An Integrated Life Cycle Eco-Improvement and *NETS*-Green Productivity Index of Vending Machines

Sate Sampattagul*, **Seizo Kato, Anugerah Widiyanto, Yucho Sadamichi, Yukio Kimura**

Department of Mechanical Engineering, Faculty of Engineering, Mie University,

1515 Kamihama-cho, Tsu, Mie 514-8507, JAPAN

*Corresponding author. Tel: +81-59-231-9747; Fax: +81-59-231-9383; E-mail: sate@es.mach.mie-u.ac.jp

1. Background, Scope and Goal

Vending machines (VM) have been operating in the whole country of Japan about 5.5 million sets (2002) and annually consuming electricity as much as about 0.7% of the domestic power generation; the total amount electricity consumption of vending machines is average about 8 [billion-kWh]. This social fact requires us to analyze and estimate the environmental impacts of VM numerically and then to improve them much more friendly to the environment concretely.

Recently, VM makers have been attempted to minimize the environmental impacts such as energy saving of used electricity, substitution of specified Freon refrigerants, and recycle of waste materials. This friendly policy, however, has been not evaluated numerically yet from the LCA (Life Cycle Assessment) concept. Additionally concrete DfE (Design for Environment) strategy has been strongly required to be derived from the LCA evaluation.

The objectives of this study are first to analyze and estimate the numerical environmental loads of typical can-drink VM, and then to evaluate the environmental friendliness over the respective life cycle stages including proposals of eco-improvement strategy for ECP (Environmental Conscious Products). In this approach, the consolidated "LCA-*NETS*" (Numerical Eco-Load Total Standardization) scheme is successfully applied as a powerful decision-making tool from the environmental viewpoint. This innovative theory has developed in our laboratory and will be mentioned in the following session. Besides, a cost oriented scheme from the LCC (Life Cycle Costing) viewpoint called "Green Productivity Index (GPI)" is introduced here as another decision-making indicator toward much more ECP development; this well serve numerically deterministic information of compromise between "want to expect" and "want to pay". The GPI proposed here is applied to various kinds of can-drink VM and the investment for eco-improvement is evaluated from the environment efficiency of technical-economical aspects. The optimum strategy is well oriented with the integrated NETS and GPI tools.

2. Methodology and Inventory Data (ID) Collection

2.1 LCA-*NETS* and GPI

The consolidated environmental load evaluation method "LCA-*NETS*" developed by our laboratory proposes to consolidate quantitatively and totally evaluate various environmental loads with different causes using the same standard. The method standardizes the objective indices, for example various statistical data and regulation values, published by such public organizations as the United Nations and the Japanese Government. We often encounter examples of standardization using subjective factors such as weighting coefficients. The first feature of our method is that we employ objective standardization only and exclude subjective operating parameters as much as possible. When analyzing an environmental load (for example, global warming due to CO_2 emission), it is expressed by standardizing on the basis of the Loader-Receiver Tolerance Balance Theory that balances the MTV (Maximum Tolerable Value) that the Loader (VM makers) can emit or consume and the MTV that the Receiver (primarily people and other ecosystem) affected by the load can tolerate. This approach has an additional feature of allowing a quantitative evaluation of the various environmental loads (i = 1, 2, …, n) completely in the new unit [NETS]. The total LCA eco-load over the entire stage (j = 1, 2, …, n) is estimated numerically as the following.

$$\text{EcL [NETS]} = \sum_{i,j=1}^{n}\left[\left(\frac{\text{Reveivers MTV[NETS]}}{\text{Loaders MTV [kg, kWh, etc]}}\right)_i \times \text{Q}_i\text{[kg]}\right]_j \qquad (1)$$

The GPI technique is approached for enhancing industrial productivity and environmental improvement for their overall socio-economic development at once, which is a necessary decision-making tool for evaluating green productivity growth. This merit could be verified here to be an appropriate indicator addressing both the productivity and environmental aspects of VM. VM makers are encouraged to seek for the improvement on the environmental performance, resulted from the concept of "extended producer's responsibility". The GPI analysis is calculated in terms of the following definitions:

$$\text{Green Productivity Index} = \frac{\text{Benefit - Cost}}{\text{Environmental Impact}} \qquad (2)$$

$$\text{GPI} = \frac{\text{LCB - LCC}}{\text{EcL[NETS]}} \qquad (3)$$

2.2 Can-drink Vending Machine Inventory Data

The total mass of a reference vending machine (a 2000-year machine, width of 999 [mm] and depth of 640 [mm], and height of 1,830 [mm]) is about 230 [kg] and its composition material in the state where is not filled up with the can, contain of steel about 84%, plastic 10%, copper 3% and other 3% , the electricity power consumption in a use stage per year is about 2,300 [kWh/year], and the life span is average about 5 years.

In addition, almost all of INPUT(s) (fuel, material, subcontract parts, electric power, etc.) and OUTPUT(s) (product, waste, etc.) concerning the manufacturing, the transportation concerning each stage, the maintenance of a use stage were collected and developed for the Life cycle inventory data which include also the experimental data of disposal and recycling.

3. Results and Discussion

As the results, the environmental loads were obviously occurred at the material supply stage about 54 [NETS/VM] or approximately about 90% of the whole life cycle, due to the natural resources have been tremendous consumed. Furthermore, the industrial waste also caused the mainly environmental problems. Environmental loads of VM have been reduced greatly or about 35% from 1993-year model to 2000-year model by applying the Eco-improvement methodology and the reduction of non-harmful materials.

CO_2 discharge was emitted at the use stage equal to 400 [kgCO_2/VM] or approximately about 83% of the whole life cycle, due to the consumption of the electricity when VM was operating. By the effort to save the energy of the new type of the VM, the CO_2 discharge has been decreased around 60% from 1993-year model to 2000-year model at use stage.

Moreover, the GPI of VM indicated the correlation between LCA, LCB and LCC results that the new type of VM proved the advantages both in ecology and economy. If the environmental impacts were reflected in a rational way within the product price, GPI could offer an overall lower cost to customers and encourage the selection of high GPI products. Eventually, the VM maker was highly motivated to increase consumer demand for green and environmental friendly products.

4. Conclusion, Recommendations and Outlook

It could be shown that the innovative scheme is helpful as the decision-making tool to minimize the environmental impacts from the VM. LCA-*NETS* and ECP methodology are extremely practical apparatus for further ecological VM improvements. In addition, focusing on one particular stage of the life cycle may only lead to the shifting of the environmental impacts to other stages. Instead, the consumers' selection of qualified GPI products from entire life cycle viewpoint should promote efforts toward reducing their environmental loads throughout the life cycle, including the manufacturing and recycling stages, finally leading to the creation of a sustainable society. For the future tasks, a quantitative evaluation method for GPI needs to be developed more and more to construct the sustainable economy, which also requires reducing of environmental impacts as a whole. The GPI should be promoted as the key to shift the attitude of the green product market in the future.