Linear Programming for Better Diet for Prisoners

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Abstract. Physical and mental illnesses of incarcerated people caused by nutritional imbalance is a prevailing issue in America. Meanwhile, prisons are facing requests from the state for budget cuts, disabling them to expand the prison meal options in number. However, there is currently a lack in the research focused on improving prison meal plans. Hence in this work, a most cost-efficient and healthiest combination of food is devised through a linear programming model. The constraints in this model include the average prices of the raw materials needed for the prison menu and the nutritional demand of an average male prisoner. Then the problem is converted to canonical form and an optical solution is generated after computerized process. The result is a combination of 1133.09 g carrot, 962.51 g broccoli, 1788.23 g onion, 1402.5 g pepperoni, and 448.53 ml milk. This work provides suggestions for meal planning in American prisons.

Keywords: Linear programming · diet plan · prison · budget control · health

1 Introduction

Few are aware of the inadequate and unhealthy prison food that leads to chronic illnesses and mental issues among more than one million incarcerated Americans. Previous studies have provided important information on the nutritional structure of prison food: high in sodium, sugar, and saturated fat while low in vitamins, fiber, and water. Prisons tend to offer unhealthy refined food options due to funding limitations. Because it is difficult to devise a solution that maximizes nutrients and minimizes cost, there is little published work suggesting an optimal meal plan for the incarcerated population. Therefore, this study generates a healthy and cost-efficient combination of food meeting the nutritional demand of male prisoners from age 19 to 50.

2 Background

2.1 Nutritional Deficiency in Prison Food

The majority of incarcerated people across the USA suffer from a nutritional deficiency in prison food. Statistics have proven that meal offered in jail does not meet the recommended nutritional intake. Massachusetts Department of Correction Statement of

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Nutritional Adequacy suggests that 50.5% of blacks, 29.3% of whites, and 14.3% of Asian inmates do not receive the recommended amount of vitamin D [1]. In Washington prisons, inmates are fed with a meal plan that includes too much refined starches, added sugar, and sodium and too few fruits, vegetables, whole grains, and lean protein. Furthermore, inmates have highly limited healthy food options on the commissary list. More than 90% of the food available is in the "Avoid" category according to Washington's Healthy Nutrition Guidelines for Vending Machines [2]. The prison population is victimized by insufficient and unwholesome prison food. According to the Incarcerated Workers Organizing Committee, 94% of former inmates surveyed were not fed until feeling full. Another survey finds that only 29% of prisoner survey respondents described the food they received as "good" or "very good". Prisoners negatively comment on their menu content. "It's all chips or potatoes." "There's not a good variety of fruit and veg at all. No greens in veg. No oranges, etc."

2.2 Devastating Consequences Related to Dietary Deficiency

A poor and unbalanced prison diet does nothing to help sustain a healthy mind or body. Unhealthy food in prison leads to the prevalence of illnesses among prisoners. Nutritional deficiencies, cardiovascular disease, diabetes, high cholesterol, and other serious medical issues arise from poor nutrition. 30% of inmates have hypertension. 10% of them have heart problems. And 9% of them suffer from diabetes. The percentage is higher than the national average. The poor food service results in the shocking fact that around 51% of state prisoners as well as 43% of federal prisoners have chronic diseases, as reported by the Bureau of Justice Statistics [3]. Apart from healthy issues, prison disturbance is partly due to the unsatisfactory food supply. Prisoners who are not well-fed are more likely to show aggression and dissent. Studies have shown the importance of nutrition to reduce disciplinary incidents in jail.

2.3 Limited Food Budget

According to the Administrations, recent years have witnessed an increase in requests from the state to jail to decrease the food budget. This indicates the decreasing ability of prisons to support a proper meal for incarcerated people. In Texas in 2019, only 4% of the budget assigned to correction facilities went to prisoner's dinner table.

3 Methodology

The programming technique used in this model is simplex method for linear programs. The final result, which is the menu with 11 different kinds of foods is generated using simplex method by developing the mathematical model along with a variety of food data.

3.1 Data Descriptions

Aware of all the existing problems regarding the food of those incarcerated people, we decided to come up with the most optimal solution for food combinations for them, increasing their nutritional intake while limiting the government budgets simultaneously. We acquired an FCI commissary list on the official website of the Federal Bureau of Prisons website [4]. Based on the Food column on the first page of the list, we looked up the raw materials that are essential for making those listed foods which can be seen in the Table 1.

Given that the majority of prisoners all over the United States are now suffering from nutritional scarcity and the low elements intake may lead to a series of devastating effects on the human body, we gather data from the National Institutes of Health, which demonstrates the Dietary Reference Intakes (DRIs) [5]. Table 2 integrates the recommended dietary allowances and adequate intake data that we used for the construction of the target b matrix. To make the data more accurate, we chose nutritional elements ranging from macromolecules to micromolecules. Carbohydrates, fiber, and fat are essential for the human body because they can help generate energy and heat. Water is essential since about 70% of the human body is made up of water [6]. Protein serves various functions in our body, ranging from digestion, transportation, and the construction of our immune system. Other vitamins are essential because they have diverse biochemical functions. Other trace elements are of vital importance since they exist within our blood. Because the majority of the prison population is made up of adult males within the age range from 19 to 40 years old, all the data referred from the DRI report is corresponding to this age and sex range.

After the minimum daily requirements are obtained from official guidance, we found out the specific nutrition facts of our raw materials. Since the government funding is limited, the only constraint that is taken into our consideration is the minimization of the price of foods. So we went online and searched for the average food price in the United States of our raw materials [7]. Then we define our foods with corresponding variables, which are shown in Table 3 and Table 4.

Table 1. Raw materials needed for foods in the prison

Meat:	Tuna	Salmon	Chicken	Beef	Spam	Pepperoni	Turkey
Grain:	Beans						
Condiments:	Pepper	Garlic	Coriander	Mustard	Cheese		
Flour:	Corn flour						
Vegetables:	White Rice	Tomato	Potato	Onion	Broccoli	Carrot	Cabbage
Drink:	Water	Milk					

Table 2. Dietary Reference Intakes of essential elements for 19 ~ 50 adult male

	Minimum Daily requirement
Water (g/d)	3700
Carbohydrate(g/d)	130
Fiber(g/d)	38
Fat(g/d)	61
Protein(g/d)	56
V - A (μg/d)	900
V - C (mg/d)	90
V - E (mg/d)	15
Calcium (mg/d)	1000
Sodium (mg/d)	1500
Potassium (mg/d)	3400

Table 3. Food prices and corresponding variables

	X1 = Rice (100 g)	X2 = Navy beans (100 g)	X3 = Chicken (100 g)	X4 = Beef (100 g)	X5 = Tomato (100 g)	X6 = Potato (100 g)	X7 = Carrot(100 g)
Water (g/d)	10.7	0	0	0	94.7	8.28	88
Carbohydrate(g/d)	28.7	13	0	0	3.9	79.9	9.6
Fiber(g/d)	0.4	0	0	0	1.2	5.4	2.8
Fat(g/d)	0.19	0	14	15	0.42	0.95	0.24
Protein(g/d)	2.36	6	27	26	0.7	8.11	0.93
V - A (ug/d)	0	0	0	0	42	0	835
V - C (mg/d)	0	93	0	1	14	5.9	5.9
V - E (mg/d)	0	0	0	0	0.54	0.66	0.66
Calcium (mg/d)	10	15	0	1	10	44	33
Sodium (mg/d)	3	13	89	72	5	48	69
Potassium (mg/d)	127	307	223	318	237	1270	320
Cost of Foods ($/100 g)	0.11$	0.08$	0.23$	0.96$	0.42$	0.26$	0.22$

3.2 Model Description and Development

The method of linear programming is used to develop an optimal choice between 14 variables. There are three major components in the mathematical model, including objective

Table 4. Food prices and corresponding variables

	X8 = Broccoli(100 g)	X9 = Spam (100 g)	X10 = Onion (100 g)	X11 = Pepperoni 100 g	X12 = Turkey (100 g)	X13 Salmon (100 g)	X14 = Milk(100 g)
Water (g/d)	89.3	0	89.11	0	0	0	60
Carbohydrate(g/d)	6.64	4.6	9.34	4.04	2	0	5.2
Fiber(g/d)	2.6	4.6	1.7	0	0	0	0
Fat(g/d)	0.37	27	0.1	40.28	7	1.3	0
Protein(g/d)	2.82	13	1.1	20.35	29	28	30
V - A (ug/d)	31	0	0	0	0	0	0
V - C (mg/d)	89.2	0	7.4	1	0	6	0
V - E (mg/d)	0.78	0	0	0.01	0.02	0.25	0
Calcium (mg/d)	33	10	23	20	1	3	125
Sodium (mg/d)	69	1411	146	1788	103	47	44
Potassium (mg/d)	320	409	1	315	239	522	0
Cost of Foods ($/100 g)	0.23$	0.87$	0.27$	0.71$	1.5$	2.5$	0.48$

Problem is

$$\text{Min } Z = 0.11x_1 + 0.18x_2 + 0.23x_3 + 0.96x_4 + 0.42x_5 + 0.26x_6 + 0.32x_7 + 0.23x_8 + 0.87x_9 + 0.27x_{10} + 0.71x_{11} + 1.5x_{12} + 2.5x_{13} + 0.48x_{14}$$

subject to

$$
\begin{aligned}
&10.7x_1 + 94.7x_5 + 8.28x_6 + 88x_7 + 87.3x_8 + 89.11x_{10} + 60x_{14} \geq 3700\\
&28.7x_1 + 13x_2 + 7x_4 + 3.9x_5 + 79.9x_6 + 9.6x_7 + 6.64x_8 + 4.6x_9 + 9.34x_{10} + 4.04x_{11} + 2x_{12} + 5.2x_{14} \geq 130\\
&0.4x_1 + 1.2x_5 + 2.8x_7 + 4.6x_9 + 0.1x_{10} + x_{14} \geq 38\\
&0.19x_1 + 14x_3 + 15x_4 + 0.42x_5 + 0.95x_6 + 0.24x_7 + 27x_9 + 0.1x_{10} + 40.28x_{11} + 7x_{12} + 1.3x_{13} \geq 61\\
&2.36x_1 + 6x_2 + 27x_3 + 26x_4 + 0.7x_5 + 8.11x_6 + 2.82x_8 + 13x_9 + 1.1x_{10} + 20.35x_{11} + 29x_{12} + 28x_{13} + 30x_{14} \geq 56\\
&42x_5 + 835x_7 + 31x_8 \geq 900\\
&93x_2 + 14x_5 + 5.9x_6 + 5.9x_7 + 89.2x_8 + 7.4x_{10} + x_{11} + 6x_{13} \geq 90\\
&0.54x_5 + 0.66x_6 + 0.66x_7 + 0.78x_8 + 0.01x_{11} + 0.02x_{12} + 0.25x_{13} \geq 15\\
&10x_1 + 15x_2 + 10x_5 + 44x_6 + 10x_9 + 23x_{10} + 20x_{11} + x_{12} + 3x_{13} + 125x_{14} \geq 1000\\
&3x_1 + 13x_2 + 89x_3 + 72x_4 + 5x_5 + 48x_6 + 69x_7 + 67x_8 + 1411x_9 + 146x_{10} + 1788x_{11} + 103x_{12} + 47x_{13} + 44x_{14} \geq 1500\\
&127x_1 + 307x_2 + 223x_3 + 318x_4 + 237x_5 + 1270x_6 + 320x_7 + 317x_8 + 4090x_9 + x_{10} + 315x_{11} + 239x_{12} + 522x_{13} \geq 3400
\end{aligned}
$$

and $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14} \geq 0$;

Fig. 1. The objective function generated including decision variables and constraints

function, decision variables and constraints to be met in Fig. 1. 14 variables are the masses of 14 kinds of food included in the diet menu, as shown in Table 5.

Minimizing the total food cost:

$$(Total\ cost)min = \sum_{i=1}^{14} xi * pi \ldots \tag{1}$$

Xi represents the decision variable of a total of 14 food items, and Pi refers to the corresponding price of the unique variable Xi.

$$Lowerbound \ll \sum_{i=1}^{14} * \sum_{j=1}^{11} cij \ldots \tag{2}$$

Table 5. Types of food listed in the model

Meat	Grain	Vegetable	Drinks
Chicken	Rice	Tomato	Milk
Beef	Navy beans	Potato	
Spam		Carrot	
Beef		Broccoli	
Pepperoni		Onion	
Turkey			
Salmon			

Equivalent to:

$$A * x \geq b \ldots \quad (3)$$

Cij represents the nutrient content for a total of 11 categories of nutrients, and for each Xi, Cj differs.

The problem is converted to canonical form by adding slack, surplus and artificial variables as appropriate.

As the constraint-1 is of type '≥' we should subtract surplus variable S1, and add artificial variable A1.

As the constraint-2 is of type '≥' we should subtract surplus variable S2, and add artificial variable A2.

As the constraint-3 is of type '≥' we should subtract surplus variable S3, and add artificial variable A3.

As the constraint-4 is of type '≥' we should subtract surplus variable S4, and add artificial variable A4.

As the constraint-5 is of type '≥' we should subtract surplus variable S5, and add artificial variable A5.

As the constraint-6 is of type '≥' we should subtract surplus variable S6, and add artificial variable A6.

As the constraint-7 is of type '≥' we should subtract surplus variable S7, and add artificial variable A7.

As the constraint-8 is of type '≥' we should subtract surplus variable S8, and add artificial variable A8.

As the constraint-9 is of type '≥' we should subtract surplus variable S9, and add artificial variable A9.

As the constrain-10 is of type '≥' we should subtract surplus variable S10, and add artificial variable A10.

As the constraint-11is of type '≥' we should subtract surplus variable S11, and add artificial variable A11.

By running through the computerized process of linear programming (including necessary addition of slack variables and artificial variables), cost of minimum can be solved.

3.3 Results and Discussions

The final diet choose is designed based on the constraints and requirements provided by the previous table. Linear programming approach is used in the study, along with 14 variables.

The results obtained will be shown:

x1 = 0, x2 = 0, x3 = 0, x4 = 0, x5 = 0, x6 = 0, x7 = 11.3309, x8 = 9.6251, x9 = 0, x10 = 17.8823, x11 = 1.4025, x12 = 0, x13 = 0, x14 = 4.4853. Min Z = 13.8166

The different 14 variables of food items xj are put into the linear programming calculator, and it is noted that all the constraint conditions of nutrient requirements are met. The outcome turns out to be omitting 9 variables of the food item, keeping 11.3309*100 g carrot, 9.6251*100 g broccoli, 17.8823*100 g onion, 1.4025*100 g pepperoni, and 4.4853*100 ml milk. The cost of minimization is 13.8166 dollars. Meanwhile, an average prisoner's daily nutritional requirements can be met, as seen in Table 2. Note that this linear programming only takes 14 variables into consideration, and the cost is solely determined based on the national average market, which is not the case in reality that different conditions of states must be considered. This linear programming aims to meet the full nutrition requirement of humans, including C6, C7, and C8 of vitamins, which is unlikely to be covered in prison regulations. As a result, the outcome seems to deviate greatly from reality, and the minimum cost is significantly high.

The calculation process of this experiment is relatively less complicated, because the data and calculation methods we chose are relatively simple and easy to understand. The data we mainly use is the nutrient content of the main ingredients in prison, so as to select the most suitable food with the price and nutritional content, so the choice of food is also very streamlined, but the nutrients in it only cover the basic nutrients needed by the human body, so some less important nutrients may be ignored in the calculation process. At the same time, our model is relatively simple, mainly looking at the proportion of nutrients to select the amount required for each food, and the price is also a relatively low value in the US market, which may ignore the changes in the price of some ingredients in different seasons [8], and if these factors are added in the future, it may also lead to some changes in the final calculation results. Therefore, our calculation is relatively a one-year average, which is broad, but there may be long-term factors that we overlook, such as inflation [9].

Our analysis results finally selected five kinds of ingredients, in fact, this is also an ideal situation, not very suitable for application in practice, because it is basically impossible for a prison to use only these five ingredients a year, although this can ensure the health of people in prison, but it is not conducive to their mental health, eating the same food for a long time will cause people's disgust and dissatisfaction [10]. Therefore, in our future improvements, we will design and calculate a variety of different food combinations, different seasons, different groups of people will have different food choices, and finally achieve an optimal plan and price for the year, while also ensuring the physical health and mental health of prisoners and staff. In this way, our solutions are more suitable for practical use and more valuable.

4 Conclusion

Through our analysis of the food available in prison, the average price of food in the United States, and the basic nutrients needed by the human body, we constructed a mathematical model of the relationship between them and came up with the optimal choice of food: carrot, broccoli, onion, pepperoni, and milk. This combination of food is most cost-effective and covers the basic nutrients that the human body needs. The study faces limitations in the perspectives of practicality and magnitude. Thus we find further research on the following aspects necessary. The first is the choice of food. The foods involved in our model are all relatively common ingredients. If the variety of foods is expanded, a more cost-effective result may be obtained. Second, the food prices we determine are based on an average price calculated by the U.S. market and will be relatively lower than the market price. In the future, we will find a more affordable price for the ingredients used in prison kitchens. Finally, the number of human nutrient requirements we take into account are the needs of male prisoners from 19 to 50 years old. However, female also takes up a fair percentage of the prison population and their nutritional demand, which is different from male's, should be considered. Hence we will devise a linear programming model catering to female inmates' needs in the future to make our research more comprehensive.

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