

Branch and Bound Method in Determining Integer Linear Programming Solutions from UMKM Rendang Nan Lamak, Padang City

Alvin Ardiansyah Putra¹, Nurweni Putri^{1*}, Iswan Rina¹, and Aulia Oktavia²

¹ Mathematics Department, Dharma Andalas University, West Sumatera Province, Indonesia

² Electrical Engineering Department, Padang State Polytechnics, Padang, West Sumatera Province, Indonesia

*Corresponding email: nurweni@unidha.ac.id

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Abstract: After Indonesia was hit by COVID-19 in 2019, it had an impact on the Indonesian economy. Many companies have closed and laid off employees (PHK), so the unemployment rate has increased. This event made people think creatively and innovatively by creating their own businesses to meet their daily needs. This has resulted in the emergence of many micro, small, and medium enterprises (UMKM) from various regions or cities, including the city of Padang. UMKM Rendang Nan Lamak is engaged in the food sector, namely processed rendang dishes. Especially for Rendang Nan Lamak, it serves several variants of rendang dishes, such as beef rendang, fern rendang, lokan rendang, and lokan fern rendang. The purpose of this research is to find out the maximum profit by using the Branch and Bound Method in determining Integer Linear Programming solutions from UMKM Rendang Nan Lamak.

Keywords: Profit, Optimization, Branch and Bound Method

1. Introduction

After Indonesia was hit by Covid in 2019, it had an impact on the Indonesian economy. Many companies closed and laid off employees so that the unemployment rate increased. This incident made people think creatively and innovatively by creating their own businesses to meet their daily needs. This resulted in the emergence of many micros, small and medium enterprises (UMKM) from various regions or cities, including in Padang City (Maulida & Ahmad, 2017). One of the (UMKM) in Padang City is the UMKM of rendang cuisine. Rendang is a heavy meal, usually rendang is served in only one variant, namely beef rendang.

Many rendang UMKM have emerged in Padang City, one of which is Rendang Nan Lamak produced by Mrs. Vira Agusta. Currently, one of the problems faced by Mrs. Vira is that she has not been able to optimize the profits of her rendang production. In order for the Rendang Nan Lamak UMKM to always advance and develop, Mrs. Vira must be able to optimize her own rendang production. With this problem, a mathematical model is needed that can calculate the optimization

of rendang production. The model used to calculate optimization is the Linear Program (Aji *et al.*, 2014) The solution to the optimal results of the Linear Program can be a fractional number. However, for certain cases, this fractional number solution cannot be accepted, such as optimizing the number of people or the number of units of goods. In this problem, Mrs. Vira's UMKM has limitations in selling her rendang. Mrs. Vira's UMKM only serves rendang sales in 1 kg packaging. With this limitation, the solution must use Integer Linear Programming [9]. One of the most effective ways to solve the Integer program is to use the Branch and Bound Method compared to other integer calculation methods (nur *et al.*, 2019).

Based on the description above, this is the reason that makes the author interested in conducting research on the use of the Branch and Bound Method in determining the Integer Linear Programming solution of UMKM Rendang Nan Lamak, Padang City. In this study, the author took the decision variable (x_1) for beef rendang, the decision variable (x_2) for lokan rendang, the decision variable (x_3) for fern rendang and the decision variable (x_4) for lokan fern rendang. The maximum profit results will later describe which type of rendang is most in demand by consumers, this study only uses two production factors, namely raw materials and rendang variants. To facilitate the calculation in this study, the author uses the help of POM-QM Windows V5 software.

2. Methods

Simplex Method

The Simplex Method Linear Program is a solution method to find the maximum solution iteratively (iteratively) starting from the initial baseline (unused resources) (Fikri *et al.*, 2021). In the Simplex Method, the model is changed in the form of tables and then mathematical steps are performed on the table (Hikmah & Nusyafitri, 2017). Mathematical steps are the replication of the process of moving from one extreme point (corner point) to another extreme point in the solution area so as to obtain an optimal value (Rumetna *et al.*, 2020).

The steps to complete the Simplex Method are, (Pratiwi, 2015).

1. Identifying problems

In identifying problems there are several points that must be determined, namely (Oktavia *et al.*, 2024),

- a. Define the objective function: maximization or minimization
- b. Define decision variables
- c. Determine the limits you have
- d. Problems that must be solved.

2. Create a mathematical model

Mathematical models are made from identifying objective functions, decision variables, constraint functions and problems to be solved.

3. Troubleshooting

In solving the problem there are several steps that must be taken, namely,

- a. Change the model to standard form

The model can be changed in the form of the following points:

- (i). For constraint functions

- If the tag then a Slack Variable should be added $\leq (S)$
 - The index of the slack variable must correspond to the order of the constraint position (if and means it is constraint 1 and constraint 2). S_1S_2 .
- (ii). For objective functions, add objective functions according to existing slack variables and artificial variables by providing a zero coefficient value for each variable.

$$Maks Z = c_1x_1 + c_2x_2 + 0S_1 + 0S_2.$$

- b. Arrange the purpose and constraint functions according to their slack and artificial variables to include in the simplex table.

Table 1. Simplex Table

C_j							
CB	Base	x_1	x_2	S_1	S_2	b_i	R_i
	S_1						
	S_2						
	Z_j						
	$C_j - Z_j$						

Simplex Table Description:

- CB = Coefficient of the objective function for the base variable
- Base Variable = Variable whose value is not zero
- x_1 & x_2 = Coefficient of production
- Slack variables = Coefficient of slack variables in objective function
- b_i = Quantity or right value
- Column headers = Variables & coefficients in the objective function
- s_1 & s_2 = Equations in constraint functions
- Z_j = Total profit earned
- $- C_jZ_j$ = Net profit (problem to be solved)
- R_i = divided by the key column. b_i

- c. Define key fields

Select the $C_j - Z_j$ row that has the largest positive value if there are two equal ones can choose one.

- d. Define a key row

The key row is determined by dividing the value of b_i by each number in the key column. The key row is the row with the smallest result, if there is the same you can choose one.

'Ignore if there is a negative value and infinity'

- e. Specifying key numbers (element pivots)

Select a number at the intersection of the key row and key column.

- f. Breaking by Iteration

The steps to solve it by means of Iteration are as follows:

- i. Create a new Table with the name "Iteration Table 1".
- ii. Replace the value CB on the key row with the value on the key column C_j
- iii. Replace the base variable. Suppose the key row is on the row S_1 , then it will go out of the base and its place is replaced with the key column mix production variable (x_1 or x_2).
- g. Find a new number on the key row by dividing all the numbers on the key row by the key number (pivot element).
- h. Find new Numbers on non key rows with formula
(CB value and base variable unchanged)

$$\begin{aligned} \text{(New number on non-key row)} &= \text{(old number on non-key line)} - \{ \text{New numbers on the lock row} \times \text{The number of the key column intersects with the row you are looking for} \} \end{aligned}$$

- i. Fill in each column Z_j
Sum the multiplication of each number in the CB column with the mix product column whose value will be searched according to the sum of the constraint function equations.
- j. Fill in the $C_j - Z_j$ columns.
- k. The optimal solution is obtained if the value in the column $C_j - Z_j$ is zero or negative. If there is still a positive value, repeat step 4 until the line $C_j - Z_j$ does not contain a positive value.

Integer Linear Programming

Integer Linear Programming is a linear program model that is specifically used to adjust a problem where the value of the decision variables in optimal solution must be an Integer number (Saudin & Kiki, 2015). In other words, among the various integers, we must look for the values of feasible variables and make the maximum objective function. The use of integer variables provides additional flexibility in model creation (Sopacua & Pailin, 2015).

Linear Programming integers are needed when decisions have to be made in the form of integers (not fractions that often occur when we use the Simplex Method). The mathematical model of integer programming is actually the same as the *linear programming model*, with the added constraint that the variable must be an integer.

Branch and Bound Method

This method is one of the methods to produce the optimal completion of linear programming that produces integer decision variables (Purba & Ahyaningsih, 2020). As the name implies, this method divides the problem into sub-problems (branching) whose initial solution is in the form of fractional numbers and then creates an upper and lower branches for each variable of the fractional number decision to have an integer value, thus forming a search tree structure that generates new branches and performs constraints (bounding) to achieve the optimal solution (Supatimah et al., 2019).

The steps of the Branch and bound Method in determining the Integer solution are as follows (Elfira et al, 2020):

- a) Get the optimal Simplex solution from a linear program model that is still not Integer.

- b) Specify the Simplex solution as the upper bound, while the rounded solution down as the lower bound.
- c) Select the variable with the largest fractional portion for the branch. Create two new constraints for these variables that reflect the division of Integer values. The result is a limitation and a limitation $\leq \geq$.
- d) Create two sub-problems, one with \leq constraints and one with \geq constraints.
- e) Solve the linear program model with new constraints and added constraints added to each sub-problem.
- f) If this process results in a feasible Integer solution, meaning that the optimal solution value is between the upper and lower bounds and already has an Integer value, then the solution is feasible.
- g) If there is no feasible Integer solution, branch again.
- h) Repeat step C.

To make it easier to understand the steps in the Simplex Method and the Branch and Bound Method, consider the following image:

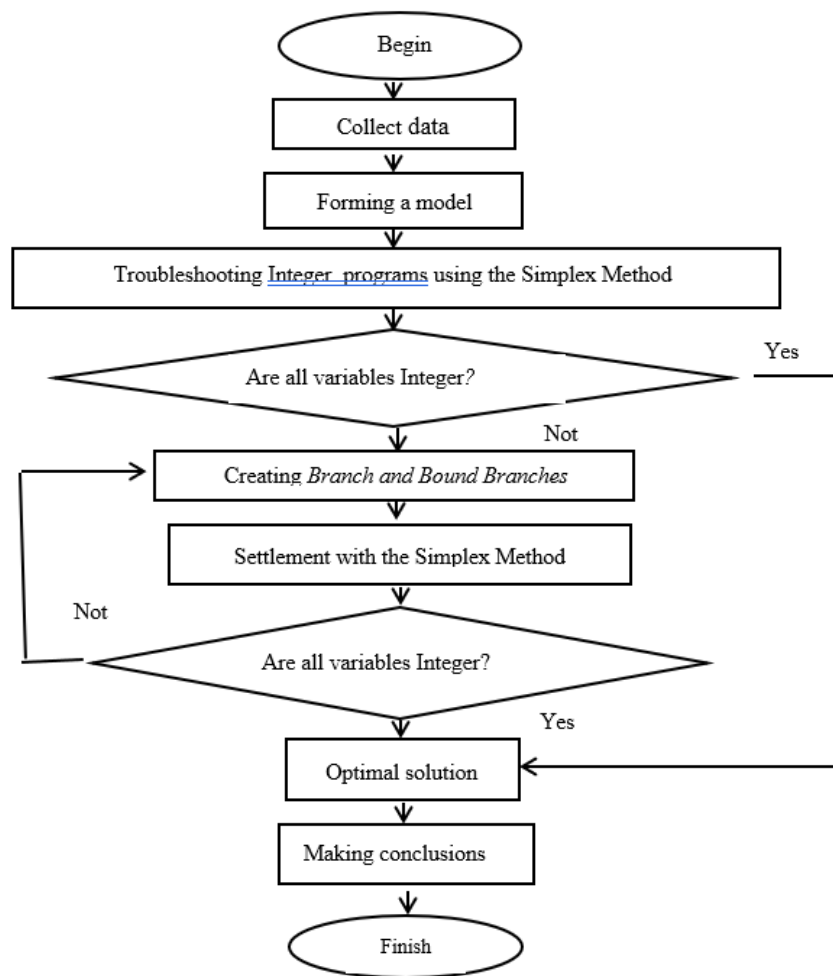


Figure 1. Flowchart Branch and Bound Method

3. Results and Discussion

UMKM Rendang Nan Lamak

In this study, Rendang Nan Lamak produced by Mrs. Vira Agusta were used. After observations in the field in the form of questionnaires, interviews and interviews were obtained data on raw material needs and profits in one production. Where one production produces 2 kg of rendang each can be seen in the following Table 2:

Table 2. Needs and Availability of Raw Materials for One-Time Production (2 kg of rendang)

NO	Constraints	Production Requirements (kg)				In Stock (Kg)
		x_1	x_2	x_3	x_4	
1.	Beef	1	0	0	0	2
2.	Lokan	0	3	0	2	6
3.	Vegetable Fern	0	0	10	5	15
4.	Coconut Cream	1,5	1,5	1,5	1,5	6
5.	Red Chili	0,5	0,5	0,5	0,5	2
6.	Red Onion	0,1	0,08	0,06	0,07	0,5
7.	Garlic	0,09	0,07	0,05	0,06	0,5
8.	Cayenne pepper	0,25	0,25	0,25	0,25	1

Table 3. Profit of One-Time Sale of Production (2 kg of rendang)

NO	Description	Sum			
		Beef Rendang	Rendang Lokan	Rendang please	Rendang Fern Lokan
1.	Production Cost	IDR 157,000	IDR 82,000	IDR 102,000	IDR 127,000
2.	Selling Price	IDR 300,000	IDR 150,000	IDR 195,000	IDR 190,000
3.	1x production advantage	IDR 143,000	IDR 68,000	IDR 93,000	IDR 63,000
4.	Advantages of 1 kg of rendang	IDR 71,500	IDR 34,000	IDR 46,500	IDR 31,500

Based on **Table 2**, a linear system with an obstacle function is obtained,

$$\begin{aligned}
 &x_1 \leq 2, \\
 &3x_2 + 2x_4 \leq 6, \\
 &10x_3 + 5x_4 \leq 15, \\
 &1,5x_1 + 1,5x_2 + 1,5x_3 + 1,5x_4 \leq 6, \\
 &0,5x_1 + 0,5x_2 + 0,5x_3 + 0,5x_4 \leq 2, \\
 &0,1x_1 + 0,08x_2 + 0,06x_3 + 0,07x_4 \leq 0,5, \\
 &0,09x_1 + 0,07x_2 + 0,05x_3 + 0,06x_4 \leq 0,5, \\
 &0,25x_1 + 0,25x_2 + 0,25x_3 + 0,25x_4 \leq 1.
 \end{aligned} \tag{3}$$

Notice in equation (3), it is known that all constraint functions have a sign \leq so a Slack variable is added to the constraint function. As a result, an obstacle function containing Slack variables is obtained,

$$x_1 + S_1 = 2,$$

$$\begin{aligned}
 3x_2 + 2x_4 + S_2 &= 6, \\
 10x_3 + 5x_4 + S_3 &= 15, \\
 1,5x_1 + 1,5x_2 + 1,5x_3 + 1,5x_4 + S_4 &= 6, \\
 0,5x_1 + 0,5x_2 + 0,5x_3 + 0,5x_4 + S_5 &= 2, \\
 0,1x_1 + 0,08x_2 + 0,06x_3 + 0,07x_4 + S_6 &= 0,5, \\
 0,09x_1 + 0,07x_2 + 0,05x_3 + 0,06x_4 + S_7 &= 0,5, \\
 0,25x_1 + 0,25x_2 + 0,25x_3 + 0,25x_4 + S_8 &= 1,
 \end{aligned}
 \tag{4}$$

$$x_i \geq 0, i = 1, 2, 3, 4 \text{ dan } S_j \geq 0, j = 1, 2, \dots, 8.$$




Based on Table 3, the objective function is obtained, namely,

$$\text{Max } Z = 71.500x_1 + 34.000x_2 + 46.500x_3 + 31.500x_4 + 0S_1 + 0S_2 + 0S_3 + 0S_4 + 0S_5 + 0S_6 + 0S_7 + 0S_8.
 \tag{5}$$

In equation 5 there is an S variable where the S variable is added because for the sign constraint function, \leq , the S variable (slack variable) must be added. Based on Table 2 and Table 3, the Initial Table is formed in obtaining maximum profit using the Simplex Table Method as shown in Table 4 as follows:

Table 4. Initial Table

C	Cj	71.500	34.000	46.500	31.500	0	0	0	0	0	0	0	0	0	0	0	0	b_i	R_i
B	Basis	x_1	x_2	x_3	x_4	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8						
0	S_1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	2/1 = 2
0	S_2	0	3	0	2	0	1	0	0	0	0	0	0	0	0	0	0	6	6/0 = undefined
0	S_3	0	0	10	5	0	0	1	0	0	0	0	0	0	0	0	0	15	15/0 = undefined
0	S_4	1,5	1,5	1,5	1,5	0	0	0	1	0	0	0	0	0	0	0	0	6	6/1,5 = 4
0	S_5	0,5	0,5	0,5	0,5	0	0	0	0	1	0	0	0	0	0	0	0	1	1/0,5 = 4
0	S_6	0,1	0,08	0,06	0,07	0	0	0	0	0	1	0	0	0	0	0	0	0,5/0,1 = 5	5
0	S_7	0,09	0,07	0,05	0,06	0	0	0	0	0	0	0	1	0	0	0	0	0,5/0,09 = 5,55	5
0	S_8	0,25	0,25	0,25	0,25	0	0	0	0	0	0	0	0	1	0	0	0	1	1/0,25 = 4
	Z_j	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	C_j	71.500	34.000	46.500	31.500	0	0	0	0	0	0	0	0	0	0	0	0		
	$-Z_j$																		

 = key field  = key line  = key number

Based on Table 4, we can determine the value in the row Z_j . Because the results of the $C_j - Z_j$ line still have positive values, the solution is not maximum. The solution to be maximum if the value of the line $C_j - Z_j$ is already negative or 0. For the next stage, Iteration must be done by creating the Iteration Table 1 which is seen in Table 6 as follows:

From the key row we have to change the existing number on the key row to get the new number on the key row seen in the following Table 5:

Table 5. Finding New Numbers on Key Rows

Old lock row	1	0	0	0	1	0	0	0	0	0	0	0	0	2
Key numbers	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BK's new numbers	1	0	0	0	1	0	0	0	0	0	0	0	0	2

The new number of the key row is moved to the new key row in the iteration table 1 As for the empty row, i.e. the non key row is specified in the way,

$$\begin{aligned}
 & \text{(New number on non-key row)} = \text{(old number on non-key line)} - \{ \text{New numbers on the lock row} \times \text{The number of the key column intersects with the row you are looking for} \}
 \end{aligned}$$

Table 6. Iteration Table 1 (Iteration Table 1 Final Result)

CB	C_j	71.50	34.00	46.50	31.50	0	0	0	0	0	0	0	0	0	b_i	R_i
	Basis	x_1	x_2	x_3	x_4	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8			
71.50	x_1	1	0	0	0	1	0	0	0	0	0	0	0	2	$2/0 = \infty$	
0	S_2	0	3	0	2	0	1	0	0	0	0	0	0	6	$6/0 = \infty$	
0	S_3	0	0	10	5	0	0	1	0	0	0	0	0	15	$15/10 = 1,5$	
0	S_4	0	1,5	1,5	1,5	-1,5	0	0	1	0	0	0	0	3	$3/1,5 = 2$	
0	S_5	0	0,5	0,5	0,5	-0,5	0	0	0	1	0	0	0	1	$1/0,5 = 4$	
0	S_6	0	0,08	0,06	0,07	-0,1	0	0	0	0	1	0	0	0,3	$0,3/0,06 = 5$	
0	S_7	0	0,07	0,05	0,06	-0,09	0	0	0	0	0	1	0	0,32	$0,32/0,05 = 6,4$	
0	S_8	0	0,25	0,25	0,25	-0,25	0	0	0	0	0	0	1	0,5	$0,5/0,25 = 2$	
	Z_j	71.50	0	0	0	71.50	0	0	0	0	0	0	0	143.00		
		0				0								0		
	C_j	0	34.00	46.50	31.50	-	0	0	0	0	0	0	0			
	$-Z_j$	0	0	0	0	71.50										
						0										

The results of the first, second, third, and seventh nonkey rows are moved to Table 6 of the Iteration Table 1. Before forming the Iteration Table 1, first determine the value of the Z_j row and the $C_j - Z_j$

line. Once the value on the Z_j row is obtained, the next step is to subtract the C_j row by the Z_j row. Thus Table 6 of the Iteration Table 1 is formed which can be seen in the following table.

Based on Table 6, the result of the value of $C_j - Z_j$ is still positive, the value is still not maximum, so it is continued to the next Iteration Table in the same way when creating Iteration Table 1. After searching for several iteration tables, the optimal final result can be found in the following 3rd iteration table:

Table 7. Iteration Table 3 (Iteration Table 3 Final Result)

CB	C_j	71.5	34.0	46.5	31.5	0	0	0	0	0	0	0	0	0	b_i
		00	00	00	00										
	Basis	x_1	x_2	x_3	x_4	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8		
71.5	x_1	1	0	0	0	1	0	0	0	0	0	0	0	0	2
0	S_2	0	0	0	0,5	3	1	0,3	-2	0	0	0	0	0	4,5
46.5	x_3	0	0	1	0,5	0	0	0,1	0	0	0	0	0	0	1,5
34.0	x_2	0	1	0	0,5	-1	0	-0,1	0,666	0	0	0	0	0	0,5
0	S_5	0	0	0	0	0	0	0	-	1	0	0	0	0	0
									0,333						
0	x_2	0	0	0	0	-0,02	0	0,00	-	0	1	0	0	0	0,17
									2						
									0,053						
									3						
0	S_7	0	0	0	0	-0,02	0	0,00	-	0	0	1	0	0	0,21
									2						
									0,046						
									7						
0	S_8	0	0	0	0	0	0	0	-	0	0	0	1	0	0
									0,166						
									7						
	Z_j	71.5	34.0	46.5	40.2	37.50		1.25	22.66						229.7
		00	00	00	50	0		0	7,8						50
	C_j	0	0	0	-	-		-	-						
	$-Z_j$				8.75	37.50		1.25	22.66						
					0	0		0	7,8						

Because the value in the column $C_j - Z_j$ has a value of zero or negative, the solution is optimal and the calculation is stopped by doing three iterations, the result of solving the variable value is obtained, and the value of $Z = 229,750.x_1 = 2, x_2 = 0,5x_3 = 1,5x_4 = 0$

Branch and Bound Method

Based on the results of the linear program through the Simplex Method, the optimal values = 2, = 0.5, $x_1 x_2 x_3 = 1.5$ and = 0 and $Z = \text{Rp } 229,750$. x_4 Because the value of the expected decision variable is Integer, then continued with Integer Linear Programming using the Branch and Bound Method. The calculation steps of the Branch and Bound Method are as follows:

- a) The results of the simplex solution are =2, =0.5, $x_1 x_2 x_3 = 1.5$ and =0. x_4 From the results of the simplex solution, it can be seen that the variables that are still not Integer are = 0.5 and $x_2 x_3 = 1.5$.
- b) The result of the simplex solution is = 2, = 0.5, $x_1 x_2 x_3 = 1.5$ and = 0 and $Z = \text{Rp } 229,750$, because $x_4 x_2$ and x_3 not an Integer number then this solution is not feasible. However, the revenue value of the simplex Z solution = $\text{Rp } 229,750$ is used as the upper limit (BA). With the downward rounding method, the solution x_1 value = 2, = 0 $x_2 x_3 = 1$ and = 0 with the income value $x_4 Z = \text{Rp } 189,500$ is used as the lower limit.
- c) Select the variable with the largest fractional portion for the branch. Create two new constraints for these variables that reflect the division of Integer values. The result is a limitation and a limitation $\leq \geq$.

The largest fractional variables are $x_2 = 0.5$ and = 1.5. Create two new constraints of the largest fraction for variables $x_3 x_2 = 0 x_2 \leq$ and $x_2 \geq 1$ and for variables 1 and . $x_3 = x_3 \leq x_3 \geq 2$

- d) For the first case, create two sub-problems, namely, sub-problem 1 and sub-problem 2 with variable values of $x_2 \leq 0$ and $x_2 \geq 1$. For the second case, also create two sub problems, namely: sub problem 3 and sub problem 4 with variables 1 and . $x_3 \leq x_3 \geq 2$
- e) The linear program model used is the Simplex Method with the help of POM-QM V5 software which can be seen in the following image of the branching tree.

Before looking for the value of each constraint first assume the initial value for the first case and the second case i.e., the solution value of the Simplex Method can be seen in the following branching tree:

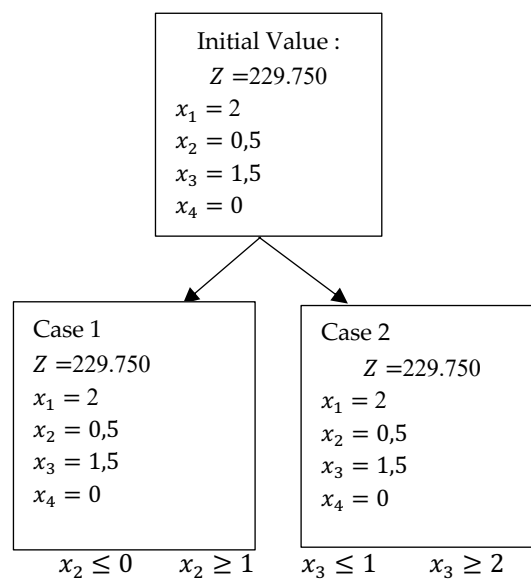


Figure 2. Branching tree of the initial values of Case 1 and Case 2

Furthermore, to find the solution value of each case one and case two, where for the first case it is divided into two sub-problems, namely sub-problem one and sub-problem two, and for the second case it is also divided into two sub-problems, namely sub-problem three and sub-problem four, the Simplex Method Linear Program is used with the help of the POM-QM V5 software, which can be seen in the following figure:

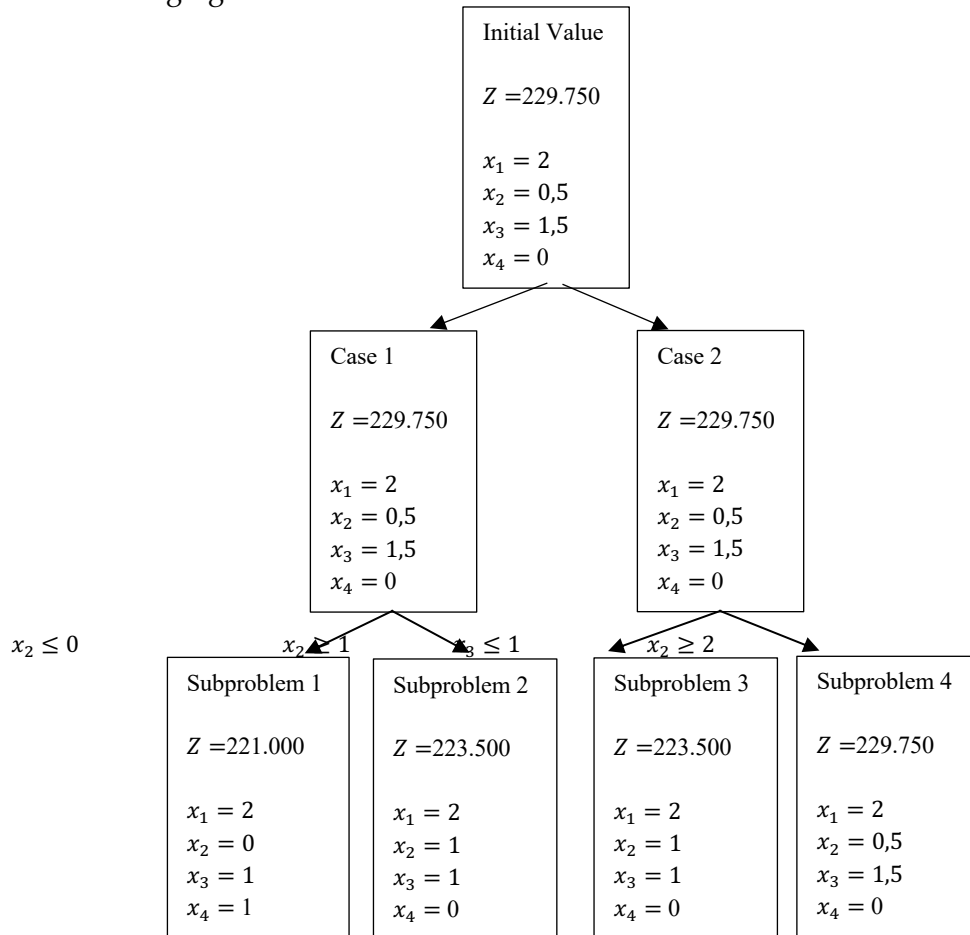


Figure 3. Final results of branching for case 1 and case 2

Based on Figure 3. The most optimal value and the value of the solution that is between the upper and lower bounds with greater advantages are in sub problem 2, $x_2 \geq 1$, and sub problem 3, $x_3 \leq 1$, with the solution variable values $x_1 = 2$, $x_2 = 1$, $x_3 = 1$, and $x_4 = 0$ and $Z = 223,500$. Because the values in sub-problem 2 and sub-problem 3 have the exact same optimal solution value, the optimal solution value is at $x_2 \geq 1$ and $x_3 \leq 1$.

Conclusion

Based on calculations using the Branch and Bound Method on Rendang Nan Lamak owned by Mrs. Vira Agusta, it resulted in an optimal sales profit of Rp. 223,500. If production is increased for beef rendang by 2 kg, lokan rendang 1 kg and fern rendang 1 kg more than the previous production. So that there was an increase in profits from the initial profit of Rp. 183,500 to reach the optimal profit of Rp. 223,500. As a result, the profit difference from before and after optimization was obtained was Rp. 40,000. After calculations, it can be seen that the one that has experienced a lot of production increase is beef rendang. So that for rendang that is in great demand by consumers is beef rendang.

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