Available online at: http://e-jurnal.lppmunsera.org/index.php/INTECH

Jurnal INTECH Teknik Industri Universitas Serang Raya

ISSN (Print) 2407-781X ISSN (Online) 2655-2655

Optimization of Multi-Product Production Combination Based on Integer Linear Programming in Garment SMEs to Minimize Production Costs

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ARTICLE INFORMATION

Article history:

Received: March 27, 2026
Revised: June 11, 2026
Accepted: June 18, 2026

Keywords

Integer Linear Programming
Minimize Production Cost
Operations Research
Optimization
Production Planning

ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) in the garment sector frequently face production planning challenges arising from demand fluctuations, limited raw materials, capacity constraints, and inadequate inventory management, which ultimately increase operational costs. This study proposes an integrated forecasting–optimization framework combining single exponential smoothing (SES) and integer linear programming (ILP) to determine the optimal multi-product production combination that minimizes total production and inventory costs in a garment MSME in Jiddah. Historical production data of five products over 12 periods were used to forecast demand, which subsequently served as input for the optimization model. The model was solved using LINGO 21 under three scenarios: (1) considering safety stock and capacity constraints, (2) excluding safety stock, and (3) excluding production capacity constraints. The forecasting results produced an average mean absolute percentage error (MAPE) of 5.79%, indicating highly accurate demand estimates. The optimization results showed that Model 2 generated the lowest total cost of IDR 277,755,500 with a production quantity of 8,157 units and no ending inventory. However, Model 1 was identified as the most appropriate scenario for implementation because it maintained a safety stock of 200 units per product while satisfying production and raw material constraints, resulting in a total production of 9,157 units and a total cost of IDR 312,878,500. Furthermore, Model 3 produced the same solution as Model 1, indicating that production capacity was not a binding constraint under the existing operating conditions. Sensitivity analysis confirmed that the safety stock is a critical factor influencing production decisions, inventory levels, and total costs. Theoretically, this study extends conventional ILP applications by integrating demand forecasting and inventory policy considerations into a single decision-making framework for data-limited MSMEs. Managerially, the proposed model provides practical decision support for balancing cost efficiency and inventory security in multi-product production planning.

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1. INTRODUCTION

Micro, Small, and Medium Enterprises (MSMEs) play a strategic role in the Indonesian economy, driving local economic growth. In particular, MSMEs in the garment sector face business competition and continue to struggle to manage production costs (Widyarti et al, 2025). MSMEs in the garment sector also face various challenges, namely fluctuations in raw material prices, market demand, increased operational costs, and limited production capacity (Alam et al, 2024; R. S. Wahyuni et al, 2025; Mardiningsih & Niaga, 2025). Errors in estimating raw materials can result in waste of inventory cost and increased production costs (R. Wahyuni et al, 2025). Failure to meet demand in a timely manner can result in lost sales opportunities, while overproduction can also increase storage costs and the risk of losses (Lesmana et al, 2025). To reduce production costs and meet market demand, a mathematical model-based optimization technique is required to overcome these obstacles (Oktavia et al, 2024).

Optimization is a mathematical approach aimed at obtaining the best solution while considering various constraints (Tunçel, 2024). Various optimization techniques, including Linear Programming (LP), Integer Linear Programming (ILP), and Mixed Integer Linear Programming (MILP), have been widely applied to improve operational efficiency, optimize resource utilization, and reduce costs across different industrial sectors (Lindahl et al, 2023). In production and supply chain systems, optimization approaches have been used to minimize production costs in hybrid flow-shop scheduling environments (Ullah et al, 2025), improve operational efficiency in supply chain networks through MILP models (Li et al, 2024), determine optimal production combinations for profit maximization (Ismail & Laela, 2024), perform machine scheduling while considering carbon emission reduction (Kucukkoc, 2024), and minimize transportation costs in manufacturing industries (Tannady et al, 2025).

Linear programming has become one of the most widely used optimization approaches for determining optimal resource allocation under limited capacity conditions (N & Jandhayala, 2023; Todorova et al,

2026). Previous studies have successfully applied linear programming and Integer Linear Programming to determine optimal material combinations, improve resource efficiency, and maximize organizational performance (Hamidah et al, 2026; Rosi et al, 2025; Yusnita & Utomo, 2024). Although these studies demonstrate the effectiveness of optimization techniques in improving decision-making quality, most assume that demand information is already known with certainty and that production-related data are readily available. Such assumptions may not adequately represent the operational conditions of MSMEs, which commonly experience demand uncertainty, limited historical records, and less structured production planning systems.

Optimization approaches have been extensively applied in the garment and apparel industry to support production planning, improve resource utilization, and reduce operational costs. Previous studies have shown that MILP can minimize total production costs by considering inventory and setup costs in garment manufacturing (Al-Mahmud et al, 2025), while optimization models have also been used to improve operational efficiency, workload balancing, and resource utilization in garment production lines (Kong et al, 2025). Other studies developed optimization models to determine the optimal number of inspectors based on inspection costs and volumes (Ahmad & Kamruzzaman, 2025), improve resource utilization in apparel factories (Abeje et al, 2025), determine optimal production combinations in sewing businesses (Hutauruk et al, 2023), and minimize makespan in garment production systems (Ky Phuc et al, 2024). However, most of these studies focused on medium- and large-scale garment manufacturers with relatively mature production planning systems and comprehensive operational databases. Consequently, their findings may not be directly applicable to garment MSMEs that operate under limited data availability, fluctuating demand, and resource constraints.

MSMEs in the garment sector are highly sensitive to changes in production costs and market demand dynamics. Cost minimization is essential for maintaining business sustainability because MSMEs generally operate with limited capital and relatively small profit margins. Any increase in production costs can directly reduce profitability. Furthermore, production cost management is closely related to inventory management. Poor production planning may result in excessive inventory levels, increasing storage costs, and reducing operational efficiency. Therefore, production planning decisions that simultaneously consider production and inventory costs are crucial for improving operational performance and ensuring the sustainability of garment MSMEs.

Another challenge commonly faced by garment MSMEs is the absence of systematic demand recording practices. Production decisions are often based on managerial experience rather than quantitative demand analysis, leading to mismatches between production quantities and actual market requirements. As documented demand data are frequently unavailable, forecasting techniques based on historical production data become essential for estimating future demand. Various forecasting methods have been developed, including moving averages, exponential smoothing, ARIMA, and machine-learning-based approaches. However, advanced forecasting methods generally require larger datasets, more complex parameter estimation procedures, and sufficient historical observations to capture trends and seasonal patterns. In contrast, MSMEs often possess limited historical records and short planning horizons. Therefore, single exponential smoothing (SES) was selected because of its simplicity, low computational requirements, and suitability for short-term demand forecasting under limited data conditions. The forecasting results can subsequently be utilized as input parameters in production optimization models, enabling more data-driven production planning decisions.

Based on the literature review, several research gaps have been identified. First, most optimization studies assume that demand information is readily available and is accurately documented. Second, previous optimization studies in the garment sector primarily focused on medium- and large-scale manufacturers, rather than MSMEs. Third, forecasting and production optimization are often treated as separate decision-making problems, leading to production plans that do not adequately reflect the actual demand conditions. Furthermore, studies integrating demand forecasting and Integer Linear Programming for multi-product garment MSMEs operating under limited demand information remain relatively scarce.

Unlike previous studies that generally assume that demand information is readily available and focus on medium- or large-scale manufacturing systems, this study proposes an integrated forecasting–optimization framework that combines single exponential smoothing (SES) and integer linear programming (ILP) for multi-product garment MSMEs operating under limited demand information. Furthermore, this study evaluates the impact of safety stock policies and production capacity constraints through scenario-based optimization and sensitivity analysis. This integrated approach constitutes the main novelty and scientific contribution of this study. Therefore, this study aims to develop an integrated forecasting–optimization model capable of minimizing total production and inventory costs while providing practical decision support for garment MSMEs.

2. RESEARCH METHODS

This study was conducted on MSMEs in Jiddah, specifically in the garment sector producing Daster. This study focuses on determining the optimal production quantity for five product types while accounting for production capacity, production costs, and inventory costs. The main problems faced by SMEs in Jiddah include uncertain production volumes, limited availability of raw materials, and fluctuating market demand. Therefore, an optimization approach is required to determine the optimal production quantities to minimize production costs.

Optimization is a method for determining the best alternative selection by considering various constraints and limitations (Devani et al, 2020). This optimization research uses integer linear programming. Linear

http://dx.doi.org/10.30656/intech.v12i1.11981

programming is a mathematical method that can help determine the optimal allocation of a company's limited resources (Oladejo et al, 2019). Integer Linear Programming (ILP) is an optimization method in which the objective function and all constraints are linear, and all values are integers (Scavuzzo et al, 2024).

Optimization using integer linear programming (ILP) is needed to determine the production quantity combination that minimizes production costs based on the problems faced by MSMEs in Jiddah. Before performing optimization, a model assumption is needed that accounts for various constraints in the actual conditions of MSMEs. The following are the model assumptions that will be used in the data processing:

1) Production planning is carried out for the next period and covers five products manufactured by MSMEs in Jiddah.
2) All parameters, such as demand, production cost per unit, inventory cost per unit, production capacity per period, fabric capacity per period, fabric requirements per unit for each product, safety stock, and product stock quantities, are known with certainty and do not change during the planning period.
3) Product demand is obtained using forecasting methods based on historical production data.
4) The relationship between the decision variables and parameters is linear; therefore, changes in the production volume are directly proportional to changes in production costs.
5) The production quantity of each product in each period is a decision variable and can only be an integer and a non-negative value.
6) The inventory of each product follows the inventory balance equation, whereby the ending inventory for the period is obtained from the beginning inventory plus production minus the demand for that period.
7) All demand in each period must be fulfilled, and inventory shortages are not allowed.
8) The safety stock is set as the minimum inventory limit that must be maintained at the end of each period.
9) The production capacity and fabric availability capacity are the maximum limits of resource usage that cannot be exceeded in each period.
10) All products use the same production resources and raw materials, so that the production capacity and fabric capacity are limited and shared by all five products.
11) Production and storage costs per unit of product are considered constant and are not affected by the amount of production.

After the model assumptions were established, three mathematical model scenarios were developed within the integer linear programming (ILP) framework to analyze the effects of production policies on total costs. The model scenarios used in this study are as follows:

1) Model 1: Minimization of total production and inventory costs by considering production capacity constraints, raw material (fabric) capacity, and the application of safety stocks.
2) Model 2: Minimization of total production and inventory costs by considering production capacity and raw material capacity constraints, but without the application of safety stocks.
3) Model 3: Minimization of total production and inventory costs by considering safety stock but without production capacity constraints.

Three model scenarios were developed to systematically test the impact of operational policies on total production costs. The first model represents realistic conditions by considering all constraints and safety stock as a basis for comparison. The second and third models were developed to analyze separately the impacts of safety stock and production capacity constraints on optimal production decisions. A comparison of these three models enables the identification of the most significant factors affecting the cost structure and provides recommendations for more efficient production policies for MSMEs.

The data used in this study were obtained through observation and documentation of MSMEs. The data include historical production data for demand forecasting, production costs per unit, storage costs per unit per period, production capacity per period, raw material (fabric) availability, fabric requirements per unit, initial inventory for each product, and safety stock value. Demand in the planning period was determined using forecasts from the single exponential smoothing method based on available historical data. The planning horizon was set for the next period to describe short-term production planning.

Demand forecasting was performed using the single exponential smoothing (SES) method. Various forecasting techniques, including moving average, Holt's exponential smoothing, ARIMA, and machine-learning-based approaches, have been developed to estimate future demand. However, the suitability of a forecasting method depends on the characteristics of the available data and forecasting objective. The objective of this study was to generate short-term demand estimates that serve as input parameters for production planning optimization. The historical data available for this study consisted of only 12 observation periods, which is relatively limited for the application of more advanced forecasting methods. Furthermore, preliminary examination of the historical demand data indicated no strong trend or seasonal pattern. According to forecasting theory, Single Exponential Smoothing is particularly appropriate for stationary demand data that fluctuate around a relatively constant mean without significant trend or seasonality (Hyndman & Athanasopoulos, 2021). Compared with methods such as Holt's exponential smoothing, which is designed for trend data, or ARIMA and machine-learning-based models, which generally require larger datasets and more complex parameter estimation, SES provides a more suitable and reliable approach for short-term forecasting under limited-data conditions. Therefore, SES was selected as the forecasting method in this study.

The optimization model was developed using the integer linear programming (ILP) approach to minimize the total production and inventory costs over three planning periods.

Index

$I = 1, 2, \dots, 5$

Parameters
D_i= Demand for product *i*
C_i = Production cost per unit of product *i*
H_i = Inventory cost per unit of product *i* per period
a_i = Raw material requirements per unit of product *i*
K = Maximum production capacity
Fabric = Maximum raw material availability capacity
I_{i0} = Initial inventory of product *i*
SS_i = Minimum safety stock product *i*

Objective Function

$$\text{Min } Z = \sum_{i=1}^{5} C_i X_i + \sum_{i=1}^{5} H_i I_i \quad (1)$$

Constraints

1. Model 1
   a. Inventory Balance
   $$I_{i1} = I_{i0} + X_{i1} - D_{i1} \quad (2)$$
   b. Demand fulfillment with safety stock
   $$I_{i0} + X_{i1} \geq +D_{i1} + SS_i \quad (3)$$
   c. Production capacity
   $$\sum X_i \leq K \quad (4)$$
   d. Raw material capacity
   $$\sum a_i X_i \leq Fabric \quad (5)$$
   e. Integer and non-negative
   $$X_i, I_i \in \mathbb{Z} \geq 0 \quad (6)$$
2. Model 2
   a. Inventory Balance
   $$I_{i1} = I_{i0} + X_{i1} - D_{i1} \quad (7)$$
   b. Demand fulfillment without safety stock
   $$I_{i0} + X_{i1} \geq +D_{i1} \quad (8)$$
   c. Production capacity
   $$\sum X_i \leq K \quad (9)$$
   d. Raw material capacity
   $$\sum a_i X_i \leq Fabric \quad (10)$$
   e. Integer and non-negative
   $$X_i, I_i \in \mathbb{Z} \geq 0 \quad (11)$$
3. Model 3
   a. Inventory Balance
   $$I_{i1} = I_{i0} + X_{i1} - D_{i1} \quad (12)$$
   b. Demand fulfillment with safety stock
   $$I_{i0} + X_{i1} \geq +D_{i1} + SS_i \quad (13)$$
   c. Integer and non-negative
   $$X_i, I_i \in \mathbb{Z} \geq 0 \quad (14)$$

In performing optimization using Integer Linear Programming, this research was carried out through several systematic stages, as follows:

1) Problem identification, which involves examining production planning issues in garment MSMEs.
2) Data collection included historical production data, production costs per unit, storage costs per unit, production capacity, fabric availability capacity, fabric requirements, initial stock levels, and safety values.
3) Demand forecasting was carried out using the single exponential smoothing (SES) method based on historical production data to obtain demand estimates for the planning period.
4) Model assumption formulation, which is adjusted to the actual conditions of MSMEs and uses parameters from previously collected data.
5) Formulation of a mathematical model by setting an objective function in the form of minimizing total production costs and constraints in accordance with the real conditions of MSMEs
6) The model was implemented using LINGO 21 software to obtain the optimal solution in the form of the production quantity of each product and the minimum total cost.
7) Computational experiments were conducted using the following three models:
   a. Model 1: Minimization of production costs by considering production capacity and the application of safety stocks.
   b. Model 2: Minimization of production costs by considering production capacity but without the application of a safety stock.
   c. Model 3: Minimization of production and inventory costs by considering the implementation of safety stock but without production capacity constraints.
8) The optimization results were analyzed by comparing the total production costs and optimal production quantities in each scenario to determine the effects of production capacity and safety stock policies on the cost structure and production decisions.

3. RESULTS AND DISCUSSION

This study used actual data from a Jiddah MSME that produced five different types of products. This study used historical production data for five products over 12 periods (weeks). Table 1 presents historical data for 12 periods across the five products.

Table 1. Historical production data for 12 periods

Period	Product 1	Product 2	Product 3	Product 4	Product 5
1	1798	1997	2189	1796	1595
2	1799	1999	2076	1600	1799
3	2000	2100	2194	1396	1800
4	1800	1950	1994	1700	2000
5	1822	1900	2100	1600	1500
6	2002	2077	2099	1600	1580
7	1802	1998	2199	1900	1596
8	1800	1979	2100	1800	1680
9	1778	2050	1998	1540	1700
10	1800	2000	1999	1500	1900
11	1599	1999	2000	1480	1800
12	1998	1998	2100	1598	1798

3.1. Forecasting Results

Table 1 shows data indicating fluctuations in production quantities across periods, reflecting variations in market demand and production decisions. Product 3 consistently recorded the highest production volume, while Product 4 generally recorded the lowest. These fluctuations demonstrate the need for a forecasting method that can estimate future demand more accurately to support production planning decisions. This study uses historical production data for five products over 12 periods (weeks) to forecast demand using the single exponential smoothing (SES) method, with the forecasts informing decisions for the next production period.

http://dx.doi.org/10.30656/intech.v12i1.11981

Table 2. Result demand forecast for 5 product

Variable	Product 1	Product 2	Product 3	Product 4	Product 5
Forecast	1850	2001	2057	1563	1796
Alpha	0.5	0.5	0.5	0.5	0.5
Bias	9.321	0.799	-23.917	-42.222	36.493
MAD	111.799	51.729	75.28	144.518	130.845
MSE	20783.9	4654.9	7866.9	30718.9	29714.2
Standard Error	159.382	75.427	98.057	193.766	190.571
MAPE	6.01%	2.57%	3.65%	9.10%	7.60%

Table 3. Initial inventory, cost, and fabric requirements

Product	Initial Inventory (Pcs)	Production Cost (Rp/Pcs)	Inventory Cost (Rp/pcs)	Fabric (cm/ pcs)
1	40	33,500	1,005	216
2	150	33,500	1,005	216
3	120	34,500	1,035	230
4	450	34,500	1,035	230
5	350	34,500	1,035	230

Demand forecasting used single exponential smoothing (SES) with α = 0.5. SES is suitable for short-term forecasting with limited data and yields stable demand estimates for the optimization model. Forecasted demands are: 1,850 units, 2,001 units, 2,057 units, 1,563 units, and 1,796 units.

The model's performance was evaluated using Bias, Mean Absolute Deviation (MAD), Mean Squared Error (MSE), Standard Error, and Mean Absolute Percentage Error (MAPE). The MAPE values obtained were 6.01%, 2.57%, 3.65%, 9.10%, and 7.60%, with an average of 5.79%. Based on (Lewis, 1982) classification, all MAPE values were below 10%, indicating highly accurate forecasting. Additionally, the relatively small bias values (-42.222 to 36.493 units) indicate that the model does not exhibit a significant tendency to over- or underforecast.

The results indicate that the SES method produces accurate and consistent demand estimates, making it suitable as a demand parameter in an integer linear programming (ILP) model to determine the optimal production combination and minimize total production and inventory costs.

Jiddah SMEs have a maximum raw material capacity of 2,500,000 cm/week and a maximum production capacity of 10,000 pcs/week, respectively. There is also a safety stock of 200 pcs/week for each product in the assembly line. Each type of daster product has different characteristics in terms of fabric requirements and production costs. The initial data used in the optimization model are listed in Table 2.

The data in Table 3 served as the basis for modeling in LINGO 21 to determine the optimal production combination that minimizes the total production costs, subject to various constraints. The inventory values represent the initial inventory available at the beginning of the planning period. In addition, a safety stock level of 200 units was established for each product as a minimum inventory reserve to protect against demand uncertainty and potential stockout risks during the planning period. Therefore, the safety stock value is independent of the initial inventory level and serves as an inventory policy parameter in Models 1 and 3.

3.2. Optimization Results

3.2.1. *Model 1*

After determining the mathematical model and function constraints for each scenario, data processing was performed using LINGO 21. Fig. 1 shows the optimization results of model 1, with an objective value of minimum production cost of IDR 312,878,500 and an infeasibility value of 0.000000. This value indicates that the model is optimal and valid, that it does not violate the constraints, and that the solution is acceptable. To obtain the production and inventory combinations in Model 1, equations (2) through (6) in the data processing were used. The results for the production and inventory combinations in Model 1 (Table 4).

```
Global optimal solution found.
Objective value:                0.3128785E+09
Objective bound:                0.3128785E+09
Infeasibilities:                0.000000
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Fig. 1. Optimal solution results of model 1

Table 4. Results of the combination of production volume and inventory volume in model 1

Product	Production Quantity (Pcs/week)	Inventory Quantity (Pcs/week)	Fabric Usage (cm/week)
1	2010	200	434160
2	2051	200	443016
3	2137	200	491510
4	1313	200	301990
5	1646	200	378580
Total	9157	1000	2049256

3.2.2. *Model 2*

To obtain the production and inventory combination in Model 2, equations (7) through (11) in the data processing were used. Fig. 2 shows the optimization results of Model 2, with an objective value of minimum production cost of Rp 277,755,500 and an infeasibility value of 0.000000. This value indicates that the model is optimal and valid, that it does not violate the constraints, and that the solution is acceptable.

Global optimal solution found.	
Objective value:	0.2777555E+09
Objective bound:	0.2777555E+09
Infeasibilities:	0.000000

Fig. 1. Optimal solution results of model 2

Model 2 excludes the safety stock requirement while maintaining production and fabric capacity constraints. As a result, the model produces only the quantities required to satisfy forecasted demand after considering the available initial inventory. Consequently, total production decreases to 8,157 units with zero ending inventory and fabric consumption of 1,824,856 cm/week. This reduction in inventory holding requirements lowers the total cost to IDR 277,755,500, making Model 2 the least costly scenario (Table 5).

Table 5. Results of the combination of production volume and inventory volume in model 2

Product	Production Quantity (Pcs/week)	Inventory Quantity (Pcs/week)	Fabric Usage (cm/week)
1	1810	0	390960
2	1851	0	399816
3	1937	0	445510
4	1113	0	255990
5	1446	0	332580
Total	8157	0	1824856

3.2.3. *Model 3*

To obtain the production and inventory combination in model 3, equations (12) through (14) in the data processing were used. Fig. 3 shows the optimization results of Model 3, with an objective value of minimum production cost of Rp 312.878.500 and an infeasibility value of 0.000000. This value indicates that the model is optimal and valid, that it does not violate the constraints, and that the solution is acceptable. To obtain the production and inventory combination in model 3, equations (12) through (14) in the data processing were used. The results for the combination of production and inventory quantities in Model 3.

Global optimal solution found.	
Objective value:	0.3128785E+09
Objective bound:	0.3128785E+09
Infeasibilities:	0.000000

Fig. 2. Optimal solution results of model 3

Model 3 maintains the safety stock requirement but removes the production capacity constraint. The optimization results generate the same production and inventory quantities as Model 1, namely 9.157 units of production and 1,000 units of ending inventory, with fabric consumption of 2,049,256 cm/week. This indicates that the production capacity limit of 10,000 units per week is not a binding constraint because the optimal production quantity remains below the available capacity (Table 6).

Table 6. Results of the combination of production volume and inventory volume in model 3

Product	Production Quantity (Pcs/week)	Inventory Quantity (Pcs/week)	Fabric Usage (cm/week)
1	2010	200	434160
2	2051	200	443016
3	2137	200	491510
4	1313	200	301990
5	1646	200	378580
Total	9157	1000	2049256

The optimization results demonstrate that safety stock policy has a greater influence on production decisions than production capacity constraints. Models 1 and 3 produce identical results because both maintain a safety stock of 200 units per product, resulting in total production of 9,157 units and ending inventory of 1,000 units. The identical solutions indicate that the production capacity limit of 10,000 units per week is not active, as the optimal production quantity remains below the available capacity.

In contrast, Model 2 eliminates the safety stock requirement, reducing total production to 8,157 units and eliminating ending inventory. Consequently, Model 2 achieves the lowest total cost of IDR 277,755,500. However, despite its lower cost, the absence of inventory reserves may increase the risk of stock shortages under demand fluctuations. Therefore, Model 1 is considered the most appropriate scenario for implementation because it balances cost efficiency with inventory security while remaining within production and raw material capacity limits.

Fig. 4 shows the comparison of total costs generated by the three optimization models. Model 2 produces the lowest total cost of IDR 277,755,500 because it does not require safety stock maintenance. In contrast, Models 1 and 3 generate identical total costs of IDR 312,878,500, indicating that production capacity is not a binding constraint under the current operating conditions. These results suggest that inventory policy, particularly safety stock requirements, has a greater impact on total cost than production capacity limitations.

3.3. Sensitivity Analysis

Sensitivity analysis was conducted to evaluate the impact of changes in safety stock levels on the optimal solution produced by Model 1. Table 7 presents the resulting changes in total production, ending inventory, and total cost for each scenario analyzed in the sensitivity analysis.

http://dx.doi.org/10.30656/intech.v12i1.11981

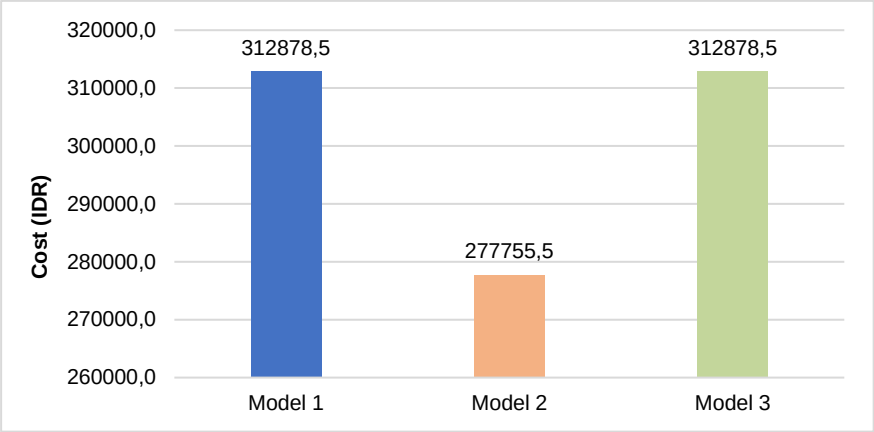


Fig. 4. Comparison of total cost across optimization models

The sensitivity analysis results indicate that the safety stock parameter has a direct and positive influence on production decisions and total costs. As the safety stock level increases from 100 to 300 units per product, total production rises from 8,657 units to 9,657 units, while ending inventory increases from 500 units to 1,500 units. Consequently, total cost increases from IDR 295,317,000 to IDR 330,440,000. This trend demonstrates that higher inventory protection requires additional production and inventory holding activities, leading to increased operational costs.

Table 7. Sensitivity Analysis Results

Sce-nario	Safety Stock (Pcs/ product)	Total Production (pcs)	Ending Inventory (pcs)	Total Cost (IDR)
S1	100	8657	500	295.317.000
S2	150	8907	750	304.097.800
S3	200	9157	1000	312.878.500
S4	250	9407	1250	321.659.200
S5	300	9657	1500	330.440.000

Furthermore, the results reveal an approximately linear relationship between safety stock and total cost. Every increase of 50 units in safety stock per product raises total production by approximately 250 units and increases total cost by around IDR 8.7 million to IDR 8.8 million. This finding indicates that safety stock is a sensitive decision parameter within the proposed optimization model.

From a managerial perspective, the results highlight the trade-off between cost efficiency and inventory security. Lower safety stock levels reduce operational costs but increase the risk of stock shortages when actual demand exceeds forecasted demand. Conversely, higher safety stock levels provide greater protection against demand uncertainty but require additional production and inventory investment. Therefore, the base scenario of 200 units per product is considered the most balanced policy because it provides inventory protection while maintaining a reasonable increase in total cost.

Fig. 5 illustrates the relationship between safety stock levels and total cost. The results show a positive and nearly linear trend, indicating that higher safety stock levels consistently increase total production and inventory holding costs. As safety stock increases from 100 to 300 units per product, total cost rises from IDR 295,317,000 to IDR 330,440,000. This finding confirms that safety stock is a sensitive decision variable within the proposed optimization model and highlights the trade-off between inventory security and cost efficiency.

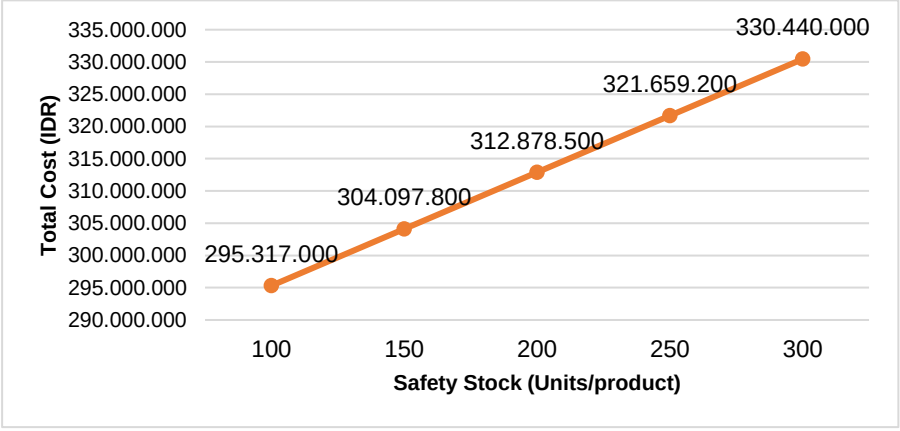


Fig. 5. Impact of safety stock levels on total cost

3.4. Research Implications

3.4.1. *Managerial Implications*

These findings have clear implications for garment MSME managers. Inventory policy has a stronger impact on production decisions than production capacity, as shown by Models 1 and 3. Focus on inventory planning and safety stock management, not just increasing production capacity. Use the forecasting–optimization framework to develop data-driven production plans that account for demand forecasts, resource constraints, and inventory requirements simultaneously.

Comparing Models 1 and 2 shows a trade-off between cost and inventory security. Model 2 has the lowest cost but no safety stock, increasing the risk of shortages if demand is uncertain. Model 1 is more reliable because it includes safety stock. Set inventory policies that balance costs and service reliability based on your level of demand uncertainty

3.4.2. *Theoretical Implications*

This research contributes to the development of production planning and operations research by integrating demand forecasting methods and Integer Linear Programming within a single decision-making framework for garment SMEs. Unlike many previous optimization studies that assume demand data is known with certainty, this research uses forecasting results as input parameters in the optimization model. The research results show that inventory policies, particularly the implementation of safety stock, have a greater influence on production decisions than production capacity constraints when available capacity still meets production needs. These findings expand the application of Integer Linear Programming to production planning under demand uncertainty and data limitations commonly encountered by SMEs.

3.4.3. *Integration with Previous Research*

The results of this study align with previous research indicating that Linear Programming and Integer Linear Programming are effective for optimizing resource allocation and reducing operational costs (Hamidah et al, 2026; N & Jandhayala, 2023; Rosi et al, 2025). The findings of this study also support those of (Al-Mahmud et al, 2025) and (Ismail & Laela, 2024), which show that optimization models can produce more efficient production planning decisions. However, most previous studies assume that demand data is available and generally focus on medium to large-scale manufacturing companies. Unlike previous studies that primarily focused on optimization under known demand conditions, this study integrates forecasting and optimization within a single framework, enabling production planning decisions to be generated under limited demand information. This approach is particularly relevant for garment MSMEs, which often lack structured demand records and comprehensive operational databases. Unlike that study, this study integrates the Single Exponential Smoothing and Integer Linear Programming methods to address the data limitations commonly faced by garment SMEs. The main strength of this research lies in its ability to evaluate the impact of safety stock policies through various optimization scenarios and sensitivity analysis. Nevertheless, this research still has limitations because it was conducted on only one MSME with a short-term planning horizon, so generalizing the results to other industrial sectors should be done with caution.

4. CONCLUSION

This study integrated Single Exponential Smoothing (SES) and Integer Linear Programming (ILP) to support production planning decisions in a garment MSME. The forecasting results produced an average MAPE of 5.79%, indicating highly accurate demand predictions. The optimization results showed that Model 2 achieved the lowest total cost of IDR 277.755.500 by eliminating safety stock requirements. However, Model 1 was identified as the most appropriate production planning scenario because it maintained a safety stock of 200 units per product while satisfying demand and resource constraints, resulting in a total production of 9.157 units and a total cost of IDR 312.878.500. In addition, the identical solutions obtained from Models 1 and 3 indicate that production capacity was not a binding constraint under the existing operating conditions. The sensitivity analysis further confirmed that safety stock is a critical parameter influencing production quantity, inventory levels, and total cost.

Despite these findings, this study has several limitations. The analysis was conducted using data from a single garment MSME and relied on only 12 historical demand periods, which may limit the generalizability of the results. Furthermore, the optimization model only considered production costs, inventory costs, production capacity, fabric capacity, and safety stock. Future research is therefore recommended to employ longer historical datasets, evaluate alternative forecasting approaches, and incorporate additional operational factors such as demand uncertainty, labor constraints, and lead-time variability. Expanding the study to different MSMEs or industrial sectors may also provide broader insights into the applicability of the proposed forecasting–optimization framework.

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