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# Development of Weighting Factors for Time Consumption Method -Comparison of Beverage Containers

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This study was to develop weighting factors for Time Consumption Method (TCM)-a life cycle impact assessment method. The basic concept of TCM to evaluate environmental impacts from the viewpoint of time consumption towards environmental crises was proposed by Yasui in 1998. In the evaluation process, weighting factor was expressed as "Fatality of the crisis" divided by the "Years to the crisis". The "Fatality of the crisis" and the "Years to the crisis" were calculated from survey questionnaires. TCM and other LCIA methods were applied to beverage containers using life cycle inventory data in Japan. Using EPS2000, EI95, EI99 and LIME, a one-way glass bottle is better in term of environmental impacts than three-pieces-steel can. In contrast, Japanese methods (TCM, Nagata's) and EP97 result concluded in the opposite way. This difference was caused by the weighting factor of solid wastes. The European methods tend to emphasize on energy consumption and $CO_2$ emission rather than wastes. On the contrast, EP97 counted weighting factor of wastes. In addition in this study, solid wastes were not evaluated in LIME method. The result suggested that TCM was adaptive to assess environmental effects in Japan.
Key words: LCA, LCIA, Time Consumption Method, weighting factor, beverage container

## 1. INTRODUCTION

Life Cycle Assessment (LCA) has been widely used to evaluate environmental impacts of materials or products. A numerous case studies on using LCA were reported. Along with the development of LCA, Life Cycle Impact Assessment (LCIA) has also improved especially in European countries. There are also some LCIA methods developed in Japan by projects among universities, academy, research institutes, and companies. However, there is no international or domestic consensus on any developed LCIA methods in Japan, because it is still on study phase.

Fig. 1showed the framework of LCIA. There are two major types of LCIA methods, endpoint and midpoint methods. In the endpoint methods, environmental impacts are calculated by the cause-effect relationship models from input and output to safeguard subjects using scientific determined factor numbers. In the midpoint methods, part of the factor numbers are collected by panels or questionnaires as public consensus and inducted into the environmental impact models. The former is represented by Eco-indicator 95/99

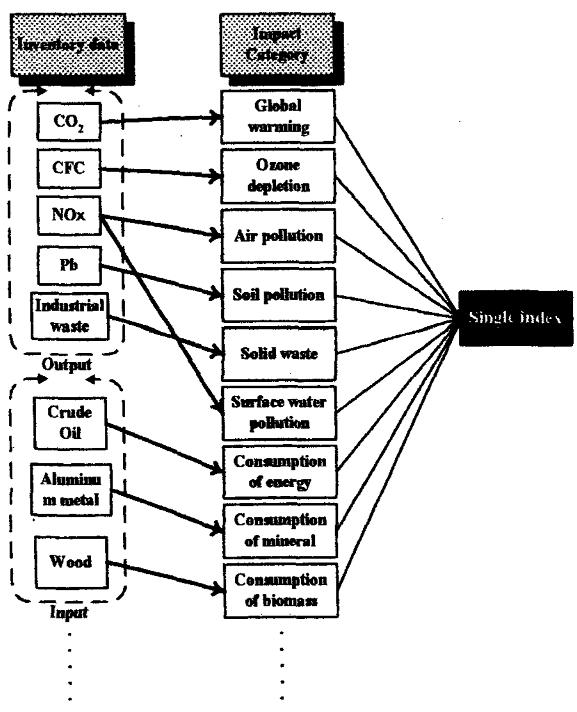


Fig. 1 Framework of LCIA

in the Netherlands, EPS2000 in Sweden and Life-cycle Impact assessment Method based on Endpoint modeling (LIME) in Japan, while the latter by Ecopoint97 in Swiss, Panel method, JEPIX, and Time Consumption Method (TCM) in Japan. Endpoint methods are characterized by its transparency and scientific basis. It ,however, still have some difficulties such as: (1) impossibility in assessing uncertain environmental matters or potential safeguard subjects; (2) difficulties dealing with those matters which do not cause any damages now but may cause in future; and (3) Uncertainty caused from repeated accumulation between related subjects. On the contrast, midpoint impact methods have possibilities in dealing with uncertain and potential environmental impacts and inducting some parts of endpoint method, and difficulties because: (1) panels and respondents required to have broad and fair scientific knowledge; (2) no consensus has been established for data collection and treating bias; and (3) it impose burden for panels and respondents answering certain numbers of questionnaires.

This study was focused on TCM, one of the midpoint assessment methods, because of its flexibility compared with endpoint methods and uniqueness in considering time dimension. In this research, the weighting factor of TCM was improved and its adequacy was discussed in applying to beverage containers.

## 2. THEORY

TCM was introduced by one of the authors, I. Yasui [1][2][3]. Its basis idea was "crisis". In short, every human activity consumes time to cause crisis by excess consumption of resources and environmental emission eventually. Estimation requires respondents to have the knowledge about how long it would take and what kind of crisis it would impose. The significance for each category, $W_i$, was expressed as equation (1).

$$W_i = \sum_j^n \left\{ \frac{R_{ij}/T_{ij}}{\sum_m^{10} \left( R_{ij}/T_{ij} \right)} \right\} \Bigg/ n \qquad (1)$$

i, m: one of the categories

j: one of the respondents

$R_{ij}$: answered fatality value of category "i" from respondent "j"

$T_{ij}$: answered years-to-crisis value of category "i" from respondent "j"

n: number of respondents

$$E_{tcm} = \sum_i^{10} \left[ W_i \times \left\{ \frac{I_{ik} \times C_{ik}}{\sum_p \left( A_{ip} \times C_{ip} \right)} \right\} \right] \qquad (2)$$

Etcm: time consumption value [year]

Wi: significance for category "i"

k, p: the number of the inventory value in a category

$I_{ik}$: the inventory value of "k" in "i" category

$C_{ik}$: the weighting factor for intra-category value of "k" in "i" category

$A_{ik}$: the input or output value of "k" in "i" category

Table I Environmental categories for TCM

| Category | Substance |
|---|---|
| Global warming | CO2, CH4, N2O, HFC134a, HFC else, PFC, SF6, CFC-11, CFC-12, et cetera |
| Ozone layer depletion | CFC-11, CFC-12, CFC-113, HCFC-22, HCFC-123, et cetera |
| Air pollution / Acidification | SOx, NOx, CO, Dust(SPM), PAH, CH4, VOC, et cetera |
| Soil pollution | Cadmium, Chromium(VI), Cyanide, Fluorine compound, Zinc, Lead, Mercury, Copper, Organophosphorus compound, Organochlorine compound, Arsenic, et cetera |
| Solid waste | (Total weight) |
| Consumption of energy | Crude oil, Coal, Natural gas, Uranium, et cetera |
| Consumption of biomass | Wood (Plantation, Rainforest), Freshwater (Surface, Ground), Crop, et cetera |
| Consumption of mineral | Nonferrous metal, Precious metal, Rare metal, Arsenic, Phosphor, Cadmium, Zirconium, Manganese, et cetera |
| Surface water pollution / Nutrient enrichment | BOD, COD, n-Hex, SS, Cadmium, Chromium(VI), Cyanide, Fluorine compound, Phosphorus compound, Zinc, Lead, Mercury, Nitrogenous substance, Copper, Organophosphorus compound, Organochlorine compound, Arsenic, et cetera |
| Other matters | Malodor, Landscape, Light pollution, Noise pollution, Vibration pollution, Electromagnetic pollution, Waste heat, Radiation, Occupational safety |

**Table II Characteristics of each cluster**

| Name of the cluster | Characteristics of each cluster |
|---|---|
| TCM-1 | The subjects who gave importance to "Consumption of biomass" for e.g. 70% of whole weight |
| TCM-2 | The subjects who gave importance to "Consumption of mineral" for e.g. 40% of whole weight |
| TCM-3 | The subjects who gave importance to "Global warming" for e.g. 40% of whole weight |
| TCM-4 | The subjects who gave importance to "Consumption of energy" for e.g. 20% of whole weight, to "Consumption of biomass", "Consumption of mineral" and "Air pollution" relatively |
| TCM-5 | The subjects who gave importance to "Consumption of biomass", "Global warming" and "Air pollution" relatively |
| TCM-6 | The subjects who gave importance to "Ozone layer depletion" for e.g.35% and to "Global warming" |
| TCM-7 | The subjects who gave importance to "Air pollution" for e.g. 40% and to "Surface water pollution" |
| TCM-8 | The subjects who gave importance to "Other matters" for e.g. 26% and to "Soil pollution" |
| TCM-9 | The subjects who gave importance to "Solid waste" relatively |
| TCM-10 | The subjects who gave importance to "Solid waste" for e.g. 70% |

## 3. EVALUATION PROCEDURE

First, environmental matters were re-sorted into 10 categories as shown in Table I. These each category should be weighted by not only scientific technology but public consensus such as its priority, then sum up into single index. Practical method to determine the weighting factor of inter category was described as below:

The questionnaire items were "how many years would it take to impose the crisis?" and "how fatal would the crisis?" for each environmental category under the assumption that contemporary input and output issue would cause certain environmental crisis in the future. The boundary of the input and output was set on whole Japan and fatality was expressed with no dimension. Before this questionnaire, lecture about environmental cause-effect was held for about half an hour. 91 answers were collected among university students.

The Wi value in equation (1) was calculated from the answers. Whole answered value was classified into some

groups using c-Means, one of the cluster analysis methodologies [4]. Then, $W_i$ value was determined for each cluster. Eventually, a proper number of the cluster was determined as 10 by trial-and-error method. Table II showed the characters and abbreviated name of each cluster, including average value abbreviated as TCM-av. The weighting factor for each inventory was determined using Etcm per unit inventory calculated by average $W_i$ of total and each 10 cluster.

## 4. CASE STUDY

### 4.1 Conditions

The environmental impact of beverage container was calculated under assumptions as described below.

- Liquid waste was considered as one tenth of solid waste
- No significant effect was considered in resource consumption, ozone depletion and any kind of serious hazardous matters
- If the assumption listed above was false, there would have gap between this result and actual environmental impact

### 4.2 Result and discussion

Fig. 1 showed the predicted impact result from TCM-av. Total environmental impact value was relatively greater in one-way glass bottle and steel can and

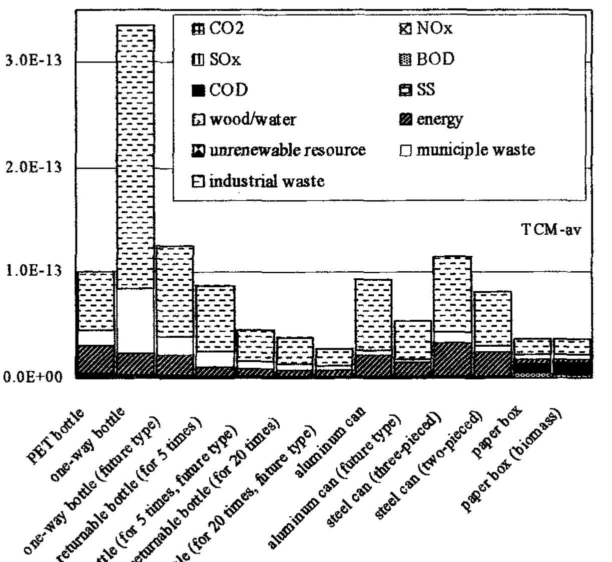


Fig. 2 LCIA result using TCM-av

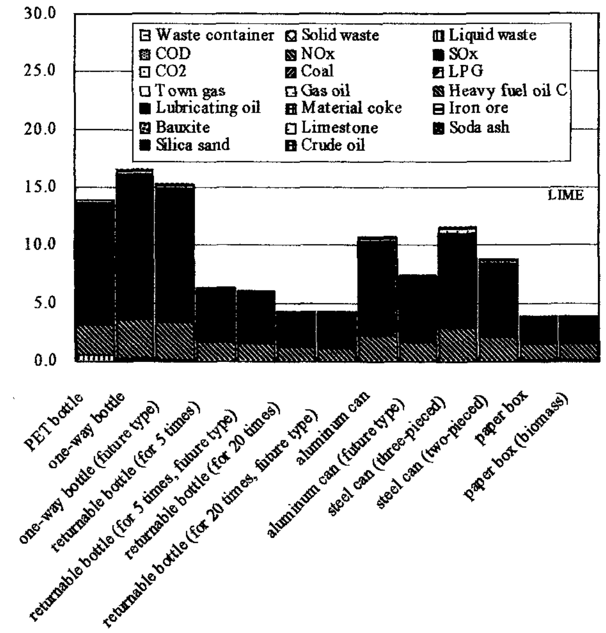


Fig. 3 LCIA result using LIME

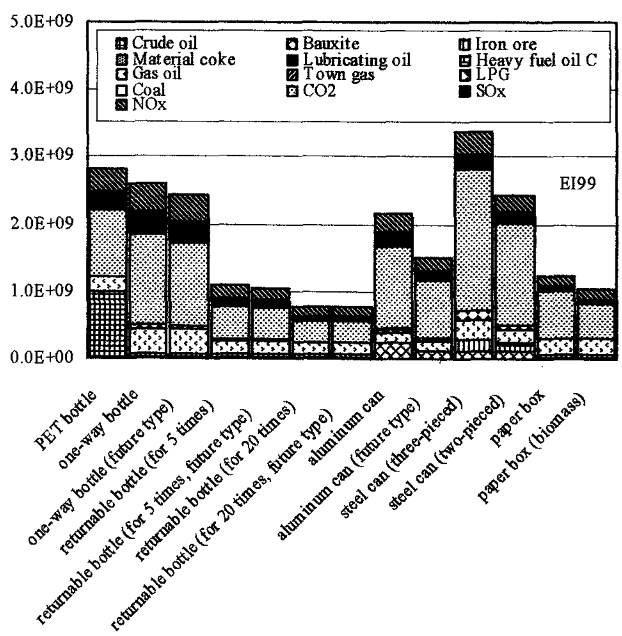


Fig. 4 LCIA result using EI99

smaller in returnable bottle, PET bottle, aluminum can and paper box. Especially, calculated environmental impact of one-way bottle was about three times greater than that of PET bottle, returnable bottle, aluminum can and steel can, and 9 times as much as that of paper box. All kinds of future-typed container were estimated to have smaller effects than contemporary. Future environmental impact of one-way bottle was predicted as one third of that of contemporary. It was, however, still 20% greater than that of contemporary returnable bottle. Environmental impacts of other future-typed container was estimated to be from 20 to 50% lower than that of contemporary. Focusing on returnable bottle, 5-times-returned bottle would impose the half impact in future type, but it was 20% higher than contemporary 20-times-returned bottle. This result concluded that more the numbers of the return become, the smaller the impact would be from this estimation. While each content of impact differ, the total impact value indicated the tendency similar to TCM-av. Fig. 2 and Fig. 3 also showed calculated value using other LCIA methods such as LIME and EI99. These results roughly showed the similar tendency to TCM with some exception. The impact of glass bottle was predicted as same as that of PET bottle using these two methods. In addition, calculated environmental impact of metal cans were relatively great when using EI99. This was due to the difference in weighting inter-subjects. In LIME methodology, airborne pollutant was given a relatively significant in overall environmental effect, and generated waste was considered to have impact only on the usage of lands. On the other hand, $CO_2$ emission and resource consumption have relatively high weighting factors in EI99. In addition, handling of solid waste in LCIA has caused much difference in the overall impact results. Thus, LCIA methodology would be required to consider the environmental effects from solid waste when it is applied in Japan.

## 5. CONCLUSION

This study was concluded as below.

・Calculations using major LCIA methods including TCM showed the similar trends in total value, while each components were different.

・TCM could represent the major LCIA method considered from the comparison.

## REFERENCE

[1]Itaru YASUI, "Life Cycle Impact Assessment to Evaluate Global Sustainability", Ecometrics'98, Lausanne, (1998)

[2]D. Hunkeler, I. Yasui, et al., "LCA in Japan; Policy and progress", Okobilanzen VI, UTECH BERLIN'98, (1998)

[3]Itaru YASUI, "A New Scheme of Life Cycle Impact Assessment Method Based on the Consumption of Time", 3-5, p89, 3rd International Conference on Ecobalance, Tsukuba, 1998

[4]Sadaaki Miyamoto, "Guideline for cluster analysis", Morikita Publishing, p14, (1999)

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