Available online at https://journal.rescollacomm.com/index.php/ijqrm/index

**International Journal of Quantitative Research and Modeling**

e-ISSN 2721-477X
p-ISSN 2722-5046

Vol. 4, No. 1, pp. 57-64, 2023

# Apparel Production Optimization Model with Branch and Bound Method (Case Study: Sawargi Jersey Confectionery, West Java)

Athaya Alyanisa[1*], Julita Nahar[2], Nursanti Anggriani[3]

[1,2,3] *Department of Mathematics, Faculty of Mathematics and Natural Science, Universitas Padjadjaran, Jatinangor, Indonesia*

**Corresponding author email: athaya18001@mail.unpad.ac.id*

**Abstract**

The production optimization model can find optimal results and maximum profits from a production activity by considering certain limitations. In this research, a production optimization model was created based on data on apparel production in UMKM (Usaha Mikro, Kecil, dan Menengah) Konfeksi Sawargi Jersey in West Java by applying the Integer Linear Programming model and solving it using the Branch and Bound Method with the help of Software Python. This research was conducted because there are many business actors engaged in the same field, especially in the apparel and sports sectors, considering the problems that are often faced by UMKM owners, such as raw material supplies, production time, production costs, selling prices, production profits, and production limits, minimum and maximum production. Based on this study's results, the Branch and Bound Method application to optimize apparel production obtains more optimal results and maximum profits than the actual production carried out by UMKM Konfeksi Sawargi Jersey.

*Keywords:* Optimization model, branch and bound method

## 1. Introduction

According to data from the Badan Pusat Statistik (BPS), the unemployment rate rose to 9 million people during the pandemic. Therefore, many of them have switched professions to become owners of UMKMs (Usaha Mikro, Kecil, dan Menengah) to meet their daily needs. However, it cannot be denied that many UMKM owners have gone out of business because of their poor planning system. UMKM Konfeksi Sawargi Jersey is one of the UMKMs affected by the Covid-19 pandemic due to the large number of business actors engaged in the same field and the increasing interest in sports among the public (Subhash, 2021). Therefore, it is necessary to optimize production in order to achieve maximum profit. Optimization problems are part of the problems of society, especially those engaged in the production of goods (Edwin, 1990). Optimization is a process of getting the best results from a problem that is directed at the maximum or minimum point of an objective function by not violating the given constraints (Siswanto, 2007), while production is an activity of converting resources into products or processes of converting inputs into outputs (Aharoni, 2011). In many real-world problems, often more than one objective need to be optimized. Indeed, a decision maker may be interested in minimizing one objective, e.g., operational costs, while at the same time maximizing customer satisfaction (Forget et al., 2022).

Linear programming is an optimization method that applies to problem solutions in which the objective function and constraint function appear as linear functions of the decision variables (Rao, 2009). The Simplex method is one of the solving techniques in linear programming that is used as a decision-making technique in problems related to optimal resource allocation. The Simplex method is used to find the optimal value of linear programming which involves many constraints and many variables (more than two variables) (Meester, 2001).

In some production optimization problems with linear programming models, the decision variable will really make sense only if it has an integer value. For example, in determining the number of workers, machines, and vehicles used in an activity the value must be an integer. If integer values are the only way to satisfy the linear programming formulation, then the problem is Integer Linear Programming (Hillier & Lieberman, 2001). Thus, the problems in this study can be solved using the Integer Linear Programming model using Branch and Bound Method because the number of products produced must be integers (Mehdizadeh & Jalili, 2019).

## 2. Literature Review

### 2.1 Integer Linear Programming

Integer Linear Programming is linear programming where some or all variables are required to be non-negative integer (Morrison, 2016). The basic form of Integer Linear Programming is (Haberl, 1991):

$$\begin{aligned} &\text{Maximize } f(x_1, x_2, \dots, x_n) = c_1x_1 + c_2x_2 + \dots + c_nx_n \\ &\text{s.t} \quad a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \leq b_1 \\ &\quad a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \leq b_2 \\ &\quad \vdots \\ &\quad a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \leq b_m \\ &\quad x_1, x_2, \dots, x_n \geq 0 \\ &\quad x_1, x_2, \dots, x_n \in \mathbf{Z} \end{aligned} \tag{1}$$

where $c_j, b_j$, and $a_{ij}$ $(i = 1,2, \dots, m; j = 1,2, \dots, n)$ are constants and $x_j$ is decision variables.

Integer Linear Programming can be solved one way with the Branch and Bound Method. The basic concept of this method is branching and limiting, namely partitioning the problem into several subproblems and calculating the upper and lower bounds for the optimal solution to the subproblem that leads to a solution so that the optimal solution is found. Problem-solving is done partially by limiting the best solution to each sub-problem and removing sub-problems that do not meet the optimal solution requirements (Hillier & Lieberman, 2001).

### 2.2 Branch and Bound Method

The Branch and Bound method is the usual method used in Integer Linear Programming calculations (Simon, 1988). The Branch and Bound method can be used in optimization and will obtain optimal product allocation capacity results so that this method can also obtain greater profits (Rahimullaily, 2023). The basic form of the Branch and Bound Method is (Hillier & Lieberman, 2001):

$$\text{Maximize} \quad Z = \sum_{j=1}^{n} c_j x_j,$$

s.t

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i, \quad \text{for } i = 1,2, \dots, m,$$

and

$$\begin{aligned} &x_j \geq 0, && \text{for } j = 1,2, \dots, n. \\ &x_j \in \mathbf{Z}, && \text{for } j = 1,2, \dots, I; I \leq n. \end{aligned} \tag{2}$$

The algorithm of Branch and Bound Method are (Siswanto, 2007):

1. Complete a Linear Programming model using the Simplex Method.
2. Checking the optimal solution, if the expected basis variable is an integer value, then the optimal solution has been reached. If not then proceed to Step 3.
3. Choose the variable that has the largest fractional difference with the integer number of each variable to be branched into subproblems.
4. Making $x_j^* \leq x_j \leq x_j^* + 1$ as a new constraint, but because the range does not provide integer programming, the consequence is that the integer value $x_j$ fulfills one of the conditions, there are $x_j^* \leq x_j$ and $x_j \geq x_j^* + 1$.
5. Solving a linear programming model with new constraints added to each subproblem. If the expected solution is an integer, then go back to Step 4. If not, go back to Step 3.
6. If the solution of one of these subproblems has an integer value and the other solutions do not have a solution (not feasible), then the branching is not continued or stops.
7. Choose the optimal solution. If there are several subproblems that have integer-valued solutions, then the solution that has the largest $Z$ value is chosen if the objective function is the maximum and the solution that has the smallest $Z$ is chosen if the objective function is minimum to be used as the optimal solution.

## 3. Materials and Methods

### 3.1. Materials

The object of research in this thesis is an optimization model for apparel production using the Branch and Bound Method by considering raw material supplies, production time, production costs, selling prices, production profits, and minimum and maximum production limits obtained from UMKM Konfeksi Sawargi Jersey. The data used in this study is data on apparel production at the UMKM Konfeksi Sawargi Jersey from December 1 2021 to December 31 2021. This data was obtained from the results of interviews with the owner of the UMKM Konfeksi Sawargi Jersey.

### 3.2. Methods

The method used in this research is literature study, which collects various literature such as journals, books, and writings related to this research. Furthermore, collecting data used in research by conducting interviews. Then determine the optimization model for apparel production using Integer Linear Programming with the Branch and Bound Method based on research data. After the model is found, a numerical simulation is carried out using Python software to obtain the optimal solution.

## 4. Results and Discussion

The following is the data used in the study.

**Table 1:** Raw material inventory data for each type of apparel

| Number | Types of Raw Materials | Apparel Type | | | | | Raw Material Inventory |
|---|---|---|---|---|---|---|---|
| | | Long-sleeved sports clothes | Short-sleeved sports clothes | Short sports pants | Training pants | Jacket | |
| 1 | Dryfit polimesh fabric | 4.5 m | 2 m | - | - | - | 1,500 m |
| 2 | Lotto fabric | - | - | 1 m | 2.3 m | 3.2 m | 1,250 m |
| 3 | Printer ink | 0.035 l | 0.03 l | 0.02 l | 0.04 l | 0.02 l | 28 l |
| 4 | Paper | 2.1 m | 1.6 m | 1 m | 2.5 m | 3.4 m | 2,200 m |
| 5 | Thread | 0.6 m | 0.4 m | 0.3 m | 2.6 m | 1 m | 525 m |
| 6 | Zipper | - | - | - | - | 1 piece | 30 pieces |
| 7 | Rubber | - | - | 0.5 m | 0.5 m | - | 235 m |
| 8 | Plastic | 1 piece | 1 piece | 1 piece | 1 piece | 1 piece | 1,070 pieces |

**Table 2:** Manufacturing time for each clothing product

| Number | Product *i* | Time (Hour/Pcs) |
|---|---|---|
| 1 | Long-sleeved sports clothes | 4 |
| 2 | Short-sleeved sports clothes | 3 |
| 3 | Short sports pants | 2 |
| 4 | Training pants | 3 |
| 5 | Jacket | 6 |
| | Total Hours Worked | 2100 Hour/Month |

**Table 3:** Data on production costs, selling prices, profits of apparel products

| Number | Product *i* | Selling Prices (IDR/Pcs) | Production Costs (IDR/Pcs) | Profit (IDR/Pcs) |
|---|---|---|---|---|
| 1 | Long-sleeved sports clothes | 140,000 | 115,000/Pcs | 25,000 |
| 2 | Short-sleeved sports clothes | 125,000 | 90,000/Pcs | 35,000 |
| 3 | Short sports pants | 65,000 | 55,000/Pcs | 10,000 |
| 4 | Training pants | 75,000 | 60,000/Pcs | 15,000 |
| 5 | Jacket | 165,000 | 145,000/Pcs | 20,000 |
| | Capital Price | | | 70,000,000 |

**Table 4:** Minimum and maximum production for each apparel product

| *i* | Product *i* | Minimum Production (Pcs/Month) | Maximum Production (Pcs/Month) |
|---|---|---|---|
| 1 | Long-sleeved sports clothes | 30 | 60 |
| 2 | Short-sleeved sports clothes | 288 | 400 |

| | | | |
|---|---|---|---|
| 3 | Short sports pants | 400 | 450 |
| 4 | Training pants | 5 | 25 |
| 5 | Jacket | 30 | 75 |

**Table 5:** The actual production amount of each apparel product

| $i$ | Product $i$ | Production Amount (Pcs/Month) |
|---|---|---|
| 1 | Long-sleeved sports clothes | 20 |
| 2 | Short-sleeved sports clothes | 300 |
| 3 | Short sports pants | 300 |
| 4 | Training pants | 5 |
| 5 | Jacket | 30 |

Based on these data, the optimization model for planning apparel production to obtain maximum profit for UMKM Konfeksi Sawargi Jersey is:

$$\begin{aligned}
\text{Maximize} \quad & Z = 25{,}000x_1 + 35{,}000x_2 + 10{,}000x_3 + 15{,}000x_4 + 20{,}000x_5 \\
\text{s.t} \quad & 4.5x_1 + 2x_2 \leq 1500 \\
& x_3 + 2.3x_4 + 3.2x_5 \leq 1250 \\
& 0.035x_1 + 0.03x_2 + 0.02x_3 + 0.04x_4 + 0.02x_5 \leq 28 \\
& 2.1x_1 + 1.6x_2 + x_3 + 2.5x_4 + 3.4x_5 \leq 2200 \\
& 0.6x_1 + 0.4x_2 + 0.3x_3 + 2.6x_4 + x_5 \leq 525 \\
& x_5 \leq 30 \\
& 0.5x_3 + 0.5x_4 \leq 235 \\
& x_1 + x_2 + x_3 + x_4 + x_5 \leq 1070 \\
& 4x_1 + 3x_2 + 2x_3 + 3x_4 + 6x_5 \leq 2100 \\
& 115{,}000x_1 + 90{,}000x_2 + 55{,}000x_3 + 60{,}000x_4 + 145{,}000x_5 \\
& \qquad \leq 70{,}000{,}000 \\
& x_1 \geq 30 \\
& x_2 \geq 288 \\
& x_3 \geq 400 \\
& x_4 \geq 5 \\
& x_5 \geq 30 \\
& x_1 \leq 60 \\
& x_2 \leq 400 \\
& x_3 \leq 450 \\
& x_4 \leq 25 \\
& x_5 \leq 75 \\
& x_i \geq 0 \quad \forall i = 1,2,3,4,5 \\
& x_i \in \mathbb{Z} \quad \forall i = 1,2,3,4,5
\end{aligned} \tag{3}$$

With the help of Python software, the optimal solution is obtained from equation (3) as follows:

$$Z = 16{,}916{,}666.549999997$$
$$x_1 = 30;\ x_2 = 328.33333;\ x_3 = 400;\ x_4 = 5;\ x_5 = 30$$

The optimal solution obtained is not yet an integer value so that equation (3) is solved using the Branch and Bound Method. The first stage is the branching stage. Variable that is not yet integer is $x_2 = 328.33333$. Two subproblems are added as new constraints on equation (3), there are $x_2 \leq 328$ for subproblem 1 and $x_2 \geq 329$ for subproblem 2.

**1st Iteration**

**Table 6:** Subproblem 1 and subproblem 2

| Subproblem 1 | Subproblem 2 |
|---|---|
| Equation (3) plus the constraint $x_2 \leq 328$ | Equation (3) plus the constraint $x_2 \geq 329$ |
| Linear Programming Solution<br>$Z = 16{,}911{,}250$<br>$x_1 = 30.25;\ x_2 = 328;\ x_3 = 400;$<br>$x_4 = 5;\ x_5 = 30$ | Does not have a feasible solution |

$Z$ value in subproblem 1 is 16,911,250 and the solutions are $x_1 = 30.25$, $x_2 = 328, x_3 = 400, x_4 = 5$, and $x_5 = 30$. There is one solution that is still not an integer, so the branching stage is carried out in subproblem 1. The variable that is not yet an integer is $x_1 = 30.25$. Two subproblems are added as new constraints on equation (3), there are $x_1 \leq 30$ for subproblem 3 and $x_1 \geq 31$ for subproblem 4. Whereas in subproblem 2, the solution does not have a solution (not feasible) so that the fathoming stage is carried out.

**2nd Iteration**

**Table 7:** Subproblem 3 and subproblem 4

| Subproblem 3 | Subproblem 4 |
|---|---|
| Equation (3) plus the constraints $x_2 \leq 328$ and $x_1 \leq 30$ | Equation (3) plus the constraints $x_2 \geq 329$ and $x_1 \geq 31$ |
| Linear Programming Solution | Linear Programming Solution |
| $Z = 16{,}910{,}000$ | $Z = 16{,}895{,}000$ |
| $x_1 = 30$; $x_2 = 328$; $x_3 = 400.5$; $x_4 = 5$; $x_5 = 30$ | $x_1 = 31$; $x_2 = 327$; $x_3 = 400$; $x_4 = 5$; $x_5 = 30$ |

$Z$ value in subproblem 1 is 16,910,000 and the solutions are $x_1 = 30$, $x_2 = 328, x_3 = 400.5, x_4 = 5$, and $x_5 = 30$. There is one solution that is still not an integer, so the branching stage is carried out in subproblem 3. The variable that is not yet an integer is $x_3 = 400.5$. The two subproblems added as new constraints are $x_3 \leq 400$ for subproblem 5 and $x_3 \geq 401$ for subproblem 6.

$Z$ value in subproblem 4 is 16,895,000 and the solutions are $x_1 = 31$, $x_2 = 327, x_3 = 400, x_4 = 5$, and $x_5 = 30$. All solutions are integers so that the solution becomes a new feasible solution.

**3rd Iteration**

**Table 8:** Subproblem 5 and subproblem 6

| Subproblem 5 | Subproblem 6 |
|---|---|
| Equation (3) plus the constraints $x_2 \leq 328$, $x_1 \leq 30$, and $x_3 \leq 400$ | Equation (3) plus the constraints $x_2 \geq 329$, $x_1 \geq 31$, and $x_3 \geq 401$ |
| Linear Programming Solution | Linear Programming Solution |
| $Z = 16{,}909{,}999.9995$ | $Z = 16{,}903{,}333.450000003$ |
| $x_1 = 30$; $x_2 = 328$; $x_3 = 400$; $x_4 = 5.3333333$; $x_5 = 30$ | $x_1 = 30$; $x_2 = 327.66667$; $x_3 = 401$; $x_4 = 5$; $x_5 = 30$ |

$Z$ value in subproblem 1 is 16,909,999.9995 and the solutions are $x_1 = 30$, $x_2 = 328, x_3 = 400, x_4 = 5.3333333$, and $x_5 = 30$. There is one solution that is still not an integer, so the branching stage is carried out in subproblem 5. The variable that is not yet an integer is $x_4 = 5.3333333$. The two subproblems added as new constraints are $x_4 \leq 5$ for subproblem 7 and $x_4 \geq 6$ for subproblem 8.

**4rd Iteration**

**Table 9:** Subproblem 7 and subproblem 8

| Subproblem 7 | Subproblem 8 |
|---|---|
| Equation (3) plus the constraints $x_2 \leq 328$, $x_1 \leq 30$, $x_3 \leq 400$, and $x_4 \leq 5$ | Equation (3) plus the constraints $x_2 \geq 329$, $x_1 \geq 31$, $x_3 \geq 401$, and $x_4 \geq 6$ |
| Linear Programming Solution | Linear Programming Solution |
| $Z = 16{,}905{,}000$ | $Z = 16{,}896{,}666.549999997$ |
| $x_1 = 30$; $x_2 = 328$; $x_3 = 400$; $x_4 = 5$; $x_5 = 30$ | $x_1 = 30$; $x_2 = 327.33333$; $x_3 = 400$; $x_4 = 6$; $x_5 = 30$ |

Subproblems 6, 7, and 8 are fathomed based on test 1 in the fathoming stage because $Z \leq Z^*$ and denoted by F(1).

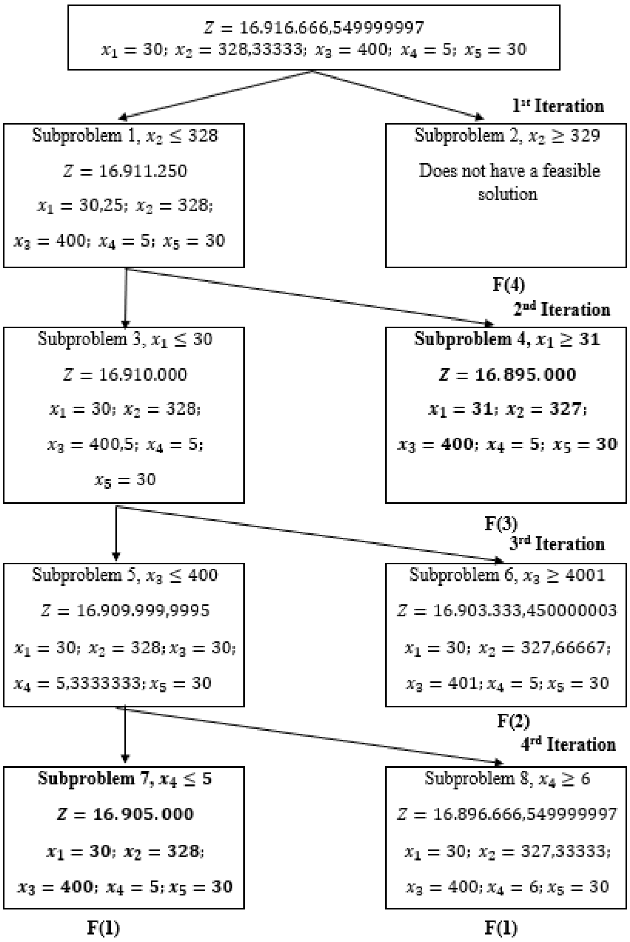


**Figure 1:** Tree diagram of Branch and Bound Method solutions

Figure 1 shows that all subproblems have been fathomed so that there are no subproblems that need to be branched. Therefore, the optimal solution for the apparel production problem is the solution of subproblem 7 are $x_1 = 30, x_2 = 328, x_3 = 40, x_4 = 5$, and $x_5 = 30$ with $Z^* =$ IDR16,905,000.00. If this value is compared with the production data carried out by the company, it looks like the following:

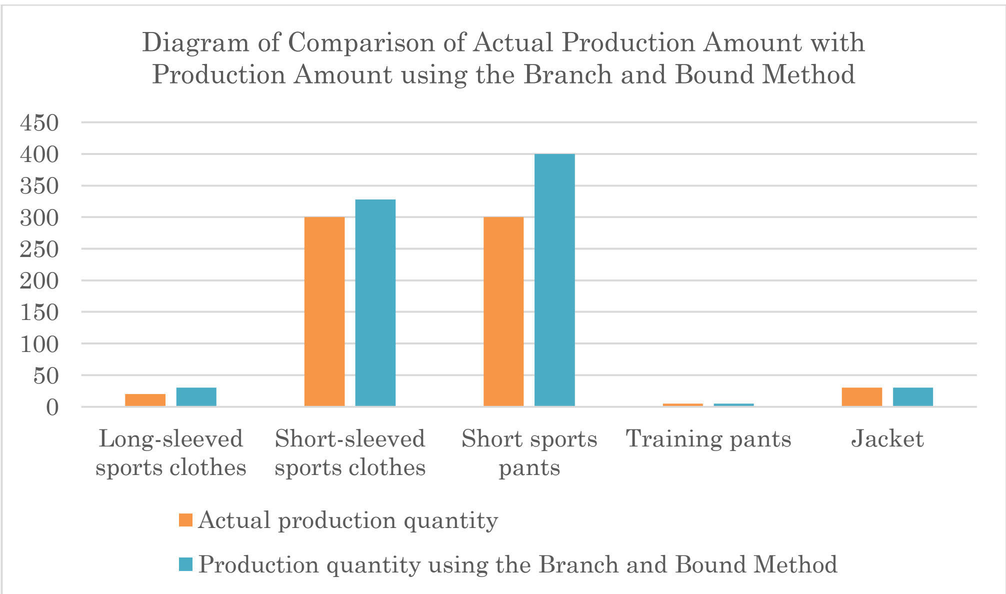


**Figure 2:** Comparison diagram of actual production quantities with quantities production using the Branch and Bound Method

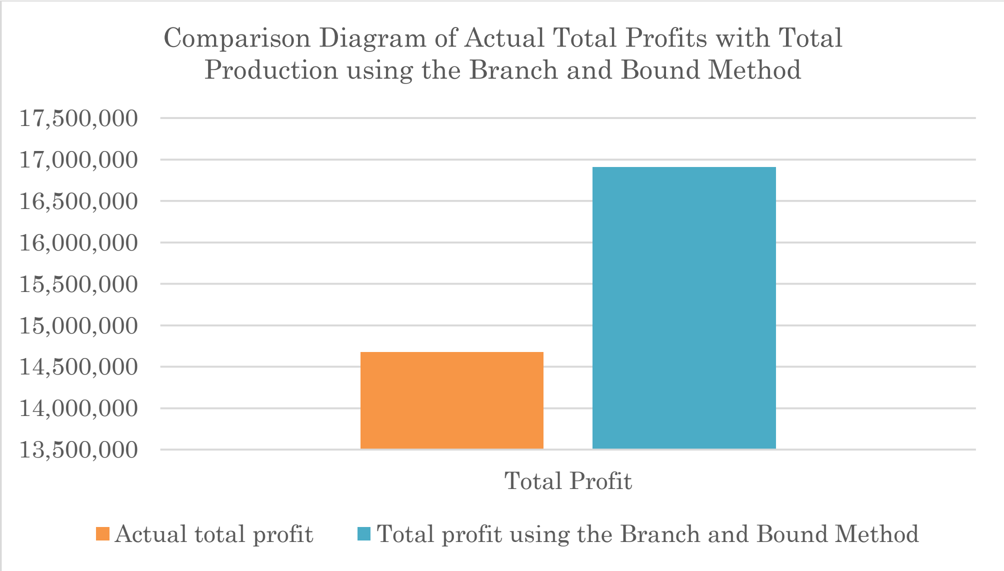


**Figure 3:** Chart comparing actual total profit to total profit using the Branch and Bound Method

In Figure 2, it is shown that the total production of apparel using the Branch and Bound Method is greater than the actual production of apparel. In Figure 3, it is shown that in actual production, the UMKM Konfeksi Sawargi Jersey made a profit of IDR14,675,000.00, while in the calculation results using the Branch and Bound Method the profit was IDR16,905,000.00 so that there was a profit difference of IDR2,230,000.00 or an increase of 15.2% of the actual production profit. Therefore, the application of the Branch and Bound Method in determining the amount of apparel production gains greater profits compared to the production of apparel carried out by business owners under actual conditions.

## 5. Conclusion

Based on the calculations that have been done, it can be concluded that the model created succeeded in determining optimal results on the amount of apparel production to maximize profits and the results of numerical simulations can show more optimal results in determining the amount of apparel production using the Branch and Bound Method. The Sawargi Jersey Confectionery UMKM is capable of producing 30 long-sleeved sports clothes, 328 short-sleeved sports clothes, 400 short sports pants, 5 training pants, and 30 jackets with a profit of IDR16,905,000.00.

## References

Aharoni, Y., Tihanyi, L., & Connelly, B. L. (2011). Managerial decision-making in international business: A forty-five-year retrospective. *Journal of World Business, 46*(2), 135-142.

Edwin, K. W., & Curtius, F. (1990). New maintenance-scheduling method with production cost minimization via integer linear programming. *International Journal of Electrical Power & Energy Systems, 12*(3), 165-170.

Forget, N., Gadegaard, S. L., Klamroth, K., Nielsen, L. R., & Przybylski, A. (2022). Branch-and-bound and objective branching with three or more objectives. *Computers & Operations Research*, 148, 106012. https://doi.org/10.1016/j.cor.2022.106012.

Haberl, J., Nowak, C., Stettner, H., Stoiser, G., & Woschitz, H. (1991). A branch-and-bound algorithm for solving a fixed charge problem in the profit optimization of sawn timber production. *Zeitschrift für Operations Research, 35*, 151-166.

Hillier, F. S., & Lieberman, G. J. (2001). *Introduction to Operations Research* (7th ed.). McGraw-Hill.

Meester, G. A., Ault, J. S., Smith, S. G., & Mehrotra, A. (2001). An integrated simulation modeling and operations research approach to spatial management decision making. *Sarsia, 86*(6), 543-558.

Mehdizadeh, E., & Jalili, S. (2019). An Algorithm Based on Theory of Constraints and Branch and Bound for Solving Integrated Product-Mix-Outsourcing Problem. *Journal of Optimization in Industrial Engineering*, *12*(1), 167–172. https://doi.org/https://doi.org/10.22094/JOIE.2018.664.1429.

Morrison, D. R., Jacobson, S. H., Sauppe, J. J., & Sewell, E. C. (2016). Branch-and-bound algorithms: A survey of recent advances in searching, branching, and pruning. *Discrete Optimization, 19*, 79-102.

Rahimullaily, R., Darwas, R., & Purwasih, R. (2023). Optimization of bakery production by using branch and bound approach. *Computer Science and Information Technologies*, *4*(1), 50-58.

Rao, S. S. (2009). *Engineering optimization: Theory and practice* (4th ed.). John Wiley & Sons, Ltd.

Simon, F. Y. P. (1988, July). Integer linear programming neural networks for job-shop scheduling. *In IEEE 1988 International Conference on Neural Networks* (pp. 341-348). IEEE.

Siswanto. (2007). *Operation Research* (1st ed.). Erlangga.

Subhash, A. K., Maldonado, D. R., Kajikawa, T. M., Chen, S. L., Stavrakis, A., & Photopoulos, C. (2021). Public interest in sports medicine and surgery (anterior cruciate ligament, meniscus, rotator cuff) topics declined following the COVID-19 outbreak. *Arthroscopy, sports medicine, and rehabilitation*, *3*(1), e149-e154.