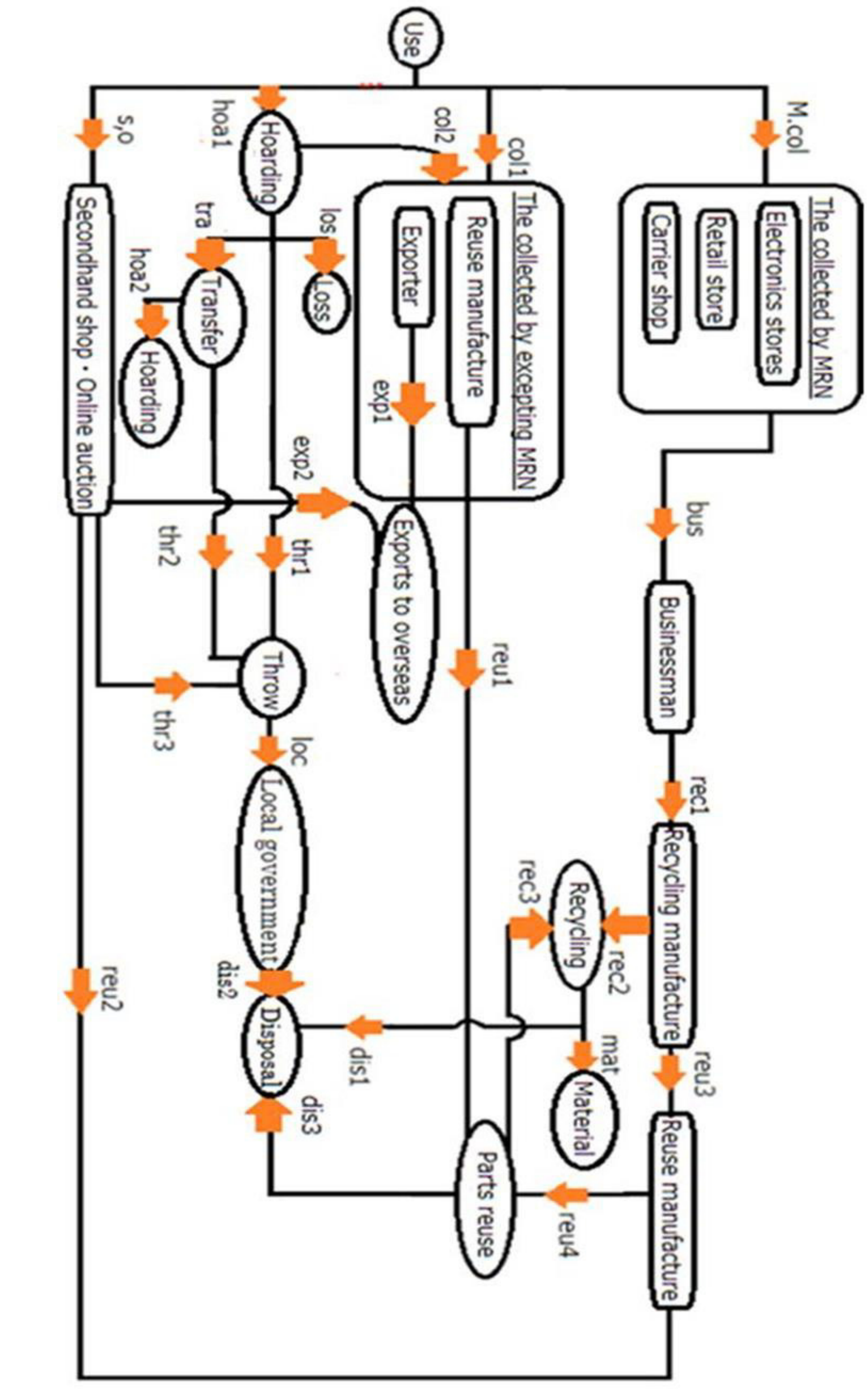

Fig.3 Material flow of used mobile phones

3. Calculation of environmental impact

3.1Estimation of environmental impact of transportation

Since the goal of this paper is to know the key factors to reduce environmental impact in material flow of used mobile phones, it is necessary to calculate environmental impact (CO_2 emission only) first. The first item is environmental impact regarding transportation. Since the average weight of a mobile phone is 0.132kg per unit [12], it is possible to calculate the environmental impact regarding transportation by Eq.(1).

$$Et[kg\text{-}CO_2] = \{Ct[g\text{-}CO_2/t \cdot km] \times d_{A\to B}[km] \times (M.col\,.[unit] \times 0.132[kg/unit] \times 10^{-3})[t]\} \times 10^{-3} \quad (1)$$

Where *Et*: environmental impact of transportation, *Ct*: unit CO_2 emission of transportation, $d_{A\text{-}B}$: distance from point A to B

3.2 Estimating environmental impact of each activity

The next step is to estimate environmental impact of each activity such as recycling process, export to overseas, disposal, component reuse etc. In recycling process, plastic parts are usually treated by petrochemical process. Since the average weight of plastics per a phone is about 0.07184kg/unit [13], environmental impact of recycling process can be calculated by Eq.(2).

$$Er[kg\text{-}CO_2] = 0.07184[kg/unit] \times mat[unit] \times 1.8[kg{-}CO_2/kg] \quad (2)$$

Where *Er*: environmental impact of domestic recycling process

On the other hand, although exported used products are usually reused, they will be finally need to be recycled. Recycling process in some countries are sometimes inadequate processes [14]. Thus, for exported products, the paper calculates environmental impact by Eq.(3).

$$Ero[kg\text{-}CO_2] = 0.07184[kg/unit] \times (exp1 + exp2)[unit] \times 3.0[kg{-}CO_2/kg] \quad (3)$$

Where *Ero*: environmental impact of overseas recycling process

In the case of disposal, another calculation is necessary. Usually plastic parts are incinerated as waste. Average ratio of carbon in plastics is shown as 73.5% [15]. Therefore, the environmental impact of combustion can be calculated by Eq.(4).

$$Ec[kg\text{-}CO_2] = 0.07184[kg/unit] \times (dis1 + dis2 + dis3)[unit] \times 0.735 \times \frac{44}{12} \quad (4)$$

In estimating the effect of recycling, it is necessary to consider reduced environmental impact by using recycled materials. In this paper, the effect of recycling was calculated based on the weight of copper which can be recovered from used mobile phones. It is said that about 100kg of copper can be recovered from 1t of used mobile phones [16], and environmental impact in producing copper material is estimated as 2.38kg-CO2/kg-Cu [16], the reduced environmental impact by recovering copper from used mobile phones is calculated by Eq.(5).

$$Em[kg\text{-}CO_2] = mat[unit] \times 0.000132[t/unit] \times 100[kg - Cu/t] \times 2.38[kg{-}CO_2/kg - Cu] \quad (5)$$

Where, *Em*: reduced environmental impact by material recovery

Regarding component reuse, environmental impact of component reuse activity was estimated as 0, since components are manually disassembled in component reuse process.

4. Sensitivity analysis of the material flow

4.1 Method of sensitivity analysis

In this paper, in order to know important factors to reduce environmental impact and establish a more sustainable production, sensitivity analysis was applied. In the analysis, aforementioned variables in the material flow were assigned as parameters of the analysis and current value of each parameter was set as the initial value. By applying the sensitivity analysis it is possible to know the effect of change of each parameter on the total environmental impact. To carry out the analysis, some practical conditions were determined accordingly to the material flow. These are the conditions.

use=M.col+col1+hoa1+s,o

bus=rec1=rec2+reu3

hoa1=los+thr1+tra

reu2+reu3=reu4

thr1+thr2+thr3=loc

4.2 Assumptions in calculating the sensitivities

Based on Eqs.(1) through (5) and above-mentioned conditions, relations between parameters can be described. The sum of 5 equations indicates the total environmental impact of the material flow. Then partial difference by each parameter was applied to the sum, in order to know the effectiveness of parameter changes. In the calculation, 2 parameters among 3 basic flows after use are fixed and the deviation of total environmental impact when the other one changes was calculated.

4.3 Results of the sensitivity analysis

Table 4 shown below is the result of the sensitivity analysis about 3 major parameters. Fig.4 is the viewgraph based on the same calculation results.

Table 4 Deviation of environmental impact

Variable	Meaning	Change of environmental impact (kg-CO_2)
M.col	Collection by MRN	0.1597kg
col1	Collection other than MRN	0.2939kg
s,o	Collection by second hand retailers	0.1673kg

Fig. 4 Result of the sensitivity analysis

4.4 Discussion

By looking at the environmental impact of each activity precisely, some bottlenecks in maintaining sustainability can be focused. For example, Table 5 shows the top five environmental impact in transportation. The values of environmental impact mean the total value for all the transported products. Table 6 is also showing total environmental impact of each activity in the material flow.

Table 5 Environmental impacts of transportation

Corresponding flow	Total environmental impact [kg-CO_2]
Collection other than MRN > Export to overseas	49,600
Second-hand shop > Export to overseas	4,060
Use > Collection other than MRN	5,560
Business sectors > Recycling facilities	2,910
Use > Collection by MRN	1,110

Table 6 Environmental impacts of activities

Corresponding activity	Total environmental impact [kg-CO_2]
Domestic recycling	86,500
Overseas recycling	1,160,000
Disposal	1,420,000
Material recovery	-210,000

Regarding the environmental impact of transportation, “export to overseas” has much higher impact compared to other items. Domestic transportations are not very important in the aspect of environmental impact. However, export has some importance. Table 3 also shows that recycling process in overseas can have some negative effect. These results suggest that even if the export of second-hand products is equivalent to prolonging product life, people have to be careful in exporting used products without any restrictions. So, agreeable strategies are to settle recycling facilities, second-hand product retailers and component reuse companies nearby the places where large population exists and shorten the transportation distances. And when export is necessary, some efforts to reduce transportation distances are required. Plus, recycling processes especially in developing countries sometimes have problems. Without establishing proper recycling processes in every destination country, export of used products cannot be the best end-of-life option.
The result of the sensitivity analysis also suggests an important strategies on end-of-life treatment of used mobile phones. Under the current situation including collection rate, recycling rate, hibernation rate, etc. collection by MRN will be the best strategy. Since the purpose of collection of used mobile phones by MRN are only for material recycling and some component reuse, such collection does not contribute in extending the product life such as second-hand use. But, even so, the adequate recycling process and high material recovery rates can make “collection by MRN” as the best strategy. On the other hand, “collection other than MRN” is not the desired strategy, since rather large portion of such mobile phones will be exported. Even if it is effective in prolonging product life as second-hand use, long transportation distance and less efficient recycling process will cancel the good effect.

5 Conclusions

This paper investigated the data which were available from trade statistics, information on internet and other sources. Then, the paper illustrated a material flow of used mobile phones. Based on the illustrated material flow, simple mathematical model to calculate environmental impact regarding end-of-life treatment was calculated. In the calculation, a sensitivity analysis was applied to know how much amount of CO2 emission will be generated if one unit of used mobile phone increases. The result showed that collection by MRN is the best strategy in reducing environmental impact. Although the collection by MRN aims material recycling mainly and does not contribute in extending the product life, it is a good strategy because of efficient recycling processes, high material recovery rate and short distance of transportation.

As the future work, it is necessary to enhance the preciseness and reliability of the data. Plus, it is also important to carry out dynamic analysis. Since it is always a question in end-of-life treatment of used products; "short product life and complete collection" versus "long product life and partial collection." Which is better? To answer this question, it is necessary to consider time factors in analysing the material flow.

Reference

[1] Ministry of Environment, Ministry of Economy, Trade and Industry: "Report of the study group about recovery of the rare metal and proper processing of used small household appliances," (2010). (In Japanese)

[2] http://www.tca.or.jp/press_release/2014/0624_638.html. (Accessed 30/01/15)

[3] Report of committee for recycling systems and re-utilization of valuable metals in small-sized e-waste, http://www.env.go.jp/council/former2013/03haiki/yoshi03-24.html. (In Japanese)

[4] Kojima M., Yoshida A., Sasaki S., Chung S.W. , Chapter 8 Transboundary Movement of Hazardous Waste: Lessons from uncovered cases. In: Kojima M., Michida E., Economic Integration and Recycling in Asia, Institute of Developing Economies, (2009) 129-148

[5] Yoshida A., Tasaki T., Terazono A., Material flow analysis of used personal computers in Japan. Waste Manage., 29 (5) (2009) 1602-1614.

[6] Osibanjoa, O., Nnoromb, I.C. , Material flows of mobile phones and accessories in Nigeria: Environmental implications and sound end-of-life management options, Environmental Impact Assessment Review, Volume 28, Issues 2–3 (2008) pp.198–213.

[7] Yaanga, J., Lua, B., Xub, C. , WEEE flow and mitigating measures in China, Waste Management, Volume 28, Issue 9 (2008) pp.1589–1597.

[8] Kim, M. Jang, Y.C., Management of used & end-of-life mobile phones in Korea: A review, Resources, Conservation and Recycling, Volume 55, Issue 1, (2010) pp.11–19.

[9] Ongondo, F.O., Williams, I.D., Mobile phone collection, reuse and recycling in the UK, Waste Management, Volume 31, Issue 6, (2011) pp. 1307–1315.

[10] http://www.garbagenews.net/archives/2059042.html. (Accessed 30/01/15)

[11] http://www.mobile-recycle.net/. (Accessed, 09/05/15)

[12] http://www.env.go.jp/recycle/report/h23-01/01.pdf,. (Accessed, 30/01/15)

[13] Takeshima, A., H, Itsubo, T. (2007),: LCA Including Dsiposal and Recycling stages of a MobileTelephone, Proceedings of 2nd Conference of Japan LCA Society, March 2007, Tokyo Japan, pp282-283.

[14] Chia, X., Streicher-Porteb, M., Wanga, M., Markus, A., Informal electronic waste recycling: A sector review with special focus on China, Waste Management, Volume 31, Issue 4, (2011) pp.731–742.

[15] https://www.mitsui.com/jp/ja/business/challenge/1190511_1589.html, (Accessed, 30/01/15)

[16] http://www.komatsu-kenki.co.jp/saiseki/technology/front_line-02.html, (Accessed, 30/01/15)