Multi-criteria evaluation techniques for sustainable packaging systems

Huo, Lijiang

Saito, Katsuhiko

(Citation)
日本包装学会誌,17(3):167-178

(Issue Date)
2008

(Resource Type)
journal article

(Version)
Version of Record

(URL)
https://hdl.handle.net/20.500.14094/90001142

一般論文～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～～

Multi-criteria Evaluation Techniques for Sustainable Packaging Systems

Lijiang HUO* and Katsuhiko SAITO**

Packaging systems are influenced by multiple elements throughout entire life cycle. They have to meet packaging process requirements, distribution efficiency requirements, environmental requirements, economic requirements and social requirements as well. There is increasing recognition that multi-criteria evaluation techniques are essential to create a sound packaging system in practice. Particularly, it is necessary to increase the knowledge to select packaging systems that optimally meet social and economical as well as environmental performance requirements. This paper aims at characterizing the multi-criteria evaluation techniques adopting multi-criteria decision making (MCDM) methods and their application to sustainable packaging systems. As one of the most popular MCDM methods used, analytic hierarchy process (AHP) with some of its variants applied in evaluation of sustainable packaging systems has been presented. The research has explored how these variants and their interrelationships can be effectively modeled into a decision support tool for the selection, in order to finally coordinate interrelationships among complex factors involving product itself, packaging material, transportation and distribution chain characteristics against a multitude of requirements and to implement sustainability during new design or innovation in packaging systems.

Keywords : sustainable packaging systems; multi-criteria evaluation; analytic hierarchy process (AHP)

1. Introduction

Packaging systems add values to the products, which combines economic, environmental and social considerations, by fulfilling manifold functions at different level as primary, secondary or tertiary packaging throughout related product supply chains. The packaging system functionality is thus affected by the performance of each level and by the interactions between these levels and the interaction of a packaging system with product, physical and macro environment. [1] It has been discussed that how to feasibly coordinate interrelationships among factors of product, packaging material, transport and distribution chain characteristics against a multitude of requirements in making a good selection of packaging systems or products. [2] [3] [4] [5] There is increasing recognition that establishment of the multi-criteria for packaging systems and relevant evaluation techniques are essential to create a sound packaging system in practice. The multi-criteria evaluation techniques adopting MCDM methods are then

* Professsor Lijiang HUO: School of Textile and Light Industry, Dalian Polytechnic University, China, Dalian 116034, Liaoning Province, China. Tel: +86 (0)411 86324879; Fax: +86 (0)411 86323438; Email: huolijiang@gmail.com
**Professor (Dr.): Katsuhiko SAITO: Graduate School of Maritime Sciences, Kobe University, Japan, 5-1-1, Fukae, Higashinada, Kobe 6580022, Japan. Tel:(078)431-6341; Fax:(078)431-6364; Email: ksaito@maritime.kobe-u.ac.jp

carried out to quantify impacts into numerical scores and hence establish a ranking by which hierarchy of best suitable materials, products or well production of expected general goal or objective. [6,7]

The MCDM techniques assume that a decision may impact a variety of parameters, referred to as ''impact-factors''. Impacts of the decision on some of these ''impact-factors'' may be positive, and on the others negative. Upon evaluation and aggregation of impact on all impact-factors, a decision having positive impact in aggregate is generally suitable for implementation. [6] In the MCDM procedures, the final impact of a decision is resolved into sub-impacts on constituent impact-factors. These sub-impacts are further resolved into sub sub-impacts such that impact-factors with measurable criteria or indicators reside at the comparative bottom of the hierarchy.

Among others, multi-criteria evaluation based on AHP has been regarded as a decision support tool to solve complex decision problems, as for example evaluation of packaging materials, products or production for making an optimum choice. [8,9,10]

2. Methodology of MCDM based on AHP

The MCDM based on AHP uses a multilevel hierarchical structure of objectives, criteria, sub-criteria and alternatives. The pertinent data are derived by using a set of pair-wise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual criterion. Finally, alternatives can be compared to some absolute standard or to each other such that the comparison results and the criteria priorities can be synthesized into single statistics, each representing an alternative that can be further analyzed for sensitivity to changes in judgments. The AHP method provides structured framework for setting priorities on each level of the hierarchy and comparing each pair of decision factors at a given level of the model for their relative importance with respect to their parent. [11] The structured framework of AHP can be illustrated by Fig. 1.

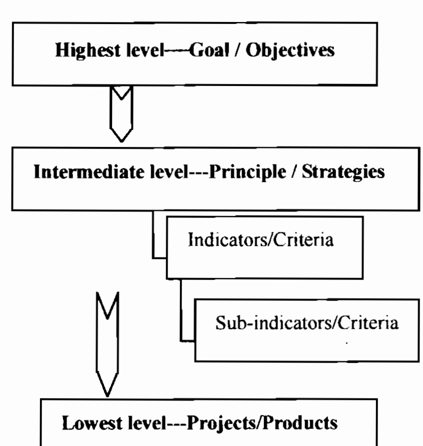

Fig. 1 Structured framework of AHP

The levels in the AHP are divided into three sorts including highest level, i.e. level of general goal or objective; intermediate levels presenting principles, measures, strategies, schemes, multi-criteria, indicators etc. and also embodying sub-indicator levels for achieving the general goal; and lowest level which is consisted of alternatives, as for example, different projects or products and systems need to be evaluated. [12) 13)] On each level of the hierarchy, the user rates the importance of each impact-factor against all others in that group. Based on the assigned relative weights, absolute weights of various 'impact-factors' are determined and normalized. The impact-factors on each level are then aggregated and the results are delivered to the next higher level until the score at the top-level, or the final score is determined. In case the aggregate impact of a decision is negative or not sufficiently positive, mitigation measures should be incorporated, which is always associated with some cost, are often necessary for making a decision acceptable.

Through this process, the AHP helps decision-makers create a model of their priorities where the weight of the decision is distributed from the goal downwards. The goal is 100% of the decision, the top level of objectives share this 100% weight between them, and the weight continues to be distributed down to the bottom of the decision model where alternatives can be weighted based on their total percentage value out of 100%. Because synthesis of AHP models is a linear multiplication and addition process (all influence flows downward), the mathematics associated with doing sensitivity ("what-if ") analysis are fairly straight forward. If a user increases the weight of a criterion, the alternatives that performed well on that criterion will always get increasingly higher scores. The scale recommended by Saaty [13)] is 1 through 9, with 1 meaning no difference in importance of one criterion in relation to the other and 9 meaning one criterion is extremely more important than the other, with increasing degrees of importance in between. Only half the comparisons need to be made in the process, the "reverse" comparisons simply use the reciprocal values in the matrix of comparisons that results. The essence of the AHP calculations involves solving an eigenvalue problem involving this reciprocal matrix of comparisons. [11)]

In addition, consistency of the comparisons in the AHP process deserves special attention. As Saaty [13)] described, the method involves redundant comparisons to improve validity recognizing that participants may be uncertain or make poor judgments in some of the comparisons. This redundancy leads to multiple comparisons that may lead to numerical inconsistencies. For example, if criterion A is just as important as criterion B, then the pair-wise judgments for A and B to any other criterion should be identical. When this doesn't happen in the judgment process, inconsistency can arise. Saaty [13)] suggested the error in these measurements is tolerable only when it is of a lower order of magnitude (10%) than the actual measurement itself. Consistency ratios (CR) can be calculated and compared to indexes derived from random judgments. As long as the CR equals 0.10 or less, analysis can proceed. Saaty [13)] also emphasized that greater consistency does not imply greater accuracy, and judgments should be altered only if compatible with one's understanding. Otherwise, more information may be necessary or the hierarchy may need reexamination.

3. Multi-criteria Evaluation

3.1 Principles for establishing multi-criteria

The multi-criteria evaluation should be carried out under direction of sustainable packaging principles since sustainability has been regarded as absolute trend of development of packaging systems. Generally, 'triple bottom line' principle has been adopted in journey of sustainable development. [14] Concretely, the essence of the principles for sustainable packaging systems has been addressed as effective, efficient, cyclic, and safe, presented as follows, [15]

- It adds real value to society by effectively containing and protecting products as they move through the supply chain and by supporting informed and responsible consumption.
- Packaging systems are designed to use materials and energy as efficiently as possible throughout the packaged product life cycle including its interactions with associated support systems.
- Packaging materials are cycled continuously through natural or industrial systems.
- Packaging components do not pose any health or environmental risks to humans or ecosystems. When in doubt the precautionary principle applies.

The principles indicate the responsibilities and performance of would-be sustainable packaging systems, which combines social, economic and environmental considerations. Therefore, establishment of multi-criteria for selecting optimum packaging systems have to be undertaken under direction from the framework.

3.2 Multi-criteria embodying environmental impact data

In accordance with the aforementioned principles, the multi-criteria covering concern throughout packaging life cycle commonly involves packaging strategy, packaging functionality, sustainability characteristics (energy, emissions, etc.) of basic materials and components by package design, product performance, life cycle impact data, material characteristics and consumption, distribution and transport scenarios, production capabilities and efficiencies, and post-use waste management. Particularly, evaluation with the multi-criteria has been developed to provide generic guidance and information on typical technical and environmental characteristics for decision making in packaging materials and systems. [4] [5] Life cycle assessments (LCA) method is then extended to incorporate a multi-criteria evaluation of the environmental impacts defined as the criteria for selecting materials or optimizing products and systems.

The complex LCA data and packaging waste management and recycling data have been considered to be converted and incorporated into a tool in order to offer quick assessment for day-to-day business of food and beverage packaging. [5] The quick assessment tool will report against a range of environmental indicators including depletion of nonrenewable resources, generation of greenhouse gases, energy use, landfill and litter, key performance indicators (KPIs) and environmental code of practice for packaging (ECoPP) for companies. [5] An example of what data is being collected from the companies for entering into the tool is shown by Fig. 2 and framework of the tool is illustrated by Fig. 3 [5]

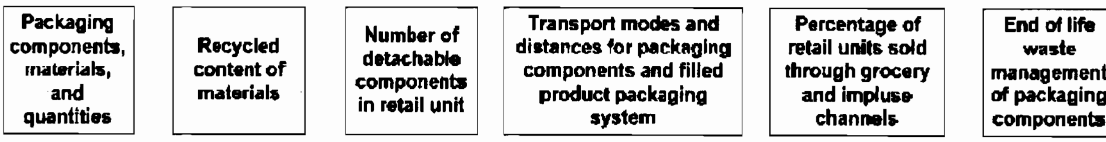

Fig. 2 Case study data collection in the quick assessment tool

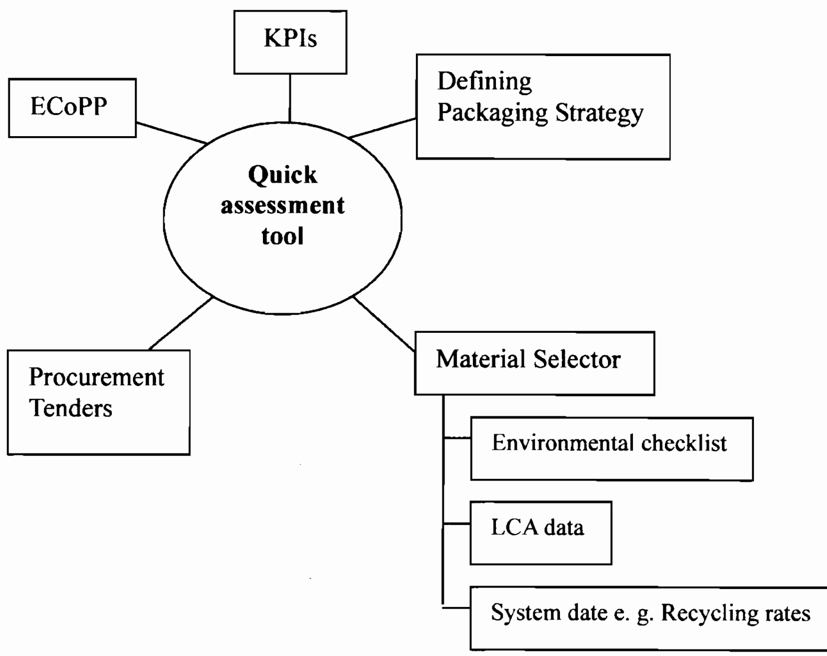

Fig. 3 Framework of the quick assessment tool

3.3 Multi-criteria indicating multidimensional functions

The assessment of functions is essential in applying LCA to packaging because LCA must be put to use a tool for promoting technological development. [16] The basic packaging functions during transportation, storage and distribution are protection, user-friendly and communication. However, it is widely believed that there is a connection, between economic development and environmental burdens, which must be served to realize our goal of sustainable development of packaging systems. At the same time, it is worthwhile to consider the advanced functions of packaging and their social significance to our society. So the multi-criteria for comprehensive evaluation in the research attempt to indicate multidimensional functions (described by Fig. 4 of section 3.4) of modern packaging systems under framework of sustainability.

3.4 Evaluative model used in selection

3.4.1 AHP-based model

A comparative analysis between packaging systems or products or production in terms of the multi-criteria is needed for arriving at a correct decision. Model of multi-criteria evaluation for selecting packaging systems is constructed by methodology of AHP with considerations of 'triple bottom line' principle, sustainable packaging principles and above-mentioned multi-criteria method.

The AHP-based model for evaluating packaging systems uses established procedures to capture the best rank from judgments through weighting. The decision process is the synthesized into a hierarchy by which it is used to compare alternatives, one at a time, in the context of priorities. The multi-criteria evaluation adopted consists of identifying a list of alternative courses of actions and a set of evaluative criteria as well as numerical weights reflecting the importance of these criteria in relevance to the problem of packaging systems considered. The prominent and frequent use of multi-criteria evaluation in finding suitable solutions for the various environmental problems has necessitated the consideration of environmental impact as one among many primary criteria in the assessment of packaging products, production and materials. The AHP-based model has then been considered incorporating with LCA data of targets evaluated in related assessment procedures.

The detailed multi-criteria within the AHP-based model are identified by integrating requirements of traditional technical performance with considerations of economical and environmental benefits as well as advanced social functions, and with case studies demonstration on packaging products and production, finally reaching a decision which points out one of alternatives performing better in all-round evaluation of packaging sustainability. The AHP-based model is built and presented by Fig. 4.

As shown in Fig. 4, sustainable packaging system located at the highest level of the model is general goal in the evaluation. The general goal must be allocated into criteria which match elements of sustainability of packaging systems in three aspects, i.e. social, economical and environmental concerns. The sub-criteria presenting environmental functions of packaging systems can be chosen in terms of ISO 14000 series standards and state of the art impact indicator methods. The others attempting to reflect social and economic/commercial functions of packaging systems are chosen by well-known knowledge and methodology in the field of packaging science and technology. Since the part mainly focuses on the development of the comprehensive framework, the criteria and sub-criteria should be identified once again under the framework when they are used in specific case studies. The general goal would also be definite product or production expected to be the best in evaluation.

The evaluation in which the scores for each packaging system are determined by the performance of the alternative against the various criteria and sub-criteria considered within the hierarchy of the model. The total or the sum of the scores for each packaging system helps determine the ranking of the alternatives and therefore arrive at the selection of the best possible option. The numerical value of CR of the hierarchy should be calculated and controlled within range of less than 0.10 during making case studies demonstration in order to make them credible.

3.4.2 Case studies

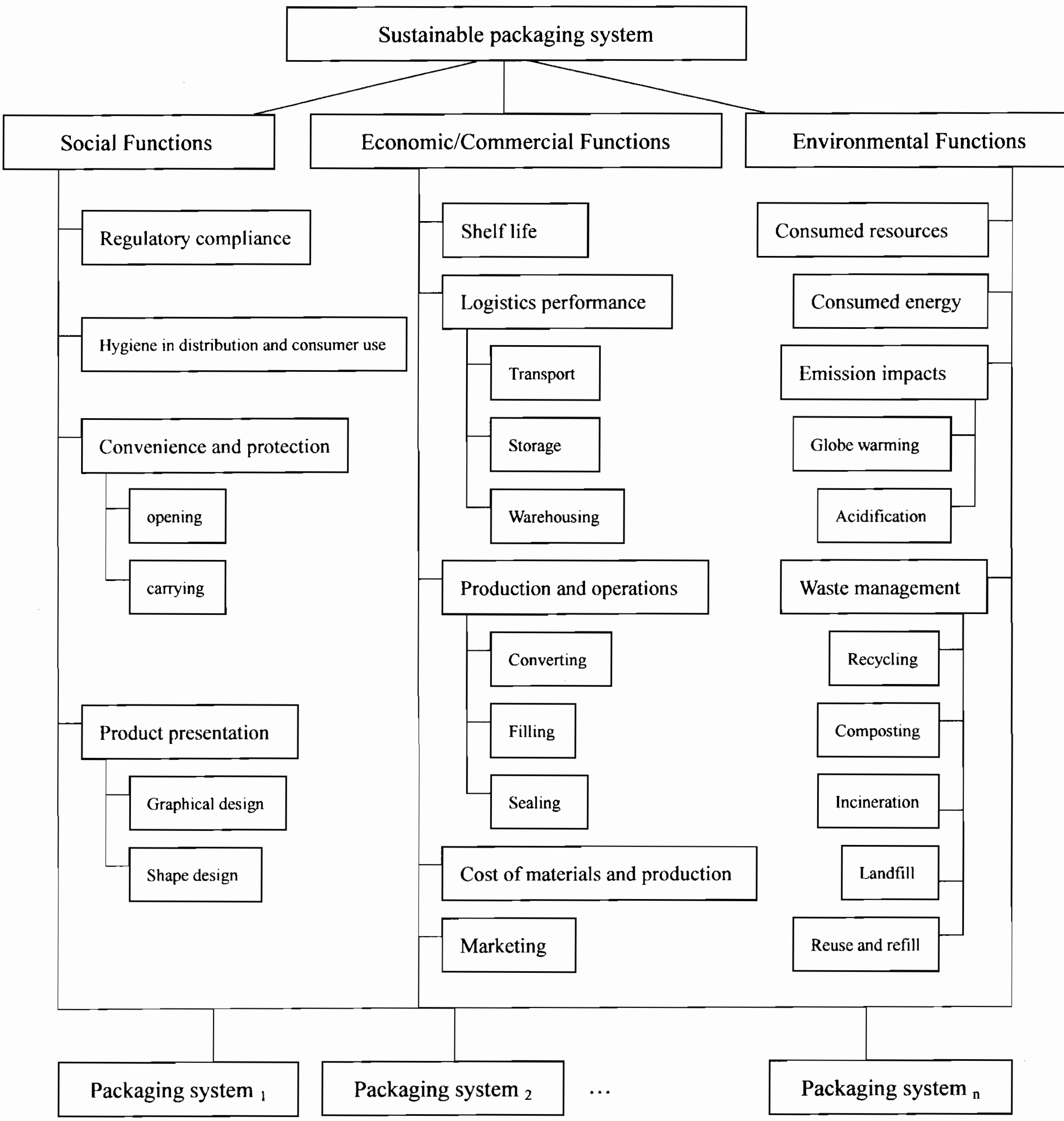

Fig. 4 AHP-based model for selecting packaging systems

The idea of AHP-based model was used in selection of pulp moulded packaging products as case study demonstration. Seven steps were taken in the evaluation process: defining goal and scoping; inventory analysis; environment impact assessment; weighing nine impact-factors within hierarchy of the AHP-based model; building matrixes and checking out consistency; calculating scores of alternatives; and making optimum option.

In concrete terms, alternatives located at the lowest level (S_n level) of the model were two kinds of typical production of pulp moulded packaging products in China. The best choice needed to be obtained by the assessment. However, multi-criteria indicating multidimensional functions of the targets must be translated into definite indicators. As one kind of industrial products in practice, pulp moulded packaging are mainly presented by cost, quality and environmental burdens. So we chosen economical benefits (P_1), technological performance (P_2) and environmental impacts (P_3) as indicators located at intermediate P_n level under the highest level (A level) of the hierarchy. Sustainable pulp moulded packaging placed at the A level was general goal of the assessment. The nine impact-factors were identified as sub-indicators located at intermediate M_n level, which were investment(M_1), running cost(M_2), consumed energy(M_3), quality and stability(M_4), acidification(M_5), global warming(M_6), handling wastes(M_7), noise(M_8) and sensitive points(M_9).

During the assessment, functional unit was a set of pulp moulded packaging product for transporting 25inch color TV set. System boundary started at collection of raw materials and ended at obtaining of pulp moulded products. The general processes of the production included collection raw materials, producing pulp, moulding, drying and handing wastes. But there were differences on source of raw materials, source of energy, investment and location between the two targets (called them as No. 1 packaging and No. 2 packaging hereafter). We investigated inventory about input and output of the production and then calculated environmental impacts (EB) of the targets. According to life cycle impact assessment method, the EB of each type of environmental impact can be calculated by following expressions,

$$EB = (W_a \times PF_a) + (W_b \times PF_b) + (W_c \times PF_c) + \dots$$

Where: a、b、c--various chemicals contained by release

W--weight of various substances

PF--potential factors of environmental impact made by various substances

The inventory and environmental impacts (EB) of the targets were shown at Table 1.

Quantitative and qualitative evaluation methods were used to determined comparative importance of elements in the analytic hierarchy. Standardization degrees (SD) of estimation matrix A-P_n and P_n-M_n were given by qualitative evaluation methods. The SD of estimation matrix M_n-S_n were given by quantitative evaluation methods.

Table 1 Inventory and environmental impacts (EB) of the evaluative targets

Items		No. 1 packaging	No. 2 packaging
Factory district	Equipments (10000 RMB Yuan)	700	800
	Construction (10000 RMB Yuan)	400	600
	Sensitive points	Far	Close
Raw materials	Price (RMB Yuan/t)	1000	1200
	Impurities (percentage)	0.8	0.1
Producing pulp	Solid wastes (kg/d)	30.058	3.639
	Waste water (kg/d)	7.900	7.900
Moulding and Drying	CO_2 (t/d)	4.186	4.582
	SO_2 (t/d)	0.005	0.068
	CO (t/d)	0.00004	0.00159
	NO_2 (t/d)	0.00035	0.00166
	NO_x (t/d)	0.00314	0.01493
Running cost (RMB Yuan/set)	Consumed electricity	2.896	3.084
	Consumed water	0.006	0.007
	Consumed fuel	1.663	0.469
	Materials	3.100	3.604
	Equipment depreciation	1.610	2.300
	Salary	1.440	0.600
	Maintenance fund	0.150	0.188
	Management	0.375	0.375
Environmental impact (EB)	Global warming	1423.305	1512.181
	Acidification	1.854	22.887
Conforming product (percentage)		98%	98%

The technological performance (P_2) of targets was regarded as the most important indicator for pulp moulded packaging and its SD was set as the highest grade. Since producers must control the costs within acceptable scope according to marketing requirements, environmental benefit (P_3) was set in second position within the hierarchy. The estimation matrix A-P_n was as follows:

Estimation matrix A-P_n

A	P_1	P_2	P_3	W
P_1	1	1/5	1/3	0.106
P_2	5	1	3	0.634
P_3	3	1/3	1	0.261

Through calculation, most latent root of A-P_n, λ_{max}=3.036, eigenvector W=$[0.106, 0.634, 0.261]^T$. So the three indicators of P_n level were weighed as 0.106, 0.634 and 0.261. Then the consistency of A-P_n was checked out by formulas: CR = CI/RI, CI = $(\lambda_{max} - n)/(n-1)$. The calculation showed CR=0.092<0.1, such that the weighing were feasible. The authors also established P_n-M_n, M_n-S_n and checked up consistency of the matrixes by the same method. The weighing of general ranking of the alternatives with considerations of nine impact-factors were shown at Table 2.

Table 2 Weighing of general ranking of alternatives

M / S	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	Weighing of general ranking
	0.088	0.018	0.106	0.528	0.043	0.128	0.065	0.009	0.016	
S_1	0.652	0.475	0.516	0.500	0.925	0.515	0.500	0.167	0.833	0.540
S_2	0.348	0.525	0.484	0.500	0.075	0.485	0.500	0.833	0.167	0.460

The above-mentioned analysis emphasized on technological performance, at the same time taking account into environmental and economical benefits of targets. The weighing of general ranking of No.1 and No.2 packaging were 0.540 and 0.460 respectively. The results showed that the No.1 packaging had advantage over No.2 packaging. The results coincided with practical situation. So the No.1 packaging could be recommended as priority for new design or innovation on existing production of pulp moulded packaging products by using the AHP-based model.

4. Conclusions

The use of multi-criteria methods has been noticed in evaluating and comparing the various packaging technologies and materials. They are particularly relevant in the valuation stage in the life cycle assessment of processes or methods that are being considered for comparison.

The multi-criteria used in current evaluation cover concerns throughout packaging life cycle and a wide range of environmental indicators of individual packaging are reported. Further, multi-criteria evaluation tool for making a choice in selection of packaging systems can be applied widely in practice. The model adopting the methodology of AHP for selecting package systems with incorporation of LCA data and sustainable packaging elements is set up and has been demonstrated with case studies. The method of comprehensive evaluation for packaging systems is regarded as credible by calculating and comparing the numerical value of CR of related hierarchy. Moreover, the model incorporates elements of sustainable packaging principles so that it can be used to make it implemental in developing sustainability of packaging systems. It is proven that the method is feasible but needs to be simplified in practice.

As for the ongoing research, the next key step would add additional criteria for sustainable packaging systems with emphasis on synthesizing and interpreting the large amounts of complex data into user-friendly indicators.

Acknowledgements

The authors would like to thank Japan Society for the Promotion of Science for financing this research of RONPAKU program (CSC-10608). We also thank anonymous referees very much for their invaluable comments on the paper.

References

1) Hellström D. and Saghir M.: Packag. Technol. Sci., 20, 197-216 (2007)
2) Olsmats C. and Dominic C. : Packag. Technol. Sci., 16, 9-14 (2003)
3) Epstein M. J. and Wisner P. S. Using a Balanced Scorecard to Implement Sustainability.: Environmental Quality Management, Winter, 1-10 (2001)
4) Material Assessment Tool, Sustainable Packaging Coalition, USA. http://www.sustainablepackaging.org, (2006)
5) PIQET, Sustainable Packaging Alliance, Australia. http://www.sustainablepack.org, (2006)
6) Bose P. and Chakrabartiy R. : Civil Eng. And Env. Syst., 20, 31-48 (2003)
7) Chang S. Y. and Bindiganaville K. : Environmental Informatics Archives, 3, 118-129 (2005)
8) Huo L. : Packaging Engineering (In Chinese), 24(3), 24-25, 35 (2003)
9) Huo L. : China Packaging Industry (In Chinese), 104(2), 36-39 (2003)
10) Huang C., Ma H. : Science of the Total Environment, 324, 161-172 (2004)
11) Zhao H. et al. Analytic Hierarchy Process (In Chinese). Science Press, China, p. 20 (1986)
12) Take the first step toward better decisions-Decision Lens. www.decisionlens.com. March (2006)
13) Saaty, T.L. Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. University of Pittsburg Press, (1994)
14) Pira, UK. Is your packaging really sustainable? http://www.piranet.com, August (2003)
15) Sonneveld K., James K., Fitzpatrick L. and Lewis H. : 22nd IAPRI Symposium, Brazil (2005)
16) Oki Y. and Sasaki H. : Packag. Technol. Sci., 13, 45-53 (2000)

（原稿受付　2007 年 12 月 17 日）
（審査受理　2008 年 4 月 25 日）

持続可能な包装システムに対する多面的評価手法

霍　李江、斎藤　勝彦

包装システムは、環境・経済・社会システムなど、ライフサイクルのいろいろな局面に影響を与えている。実際に包装システムをどのように構築すべきか、多面的な評価によって考えていくべきであるとの認識が高まってきている。どのような包装形態にすべきであるかを決定するために、社会的・経済的要求に適合させ、なおかつ環境にも配慮したものとして、その姿を具体化していくための知識と経験がより求められている。本研究の目的は、多面的評価手法として多目的評価意思決定法（ＭＣＤＭ）を持続可能な包装システムの評価に適用することにある。そして持続可能な包装システムの評価において、最も一般的なＭＣＤＭとしての階層分析法（ＡＨＰ）を適用する。ここでは、革新的な包装システムを提案・設計していく上で、持続可能性ということを評価尺度とし、製品そのもの、包装資材、輸送や物流過程の特性など、複雑に要因が絡み合った項目をときほぐしていくことで、包装システムの決定のための援用ツールとして応用されていくことにつなげたい。

キーワード: 持続可能な包装システム、多面的評価、階層分析法（ＡＨＰ）