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Using the Linear Programming Model in Determining the Potential Production Capacities by Employing the Parametric Programming Method

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A B S T R A C T

This research aims to use the linear programming method to identify underutilized production capacities within the company's production lines by employing the parametric programming method as a supporting tool. It is considered a fundamental and important method that helps make the best use of the resources available to companies and aids decision-makers in making accurate, scientifically-based decisions. The study includes identifying unused capacities within four production lines of a dairy company: the dairy production line and the confectionery production line. The study identifies unused capacities within the natural juice and beverages production line and the bakery production line. Based on the results obtained and a comparison with actual achievements, it identifies the unused production capacities. This approach grants the model greater flexibility and uses it as a foundational basis for determining optimal values in the future.

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1. Introduction

Economic institutions are generally considered open systems, possessing the ability to interact with all surrounding environmental elements, both internal and external. Consequently, they continuously strive to achieve their fundamental goals of survival, growth, and continuity by enhancing their performance levels. Their performance can be mathematically expressed as the product of desire and capability, where the result becomes zero if either factor is absent and increases as either or both factors improve [5]. Desire can be enhanced through modern human resource management techniques, while the institution seeks to boost its productive capacity by employing the most effective quantitative methods [13]. Modern economic institutions possess untapped sources of energy, and many researchers have noted that harnessing these resources represents a crucial strength in facing an environment

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characterized by high complexity, intense competition, and uncertainty. Therefore, identifying and developing these resources is one of management's primary tasks, achieved by improving production methods and optimizing resource use to maximize efficiency through revenue growth, cost reduction, and effort conservation. This, in turn, enhances their competitive capabilities and ensures continuity and growth. Achieving this requires ongoing research into factors that enable optimal utilization of production capacity and financial performance improvement, which can only be achieved by updating measurement methods to keep pace with developments in this field [3]. Quantitative economics techniques contribute to finding the optimal situation for institutions, with linear programming being one of the most widely used methods in operations research.

1.1. Problem Statement: The research problem is identified through the presence of unused capacities within most companies, particularly production companies. The linear programming approach is used to formulate the production plan and identify unused or wasted capacities.

1.2. Research Objective: The objective of this research is to illustrate how to use linear programming with Excel Solver to determine the optimal total production quantity for a company given its available resources. It aims to compare the actual profits achieved with the potential and identify the quantity and percentage of unused capacities. Additionally, the research seeks to highlight the importance and value of linear programming in improving and supporting production planning decisions within the company and to provide decision-makers with the ability to adjust production plans according to changes in the production environment.

2. Previous Studies:

To gain a comprehensive understanding of the topic under study and to enrich the knowledge base by reviewing a range of previous studies to avoid repetition and achieve integration, the following are mentioned:

- The researcher (Ghassan Qasem Dawood Al-Lami, 2007) conducted a study that addressed the application of production capacity strategies at the Karbala Cement Plant over an 8-year period. The study focused on the fundamental aspects of production capacity strategies and the practical application of various production capacity strategies.
- The researcher (Salah Mahdi Abbas Al-Barmani, 2011) presented a study titled "Using Linear Programming to Determine the Optimal Production Mix for the Wasit General Industries Company." The study demonstrated how linear programming can be used to determine the optimal production mix for the spinning and weaving factory in Wasit province, within the Wasit Textile Industries Company.
- The research titled Optimal Product Mix in the Medical Cotton Products Factory in Baghdad Using Linear Programming, presented in 2013 by the researcher (Al-Nasr, Radab Shaker Mahmoud), aimed to optimally allocate the company's available resources using linear programming for the year 2010. The goal was to achieve high production levels and, consequently, high profit levels by maximizing the objective function value. The study relied on data from the company and conducted sensitivity analysis to understand the changes in the optimal product mix, as well as the impact on profit levels, to align with the company's growth requirements.
- The researcher (Mohamed Haitham Al-Debis, 2014) explored how to apply Time-Driven Activity-Based Costing (TDABC) to identify the system's ability to reveal unused production capacity within the company's resources. The study concluded that this system can effectively and simply identify unused capacities.
- The study presented by both (Mekid Ali and Amal Ben Jorah Al-Arabi, 2016) focused on the importance and value that linear programming adds to improving and supporting production planning decisions. It also emphasized allowing decision-makers to adjust plans according to surrounding variables.
- (Abd Al-Ali Mohamed and Ben Sabbah Elias, 2021) presented a study aimed at utilizing mathematical and scientific methods by employing specialized frameworks in operations research related to production planning and operations. This approach helped in achieving lower costs while increasing profits.

3. Linear Programming and Its Role in Identifying Unused Energy

3.1. Introduction to Linear Programming

Linear programming models are among the simplest and easiest mathematical models to create. They can be used to address industrial, governmental, and production-related problems in companies and organizations. Additionally, they assist managers in planning and making production decisions regarding the allocation of limited material and human resources among the best available uses. This approach is called "programming" because it focuses on finding the programs that achieve the desired goal among a set of possible programs, while "linear" means that all relationships between different elements of the mathematical model of the problem are linear [5], [3] .

- It is a mathematical method used to solve economic problems with a specific format, characterized by the presence of an objective function for maximization or minimization, along with multiple alternatives to achieve the objective function, while considering a set of constraints (limitations) with limited production resources to implement each alternative. Thus, the model, in general, is a part that carries the characteristics of the whole, so that everything positive in the model is positive for the whole, and everything negative in the model is negative for the whole[6] .

3.2. Conditions of Linear Programming

To formulate a mathematical model for linear programming problems, it is essential to understand the components or conditions of linear programming:

- Objective Function: This involves finding the maximum or minimum value of the objective function. Typically, the objective function is expressed in natural or monetary terms and represents a quantitative goal, such as achieving the lowest cost or the highest profit.
- Constraints: Variables are linked through inequalities or equations, or a combination of both.

Non-Negativity constraints: constraints on the variables themselves, where negative values are excluded. These are referred to as non-negativity constraints. [16]

3.3. The Relationship Between Variables: Linear Relationship in Both the Objective Function and Constraints

Linear programming has numerous applications, and its use in production planning is determined by the following topics:

- It is used to achieve optimal use of materials as well as to ensure the required quantities of raw materials are used in the production of specific goods. It also helps in the optimal determination of production capabilities and provides alternatives. Additionally, it aids in the optimal distribution of production capacity among different products by studying the suitable mix of products. [8], [7]

3.4. Assumptions of Linear Programming: [6], [14]

To solve a problem effectively and obtain more accurate solutions, the following assumptions are necessary:

- Linearity: The relationship between the objective function and inequalities must be linear.
- Additivity: The amount of raw materials entering production and the quantities of production must be additive.
- Boundedness: Activities and resources are limited.
- Divisibility: Outputs and their production resources can be divided.
- Defined Relationships: The mathematical relationships are known and fixed.
- Non-Negativity: The size of the activity cannot be negative.
- Known Values: All values must be known.
- Independence: Production elements are independent.

4. Production Capacity: Its Concept and Importance

Production capacity is one of the most effective strategies that can be relied upon to address environmental conditions and challenges to achieve desired goals. Researchers have various perspectives on defining a comprehensive and specific concept of production capacity[16]. Accordingly, it is defined as a measure of an organization's ability to provide the required goods and services to customers at the desired level and within an appropriate time frame, representing the maximum level of production. Among these various concepts, the broadest, best, and most comprehensive definition is the amount of output that can be achieved. Production capacity is a fundamental support in implementing organizational strategies and achieving objectives. Additionally, it assists in meeting customer needs in a timely manner and impacts the efficiency of cost estimation and facility maintenance. Capacity, or the amount of capacity, affects the organization's ability to serve customers quickly and efficiently. Finally, capacity requires investment, and since all managers seek a good return on investment, the costs and revenues of capacity planning decisions must be carefully considered. [15], [8]

4.1. Types of Production Capacity

There are several types of production capacity:

- Design capacity: This represents the number of units that can be produced according to specific conditions and technical specifications. It is the highest possible production capacity.
- Available capacity: This is the number of units that are actually completed, representing the capacity expected to be achieved.
- Idle capacity: This refers to the number of unused or latent units of production capacity due to various reasons.
- Actual capacity: This is the real and utilized capacity, representing the production achieved within a specific time frame. [3], [6]

4.2. Building a Total Production Planning Model for the Period 2018 – 2022:

A decision will be made to plan the production quantities of food products in the General Company for Food Industries as a whole, using the various resources available to the company. This will be achieved through the application of linear programming. This involves determining the various quantities available from the factory management to be produced in a way that allows the company to operate at its optimal activity level, enabling it to maximize its profits (total profit function).

4.3. Building the General Mathematical Model for Food Production at the General Company for Food Industries: [1], [10]

The focus will be on the four main food production factories of the company:

1. Dairy Factory: Specializes in the production of full-fat milk, yogurt, cheddar cheese, mozzarella cheese, and butter.
2. Confectionery Factory: Specializes in the production of chocolate cake, cookies, fruit tarts, dry sweets, and biscuits.
3. Juice and Beverage Factory: Specializes in the production of orange juice, apple juice, soft drinks, grape juice, and mineral water.

Bakery Factory: Specializes in the production of (white bread, brown bread, croissants, toast bread, pastries).

Objective Function: $$max\ z = \sum_{i=1}^{n} C_i X_{ij} \ , \qquad \text{..........(1)}$$

Subject to:

Available Capacity Constraints: $$\sum_{i=1}^{m} a_i X_{ij} \le b_i \ , \qquad \text{..........(2)}$$

Non-Negativity Constraints: $$\sum_{i=1}^{n} X_{ij} \ge 0 \ , \qquad \text{..........(3)}$$

5. Practical Aspect:

In this section of the research, our goal is to build an optimal production model aimed at maximizing total profits by utilizing various resources available in the company. To demonstrate the mechanism used to identify underutilized capacities in the production process, we will propose a production company specialized in the food industry that owns four factories. The first factory specializes in dairy production, the second factory specializes in sweets production, the third factory specializes in juices and beverages, and the fourth factory specializes in baked goods. Each factory produces five different products. Therefore, we will need to provide data on the types of products produced by the company, as well as the profits for each product, which are calculated by the difference between the selling price and the production cost of each product. The table below shows the selling price per unit and the production cost per unit, in addition to information regarding the basic material used in production and its quantities.

First: Data Related to Profits:

Table 1 : Data on Product Types with the Specified Amount of Profits

Factory Name	Product Type	Production Cost per Unit (USD)	Selling Price per Unit (USD)	Profit per Unit (USD)
Dairy Factory	Full Cream Milk	1.00	1.50	0.50
	Yogurt	0.80	1.20	0.40
	Cheddar Cheese	1.50	2.00	0.50
	Mozzarella Cheese	1.60	2.10	0.50
	Butter	2.00	2.50	0.50
Sweets Factory	Chocolate Cake	2.00	3.00	1.00
	Cookies	1.50	2.50	1.00
	Fruit Tart	2.50	3.50	1.00
	Dry Sweets	1.80	2.80	1.00
	Biscuits	1.00	1.80	0.80
Juice and Beverages Factory	Orange Juice	1.00	1.50	0.50
	Apple Juice	1.10	1.60	0.50
	Soft Drink	0.90	1.40	0.50
	Grape Juice	1.20	1.70	0.50
	Mineral Water	0.60	1.00	0.40
Bakery Factory	White Bread	0.50	1.00	0.50
	Brown Bread	0.60	1.10	0.50
	Croissant	1.00	1.80	0.80
	Toast Bread	0.70	1.20	0.50
	Pastries	0.80	1.50	0.70

Second: Data Related to Raw Materials: Used by the Company for Each Product, in Addition to Data on the Quantity Demanded for Each Product, Based on:

- The expected annual sales quantity in relation to demand.
- The annual availability of active material, as well as the quantities required to produce one unit of each product, as shown in the table below:

Table 2 : Data on Expected Annual Demand Quantities and the Quantity of Raw Material Required to Produce One Unit of the Products Under Study, Along with the Annual Availability for Each Product

No.	Product Type	Raw Material Used in Production	Quantity of Raw Material Used to Produce One Unit	Annual Availability of Raw Material (g)	Annual Sales Quantity (per unit)
1	Full Cream Milk	Milk	1.00 L	1,000,000 L	500,000
2	Yogurt	Milk	0.80 L	1,000,000 L	400,000
3	Chocolate Cake	Chocolate	0.15 g	200,000 g	100,000

4	Orange Juice	Orange	1.00 L	500,000 L	300,000
5	Pastries	Flour	0.35 g	350,000 g	180,000
6	Cheddar Cheese	Milk	1.50 L	1,000,000 L	200,000
7	Mozzarella Cheese	Milk	1.60 L	1,000,000 L	150,000
8	Grape Juice	Grapes	1.20 L	300,000 L	200,000
9	Butter	Milk	2.00 L	1,000,000 L	100,000
10	Mineral Water	Chlorine	0.60 L	1,000,000 L	500,000
11	Cookies	Flour	0.20 g	350,000 g	120,000
12	Fruit Tart	Flour	0.25 g	350,000 g	80,000
13	Dry Sweets	Sugar	0.10 g	100,000 g	90,000
14	Biscuits	Flour	0.15 g	350,000 g	130,000
15	Apple Juice	Apples	1.10 L	400,000 L	250,000
16	Soft Drink	Water	0.90 L	600,000 L	350,000
17	White Bread	Flour	0.30 g	350,000 g	300,000
18	Brown Bread	Flour	0.35 g	350,000 g	250,000
19	Croissant	Flour	0.40 g	350,000 g	150,000
20	Toast Bread	Flour	0.30 g	350,000 g	200,000

Third: Data Related to Working Hours:

The available daily working time is determined, along with the estimated production days per year, which are as follows: 300 days for the dairy factory, 280 days for the sweets factory, and 320 days for the juice and beverage factory, excluding holidays and occasions.

The daily production capacity is calculated as follows:

Available daily working time in minutes = available daily working time in hours * 60

Available annual working time in minutes = available daily working time in minutes * Actual working days per year.

Time to produce one unit of the product = available daily working time / daily production capacity.

As shown in the table below:

Table 3 : Data on Available Working Hours for the Production Process and Maximum Production Capacity

Product Type	Available Working Time per Day (minutes)	Available Working Time Annually (minutes)	Actual Daily Production Capacity	Time to Produce One Unit (minutes)	Total Available Working Time for Each Production Line Annually (minutes)
Full Cream Milk	480	144,000	480	1	720,000
Yogurt	480	144,000	320	1.5	
Cheddar Cheese	480	144,000	240	2	
Mozzarella Cheese	480	144,000	192	2.5	
Butter	480	144,000	160	3	
Chocolate Cake	480	134,400	96	5	672,000

Cookies	480	134,400	120	4	
Fruit Tart	480	134,400	80	6	
Dry Sweets	480	134,400	160	3	
Biscuits	480	134,400	137	3.5	
Orange Juice	480	134,400	240	2	
Apple Juice	480	134,400	192	2.5	
Soft Drink	480	134,400	320	1.5	672,000
Grape Juice	480	134,400	192	2.5	
Mineral Water	480	134,400	480	1	
White Bread	480	124,800	240	2	
Brown Bread	480	124,800	192	2.5	
Croissant	480	124,800	160	3	624,000
Toast Bread	480	124,800	240	2	
Pastries	480	124,800	192	2.5	
	9,600	2,688,000	4,433		

*The number of annual production days is 300 days for the dairy factory, 280 days for the sweets factory, 320 days for the juice and beverages factory, and 260 days for the bakery factory.

5.1. Building the Mathematical Model:

Based on the nature of the problem and the research objectives, and drawing on the various data collected, we first formulate the general structure of the mathematical model. However, before that, we need to conduct the encoding process and define the units of measurement as a first step. This is followed by identifying both the objective function and the mathematical constraints of the model, ultimately leading us to the complete mathematical formulation of the model.

5.1.1 Symbols and Units of Measurement:

The products under study are represented by Xi, where i = 1, 2,..., 20. The products are organized according to the presentation shown in the previous data tables, which will be confirmed through the solution table that will be presented later.

Units of measurement used are as follows: (box: for production quantities, US dollar: for profits, gram: for raw materials, minutes: for available working time, hours of work: for production capacity).

5.1.2. Building the Objective Function

Based on the criterion of optimizing the company's activities, which is maximizing the company's profit revenues, and in light of the data presented in Table (1), the objective function is constructed as follows:

Raw material constraints

$x_1 + 0.80\, x_2 + 1.50\, x_6 + 1.60\, x_7 + 2\, x_9 \leq 1000000$

$0.15\, x_3 \leq 200000$ $\quad x_4 \leq$ 500000

$0.35\, x_5 + 0.20\, x_{11} + 0.25 x_{12} + 0.15\, x_{14} + 0.30 x_{17} + 0.35 x_{18} + 0.40 x_{19} + 0.30 x_{20} \leq 350000$

$1.20\, x_8 \leq 300000$

$0.60 x_{10} \leq 1000000$

$0.10 x_{13} \leq 100000$

$1.10 x_{15} \leq 400000$

$0.90\, x_{16} \leq 600000$

Demand Constraints

$x_1 \leq 500{,}000$ $\quad x_{11} \leq 120{,}000$

$x_2 \leq 400{,}000$ $\quad x_{12} \leq 80{,}000$

$x_3 \leq 100{,}000$ $\quad x_{13} \leq 90{,}000$

$x_4 \leq 300{,}000$ $\quad x_{14} \leq 130{,}000$

$x_5 \leq 180{,}000$ $\quad x_{15} \leq 250{,}000$

$x_6 \leq 200{,}000$ $\quad x_{16} \leq 350{,}000$

$x_7 \leq 150{,}000$ $\quad x_{17} \leq 300{,}000$

$x_8 \leq 200,000$ $x_{18} \leq 250,000$
$x_9 \leq 100,000$ $x_{19} \leq 150,000$
$x_{10} \leq 500,000$ $x_{20} \leq 200,000$

Labor Constraints by Production Lines Based on the Data Available in Table (3) as Follows:
Production line constraints

$x_1 + 1.5x_2 + 2x_3 + 2.5x_4 + 3x_5 \leq 72000$
$5x_1 + 4x_2 + 6x_3 + 3x_4 + 3.5x_5 \leq 672000$
$2x_1 + 2.5x_2 + 1.5x_3 + 2.5x_4 + x_5 \leq 67200$
$2x_1 + 2.5x_2 + 3x_3 + 2x_4 + 2.5x_5 \leq 62400$

Non-negativity Constraint

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_1, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, x_{20} \geq 0$

By defining the objective function aimed at maximizing the company's total profits and establishing a set of mathematical constraints, we can prepare the production program for the company using Excel.
Based on the study model that was developed and using Excel with the Solver add-in, this model was solved, leading to the results shown in the table below:

5.1.3. Identifying unused capacities:

By comparing them with what has actually been achieved, as shown in the table below.

Table 4 : illustrates the unused capacities and their percentages based on Solver outputs

Product Type	Product Code	Optimal Solution Quantity	Actual Production Quantity	Unused Capacities	Unused Capacity Percentage
Whole Milk	X_1	21600.01967	144000	-122399.9803	-
Yogurt	X_2	0	96000	-96000	-
Cheddar Cheese	X_3	0	72000	-72000	-
Mozzarella Cheese	X_4	9599.98033	57600	-48000.01967	-
Butter	X_5	0	48000	-48000	-
Chocolate Cake	X_6	200000	26880	173120	87%
Cookies	X_7	150000	33600	116400	78%
Fruit Tart	X_8	200000	22400	177600	89%
Dry Sweets	X_9	100000	44800	55200	55%
Biscuits	X_{10}	500000	38630	461370	92%
Orange Juice	X_{11}	120000	67200	52800	44%
Apple Juice	X_{12}	80000	53760	26240	33%
Soft Drink	X_{13}	90000	89600	400	0%
Grape Juice	X_{14}	130000	53760	76240	59%
Mineral Water	X_{15}	250000	134400	115600	46%
White Bread	X_{16}	350000	62400	287600	82%
Brown Bread	X_{17}	300000	49920	250080	83%
Croissant	X_{18}	250000	41600	208400	83%
Toast Bread	X_{19}	122500	62400	60100	49%
Pastries	X_{20}	200000	49920	150080	75%

Based on the results obtained from the Excel Solver outputs, as shown in Table No. (4), the volumes and percentages of unused capacities in the production of each of the company's products were determined. By comparing the optimal profit amount of $2,101,850 with the company's actual profit amount of $698,072, it was found that the cost of unused capacities within the four production lines owned by the company is approximately $1,403,778.

As for the values that bear a negative sign for unused capacity, they indicate the actual production amount that the company should avoid producing. Instead, the resources used for such production should be redirected to increase other products, based on the principle of optimizing production decisions. Since the food industry company operates in a highly dynamic and rapidly evolving environment, the results obtained may become ineffective. To add greater practical value to the model, we study all possible scenarios of changes that may affect the program's constants using parametric programming. This analysis allows the production management to gain a deeper understanding of the potential impacts of changes and helps monitor their effect on the optimal solution and the company's overall objective. This enables determining the sensitivity of the optimal solution to those changes. through this analysis, we can create a summary table that includes all possible optimal solutions resulting from potential changes to the program's constants. In this case, the role of the production management official is to study the market conditions at a specific time to select the optimal production quantities and compare them with the company's specified range. This helps determine the maximum possible profit that can be achieved.

Based on the above, production and profit can be estimated and planned with high accuracy by adhering to the production quantities resulting from the program's outputs. As a result, the achieved outcomes will be very close to, or even match, the actual planned results, which in turn contributes to achieving optimal performance for the company. This will have a positive impact on the management process, as well as on other relevant stakeholders and the overall interests of the company.

5. Conclusions:

The results obtained show that linear programming is an important tool that productive companies can rely on for planning to achieve their goals. This is achieved by making optimal use of their available resources.
It has been shown that the loss of profits due to unused capacities is estimated at $2,101,850. The negative value in Table 4 for unused energy indicates the actual production value that must be abandoned. As a result, resources used to achieve it should be redirected to increase other products, in line with the principle of rationalizing production decisions, thereby utilizing its resources to achieve an increase in the company's other products.

6. Recommendations:

It is essential to use mathematical methods to identify and find solutions to economic problems. Efforts should be made to establish an advanced production system that relies on quantitative methods and advanced programs, through which production companies can achieve optimal production capacities that fulfill their objectives.

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