Utilizing the Excel spreadsheet program for Formulating and solving linear programming models

Maryam Ahmed Salem Alramah
Department of Statistics, Faculty of Science, University of Tripoli

ملخص:

يهدف هذا البحث إلى إبراز أهمية استخدام جداول البيانات في حل العديد من المشاكل التي يواجهها الاقتصاديون وصناع القرار بشكل عام، والطلاب الجامعيون بشكل خاص. تساهم جداول البيانات في تقليل العديد من الصعوبات التي يواجهها الطلاب في الوصول إلى برامج التحليل الكمي المتخصصة. كما أن فهم وتطبيق مثل هذه البرامج يمكن أن يكون مستهلكًا للوقت والمال. تستخدم جداول البيانات لحل العديد من النماذج الواقعية للبرمجة الخطية في مجالات مختلفة مثل تخصيص الموارد، وجدولة الإنتاج، واتخاذ القرارات الإدارية، وحل مشاكل النقل. تشتهر جداول البيانات بسهولة فهمها وتطبيقها، حتى بالنسبة لأولئك الذين لا يمتلكون معرفة كافية بالأسس الرياضية وراء نماذج البرمجة الخطية والتحليل الكمي. يحتوي هذا البحث على مثال عملي لبناء وصياغة وحل نموذج رياضي باستخدام هذه الطريقة.

الكلمات الرئيسية: البرمجة الخطية، برنامج جداول البيانات اكسل، بحوث العمليات، البرمجة الخطية.

Abstract: This research aims to highlight the importance of using spreadsheets to solve many of the problems faced by economists, decision-makers in general, and university students in particular. Spreadsheets contribute to reducing many of the difficulties students face in accessing specialized quantitative analysis software. Also, understanding and applying such software can be time-consuming and costly. Spreadsheets are used to solve many realistic linear programming models in various fields such as resource allocation, production scheduling, managerial decision-making, and transportation problem solving. Spreadsheets are known for their ease of understanding and application, even for those who do not have sufficient knowledge of the mathematical foundations behind linear programming models and quantitative analysis. This research contains a practical example of building, formulating and solving a mathematical model using this method.

Keywords: Linear Programming, Excel spreadsheet program, Operation Research, Linear programming.

1- **Introduction**:

Linear programming models have been used in many economic problems, whether they are related to production, finance, or administration. Firstly, linear programming helps in solving problems related to the allocation of scarce resources among alternative uses, aiming to achieve maximum efficiency in this distribution. Additionally, linear programming models are used in production scheduling and in making decisions related to key management functions such as planning, organizing, and controlling. Linear programming also contributes to solving transportation and distribution problems by minimizing costs when transporting and distributing production to other areas [1]. Furthermore, linear programming is used to measure the efficiency of performance of economic and administrative units with similar inputs and outputs.

However, linear programming models require specialized expertise for practical application. Additionally, solving linear programming problems requires special software, which tends to be relatively expensive. Moreover, mastering these software programs requires a considerable amount of time [2,3].

Electronic spreadsheets are utilized to address numerous linear programming models, such as resource allocation problems, transportation logistics, decision-making processes, and production scheduling. In contrast, the Excel spreadsheet program stands out for its user-friendly interface and accessibility, making it easy for individuals with expertise in linear programming, quantitative analysis, and computer skills to utilize and comprehend [4].

The aim of this research is to highlight the importance of using electronic tables to solve many mathematical problems facing decision makers and implementers, and it is used to reduce the difficulties that researchers face in obtaining ready-made software for quantitative analysis, which is expensive and difficult to understand and when applied, it takes a period of time to absorb it. Hence, the purpose of this paper is to demonstrate the use of spreadsheets in solving linear programming problems.

2- Spreadsheet and Linear Programming Models:

Linear programming models can be solved using three methods [5]:

A. Graphical Method: This method can only be used for two variables.

B. Ordinary Method: This involves the simplex method, which requires many complex and lengthy calculations.

C. Using ready-made software programs, which are usually expensive and difficult to handle.

By using spreadsheets, especially Excel, we can overcome the difficulties encountered with the aforementioned methods. Excel has many features, including ease of use and versatility. It can be used in various fields such as financial and statistical analysis, different types of graphical representations, mathematical functions, table analysis, and management. Additionally, Excel provides the capability to solve linear programming models through the Solver feature [6]. To illustrate this, the following practical example is provided.

3- Practical Example:

Let's consider a company that produces two types of furniture: chairs (CX_1) and tables (TX_2). The company uses wood and labor in its production process. The company has 1200 available work hours and $5000 for purchasing wood. To produce one chair, it requires 4 work hours and $10, while producing one table requires 7 work hours and $35. Producing one chair yields a profit of $9, and producing one table yields a profit of $20. The question is, what is the optimal mix of products that maximizes profits?

This example can be formulated as a linear programming model in the following format:

$$Maximize\ Z(Profit) = 9CX_1 + 20TX_2$$

$$Subject\ to:$$

$$4CX_1 + 7TX_2 \leq 1200$$

$$10CX_1 + 35TX_2 \leq 5000$$

$$CX_1, TX_2 \geq 0$$

- Work constraint: This constraint limits the total available working hours to 1200 hours.

- Wood constraint: This constraint limits the total available budget for purchasing wood to $5000.

- Non-negativity constraint: This constraint ensures that the decision variables (the quantities of chairs and tables produced) cannot take negative values.

4 - Formulating and Solving the Linear Programming Model in Excel:

To formulate and solve the linear programming model in Excel, follow these steps:

1. Enter the data correctly: enter the data as shown in Figure 1 as follows:

- Enter the constraint variable and R.H.S (Side Right hand) (see cells B6:C6, B7:C7, and G6:G7). These cells are called data cells.

- Enter the decision variable data (in this step, only name the cells and enter an initial value for each decision variable, see cells B4 and C4). These cells are called changing cells.

- Enter the objective quantity (the objective function), which can be either profit maximization or cost minimization (and should be in the form of an equation depending on the values of the decision variables). The cell containing this quantity (see cell E5) is called the target cell.

- Enter the constraint values (which include both sides, the left side represents the resources used, and the right side includes the available resources). The output from the left side constraints (see cells E6:E7) is called output cells.

C1 | Solve the Linear Programming problem(LPP)

	A	B	C	D	E	F	G
1			Solve the Linear Programming problem(LPP)				
2							
3		x1	x2		Result	The signal	RHS
4	Basic decision variables	0	0				
5	Objective Function Z	9	20		$ -		
6	Constraint-C 1	4	7		0	≤	1200
7	Constraint-C 2	10	35		0	≤	5000
8							

Figure 1: Excel Worksheet with Data

2. Write the required formulas: write the formulas in Excel to represent the objective function and the constraints. Use cell references to refer to the changing cells and data cells. In this example, the following formula can be used to calculate the value of the objective (total profit), see Figure 2 and 3:

$$Objective = SUMPRODUCT\ (B4{:}C4, B5{:}C5)$$

This formula multiplies the quantity of each product (chair or table) by the profit value per unit, then adds up the results to obtain the total profit. For the constraints, a similar formula can be used to calculate the sum of the resources used and compare it with the available resources. In other words, we use the SUMPRODUCT function as illustrated in Figure 2, and this function is used to find the product sum of specific cells in two ranges. For example, $SUMPRODUCT(B4{:}C4, B7{:}C7)$ this formula sums the result obtained from B4*B7 with C4*C7. Both ranges must be of the same size (equal number of rows and columns). For linear programming models, it is always necessary to use the SUMPRODUCT or SUM function for the objective and constraints to ensure linearity of the equation.

	A	B	C	D	E	F	G
1			Solve the Linear Programming problem(LPP)				
2							
3		x1	x2		Result	The signal	RHS
4	Basic decision variables	0	0				
5	Objective Function Z	9	20		$ -		
6	Constraint-C 1	4	7		0	≤	1200
7	Constraint-C 2	10			=SUMPRODUCT(B4:C4,B7:C7)		5000

Figure 2: Formulas Entry

Define the target cell (objective function): identify the cell that contains the objective quantity (the target cell). This cell will be used to optimize the objective function. Once we ensure that all the data is entered, containing the elements of the linear programming model (data, decision variables, objective function, constraints), we proceed to the next step:

- Select the Solver command from the Tools menu.

To choose the target cell, we select the button next to the Set target cell group from the Solver window (see Figure 4). Then, we take one of the following actions:

1. Click on the cell representing the objective function.

	A	B	C	D	E	F	G
1			Solve the Linear Programming problem(LPP)				
2							
3		x1	x2		Result	The signal	RHS
4	Basic decision variables	0	0				
5	Objective Function Z	9			=SUMPRODUCT(B4:C4,B5:C5)		
6	Constraint-C 1	4	7		0	≤	1200
7	Constraint-C 2	10	35		0	≤	5000
8							

Figure 3: Formulas Entry

2. Type the address of the cell representing the objective function.

Then, we select either Maximize or Minimize, depending on whether the objective function is a maximization or minimization.

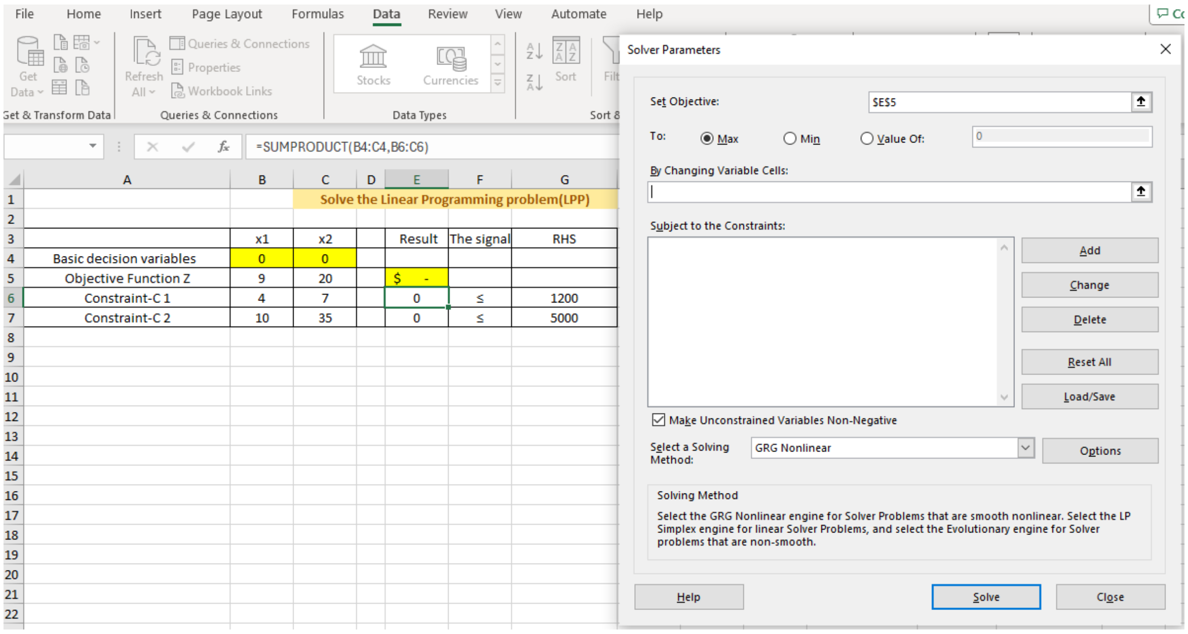

Figure 4: Define the target cell (objective function)

It should be noted that the target cell is only one cell, and this cell contains the equation that achieves the objective function.

4- Defining the changing cells:

In this step, we identify the decision variable cells that the Solver will change their values when attempting to find the maximum value of the model (see Figure 5). In other words, Identify the cells that represent the decision variables (the changing cells). These are the cells whose values will be adjusted to optimize the objective function. To do this, we follow these steps:

- Click on the "By changing Cell" option button, and then take one of the following actions:

1. Select the cells representing the decision variables.
2. Type the addresses of the cells representing the decision variables.

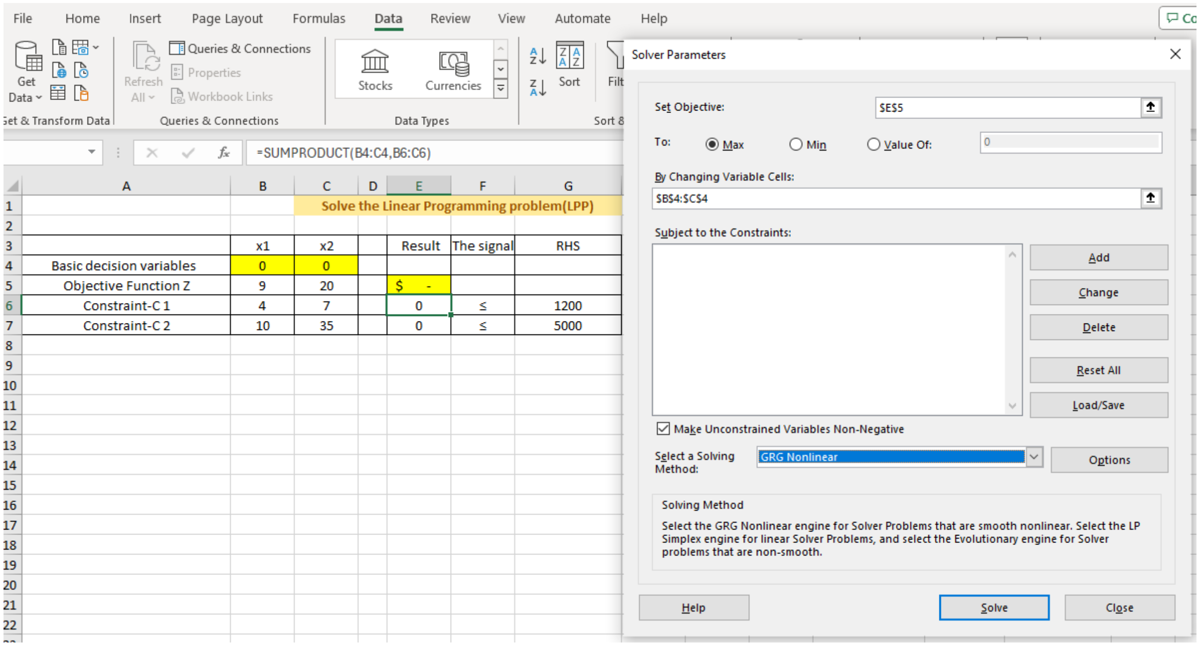

Figure 5: Defining the changing cells.

5- Adding constraints:

- Add the constraints to the model by writing formulas in Excel that represent the limitations on the decision variables. To begin adding constraints, click on the "Add" button in the Solver window. A new dialog box will appear with the cursor in the "Cell Reference" field (see Figure 6). Then, take one of the following actions:

1. Click on the cells that you want to be constrained.
2. Type the cell references that you want to be constrained.

From the "Inequality" dropdown menu, choose the desired inequality (e.g., "<=, >=") for the constraint. Then, click on the "Constraint" option button, and take one of the following actions:

1. Click on the cells containing the constraint values.
2. Type the cell references containing the constraint values.

After selecting the constraints, click on the "Ok" button to return to the Solver window.

6- Solution Options:

Configure the Solver tool in Excel to define the optimization problem. Specify whether you want to maximize or minimize the target cell value and set any additional constraints or preferences. When you have selected the target cells, variable cells, and constraints, the Solver window will appear as shown in Figure 7.

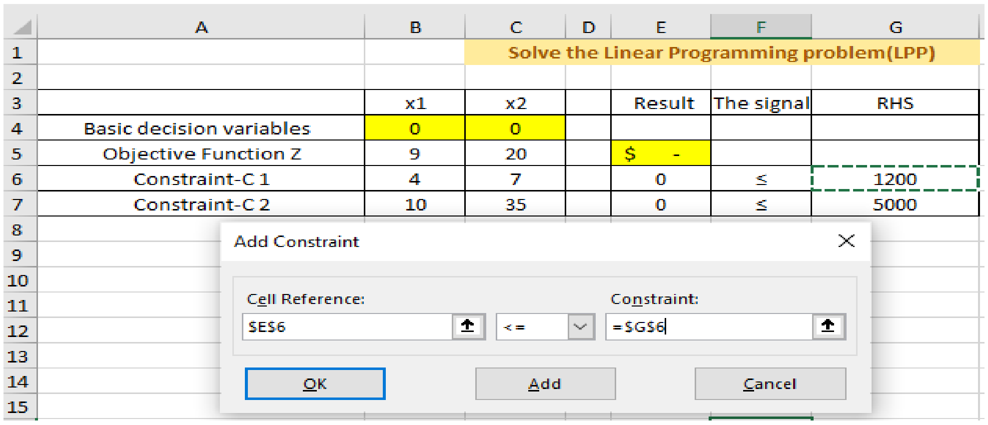

Figure 6: Adding constraints.

The last thing to note is the "Options" button in the Solver window. When you click on this button, the Select a Solving Method, here, you should check the boxes for "Simplex LP. Then, click on the "Ok" button, see Figure 7.

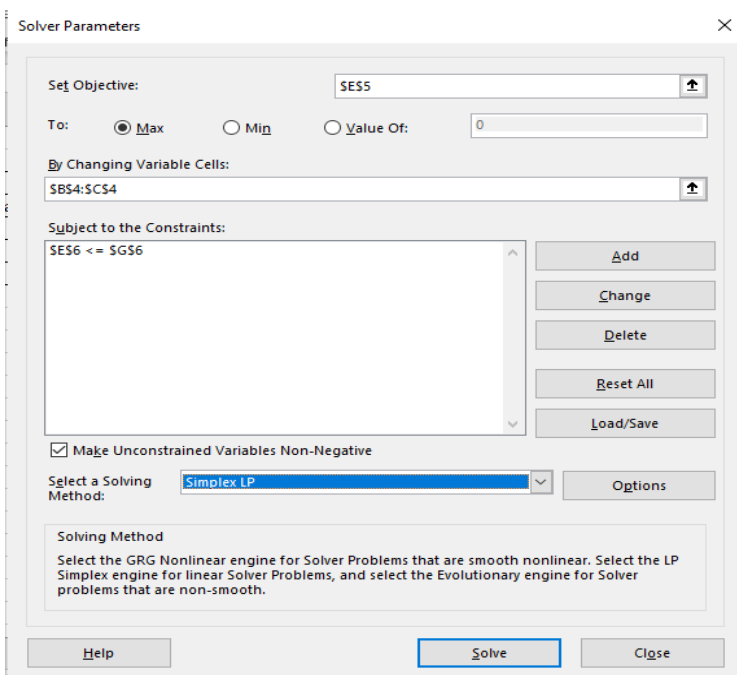

Figure 7: Solver window

7- Solving the Model:

After formulating the model and selecting the desired options, click on the Solve button. Subsequently, one of the following four messages will appear:

1. "Solver found a solution. All constraints and optimality conditions are satisfied," indicating that Solver has found the optimal solution to the model.
2. "Cell values did not converge," indicating that the target cell reaches infinity. This may result from forgetting to write a constraint or entering an incorrect function.
3. "Solver could not find a feasible solution," indicating that no feasible solution was found. This may result from incorrect input of constraints or functions.
4. "Conditions for Assume Linear Model not Satisfied," indicating the input of a non-linear function or formula.

If Solver finds the optimal solution, a window with several options will appear (refer to Figure 8a, b). Choose the first option if you want to keep the optimal solution in the Excel worksheet. If you choose the second option, you will obtain the initial values entered in the Excel worksheet. In other words, run the Solver tool to find the optimal solution for the linear programming model based on the specified constraints and objectives.

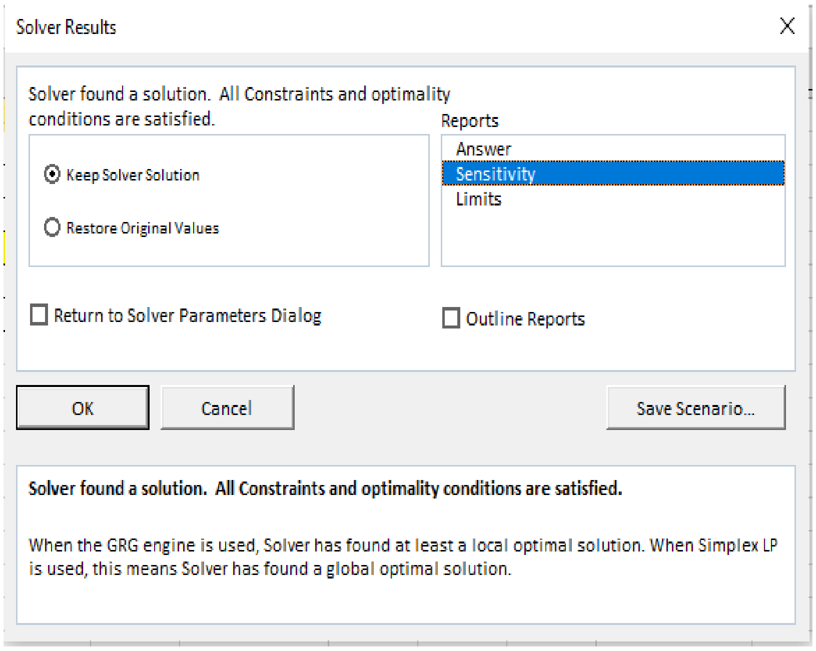

Figure 8a: The Optimal Solution

		Solve the Linear Programming problem(LPP)				
	x1	x2		Result	The signal	RHS
Basic decision variables	100	114.2857				
Objective Function Z	9	20		$ 3,185.71		
Constraint-C 1	4	7		1200	≤	1200
Constraint-C 2	10	35		5000	≤	5000

Figure 8b: The Optimal Solution

From the optimal solution, we find that the company should produce 100 chairs and 114.29 tables to achieve its highest profit, which amounts to $3185.71.

5- The sensitivity analysis:

Conducted after obtaining the optimal solution, provides additional insights into the problem. The answer report generated by Solver offers detailed information about the optimal solution “Sensitivity Analysis” [7], including which constraints are binding and which are not. It also illustrates the non-binding constraints (see Figure 9).

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$E$5	Objective Function Z Result	$ 3,185.71	$ 3,185.71

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$4	Basic decision variables x1	100	100	Contin
$C$4	Basic decision variables x2	114.2857143	114.2857143	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$E$6	Constraint-C 1 Result	1200	$E$6<=$G$6	Binding	0
$E$7	Constraint-C 2 Result	5000	$E$7<=$G$7	Binding	0

Figure 9: Answer Report

Sensitivity analysis or sensitivity report informs us about how changes in data (such as constraints) affect the optimal solution [7]. (See Figure 10) Additionally, the sensitivity report contains important information. For instance, looking under the Shadow Price column, the value 1.64286 represents the increase in the objective function resulting from increasing the working hours from 1200 to 1201.

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$5	Basic decision variables x1	100	0	9	2.428571429	3.285714286
$C$5	Basic decision variables x2	114.2857143	0	20	11.5	4.25

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$E$7	Constraint-C 1 Result	1200	1.642857143	1200	800	200
$E$8	Constraint-C 2 Result	5000	0.242857143	5000	1000	2000

Figure 10: The sensitivity analysis

6- Conclusions and suggestions:

In conclusion, over the past years, the importance and role of using spreadsheets in quantitative and statistical analysis have become evident. They have greatly contributed to overcoming many challenges faced by economists and decision-makers due to their advantages and functionalities in various fields such as forecasting, marketing, financial analysis, and others.

Moreover, the ease of handling these spreadsheets has made them more accessible and user-friendly, enabling a wider range of users to benefit from their capabilities. However, it's important to continuously explore and improve upon spreadsheet-based methods to ensure their effectiveness and relevance in evolving business environments. In addition to formulating and solving linear programming models, the use of Excel extends beyond that to encompass various other operations research applications such as nonlinear models, queueing theory, inventory problems, simulation models, and dynamic programming. Excel's versatility lies in its ability to integrate with Visual Basic Application (VBA) for programming, enabling a wide range of functionalities and applications. This integration opens up vast possibilities for operations research within spreadsheets, particularly in the realm of operations research [8].

Based on the research and analysis, some important conclusions and recommendations can be drawn:

Conclusions:

1. The Importance of Spreadsheets in Analysis and Decision Making: The study has demonstrated the vital role of spreadsheets in facilitating analysis and decision-making processes across various fields.

2. Efficiency and Speed in Processing: Using spreadsheets helps reduce the time required for analysis and processing tasks, enhancing work efficiency and improving decision quality.
3. Flexibility and Customization: Spreadsheets offer significant flexibility in data manipulation and analysis, allowing users to tailor their analyses to different scenarios.
4. Cost-effectiveness: Compared to other analytical software, spreadsheets are relatively low-cost tools, making them accessible to a wider range of users.

Recommendations:

1. Continuous Training Provision: Organizations should provide ongoing training for employees to effectively use spreadsheets, including learning new techniques and features.
2. Exploration of More Functions and Capabilities: Users should explore additional functions and capabilities of spreadsheets that can help improve their processes and decision-making.
3. Enhancement of Security and Privacy: Users should take necessary measures to protect their data and maintain privacy while using spreadsheets, including using strong passwords and encrypting data.
4. Promotion of Collaboration and Sharing: Institutions can promote collaboration and sharing among employees by using spreadsheets as a tool for working together on projects and easily sharing data.

By adopting these recommendations, organizations and individuals can maximize the potential of spreadsheets and improve their performance and strategic decision-making with greater efficiency.

References:

1. Rashed, I. G. A. A., Abdel-Mageed, H. N., & Matouk, R. E. (2021). Biogas Utilization Model Using Linear Programming for Layer Farms. *MEJ-Mansoura Engineering Journal*, *39*(4), 1-18.
2. SHALABY, Z. A. (2000). Solving linear programming models by spreadsheet software packages. *Economics and Administration*, *14*(2).
3. Monardes-Concha, C., Serrano-Julio, C., & Hoffmann, C. (2023). Linear programming-based decision support system for grapes transport planning in CAPEL. *International Transactions in Operational Research*, *30*(4), 1874-1900.
4. Hozak, K. (2021). Online software using randomization and automated grading to help teach linear programming with Excel and Solver in business courses. *Journal of Education for Business*, *96*(5), 327-334.

5. Selvi, R. P., Sivasankari, B., & Vasanthi, R. (2020). Optimization using MS-Excel Solver. *Biotica Research Today*, *2*(10), 1061-1062.
6. Maghsoodi, A. I., Riahi, D., Herrera-Viedma, E., & Zavadskas, E. K. (2020). An integrated parallel big data decision support tool using the W-CLUS-MCDA: A multi-scenario personnel assessment. *Knowledge-Based Systems*, *195*, 105749.
7. McFedries, P. (2022). *Microsoft Excel formulas and functions (Office 2021 and Microsoft 365)*. Microsoft Press.
8. Incerti, D., & Jansen, J. P. (2021). hesim: Health economic simulation modeling and decision analysis. *arXiv preprint arXiv:2102.09437*.