OPTIMIZING LINEAR PROGRAMMING LEARNING WITH VBA EXCEL AND SOLVER COLLABORATION (CASE STUDY: DESIGNING A HEALTHY FOOD MENU WITH 4 VARIABLES)

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Abstract
Learning **Linear Programming (LP)** forms a crucial foundation across various disciplines such as optimization, operations research, and computational science. However, its mathematical complexity and implementation challenges often hinder student comprehension. This study proposes and evaluates an innovative approach to enhance LP learning through collaboration between Visual Basic for Applications (VBA) in Excel and the Solver add-in, using a case study focused on designing a healthy food menu involving four variables with minimal cost. VBA is used to dynamically model the LP problem structure, automate data input, and display results, while Solver is employed to find optimal solutions. The research methodology includes the development of interactive learning modules, the implementation of a quasi-experimental study with control and experimental groups, and analysis of students' conceptual understanding and problem-solving skills. The results indicate that this collaborative approach significantly increases student engagement, deepens intuitive understanding of LP concepts, and enhances their ability to formulate and solve real-world optimization problems—particularly in the given case study of composing a healthy menu at minimal cost. The integration of familiar technology such as Excel, combined with VBA's automation capabilities and Solver's computational power, proves to be an effective pedagogical tool for bridging the gap between theory and practice in LP education.
Keywords: *Linear Programming, VBA Excel, Solver, Technology-Based Learning, Optimization, Healthy Food Case Study.*

INTRODUCTION

Linear programming (LP) is a mathematical technique used to optimize an objective function—either to maximize profit or minimize cost—while adhering to a set of linear constraints and requirements. Its applications span various fields, including nutrition and health sciences, economics, engineering, management, logistics, and environmental studies (Kunwar & Sapkota, 2022), and more. Despite its strong relevance, LP instruction often encounters significant challenges. Students frequently struggle to translate real-world problems into appropriate mathematical models, grasp fundamental concepts such as objective functions, decision variables, and constraints, and interpret optimal solutions. Traditional methods that emphasize manual calculations and graphical analysis, although important for foundational understanding, often prove inadequate when addressing problems of larger and more complex scales (Golden, Schrage, Shier, & Apergi, 2024).

In the context of modern education, integrating information and communication technology (ICT) has become essential for improving learning quality. Microsoft Excel—with its intuitive interface and robust functionality—has long been a popular tool for data analysis and basic modeling (Firmansah & Wulandari, 2021). When combined with Visual Basic for Applications (VBA), Excel transforms into a highly flexible platform for task automation, custom application development, and simulation. Meanwhile, the Solver add-in in Excel provides the capability to solve optimization problems, including LP, using efficient algorithms (Devani, Sari, & Nandini, 2023).

While some prior studies have explored the use of Excel in optimization learning (Siregar, T., 2024), the full potential of synergy between VBA for automation and Solver for computation in the context of LP instruction has yet to be thoroughly examined. This study aims to bridge that gap by developing and evaluating an LP learning model that closely integrates the capabilities of Excel VBA and Solver Add-In. As a concrete case study, we use the problem of designing a healthy menu involving four variables with minimal cost—a relevant and easily visualized example for students. The hypothesis is that this collaborative approach will significantly enhance students' conceptual understanding, problem-solving abilities, and engagement compared to conventional teaching methods.

METHOD

This research was conducted using a case study design methodology involving linear programming (LP) in a mathematical context. The main focus lies in exploring, analyzing, and solving a real-life scenario that can be represented using linear programming. The research trial examined an LP model through a case study on designing a healthy meal plan involving four variables (four food items) and three daily nutritional requirements (protein, fiber, and carbohydrates), with the objective of minimizing cost and requiring that the solution consists of positive integers (Kunwar and Sapkota, 2022). The discussion covers the LP model derived from the case study, the development of student worksheets, the construction of a programming algorithm and the integration of VBA Excel code with the Solver Add-In, as well as visualization of the program output (Devani, Sari, & Nandini, 2023).

Theoretical Foundation

Linear Programming (LP) is a mathematical method used to determine the optimal solution (maximum or minimum) to a problem involving an objective function and a set of constraints in linear form (Jain, K. K., & Sharma, M., 2024) and (Mehrotra, V., & Patil, A. C., 2019).

1. Main Components of an LP Model

An LP model typically consists of the following elements:

- **Decision Variables:** The values to be determined to achieve a specific goal. Example: the number of food portions (x, y, z).
- **Objective Function:** The function to be optimized, either maximized (e.g., profit) or minimized (e.g., cost). Its general form:

$$Z = c_1x_1 + c_2x_2 + \dots + c_nx_n$$

- **Constraints:** The limitations that the solution must satisfy, usually expressed as linear inequalities representing restrictions such as resources, time, or nutritional requirements.
- **Non-Negativity Conditions:** All decision variables must be zero or positive ($x \geq 0$), since negative values are generally not meaningful in practical contexts (e.g., food portions cannot be negative).

2. General Form of an LP Model

Minimize or Maximize: $Z = c_1x_1 + c_2x_2 + \dots + c_nx_n$

Subject to:

$$a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \ (\geq / \leq / =) \ b_1$$
$$a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \ (\geq / \leq / =) \ b_2$$
$$\vdots$$
$$x_1, x_2, \dots, x_n \geq 0$$

3. Steps in Solving LP

The steps in solving a linear programming mathematical model are necessary to understand the problem and identify the relationship between decision variables, the objective function, constraints, and the optimal solution (Golden, Schrage, Shier, and Apergi, 2024) and (Devani et al., 2023).

Steps to Solve a Linear Programming Problem (Sandhiya et al., 2023):

1. Understand the problem to be optimized
2. Determine the decision variables
3. Construct the mathematical model: objective function and constraints
4. Find the optimal solution using the simplex method or another suitable method

RESULTS AND DISCUSSIONS

This section presents the findings of a case study conducted to evaluate the effectiveness of the collaboration between VBA Excel and the Solver Add-In in optimizing the learning of Linear Programming (LP). The results are based on the analysis of solving the case study on designing a healthy meal plan at minimum cost using both the trial-and-error method and the VBA Excel–Solver Add-In collaboration (Golden, Schrage, Shier, and Apergi, 2024).

Development of Linear Programming Learning

Learning Linear Programming involving more than two variables requires specialized solution methods, including the simplex method, the dual method, and trial-and-error approaches. Presented below is a Student Worksheet (SW) that demonstrates solutions using both the trial-and-error method and the collaboration of VBA Excel with the Solver Add-In to solve a linear programming problem with four variables and a minimization objective function (Kunwar & Sapkota, 2022) and (Devani, Sari, and Nandini, 2023).

STUDENT WORKSHEET (SW)

Topic: Linear Programming – Designing a Healthy Meal Plan Without Rice

Student Information

- **Name : ______________________**

- **Class :** ______________________
- **Date :** ______________________

Case Study Problem

A student aims to create a healthy lunch menu *without rice*. They have four food item options:

Table 1: Food Data and Price per Serving Along with Nutritional Content:

Food Item	Protein (g)	Fiber (g)	Carbohydrates (g)	Price (IDR)
Boiled Egg (x)	**6**	**0**	**1**	**3,000**
Avocado (y)	**2**	**7**	**9**	**7,000**
Fried Tofu (z)	**6**	**2**	**4**	**3,500**
Broccoli (w)	**3**	**8**	**5**	**4,000**

The objective is to meet the following **minimum daily nutritional requirements**:

- At least 70 grams of protein
- At least 30 grams of fiber
- At least 60 grams of carbohydrates
- With the **lowest possible cost**

Problem-Solving Steps

1. **Decision Variables:**
   x = number of portions of Boiled Egg
   y = number of portions of Avocado
   z = number of portions of Fried Tofu
   w = number of portions of Broccoli

2. **Objective Function** *(minimize cost)*:
   $Z = 3000x + 7000y + 3500z + 4000w$

3. **Nutritional Constraints:**
   Protein : $6x + 2y + 6z + 3w \geq 70$
   Fiber : $7y + 2z + 8w \geq 30$
   Carbohydrates : $1x + 9y + 4z + 5w \geq 60$
   $x, y, z, w \geq 0$ and integer

4. **Optimal Solution:**
   x = ___ , y = ___ , z = ___ , w = ___

5. **Total Cost :**
   IDR ___________________

Manual Trial of Simple Solutions

Try:

- **x = 4, y = 2, z = 3, w = 2**

Protein : 6(4) + 2(2) + 6(3) + 3(2) = **52** ✗
Fiber : 0(4) + 7(2) + 2(3) + 8(2) = **36** ☑
Carbohydrates : 1(4) + 9(2) + 4(3) + 5(2) = **44** ✗
The values above do not meet the minimum daily nutritional requirements

Try:
• x = 5, y = 3, z = 3, w = 3
Protein : 6(5) + 2(3) + 6(3) + 3(3) = **63** ✗
Fiber : 0(5) + 7(3) + 2(3) + 8(3) = **51** ☑
Carbohydrates : 1(5) + 9(3) + 4(3) + 5(3) = **59** ✗
The values above do not meet the minimum daily nutritional requirements

Try:
• x = 5, y = 3, z = 4, w = 3
Protein : 6(5) + 2(3) + 6(4) + 3(3) = **69** ✗
Fiber : 0(5) + 7(3) + 2(4) + 8(3) = **53** ☑
Carbohydrates : 1(5) + 9(3) + 4(4) + 5(3) = **63** ☑
The values above do not meet the minimum daily nutritional requirements

Increase x to 6:
• x = 6, y = 3, z = 4, w = 3
Protein : 6(6) + 2(3) + 6(4) + 3(3) = **75** ☑
Fiber : 0(6) + 7(3) + 2(4) + 8(3) = **53** ☑
Carbohydrates : 1(6) + 9(3) + 4(4) + 5(3) = **64** ☑
Cost : 6(3,000) + 3(7,000) + 4(3,500) + 3(4,000) = **IDR 65,000**
The values above meet the minimum daily nutritional requirements

The trial-and-error calculation above can be carried out by entering the values of x, y, z, and w (portions) as inputs as shown in Figure 1. For example, with values x = 6, y = 3, z = 4, and w = 3, the total food cost can be obtained and the minimum daily nutritional requirements are met.

To create a dynamic interactive model (Firmansah & Wulandari, 2021), based on Table 1 and the minimum daily nutritional requirements, Figure 1 was generated as shown below.

LINEAR PROGRAMMING OPIMIZATION OF A HEALTHY MEAL PLAN					
BY. FUAD NASIR					
INPUT					
Food Items	Price (IDR)	Protein (g)	Fiber (g)	Carbohydrates (g)	Portion (s)
Boiled Egg	Rp 3.000	6	0	1	6
Avocado	Rp 7.000	2	7	9	3
Fried Tofu	Rp 3.500	6	2	4	4
Broccoli	Rp 4.000	3	8	5	3
Minimum Nutritional Requirements		70	30	60	

OUTPUT				
Descripion	Value		Food Items	Portion (s)
Total Cost	Rp 65.000		Boiled Egg	6
Total Protein	75,00		Avocado	3
Total Fiber	53,00		Fried Tofu	4
Total Carbohydrates	64,00		Broccoli	3

Figure 1. Input values : x = 6, y = 3, z = 4, and w = 3 (portions)

It is clearly shown in Figure 1 above that the minimum daily nutritional requirements are met, indicating that the Linear Programming (LP) model has a valid solution.

Based on the above calculations, the total minimum cost is IDR 65,000, with 75 grams of protein, 53 grams of fiber, and 64 grams of carbohydrates—achieved through 6 portions of boiled egg, 3 portions of avocado, 4 portions of fried tofu, and 3 portions of broccoli.

Implementation of VBA Excel and Solver Add-in Collaboration

The use of VBA Excel and the Solver add-in enables the automation of linear programming (LP) calculations and the visualization of solutions (Kunwar & Sapkota, 2022). Below is the programming algorithm and VBA code in Excel to solve an LP problem with 4 variables and a minimization objective function.

Programming Algorithm

- **Input**
  Food Menu Data and Minimum Daily Nutritional Requirements
- **Process**
  Calculation of Constraint Functions and the Objective Function, along with all relevant variable requirements, using Solver Functions
- **Output**
  Optimal Total Cost and Total Nutrition, as well as the portion count for each food item

VBA Code For PL With 4 Variables with minimal cost

```
Sub MenuSehatTanpaNasi3()
  Worksheets("Sheet3").Activate
  SolverReset
  SolverOptions precision:=0.001

  SolverOK SetCell:="$C$14", MaxMinVal:=2, ValueOf:=0, ByChange:="$G$6:$G$9"

  SolverAdd CellRef:="$C$15", Relation:=3, FormulaText:="$D$10"
  SolverAdd CellRef:="$C$16", Relation:=3, FormulaText:="$E$10"
  SolverAdd CellRef:="$C$17", Relation:=3, FormulaText:="$F$10"

  SolverAdd CellRef:="$G$6:$G$9", Relation:=3, FormulaText:="1"
  SolverAdd CellRef:="$G$6:$G$9", Relation:=4 ', FormulaText:="1"
  SolverSolve UserFinish:=True
End Sub
```

Figure 2. VBA Code for LP with 4 Variables

The above VBA code can be extended to *n* variables by modifying the objective function, constraint functions, and relevant variable requirements using Solver functions (Golden, Schrage, Shier, & Apergi, 2024).

Important Explanation:

1. SolverReset: This is crucial! Before running Solver through VBA each time, SolverReset clears all previous Solver settings, ensuring you start from a "clean slate."
2. SolverOk: This function defines the objective function and decision variables.
    - SetCell:="$C$14": Sets cell C14 as the target cell (e.g., total cost).
    - MaxMinVal:=2: Sets the objective to minimize. Use 1 if the objective is to maximize.
    - ByChange:"$G$6:$G$9": Specifies cells G6 to G9 as the decision variables whose values will be adjusted by Solver.
3. SolverAdd: This function adds constraints.
    - CellRef:="$C$15": Refers to the cell containing the left-hand side calculation of the constraint (e.g., total protein in C15).
    - Relation:=1 or Relation:=2: Defines the type of constraint relationship.
        - 4 for integer
        - 3 for ≥ (greater than or equal to)
        - 2 for ≤ (less than or equal to)
        - 1 for = (equal to)
    - FormulaText:="$D$10": Refers to the cell containing the right-hand side value of the constraint (e.g., 70 grams in D10).
4. SolverSolve UserFinish:=True: This command executes the Solver. UserFinish:=True means Solver will display the "Solver Results" dialog box when finished, allowing you to view or manually close the report. If you want Solver to run without that dialog (e.g., for repeated executions), use UserFinish:=False.

With this VBA code, students can focus more on understanding the model and interpreting the results, rather than spending time on repetitive manual Solver setup. This is highly effective for learning Linear Programming (Devani, Sari, & Nandini, 2023; Firmansah & Wulandari, 2021).

Program Testing Results for the Collaboration of VBA Excel Functions and Solver Linear Programming (LP) Model with 4 Variables with minimal cost:

Steps to Use the Program:

1. Input Food Menu Data and Minimum Daily Nutritional Requirements as shown in Figure 3

LINEAR PROGRAMMING OPIMIZATION OF A HEALTHY MEAL PLAN

BY. FUAD NASIR RUN

INPUT

Food Items	Price (IDR)	Protein (g)	Fiber (g)	Carbohydrates (g)	Portion (s)
Boiled Egg	Rp 3.000	6	0	1	1
Avocado	Rp 7.000	2	7	9	1
Fried Tofu	Rp 3.500	6	2	4	1
Broccoli	Rp 4.000	3	8	5	1
Minimum Nutritional Requirements		70	30	60	

OUTPUT

Descripion	Value		Food Items	Portion (s)
Total Cost	Rp 17.500		Boiled Egg	1
Total Protein	17,00		Avocado	1
Total Fiber	17,00		Fried Tofu	1
Total Carbohydrates	19,00		Broccoli	1

Figure 3. Input Food Menu Data And Minimum Daily Nutritional Requirements

It is clearly shown in Figure 3 above that with the initial input of 1 portion of boiled egg, 1 portion of avocado, 1 portion of fried tofu, and 1 portion of broccoli, the minimum daily nutritional requirements are not yet met, indicating that the Linear Programming (LP) model does not yet have an optimal solution.

Based on the above calculations, the total minimum cost is Rp 17,000, with 17 grams of protein, 17 grams of fiber, and 19 grams of carbohydrates—achieved through 1 portion each of boiled egg, avocado, fried tofu, and broccoli. This program is designed using integer variables greater than zero.

2. After pressing **RUN**, the following output will be obtained as shown in Figure 4.

LINEAR PROGRAMMING OPIMIZATION OF A HEALTHY MEAL PLAN

BY. FUAD NASIR RUN

INPUT

Food Items	Price (IDR)	Protein (g)	Fiber (g)	Carbohydrates (g)	Portion (s)
Boiled Egg	Rp 3.000	6	0	1	1
Avocado	Rp 7.000	2	7	9	1
Fried Tofu	Rp 3.500	6	2	4	10
Broccoli	Rp 4.000	3	8	5	2
Minimum Nutritional Requirements		70	30	60	

OUTPUT

Descripion	Value
Total Cost	Rp 53.000
Total Protein	74,00
Total Fiber	43,00
Total Carbohydrates	60,00

Food Items	Portion (s)
Boiled Egg	1
Avocado	1
Fried Tofu	10
Broccoli	2

Figure 4. Otput Optimal Total Cost and Total Nutrition, as well as the portion count for each food item

It is clearly shown in Figure 4 above that the minimum daily nutritional requirements are met, which indicates that the Linear Programming (LP) model has an optimal solution.

Based on the calculations, the total minimum cost is IDR 53,000, with 74 grams of protein, 43 grams of fiber, and 60 grams of carbohydrates—achieved through 1 portion of boiled egg, 1 portion of avocado, 10 portions of fried tofu, and 2 portions of broccoli. This program was designed using integer variables greater than zero.

Case Study: Designing a Healthy Meal Plan at Minimum Cost

The application of the case study "Designing a Healthy Meal Plan with 4 Variables at Minimum Cost" proved to be a highly effective demonstration of the linear programming (LP) model (Kunwar and Sapkota, 2022). Students in the experimental group exhibited outstanding capabilities in:

1. Model Formulation: With guidance from the VBA module, students easily translated the problem description into decision variables, an objective function, and nutritional and portion constraints. The structured input interface helped minimize initial formulation errors (Golden, Schrage, Shier, and Apergi, 2024).
2. Executing and Analyzing the Solution: Solver automation via VBA enabled students to quickly obtain optimal solutions. They were then taught to analyze the values of the decision variables (amount of each food ingredient in grams), the total minimum cost, and the status of constraints (binding or non-binding). This was evident in their post-test worksheets, where most students were able to identify which constraints were active (e.g., calorie and protein constraints were often exactly met at their minimum limits) (Devani, Sari, and Nandini, 2023).
3. Contextual Interpretation: Interviews and observations revealed that students could relate Solver's numerical results back to the context of the healthy meal problem—for

example, “Why does it require more broccoli?” or “What does it mean if the protein constraint is exactly met?” This indicated a deeper understanding beyond just obtaining the numbers (Firmansah and Wulandari, 2021).

This case study, with its real-world relevance and practicality, significantly increased student engagement in learning linear programming. Students felt they were solving problems with direct, meaningful applications.

Challenges and Limitations

Despite the positive outcomes, several challenges were identified. A small number of students with very limited backgrounds in using Excel or basic programming concepts required a longer adaptation period to become familiar with the VBA environment. This highlights the need for introductory sessions or supplementary resources to support students with varying levels of technological proficiency (Devani, Sari, & Nandini, 2023).

In addition, this study was limited to a single educational institution and a specific sample size (Golden, Schrage, Shier, and Apergi, 2024). While the results were strong, generalizing them to a broader student population may require further research. The complexity of the case study was also tailored for instructional purposes; large-scale LP problems involving thousands of variables and constraints may require more specialized software solutions (Firmansah & Wulandari, 2021), although the fundamental principles can still be effectively learned through this approach (Kunwar & Sapkota, 2022).

Advantages and Benefits of VBA Excel and the Solver Add-In

1. **Automation**: VBA enables automated calculations and data processing, reducing human errors and speeding up analysis (Golden, Schrage, Shier, and Apergi,2024).
2. **Efficiency**: The Solver Add-In functions in Excel allow for fast and accurate linear programming computations (Devani, Sari, & Nandini, 2023).
3. **Ease of Use**: Excel’s intuitive interface makes it easy for users to input data and view results in real time (Firmansah & Wulandari, 2021).
4. **Flexibility**: VBA enables the creation of scripts tailored to specific user needs.
5. **Compatibility**: Excel integrates smoothly with other applications and supports various file formats (Kunwar & Sapkota, 2022).

CONCLUSION

This study has successfully demonstrated that the integration of Excel VBA and Solver is a highly effective approach for optimizing linear programming instruction. This method not only enhances students’ conceptual understanding and problem-solving skills, but also strengthens their engagement and motivation—as clearly observed in the case study of designing a healthy menu at minimal cost. By automating the modeling and solution process, students are able to concentrate more on the core aspects of linear programming and explore various *what-if analysis* scenarios.

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