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OPTIMISING CONCURRENT BUSINESS-PRODUCT-PROCESS-SUPPLY CHAIN DESIGN

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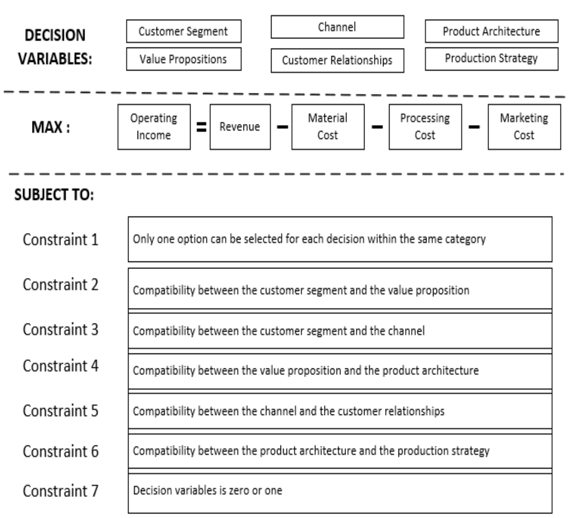
Graphical abstract



Abstract

Three-dimensional concurrent engineering (3DCE) requires alignment with the business strategy; otherwise, the design may become unusable. Furthermore, 3DCE design and business strategy must be developed concurrently to reduce the iterative decision-making processes. This study proposes a model that integrates essential business model aspects into 3DCE, representing concurrent decision-making. The model improves previous reference models and uses a real-world case of small and medium enterprise (SME). This study found that decision-makers can initiate from any aspect of the framework and use their ideas as a foundation to inspire alternative decisions; the model provides quantitative analysis for objective decision-making and achieves optimal configurations concurrently. The proposed model can accelerate new product development and eliminate iterations in decision-making.

Keywords: product development, concurrent engineering, three-dimensional concurrent engineering, business model canvas, optimisation model

1.0 INTRODUCTION

Three-dimensional concurrent engineering (3DCE) is a promising approach for concurrently designing products, processes, and supply chains [1]. 3DCE involves comprehensive aspects and offers an evaluation mechanism for alternative designs to obtain the best solution. 3DCE requires alignment with other business strategies, such as planning for the value of the products offered to consumers [2,3] and defining the consumer segments to be targeted [4]. Consequently, 3DCE designs that do not align with the essential business strategy may require significant adjustments or become unusable.

Previous 3DCE studies revealed several findings. Production planning has yet to be widely discussed, having been addressed in research by Addo-Tenkorang et al. (2017) [5] and Varl et al. (2020) [6]. Furthermore, the 3DCE supply chain aspect is limited to considering only potential suppliers without incorporation into distributors, though distribution planning is addressed in an article by Varl et al. (2020) [6]. These findings indicate a potential to enhance 3DCE by incorporating additional sub-aspects into the design.

Several previous research studies used two types of criteria performance to select the best configuration: multicriteria or financial criteria. Shidpour et al. (2013) considered multicriteria in decision-making, which are the ergonomic, serviceability, aesthetic, and facility aspects [7], while Varl et al. (2020) added other qualitative aspects related to design flexibility [6]. Meanwhile, several studies have integrated the examination of cost and revenue into evaluating optimal design solutions [8-13]. The application of financial criteria provides comparatively more interpretable results than multicriteria. Therefore, this criterion is a promising indicator for identifying the optimal design configuration.

In addition, a business model canvas (BMC) is a strategic tool that outlines essential business strategies. BMC directs the formulation of integrated strategies for value delivery, creation, and viability analysis [14]. Formulating value delivery strategies can enhance 3DCE such that the design results fit the target customers, the product is appropriately stated, and the product is delivered through the proper channels. The formulation of the value creation strategy is similar to the 3DCE results, but the 3DCE design results are even more operational. Value viability analysis could complement 3DCE in terms of a complete economic analysis because it involves revenue and costs.

Several researchers have developed frameworks that comprehensively integrate business models into product design. Jin et al. (2021) developed a simulation tool that integrates business models with product design by focusing on process aspects and manufacturing facilities [15]. Alix and Zacharewicz (2021) proposed an iterative method for finding the configuration of the product, process, and supply chain with business models [16]. Furthermore, Trapsilawati et al. (2022) introduced a framework for finding the proper strategic plan and then implemented it in a configuration design of a business model with 3DCE [17]. These three studies demonstrate business strategy integration with product design, but the decision-making result is achieved through sequential steps.

The integration framework requires selecting essential parts of the business model canvas to incorporate into 3DCE, formulating the compatibility between integrated aspects to perform concurrent work, and defining the appropriate financial equation as shared criteria among stakeholders. This study aims to improve the integration of essential business models into product-process-supply chain design (3DCE) by introducing a new framework that incorporates concurrent decision-making mechanisms. This research introduces an optimisation framework that enables simultaneous decision-making during early product development by aligning product design with operational and business considerations. This optimisation model simplifies the concurrent development of alternative design configurations to reduce repetitive decision-making.

The paper is organised into four sections to present this research. The first section introduces the background of the study, outlines the research problem, and states the research objectives. The second section outlines the methodology, including the framework, real-world case, and model optimisation development. The third section describes optimal decision-making, sensitivity analysis, limitations, and implications. The fourth section discusses the conclusion, highlighting findings related to the proposed model.

2.0 METHODOLOGY

This section covers framework development, the real-world case, and the optimisation model. Framework development relies on theoretical ideas from previous research. The real-world case is a problem related to product design in a Small Medium Enterprise (SME). The Framework and real-world case are the basis for developing the optimisation model.

2.1 Theoretical Framework

BMC offers a framework for evaluating business demand, feasibility, and profitability. The value delivery of BMC ensures that demand adequately serves the target consumer segment, guaranteeing a sizable consumer base interested in the value proposition while effectively reaching and retaining loyal customers. In terms of feasibility, the value creation of BMC ensures that the business is well-controlled, organized for economies of scale, and has key resources, activities, and partners. In terms of business profitability, the value viability of BMC assures that the company has a good income level, consumers are willing to pay according to the set price, and the cost is reasonable to make it sustainable [14].

Three-dimensional concurrent engineering comprises product, process, and supply chain design. Product design emphasises specifications, including materials. Process design emphasises how products are produced, including methods and tools. Supply chain design is related to planning materials or products for the company and products delivered to consumers. Since 3DCE is one of the developments of concurrent engineering, the result is in product, process, and supply chain configurations [18].

Part of BMC's value delivery is selecting customer segments and the value proposition related to 3DCE in product design. Other aspects of BMC's value delivery, channels, and relationships are associated with 3DCE in terms of supply chain design. BMC's value creation consists of key activities and resources related to 3DCE concerning process design. Another part of value creation is key resources associated with 3DCE regarding supply chain design. This BMC-3DCD relationship is the basis for the development of the optimisation model.

The proposed framework has two main aspects: business design and 3DCE. The business design determines decision-making for customer segments, value propositions, channels and relationships, key activities, and partners and resources. The 3DCE consists of product, process, and supply chain design. The product and process aspects adopt the model of Ilhami et al. (2021) [19], while the supply chain aspects adopt the model of Guan et al. (2019) [4]. The process design includes planning for the manufacturing and assembly processes. The supply chain design consists of the supplier and the distributor. The framework integrates the planning of key activities, partners, and resources with 3DCE design.

2.2 The Real-World Case

This study utilized the actual case of an SME that produces packaged goods from traditional Indonesian foods. The design idea was initiated from the supply chain aspect. The company has low-cost raw materials that are scrapped from the main product. The material will be transformed into a new product variant to increase its economic value. In addition, the new design is also driven by competitors who have produced equivalent products. Therefore, the alternative concepts refer to other existing product variants.

The company considers two customer segments, three value propositions, two channels, two customer relationships, and three product architectures. Each product architecture has two main components: the main and the packaging components. The production of the main component can be processed in-house or by subcontract.

Each product architecture has the same main component type. Table 1 describes the part types, associated requirements, costs, and corresponding supplier IDs. Table 2 contains data for processing the main component, which consists of the process sequence, machines used, labour requirement, and time required.

Table 1 Part data for the main component

Part ID	Quantity requirement per batch (in unit)	Cost per batch (in thousand Rupiahs)	Supplier ID
Ingredient A	10	50	Supplier MC1
Ingredient B	1	48.4	Supplier MC2
Ingredient C	2	30.32	Supplier MC2
Ingredient D	0.15	0.183	Supplier MC2
Ingredient E	0.15	10	Supplier MC2
Ingredient F	1.5	20	Supplier MC3
Ingredient G	10	25	Supplier MC4
Ingredient H	0.25	0.084	Supplier MC2

Table 2 Processing data for the main component

Process Sequence	Processing ID	Machine ID	Labor req. (person)	Time req. (hour)
1	Prod Proc 1	*	1	1
2	Prod Proc 2	*	1	1
3	Prod Proc 3	Machine A	1	2
4	Prod Proc 4	Machine B	1	4

* denotes manual processing

Table 3 Part data for packaging component

Part	Qty req. per batch for PA1 (in units)	Qty req. per batch for PA2 (in units)	Qty req. per batch for PA3 (in units)	Cost per batch (in thousand Rps)	Supp. ID
ComPack 1	70	70		1.025	Supp. PC2
ComPack 2	70			1.995	Supp. PC1
ComPack 3	70		70	0.08	Supp. PC3
ComPack 4	70	70		0.084	Supp. PC3
ComPack 5	3.5	3.5	3.5	5.15	Supp. PC5
ComPack 6		70		2	Supp. PC4
ComPack 7		70		0.556	Supp. PC1
ComPack 8		70		0.03	Supp. PC6
ComPack 9			70	3	Supp. PC1

Notes: PA1 (Product Architecture 1), PA2 (Product Architecture 2), PA3 (Product Architecture 3).

The three product architectures have different packaging components, leading to differences in part structures and processing steps. Table 3 presents the types of parts for each architecture product, the required quantities, part costs, and the supplier identities. Table 4 details the process sequence, machines required, and time required. The labour requirement for every process requires only one labour.

The exact sequence of packaging design development activities applies to each architectural product, but the duration of the activities required differs. Table 5 describes the time requirements associated with each product development activity for every architectural product.

Table 6 comprises the remaining data necessary to determine the business-product-process-supply chain configuration. Data related to the product refers to data like the product being developed. Other data are estimations based on the company's current conditions.

Table 4 Processing data for the packaging component

Product Architecture	Processing ID	Machining ID	Time req. (hour)
PA1	AssProc1	*	1.17
	AssProc2	Machine C	0.29
	AssProc3	*	0.70
	AssProc4	*	0.58
	AssProc5	Machine D	0.58
	AssProc6	*	0.58
	AssProc7	*	0.58
	AssProc8	Machine E	1.17
	AssProc9	Machine F	0.58
	AssProc10	*	1.17
PA2	AssProc1	*	1.17
	AssProc2	Machine C	0.29
	AssProc3	*	0.70
	AssProc11	*	0.58
	AssProc12	*	0.29
	AssProc13	*	0.29
	AssProc7	*	0.58
	AssProc8	Machine E	1.17
	AssProc9	Machine F	0.58
	AssProc10	*	1.17
PA3	AssProc14	*	1.17
	AssProc2	Machine C	0.29
	AssProc3	*	0.70
	AssProc15	*	0.58
	AssProc5	Machine D	0.58
	AssProc10	*	1.17

* denotes manual processing. Each processing task requires only one person

Table 5 Development activities for the packaging component

Activity	ID	Pred. Activity	Dur. for PA1 (in days)	Dur. for PA2 (in days)	Dur. for PA3 (in days)
Photo session	A1	-	1	1	1
Drafting Packaging Design	A2	A1	3	1	3
Trial Design	A3	A2	1	1	3
Confirmation and Design Change	A4	A3	3	1	4
Printing	A5	A4	2	1	2
Delivery	A6	A5	1	1	1

Notes: PA1 (Product Architecture 1), PA2 (Product Architecture 2), PA3 (Product Architecture 3).

Table 6 Additional data of the real-world case

Data descriptions	Data values
Demand per month (in thousand units)	0.2
Quantity of units in one batch	70
Number of Month	12
Marketplace cost per year (in thousand Rupiahs)	10800
Direct Selling cost per year (in thousand Rupiahs)	9000
Estimated Percentage of total sales for Marketplace	80%
Estimated Percentage of total sales for Direct Selling	100%
Percentage Seling price from normal price for marketplace	95%
Percentage Seling price from normal price for Direct Selling	80%
Number of Labor requirement for self-service per month	1
Number of Labor requirement for personal assistance per month	2
Multiplier index for processing time (inhouse production strategy)	1
Multiplier index for processing time (subcontract production strategy)	0.8
Multiplier index for processing Cost (inhouse production strategy)	1
Multiplier index for processing Cost (subcontract production strategy)	1.2
Price per unit (in thousand Rupiahs)	65
Hourly employee wage (in thousand Rupiahs)	17.5
Machine A costs per hour (in thousand Rupiahs)	1
Machine B costs per hour (in thousand Rupiahs)	2
Machine C costs per hour (in thousand Rupiahs)	2
Machine D costs per hour (in thousand Rupiahs)	3
Machine E cost per hour (in thousand Rupiahs)	2
Machine F costs per hour (in thousand Rupiahs)	3

2.3 Optimisation Model

This study proposed a model to find the optimal configuration to support the application of the developed framework. The formulation development uses reference models from Ilhami et al. (2021) [19] and Shidpour et al. (2013) [7]. Figure 1 depicts the structure of the optimisation model used.

This study specifies six decision variables. The four variables of customer segment, value proposition, channel, and customer relationships are part of business design. Meanwhile, product architecture and production strategy integrate 3DCE and business design. The objective function only involves financial values relevant to the selected decision variables to simplify the calculation process. Furthermore, this study sets constraints to represent the compatibility between decisions.

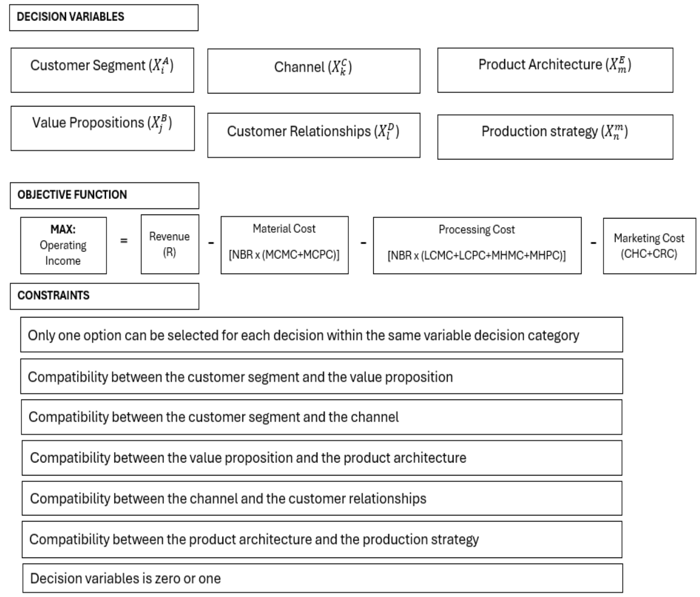


Figure 1 Optimisation model structure.

The following subsection discusses sets and indices, definitions of parameters and variables, decision variables, variable formulation, objective function formulation, and constraint formulation.

2.3.1 Sets And Indices

G: set of part types for the main component, where $g \in G$. The alternatives include part type *g*, ranging from 1 to 8.

H: set of part types for the packaging component, where $h \in H$. The alternatives include part type *h*, ranging from 1 to 9.

I: set of the customer segment types, where $i \in I$. The alternatives include: (1) Personal customer (CS1) and (2) Business Customer (CS2).

J: set of value proposition types, where $j \in J$. The alternatives include: (1) Premium taste and appearance (VP1), (2) Premium taste and fresh appearance (VP2), and (3) Premium taste and simple appearance (VP3).

K: set of channel types, where $k \in K$. The alternatives include: (1) Marketplace (CH1) and (2) Direct Selling (CH2).

L: set of customer relationship types, where $l \in L$. The alternatives include: (1) Self-service (CR1) and (2) Personal Assistance (CR2).

M: set of product architecture types, where $m \in M$. The alternatives include: (1) Product Architecture 1, (2) Product Architecture 2, and (3) Product Architecture 2).

N: set of production strategy types, where $n \in N$. The alternatives include: (1) in-house main component production, (2) subcontract main component production.

2.3.2 Parameters And Variables

CHC : the total channel cost

$CHCP_k^{XC}$: the channel cost per year for decision channel type *k.*

CRC : the total customer relationship cost.

HEW : the hourly employee wage.

LCMC : the total labour cost for the main component.

LCPC : the total labour cost for the packaging component.
LR_{l}^{XD} : the labour requirement per month for customer relationship type *l*.
$LRMC_{m,g}^{XE}$: the labour requirement per batch for processing the main component of product architecture type *m* with part type *g*.
$LRPC_{m,h}^{XE}$: the labour requirement per batch for processing the packaging component of product architecture type *m* with part type *h*.
MCMC : the total material cost per batch for the main component.
$MCMC_{m,g}^{XE}$: the material cost per batch for main component of product architecture type *m* with part type *g*.
MCPC : the total material cost per batch for the packaging component.
$MCPC_{m,h}^{XE}$: the material cost per batch for the packaging component of product architecture type *m* with part type *h*.
MEW : the monthly employee wage.
MHCMC : the total machine hour cost for processing main components.
$MHCMC_{m,g}^{XE}$: the machine hour cost for the processing main component of product architecture type *m* with part type *g*.
MHCPC : the total machine-hour cost for the processing packaging components.
$MHCPC_{m,h}^{XE}$: the machine our cost for processing the packaging component of product architecture type *m* with part type *h*.
$MHRMC_{m,g}^{XE}$: the machine hour requirement per batch for processing the main component of product architecture type *m* with part type *g*.
$MHRPC_{m,h}^{XE}$: the machine hour requirement per batch for processing the packaging component of product architecture type *m* with part type *h*.
$MIPT_{n}^{Xm}$: the processing-time multiplier index for main component of product architecture type *m* with production strategy type *n*.
$MIPTC_{n}^{Xm}$: the processing-time-cost multiplier index for the main component of product architecture type *m* with production strategy type *n*.
$MRMC_{m,g}^{XE}$: the material requirement per batch for the main component of product architecture type *m* with part type *g*.
$MRPC_{m,h}^{XE}$: the material requirement per batch for the packaging component of product architecture type *m* with part type *h*.
NBR : the number of batches required.
P : the price per unit product.
PT_{k}^{XC} : the estimated percentage of total sales sold for decision channel type *k*.
$PTMC_{m,g}^{XE}$: the processing time per batch for the main component of product architecture type *m* with part type *g*.
$PTPC_{m,h}^{XE}$: the processing time per batch for the packaging component of product architecture type *m* with part type *h*.
Q : the demand per month.
R : the total revenue.
S : the number of units product in one batch.
SP_{k}^{XC} : the percentage selling price from normal price for decision channel type *k*.
T : the number of months.

Decision Variables

$$X_i^A = \begin{cases} 1, & \text{if customer segment type } i \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

$$X_j^B = \begin{cases} 1, & \text{if value proposition type } j \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

$$X_k^C = \begin{cases} 1, & \text{if channel type } k \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

$$X_l^D = \begin{cases} 1, & \text{if customer relationship type } l \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

$$X_m^E = \begin{cases} 1, & \text{if product architecture type } m \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

$$X_n^m = \begin{cases} 1, & \text{if product architecture type } m \text{ with main component production strategy type } n \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

2.3.3 Variables Formulation

Revenue, represented by Equation (1), is calculated as the product of monthly demand, number of months and price. The selected channel decision influences demand and price. Demand is adjusted based on the estimated percentage of total sales for a particular channel, while the price is adjusted based on the percentage of selling price according to the selected channel.

$$R = Q.T.P.\sum_{k=1}^{K} PT_k^{XC}.SP_k^{XC}.X_k^C \tag{1}$$

Equation (2) represents the number of batches required, which is the multiplication of demand by the period and then divided by the number of units in a batch. This value is adjusted by the percentage of total sales based on the selected channel.

$$NBR = \frac{Q.T}{S}.\left(\sum_{k=1}^{K} PT_k^{XC}.X_k^C\right) \tag{2}$$

Equation (3) and Equation (4) represent the material cost for the main and packaging components, respectively. The material cost per batch is the multiplication of the required material and the cost according to the selected product architecture.

$$MCMC = \left(\sum_{m=1}^{M}\sum_{g=1}^{G} MRMC_{m,g}^{XE}.MCBMC_{m,g}^{XE}.X_m^E\right) \tag{3}$$

$$MCPC = \left(\sum_{m=1}^{M}\sum_{h=1}^{H} MRPC_{m,h}^{XE}.MCBPC_{m,h}^{XE}.X_m^E\right) \tag{4}$$

Equations (5) and (6) determine the labour cost per batch for the main and packaging components. The labour cost per batch is the multiplication of labour requirements and processing time based on the selected product architecture and hourly employee wage. For the main component, labour cost considers the multiplier index for time and cost based on the selected main component production strategy.

$$LCMC = \left(\sum_{n=1}^{N}\sum_{m=1}^{M} MIPT_n^{Xm}.MIPTC_n^{Xm}.X_n^m\right).\left(\sum_{m=1}^{M}\sum_{g=1}^{G} LRMC_{m,g}^{XE}.PTMC_{m,g}^{XE}.X_m^E\right).HEW \quad (5)$$

$$LCPC = \left(\sum_{m=1}^{M}\sum_{h=1}^{H} LRPC_{m,h}^{XE}.PTPC_{m,h}^{XE}.X_m^E\right).HEW \quad (6)$$

Equations (7)and (8) calculate the machining cost per batch for the main and packaging components, respectively. The machining cost per batch is calculated by multiplying the machining time requirements according to the selected product architecture and the machining cost for each machine used. The machining cost considers the multiplier index for time and cost for the main component based on the selected main component production strategy.

$$MHCMC = \left(\sum_{n=1}^{N}\sum_{m=1}^{M} MIPT_n^{Xm}.MIPTC_n^{Xm}.X_n^m\right).\left(\sum_{m=1}^{M}\sum_{g=1}^{G} MHRMC_{m,g}^{XE}.MHCMC_{m,g}^{XE}.X_m^E\right) \quad (7)$$

$$MHCPC = \left(\sum_{m=1}^{M}\sum_{h=1}^{H} MHRPC_{m,h}^{XE}.MHCPC_{m,h}^{XE}.X_m^E\right) \quad (8)$$

Equation (9) explains the channel cost based on the selected channel. The channel cost is calculated by multiplying the number of years with the cost per year according to the selected channel.

$$CHC = \frac{T}{12}.\sum_{k=1}^{K} CHCP_k^{XC}.X_k^C \quad (9)$$

Equation (10) is the customer relationship cost, which considers the number of workers required according to the selected customer relationship and the number of months.

$$CRC = T.MEW\sum_{l=1}^{L} LR_l^{XD}.X_l^D \quad (10)$$

2.3.4 Objective Function Formulation

Operating income is a reduction from revenue due to material costs, processing costs, and Marketing costs. Material and processing costs are the needs for both material and processing costs of the main and packaging components according to the number of batches produced. Meanwhile, marketing cost is the sum of channel and customer relationship costs. The formula for each element of the financial objective function can be seen in Figure 1.

2.3.5 Constraint Formulation

Constraint classification 1 (Equation(11)-(16)) limits only one option to be selected for each decision within the same variable decision category.

$$\sum_{i=1}^{I} X_i^A = 1 \quad (11)$$

$$\sum_{j=1}^{J} X_j^B = 1 \quad (12)$$

$$\sum_{k=1}^{K} X_k^C = 1 \quad (13)$$

$$\sum_{l=1}^{L} X_l^D = 1 \quad (14)$$

$$\sum_{m=1}^{M} X_m^E = 1 \quad (15)$$

$$\sum_{n=1}^{N}\sum_{m=1}^{M} X_n^m = 1 \quad (16)$$

Constraint classification 2 represents the compatibility between customer relationship and value proposition. Equation (17) indicates that customer relationship type 1 is only for value proposition type 1 or 2, while Equation (18) describes customer relationship type 2 for value proposition type 3.

$$X_1^A \le X_1^B + X_2^B \quad (17)$$

$$X_2^A \le X_3^B \quad (18)$$

Constraint classification 3 represents the compatibility between customer relationships and channels. Equation (19) explains that customer relationship type 1 is exclusive to channel type 1, while Equation (20) explains that customer relationship type 2 is exclusive to channel type 2.

$$X_1^A \le X_1^C \quad (19)$$

$$X_2^A \le X_2^C \quad (20)$$

Constraint classification 4 represents the compatibility between value proposition and product architecture. Equation (21) explains that value proposition type 1 is exclusive to product architecture type 1, Equation (22) explains that value proposition type 2 is exclusive to product architecture type 2, and Equation (23) explains that value proposition type 3 is exclusive to product architecture type 3.

$$X_1^B \le X_1^E \quad (21)$$

$$X_2^B \le X_2^E \quad (22)$$

$$X_3^B \le X_3^E \quad (23)$$

Constraint classification 5 represents the compatibility between channels and customer relationships. Channel type 1 is only for customer relationship type 1, according to Equation (24), and channel type 2 is only for customer relationship type 2, according to Equation (25).

$$X_1^C \le X_1^D \quad (24)$$

$$X_2^C \le X_2^D \quad (25)$$

Constraint classification six states that only one the main component strategy is selected from one selected product architecture, as stated in Equation (26).

$$X_m^E \leq \sum_{n=1}^{N} X_n^m \quad \text{for } m = 1,2,3. \tag{26}$$

Constraint classification seven specifies that the decision variable can only be 0 or 1, as indicated in Equation (27).

$$X_i^A, X_j^B, X_k^C, X_l^D, X_m^E, X_n^m \in \{0,1\} \quad \forall\, i,j,k,l,m,n \tag{27}$$

3.0 RESULTS AND DISCUSSION

This subsection discusses the result, sensitivity analysis, limitations, and implications. The results consist of optimal configuration, performance, and a Gantt chart of packaging component development. Sensitivity analysis aims to see how the optimal configuration varies in response to changes in several parameters. The limitation discusses the boundary of research addressed in this study, while the implication highlights the contribution of this research.

3.1 Optimal Decision Making

Table 7 displays the result from the optimisation model, and Table 8 shows the decision performance. Figure 2 compares the revenue and cost elements, and Figure 3 shows a Gantt plan for packaging component development.

The optimal solution configuration is personal customer—premium taste and fresh appearance—marketplace—self-service-product architecture 2— the main component is processed by subcontract. The component-supplier and component-process configurations result from the selected product architecture, type 2. The ratio of operating income to revenue is 44.93%, indicating that this configuration is promising. This optimal choice requires 6 days of packaging component development time.

Table 7 Business-product-process-supply chain decision

Aspects	Decisions
Customer Segments	Personal Customer
Value propositions	Premium taste and fresh appearance (VP2)
Channel	Marketplace
Customer Relationships	Self-service
Product Architecture	Product Architecture 2
Main component production strategy	sub-contract
Part-Supplier for main component	Ingredient A-Supplier MC1; Ingredient B-Supplier MC2; Ingredient C-Supplier MC2; Ingredient D-Supplier MC2; Ingredient E-Supplier MC2; Ingredient F-Supplier MC3; Ingredient G-Supplier MC4; Ingredient H-Supplier MC2
Part -Supplier for packaging Component	ComPack1-Supplier PC2; ComPack2-Supplier PC1; ComPack3-Supplier PC3; ComPack4-Supplier PC3; ComPack5-Supplier PC5; ComPack6-Supplier PC4; ComPack7-Supplier PC1; ComPack8-Supplier PC6
Process-Machine for Main Component	Prod Proc 1-*; Prod Proc 2-*; Prod Proc 3-Machine A; Prod Proc 4-Machine B
Process-Machine for Packaging component	AssProc1-*; AssProc2-Machine C; AssProc3-*; AssProc11-*; AssProc12-*; AssProc13-*; AssProc7-*; AssProc8-Machine E; AssProc9-Machine F; AssProc10-*

Table 8 Performances of the decision

Aspects	Performances
Operating Income (in Million Rupiahs)	53.27
Total Processing Time (hours)	325.30
Packaging Development Time (days)	6.00
Main component processing Time (hours)	175.54
Packaging Processing Time (hours)	149.76

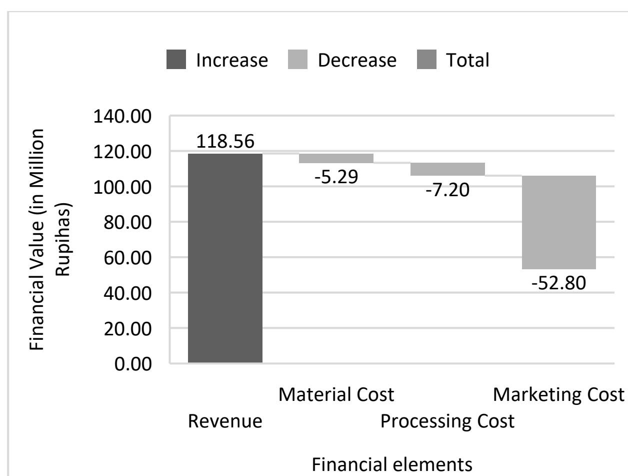


Figure 2 Waterfall chart of financial performance for the decision.

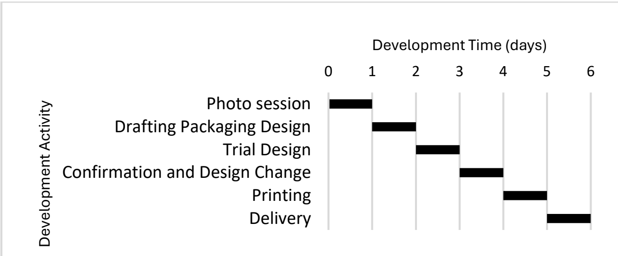


Figure 3 The result of development activity Gantt chart.

3.2 Sensitivity Analysis

Determining the Business model canvas requires various tests of several assumptions to provide a comprehensive understanding of the results obtained [20]. Sensitivity testing aims to examine different conditions to assess the solution results. This study conducted a sensitivity analysis of several parameters' changes, including monthly demand, the estimated percentage of total sales for Marketplace, the estimated percentage of total sales for direct selling, the multiplier index for time processing (subcontract production strategy), and the multiplier index for time processing (subcontract production strategy). Changes are only made to one parameter, while the unchanged parameters use the data in the initial condition (base scenario).

3.2.1 Change In The Monthly Demand

Changes were made to the monthly demand parameter, expressed in thousands of units, by incrementing the range from 0.05 to 0.4 by 0.05. Figure 4 illustrates the change in operating income based on the value of demand per month. This parameter change shows that operating income forms a linear pattern with a positive gradient. Negative operating income values are found at monthly demand values below 0.1.

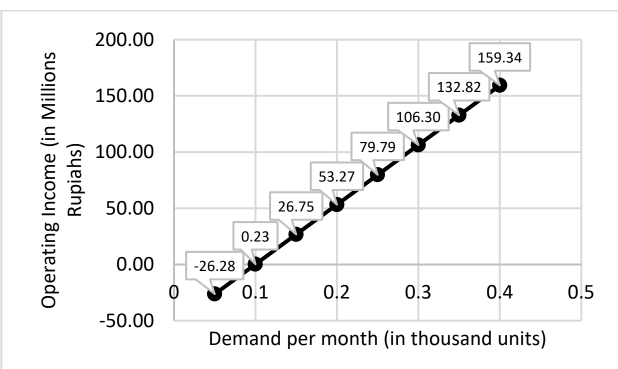


Figure 4 Operating income performance for different monthly demand.

3.2.2 Change In The Estimated Percentage Of Total Sales For Marketplace.

Changes were made to the estimated percentage of total sales for Marketplace by increasing the range from 40% to 120% by 10%. The estimated percentage of total sales for the marketplace parameter that deviates from the optimal results in the base scenario occurs when the value is at or below 50%, yielding the same operating income. As for values above 50%, the optimal configuration does not change but the optimal operating income increases.

Table 9 shows the optimal configuration decision at a parameter value of 50%, Table 10 shows the performance of the selected optimal decision, and Figure 5 shows the Gantt chart of packaging component development activities for product architecture 3. The optimal configuration is business customer—premium taste and simple appearance—direct selling—personal assistance—product architecture 3— the main component is processed by subcontract. This decision requires 14 days of packaging component development time.

3.2.3 Change In The Estimated Percentage Of Total Sales For Direct Selling

Changes were made to the estimated percentage of total sales for direct selling by incrementing the range from 50% to 140% by 10%. From value 50% to 120%, the optimal configurations are like those provided in Table 7, and the operating income is equal to the optimised result in the base scenario. From the value at 130% to 140%, the optimal configurations are like those provided in Table 9, and the operating income is greater than the optimised result in the base Scenario.

3.2.4 Change In The Multiplier Index For Processing Time (Subcontract Production Strategy)

Changes were made to the multiplier index for processing time (subcontract production strategy) by increasing the range from 65% to 90% by 5%. For the value at 65% to 75%, the optimised decision results are like those provided in Table 7, and operating incomes are higher than the optimised result in the base Scenario. For the value at 85 to 90%, optimised decision results are like those provided in Table 7, except that the main component strategy is in-house production was selected, and operating incomes are less than the optimised result in the base scenario.

Table 9 The decision for the estimated percentage of total sales for marketplace at 50%

Aspects	Decisions
Customer Segments	Business Customer
Value propositions	Premium taste and simple appearance (VP3)
Channel	Direct Selling
Customer Relationships	Personal Assistance
Product Architecture	Product Architecture 3
Main component production strategy	sub-contract
Part-Supplier for main component	Ingredient A-Supplier MC1; Ingredient B-Supplier MC2; Ingredient C-Supplier MC2; Ingredient D-Supplier MC2; Ingredient E-Supplier MC2; Ingredient F-Supplier MC3; Ingredient G-Supplier MC4; Ingredient H-Supplier MC2
Part -Supplier for packaging Component	ComPack3-Supplier PC3; ComPack5-Supplier PC5; ComPack9-Supplier PC1
Process-Machine for Main Component	Prod Proc 1-*; Prod Proc 2-*; Prod Proc 3- Machine A; Prod Proc 4-Machine B
Process-Machine for Packaging component	AssProc14-*; AssProc2-Machine C; AssProc3-*; AssProc15-*; AssProc5-Machine D; AssProc10-*

Table 10 The result performance for the estimated percentage of total sales for marketplace at 50%

Aspects	Performances
Operating Income (in Million Rupiahs)	21.65
Total Processing Time (hours)	342.63
Packaging Development Time (days)	14.00
Main component processing Time (hours)	219.43
Packaging Processing Time (hours)	123.20

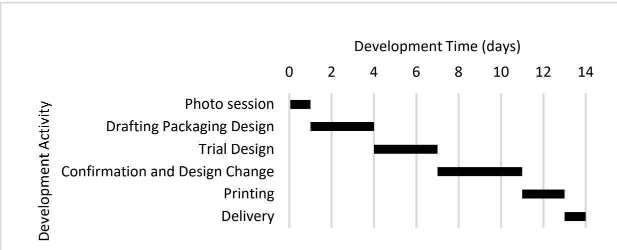


Figure 5 Gantt chart of packaging component development activities for product architecture 3.

3.2.5 Change In The Multiplier Index For Processing Cost (Subcontract Production Strategy)

Changes were made to the multiplier index for processing cost (subcontract production strategy*)* by increasing the range from 50% to 140% by 10%. For the value at 50% to 110%, the optimised decision results are like those provided in Table 7, and operating incomes are higher than the optimised result in the base Scenario. For the value at 130 to 140%, optimised decision results are like those provided in Table 7, except that the main component strategy is in-house production was selected, and operating incomes are less than the optimised result in the base scenario.

3.3 Limitations

The model was developed based on the real-world case, so it would require customisation for a different case. The study estimates parameters related to product data using historical data from equivalent products. Meanwhile, some parameters are estimated based on rational value. This study uses sensitivity analysis to represent multiple conditions that affect the optimised decision.

3.4 Implications

This study demonstrates the improvement in decision comprehensiveness and design speed in the product design process. These advantages result from the following: i. the decision-maker may initiate from any aspect of the frameworks so that the idea of a decision-maker can become the basis for development and trigger the development of other decision-makers to produce alternative decisions; ii. the model provides quantitative analysis as a basis for objective decision-making; iii. the framework obtains the optimal configurations concurrently, so iterative decision-making is unnecessary.

4.0 CONCLUSION

This study proposed a model for determining optimal concurrent business-product-process-supply chain design. The proposed model improves Three-dimensional concurrent engineering (3DCE) by integrating the essential business aspects from Business Model Canvas (BMC), resulting in an optimal solution that concurrently configures business-product-process-supply chain configurations. The objective function and constraint equation cover the relationship between decisions. This optimisation model eliminates the requirement for an iterative solution search.

The search for the best solution and the subsequent sensitivity analysis revealed that the optimal configuration is insensitive to small parameter variations. First, the system remains profitable up to a 25% decline in monthly demand compared to the real-world case. Second, relative to the real-world case, the strategy of selling through the marketplace remains valid up to a 37.5% decrease in marketplace sales or a 30% increase in direct selling. Third, the subcontracting strategy remains optimal provided that increases in the processing-time and processing-cost multipliers remain within 5% and 8.3%, respectively, relative to the real-world case.

The application or real-world case also demonstrated that the decision-maker may initiate from any part of the aspect. The initiation idea can become the basis for developing alternative decisions from other aspects. In addition, it also guides decision-making toward generating alternatives that are compatible with other stakeholders Furthermore, model users can adjust the objective and constraint function equations to use the model for different cases.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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