AN INTEGER PROGRAMMING APPROACH FOR OPTIMIZING RAW MATERIALS FOR LOAF BREAD PRODUCTION IN A SMALL-SCALE LOCAL BAKERY

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ABSTRACT: *This study investigates the optimization of raw materials usage in a local bakeshop in the Philippines that specializes in producing three loaf bread sizes: small, medium, and large. Currently, the bakery utilizes a static list of raw materials in planning its purchases, making it vulnerable to sudden market price fluctuations. The objective is to utilize the integer linear programming (ILP) approach to determine the optimal production plan that will maximize profit for the bakery. The 2022 data of raw materials cost and profit from the bakery were used to build the ILP model. This resulted in a daily production plan of 80 units of medium size, 28 units of small size and 17 units of large size. This production plan would yield a maximum profit of ₱2,445 daily for the bakery. With this, it is recommended for the bakery to prioritize the production of medium-sized loaf bread while continuing the production of small and large sizes. The bakery should also reconsider the pricing and profitability of the small and large sizes. This study hopes to provide Philippine MSMEs such as local bakeries with a simplified quantitative framework to help them adopt a more dynamic and market-responsive production plan.*

Keywords: optimization, raw material usage, integer linear programming, bakery production, MSMEs

1. INTRODUCTION

Raw material usage optimization is a very important yet somehow overlooked concept in operations management, especially in the context of small and medium enterprises in the Philippines. In operations management, optimization is the aspect that involves decisions on how to use resources efficiently and effectively [1].

In the Philippines, micro, small and medium enterprises (MSMEs) such as local bakeries very rarely employ quantitative techniques to manage their operations let alone their raw materials usage and inventory. This affirmation regarding material resource planning among MSMEs in Indonesia is supported by a previous investigation [2]. The monitoring of raw materials usage and inventory is critical for bakeries in the Philippines because many of its ingredients such as flour, milk and lard often come from imports and their prices are highly sensitive to external factors. The computations that local bakeries employ for the purchase of raw materials are often static and vulnerable to changes in the cost of raw materials. This is why, for local bakeries, it is highly recommended to utilize quantitative techniques to optimize the use of raw materials.

Linear programming (LP) is one of the most popular quantitative techniques in optimization. This is mainly due to its simplicity and straightforward approach. Because of this, it has found its way into many applications such as in scheduling, river conservation, reforestation, energy efficiency and human and animal health. An investigation in 2012 examined alternative feed rations for the grower stage of backyard swine [3]. They used LP to minimize the cost of feeds by utilizing ten locally available alternative ingredients at the same time ensuring that the feeds contained the necessary amounts of crude protein, crude fiber, crude fat, calcium, moisture and phosphorus. A study conducted in 2016 further explored the use of linear programming (LP) for the feed ration of pre-starter swine, with the objective of minimizing the cost of feeds for farmers by utilizing locally available feed ingredients in the Philippines [4]. The study revealed potential feed alternatives that were cheaper than the commercial pre-starter feed while still containing the required amount of calcium, crude protein, moisture, crude fiber, phosphorus and crude fat for pre-starter swine. A study in 2012 employed linear programming (LP) to optimize nutrient intake from street food snack consumption among college students [5]. By minimizing the total cost of the street food snacks, the study was able to provide suitable combinations of street food snacks that could satisfy the nutritional needs of college students at different age groups while ensuring that their budget constraints are met. In 2015, a study utilized a similar approach to investigate the formulation and development of snacks for public secondary school students [6]. Out of 30 recipes consisting of various ingredients, they used LP to identify two modified recipes of fried banana spring rolls which required minimum ingredients to satisfy the calories, fats, carbohydrates and protein needs of the students. They also explored the palatability of the new recipes developed. Recently, the approach was employed to examine daily lunch options among college students [7]. LP was used to find out which lunch combinations satisfy the nutritional requirements of college students of varying ages, sexes, BMI classification, and budgetary constraints. They further incorporated the models into an Excel-based program to present a decision support system (DSS) for determining lunch menu options.

The goal of this study is to utilize a quantitative technique called Integer Linear Programming (ILP) in the optimization of raw materials usage for small-scale local bakeries in the Philippines. The bakery currently uses a static list of materials for its weekly purchase of inventories and supplies. This makes it vulnerable to rapid fluctuations in the price of imported ingredients such as flour. With the use of ILP, it is hoped that this study will be able to provide the small-scale local bakery with a more dynamic computational technique that will allow it to rapidly adjust its purchasing plan to catch up with changes in the cost of raw materials.

This study also hopes to provide a simple quantitative framework that will enable other local bakeries and MSMEs to utilize ILP to improve their own operations and make them more prepared for market-driven changes in material costs. This study is limited only to the operations of a small-scale local bakery, with primary data obtained from actual firm operations in the year 2022. This study is also limited to the use of ILP as a straightforward method to optimize their raw material usage. While more powerful quantitative methods may be more applicable, the simplicity of the ILP method makes it more readily adaptable for the workers and scale of operations of a small-scale local bakery and other MSMEs in the Philippines.

2. LITERATURE REVIEW

2.1. Optimization

Optimization is defined in the Business Dictionary as the process of finding the "alternative with the most cost-effective or the highest achievable performance under given constraints by maximizing desired factors and minimizing undesired ones [1]. It is an important concern in Operations Management, which is concerned with managing the transformation of raw materials into goods and services. Optimization influences various operational management decisions including input management in the efficient use of resources, facilities management in minimizing breakdowns and delays, and output management in delivering goods in the most efficient manner. Most industries that are capable of adopting optimization in their operations do so with the goal of achieving maximum profit while minimizing costs and other negative externalities.

Just as optimization is providing benefits to large industries, it is also beneficial for Micro, Small and Medium Enterprises (MSMEs). It has been explained that optimization, particularly in inventory management, is crucial for MSMEs globally as it minimizes the cost of carrying inventory, leading to service and profit optimization [2]. It has been perceived that MSMEs tend to adopt optimization and other business intelligence and analytics systems based on factors such as relative advantage, complexity, top management support, competitive pressure, and innovativeness [8]. Similarly, it has been found that profitability is the main driver for MSMEs to adopt modern strategies in supply chain management [9]. Thus, the proper choice of techniques can lead to motivating MSMEs to adopt optimization in their operations.

2.2 Integer Linear Programming (ILP)

Integer Linear Programming (ILP) is a quantitative technique for mathematical optimization that makes use of linear objective functions and constraints and restricts some or all variables to be integers [10]. The standard function for the ILP model is discussed in the methodology section. This study selected the ILP approach due to its versatility, simplicity in setting up the model and speed of computing using available software.

ILP as an optimization approach has been utilized by many studies in various fields of application. In 2017, a study utilized Integer Linear Programming (ILP) alongside Linear Programming (LP) models to maximize the net present value of timber production in Iran. The study considered five tree species as variables and the available planting area as constraints [11]. The models favored the planting of bald cypress as the first priority for the forest plantation. In 2018, a study utilized Integer Linear Programming (ILP) to minimize a building's external wall thermal transmittance, with the aim of improving the building's energy efficiency [12]. Several ILP models were used to identify the proper material and wall thickness combinations that will result in the optimal thermal transmittance. They found seven optimal solutions for seven scenarios of interest including minimum budget, minimum wall thickness, maximum budget, maximum wall thickness, combination budget and thickness and minimum thermal transmittance. The Integer Linear Programming (ILP) framework was utilized to simplify the computation of common conservation problems for rivers, including Marxan and Marxan with Zones [13]. In this study, the ILP framework outperformed the more commonly used simulated annealing approach to achieve optimality within thirty seconds to one hour for a range of complex problems. These studies show that ILP, when properly utilized, can provide a simple and fast quantitative approach to optimization problems.

2.3 The case of a small-scale local bakery

The goal of this study is to utilize ILP in the optimization of raw materials usage for small-scale local bakeries in the Philippines. For 12 years, the bakery has specialized in the production of loaf bread, which is a staple food in the community. The loaf bread is produced in three sizes: (1) small at 250g worth P30/unit, (2) medium at 350g worth P40/unit, and (1) large at 700g worth P50/unit

With less than two million pesos in terms of capitalization and at least five workers in 2022, the bakery is considered a micro-enterprise and does not yet have the capacity to utilize sophisticated quantitative techniques to plan out the inventory and usage of its raw materials. The bakery currently uses a static list of raw material amounts when it replenishes its inventory once a week. This has worked well in the past. However, with the post-pandemic market and inflation, the bakery has struggled to keep up with highly fluctuating prices of imported commodities especially flour, which is their main ingredient. Often, when faced with high production demand, the bakery faces shortages in their inventory which forces them to make unplanned purchases even when raw material prices are high. This leads to unexpected increases in their raw materials cost

2.4 Related Studies

Several studies outside the Philippines have also utilized several LP models for the optimization of the performance of local bakeries. In the study, an LP model with three products and six constraints was utilized to maximize the income of a bakery in Mumbai [14]. It was concluded that to obtain maximum income for the bakery, they needed to produce more units of cupcakes compared to pastries and cakes to obtain a maximum income of Rs 30,425. In the study, the profit in the bread production of Daily Bakery Sdn Bhd was maximized using a mixed Integer Linear Programming (ILP) model with eight variables and sixteen constraints [10]. They found out that the optimum result consisting of the eight products yields a maximum profit of RM 65,377.29 per day. In 2022, a study compared Integer Linear Programming (ILP) to Linear Programming (LP) to optimize the profit of Temptilicious Enterprise, a small bakery enterprise in Malaysia [15]. Using an ILP model with three variables and ten constraints, they were able to achieve a production plan which resulted in a maximum profit of RM 446.99. In their study, Linear Programming (LP) with three variables and six constraints was used for the optimal use of raw materials in Goretta bakery, a bakery in Nigeria that also produces loaf bread [16]. The result showed that only a combination of the small loaf and big loaf is needed to achieve a maximum profit of N20,385.00. In 2019, Linear Programming (LP) with five variables and eight constraints was used to maximize the profit of Landmark University Bakery [17]. This resulted in concentrating on two bread types, family-size bread and chocolate bread, in order to maximize the profit at N1,860,000 per month.

3. METHODOLOGY

The goal of this study is to utilize a quantitative optimization approach called Integer Linear Programming (ILP) in the optimization of raw materials usage for small-scale local bakeries in the Philippines. This study utilized primary data obtained from actual operations. This study applied the ILP approach to come up with a suitable optimization model for raw materials usage and to determine the optimal production plan that will maximize the firm's profit while minimizing the amount of raw materials used.

In 2016, a standard linear programming model with n decision variables and m constraints was supplied, as stated in the following form [16]:

Optimize (max or min)

$Z = c_1 x_1 + c_2 x_2 + \ldots\ldots \ldots.. + c_n x_n$

Subject to functional constraints

$a_{11} x_1 + a_{12} x_2 + \ldots\ldots \ldots.. + a_{1n} x_n$ (≤, =, ≥) b_1

$a_{12} x_1 + a_{22} x_2 + \ldots\ldots \ldots.. + a_{2n} x_n$ (≤, =, ≥) b_2

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$a_{m1} x_1 + a_{m2} x_2 + \ldots\ldots \ldots.. + a_{mn} x_n$ (≤, =, ≥) b_m

Non-negativity and integer constraints

$x_1, x_2, \ldots\ldots \ldots.. x_n \geq 0$ and integer

Where $c_1, c_2,$ -----, c_n represent the per unit profit (or cost) of decision variables $x_1, x_2,$ -----, x_n to the value of the objective function. And a_{11}, a_{12} -----, a_{2n} -----, a_m, a_{m2}, ----- a_{mn} represents the amount of resource consumed per unit of the decision variables. The b_i represents the total availability of the i^{th} resource. Where Z represents the measure of performance which can be either profit, cost, etc.

In this study, the decision variables $x_1, x_2,$ -----, x_n consist of various sizes of loaf bread produced by the bakery. Then, $c_1, c_2,$ -----, c_n represent the per unit profit of decision variables $x_1, x_2,$ -----, x_n to the value of the objective function. And a_{11}, a_{12} -----, a_{2n} -----, a_m, a_{m2}, ----- a_{mn} represent the amount of raw material consumed per unit of the decision variables. The b_i represents the total availability of the i^{th} raw material. Finally, Z represents the profit of the bakery from producing and selling the loaf bread, which in their performance objective, needs to be maximized.

The ILP model comes with the following assumptions, as supported by [14]:

1. The raw materials required are limited
2. The effective allocation of raw materials will aid optimal production and maximize profit at the same time
3. The qualities of raw materials used in the loaf bread production are standard
4. Some of the raw materials used in the loaf bread production cannot be stored for a long duration.

With these assumptions, the ILP model can hold true to represent the actual operation of the firm.

4. RESULTS AND DISCUSSION

Data Presentation

The following average data were obtained from the actual operations of a small-scale local bakery in one day in 2022 as summarized in Table 1.

First-class flour
Total amount of first-class flour available = 25 kg
Each unit of small loaf requires 0.167 kg of first-class flour
Each unit of medium loaf requires 0.200 kg of first-class flour
Each unit of large loaf requires 0.250 kg of first-class flour

White sugar
The total amount of white sugar available = 5 kg
Each unit of small loaf requires 0.033 kg of white sugar
Each unit of medium loaf requires 0.040 kg of white sugar
Each unit of large loaf requires 0.050 kg of white sugar

Yeast
The total amount of yeast available = 250 g
Each unit of small loaf requires 1.67 g of yeast
Each unit of medium loaf requires 2 g of yeast
Each unit of large loaf requires 2.5 g of yeast

Powdered milk
The total amount of powdered milk available = 500 g
Each unit of small loaf requires 3.33 g of powdered milk
Each unit of medium loaf requires 4 g of powdered milk
Each unit of large loaf requires 5 g of powdered milk

Salt
The total amount of salt available = 400 g
Each unit of small loaf requires 2.67 g of salt
Each unit of medium loaf requires 3.2 g of salt
Each unit of large loaf requires 4 g of salt

Lard
The total amount of lard available = 1 kg
Each unit of small loaf requires 0.007 kg of lard
Each unit of medium loaf requires 0.008 kg of lard
Each unit of large loaf requires 0.010 kg of lard

Water
The total amount of water available = 11.356 L
Each unit of small loaf requires 0.076 L of water
Each unit of medium loaf requires 0.091 L of water
Each unit of large loaf requires 0.014 L of water

Superfine dough
The total amount of superfine dough available = 150 g
Each unit of small loaf requires 1 g of superfine dough
Each unit of medium loaf requires 1.2 g of superfine dough
Each unit of large loaf requires 1.5 g of superfine dough

Margarine
The total amount of margarine available = 500 g
Each unit of small loaf requires 3.33 g of margarine
Each unit of medium loaf requires 4 g of margarine
Each unit of large loaf requires 5 g of margarine

Vanilla
The total amount of vanilla available = 100 g
Each unit of small loaf requires 0.67 g of vanilla
Each unit of medium loaf requires 0.80 g of vanilla
Each unit of large loaf requires 1 g of superfine vanilla

CSP anti-molds
The total amount of CSP anti-molds available = 50 g
Each unit of small loaf requires 0.33 g of CSP anti-molds
Each unit of medium loaf requires 0.40 g of CSP anti-molds
Each unit of large loaf requires 0.50 g of CSP anti-molds

Market demand
Market demand for small loaves is 28 units per day
Market demand for a medium loaf is 35 units per day
Market demand for large loafs is 17 units per day

Profit contribution per unit product (size) of bread produced
Each unit of small loaf = ₱15.00
Each unit of medium loaf = ₱20.00
Each unit of large loaf = ₱25.00

For consistency of units, the weights are converted to grams with the density of water assumed to be 1,000 g/L.

Table 1. Data obtained from a small-scale local bakery

Raw material	Product			Total Raw Materials Available
	Small Loaf	Medium Loaf	Large Loaf	
First class flour (kg)	0.167	0.200	0.250	25
White sugar (kg)	0.033	0.040	0.050	5
Yeast (g)	1.67	2	2.50	250
Powdered milk (g)	3.33	4	5	500
Salt (g)	2.67	3.2	4	400
Lard (kg)	0.007	0.008	0.010	1
Water (L)	0.076	0.091	0.114	11.356
Superfine dough (g)	1	1.20	1.50	150
Margarine (g)	3.33	4	5	500
Vanilla (g)	0.67	0.80	1	100
CSP anti-molds (g)	0.33	0.40	0.50	50
Market demand (unit)	28			
Market demand (unit)		35		
Market demand (unit)			17	
Profit (₱)	**15**	**20**	**25**	

Final ILP Model

The data were incorporated into the general ILP model to generate the specific ILP model for small-scale local bakeries where

x_1 = no. of the small loaf to be produced
x_2 = no. of medium loaf to be produced
x_3 = no. of the large loaf to be produced
Z denotes the profit to be maximized

The integer linear programming model for the above production data is given by:

Max Z = ₱15x_1 + ₱20x_2 + ₱25x_3……………………(1)
Subject to
$167x_1 + 200x_2 + 250x_3 \le 25{,}000$…………………….(2)
$33x_1 + 40x_2 + 50x_3 \le 5{,}000$………………………….(3)
$1.67x_1 + 2x_2 + 2.5x_3 \le 250$…………………………….(4)
$3.33x_1 + 4x_2 + 5x_3 \le 500$……………………………(5)
$2.67x_1 + 3.2x_2 + 4x_3 \le 400$…………………………….(6)
$7x_1 + 8x_2 + 10x_3 \le 1{,}000$…………………………….(7)
$75.71x_1 + 90.85x_2 + 113.56x_3 \le 11{,}356$……………..(8)
$x_1 + 1.2x_2 + 1.5x_3 \le 150$…………………………….(9)
$3.33x_1 + 4x_2 + 5x_3 \le 500$…………………………….(10)
$0.67x_1 + 0.80x_2 + 1x_3 \le 100$………………………...(11)
$0.33x_1 + 0.40x_2 + 0.50x_3 \le 50$………………………(12)
$x_1 \ge 28$…………………………………………………(13)
$x_2 \ge 35$…………………………………………………(14)
$x_3 \ge 17$…………………………………………………(15)
$x_1, x_2, x_3 \ge 0$ and integer…………………………….(16)

Equation (1) is the optimization equation which denotes the profit Z as the summation of the profits generated from every product size, $x_1 x_2$ and x_n. Equations (2) to (12) denote the functional constraints for the following ingredients: (2) for first-class flour, (3) for white sugar, (4) for yeast, (5) for powdered milk, (6) for salt, (7) for lard, (8) for water, (9) for superfine dough, (10) for margarine, (11) for vanilla, and (12) for CSP anti-molds, Market demand for small loaf (13), Market demand for medium loaf (14), Market demand for large loaf (15). Equation (16) denotes the non-negativity and integer constraints that prevent the model from generating negative and non-integer values.

The goal of this ILP model is to maximize Z. The model was solved using Microsoft Excel Solver version 2019, which resulted in an optimal solution of:

= 28, = 80, = 17

Z = ₱2,445

This means that the optimal production plan for a small-scale local bakery is to produce 28 units of small loaf bread, 80 units of medium loaf bread and 17 units of large loaf in one day, which would result in a maximized profit of ₱2,445.

5. CONCLUSION AND RECOMMENDATION

The ILP model revealed that the optimal production for the small-scale local bakery is 28 units of small loaf bread, 80 units of medium loaf bread, and 17 units of large loaf bread, to achieve the maximized profit of ₱2,445. This should not prevent the bakery from producing small and large sizes at higher volumes whenever necessary. This is because the study was delimited to the ILP method that considered only the availability of the raw materials and their contribution to the profit of the bakery. This did not consider other factors such as marketability of the product sizes as well as other factors that affect the cost of production such as cost of labor, utilities and other expenses.

Hence, this study recommends that small-scale local bakery to focus on the production of large loaf bread in their operations. It is also recommended to revisit the cost and pricing for the small and medium sizes and its implications on the profit generated from the two sizes.

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