Originals

# Sustainability Assessment for Optimizing Logistics-oriented Protective Packaging Design

Lijiang HUO* and Katsuhiko SAITO**

A proposed approach to sustainability assessment (SA) for optimizing protective packaging design has been developed to meet logistics requirements in this study. Quantitatively, the approach measures multiple aspects of performance for logistics-oriented protective packaging with regards to social, economic/commercial and environmental aspects and integrates the results into a sustainability indicator (SI) for directly comparing the overall benefits of the packaging solutions. The overall evaluation tends to assist in optimum selection and indication of potential improvements in designs. In particular, the social performance of the logistics-oriented protective packaging is identified and quantified, based upon quality function deployment (QFD). Single-use and ten-time reusable packaging schemes for transporting a batch of turbochargers using corrugated board box and plywood board box respectively were assessed in this study, as a case study demonstration. The results show that the main environmental impacts caused by the two protective packagings are global warming, acidification and fossil energy resource consumption for the packaging production and the turbocharger distribution. The reusable plywood board packaging was found to be the optimum scheme of the two designs because it indicates apparent advantages over the corrugated board packaging in logistics efficiency and overall benefit, when the number of uses was increased to three or more times. Problems in the designs were also identified by the SA. Finally, sensitive analysis on the SA was made.

**Keywords**: sustainability assessment (SA); logistics-oriented protective packaging; sustainability indicator (SI); plywood board box; reusable packaging; corrugated board box

## 1. Introduction

Protective packaging directly influences the efficiency of logistical processes including transport, loading, carrying, and storage throughout the supply chain. How to incorporate technical and environmental performance with an attractive cost into a packaging design for enhancing logistic efficiency is receiving more attention. There is a need for methods and tools that allow packaging evaluation-orientated logistics in order to avoid sub-optimization. [1-3] In this study, we adopted sustainability assessment (SA) to identify the logistics-oriented protective packaging designs regarding single-use and reusable packaging solutions with a case study demonstration. The related results showed merit and demerit of each design in social, economic/commercial and environmental aspects and the optimum option was indentified. The SA attempts to support integrated optimization and rational innovation in the development of logistics-oriented protective packaging.

* School of Textile and Light Industry, Dalian Polytechnic University, Dalian 116034, China. Tel: +86 (0)411 86324879;
Email: huolijiang@gmail.com
** Graduate School of Maritime Sciences, Kobe University.

## 2. Methodology

In the SA, the multiple aspects of performance of the logistics-oriented protective packaging are indentified and quantified on the basis of a physical unit and a monetary unit respectively in accordance with life cycle thinking.[4] The SI incorporating social, economical and environmental aspects is described through an expression of more-is-better elements (i.e. positive outputs) as opposed to less-is-better elements (i.e. inputs and negative outputs), given by Equation (1). [4]

$$SI = \frac{f(RVA)}{f(DCC, HCC)} \quad (1)$$

Where *RVA* represents real value added created by the protective packaging with social functionality;
*DCC* represents total consumptions for obtaining the protective packaging;
*HCC* represents environmental damage brought by the protective packaging.

According to sustainable packaging principles [5], the protective packaging social functionality is regarded as value-adding, safety, convenience, and environment-friendly. The related elements can be compared by a matrix based on quality function deployment (QFD) [6], as shown in Table 1.

In the QFD matrix, the importance of customer requirements are derived from a market survey, relationship values between the customer requirements (demand-side parameters) and the quality characteristics (supply-side parameters) are commonly chosen from among 0, 1, 3, and 9, and the relative importance of the quality characteristics is calculated by Equation (2) [6]. Actual data on quality characteristics are modified based on an improvement direction and the improvement ratios of modified actual data are calculated by normalization on the basis of the maximum, as shown in Equation (3) and Equation (4) respectively [6]. Finally, the improvement ratios are multiplied by the relative importance of quality characteristics derived from the QFD matrix and the social functionality value of the protective packaging is calculated by their sum, as shown in Equation (5) [6].

$$w_j = \frac{\sum_i (p_i \times \alpha_{ij})}{\sum_j \sum_i (p_i \times \alpha_{ij})} \quad (2)$$

where $w$ represents relative importance of quality characteristics;
$p$ represents importance of customer requirements;
$\alpha$ represents relationship value in a QFD matrix;
$i$ represents customer requirements ($i$ = 1, . . . . , $I$);
$j$ represents quality characteristics ($j$ = 1, . . . . , $J$).

*If higher is desirable,* $MF_j^n = F_j^n$ ; *if lower is desirable,* $MF_j^n = \frac{1}{F_j^n}$ (3)

$$RF_j^n = \frac{MF_j^n}{\underset{n=1,\ldots,N}{MAX}\left\{MF_j^n\right\}} \tag{4}$$

$$V^n = \sum_j \left(w_j \times RF_j^n\right) \tag{5}$$

where $F$ represents data of quality characteristics;

$MF$ represents revised ratio of quality characteristics based on improvement direction;

$RF$ represents ratio of quality characteristics;

$V$ represents social functionality value of the protective packaging;

$n$ represents protective packaging schemes ($n = 1, \ldots, N$).

The value added (VA) produced by the protective packaging with social functionality is presented by economic gains of the protective packaging in the supply chain logistics related to market, expressed by Equation (6).

$$VA = (SV_{contained\ contents} - C_{contained\ contents}) \times \frac{AC_{protective\ packaging}}{C_{contained\ contents}} \tag{6}$$

Where $SV_{contained\ contents}$ represents sale value of contained contents using the protective packaging;

$C_{contained\ contents}$ represents costs of contained contents using the protective packaging;

$AC_{protective\ packaging}$ represents allowed costs of the protective packaging, it depends on local regulations.

The VA calculation must work on the premise that technical indicators of each protective packaging design meet requirements of customers well within the framework of related social laws and regulations. But differences in social functionality of the available protective packaging still remain. A modified coefficient K representing ratio of satisfaction of the protective packaging is set up for further distinguishing the differences in the evaluation, given by Equation (7). We presumed the VA is created by the available protective packaging with average social functionality value. Therefore, the RVA created by certain protective packaging, is the VA multiplied by the K, as expressed in Equation (8). Quantitatively, the RVA represents social performance of the protective packaging.

$$K = V^n \Big/ \overline{V^n} \tag{7}$$

$$RVA = K \times VA \tag{8}$$

Where $K$ represents modified coefficient regarding ratio of satisfaction of the protective packaging;

$V$ represents social functionality value of the protective packaging;

$\overline{V}$ represents average social functionality value of the protective packaging in the evaluation;

$n$ represents protective packaging schemes ($n = 1, \ldots, N$);

$VA$ represents economic gains of the protective packaging related to market;

The DCC showed in Equation (1) is the sum of costs of consumed natural resources, consumed materials, consumed energy and equipment depreciation, maintenance, salaries and taxes related to the packaging production in terms of the protective packaging design [4]. The HCC showed in Equation (1), in this study, is calculated by life-cycle impact assessment method based upon endpoint modeling (LIME) [7]. Eco-indicator' 95 and Ecopoint model [7] are also used for validating the results of environmental damage. Therefore, the SI expressed as Equation (1) can be figured out. The bigger the SI is, the better the sustainability of the protective packaging scheme.

The procedure for optimizing logistics-oriented protective packaging design based on SA is indicated by Fig. 1.

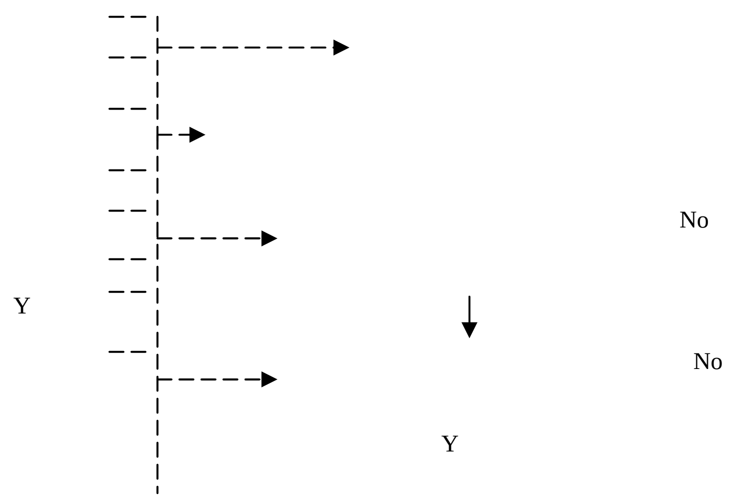



Fig. 1 An overview of the SA for optimizing logistics-oriented protective packaging

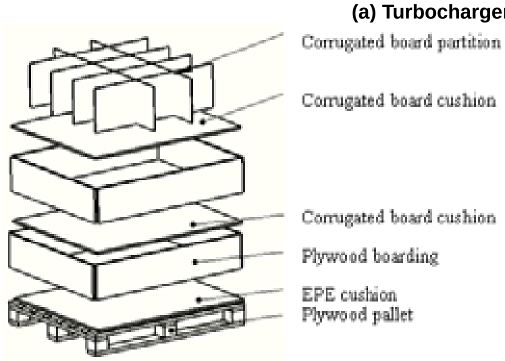
## 3. Case studies

### 3.1 Packaging designs for transporting turbochargers

Two protective packaging designs for transporting a batch of turbochargers (254×226×148mm, 5kg) adopting single-use corrugated board box and reusable plywood board box (10-time reused) respectively were assessed in this study. Analysis of various reuse times for the reusable packaging were also discussed. The turbocharger and the two protective packaging designs are shown in Fig. 2 (a), (b), (c), (d) and (e).

**(a) Turbocharger**

**(b) Corrugated board packaging for turbochargers**




**(c) Plywood packaging structure**

**(d) Plywood boarding structure**

**(e) Plywood board box**

Fig. 2 Logistics-oriented protective packaging designs for turbochargers

The two protective packaging schemes met standardized design, structural factors and the technical requirements of user. They worked under required logistical conditions, i.e. ICC 20-feet container (5.867×2.330×2.350m, 32.1m$^3$, 20.3 T) and road transport 1276 km. The two protective packaging showed technical variations in Table 2.

Table 2 Technical variations of the two protective packaging designs

| **Items** | Corrugated board protective packaging | Plywood board protective packaging |
|---|---|---|
| Materials | Plywood, polyethylene, iron wire, corrugated board (BAA/F, AA/F) | Plywood, polyethylene, iron hinge, corrugated board (AA/F) |
| Structure | Reused pallet, single-use corrugated board box and partitions single-use volatile rust preventive bag and wrap film. | Reused pallet, plywood boarding and EPE cushion, single-use corrugated board partitions, single-use volatile rust preventive bag and wrap film. |
| Pallet size | TP1, $D_4$, 800×1000 | TP3, $D_4$, 1000×1200 |
| Contained product per pallet unit | 18 | 48 |
| Weight (kg/per product) | 6.186E-01 | 3.078E-01 (10-time reused) |
| Volume (m$^3$/per product) | 2.100E-02 | 1.550E-02 |
| Transport times[1] | 100 | 70 |
| Protective capacity | Good (3) | Good (3) |
| Machinability | Good (3) | Very good (4) |
| Handleability | Good (3) | Very good (4) |
| Communication | Very good (4) | Good (3) |
| Water absorption | Yes (2) | Yes (2) |
| Causticity | No (4) | No (4) |
| Mildew resistance | Moderate (2) | Good (3) |
| Weather resisting property | Good (3) | Good (3) |
| Flammability | Yes (1) | Yes (1) |
| Disposal | Recycle (3) | Reuse and recycle (4) |

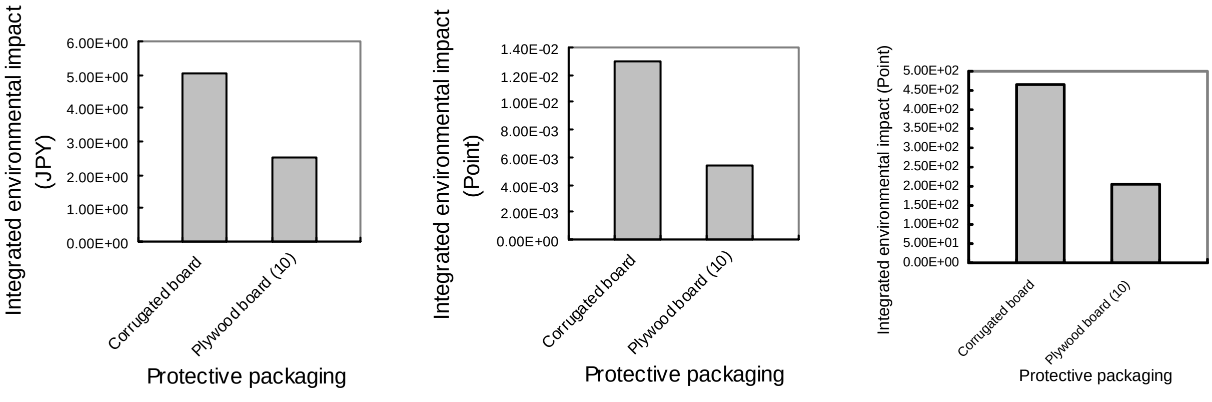
[1] The number of turbochargers needed to be distributed assumed as 100,000.

Note: Scores in parenthesis (4 = very good; 3 = good; 2 = moderate; 1 = poor; 0 = very poor.) were given by experts for making calculation.

## 3.2 SA–based optimum selection

For this study, the functional unit (FU) was defined as the protective package for a turbocharger ready for dispatch. The system boundary on basis of the life cycle commenced with collecting the raw materials and ended with the protective package disposal. The study did not include transport of raw materials and end-point recycle. By means of investigative and calculative actions, the multiple aspects of performance of the two targets within the system boundaries were quantified based on the FU, and multidimensional life cycle inventories (LCIs) were created. The LCIs and subsequent characterization result were shown in Table 3, 4, 5 and 6. As some in-house data was not available, we applied comparable average data assuming a similar situation exists in this study. JEMAI-LCA Pro with associated databases developed in accordance with the LIME were used in the evaluation [7].

The integrated environmental impacts of the protective packaging were further assessed by the LIME and the related result was presented in Fig. 3 (a). The Eco-indicator'95 and Ecopoint model also demonstrated the similar situation, as shown in Fig. 3 (b) and (c).

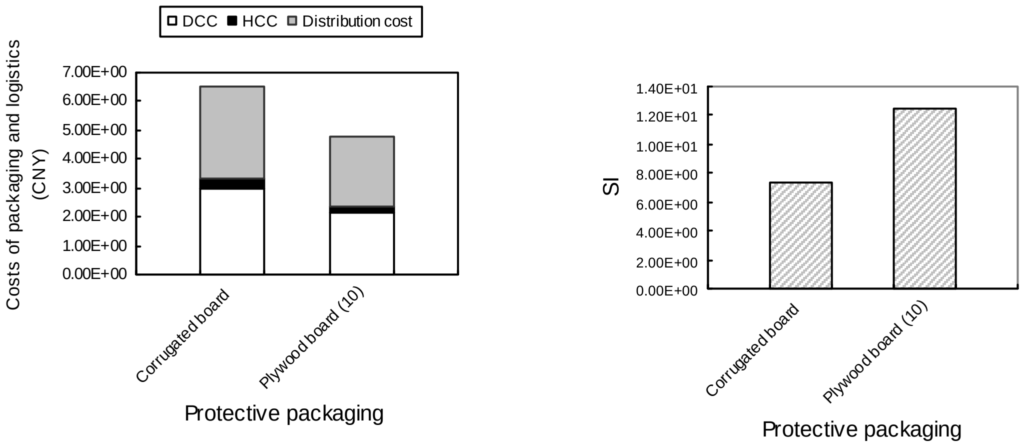



**(a) By LIME** **(b) By Eco-indicator'95** **(c) By Ecopoint**

Fig. 3 Results of integrated environmental impacts of the protective packaging designs

Through calculation (the exchange rate in 2008 [8] was adopted, i.e. 100 JPY equalled to 7 CNY), the HCC of the corrugated board packaging and plywood board packaging based on the FU were 5.03 and 2.54 JPY respectively; the distribution costs of each turbocharger using the corrugated board packaging and plywood board packaging were 3.20 CNY and 2.44 CNY respectively; and the SI of the corrugated board packaging and plywood board packaging were 7.35 and 12.53, in the order given.

The environmental damages generated by the corrugated board packaging is almost twice that of the plywood board packaging (10-time reused) due to more energy, material consumption and emissions to air during packaging production and turbocharger distribution. The results of the environmental LCI and subsequent characterization show that the main environmental burdens of the two protective packaging are due to atmospheric emissions and industrial waste landfill. They result in main impacts involving global warming, acidification and fossil energy resource consumption etc. The costs related to the plywood board packaging just account for 64% of that of the corrugated board packaging, while the SI of the reusable packaging (10-time reused) is much higher than that of the single-use packaging, as shown in Fig. 4 (a) and (b).




**(a) Results of costs** **(b) Results of SI**

Fig. 4 Final results of the SA on the two protective packaging designs

In terms of the multidimensional analysis, the plywood protective packaging (10-time reused) has apparent advantage over the corrugated board protective packaging in each aspect because of more RVA created with less DCC and HCC. The plywood board packaging was selected as the optimum scheme in this study, whereas the main weaknesses of the corrugated board packaging design were identified, i.e. low volume efficiency, more material consumption and subsequent environmental loads.

### 3.3 Results and discussion

The final results of the SA indicate that the plywood packaging (10-time reused) should be the first option for achieving good benefits in the development of the turbocharger package. So far as the general applicability of the findings are concerned, calculations regarding various reuse times (1, 2, 3, 5, 7 and 10) were carried out and the comparison results were shown in Fig. 5.

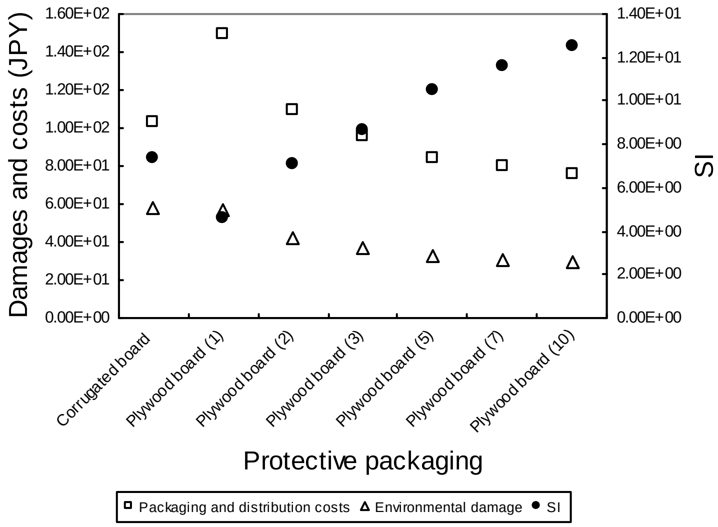



Fig. 5 Comparison results of the single-use and reusable protective packaging solutions

The sensitivity analysis shows that the most relevant parameter affecting the comparison is the reuse time that the plywood board box is used before finally being disposed of. For the case studies, both the packaging cost and the environmental damages of the reusable plywood board packaging rapidly drops below that of the single-use corrugated board packaging as the reuse time of the plywood box is increased, while the overall benefit presented by the SI of the plywood board packaging gradually increases above that of the corrugated board packaging, as shown in Fig. 5. Especially, the advantage of the reusable packaging stands out from that of the sing-use packaging after it is reused more than 3 times.

The dependency on the second parameter in order of relevance, i.e. the number of a batch of turbochargers, was set as 100,000 products needed to be distributed in the case studies. In fact, the number is conservative in practice. The study shows that the benefits of the reusable plywood board packaging are increased with the growth of the number.

Lastly, as the case study results rely partly on assumptions in the data and subjective scores given by experts, specific data should be generated for more accurate results. In addition, the target in this case study was one of mechanical products. As for other contained products with different fragility, concrete calculations and comparisons should be further undertaken.

## 4. Conclusions

The SA incorporating multi-criteria of logistics-oriented protective packaging in social, economic/commercial and environmental aspects was utilized to evaluate practical packaging designs for industrial product distribution. In particular, a newly developed indicator RVA presenting the social performance of the protective packaging was used in the case studies. The advantages and disadvantages of each protective packaging solution were identified in a transparent and direct way by the SA so that the findings can guide designer through integrated trade-off analysis to consequences. The SA can be used in the development of the logistics-oriented protective packaging for rationally optimizing schemes.

## Acknowledgements

The authors would like to acknowledge financial support provided by Japan Society for the Promotion of Science for this research (CSC-10608) and thank referees for their invaluable comments on this paper. The authors appreciate Dr. Geoff Thomas, RMIT University, Australia, for checking English.

## References

1) M Saghir. Packag. Technol. Sci. 15, 37-46 (2002).
2) C Olsmats, C Dominic. Packag. Technol. Sci. 16, 9-14 (2003).
3) D Hellstrom, M Saghir. Packag. Technol. Sci., 20, 197-216 (2007).
4) LJ Huo, K. Saito. Packag. Technol. Sci., 22, 261-273 (2009).
5) Sustainable Packaging Alliance. http://www.sustainablepackaging.org. Accessed in 2009.
6) Y Kobayashi, H Kobayashi, A Hongu, et. al. Journal of Industrial Ecology, 9, 131-144 (2005).
7) Japan Environmental Management Association for Industry. JEMAI-LCA Pro Manual (2007).
8) Exchange rate. http://www.bankofchina.com/sourcedb/lswhpj. Accessed in 2008.

（原稿受付　2009 年 11 月 27 日）
（審査受理　2010 年 4 月 28 日）

# 緩衝包装設計最適化のための持続可能性評価

霍　李江[*]、斎藤　勝彦[**]

最適な緩衝包装を目的とした持続可能性評価法を提案してきた。持続可能性を定量的に表す指標として、社会的側面や経済・商業的側面および環境適性やそれらを統合化する方法に基づいて総合的に評価を行うことが、包装の設計段階の改善に最適な方向性を見出してくれるので非常に有効である。ここでは機械製品の輸送に供せられるワンウェイタイプの段ボール箱とリユーザブルタイプの合板箱を例にとり、持続可能性評価により比較している。ふたつの緩衝包装について、環境へ影響を与える項目として、地球温暖化、酸性化、天然資源使用量の指標が大きく効いていることを示す。持続可能性指標を用いることで、３回以上のリユースをすれば物流効率の寄与によって、リユースタイプの合板箱の方がよい評価となることを明らかにする。

**キーワード：** 持続可能性評価、緩衝包装、持続可能性指標、合板箱、リユース包装、段ボール箱