



Logistical Packaging Evaluation in Automotive Supply Chains: A Multicriteria Decision-Making Approach with Industry Evidence

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Abstract: The selection of packaging containers is a critical component of the global automotive industry's logistics strategy, influencing operational efficiency and environmental sustainability. This study proposes a multicriteria decision-making approach using the Analytic Hierarchy Process to evaluate packaging container alternatives for knock-down parts logistics. A key contribution of the study is the development of practical evaluation criteria derived from expert interviews, structured into five key dimensions. Evaluations were conducted in two stages: company-wide and origin-destination specific. Survey data from six Japanese automotive companies were analyzed using a unified group approach to ensure consistency. The importance of the evaluation criteria across companies was compared using the results to identify preferred container alternatives under each scenario. Additionally, actual container usage data were compared with the model outcomes to validate the findings. The analysis revealed diverse corporate strategies and highlighted the gap between model-based rational choices and real-world practices. Notably, many firms adopt returnable containers at levels exceeding model recommendations. For outer packaging, the actual returnable-to-one-way ratio exceeded the model-based ratio for five out of six companies, with differences ranging, suggesting that environmental initiatives, such as promoting reusable assets, play a central role in decision-making. The proposed model is a structured, practical tool to support container selection decisions, providing insights into the trade-offs among logistics performance, environmental goals, and operational realities.

Keywords: Returnable containers; decision support; AHP; environmental strategy; Japanese automotive industry

1. Introduction

Packaging containers are crucial for manufacturing companies. Not only do they protect products from damage and maintain their quality, but they also reduce supply chain operating costs and ensure a seamless flow[1]. The unit price of packaging containers was previously relatively fixed and proportional to the quantity used. Today, selecting packaging containers involves more complex factors, including initial investment, operational costs, post-use

disposal, and environmental considerations. This means taking a longer-term perspective and integrating packaging container choices into the business strategy. For example, when considering a wide range of options, one-way and returnable containers each have their pros and cons, making the decision challenging for many manufacturing companies. One-way containers, while initially lower in cost and simplifying logistics by eliminating the need for return shipments, generate waste and contribute to environmental deterioration.

Conversely, returnable containers require a higher initial investment and additional logistical processes for return and cleaning. However, returnable containers offer long-term cost savings and demonstrate measurable environmental and potential economic benefits over one-way containers [2]. The choice between these container types depends on many factors. By carefully weighing these factors and examining the trade-offs between cost, convenience, and environmental impact, organizations can make informed decisions to optimize their logistics packaging strategy. This enhances operational efficiency and aligns with corporate social responsibility policies, contributing to a more sustainable future.

Globalization is inevitable, especially in the automotive industry. With their numerous components, cars source parts from regions worldwide, showing the extensive and complex nature of supply chains. For instance, an automobile engine might originate in Germany, its transmission in Japan, and its components, such as glass and electrical systems, in Asian countries or other regions. This global production model entails multifaceted challenges and considerations when selecting packaging containers for automotive components. Global supply chains are prominent in Japan's automotive industry. Japanese automakers typically procure components from around the world and assemble them into final products. In this process, the choice of packaging containers for knock-down (KD) components is essential. Due to the need to consider the circumstances of different countries and regions, various packaging containers are required to address other situations. However, for manufacturing companies, too much variety in packaging containers can be challenging to manage. Therefore, evaluating and comparing containers to determine which are optimal is essential.

Multicriteria decision-making (MCDM) is a decision-making approach that involves multiple alternatives, each evaluated based on several criteria or factors considered simultaneously. This method is highly accurate and is frequently employed by scientists in various fields, including business, engineering, environmental science, public policy, and healthcare [3-4]. In supply chain management, MCDM techniques are widely applied in various decision-making tasks, including supply chain risk assessment, supplier selection, and transportation selection [5-8]. Several MCDM approaches have gained prominence in supply chain contexts owing to their effectiveness in handling complex decision-making scenarios. Overall, the flexibility and adaptability of MCDM methods make it an essential tool for supply chain professionals seeking to make balanced, data-driven, and context-sensitive decisions in an increasingly complex and dynamic global environment. This study will take the Japanese automotive industry as an example and employ an MCDM approach to evaluate each packaging alternative. This methodology will comprehensively consider factors such as packaging expenses, logistics costs, environmental impact, and component features to determine the optimal packaging container selection strategy. Through such research, valuable insights and guidance can be provided to the automotive industry and other multinational manufacturing sectors to address packaging challenges arising from globalization.

Despite the critical role of packaging container selection in KD logistics, systematic research addressing this specific context remains scarce. Prior studies have relied on experience-based methods or single-cost optimization models, which fail to capture the multi-dimensional trade-offs inherent in global supply chains. Simulation and optimization approaches, while valuable, often rely on simplified assumptions and overlook key factors such as operational ease at overseas sites, alignment with environmental strategies, and the practical challenges of managing inner and outer packaging combinations across borders. Furthermore, the complexity of KD logistics, involving long-distance transportation, reverse logistics for returnable containers, and diverse destination country conditions, makes packaging decisions particularly challenging yet under-researched. To address this gap, this study proposes a multi-criteria decision-making framework using AHP, with evaluation criteria derived directly from expert interviews in the automotive industry. By incorporating both company-wide and origin-destination specific evaluations, this research

provides a systematic, practice-grounded approach to packaging container selection that reflects the complex realities of global KD operations.

2. Literature Review

Multi-criteria decision-making (MCDM) is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision-making. MCDM methods are designed to support decision-makers when faced with trade-offs among objectives, such as cost versus environmental impact or efficiency versus flexibility. Common MCDM approaches include the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Analytic Network Process (ANP). These methods share a common structure: identifying alternatives, defining evaluation criteria, determining criteria weights, and ranking alternatives based on their overall performance. In supply chain management, MCDM has been widely applied to supplier selection, location choice, and investment strategy.

In recent years, the choice of packaging containers in the automotive industry has become increasingly critical, driven by rapid component changes and environmental considerations. As the industry shifts from traditional gasoline-powered vehicles to electric and fuel cell vehicles, automotive component performance and shapes have undergone significant changes, driving related changes in packaging container choices. Automotive component suppliers, assembly plants, and logistics companies are working to adapt to this evolving landscape. However, decision-making in this area has primarily relied on empirical methods rather than systematic approaches. While several articles emphasize the importance of packaging container selection, these decisions still lack systematic evaluation methods [9]. Relying solely on experience is insufficient to keep pace with these rapid changes, as experience comes from trial and error. New methods that go beyond experiential-based decision-making are being explored. For example, using data analysis, simulations, and optimization algorithms, engineering-based computational methods now determine and select the best automotive packaging containers.

By leveraging these advanced techniques, the automotive industry can adapt more swiftly to changes and optimize packaging solutions more efficiently and effectively [10-11]. Some studies have focused on the operational level of containers. Na et al. [12] calculated the optimal number of containers and the total cost optimization of packaging. Cildoz et al. [13] developed a software tool that uses statistical and optimization methods to help decision-makers select the most suitable container for each part. Some research has explored selecting multiple packaging containers and comparing them through simulations to assess their effectiveness [14]. Modeling enables comparison of various packaging systems [15]. While simulation and modeling methods offer advantages for evaluating packaging containers, they also have limitations. These methods often rely on assumptions and simplified models that may not accurately reflect the complex conditions of the supply chain. Additionally, they frequently overlook several key factors in packaging selection, focusing on efficiency measures, such as total cost. To provide a comprehensive overview of existing research on packaging container selection, we summarize key studies and their methodological approaches in Table 1.

Table 1. Summary of existing studies on packaging container selection

Study	Focus Area	Methodology
Twede and Clarke, 2004 [9]	Reusable packaging systems	Conceptual framework
Mollenkopf et al., 2005 [10]	Reusable packaging viability	Relative cost approach
Silva et al., 2013 [11]	One-way vs. returnable packaging	Case study
Na et al. 2019 [12]	Container quantity optimization	Optimization model
Cildoz et al. 2024 [13]	Container selection for parts	Statistical optimization and software tool
Pålsson et al., 2013 [14]	Packaging system selection	Simulation
Škerlić and Muha, 2020 [15]	Packaging life cycle management	Modeling approach

Thus, this study adopts an MCDM approach, enabling the comprehensive consideration of various factors, such as initial investment, logistics efficiency, operational cost, and environmental impact. This comprehensive evaluation allows for a better understanding of the strengths and weaknesses of different packaging container selection schemes. MCDM offers advantages over simulation and modeling methods by considering factors beyond cost and involving stakeholders in the decision-making process. This approach provides a robust framework for selecting packaging containers in the automotive industry, ensuring well-informed decisions based on a comprehensive understanding of relevant factors. This summary highlights that while previous studies have contributed valuable insights, most focus on cost optimization or single-dimensional analysis. Few studies adopt a multi-criteria approach that integrates expert judgment across multiple dimensions, and none specifically address the KD logistics context with both company-wide and destination-specific evaluations.

3. Application of MCDM

This section provides a detailed explanation of the methodology employed, focusing on modeling performance criteria to select containers used in parts supply for automotive manufacturers. Figure 1 illustrates the overall AHP evaluation framework adopted in this study. The framework consists of four main phases: (1) identification of evaluation criteria through expert interviews, (2) pairwise comparisons of criteria to determine their relative weights, (3) pairwise comparisons of packaging alternatives against each criterion, and (4) synthesis of results to obtain final priority scores for each alternative. The following sections detail each step of this process. Section 3.1 describes the survey participants, Section 3.2.1 defines the evaluation targets, Section 3.2.2 explains the criteria identification process, and Section 3.2.3 presents the unified group approach used to aggregate expert judgments.

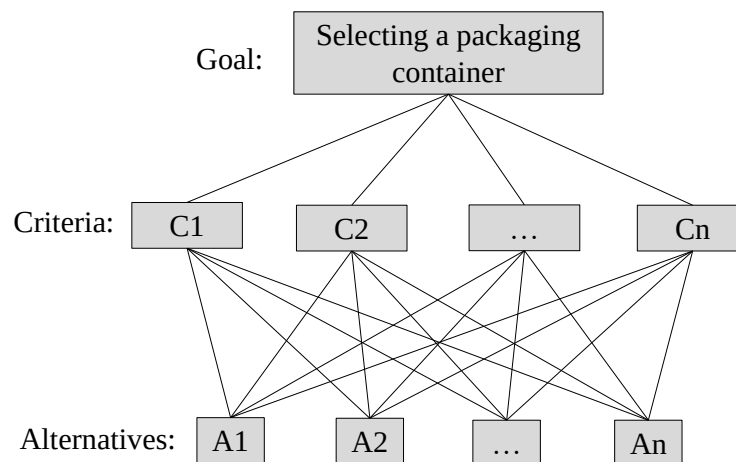


Figure 1. The AHP evaluation framework.

3.1 Survey participants

The analysis centers on multinational car/truck manufacturers that sell globally. These companies primarily operate parts manufacturing plants in Japan, China, and Southeast Asia, exporting parts to Asia, the United States, and Europe. While initially using one-way containers for component transportation, there has been a shift toward the use of returnable containers in recent years due to environmental considerations. Consequently, workshops between industry and academia have been organized to discuss container selection. These Japanese multinational automotive manufacturers have different departments that select packing containers (Table 2). To maintain the confidentiality of the firms, each automotive manufacturer is referred to as Companies A–F. Our study evaluates packaging containers for transporting components from Japanese KD factories to overseas assembly plants.

Table 2. Logistics experts for the interview and survey.

Department	Job Title
Supply Chain Procurement Department	Department Manager
Production and Logistics Department	Senior Engineer
Parts Logistics Department–Packaging	Director
Manufacturing Management Department	Director
The Logistics Planning Department's Parts Logistics Group	Primary contact
Purchasing Management Department	Section chief
Logistics Management Department, Packaging Management Section	Staff member

3.2 Evaluation method

The Analytic Hierarchy Process (AHP) is a decision-making technique that we employ to evaluate packaging containers for KD automotive components. While several MCDM methods exist, AHP was specifically chosen for this study for three primary reasons. First, given the manageable number of alternatives (four packaging combinations), AHP's pairwise comparison approach is more straightforward and less computationally intensive than methods such as TOPSIS, which are designed to rank larger sets of alternatives based on their distance from ideal solutions. Second, a core objective of this research is not only to identify preferred packaging options but also to quantify the relative importance of the five evaluation criteria from the perspective of different companies. AHP is particularly adept at deriving these weights through pairwise comparisons, providing crucial insights into each firm's strategic priorities. Third, AHP's 1-9 scale is highly suitable for processing the qualitative and semi-quantitative judgments elicited from logistics experts, effectively translating their expertise into a structured analytical framework. This method helps prioritize and select suitable containers by considering various criteria. We initially identify criteria relevant to packaging container selection. We then conduct pairwise comparisons to determine the relative importance of these criteria. Subsequently, different types of packaging containers are evaluated against each criterion through pairwise comparisons (Figure 1). By applying AHP, decision-makers can systematically assess and prioritize packaging container options based on their compatibility with the unique requirements of KD automotive component transportation. This structured approach ensures informed decision-making and optimizes packaging solutions for efficient, effective supply chain operations.

3.2.1 Evaluation target

The subjects of evaluation are the candidate packaging options for shipping KD components, including the choice between one-way and returnable containers, as well as inner and outer packaging (Figure 2, Table 3). One-way containers are designed for one-way use and are typically disposed of after delivery, whereas returnable containers, intended for multiple trips, are returned to the sender after use. Inner containers are the packaging used directly around components, while outer containers are the packaging used to transport multiple inner containers.



(Outer)



(Inner)

Figure 2. Example of outer and inner containers.

Table 3. Packaging container alternatives

Alternative	Outer	Inner	Abbreviation
(1)	Returnable	Returnable	R-R
(2)	Returnable	One-way	R-O
(3)	One-way	Returnable	O-R
(4)	One-way	One-way	O-O

3.2.2 Identification criteria

To identify relevant criteria for evaluating packaging containers, we conducted interviews with six automotive companies, each represented by at least one logistics expert from the departments listed in Table 2. The interview questions were developed based on an initial literature review and discussions with academic logistics experts. To ensure content validity, the questions were pilot-tested with two packaging logistics professionals from the automotive industry. Based on their feedback, minor adjustments were made to improve clarity and relevance. The final set of seven questions was then used in the face-to-face interviews. This pilot testing process helped ensure that the questions effectively captured the key dimensions of packaging container selection in KD logistics.

The interview topics are as follows:

Question 1: How are containers selected for the international transportation of specific production parts once the decision to supply them to overseas locations has been made?

Question 2: Ratio of one-way containers to returnable containers, along with changes over time and reasons for the changes.

Question 3: Differences in the use of cushioning materials (such as dunnage and attachments) and work hours between one-way and returnable containers.

Question 4: Differences in container types based on part categories and shipping regions.

Question 5: Correspondence between one-way and returnable containers and generic versus dedicated containers.

Question 6: Differences in purchasing strategies between one-way and returnable containers.

Question 7: Disposal guidelines for one-way containers at destination sites.

Through face-to-face interviews with personnel from the packaging departments of automotive companies, as well as insights from academic logistics experts, we derived the following preliminary criteria, as outlined in Table 4.

Table 4. Preliminary criteria extracted from interviews.

Preliminary Criteria
Container Conversion, Return Mechanism, Transportation Lead Time, Part Size, Linkage to Production Lines, Purchasing Cost, Transportation burden, Disposal Cost, Management Cost, Residual Value, Initial Investment, Purchase Price, Container Management Cost, Ease of Purchase/Lease, Convenience of Return Scheme, Return Lead Time, Return Freight, Annual Turnover Rate, Container Durability, Distance, Load Capacity, Packing Efficiency, Ease of Disassembly, Ease of Identification, Line Deployment Ease, Usage of Packaging Material

Our analysis of the preliminary criteria identified the following five main criteria.

Criteria 1: Container procurement ease

This term refers to items associated with the purchase and use of packaging within a specific period, including packaging costs and various management issues, such as storage, inspection, inventory, maintenance, repair, and replenishment.

Criteria 2: Container transportation burden

This includes the costs of container transportation, return, and transfer, as well as other transportation activities. Factors include transportation distance, lead time, container size, weight, compression ratio, tariffs, and return loads.

Criteria 3: Total operational ease

This includes loading and unloading operations in the logistics process, the efficiency of removing parts from the packaging, the efficiency of connecting (discharging) to the production line, the effort required to dismantle, fold, and reassemble packaging, and the transfer work required when packaging conversion is needed.

Criteria 4: Product-specific correspondence

This refers to the ability to adapt to the characteristics and properties of shipped products, such as shape, size, weight, and volume fluctuations, within a specific period.

Criteria 5: International site feasibility

This refers to whether the overseas base (parts shipping destination) can smoothly manage, store, and return the packaging, and the difficulties involved in establishing and maintaining the system and scheme for this purpose.

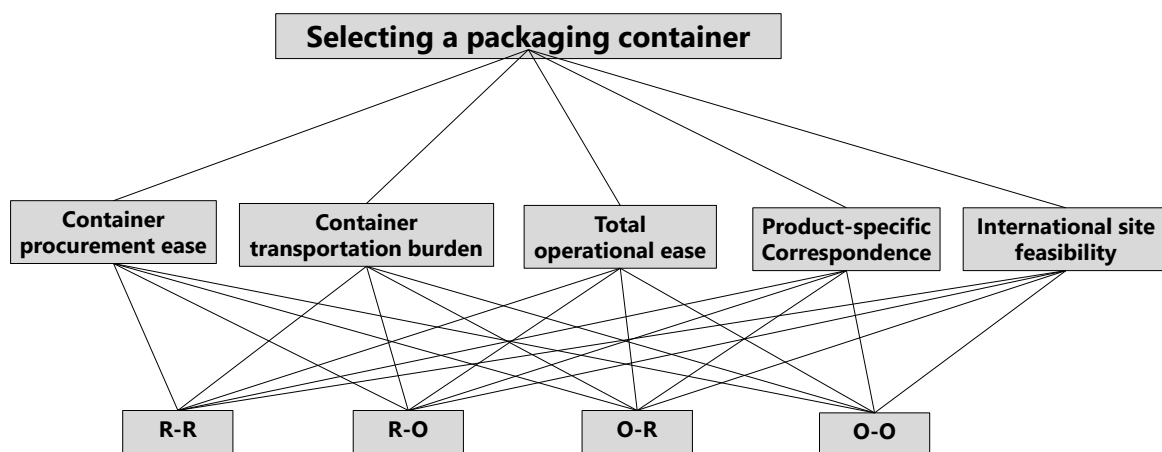


Figure 3. The proposed AHP framework.

The consolidation of the 26 preliminary criteria into five main dimensions was not an arbitrary decision but the result of an iterative, data-driven process. Through systematic content analysis of the interview transcripts, the preliminary criteria naturally clustered into five distinct thematic groups based on semantic similarity and underlying decision logic (Figure 3). To test the robustness of this structure, we evaluated alternative dimensional configurations, including four-dimensional and six-dimensional solutions. The four-dimensional solution resulted in overly broad categories that merged distinct concepts, for example, combining procurement costs with transportation costs, which experts consistently treat as separate considerations in practice. Conversely, the six-dimension solution produced overly granular categories, such as splitting "operational ease" into disassembly ease and line-side deployment ease, which experts found redundant and artificial in real-world decision-making. The proposed five-dimensional structure was then validated through follow-up consultation with the same logistics experts (Table 2). They confirmed that the five dimensions comprehensively capture all key decision factors without significant conceptual overlap, accurately reflecting their actual decision-making process. Additionally, from a methodological perspective, five dimensions provide an optimal balance for AHP-based pairwise comparisons, requiring 10 comparisons, thereby minimizing cognitive burden on respondents while maintaining sufficient analytical granularity. This design choice contributed to the consistency ratios observed in the evaluation results (Tables 5-10).

3.2.3 A unified group approach

The AHP questionnaire is answered by logistics professionals responsible for the logistics of the KD automotive components. Participants are presented with a series of questions structured around the five criteria mentioned above, which are the basis for evaluating four alternative packaging options. Participants are tasked with providing pairwise comparisons between the requirements and alternatives, expressing their judgments on the relative importance or preference of each criterion and the suitability of each alternative. However, participants' answers from the same company to business questions in a survey may be highly

inconsistent. To eliminate these biases and obtain a consistent value, we propose a unified group approach that assigns weights to each group member's answers. We began by comparing the criteria pairwise. The 20 logistics experts responsible for KD automotive component logistics across six automotive companies completed the criteria comparisons independently. We then used a unified group approach to eliminate bias, resulting in a unified comparison value for each company to calculate the weighted mean of the criteria comparisons, which can be expressed mathematically as follows. Let n represent the number of logistics experts from each company. For each company i and criterion j , the unified criteria comparison value U_i^j is calculated as the weighted mean of the individual logistics experts' comparisons as follows:

$$U_i^j = \frac{1}{n} \sum_{p=1}^n C_{ip}^j,$$

where

U_i^j is the unified criteria comparison value for Company i of criteria j , and

C_{ip}^j represents the criteria comparison value for Company i and logistics experts p of criteria j .

The term C_{ip}^j represents the pairwise comparison score given by logistics expert p from Company i for criterion j . In the AHP questionnaire, experts were asked to compare each pair of criteria using Saaty's 1-9 scale, where 1 indicates equal importance, and 9 indicates extreme importance of one criterion over the other. For each expert, these pairwise comparisons formed a comparison matrix, from which the priority vector was derived using the eigenvalue method. The C_{ip}^j values used in the unified group approach are the normalized priority scores for each criterion from each expert's individual comparison matrix. Furthermore, the AHP method, from obtaining the evaluation values from questionnaire surveys to obtaining the weights between criteria and between alternatives, involves the following steps: data collection; bias elimination; normalization; calculation of criteria weights; calculation of alternative weights; consistency check; adjustment and iteration; and final weight assignment.

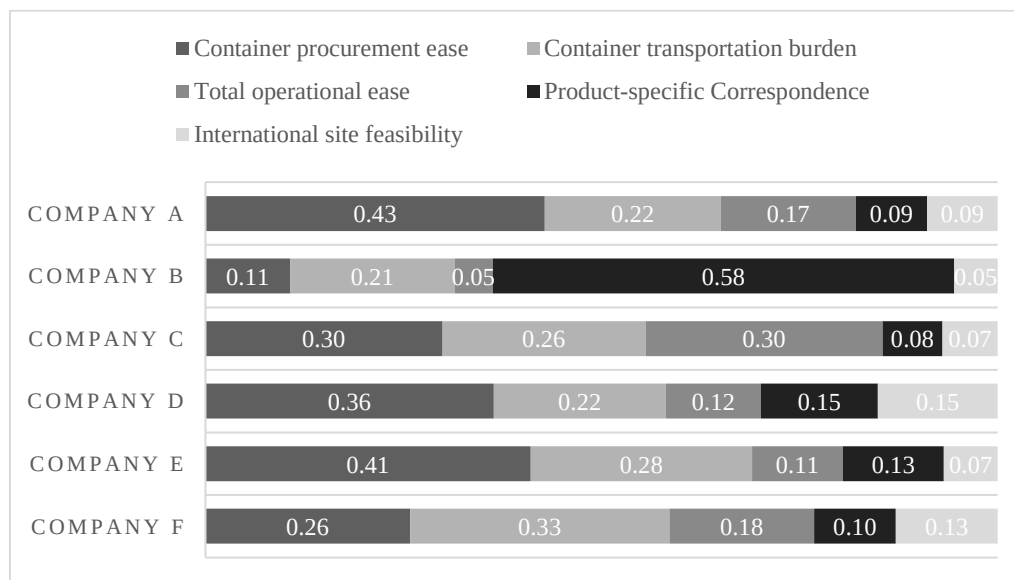


Figure 4. Results of the criteria weights

4. Results and Discussion

4.1 First round of evaluation

We have compiled the evaluation results in Figures 4 and Tables 5–10. From the results of different companies, we have gathered the following insights.

Table 5. Evaluation results for Company A.

Results	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
R-R	0.63	0.39	0.53	0.49	0.41
R-O	0.15	0.33	0.21	0.26	0.30
O-R	0.15	0.14	0.19	0.13	0.17
O-O	0.07	0.14	0.07	0.12	0.12
(C.I.)	0.04	0.05	0.09	0.04	0.06
Weights	0.43	0.22	0.17	0.09	0.09

Table 6. Evaluation results for Company B.

Results	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
R-R	0.04	0.05	0.08	0.05	0.26
R-O	0.30	0.56	0.28	0.26	0.57
O-R	0.10	0.11	0.21	0.11	0.06
O-O	0.56	0.28	0.42	0.58	0.12
(C.I.)	0.10	0.05	0.04	0.03	0.04
Weights	0.11	0.21	0.05	0.58	0.05

Table 7. Evaluation results for Company C.

Results	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
R-R	0.52	0.06	0.48	0.07	0.36
R-O	0.32	0.20	0.28	0.23	0.25
O-R	0.05	0.18	0.14	0.07	0.10
O-O	0.11	0.56	0.11	0.62	0.29
(C.I.)	0.14	0.07	0.07	0.08	0.02
Weights	0.30	0.26	0.30	0.08	0.07

Table 8. Evaluation results for Company D.

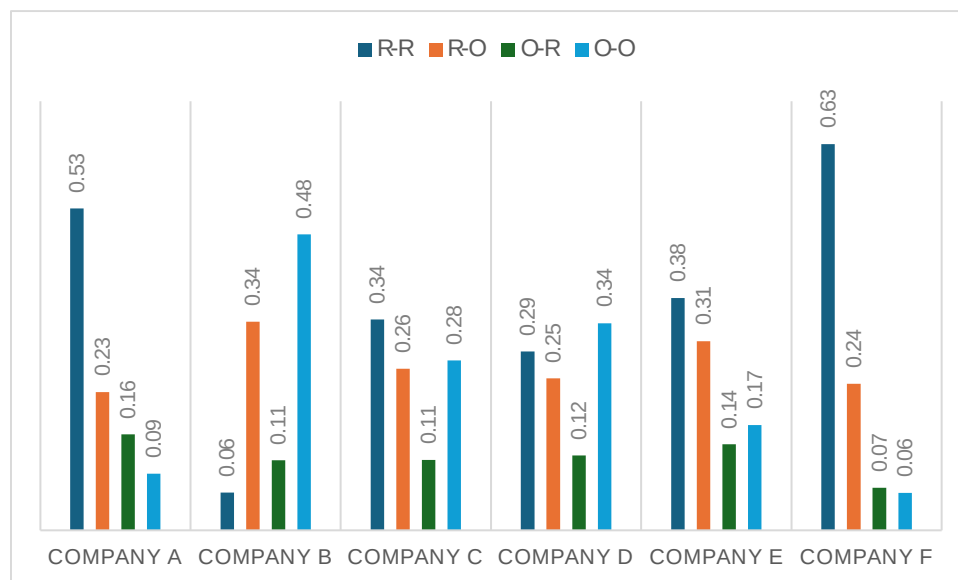
Results	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
R-R	0.18	0.02	0.07	0.01	0.02
R-O	0.13	0.03	0.03	0.03	0.03
O-R	0.03	0.04	0.01	0.03	0.02
O-O	0.02	0.13	0.01	0.08	0.09
(C.I.)	0.02	0.06	0.08	0.03	0.02
Weights	0.36	0.22	0.12	0.15	0.15

Table 9. Evaluation results for Company E.

Results	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
R-R	0.16	0.13	0.05	0.03	0.00
R-O	0.18	0.07	0.01	0.03	0.02
O-R	0.04	0.05	0.01	0.03	0.01
O-O	0.04	0.02	0.04	0.03	0.04
(C.I.)	0.01	0.13	0.11	0.00	0.04
Weights	0.41	0.28	0.11	0.13	0.07

Table 10. Evaluation results for Company F.

Results	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5
R-R	0.62	0.61	0.70	0.61	0.61
R-O	0.24	0.27	0.20	0.22	0.23
O-R	0.10	0.05	0.06	0.09	0.06
O-O	0.05	0.06	0.04	0.08	0.10
(C.I.)	0.10	0.09	0.14	0.07	0.13
Weights	0.26	0.33	0.18	0.10	0.13

**Figure 5.** Results of alternative weights (1st round)

(1) Company A: Consistency in Favoring Returnable Packaging

The prioritization of ease in container procurement is notably higher for Company A (0.43) compared to other companies, indicating strategic foresight and a long-term perspective. This reflects a strong emphasis on the overall effort required for container procurement and use, as well as on environmental factors, including waste disposal and recycling costs. Among the alternatives, the highest composite evaluation score is observed for the returnable outer and inner packaging option (i.e., returnable–returnable, R-R: 0.53), indicating a strong preference for the R-R option among packaging logistics experts, partly influenced by the emphasis on ease of container procurement. This alignment underscores the high consistency in prioritizing alternatives that feature returnable containers for both inner and outer packaging.

(2) Company B: Emphasizing Container Compatibility in Packaging Strategy

For Company B, the prioritization of product-specific correspondence is notably higher (0.58) than for other companies. This suggests that the KD components in this automotive firm have a wide variety of shapes and sizes. Consequently, logistics experts place greater emphasis on how to accommodate these varied components effectively. In terms of alternative evaluations, the highest composite score also aligns with this emphasis, with one-way outer packaging with one-way inner packaging (O-O: 0.48) option receiving the highest rating.

(3) Companies C, D, and E: One-way external packaging and returnable internal packaging are inefficient

Three cost-efficiency criteria exhibit relatively similar evaluation values for Companies C, D, and E (Container procurement ease: 0.30/ 0.36/ 0.41; Container transportation burden: 0.26/ 0.22/ 0.28; Total operational ease: 0.30/ 0.12/ 0.11). Additionally, the comprehensive evaluation values of the three alternatives are close, particularly for the one-way external packaging and the returnable internal packaging (O-R: 0.11/0.12/0.14). This suggests that the logistics experts at Companies C, D, and E do not prefer the packaging

approach, as it may adversely affect critical criteria, such as ease of container procurement, container transportation burden, and overall operational ease.

(4) Company F: How to reduce the cost of container return and transfer while still using returnable inner and outer packaging?

In the case of Company F, it is notable that although the three cost-related criteria (container procurement ease: 0.26; container transportation burden: 0.33; total operational ease: 0.18) are relatively consistent with those of Companies C, D, and E, the final evaluation values of the alternatives indicate a completely different preference. Among the other options, the highest score is for returnable outer packaging and returnable inner packaging (R-R: 0.63). This reveals a strong consensus among the company's logistics experts on the use of returnable inner and outer packaging, resulting in a rating exceeding 0.63. However, they are also concerned about the weight of container transportation, including the cost of container return and transfer, compared with the use of returnable inner and outer packaging. Consequently, through partial weight offsetting, the composite evaluation value for returnable inner and outer packaging remains at 0.63.

4.2 Second evaluation round

This study carried out two rounds of evaluation tasks between January and May 2024, involving logistics personnel responsible for KD parts packaging configuration at six Japanese automotive companies. The first round focused on evaluating packaging container selection at the company-wide level for all KD parts (Figure 5), while the second round involved assessments based on specific overseas destinations, simulating container selection for KD parts shipments to particular international sites, referred to as origin-destination (OD)-specified evaluations (Figure 6).

In both rounds, participants conducted pairwise comparisons per the AHP method, comprising pairwise comparisons between evaluation criteria and among packaging alternatives under each criterion.

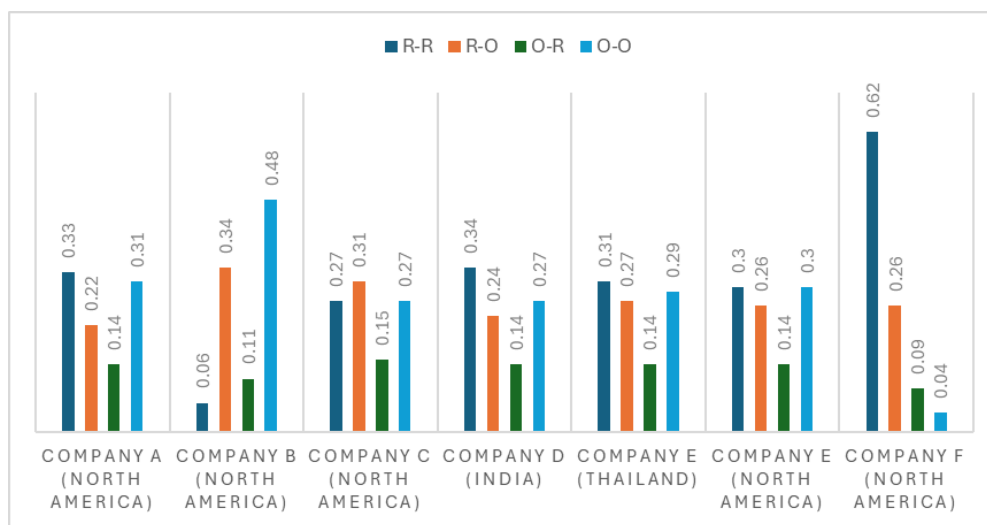


Figure 6. Results of alternative weights (2nd round)

After aggregating and processing the evaluation data, no significant differences were observed in the overall evaluation scores of the alternatives between the first (company-wide evaluation) and second rounds (OD-specified evaluation) for all companies, except for Company A. Additionally, many internal stakeholders at each company stated that the calculated evaluation scores could be effectively utilized as a rational basis for packaging container selection. These responses indicated a consensus about the validity and practical applicability of the proposed model.

(1) Interpretation of the Differences in Company A's Results:

In contrast with the other companies, a significant discrepancy was observed in Company A's evaluation results between the first and second rounds. This difference reveals two key insights:

First, selecting packaging containers in Company A appears to be more influenced by the conditions and agreements with overseas destinations. Depending on whether the receiving site has a system in place for

managing and returning containers, the choice between returnable and one-way containers may change accordingly. In such cases, the decision is made by coordinating with the receiving location, leading to variations in preference across destinations.

Second, compared to the other companies, Company A may not have a company-wide standardized strategy for selecting packaging containers. While other firms demonstrated greater consistency between the two rounds—suggesting that internal standardization and unified policies are already in place—Company A's approach appears more flexible. This flexibility may also be considered a strength, however, as it allows the company to adapt more effectively to the diverse conditions of international sites.

(2) Impact of North American Destinations on Returnable Container Preferences

In addition to Company A, four other companies (Companies B, C, E, and F) specified North America as their OD in the second evaluation round. Among them, only Company B showed no significant difference between the first and second rounds, likely because it ships its KD components exclusively to North America.

A notable trend was observed among the other three companies: evaluation scores for the R-R packaging option decreased when North America was specified as the destination, suggesting that returnable containers are less feasible in North American operations. One possible reason for this decline is the long distance between Japan and North America, which may result in longer return times for returnable containers. This logistical challenge might reduce the practicality and cost-effectiveness of using returnable containers for North American routes, thereby contributing to the lower preference in the OD-specific evaluations.

5. Actual Container Usage Versus AHP-Based Evaluation: A Comparative Analysis

A comparative analysis of the AHP model's comprehensive evaluation scores and each company's actual container usage data revealed several notable findings. Despite the variations across companies, the R/O ratio (the ratio of returnable to one-way containers) derived from the evaluation scores for outer packaging was significantly lower than the actual R/O ratio observed in FY2023 (as shown in Figures 7 and 8). For inner packaging, except for Companies A and D, which have hardly adopted returnable containers, the evaluation-based R/O ratios of the other companies are lower than their actual R/O ratios (measured by volume).

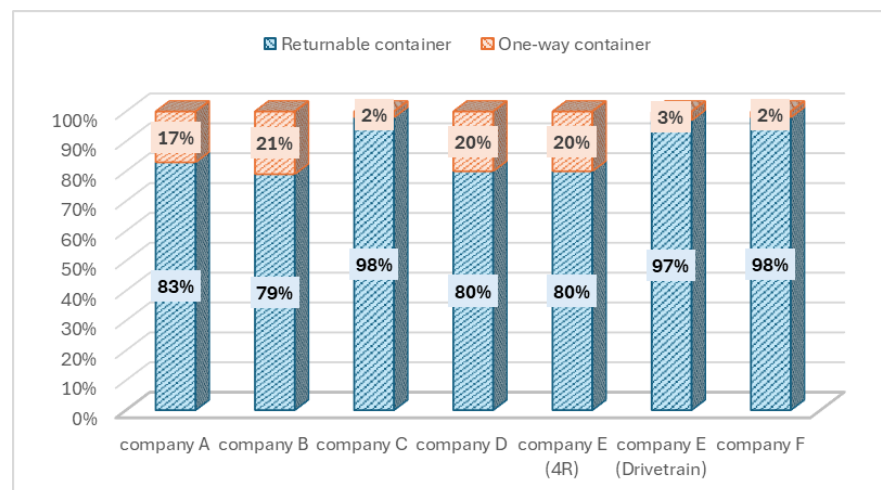
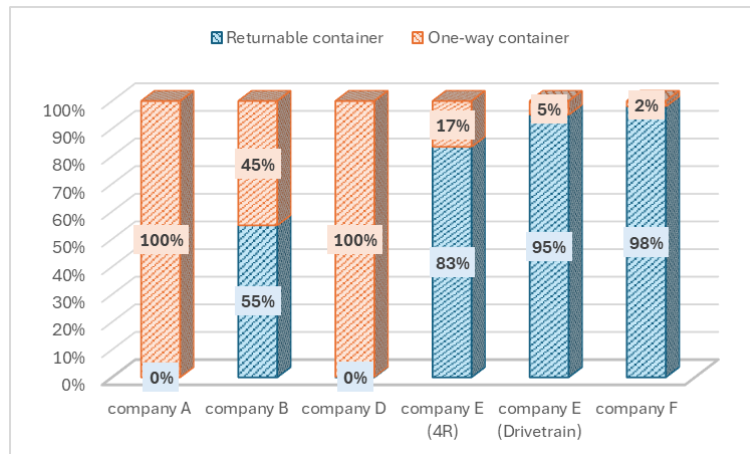


Figure 7. R/O ratio of outer packaging (by volume, FY2023 actual data)

It should be noted that the evaluation scores derived from the AHP model and the actual usage data represent inherently different dimensions. Thus, a direct comparison is not entirely appropriate. Typically, if R-R and Returnable Outer + One-way Inner (R-O) rank first and second, respectively, in the evaluation of outer packaging, it is reasonable that the actual usage ratio of returnable containers would exceed the ratio implied by the evaluation scores. However, among the five companies other than Company F, the R-R and R-O options did not necessarily occupy the top two positions in the evaluation rankings, although their actual R/O ratios for outer packaging exceeded those based on the evaluation scores. A similar trend was observed in the use of inner packaging across all companies, except for Companies A and D. These discrepancies between the

evaluation results and actual practices suggest that the number of returnable containers used in actual operations—particularly for outer packaging—substantially exceeds the rational level calculated by the evaluation model. The same discrepancy exists for inner packaging in most companies, again excluding Companies A and D.

Figure 8. R/O ratio of inner packaging (by volume, FY2023 actual data)



Assuming the evaluation model developed in this study is valid, these findings suggest that, based on the assumptions and criteria weights embedded in our AHP model, returnable containers are not always ranked as the economically optimal choice. It is important to clarify that this conclusion reflects model-based rationality, i.e., the outcome of a multi-criteria prioritization process, rather than an assessment of actual financial profitability. Due to the lack of detailed cost data, this study does not evaluate the real-world financial returns of each packaging option. Instead, the term "economic non-optimality" here refers to the lower priority assigned to returnable containers within the model's preference structure, given the participating companies' strategic weights on criteria such as procurement ease, transportation burden, and international site feasibility. Why, then, do Japanese automotive manufacturers continue to use a higher-than-optimal number of returnable containers, even when such a practice is not necessarily economically rational? The answer likely lies in each company's basic container selection policies and the ownership model of the containers. According to the interviews, most companies follow a standard policy of using returnable containers for both outer and inner packaging, except for Companies B and D (see Table 11). Furthermore, all returnable containers are purchased and owned outright by the companies themselves; they do not use rental or container-sharing schemes. This suggests that these companies may be emphasizing environmental management and promoting reusable packaging aligned with the principles of green transformation (GX) instead of prioritizing short-term cost efficiency. Additionally, under such policies, companies have made significant investments in returnable containers, resulting in a large stock of such assets. To maintain and improve asset utilization rates, there is a strong incentive to deploy returnable containers. Consequently, companies utilize returnable containers in volumes that exceed the levels considered optimal by the model, contributing to the discrepancies between evaluation scores and actual usage data. Nevertheless, determining whether prioritizing returnable containers within environmental management frameworks sacrifices economic rationality remains beyond the scope of this study. Due to the lack of available cost data, a detailed analysis of this point is not feasible. Future research should explore this matter further.

Table 11. Intercompany comparison of container selection and management systems (face-to-face interview)

[illegible]

6. Conclusion

This study evaluated packaging containers for KD automotive parts using an MCDM approach and environmentally friendly alternatives in a real-world case. We applied the AHP methodology and conducted interviews and surveys with logistics experts from six Japanese automotive companies. Key evaluation criteria were identified through qualitative interviews and structured into a five-factor framework. A unified group approach was used to assess the criteria and packaging alternatives comprehensively. Because verbal discussions typically lack consistency and traceability, our approach quantifies expert perceptions, enabling a more objective and visual comparison across alternatives. This was used to develop a decision-support tool for logistics and packaging managers. From an applied perspective, the main contribution of this study is its AHP-based evaluation model designed to assist decision makers in selecting optimal KD packaging containers under complex trade-offs. Theoretically, this research confirms that multiple interrelated factors influence the choice between returnable and one-way containers, and that cost considerations do not solely drive the selection logic. The study also revealed a unique causal chain among Japanese automotive firms: as part of their GX initiatives, companies have actively promoted the use of returnable containers and invested in company-specific R-container assets. Over time, this has led to the internalization of proprietary R-container stocks, strengthening the incentive to continue using them, even when, based on the multi-criteria preference structure of our model, such choices are not ranked as economically optimal. This finding highlights the distinction between model-based rationality and actual corporate practice, where environmental strategies and asset utilization considerations play a central role. Future research should refine group weighting mechanisms and aggregate results across companies to derive industry-wide preferences. Such insights could support future standardization efforts for KD logistics packaging.

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