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Sustainable Redesign of Plastic Packaging: Transition Single-Layer for Enhanced Efficiency and Circular Economy

Asri Dwi Puspita[1], Dini Retnowati[2*], Lena[3], Mohammad Yayan R[4]
[1,2,3,4] Program Studi Teknik Industri, Universitas Maarif Hayim Latif

*__Corresponding Author__: dini_retnowati@dosen.umaha.ac.id

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ABSTRACT
The flexible packaging industry faces increasing demand to balance product functionality with environmental sustainability. This study focuses on redesigning plastic packaging by transitioning from dual to single-layer structures. The six-phase product development methodology was employed to assess this transition's technical and economic impacts. The findings show that the single-layer design reduces raw material usage by 20%, lowers production costs by 7.5%, and shortens production time by 780 minutes per 8,000 meters of packaging. Although slight increases in Water Vapor Transmission Rate (WVTR) and Oxygen Transmission Rate (O2TR) were observed, the changes remained within acceptable industry standards, with minimal impact on product shelf life. The new design also offers significant environmental advantages, simplifying recycling processes and supporting circular economy principles. Furthermore, the House of Quality (HoQ) analysis revealed that the redesign effectively addresses critical customer needs, particularly regarding durability, affordability, and delivery efficiency. This research demonstrates the potential for sustainable innovation in the packaging industry. It provides a pathway for companies seeking to reduce environmental impacts while maintaining product performance.

INTRODUCTION

The growth of the flexible packaging industry in Indonesia, along with the increasing consumer demand for practical and durable products, has triggered increasingly fierce competition among manufacturers. In addition to efficiency and price factors, companies are currently faced with global environmental sustainability challenges. Plastic waste, especially from single-use packaging, has become one of the major problems contributing to environmental pollution and the depletion of natural resources. Plastics that are difficult to decompose naturally contribute to increased land and sea pollution [1], [2], [3]. Over 8 million tons of plastic are estimated to enter the ocean yearly, causing significant ecosystem damage [4].

In Indonesia, Government Regulation Number 27 of 2020 concerning specific waste management highlights the importance of handling plastic waste with more environmentally friendly methods. This regulation mandates a more responsible approach to waste management, especially plastics, which have the potential to pollute the environment. The flexible packaging industry, as one of the most significant users of plastics, is now under pressure to switch to more sustainable solutions [5].

In this context, the concept of Circular Economy (CE) or circular economy is one of the widely adopted approaches to answer this problem. The circular economy is an economic system that aims to reduce waste and extend the life cycle of products with a reduce, reuse, and recycle approach [6], [7], [8]. By adopting this concept, companies can improve resource efficiency and reduce the environmental impact of their products [9], [10], [11]. The flexible packaging industry, which relies heavily on plastic raw materials, is particularly relevant in adopting circular economy principles to support long-term sustainability.

One potential strategy in the application of circular economy in this industry is to redesign the composition of plastics from two layers to one layer. By reducing the number of plastic layers, companies can achieve several benefits, including reduced use of raw materials, increased energy efficiency in the production process, reduced production costs, and improved product quality [12], [13]. Furthermore, this approach can also minimize environmental impact by reducing plastic waste and increasing recycling potential [14].

This research explores the development of single-layer plastic packaging as a more efficient and sustainable alternative. By applying a six-phase product development methodology, the study aims to analyze this transition's environmental and economic benefits and its impact on operational efficiency and customer satisfaction. Through this approach, it is hoped that the resulting solutions will not only support the sustainability of the flexible packaging industry but also make a real contribution to the sustainable development goals.

MATERIALS AND METHODS

This study uses a quantitative approach that focuses on developing and evaluating plastic packaging designs from two layers to one layer. This approach involves several critical stages in the product development cycle, from identifying customer needs to testing the resulting product. The data sources in this study were obtained from the results of the material composition replacement trial, customer needs data, and work measurements carried out by the PPIC (Production Planning and Inventory Control) team from a flexible packaging company.

1. Data Source

The data sources used in this study include:

Customer needs data: Customer needs are collected through a Google Form survey of 50 respondents. This survey covers packaging durability, affordable prices, shipping speed, and designs that suit customer demands.

Material test data: This data was obtained from laboratory tests to compare the composition of two-layer and single-layer plastics. The data measured included Water Vapor Transmission Rate (WVTR), Oxygen Transmission Rate (O2TR), and packaging durability.

2. Six-Phase Product Development Methodology

The product development process in this study follows a six-phase methodology that refers to the concept of product development by [15]. These stages include:

Phase 0: Planning
In this phase, the RnD team plans to replace plastic composition by setting material, machinery, methods, human resources, and environmental parameters. Data on the price of old and new raw materials were compared, and machine performance and labor requirements were also analyzed [15].

Phase 1: Concept Development
The concept was developed to reduce plastic layers without sacrificing parameters such as WVTR, O2TR, and shelf life. The main emphasis is minimizing the environmental impact by maintaining packaging performance equal to or better than the two-layer composition [7].

Phase 2: High-Level System Design
In this phase, the system design used for the trial is ensured to be valid and measurable. The trial system is designed to collect data that can be analyzed continuously. The data collected includes production speed, material durability, and production process efficiency [1].

Phase 3: Detailed Design
In this phase, detailed planning for production preparation is carried out, including preparing raw materials, machinery, labor, and auxiliary equipment. The measurement process involves regulating the speed of the printing machine, rewinding, and slitting, as well as checking the quality at each production stage [9].

Phase 4: Testing and Refinement
Products resulting from single-layer designs are comparatively tested with two-layer products. The test includes an evaluation of the advantages and disadvantages of each design, including the duration of production time, production cost, and product quality based on WVTR and O2TR parameters [15].

Phase 5: Product Launch
After testing and repairing, the single-layer product is ready to be launched to the market. The final product visual is compared to a two-layer product to ensure quality and design consistency according to customer requirements [15].

3. Data Processing Methods

The quantitative method used in this study involves data processing using statistical analysis from customer needs survey results and comparing the performance of old and new compositions. The data is analyzed using the House of Quality (HoQ) to ensure every customer's needs are met in product development [16].

RESULTS AND DISCUSSIONS

1. Customer Needs

Based on a survey of 50 respondents, various aspects related to customer needs for packaging were identified and analyzed. The table below presents a breakdown of the parameters of customer needs, the number of respondents who chose each parameter, as well as the percentage of their contribution to the overall needs.

Table 1. Results of Customer Needs Survey for Packaging

No.	Requirement Parameters	Sum	Percentage
1	WVTR Durability of packaged products	11	22%
2	O2TR Durability of packaged products	11	22%

No.	Requirement Parameters	Sum	Percentage
3	Packaging according to the weight of the product	3	6%
4	Packaging durability target	11	22%
5	Affordable pricing	7	14%
6	Speed of delivery to customers	5	10%
7	Packaging design according to customer requirements	2	4%
Total		**50**	**100%**

From the survey results, the durability of packaging is the aspect customers pay the most attention to. As many as 22% of respondents emphasized the importance of packaging durability in maintaining product moisture, as measured by the Water Vapor Transmission Rate (WVTR). In addition, 22% of respondents also assessed the ability of packaging to prevent the entry of oxygen, as measured by the Oxygen Transmission Rate (O2TR), as an essential factor in maintaining product quality during storage.

In addition to the durability factor, the target of packaging durability of the packaged products was also assessed as the primary need by 22% of respondents. It shows that customers expect that the packaging is capable of protecting the product and must also meet the durability standards corresponding to the type of product being packaged.

From the economic side, as many as 14% of respondents want packaging at affordable prices. It indicates that while the technical aspect is crucial, customers are also sensitive to packaging costs and want an economical solution without sacrificing quality. The speed of packaging delivery to customers is also a concern for 10% of respondents. It shows that logistics and timely availability of packaging are essential to meeting customer expectations, especially in industries with high demand and fast delivery needs.

Finally, only 4% of respondents rated packaging design as a significant factor in their decision. It may reflect that customers prioritize the functionality and technical performance of the packaging over its aesthetics or visual appearance.

Overall, this survey's results underscore that customers' primary needs in flexible packaging focus on durability and technical performance that can maintain product quality, followed by affordable prices and delivery speed. These aspects form the basis for developing single-layer packaging designs, which aim to meet customer needs without sacrificing quality or production efficiency.

The survey results show that customers primarily focus on packaging durability and product protection, especially regarding moisture and oxygen control. It is in line with the research goal of redesigning the composition of plastic packaging from two layers to one layer while maintaining or improving the technical performance of the packaging. The reduction of layers on packaging is expected to meet customer needs without sacrificing the quality of the packaged product.

In addition to the customer needs data obtained through surveys, House of Quality (HoQ) analysis maps these needs into relevant technical attributes in developing single-layer packaging. The results of the HoQ analysis show that the customer's needs are most focused on the durability of the packaging against moisture (Water Vapor Transmission Rate - WVTR) and oxygen (Oxygen Transmission Rate - O2TR), with each parameter getting a priority of 22%. In addition, customers consider affordable prices and delivery speed important, with 14% and 10% contributions.

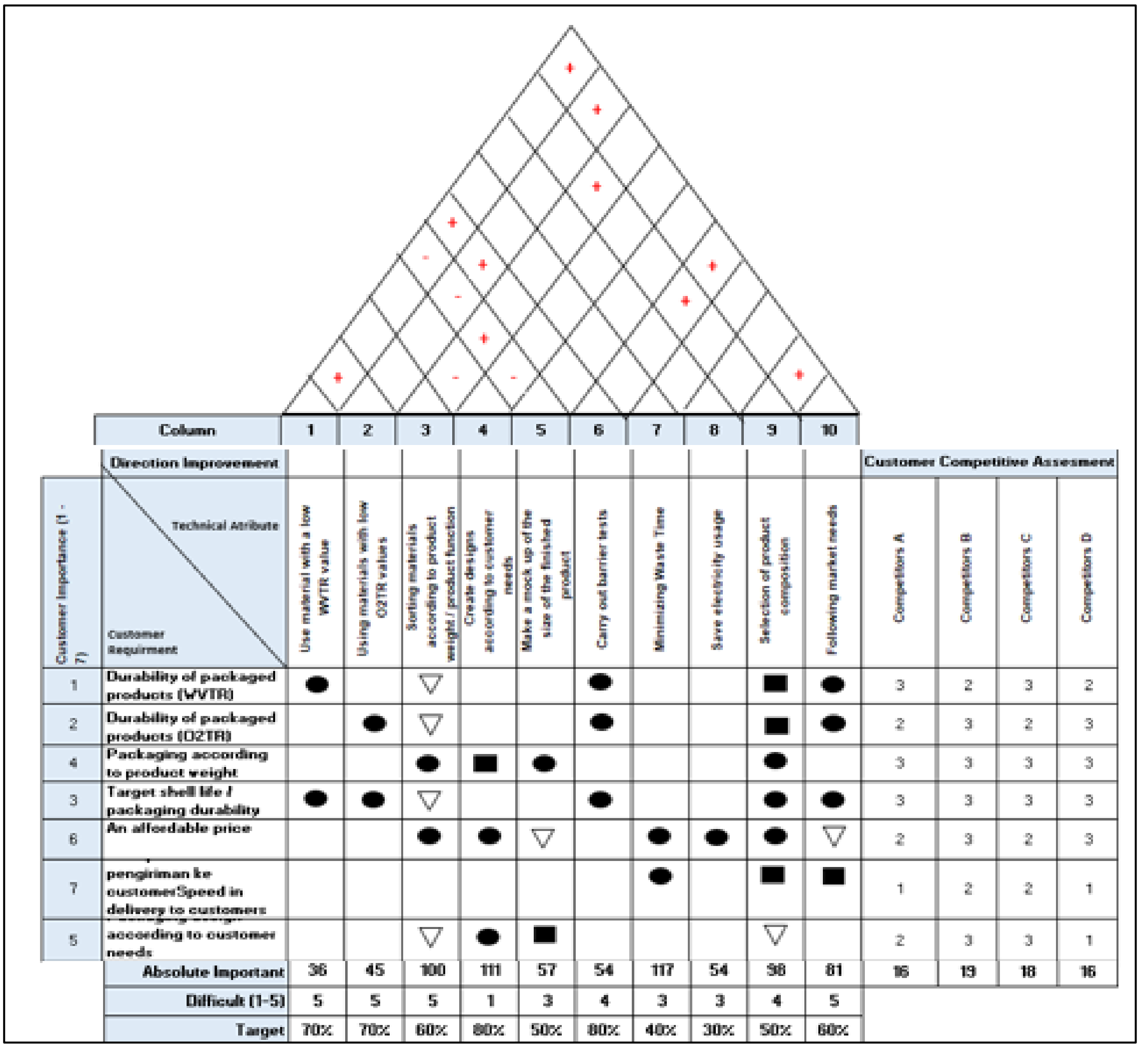

Figure 1. HOQ of the product development process

Technical attributes relevant to this need include the use of materials that have low WVTR and O2TR values, as well as packaging designs that are appropriate for the weight and type of product. These attributes are key factors that can be optimized to improve product competitiveness. For example, using materials that can reduce the WVTR value is considered a high priority to improve the durability of the packaged product. In addition, reducing wasted time during the production process was identified as an essential step to improve operational efficiency and accelerate product delivery to customers.

HoQ also revealed the company's competitive position compared to the four main competitors (Competitors A, B, C, and D). Based on this assessment, the company is showing strong performance in terms of packaging durability. However, there is room for improvement in price and delivery speed. Improvements in technical attributes, such as more efficient use of materials and optimization of production processes, will allow the company to increase its competitiveness in the market.

In addition, this analysis also shows the level of difficulty in achieving technical targets. Using materials with lower WVTR values is predicted to have a moderate difficulty level while reducing wasted time in the production process, which is considered more challenging. Nonetheless, the target of packaging moisture reduction

(WVTR) of 70% and an increase in delivery efficiency by 60% are set as realistic goals to achieve in product development.

This House of Quality analysis helps companies map customer needs into measurable and implementable technical steps in developing single-layer packaging. In addition, this analysis allows companies to understand their position in the market competition and identify areas that need improvement to meet customer expectations more effectively.

2. Six Phases of Product Design and Development

This research involves six phases in the product development process that lead to the design of single-layer plastic packaging. Each phase delivers specific results, from planning to final product testing.

Phase 0: Planning

In the planning phase, the R&D team conducts an in-depth analysis of the use of materials and resources required for the single-layer design. The results of this phase show that the use of raw materials for single-layer packaging can be reduced by up to 20% compared to two-layer designs. In addition, machine and labor requirements can be optimized, reducing production costs by 7.5% per batch of production.

Table 2. Use of Raw Materials and Production Costs

Parameter	Two-Layer	Single-Layer	Change (%)
Material Usage (kg/roll)	15	12	-20%
Production Cost (Rp/roll)	1.600.000	1.480.000	-7.50%

Phase 1: Concept Development

The concept development phase focuses on designing an initial prototype of single-layer packaging. In this phase, the R&D team evaluates several material alternatives that can be used to ensure the packaging meets functional requirements, such as WVTR and O2TR. Initial testing showed that the material selected for the single-layer design could approach the performance of the two-layer packaging, with a 12.5% improvement in O2TR and a 20% increase in WVTR.

Phase 2: High-Level System Design

In this phase, the design of the production system is updated to ensure that the transition to a single-layer design can be implemented without disrupting existing production operations. Data from testing shows that the production machine requires minimal adjustments to process single-layer packaging, reducing setup times by up to 15%. It helps to increase the overall production speed.

Phase 3: Detailed Design

The detailed design phase involves technical planning for each production component, from raw material selection to machine setup. At this stage, the time spent on rewinding and slitting on single-layer packaging is significantly reduced, resulting in production time savings of up to 780 minutes per 8,000 packaging meters.

Phase 4: Testing and Refinement

A single-layer product is tested in the testing phase to ensure it meets industry quality standards. The test results show that single-layer packaging can maintain comparable durability to two-layer packaging despite improvements in WVTR and O2TR parameters. Overall, the product's shelf life was not significantly affected, and the product successfully met customer expectations.

Table 3. WVTR and O2TR Test Results

Parameter	Two-Layer	Single-Layer	Change (%)
WVTR (g/m²/day)	0.35	0.42	20%
O2TR (cm³/m²/day)	1.2	1.35	12.50%
Masa Simpan (*shelf life*)	12 months	11.5 months	-4%

Phase 5: Product Launch

After going through a series of tests and refinements, the single-layer product is ready to be launched into the market. The product is designed to have a visual appearance comparable to double-layer packaging while offering advantages in terms of production efficiency and reduced costs. Marketing trials showed that customers did not feel a significant difference in packaging quality, which showed that the single-layer design was acceptable to the market without sacrificing customer satisfaction.

3. Discussion

The results of this study revealed some significant findings related to the redesign of plastic packaging from two layers to one layer. This change provides cost and production time advantages and offers tremendous sustainability potential. Although there was a slight increase in the Water Vapor Transmission Rate (WVTR) and Oxygen Transmission Rate (O2TR) values, these results were still within acceptable limits of flexible packaging industry standards [5], [17]. These findings indicate that the transition to single-layer packaging does not significantly compromise functional performance.

One of this research's main contributions is improving production efficiency. The single-layer packaging production process is proven to be faster because it eliminates the additional steps required in handling two-layer materials, such as the laminating process and machine adjustments for various layers. Reducing production time by up to 780 minutes per 8,000 packaging meters can significantly impact the company's production capacity. By minimizing the time required in the production process, companies can increase their daily production volume without adding machine resources or labor. It aligns with findings by [15], which showed that simplifying product design can improve overall process efficiency.

In terms of costs, 7.5% of production cost savings are also a significant achievement, especially in the context of a highly competitive packaging industry. These savings mainly stem from reducing plastic raw materials, which is one of the largest cost components in flexible packaging production. In addition, reducing production costs can also help companies offer more affordable products to consumers without having to sacrifice packaging quality or performance.

From an environmental perspective, this research supports the transition to a circular economy through reduced resource use and increased recyclability. By reducing the number of plastic layers, the carbon footprint generated from packaging production can be minimized. [9] show that material reduction strategies are one of the main approaches to achieving sustainability in the manufacturing sector. It is also consistent with the principle of reduction in the circular economy, where the use of materials is minimized without reducing the product's functionality.

More straightforward single-layer packaging also has more significant potential for recycling, as it does not require a layer separation process that usually hinders conventional recycling processes. The materials used are often different in two-layer designs, making them difficult to recycle simultaneously. The transition to homogeneous single-layer packaging can increase recycling rates and reduce the amount of plastic waste that ends up in landfills. A study by [14] also highlights the importance of packaging design in facilitating recycling to reduce long-term environmental impact.

Although the results of this study show significant benefits, the application of single-layer design on an industrial scale faces several challenges. One of the biggest challenges is adapting production machines initially designed to manage two-layer materials. Initial investment in new technology or machine adjustments may be necessary, especially for companies that have optimized their production processes for multi-layer materials. It can be a barrier for small and medium-sized companies that may not have the resources to invest in new technologies. However, in the long run, the benefits of increased efficiency and cost savings can justify the investment.

In addition, the study also highlights the importance of in-depth evaluation of other performance parameters such as tensile strength and puncture resistance. Although WVTR and O2TR are vital parameters in the food and beverage packaging industry, the mechanical aspect of the packaging is also essential, especially for products that require extra protection against impact or pressure. Further testing is needed to ensure that single-layer packaging can provide protection equivalent to two-layer packaging under various usage conditions.

The research also contributes to the literature on product redesign in favor of the circular economy. [7] state that the circular economy reduces waste. It redesigns production processes and products to make them more sustainable. In this context, this study shows that innovation in packaging design can be an effective strategy to achieve circular economy goals. By integrating circularity principles into product design, companies can improve resource efficiency and reduce environmental impact without sacrificing product performance.

The results of this study also open up opportunities for further research in other contexts, such as the reduction of layers on more complex types of packaging or the application of the same principle to non-packaged products. Further studies on the potential for similar innovations to be applied on a broader industrial scale and in other manufacturing sectors are also needed to identify more comprehensive impacts on global sustainability.

CONCLUSION

This study successfully identified the potential for developing plastic packaging from two layers to one layer as a more efficient solution in terms of cost and environmental impact. Based on the analysis of six phases of product development, the single-layer design can reduce the use of raw materials by up to 20% and result in production cost savings of 7.5% per roll. In addition, the production process has also experienced an increase in efficiency by reducing production time by 780 minutes per 8,000 meters of packaging, which has a direct impact on increasing daily production capacity.

From a technical point of view, although there are slight improvements in the Water Vapor Transmission Rate (WVTR) and Oxygen Transmission Rate (O2TR) compared to two-layer packaging, these changes are still within the limits of industry standards and do not significantly affect the shelf life of the product. The study also shows that single-layer designs are more accessible to recycle, which aligns with circular economy principles and global sustainability goals. It provides a competitive advantage for companies facing increasingly stringent regulatory pressures related to plastic waste management.

The House of Quality (HoQ) analysis conducted in this study also revealed that the primary needs of customers focus on packaging durability, affordable prices, and delivery speed. Developing more straightforward single-layer packaging while maintaining the necessary technical performance has proven to meet customer needs without sacrificing product quality. By improving the technical attributes that suit customers' needs, the company can increase its competitiveness in the market.

This research provides practical solutions for companies to reduce production costs and improve operational efficiency, offering more environmentally friendly product innovations. Applying the results of this research is expected to significantly contribute to global efforts to achieve a circular economy while increasing customer satisfaction through more efficient and sustainable product design. Further research is recommended to explore this single-layer design's mechanical aspects and potential applications in other industries.

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