Cost Optimization for Weekly Meal Planning of College Students Based on Calorie Constraints using Linear Programming (LP) Method

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2022 IEEE 14th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM) | 978-1-6654-6493-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/HNICEM57413.2022.10109597

***Abstract*— Eating a well-balanced diet is as important as exercising the body to remain healthy and avoid any sickness. A healthy diet is especially important for students who use their minds and body to accomplish tasks in their daily classes. With this, it is important to prepare a well-balanced meal for them to get the right amount of nutrients in their body. Additionally, making these meals more affordable is necessary to make them more accessible for the students. Hence, this study aims to optimize the cost of a one-week cycle menu from breakfast to dinner for college students to satisfy the nutrients their body needs using different Linear Programming (LP) techniques. After sub-dividing the subjects according to their sex and physical activeness, a Linear Programming (LP) and Integer Linear Programming (ILP) technique was used to acquire the minimized cost for a 5-day dietary plan. It was observed that LP was able to obtain a lower cost compared to the ILP method and obtained different combinations of food. As a result, it was proven that college students can afford a well-balanced diet while sticking to their budget plan.**

Keywords—Linear Programming, Nutritional Diet, Cycle Menu, Optimization, Calorie Requirement

I. INTRODUCTION

Eating a well-balanced diet is as important as exercising the body to remain healthy and avoid any sickness, especially for students. Maintaining a healthy lifestyle can influence their academic performance for the better and accomplish their daily tasks more efficiently [1]. However, students transitioning from high school to college change their lifestyle as they adapt to a different environment which consequently affects their academic performance and cognitive skills. Subsequently, there is a correlation between eating a healthy diet and GPA scores, indicating that eating a healthy diet is an excellent indicator of academic success whereas unhealthy dietary habits negatively impact academic performance [1][2]. Furthermore, adequate dietary habits of eating healthy food such as fruits, vegetables, and nuts can prevent chronic diseases from striking [3] which entails greater importance in disseminating nutritional awareness among students. With these factors and outcomes in mind, it is important to prepare a well-balanced diet for college students who are still adjusting to their new environment to perform well in their academics.

The nutrients that people consume in the greatest quantities are called macronutrients, which are categorized primarily as carbs, proteins, and fats. Macronutrients are crucial to a person's diet since they are the sum of the calories that provide the body with the energy it requires [5]. Throughout history, there have been several macronutrient diets established depending on the objectives of their dietary plan. For example, Irish farm workers adopted a diet consisting of 12 percent protein, 1 percent fat, and 87 percent carbohydrates, which resulted in an extraordinarily low diabetes-related mortality rate [4]. This diet high in carbohydrates has been used to treat diabetes and cardiovascular diseases. Obese patients with comorbidities who consume fruits and vegetables, legumes, and whole grains lose weight considerably and improve their metabolic risk factors over 12 months.

Calorie intake also plays a vital role in the nutritional status of a student. With an excessive intake of such, it can cause obesity which is prevalent in college students during their adapting stage. Obesity poses a lot of health risks including cardiovascular diseases and diabetes [3]. On the other hand, insufficient calorie intake may result in malnutrition and frequent sign of fatigue that indicates a lack of energy supply. In return, this can detrimentally affect student performance and health risks as well. Additionally, making these meals more affordable for these students is necessary to make them more accessible since one major factor of unhealthy dietary planning is financial constraints [3]. Hence, this study aims to optimize the cost of a one-week cycle menu from breakfast to dinner for college students to satisfy the nutrients their body needs using Linear Programming (LP) and Integer Linear Programming (ILP) techniques.

II. REVIEW OF RELATED LITERATURE

A. Nutritional Requirements for College Students

For students to function and perform well, they need to sustain themselves with the proper nutrients. These nutrients will significantly come from the food they eat throughout the day which is filled with vitamins and minerals. With this, it is important to have a healthy and well-balanced diet that consists of 50% of vegetables and fruits, 25% of carbohydrates, and 25% of proteins which can be seen in Fig. 1 [6]. However, it is crucial to consider that the type of carbohydrates and proteins has more impact than the quantity of the said nutrients. For example, carbohydrates from whole grains (such as wheat and quinoa), beans, fruits, and vegetables are the best sources of carbohydrates [7]. The same thing can be said of proteins where beans, poultry, and eggs are the best sources of such and should limit the number of red and processed meats such as bacon and sausages [6][8]. Therefore, studies have been conducted to integrate a multivariate dietary plan to sustain and develop human health. Consequently, generic, age-, and gender-specific guidelines have been developed to address this problem [9].

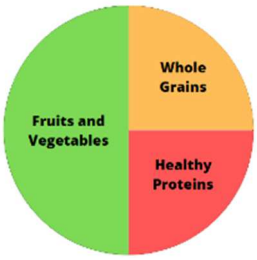

Fig. 1. The recommended proportion of nutrients per plate [1].

B. Dietary Habits of College Students

AlHazmi et al. [10] surveyed female pre-med college students and their knowledge of healthy dietary habits. Although these students

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know the correct dietary habits; due to their workload, they tend to disregard the recommended dietary guidelines which affected their Body Mass Index (BMI). Therefore, nutritional programs and diet plans must be implemented to improve dietary habits. Valen et al. [11] also assessed the nutrient and diet intake of young college students according to their national dietary recommendations and their adverse effects. They found out that the 677 students they assessed have substandard dietary habits compared to their national recommendations; moreover, male students are seen to have lower diet quality compared to female students who consume more fibrous fruits and vegetables, along with less red meat and high-density dairy products. It can be seen from these two studies that college students, regardless of their gender, have inadequate nutritional dietary habits may be because of a lack of motivation and awareness [12].

Collegiate athlete students, on the other hand, may have the motivation and awareness to be mindful of their nutrition but greatly susceptible to misconceptions on nutrition knowledge that they can use after their athletic careers [12]. These athletes consume fruits and vegetables, and lean meat which are aligned with their sports nutrition recommendations. If the sports require more endurance, they'll be advised to consume more carbohydrates as sports require more power and are advised to consume more protein [13]. In addition, to increase their general performance, they avoid fast food and fried foods. Some athletes even take supplements to increase their health and occasionally muscle repair with little to no risk [13].

C. *Recommended Nutrition for Males and Females College Students*

Calories supply the energy required for students to do their daily activities. These calories are heavily dependent on the food's carbohydrate, protein, and fat content [14]. Subsequently, determining the ideal calorie count for oneself is important to not gain too much weight and/or lead to fatigue and loss of concentration [15]. During adolescence, students' caloric intake should be higher than in their early adult years. During this developmental period, boys and girls must consume 2,800 and 2,200 calories per day, respectively, depending on their activity level [15][16] which can be seen in Tables 1 and 2.

Table 1. Calorie Requirement for Teenage Girls by Age and Activity Level [10]

Age (Male)	Not Active	Moderately Active	Active
13	2000	2200	2600
14-15	200-2200	2400-2600	2800-3000
16-18	2400	2800	3200
19	2600	2800	3000

Table 2. Calorie Requirement for Teenage Girls by Age and Activity Level [10]

Age (Male)	Not Active	Moderately Active	Active
13	1600	2000	2200
14-18	1800	2000	2400
19	2000	2200	2400

Teenagers must be more aware of what their overall health since this is the year when they become more conscious about their body image. Fortunately, body image is something that everyone can control with proper nutrition and exercise. When this practice continues to persist until early adulthood as college students, it can be beneficial for them both physically, socially, and mentally. Clusky et al. [17] assessed 523 students who just graduated from high school to college and found out that 25% of them gained >2.3 kg in 8 weeks. This phenomenon is usually caused by the adaptation to a new environment, furthermore, food on campus was unhealthy, and healthy food was unavailable because students had to prepare it themselves, which was time-consuming and costly.

According to the 2010 Dietary Guidelines for Americans [18], women aged 19 to 30 must consume between 1,800 and 2,400 calories per day, depending on their level of activity. Inactive women must consume 1,800 to 2,000 calories per day, moderately active women must consume 2,000 to 2,200 calories per day, and physically active women must consume 2,200 to 2,400 calories per day. On the other hand, Men will have a slightly higher calorie requirement due to their natural anatomy and physiology. Inactive men are restricted to consuming between 2,400 and 2,600 calories per day, while moderately active and active men are permitted to consume between 2,600 and 2,800 and 2,800 to 3,000 calories per day, respectively. It is important to note that these are merely guidelines, as individual motivations (weight loss, muscle gain, etc.) can influence calorie consumption. There are other ways to determine one's ideal calorie intake depending on their body weight. Adults (regardless of sex) can consume between 13 and 18 calories per pound, depending on their activity level, while obese adults can only consume 10 calories per pound of their ideal body weight [19].

D. *Optimization Solutions for Dietary Plans*

Linear Programming (LP) [20][21] is a mathematical modeling technique integral to the optimization problem in which a maximum and minimum objective are limited by a set of constraints. LP is frequently used to evaluate quantitative decisions involving multiple variables. In the food industry, LP has been used numerous times to either minimize the cast or maximize the profits. During World War II, it was Jerry Cornfield who paved the way and created a low-cost diet plan for soldiers (WW2). His objective was to create an inexpensive meal that meets the nutritional needs of the army [22]. Urrutia et al. [23] conducted a similar study of optimizing the cost of a 2000-calorie diet for a diabetic person without compromising their daily nutrient requirement. They used a simple method to optimize the cost of the cheapest available food for diabetic people and constrained each food with the desired amount of vitamins found in such. After which, they used the sensitivity analysis to see how an increase in one source of vitamins may affect the overall cost of the 2000-calorie diet. Another study conducted by Baharom et al. [24] focused on establishing a mathematical model for the Malaysian diet planning of hypertension patients and people avoiding hypertension. In doing this LP problem, they used LINGO software and Excel Solver [25] by using LP and IP techniques, respectively. According to their findings, the Excel Solver IP technique was able to minimize the cost better at 25.79 instead of 28.64 from the LINGO software LP technique.

III. METHODOLOGY

In initiating this study, a survey was conducted on De La Salle University (DLSU) Manila students (n=33) who were able to experience face-to-face classes before the pandemic hit the country. They were asked general questions to more specific questions such as their weekly allowance to their maximum spending per meal. It was discovered that the majority of these students allotted Php 1439.39 per week on food based on the weighted average of the results. Should one divide the weighted average of the weekly food budget, they will get Php 287.88 food budget per day. This is not consistent with the weighted average of the daily food budget. With such, this study will focus on the lower daily budget since it would cater especially to the

students who have a lower budget. This means that the minimized cost of food with enough calorie count to sustain a student should be equal to or less than Php 287.88. DLSU is known to have classes from Monday to Friday, hence, the target days of this optimization study. Furthermore, the respondents were asked for their top sources of proteins, carbohydrates, fruits, and vegetables to create a meal plan according to their choices. The top 4 categories from each source will be used as variables for the optimization which can be seen in table 3. Based on the survey, there were seven choices of carbohydrates but rice, pasta, bread, and potatoes were chosen as the top 4 sources of such. Out of the five categories of protein sources, the top 4 choices were lean meats, poultry, fish and seafood, and eggs. It shows that students do not like legumes and beans as their sources of protein. For Fruits, students prefer tropical fruits, melons, apples, and citrus fruits out of the seven categories. While they prefer leafy, cruciferous, marrow, and stem vegetables for their vegetable preferences.

Table 3. Preferred Source of Nutrients by DLSU students

Rank	Carbohydrates	Protein	Fruits	Vegetable
1st	Rice	Lean Meat	Tropical Fruits	Leafy
2nd	Pasta	Poultry	Melons	Cruciferous
3rd	Bread	Fish & Seafood	Apple	Marrow
4th	Potatoes	Eggs	Citrus	Plant Stem

A Linear Programming (LP) technique will be utilized to determine the minimum cost of a week-long dietary plan for DLSU college students that both satisfy the daily calorie requirement depending on their sex and physical activeness [18]. Based on the data provided by the survey, a combination of the different sources from table 3 will be considered and serve as the decision variables of the problem. The summary of products from these sources, the calorie count according to USDA [26], and their price based on the DTI [27] and SM Supermarket Store [28] (whichever is cheaper) as of 2022 can be seen in Table 4, where each source has 9 products of decision variables as follows:

w_i – the number of portions (100 grams) of carbohydrates products
x_i – the number of portions (100 grams) of protein products
y_i – the number of portions (100 grams) of fruit products
z_i – the number of portions (100 grams) of vegetable products

Table 4. Decision Variables with calorie count and price per 100 g

Var	Description (Integer)	Calories/ 100g (A)	Price/100g (in Php)	Var	Description (Integer)	Calories/ 100g (A)	Price/100g (in Php)
w1	White Rice	130	5.30	x1	Ground Pork (70/30)	393	24.50
w2	Brown Rice	111	6.84	x2	Beef Brisket	331	36.00
w3	Red Rice	129	8.96	x3	Chicken Breast	165	17.00
w4	Spaghetti	158	9.50	x4	Chicken Thighs	177	17.00
w5	White Bread (3)	240	12.50	x5	MilkFish	148	16.00
w6	Wheat Bread (3)	166	13.92	x6	Salmon	145	21.20
w7	Kamote	76	6.60	x7	Cream Dory	95	13.00
w8	Wheat Tortilla (2)	254	17.50	x8	Tuna	116	21.90
w9	Potatoes	87	6.90	x9	Eggs (2)	180	14.00
y1	Lettuce	15	20.00	z1	Mangoes	65	22.00
y2	Pechay	21	7.40	z2	Banana	89	10.00
y3	Spinach	23	7.00	z3	Watermelon	30	7.80
y4	Cauliflower	25	19.40	z4	Papaya	32	6.00
y5	Cabbage	24	5.50	z5	Grapes	69	28.50
y6	String Beans	31	9.30	z6	Ponkan	47	8.17
y7	Sayote	17	2.60	z7	Pomelo	38	17.20
y8	Squash	26	3.80	z8	Pineapple	51	14.00
y9	Carrots	41	8.00	z9	Apples	52	24.67

The objective function in minimizing the daily cost, given the decision variables represented in table 4 is given as (where C_i is the price/100g (in Php)):

$$Minimize\ cost = C_i w_i + C_i x_i + C_i y_i + C_i z_i \quad (1)$$

As for the constraints, it is noted that 25% of the total weight of their daily consumption must consist of carbohydrates, 25% of protein, and 50% consisting of fruits and vegetables [1]. Another variable is also introduced to be consistent with the constraints by using W, X, Y, and Z as seen in the equations below:

25% of total weight are carbohydrates:
$$0.75 * W - 0.25 * X - 0.25 * Y - 0.25 * Z = 0 \quad (2)$$
25% of total weight are proteins:
$$-0.25 * W + 0.75 * X - 0.25 * Y - 0.25 * Z = 0 \quad (3)$$
50% of the total weight is fruits and fruits
$$-0.50 * W - 0.50 * X + 0.50 * Y + 0.50 * Z = 0 \quad (4)$$
Total grams of carbohydrates:
$$w_1 + w_2 + w_3 + w_4 + w_5 + w_6 + w_7 + w_8 + w_9 = W \quad (5)$$
Total grams of proteins:
$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 = X \quad (6)$$
Total grams of vegetables:
$$y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + y_8 + y_9 = Y \quad (7)$$
Total grams of fruits:
$$z_1 + z_2 + z_3 + z_4 + z_5 + z_6 + z_7 + z_8 + z_9 = Z \quad (8)$$

Meal constraints will also be established according to the recommendations of dieticians and nutritionists. For breakfast, at least 2 whole eggs, at least 3 slices of bread, or 2 wheat tortillas, at least 100g of either mango, banana, or orange (ponkan) per day should be consumed. With this, the constraints can be seen below:

Table 5. Breakfast Meal Constraints:

	Equation	Description
Constraint 1	$x_9 \geq 5$	At least 2 whole eggs
Constraint 2	$w_6 + w_8 \geq 5$	At least 3 slices of bread
Constraint 3	$z_1 + z_2 + z_6 \geq 5$	At least 100g of either mango, banana, or orange

For lunch, at least 1 cup of brown or red rice, at least 100 grams of beef / pork, and at least 100g of apple and/or watermelon per day should be consumed. The constraints of this condition can be seen below:

Table 6. Lunch Meal Constraints

	Equation	Description
Constraint 1	$w_2 + w_3 \geq 5$	At least 1 cup of brown or red rice

Constraint 2	$x_1 + x_2 \geq 4$	At least 100g of beef or pork
Constraint 3	$z_3 + z_9 \geq 5$	At least 100g of apple and watermelon

Lastly, for dinner Constraints, at least 100 grams of chicken and fish, at least 100g of kamote, potato, or spaghetti, and at least 100g of either leafy vegetables or at least 100g of cabbage per day should be consumed which is shown below:

Table 7. Dinner Meal Constraints

	Equation	Description
Constraint 1	$x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \geq 4$	At least 100g of chicken and fish
Constraint 2	; $w_4 + w_7 + w_9 \geq 5$	100g of kamote, potato, or speghetti
Constraint 3	$y_1 + y_2 + y_3 \geq 5$	At least 100g of leafy vegetables
Constraint 4	$y_5 \geq 5$	At least 100g of cabbage

All decision variables are limited to 4 servings per week to give more variety to food and not just allot all budget to the cheapest option. Furthermore, the recommended calorie consumption of male and female students based on their activity level should be constrained by the variables Cal_F and Cal_M. This will enable the LP problem to distinguish the ideal food combination depending on gender and activity level. Ai is denoted by the calories associated with 100g (or 1 serving) of the decision variable, hence:

$$\text{Case1: } Cal_F = A_i w_i + A_i x_i + A_i y_i + A_i z_i \quad (9)$$
$$\text{Case1: } Cal_M = A_i w_i + A_i x_i + A_i y_i + A_i z_i \quad (10)$$

Since this is a budget planning for a 5-day week schedule, this study added a restriction on the food intake depending on the day which is summarized in Table 5. This will ensure that the students who will participate in this diet planning will be able to try a variety of food. Furthermore, this can be a healthy way of making sure that they can stick with this diet for a long period since they don't have to eat the same combination of food every day which might cause frustration and lack of motivation. Each day will have its objective function and the minimized cost for each day will be added to obtain the minimized meal cost for a 5-day week schedule depending on their gender and physical activeness. Should there be any conflicts with the breakfast, lunch, and dinner constraints on the given day, they will simply be removed from the constraints and let the program decide which protein will be substituted for them.

Table 8. Food Restrictions Depending on Day

Day	Mon	Tue	Wed	Thu	Fri
Restrictions	None	No Pork	No Chicken	No Fish	No Beef

Different configurations will then be assessed and summarized as a guide for people who are concerned about the budget they need for a certain calorie diet. Since there are 2 genders and 3 physical activeness options, a total of 6 weekly meal budgets will be presented and the food they need to buy to reach their calorie recommendation without the need to spend too much money. The six cases will be as follows – (1) Not Active Female–NAF, (2) Moderately Active Female–MAF, (3) Very Active Female–VAF, (4) Not Active Male–NAM, (5) Moderately Active Male–MAM, (6) Very Active Male–VAM. All variables and conditions will remain the same except for the calorie restrictions based on gender and physical activeness.

Furthermore, there were two implementations made in MATLAB – LP and ILP methods. LP gives a solution that uses decimal numbers to show the optimized solution while ILP uses integers and whole numbers while still computing for the minimum cost [29][30]. Setting up the decision variables for both LP and ILP have a similar setup although the default will be set at LP. The decision variables and constraints of both LP and ILP problems is constructed inside the MATLAB software. Consequently, prob2struct() followed by the linprog() function is necessary to obtain the optimal solutions for LP; however, for ILP, it only needs the solve() function.

IV. RESULTS AND DISCUSSION

After running six different configurations using the optimizer toolbox in MATLAB, it was able to compute the LP and ILP solution of the food combinations based on gender and physical activeness of students. Furthermore, it was also able to minimize the cost for such given the aforementioned constraints.

Case 1: LP and ILP Results for Not Active Females (NAF)

For NAFs, the combination of food can be seen in Fig. 4 as well as the weekly cost for such a combination. For the LP solution, it was able to minimize the weekly food cost for a not active female student at Php 824.35; however, for the ILP it had a slightly different combination of food and costs Php 829.49 which is around Php 5 higher than the LP solution.

Table 9. LP and ILP minimization solution for NAF

Non-Active Female (NAF)							
LP				**ILP**			
w1	0.00	**x1**	4.00	**w1**	0.00	**x1**	4.00
w2	4.00	**x2**	1.00	**w2**	4.00	**x2**	1.00
w3	1.00	**x3**	4.00	**w3**	1.00	**x3**	4.00
w4	4.00	**x4**	4.00	**w4**	4.00	**x4**	4.00
w5	3.73	**x5**	0.73	**w5**	3.73	**x5**	0.73
w6	1.00	**x6**	0.00	**w6**	1.00	**x6**	0.00
w7	0.00	**x7**	0.00	**w7**	0.00	**x7**	0.00
w8	4.00	**x8**	0.00	**w8**	4.00	**x8**	0.00
w9	1.00	**x9**	5.00	**w9**	1.00	**x9**	5.00
W	18.73	**X**	18.73	**W**	18.73	**X**	18.73
y1	0.00	**z1**	0.00	**y1**	0.00	**z1**	0.00
y2	1.00	**z2**	4.00	**y2**	3.00	**z2**	4.00
y3	4.00	**z3**	4.00	**y3**	2.00	**z3**	4.00
y4	0.00	**z4**	4.00	**y4**	0.00	**z4**	4.00
y5	5.00	**z5**	0.00	**y5**	5.00	**z5**	0.00
y6	0.00	**z6**	4.00	**y6**	0.00	**z6**	4.00
y7	4.00	**z7**	0.00	**y7**	4.00	**z7**	0.00
y8	4.00	**z8**	0.00	**y8**	4.00	**z8**	0.00
y9	2.47	**z9**	1.00	**y9**	3.00	**z9**	1.00
Y	20.47	**Z**	17.00	**Y**	21.00	**Z**	17.00
Total Cost:			**₱824.35**	**Total Cost:**			**₱829.49**

Case 2: LP and ILP Results for Moderately Active Females (MAF)

For MAFs, the LP solution was able to minimize the cost down to Php 931.74 per week compared to the ILP solution which was a slightly higher cost of Php 934.51. The same with NAF, the MAF also had different combinations of food that can cater to the required calorie requirement of a moderately active female student with 2000 calories seen in Fig. 5. It can be observed that the ratio of the carbohydrates, protein, fruits, and vegetable sources is coherent with the quarter rule mentioned in the introduction.

Table 10. LP and ILP minimization solution for MAF

Moderately Active Female (NAF)							
LP				**ILP**			
w1	1.34	**x1**	4.00	**w1**	1.00	**x1**	4.00
w2	4.00	**x2**	3.34	**w2**	3.00	**x2**	4.00
w3	1.00	**x3**	4.00	**w3**	2.00	**x3**	3.00
w4	4.00	**x4**	4.00	**w4**	4.00	**x4**	4.00
w5	4.00	**x5**	0.00	**w5**	4.00	**x5**	0.00
w6	1.00	**x6**	0.00	**w6**	1.00	**x6**	0.00
w7	0.00	**x7**	0.00	**w7**	1.00	**x7**	0.00
w8	4.00	**x8**	0.00	**w8**	4.00	**x8**	0.00
w9	1.00	**x9**	5.00	**w9**	0.00	**x9**	5.00
W	20.34	**X**	20.34	**W**	20.00	**X**	20.00
y1	0.00	**z1**	0.00	**y1**	0.00	**z1**	0.00
y2	2.67	**z2**	4.00	**y2**	4.00	**z2**	4.00
y3	4.00	**z3**	4.00	**y3**	2.00	**z3**	4.00
y4	0.00	**z4**	4.00	**y4**	0.00	**z4**	4.00
y5	5.00	**z5**	0.00	**y5**	5.00	**z5**	0.00
y6	0.00	**z6**	4.00	**y6**	0.00	**z6**	4.00
y7	4.00	**z7**	0.00	**y7**	4.00	**z7**	0.00
y8	4.00	**z8**	0.00	**y8**	4.00	**z8**	0.00
y9	4.00	**z9**	1.00	**y9**	4.00	**z9**	1.00
Y	23.67	**Z**	17.00	**Y**	23.00	**Z**	17.00
Total Cost:			**₱931.74**	**Total Cost:**			**₱934.51**

Case 3: LP and ILP Results for Very Active Females (VAF)

VAFs also have the same pattern as both NAF and MAF, wherein the LP's minimized cost is slightly lower than ILP's minimized cost at Php 1047.10 and Php 1051.50, respectively. With only a difference of Php 4.40 pesos, it can be seen from the female dietary plan that the most expensive 5-day meal menu will only cost 1051.50 pesos which are way below the allotted budget of college students at Php 1439.39.

Table 11. LP and ILP minimization solution for VAF

Very Active Female (VAF)							
LP				ILP			
w1	3.96	**x1**	4.00	**w1**	4.00	**x1**	4.00
w2	4.00	**x2**	4.00	**w2**	4.00	**x2**	4.00
w3	1.00	**x3**	4.00	**w3**	1.00	**x3**	2.00
w4	4.00	**x4**	4.00	**w4**	4.00	**x4**	4.00
w5	4.00	**x5**	1.96	**w5**	4.00	**x5**	4.00
w6	1.00	**x6**	0.00	**w6**	1.00	**x6**	0.00
w7	0.00	**x7**	0.00	**w7**	0.00	**x7**	0.00
w8	4.00	**x8**	0.00	**w8**	4.00	**x8**	0.00
w9	1.00	**x9**	5.00	**w9**	1.00	**x9**	5.00
W	22.96	**X**	22.96	**W**	23.00	**X**	23.00
y1	0.00	**z1**	0.00	**y1**	0.00	**z1**	0.00
y2	4.00	**z2**	4.00	**y2**	4.00	**z2**	4.00
y3	4.00	**z3**	4.00	**y3**	4.00	**z3**	4.00
y4	0.00	**z4**	4.00	**y4**	0.00	**z4**	4.00
y5	5.00	**z5**	0.00	**y5**	5.00	**z5**	0.00
y6	3.92	**z6**	4.00	**y6**	3.00	**z6**	4.00
y7	4.00	**z7**	0.00	**y7**	4.00	**z7**	0.00
y8	4.00	**z8**	0.00	**y8**	4.00	**z8**	1.00
y9	4.00	**z9**	1.00	**y9**	4.00	**z9**	1.00
Y	28.92	**Z**	17.00	**Y**	28.00	**Z**	18.00
Total Cost:			**₱1,047.10**	**Total Cost:**			**₱1,051.50**

Case 4: LP and ILP Results for Not Active Males (NAM)

For college male students, NAMs have to allot 1188.90 pesos (LP solution) to 1208.60 pesos (ILP solution) to sustain the caloric requirement of their body at 2400 calories shown in Fig. 7. Similar to all solutions, the combination of the food differs from one method to another since ILP requires whole integer numbers and does not accept decimals or fractions.

Table 12. LP and ILP minimization solution for NAM

Non-Active Male (NAM)							
LP				ILP			
w1	4.00	**x1**	4.00	**w1**	4.00	**x1**	4.00
w2	1.00	**x2**	4.00	**w2**	1.00	**x2**	4.00
w3	4.00	**x3**	4.00	**w3**	4.00	**x3**	4.00
w4	4.00	**x4**	4.00	**w4**	4.00	**x4**	4.00
w5	4.00	**x5**	4.00	**w5**	4.00	**x5**	4.00
w6	3.23	**x6**	0.23	**w6**	3.00	**x6**	0.00
w7	0.00	**x7**	0.00	**w7**	0.00	**x7**	0.00
w8	4.00	**x8**	0.00	**w8**	4.00	**x8**	0.00
w9	1.00	**x9**	5.00	**w9**	1.00	**x9**	5.00
W	25.23	**X**	25.23	**W**	25.00	**X**	25.00
y1	0.00	**z1**	0.45	**y1**	0.00	**z1**	3.00
y2	4.00	**z2**	4.00	**y2**	3.00	**z2**	4.00
y3	4.00	**z3**	4.00	**y3**	3.00	**z3**	4.00
y4	0.00	**z4**	4.00	**y4**	0.00	**z4**	4.00
y5	5.00	**z5**	0.00	**y5**	5.00	**z5**	0.00
y6	4.00	**z6**	4.00	**y6**	4.00	**z6**	4.00
y7	4.00	**z7**	0.00	**y7**	4.00	**z7**	0.00
y8	4.00	**z8**	4.00	**y8**	4.00	**z8**	3.00
y9	4.00	**z9**	1.00	**y9**	4.00	**z9**	1.00
Y	29.00	**Z**	21.45	**Y**	27.00	**Z**	23.00
Total Cost:			**₱1,188.90**	**Total Cost:**			**₱1,208.60**

Case 5: LP and ILP Results for Moderately Active Males (MAM)

For MAMs, they are more expensive by around 150-200 pesos with an increase of calorie requirement to 2600. Moderately Active Males, or MAMs, have to, at most, spend 1373.50 pesos (LP solution) or 1383.60 pesos (ILP solution) on food costs to supply their energy needs which are shown in Fig. 8.

Table 13. LP and ILP minimization solution for MAM

Moderately Active Male (MAM)							
LP				ILP			
w1	4.00	**x1**	4.00	**w1**	4.00	**x1**	4.00
w2	2.82	**x2**	4.00	**w2**	4.00	**x2**	4.00
w3	4.00	**x3**	4.00	**w3**	3.00	**x3**	4.00
w4	4.00	**x4**	4.00	**w4**	4.00	**x4**	4.00
w5	4.00	**x5**	4.00	**w5**	4.00	**x5**	3.00
w6	4.00	**x6**	2.82	**w6**	4.00	**x6**	4.00
w7	0.00	**x7**	0.00	**w7**	1.00	**x7**	0.00
w8	4.00	**x8**	0.00	**w8**	4.00	**x8**	0.00
w9	1.00	**x9**	5.00	**w9**	0.00	**x9**	5.00
W	27.82	**X**	27.82	**W**	28.00	**X**	28.00
y1	0.00	**z1**	4.00	**y1**	0.00	**z1**	3.00
y2	4.00	**z2**	4.00	**y2**	4.00	**z2**	4.00
y3	4.00	**z3**	4.00	**y3**	4.00	**z3**	4.00
y4	0.00	**z4**	4.00	**y4**	0.00	**z4**	4.00
y5	5.00	**z5**	0.00	**y5**	5.00	**z5**	0.00
y6	4.00	**z6**	4.00	**y6**	4.00	**z6**	4.00
y7	4.00	**z7**	1.64	**y7**	4.00	**z7**	3.00
y8	4.00	**z8**	4.00	**y8**	4.00	**z8**	4.00
y9	4.00	**z9**	1.00	**y9**	4.00	**z9**	1.00
Y	29.00	**Z**	26.64	**Y**	29.00	**Z**	27.00
Total Cost:			**₱1,373.50**	**Total Cost:**			**₱1,382.60**

Case 6: LP and ILP Results for Very Active Males (VAM)

Lastly, Very Active Males, or VAMs, need to spend at most 1600.30 pesos for the ILP solution since it provides non-fraction portions which are easier to compute and prepare. However, the LP solution is not far away from the ILP computed cost as it is only cheaper by 7 pesos at 1593.40 pesos. Combinations from these Fig.s can be referred to in Table 4 where the variables are described by the food, price, and calorie content per portion of 100 grams. Compared to the previous five configurations, the computed minimized cost for VAMs exceeds the surveyed budget by around 160 pesos. Given their physical activeness, they need to consume more food and calories to sustain their body's energy supply.

Table 14. LP and ILP minimization solution for VAM

Very Active Male (VAM)							
LP				ILP			
w1	4.00	**x1**	4.00	**w1**	4.00	**x1**	4.00
w2	4.00	**x2**	4.00	**w2**	4.00	**x2**	4.00
w3	4.00	**x3**	4.00	**w3**	4.00	**x3**	4.00
w4	4.00	**x4**	4.00	**w4**	4.00	**x4**	4.00
w5	4.00	**x5**	4.00	**w5**	4.00	**x5**	4.00
w6	4.00	**x6**	4.00	**w6**	4.00	**x6**	4.00
w7	0.00	**x7**	1.90	**w7**	1.00	**x7**	2.00
w8	4.00	**x8**	0.00	**w8**	4.00	**x8**	0.00
w9	2.90	**x9**	5.00	**w9**	2.00	**x9**	5.00
W	30.90	**X**	30.90	**W**	31.00	**X**	31.00
y1	0.00	**z1**	4.00	**y1**	0.00	**z1**	4.00
y2	4.00	**z2**	4.00	**y2**	4.00	**z2**	4.00
y3	4.00	**z3**	4.00	**y3**	4.00	**z3**	4.00
y4	0.00	**z4**	4.00	**y4**	0.00	**z4**	4.00
y5	5.00	**z5**	3.81	**y5**	5.00	**z5**	2.00
y6	4.00	**z6**	4.00	**y6**	4.00	**z6**	4.00
y7	4.00	**z7**	4.00	**y7**	4.00	**z7**	3.00
y8	4.00	**z8**	4.00	**y8**	4.00	**z8**	4.00
y9	4.00	**z9**	1.00	**y9**	4.00	**z9**	4.00
Y	29.00	**Z**	32.81	**Y**	29.00	**Z**	33.00
Total Cost:			**₱1,593.40**	**Total Cost:**			**₱1,600.30**

V. CONCLUSION AND RECOMMENDATION

In this study, a Linear Programming (LP) method and an Integer Linear Programming (ILP) method were used to minimize the cost of a 5-day dietary plan following their recommended calorie intake. Consequently, there were six cases made in the experiment based on their sex and physical activeness as NAF, MAF, VAF, NAM, MAM, and VAM, all of which have different calorie requirements. In doing such, the optimizer toolbox in MATLAB was used to describe the decision variables, construct the objective function (minimize cost), and define the constraints for breakfast, lunch, and dinner. After computing for both LP and ILP solutions, it was observed that only Very Active Males (VAM) were unable to stay below the surveyed budget with Php 1600.30. However, the rest of the configuration can access affordable and sustainable dietary plans based on their sex and physical activeness. As a result, this study suggests that college

students can access a well-balanced diet without spending too much money to perform better at school.

Acknowledgment

The author wishes to express his deepest gratitude to De La Salle University-Manila, the Department of Manufacturing Engineering and Management (DMEM), and the Department of Science and Technology - Science Education Institute (DOST-SEI) for providing the Engineering Research Development Technology (ERDT) scholarship.

References

[1] P. R. Reuter, B. L. Forster, and S. R. Brister, "The influence of eating habits on the academic performance of university students," J Am. Coll. Health, vol. 69, no. 8, pp. 921–927, 2021.

[2] A. Wald, P. A. Muennig, K. A. O'connell, and C. E. Garber, "Associations between healthy lifestyle behaviors and academic performance in U.S. Undergraduates: a secondary analysis of the American College Health Association's National College Health Assessment II," Am. J. Health Promot., vol. 28, no. 5, pp. 298–305, 2014.

[3] G. Sogari, C. Velez-argumedo, M. I. Gómez, and C. Mora, "College students and eating habits: a study using an ecological model for healthy behavior," Nutrients, vol. 10, no. 12, p. 1823, 2018.

[4] B. J. Venn, "Macronutrients and human health for the 21st century," Nutrients, vol. 12, no. 8, p. 2363, 2020

[5] G. Savarino, A. Corsello, and G. Corsello, "Macronutrient balance and micronutrient amounts through growth and development," Ital. J. Pediatr., vol. 47, no. 1, p. 109, 2021.

[6] "Healthy eating plate," The Nutrition Source, 18-sep-2012. [Online]. Available: https://www.hsph.harvard.edu/nutritionsource/healthy-eating-plate/. [Accessed: 30-may-2022].

[7] McCullough ML, Feskanich D, Stampfer MJ, Giovannucci EL, Rimm EB, Hu FB, Spiegelman D, Hunter DJ, Colditz GA, Willett WC. Diet quality and major chronic disease risk in men and women: moving toward improved dietary guidance. The American journal of clinical nutrition. 2002 Dec 1;76(6):1261-71.

[8] Akbaraly TN, Ferrie JE, Berr C, Brunner EJ, Head J, Marmot MG, Singh-Manoux A, Ritchie K, Shipley MJ, Kivimaki M. Alternative healthy eating index and mortality over 18 y of follow-up: results from the Whitehall II cohort. The American journal of clinical nutrition. 2011 May 25;94(1):247-53.

[9] Norwegian Nutrition Council (2011) Kostråd for å fremme folkehelsen og
Forebygge kroniske sykdommer - metodologi og vitenskapelig kunnskapsgrunnlag. Oslo: Norwegian Directorate of Health.

[10] A. Alhazmi and F. Aziz, "Dietary assessment and its awareness in female students from different health departments: unhealthy diet with normal BMI," J. Public Health Res., vol. 9, no. 3, p. 1799, 2020.

[11] E. L. Valen, D. Engeset, N. C. Øverby, and E. R. Hillesund, "Studentkost: a cross-sectional study assessing college students' diets: the reason for concern?" J. Nutr. Sci., vol. 9, no. E39, 2020.

[12] K. M. Eck and C. Byrd-bredbenner, "Food choice decisions of collegiate division I athletes: a qualitative exploratory study," Nutrients, vol. 13, no. 7, p. 2322, 2021.

[13] "The truths about supplements," pennmedicine.org. [Online]. Available: https://www.pennmedicine.org/updates/blogs/health-and-wellness/2020/february/the-truth-about-supplements. [Accessed: 30-may-2022].

[14] "How many calories does my teen need?," eatright.org. [Online]. Available: https://www.eatright.org/food/nutrition/dietary-guidelines-and-myplate/how-many-calories-does-my-teen-need. [Accessed: 30-may-2022].

[15] E. Coleman, "What is the normal calorie intake needed for a college student?," healthy eating | sf gate, 28-sep-2012. [Online]. Available: https://healthyeating.sfgate.com/normal-calorie-intake-needed-college-student-5544.html. [Accessed: 30-may-2022].

[16] "How many calories does my teen need?," eatright.org. [Online]. Available: https://www.eatright.org/food/nutrition/dietary-guidelines-and-myplate/how-many-calories-does-my-teen-need. [Accessed: 30-may-2022].

[17] M. Cluskey and D. Grobe, "College weight gain and behavior transitions: male and female differences," J. Am. Diet. Assoc., vol. 109, no. 2, pp. 325–329, 2009.

[18] "2010 dietary guidelines," health.gov. [Online]. Available: https://health.gov/our-work/nutrition-physical-activity/dietary-guidelines/previous-dietary-guidelines/2010. [Accessed: 30-may-2022].

[19] B. J. Hoogenboom, J. Morris, C. Morris, and K. Schaefer, "Nutritional knowledge and eating behaviors of female, collegiate swimmers," N. Am. J. Sports Phys. Ther., vol. 4, no. 3, pp. 139–148, 2009.

[20] V. D. G. Balcita, A. T. A. Bejar, T. P. P. Goy, R. K. C. Billones and E. P. Dadios, "Optimizing the allocation of renewable energy generation and energy consumption of power plants in the Philippines using linear programming," 2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), 2021, pp. 1-6, doi: 10.1109/HNICEM54116.2021.9732024.

[21] The Editors of Encyclopedia Britannica, "Linear programming," Encyclopedia Britannica. 18-jul-2017.

[22] C. Van Dooren, "A review of the use of linear programming to optimize diets, nutritiously, economically and environmentally," Front. Nutr., vol. 5, p. 48, 2018.

[23] Urrutia, J. D., Mercado, J., & Tampis, R. L. (2017). Minimization of food cost on 2000-calorie diabetic diet. Journal of Physics: Conference Series, 820, 012002. Doi:10.1088/1742-6596/820/1/012002

[24] "View of Mathematical Modelling of Diet Planning Problem for Hypertension Patients," conferencehunter.com. [Online]. Available: https://crinn.conferencehunter.com/index.php/jcrinn/article/view/256/172. [Accessed: 01-jun-2022].

[25] Briend A, Ferguson E, Darmon N. Local food price analysis by linear programming: a new approach to assess the economic value of fortified food supplements. Food Nutr Bull. (2001) 22:184–9. Doi: 10.1177/156482650102200210.

[26] "FoodData Central," usda.gov. [Online]. Available: https://fdc.nal.usda.gov/. [Accessed: 29-jun-2022].

[27] dti.gov.ph. [Online]. Available: https://www.dti.gov.ph/konsyumer/latest-srps-basic-necessities-prime-commodities/. [Accessed: 29-jun-2022].

[28] "Home page - SM Markets," smmarkets.ph. [Online]. Available: https://smmarkets.ph/. [Accessed: 29-jun-2022].

[29] A. M. O. Galindo, E. P. Dadios, R. K. C. Billones and I. C. Valenzuela, "Cost optimization for the allocation, production, and distribution of a plastic manufacturing company using integer linear programming," 2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), 2021, pp. 1-6, doi: 10.1109/HNICEM54116.2021.9731804.

[30] I. J. C. Valencia, E. P. Dadios and R. K. C. Billones, "A maximization model for food aid distribution using integer linear programming," 2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), 2021, pp. 1-6, doi: 10.1109/HNICEM54116.2021.9732003.