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Quality and Environmental Performance Indices for Electrical Appliance Recycling in Taiwan

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Abstract

Six recycling plants have started operation for recycling scrap home appliances since the spring of 2000 in Taiwan. The performance of the plants has not yet been measured during the 18-month period. The performance measurement, however, can be looked in several aspects. Because of the nature of these recycling plants, at least three aspects, namely government (representing general public), appliance manufacturers and owners of the recycling plants themselves should be considered in the performance evaluation. This study proposes various performance indices categorized in four groups: profitability, recyclability, automation and environment. The indices are different from the productivity and cost measures that are used in conventional manufacturing plants. Performances of three existing plants in Taiwan are evaluated as illustrative examples to demonstrate the use of the proposed measures. The practical implications of the performance indices are also discussed.

Keywords: Electrical appliance, performance index, recycling

1. Introduction

Starting from 2000, six recycling plants for scrap electrical appliances have operated in Taiwan. Two plants for each area, viz. northern, central and southern Taiwan, started to recycle scrap TVs, washing machines, air conditioners and refrigerators. Up to the beginning of year 2001, more than 2 million units of scrap appliances have been recycled. The amount includes approximately 940 thousands of TV, 500 thousands of washing machines, 500 thousands of refrigerators and 60 thousand of air conditioners. More than 70 thousand tons of solid waste have been reduced because of the recycling action. The manufacturers and importers of the electrical appliances have contributed approximately 1 billion NT dollars for the recycling and disposition (Cheng, 2000; Shih, 2001). A special fund management was organized to manage the disposition fee and subsidize the recycling plants that actually disassemble and recycle the scrap appliances. Among the disposition fund, more than 40% of the disposition fee have gone to the recycling plants. But until now, there was few discussion on the overall performance of the recycling plants except an evaluation project conducted by Taiwan EPA at the beginning of year 2001. But, the evaluation project has caused some debate and did not completely announce the results.

The major reason of not having a performance evaluation is twofold. First, the recycling plants that deal with waste goods are quite different from conventional manufacturing plants. General criteria for conventional factory evaluation such as quality, delivery, flexibility and cost are not suitable for evaluating the recycling plants. Secondly, the performances of the recycling plants need to be seen in different points of view. To the general public (also the local Environmental Protection Agency), the sustainability and the reduction of environmental impact are the main concern. To the downstream users of recycled materials, the quality and purity of the reclaimed materials generated in the plants is of concern. To the manufacturers of electrical appliances, the concern may include the recyclability (Fujitsu, 2000) that might become an important feedback for future product design. Finally, to the recycling plants themselves, profitability is of course the major concern.

In light of the discussion of the characteristics of the performance evaluation of the recycling plants, this study suggests a series of performance indices that can be used to evaluate the recycling plants. As mentioned earlier, since the performance evaluation is the concern of many parties, the authors categorize the performance indices into four groups: environmental and resource conservation, recyclability, operation automation and profitability.

2. Performance evaluation from different aspects

Since general public strongly urged recycling electrical appliances, Taiwan EPA promulgated the recycling regulation and organized a fund management office in 1998. The manufacturers and importers were asked to provide the disposition fee for the recycling because the recycling operation was considered non-profitable. In this case, running recycling plants follows no free market mechanism. When talking about performance evaluation, various aspects other than recycling plants and downstream users should be considered.

For instance, general public eventually bears part of the disposition fee since the manufacturers have reflected the increased cost to the product sale price. The concern of the general public should be whether the recycling operation effectively reduces the environmental impact. Besides, due to the public awareness of society sustainability, the effect of resource conservation and recycling is also an important matter.

Manufacturers and importers of the electrical appliances care the cost effectiveness of their contribution on the disposition fee. Whether the subsidy to the recycling plants is effectively used is their main concern. On the other hand, due to the ultimate goal of design for environment, whether the scrap products are easy for recycling is also the concern for future design (Yamamoto, 1999). The so-called recyclability may roughly represent their need as a feedback from the recycling operations.

For the recycling plants, the monetary return for their investment is the main concern. The cost and profit structures are important for the investors of the plants. On the other hand, the possibility of future improvement for factory management is another matter. For example, the balance and trade-off between labor operation and automation could be essential in the future.

In light of the above discussion, indices reflecting the concerns of different stakeholders are categorized into four groups in next section. Most of the indices are adopted from general literature for factory management and environmental management while several indices are suggested by the authors to explicitly show the entire performance of the recycling plants.

3. Performance evaluation and useful indices

Four groups of indices are presented in this section. The followings include the definition, derivation and implication of the indices.

3-1 Resource recycling and environmental impact reduction

Life cycle assessment (LCA) procedure is used to calculate the environmental impact reduction due to the operation of recycling plants. An LCA's software "SimaPro" is herein used to do the calculation while local LCA database is still under preparation. An environmentally weighted recycling quote suggested by Huisman et al. (2000) is employed to better measure the effectiveness of appliance recycling. Other indices are as follow.(See Table1)

Storage ratio: the ratio between the stored hazardous material and the non-recyclable materials

Purity of the recycled metal: percentage of pure metal of the recycled metal substances.

Percentage of intact plastics: percentage of plastic material in whole piece, in contrast to the mixed plastics. This index is defined so that an intact piece of recycled plastic can be distinguished from the shredded mixed plastics, which often causes difficulty in promoting the recycle value.

Percentages of non-destructive disassembly: in general, a part that is obtained from non-destructive disassembly tends to have higher recycle value, viz. direct reuse.

Percentage of destructive disassembly: denoting the percentage of reclaimed materials from manually destructive disassembly.

Percentage of machinery destruction: denoting the percentage of reclaimed materials went through shredder in this case.

3-2 Recyclability

It is not easy to objectively show the recyclability although many guidelines are in the literature for design for recycle (e.g., Yamamoto, 1995). But, most of them are reviewed subjectively. The following indices focus more on labor effort that is put in the cycling plants to show the recyclability of scrap appliances. (See Table2)

Rate of labor cost: ratio between labor cost and total operation cost

Rate of manual disassembly time of total operation time

Manual rotation: manual rotation maneuvered by operators

Tool for manual operation: types and number of tools.

3-3 Automation

For conventional manufacturing plants, automation often means quality, flexibility and delivery. But, for the recycling plants, automation may not be justified and even costly. The followings are the indices showing the work done by machine and automated equipment. (See Table3)

Energy cost ratio: Ratio between energy cost and operational cost

Equipment cost ratio: Ratio between machine cost and operation cost.

Machine time ratio: ratio between machine operation and total operation

Powered tools: types and number of power tools

3-4 Cost and profitability

Monetary reward is the major incentive of running a recycling plant. Some economic evaluation indices are presented herein. (See Table4)

Operation cost ratio: ratio between operation cost and total cost

Subsidy ratio: ratio between subsidy earned from EPA and total income

4. Illustrative cases for performance evaluation indices

Three currently operating plants in Taiwan are illustrated in this section. Tables 5 to 8 show the index values of the three plants. The bold figures denote the largest performance among the three plants. Plants A and B are better than plant C in resource and environment, automation and recyclability indices while plant C outperforms the other plants in profitability indices. Plant C uses more labor force and invests less on machine and automated equipment. The differences of the indices between plants A and B are comparably smaller since both plants adopt machine and powered equipment here and there. The performance difference between plants {A, B} and C has caused some debate in local management as well as academics. The trade-off between (1) total quality and environmental management represented by the first three groups of indices and (2) profitability represented by the last group of indices is pretty obvious in the six plants in Taiwan. At the beginning of 2001, recycling management foundation hence conducted a formal evaluation so that various levels of subsidy can be paid according to the evaluation results for each recycling plant. Fund foundation tried to use differentiated subsidy as an incentive for promoting overall performance. But, because of some political factors and the evaluation lack of a justified clear-cut standard, the ideal has failed.

The essence of the problem is that, as discussed earlier, the evaluation ought to consider different points of view of various stakeholders. More performance indices than the ones used by EPA earlier have been summarized herein. Making performance evaluation using the indices can show explicitly the standpoints of different stakeholders. They should be helpful for future negotiation among stakeholders and EPA's policy making.

5. Conclusion

Because of the nature of the recycling plants, different points of view of stakeholders support different performance evaluation criteria. This study summarizes four groups of performance indices including resource and environmental indices, recyclability indices, automation indices, and cost-profitability indices. These explicit performance indices can be a basis in future negotiation and policy making. Also, the recyclability indices can become a feedback for manufacturer's product design for environment.

The index values for three existing plants in Taiwan were illustrated. The results show that a plant rating high in resource and environmental indices may not be the one rating high in cost-profitability indices. This indirectly explains (1) the trade-off between environmental performance and profitability and (2) how different strategies were adopted by various recycling plants. Negotiating or leveraging among stakeholders using the suggested indices remains an interesting issue in the future. Finally, these values may also be used for comparison of the recycling plants run internationally.

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Table 1 Resource and environmental indices

Indices	Calculation
Environmental Impact	Eco-indicator (SimaPro)
EWRQ	$EIW_{min}=\sum EIW_{min,j}$ $EIW_{max}=\sum EIW_{max,j}$ $EWRQ=\frac{EIW_{actual}-EIW_{max}}{EIW_{min}-EIW_{max}}$
Recycling rate	$\frac{W_A}{W_{total}}\times 100\%$
Storage rate of hazardous material	$\frac{w_h}{Wc_{total}}\times 100\%$
Purity of metal	$\frac{w_{mi}}{w_m}\times 100\%$
Percentage of large-piece plastics	$\frac{w_p}{w_{pt}}\times 100\%$
Rate of manual disassemble	$\frac{x_1}{x_1+x_2+x_3}\times 100\%$
Rate of manual destructive disassemble	$\frac{x_2}{x_1+x_2+x_3}\times 100\%$
Rate of machinery destruction	$\frac{x_3}{x_1+x_2+x_3}\times 100\%$

$$EIW_{min}=\sum EIW_{min,j}=\sum w_j\times ei_{substitution,j}$$

$EIW_{min,j}=ei_{substitution,j}\times$ weight % of material j

w_j : weight percentage of material j (kg)

$ei_{substitution,j}$: env. impact of material j via recycling

$$EIW_{max}=\sum EIW_{max,j}=\sum w_j\times ei_{incineration,j}$$

$EIW_{max,j}=ei_{incineration,j}\times$ weight % of material j

$ei_{incineration,j}$: env. impact of material j via incineration

EIW_{actual} : actual environmental impact

W_A : total weight of recyclable materials (kg)

W_{total} : total weight of collected appliances (kg)

W_h : weight of stored hazardous materials (kg)

Wc_{total} : weight of non-recyclable materials (kg)

W_{mi} : pure metal weight (kg)

W_m : recycled metal substances (kg)

W_p : manual disassembled plastics before shredder (kg)

W_{pt} : total amount of plastics in an appliance (kg)

x_1 : manually non-destructive disassembled material

x_2 : manually destructive disassembled materials (kg)

x_3 : materials obtained by machine destruction (kg)

Table 2 Recyclability indices

Indices	Calculation
Rate of labor cost	$\frac{C_H}{C_{operation}}\times 100\%$
Man-hour	Man-hour of labor operation
Manual operation time rate	$R_{HT}=\frac{HT}{MT+HT}\times 100\%$
Non-destructive disassembly	$\frac{x_1}{x_1+x_2+x_3}\times 100\%$
Destructive disassembly	$\frac{x_2}{x_1+x_2+x_3}\times 100\%$
Rotation	Rotation during the disassembly
Manual tools	Types and number of tools in manual disassembly

C_H : Labor cost (dollar/month)

$C_{operation}$: operation cost (dollar/month)

R_{HT} : *ratio of manual operation time to the total operation time*

HT : manual operation time (sec)

MT : machine operation time (sec)

Table 3 Automation indices

Indices	Calculation
Energy cost ratio	$\frac{Ce}{C_{operation}}\times 100\%$
Equipment cost ratio	$\frac{C_{MA}}{C_{operation}}\times 100\%$
Machine time ratio	$R_{MT}=\frac{MT}{MT+HT}\times 100\%$
Labor cost ratio	$\frac{C_H}{C_{operation}}\times 100\%$
Manual operation time ratio	$R_{HT}=\frac{HT}{MT+HT}\times 100\%$
Powered tools	Types and number of powered tools in disassembly

C_e : Energy cost (NT dollars)

C_{MA} : Machine cost per month

Table 4. Cost-profitability indices

Indices	Calculation
Operation cost ratio	$\frac{C_{operation}}{C_{operation} + C_{MF}}$
Subsidy ratio	$\frac{P_{EPA}}{P_{EPA} + P_F}$
Cost profit ratio	$\frac{P_{EPA} + P_F}{C_{operation} + C_{MF}}$
Rate of return	$\frac{(P_F + P_{EPA} - C_H - C_e - C_{other} - C_{MA}) \times 12}{C_F + C_A}$

C_{MF} : monthly cost of land and factory building

P_{EPA} : subsidy from EPA per month

P_F : monthly sale of recycled materials

C_{other} : monthly management and other overhead cost

C_{MA} : Machine cost per month

C_F : initial investment on land and factory buildings

C_A : investment on equipment

Table 5 Resource and environmental Indices for three plants

Indices		Plants A	Plants B	Plants C
EI	friger	**1105.923mPt/unit**	1124.129mPt/unit	1143.500mPt/unit
	Wash	**199.908mPt/unit**	203.769mPt/unit	208.029mPt/unit
	TV	**130.986mPt/unit**	131.065mPt/unit	131.082mPt/unit
EWRQ	friger	**99.049%**	98.034%	86.258%
	Wash	**85.265%**	85.098%	80.777%
	TV	**99.836%**	99.695%	99.653%
Recycling rate		**70.1%**	**69.7%**	67.9%
Storage rate of hazardous material		1.5%	1.2%	**1.2%**
Metal purity	Fe	99.0%	**99.2%**	98.1%
	Cu	92.2%	**96.0%**	86.5%
	Al	92.4%	**96.0%**	91.3%
Intact plastics	friger	0%	0%	0%
	Wash	**90.0%**	87.0%	85.0%
	TV	**95.0%**	**95.0%**	90.0%
Non-destructive disassembly	friger	3.3%	3.5%	2.5%
	Wash	**30.0%**	21.3%	23.8%
	TV	66.7%	67.9%	**70.7%**
Destructive disassembly	friger	13.3%	14.2%	14.2%
	Wash	30.0%	**53.7%**	**51.2%**
	TV	33.3%	32.1%	29.3%
Destructive machine treatment	friger	83.4%	82.3%	83.3%
	Wash	**40.0%**	25.0%	25.0%
	TV	0.0%	0.0%	0.0%

Table 6 Automation indices for three plants

Indices		plants		
		A	B	C
Energy cost ratio		**5.7%**	4.6%	4.1%
Machine cost ratio		**27.9%**	26.5%	22.1%
Machine time ratio	Frig	60.7%	**63.6%**	60.0%
	Wash	**71.5%**	3.3%	3.3%
	TV	**45.8%**	**46.7%**	40.0%
Labor time ratio	Frig	**39.3%**	36.4%	**40.0%**
	Wash	28.5%	**96.7%**	**96.7%**
	TV	54.2%	53.3.0%	**60.0%**
Powered equip	Frig	2(handle 1 conveyer 1)	2(handle 1 conveyer 2)	1(conveyer 1)
	Wash	3(handle 1; conveyer2 cutter1)	2(handle 1 simple crusher 1)	1(simple crusher 1)
	TV	2(handle 1 tube cutter 4)	2(handle 1 tube cutter 4)	2(handle 1 tube cutter 4)

Table 7 Recyclability indices for three plants

Indices		Plants		
		A	B	C
Labor cost ratio		49.2%	50.1%	59.3%
Man-hour	Frig	5 persons (183sec)	6 persons(169sec)	3 persons (189sec)
	Wash	5 persons (80sec)	1 persons (290sec)	1 persons (319sec)
	TV	9 persons (149sec)	8 persons (160sec)	8 persons (180sec)
Labor operation time ratio	Frig	**39.3%**	36.4%	**40.0%**
	Wash	28.5%	**96.7%**	**96.7%**
	TV	54.2%	53.3.0%	**60.0%**
Non-destructive disassembly	Frig	3.3%	3.5%	2.5%
	Wash	**30.0%**	21.3%	23.8%
	TV	67.1%	68.7%	**70.7%**
Destructive disassembly	Frig	13.3%	14.2%	14.2%
	Wash	30.0%	**53.7%**	**51.2%**
	TV	32.9%	31.3%	29.3%
Manual rotation	Frig	1 (90°)	3 (270°)	0
	Wash	1 (90°)	7~8	8~9
	TV	6	5	5
Manual tools	Frig	5	6	5
	Wash	5	5	3
	TV	6	6	5

Table 8 Cost-profitability indices for three plants

Indices	plants		
	A	B	C
Operation cost ratio	0.69	0.69	0.74
Subsidy ratio	0.82	0.83	0.78
Income/cost ratio	1.6	1.7	2.3
Rate of return	0.46	0.49	0.81