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A Deep Learning and Metaheuristic Optimization Framework for Predictive Maintenance Scheduling and Decision Support in Smart Industrial Systems

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ABSTRACT

This study aimed to construct a comprehensive framework that fosters autonomous decision-making among Thai micro-entrepreneurs located in the lower central region, with an emphasis on enhancing packaging innovation and supporting long-term sustainable development. A quantitative research approach was adopted, utilising a stratified sampling method to gather data from a total of 316 respondents. Path analysis was employed to examine the underlying dimensions that affect self-reliance in packaging innovation. The analysis identified four principal dimensions as vital for achieving sustainable packaging design: technological competence, economic independence, psychological resilience, and socio-cultural integration. The findings also indicated that technological self-reliance exerted an indirect influence on socio-cultural integration, with culturally oriented design perspectives accounting for 19.6 percent of the variance observed. The outcomes underscore the significance of community-based decision-making frameworks that empower micro-entrepreneurs. These models hold potential to inform policy interventions and shape educational content directed at sustainable practice adoption, especially within the context of developing nations aiming to reinforce community resilience. The study offers a transferable model that demonstrates how community participation can be effectively connected to innovative packaging strategies. This approach promotes both economic sustainability and the preservation of cultural identity among micro-enterprises operating within the small business sector.

1. Introduction

In the 21st century, nations worldwide have undergone rapid economic and technological shifts, leading to disparities in individual livelihood security. These transformations have disproportionately affected those without access to adaptive skill development, resulting in severe social challenges

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among individuals lacking what may be termed ‘transformation literacy’ in a rapidly evolving global landscape. Lifelong learning has emerged as a strategic approach to empower marginalised groups by fostering the development of internal capabilities aligned with ongoing changes in the contemporary world [1]. This is particularly vital for small-scale entrepreneurs facing intense market competition. Facilitating their continuous learning within their own communities is pivotal for promoting sustainable development and elevating local product standards [13].

Sustainable development plays a crucial role in shaping visually and functionally attractive packaging for community-based products. Integrating environmental and social accountability into packaging design not only adds market value to community goods but also strengthens business performance and market competitiveness [19]. In Thailand, the principle of self-reliance has been adopted as a foundation for building resilient local economies. Government institutions have actively encouraged small entrepreneurs to embrace this principle. In practice, lifelong learning serves to enhance entrepreneurial skills within communities, enabling individuals to adopt appropriate technologies and effectively utilise indigenous resources for maximum local benefit [26]. This approach seeks to reduce external dependency in Thailand’s rural regions and reinforce distinct community identities through innovative packaging [15]. The enhancement of entrepreneurial efficiency in these regions aligns with 21st-century lifelong learning objectives, which emphasise the application of critical and contextual thinking, leveraging cultural capital to increase product value [21; 24]. Furthermore, this model supports the development of low-cost, environmentally responsible packaging that fosters circular economies and incentivises communities to convert cultural heritage into tangible value [20]. Accordingly, this research investigates the factors influencing packaging development competencies among local residents, with self-reliance identified as a central component of sustainable community growth [25].

The Thai government advocates for community development through the promotion of lifelong learning, particularly through the dissemination of knowledge linked to the creative economy and the Sufficiency Economy Philosophy. This initiative empowers micro-entrepreneurs to independently produce and distribute packaging for local products. The foundational knowledge for community packaging revolves around a ten-component framework: (1) structural integrity; (2) user-friendliness; (3) visual appeal; (4) clarity of information; (5) environmental friendliness; (6) recyclability or biodegradability; (7) reusability (Ibrahim et al., 2022); (8) contribution to sustainability; (9) expression of community identity through lifestyle, tradition, and art; and (10) distinctiveness [6]. By adhering to these components, entrepreneurs can effectively appeal to younger consumers who prioritise environmental responsibility and cultural authenticity. This approach aligns with the Sustainable Development Goals (SDGs), particularly SDG 12 on “Sustainable Consumption and Production” and SDG 13 on “Natural Resource Protection”.

The primary aim of this study is to determine the key drivers that influence the packaging development efforts of micro-entrepreneurs. Through the lens of lifelong learning, self-reliant packaging is shown to significantly improve the design skills of these individuals, ensuring their products are well-suited to community-specific needs. This research identifies the motivating elements that support rural Thai entrepreneurs in producing high-quality, self-reliant packaging that meets evolving consumer expectations.

2. Literature Review

Lifelong learning represents a fundamental approach for human capability development in the 21st century [4; 12]. It facilitates mutual support within society, enabling individuals to enhance both their cognitive abilities and essential life skills necessary for present and future resilience and well-being. Through engagement in lifelong learning, individuals expand their knowledge by participating

in collective activities involving brainstorming, planning, collaborative decision-making, and fostering a sense of responsibility for personal and communal advancement [11]. This process is particularly relevant for small-scale entrepreneurs, as it encourages the cultivation of creativity and problem-solving capabilities. These competencies are vital for entrepreneurs who face limited market access and competitive disadvantage, allowing them to improve their performance to levels comparable with larger businesses.

Importantly, lifelong learning extends beyond formal education and encompasses experiential and informal learning modes, such as community-based activities grounded in local traditions and cultural practices [14]. These community-driven learning engagements are instrumental in developing the packaging innovation and product creation skills of small business entrepreneurs through hands-on experience and peer knowledge exchange. In rural Thailand, this learning approach enables the effective transfer of practical knowledge necessary for packaging development and entrepreneurial success [10]. Packaging that aligns with the principles of sustainable development can significantly contribute to the establishment of unique product identities within communities. Research by Zhou [27] highlights that environmentally sustainable packaging not only mitigates ecological harm but also conveys a strong message of social responsibility on the part of entrepreneurs. Moreover, such practices enhance the competitive standing of community products in broader markets. Their findings further suggest that optimal packaging for local goods must integrate four key elements: cultural identity, functionality, aesthetic appeal, and environmental stewardship. When harmonised, these aspects foster the emergence of distinctive packaging identities rooted in local cultural capital [2]. This holistic approach reflects traditional craftsmanship and indigenous knowledge, contributing to added product value and providing clear market differentiation.

In the context of rural Thai communities, packaging design achieved through lifelong learning among small business entrepreneurs is grounded in the notion of self-reliant packaging. This relies on leveraging available community resources, such as artisanal skills, locally sourced and eco-friendly materials, and reusable inputs. These locally embedded resources enable communities to undertake independent production processes tailored to their specific capacities and cultural context. The present study seeks to advance the capabilities of small business entrepreneurs in rural Thailand in designing self-reliant product packaging. The objective is to ensure that newly developed packaging effectively responds to the preferences of younger consumers, who prioritise sustainability and cultural authenticity. The lifelong learning framework employed in this research is aligned with the Bio-Circular-Green (BCG) Economy Model, an initiative promoted by the Thai government to stimulate inclusive economic development. This model aims to enhance rural competitiveness and increase income opportunities while supporting sustainable production and consumption, in line with the Sustainable Development Goals (SDG 12).

3. Methodology

This research adopts a mixed methods approach as outlined by Johnson et al. [9], integrating both qualitative and quantitative elements to ensure comprehensive analysis. The implementation process comprises the following sequential stages: (1) identifying and examining the factors influencing packaging design; (2) developing innovative packaging prototypes; (3) conducting trials and performance assessments; (4) performing analytical evaluation of outcomes; and (5) assessing the satisfaction levels of small-scale entrepreneurs regarding the newly developed packaging solutions.

3.1 Population

The study population consisted of 1,500 community entrepreneurs located in the lower central

region of Thailand (Medium and Small Enterprises Statistics, 2021). A total of 316 participants were selected using stratified sampling based on the following procedure:

3.1.1 Target Provinces

Entrepreneurs were selected from four provinces within the lower central region:

- 102 from Samut Songkhram
- 82 from Samut Sakhon
- 72 from Phetchaburi
- 60 from Prachuap Khiri Khan

3.1.2 Selection Criteria

Participants were required to have more than five years of entrepreneurial experience. The sample size was determined with a 95% confidence level using the Taro Yamane formula.

3.1.3 Research Instrument

A structured questionnaire was developed to assess the influence of packaging characteristics on small business entrepreneurs and their satisfaction with newly designed packaging created through lifelong learning. The instrument consisted of observed variables and items rated on a 5-point Likert scale.

3.1.4 Validity and Reliability

The instrument demonstrated strong validity with an Index of Consistency (IOC) of 0.893 ($n = 5$), exceeding the 0.50 threshold. Reliability was confirmed through a Cronbach's Alpha (α) value of 0.889 ($n = 30$), surpassing the standard cut-off of 0.80.

3.1.5 Data Analysis

Statistical analysis was conducted using SPSS software, incorporating descriptive statistics (mean and standard deviation), exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modelling (SEM) for path analysis.

3.1.6 Ethical Approval:

This research received ethical clearance from the Institutional Review Board (IRB) of King Mongkut's Institute of Technology Ladkrabang, approval number EC-KMITL_67_050 (050/2024).

4. Results

In relation to the factors examined concerning packaging design among small business entrepreneurs in Thailand's lower central region, the analysis of responses regarding satisfaction with newly developed packaging—resulting from lifelong learning activities—was conducted through EFA following a systematic, step-by-step procedure.

4.1 Step 1: Variable Categorisation by EFA

The researchers gathered data on the satisfaction of small-scale entrepreneurs with the newly designed packaging, aiming to identify latent variables influencing their perceptions of design and production. Observed variables were assessed to extract common factors and to determine the relationships among them. This process involved examining initial agreement levels, testing the associations among observed variables, and analysing their categorical relationships. The study further explored the correlation between factors affecting the efficiency of community packaging

design, particularly regarding cost reduction and the development of self-reliant solutions. Measurement relied on 26 predefined variables and a reliable sample of 316 respondents. Community values were expected to exceed 0.611, and findings indicated a range between 0.844 and 0.946, confirming the suitability of variable grouping. The KMO value and Bartlett's Test produced a result of 0.891, validating the data for EFA. Internal consistency was confirmed with $\alpha = 0.935$. These values indicated that the dataset fulfilled all required criteria for EFA. The results confirmed that the observed variables reflected shared components of satisfaction and were appropriate for further analysis. Ultimately, the 14 variables were found to be interrelated and could be grouped into four distinct factors (Chi-square = 8399.007; df = 325; significance = .000), as presented in Table 1.

Table 1

Factor Loadings from Varimax Rotation (> 0.611).

No.	Variables	Component				Communality	Cronbach's Alpha
		Factor 1	Factor 2	Factor 3	Factor 4		
AR18	The cost of production technologies was suitable for communities.	.901				.862	.931
AR21	The technologies could enhance efficiency and reduce production costs.	.895				.841	.931
AR17	The technologies could enhance packaging quality and value.	.874				.818	.930
AR22	The technologies could facilitate sustainable packaging development.	.857				.810	.931
AR14	The packaging could reflect community identities efficiently.		.922			.920	.931
AR13	The packaging could add value to community products.		.918			.919	.931
AR15	The packaging can be used as a tool to promote community products.		.885			.866	.931
AR24	Packaging development must consider community identities.			.945		.930	.933
AR25	The concept of self-reliance created community confidence in packaging development.			.936		.912	.933
AR08	The packaging design promoted community creativity.			.832		.928	.932
AR16	The packaging development motivated learning and skill development.			.876		.831	.932
AR09	Packaging design must consider opinions of inhabitants and support manpower in local communities.				.912	.910	.932
AR23	Packaging development should require cooperation between communities and designers.				.893	.876	.932
AR20	The packaging reflects community cultures and identities.				.844	.756	.933
Sum of Squares		38.647	10.864	7.829	7.053	64.394	.932
Percentage of trace		20.938	15.548	15.079	12.793	64.394	

*Loadings < .611 did not lead to setting factors.

Based on the total variance explained through the extraction method, the analysis revealed that all 14 observed variables were grouped into four distinct factors, with corresponding factor loadings as follows: Factor 1 = 38.647, Factor 2 = 10.864, Factor 3 = 7.829, and Factor 4 = 7.053. A scree plot was subsequently generated, displaying the eigenvalues for Factors 1 to 4 in a descending slope, confirming the appropriateness of the four-factor solution. It was further determined that all 14 observed variables exhibited factor loadings greater than 0.611, thereby validating their inclusion. Collectively, these variables accounted for 64.394% of the total variance and were categorised into

four distinct factors as detailed below:

- Factor 1: AR18, AR21, AR17, AR22
- Factor 2: AR14, AR13, AR15
- Factor 3: AR24, AR25, AR08, AR16
- Factor 4: AR09, AR23, AR20

A detailed summary of these findings is provided in Table 1.

Moreover, Figure 1 presents the factor loadings of the 14 observed variables, derived using Varimax rotation, which enhances the interpretability by aligning each variable distinctly with one of four principal components. AR18, AR21, AR17, and AR22 load strongly on Factor 1, representing a dimension linked to technological competence and cost efficiency. Factor 2, comprising AR14, AR13, and AR15, reflects the significance of packaging in reinforcing product identity and enhancing promotional appeal. Factor 3, defined by AR24, AR25, AR08, and AR16, is indicative of community-driven approaches to packaging development, with a focus on creativity and self-reliance. Factor 4, which includes AR09, AR23, and AR20, underscores the relevance of communal collaboration and the integration of cultural elements in packaging design.

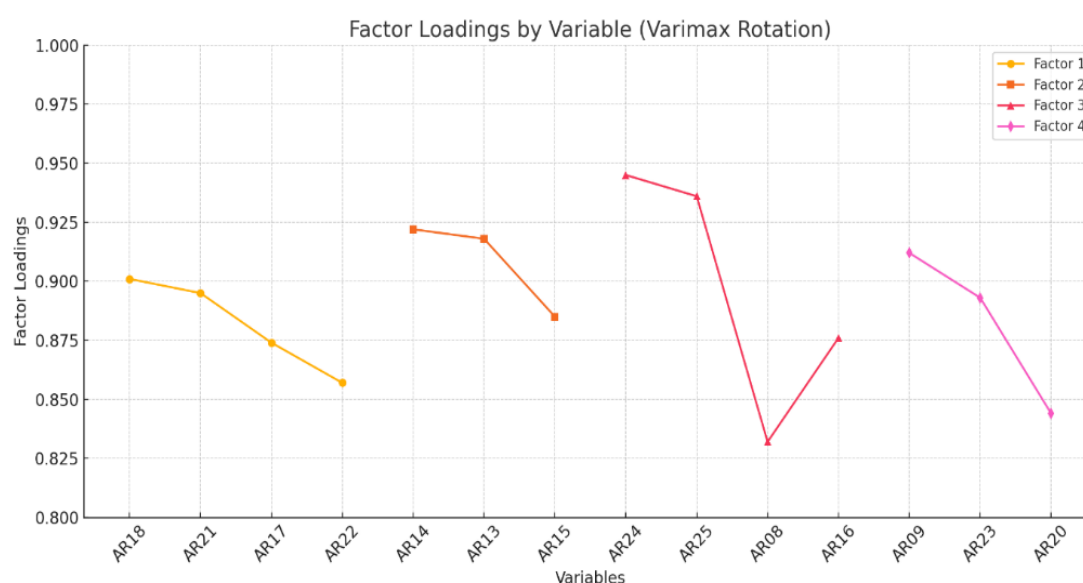


Fig.1: Factor Loadings by Variable (Varimax Rotation)

Each factor demonstrates strong internal consistency, with high communality values and a stable α of 0.932, confirming the reliability of the underlying constructs. Collectively, these factors illustrate the multifaceted nature of community packaging development, balancing technological, promotional, educational, and cultural dimensions in a cohesive framework.

Step 2: The development of new packaging designs for community products intended for implementation by small-scale entrepreneurs was based on four foundational factors.

Factor 1 (technological self-reliance), Factor 2 (economic self-reliance), Factor 3 (mental self-reliance), and Factor 4 (socio-cultural reliance). These components served as a strategic framework for guiding packaging design through participatory processes, aiming to align with consumer expectations within the Thai market. This stage also incorporated lifelong learning activities involving small entrepreneurs in the collaborative design of community product packaging, consistent with the principles of self-reliant local economies. These engagements generated long-term advantages for the communities by enhancing the entrepreneurs' capabilities in independent packaging development. The activities brought together the expertise of multiple stakeholder groups, including entrepreneurs, consumers, designers, and local residents. The central focus on collaborative

participation among these groups ultimately fostered a deeper sense of community self-reliance.

Step 3: This stage involved assessing the satisfaction levels of small-scale entrepreneurs with the newly developed packaging designs, which were the outcome of participatory lifelong learning initiatives. The evaluation focused on the effectiveness of these activities in enhancing packaging solutions that reflect both functional requirements and the specific needs of community-based enterprises.

As presented in Table 2, the evaluation of small-scale entrepreneurs' satisfaction with the newly developed packaging—produced through participatory lifelong learning—revealed high satisfaction levels across all four factors. These were ranked in descending order as follows: (1) technological self-reliance, (2) economic self-reliance, (3) mental self-reliance, and (4) socio-cultural reliance. To assess data normality for the 302 valid responses, skewness values were found to be below 3 and kurtosis values below 10, indicating the dataset met the required statistical thresholds for further analysis. Subsequently, all four factors were examined using CFA (path analysis) to investigate the relationships among observed variables influencing satisfaction with the new packaging. This analysis served as a statistical validation step, assessing the suitability of the dataset for factor analysis. The results showed that the KMO value was acceptable (KMO = 0.849), and Bartlett's Test of Sphericity yielded a significant result (7735.231; df = 91; Sig. = .000), confirming the adequacy of the correlations among variables. All 14 observed variables were found to be interrelated and appropriate for further analysis using CFA, with $\alpha = 0.916$, indicating strong internal consistency. The items included in the instrument were therefore considered suitable for data collection, as detailed in Table 2.

Table 2

Satisfaction of Small Business Entrepreneurs with the New Packaging (n = 302).

No.	Item	Mean	S.D.	Satisfaction Level	Skewness	Kurtosis
1	Technological Self-Reliance					
Tec01	The cost of the production technologies was suitable for communities.	4.007	0.706	High	-1.693	-1.141
Tec02	The technologies could enhance efficiency and reduce production costs.	4.003	0.684	High	-1.815	-.379
Tec03	The technologies could enhance packaging quality and value.	4.023	0.674	High	-1.129	-1.341
Tec04	The technologies could facilitate sustainable packaging development.	4.030	0.762	High	-2.945	-.889
Total		4.016	0.678	High	-1.286	-1.599
2	Economic Self-Reliance					
Eco01	The packaging could reflect community identities efficiently.	3.983	0.780	High	-1.908	-2.166
Eco02	The packaging could add value to community products.	3.974	0.773	High	-1.844	-2.022
Eco03	The packaging can be used as a tool to promote community products.	3.937	0.751	High	-1.625	-1.555
Total		3.965	0.759	High	-2.048	-1.769
3	Mental Self-Reliance					
Men01	Packaging development must consider community identities.	3.778	0.725	High	1.099	-2.531
Men02	The concept of self-reliance created community confidence in packaging development.	3.775	0.726	High	1.161	-2.563
Men03	The packaging design promoted community creativity.	3.811	0.743	High	.881	-2.869
Men04	Packaging development must consider community identities.	3.811	0.734	High	1.139	-2.985
Total		3.794	0.717	High	1.230	-2.983
4	Socio-Cultural Reliance					
Soe01	The packaging design must consider the opinions of inhabitants and support manpower in local communities.	3.884	0.767	High	-.477	-2.611
Soe02	Packaging development should require cooperation between the communities and designers.	3.864	0.755	High	-.689	-2.049

No.	Item	Mean	S.D.	Satisfaction Level	Skewness	Kurtosis
Soe03	The packaging reflects community cultures and identities.	3.934	0.712	High	-.104	-2.660
Total		3.894	0.706	High	.142	-2.687

Figure 2 illustrates the mean satisfaction scores reported by 316 small-scale entrepreneurs across four dimensions of self-reliance in relation to newly introduced packaging technologies. The highest satisfaction was observed in the area of technological self-reliance ($M = 4.016$), suggesting strong approval of both the appropriateness and effectiveness of the adopted technologies. This was followed closely by economic self-reliance ($M = 3.965$), indicating a favourable perception of the added economic value that packaging contributes to community products. Satisfaction with socio-cultural reliance was also notably positive ($M = 3.894$), underscoring the relevance of designs that are culturally informed and socially embedded.

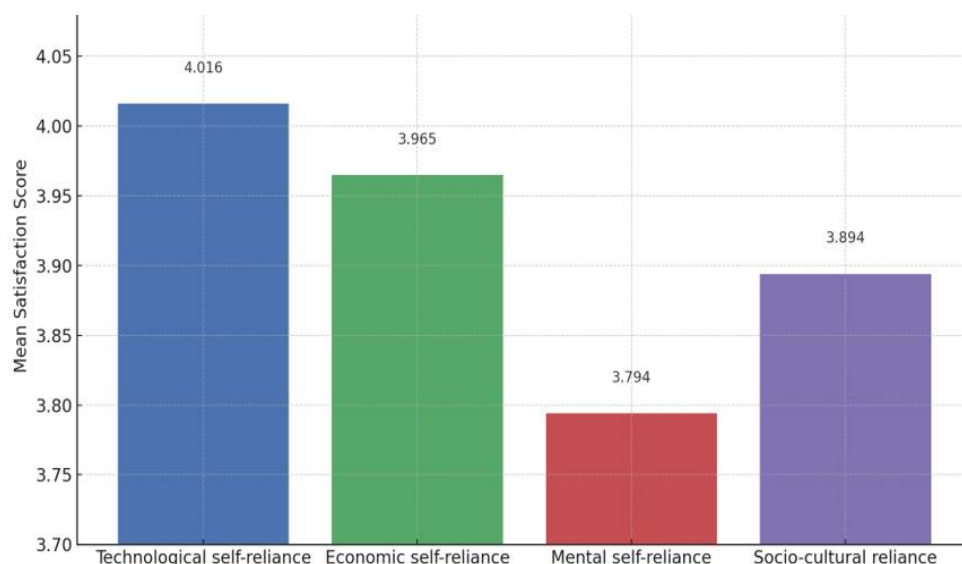


Fig.2: Satisfaction of Small Business Entrepreneurs with New Packaging

Although mental self-reliance recorded the lowest mean score among the four dimensions, it remained within a high range ($M = 3.794$), reflecting the perceived importance of creativity and motivational aspects in the packaging development process. Overall, satisfaction across all four domains was consistently high, suggesting that the packaging innovations achieved through participatory efforts were well-received by the entrepreneurial community.

Table 3 presents the master validity assessment, which includes composite reliability (CR), average variance extracted (AVE), maximum shared variance (MSV), and maximum reliability Max(H), following the approach of Menon et al. (2023). The findings confirm that the dataset demonstrates strong validity and reliability in representing the intended constructs. All statistical indicators met the established criteria: $CR > 0.70$, $AVE > 0.50$, $MSV < AVE$, and $CR < Max(H)$. These results indicate sufficient discriminant validity, as the factors were clearly distinct and uncorrelated. Each construct was confirmed to be statistically separable and independently measurable, as detailed in Table 3.

Table 3

Master Validity Analysis, with CR, AVE, MSV, and MaxR(H).

Observed Variables	CR	AVE	MSV	MaxR(H)
[1] Technological Self-Reliance: The cost of production technologies was suitable for communities.	0.959	0.855	0.185	0.988

[2] Economic Self-Reliance: The packaging could add product value and promote community economies.	0.990	0.970	0.185	1.003
[3] Mental Self-Reliance: Creativity and awareness of community entrepreneurs toward packaging design was improved.	0.983	0.937	0.125	1.000
[4] Socio-Cultural Reliance: The packaging design reflects community identities.	0.946	0.855	0.136	0.973

Figure 3 illustrates the average satisfaction levels reported by small-scale entrepreneurs across four dimensions of self-reliance in relation to newly implemented packaging initiatives. The highest satisfaction was observed in Technological Self-Reliance (M = 4.016), followed closely by Economic Self-Reliance (M = 3.965). Socio-Cultural Reliance ranked third with a mean score of 3.894, while Mental Self-Reliance recorded the lowest, though still high, mean of 3.794. Despite the marginal differences between dimensions, all four demonstrated consistently elevated satisfaction levels. These findings suggest a strong positive reception of the new packaging solutions and their effective alignment with both the practical requirements and cultural expectations of community-based entrepreneurs.

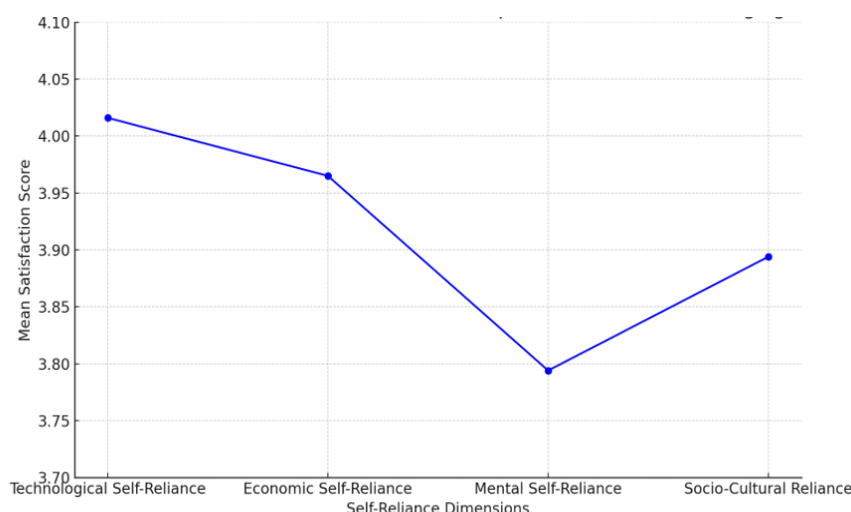


Fig.3: Mean Satisfaction of Small Business Entrepreneurs with New Packaging

Table 4 presents the CFA outcomes concerning the factors influencing community product packaging design among entrepreneurs who engaged in lifelong learning activities. The results indicated that the model fit indices satisfied established thresholds: $\chi^2 = 83.793$, $df = 66$, relative $\chi^2 = 1.270$, $p\text{-value} = 0.069$, $RMSEA = 0.032$, $RMR = 0.047$, $GFI = 0.962$, $AGFI = 0.940$, $NFI = 0.989$, $TLI = 0.997$, and $CFI = 0.998$. Specifically, the indices conformed to the following acceptable criteria: relative $\chi^2 < 2$; $RMSEA$ and $RMR < 0.050$; GFI , NFI , and $TLI > 0.950$; and $AGFI > 0.900$. The findings confirmed a strong alignment between the newly developed packaging factors and the satisfaction levels of participating small-scale entrepreneurs. It may therefore be concluded that the self-reliant packaging design model developed through lifelong learning initiatives effectively addressed the design and production needs of entrepreneurs in rural Thailand, particularly for community-based processed agricultural products. The model was grounded in four key dimensions: Factor 1 (technological self-reliance), Factor 2 (economic self-reliance), Factor 3 (mental self-reliance), and Factor 4 (socio-cultural reliance). When entrepreneurs are able to incorporate these four elements into their packaging practices, it leads to enhanced satisfaction, reduced production costs, and alignment with community capabilities, all of which contribute to long-term sustainability.

Table 4
Confirmatory Factor Analysis (Path Analysis)

Observed Variables	Technological Self-Reliance			Economic Self-Reliance			Mental Self-Reliance			Socio-Cultural Reliance			r^2
	<i>b</i>	β	<i>S.E.</i>	<i>b</i>	β	<i>S.E.</i>	<i>b</i>	β	<i>S.E.</i>	<i>b</i>	β	<i>S.E.</i>	
Tec01	.841	.908	.052**	-	-	-	-	-	-	-	-	-	.824
Tec02	.790	.880	.059**	-	-	-	-	-	-	-	-	-	.774
Tec03	.766	.866	.062**	-	-	-	-	-	-	-	-	-	.749
Tec04	1.000	1.000	-	-	-	-	-	-	-	-	-	-	1.000
Eco01	-	-	-	1.000	1.000	-	-	-	-	-	-	-	1.000
Eco02	-	-	-	.983	.992	.013**	-	-	-	-	-	-	.984
Eco03	-	-	-	.926	.961	.018**	-	-	-	-	-	-	.924
Men01	-	-	-	-	-	-	1.000	1.000	-	-	-	-	1.000
Men02	-	-	-	-	-	-	.999	.997	.005**	-	-	-	.994
Men03	-	-	-	-	-	-	.995	.971	.014**	-	-	-	.942
Men04	-	-	-	-	-	-	.913	.901	.025**	-	-	-	.812
Soc01	-	-	-	-	-	-	-	-	-	1.000	.980	-	.960
Soc02	-	-	-	-	-	-	-	-	-	.916	.957	.024**	.915
Soc03	-	-	-	-	-	-	-	-	-	.787	.830	.033**	.689

Chi-Square = 83.793 ; df = 66, Relative Chi-Square = 1.270, P-Value = 0.069, GFI = 0.962, AGFI = 0.940, NFI = 0.989, TIL = 0.997, CFI = .998, RMSEA = 0.030, RMR = 0.047 [* P < .05; ** P < .01]

Figure 4 presents the R^2 values for the observed variables across the four dimensions of self-reliance—technological, economic, mental, and socio-cultural—as derived from CFA. These R^2 values reflect the proportion of variance in each observed variable explained by its respective latent construct. The analysis revealed consistently strong relationships across all variables, with R^2 values ranging from 0.689 (Soc03) to 1.000 (Tec04, Eco01, Men01). Observed variables associated with technological and economic self-reliance demonstrated particularly high explanatory power, frequently exceeding 0.900. In contrast, indicators related to mental self-reliance exhibited a modest downward trend, though their explanatory capacity remained statistically significant. Socio-cultural reliance variables showed greater variability in R^2 values. Collectively, the high R^2 scores across all dimensions affirm the robustness, reliability, and construct validity of the measurement model.

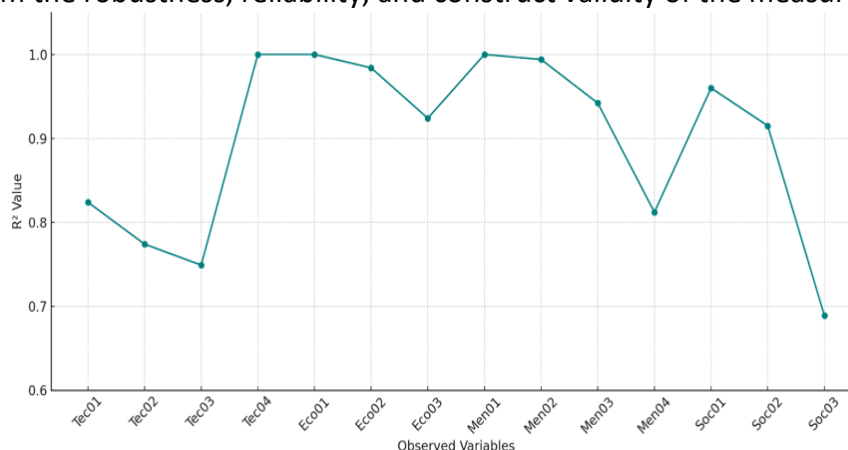


Fig.4: R2 Values for Observed Variables in Confirmatory Factor Analysis

Figure 5 illustrates the outcomes of the SEM and path analysis, confirming the structural relationships among the self-reliance dimensions. The analysis demonstrated that mental self-reliance exerted a direct influence on socio-cultural reliance, while economic self-reliance showed both direct and indirect effects on the same construct. Technological self-reliance did not exert a direct influence but affected socio-cultural reliance indirectly through both economic and mental self-reliance. The combined influence of technological, economic, and mental self-reliance accounted for 19.6% of the variance in socio-cultural reliance. Among these, economic self-reliance had the

strongest influence, followed by mental self-reliance and technological self-reliance, respectively. The decomposition of effects, expressed as total effect (TE), which is the sum of direct effect (DE) and indirect effect (IE), is as follows:

- Mental Self-Reliance = $0.263(DE) + 0(IE) = 0.263$
- Economic Self-Reliance = $0.286(DE) + 0.315 \times 0.236(IE) = 0.360$
- Technological Self-Reliance = $0(IE) + 0.431 \times 0.286(IE1) + 0.431 \times 0.315 \times 0.263(IE2) = 0.159$

These results validate the hierarchical influence of the constructs, confirming that the model accurately represents the interdependencies among self-reliance dimensions within the context of community packaging development.

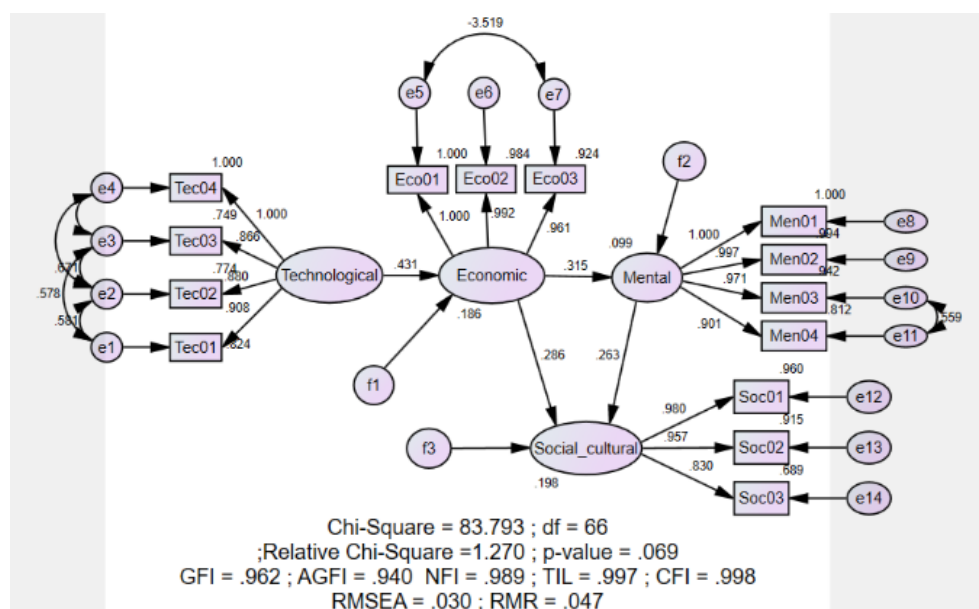


Figure 5: Path Analysis Presenting the Attributes of New Packaging Designed by the Studied Factors

Note: [1] Technological Self-Reliance = Suitable Packaging Production Technologies for Communities. [2] Economic Self-Reliance = Packaging Enhances Product Value and Promotes Community Economics. [3] Mental Self-Reliance = Creativity and Awareness of Packaging Design and Development. [4] Socio-Cultural Reliance = Packaging Design that Represents Community Identities.

5. Discussion

This study on the factors influencing packaging design among small business entrepreneurs in rural Thailand, stemming from lifelong learning activities aimed at enhancing their design skills for self-reliance, sought to promote sustainable development by increasing the efficiency of entrepreneurs who traditionally faced limited opportunities and market competition. The application of lifelong learning to foster packaging design skills primarily utilised the capital inherent in their communities—such as skills, materials, technology, culture, and various locally accessible resources [3]. The primary objective was to demonstrate community efficacy through integrating and establishing activities that encourage self-reliant packaging development for small entrepreneurs to supply the market, addressing current and anticipated consumer demands. Lifelong learning activities stimulated skill acquisition, motivating entrepreneurs to create packaging that reflected their cultural identity. Four principal factors underpinning success in skill and knowledge development were identified: (1) technological self-reliance, (2) economic self-reliance, (3) mental self-reliance, and (4) socio-cultural reliance.

Factor 1 – Technological Self-Reliance: Community-available technologies were critical in facilitating self-sufficient packaging design and production among entrepreneurs. The relatively low cost of new packaging production enabled competitive pricing strategies. This factor also supported

the development of packaging compatible with locally processed agricultural goods, thereby enhancing competitiveness for rural small business entrepreneurs in Thailand [16]. Additionally, it encouraged the adoption of technologies congruent with local lifestyles while promoting sustainable eco-friendly practices ([7].

Factor 2 – Economic Self-Reliance: Packaging design and production that are self-sufficient empower entrepreneurs to compete effectively and increase the economic value of community-processed agricultural products through enhanced packaging. Such packaging helps to convey community identity narratives that positively influence consumer perception and purchasing decisions. Encouraging autonomous learning to enhance value addition in tandem with packaging design strengthens market competitiveness and supports the establishment of circular economies within communities by leveraging employment and local resources [17]. This process fosters cyclical community economies based on sharing and income distribution [22]. Community-driven development strategies that engage inhabitants enhance societal strength and promote cooperation, leading to sustainable economic growth through effective production of processed agricultural goods [23].

Factor 3 – Mental Self-Reliance: Entrepreneurs were encouraged to apply creativity and self-confidence in designing packaging for their processed agricultural products. Self-efficacy plays a pivotal role in enabling the courage required for acquiring new skills and knowledge. A determined mindset facilitates expression of local perspectives and identities, thereby fostering packaging differentiation. The lifelong learning framework implemented in this study enhanced problem-solving capabilities and promoted self-reliant packaging production [18]. This factor underlined the necessity of mental self-reliance for participatory community empowerment and effective problem-solving. Such creative engagement fostered a challenge-driven motivation for packaging design, incorporating cultural values to meet the preferences of younger consumers [8].

Factor 4 – Socio-Cultural Reliance: This factor involved employing cultural capital and local values as inspiration for packaging design, integrating symbolism, customs, beliefs, and artistic traditions. Entrepreneurs utilised these cultural identities to attract younger consumers through packaging innovations emerging from lifelong learning activities. Socio-cultural reliance in packaging facilitates the transmission of intangible cultural heritage to wider audiences, thereby preserving community culture. This preservation strengthens community cohesion and fosters pride in the harmonious fusion of cultural capital and packaging design [5]. Furthermore, this factor aligns with the principles of the creative economy, where cultural capital drives innovation and differentiation in packaging, transforming products into community heritage artefacts while simultaneously contributing to economic modernization.

Identifying these four factors provides a valuable data source to develop a variety of lifelong learning activities aimed at improving the efficiency of rural entrepreneurs in Thailand. This enables the establishment of sustainable packaging design processes grounded in community self-reliance through lifelong learning. Such efforts foster secure local economies, conserve cultural capital, and enhance systematic problem-solving and creative capacities. The research process heightened entrepreneurs' awareness of self-reliance and skill development, encouraging adaptability to market changes and evolving consumer demands. The sample presents some biases potentially affecting internal and external validity. Over- or under-representation of certain factors may lead to over- or underestimation of effects, limiting the generalisability of findings. Expanding the sample to include micro-entrepreneurs from diverse regions and economic contexts would increase data variability and strengthen validity. Additionally, revising selection criteria to better represent all relevant experiences is advisable. The reliance on self-report data presents another limitation due to possible social desirability bias. Integrating qualitative methods such as interviews and focus groups could

elucidate the decision-making processes underlying packaging innovation. Moreover, the cross-sectional design restricts causal inference, whereas longitudinal studies would better assess progression over time and validate causal relationships, particularly regarding self-reliance's influence on adopting sustainable packaging practices.

The findings contribute to sustainable development and micro-entrepreneur empowerment in emerging economies. The framework comprising technological competence, economic independence, mental resilience, and socio-cultural integration offers guidance for policymakers and practitioners to foster local innovation. Emphasising packaging design that reflects entrepreneurial spirit and local identity underscores the role of cultural relevance in creating competitive markets and enhancing community pride. This is especially significant in light of increasing global attention to sustainability and cultural preservation. Future research could investigate the dynamics of self-reliance in packaging innovation across diverse cultural settings, comparing rural and urban micro-entrepreneurs or different product sectors. Examining networking and community collaboration strategies may reveal how local communities support packaging innovation and sustainable practices. Additionally, exploring the long-term economic and environmental impacts of self-reliance could yield deeper understanding of the enduring effects of entrepreneurial initiatives. Expanding this study to include case studies in emerging economies, particularly startups, could provide broader insights into sustainable micro-entrepreneurship globally.

6. Conclusion

The findings on factors influencing self-reliant packaging design efficiency among small entrepreneurs in rural Thailand indicate that the newly developed packaging for processed agricultural products generated high satisfaction and positive perceptions. Analysis of 26 observed variables using EFA (KMO and Bartlett's Test = .891) confirmed the data's suitability for categorisation. Four factors emerged from 14 related variables: (1) technological self-reliance, (2) economic self-reliance, (3) mental self-reliance, and (4) socio-cultural reliance. Entrepreneurs engaged in lifelong learning demonstrated capability in self-reliant packaging design and problem-solving, responding effectively to consumer demands through collaborative community efforts. Application of these four factors enhanced satisfaction, reduced production costs, and supported sustainable sales growth. Path analysis revealed that mental self-reliance directly influenced socio-cultural reliance, while economic self-reliance had both direct and indirect effects. Technological self-reliance impacted socio-cultural reliance indirectly through economic and mental self-reliance. Together, these variables accounted for 19.6% of the variance in socio-cultural reliance. Hence, leveraging efficient packaging design and local technologies fosters self-reliance, which can stimulate local economic growth through increased employment and economic circulation. Enhancing entrepreneurs' skills contributes to cost reduction, while incorporating local identity strengthens product competitiveness, facilitating market advancement. This approach promotes the active participation of local small business entrepreneurs, reinforcing community cohesion through self-reliance grounded in lifelong learning. Consequently, rural Thai communities can apply these competencies in practical business contexts, establishing a foundation for sustainable competitiveness among small entrepreneurs.

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