# Cost-Effective Weekly Food Planning for Achieving Optimal Nutrition Requirements

## 1. Problem Statement:

The University of Bristol attracts more than 33% of international students from around 183 countries as of University of Bristol (2023), which is expected to increase over time. Most international students experience challenges budgeting and setting up their meal routines because they are unaware of the price and availability of food products in UK supermarkets. Due to this, most students develop the habit of eating highly processed, readily available food or ordering out which impacts their health and financial well-being, leading to increased stress, which may affect their academic performance. This report aims to give students insights into the list of food items that must be purchased weekly while ensuring they meet all the nutritional requirements set by the National Health Services (NHS). We applied linear programming and Mixed-integer linear programming (MILP) methods to a suggested list of whole foods and identified items that satisfy their nutritional requirements under an average budget. The model helps students plan and be prepared by budgeting and crafting their dietary schedules to lead healthy lives even before arriving in the UK for their academics.

## 2. Model Development:

Our model uses mixed integer linear programming (MILP) and LP to meet the nutritional requirements under a budget. We have considered this method because all the nutritional requirements are treated as continuous variables. At the same time, every fruit or vegetable is an integer or binary variable since Public Health England (2018) suggests that everyone should include five kinds of fruit and vegetables daily. The MILP enables us to include continuous and integer variables under the same model to select and add optimal combination of fruits and vegetables. We then convert the MILP model to an LP to get detailed sensitivity analysis of cost and nutrient constraints making it the most suitable method to achieve our objective

### *2.1 Data collection and processing*

We have collected the daily recommended nutrition requirements for a person from public health England (2016) and nutrition content in 100gm of all the food from public health England (2021). The food items were selected, considering health as our priority; we have selected 42 whole food items as recommended by the NHS. We have collected students' weekly average spending on groceries and the prices of respective food items from the Sainsbury's website.

The collected nutritional data were scaled based on the nutrition provided by 100gm of the respective food item. However, the price list collected for all the food items from Sainsbury varied in price based on the weights of the respective food items. So, we have scaled the prices of all the food items per 100gm to ensure that all the nutritional and price data are normalised to a standard scale. We have standardized price per 100g nutrition as it ensures accurate comparison between the weight and the cost of the food items.

### *2.2 Variables*

| Notation | Description | Type |
|---|---|---|
| $x_i$ | Daily intake of food | Decision variable (Continuous) |
| $y_i$ | Price of food | Input variable (Constant) |
| $e_i$ | **Energy** contained in food **i** | Input variable (Constant) |
| $p_i$ | **Protein** contained in food **i** | Input variable (Constant) |
| $f_i$ | **Fat** contained in food **i** | Input variable (Constant) |
| $sf_i$ | **Saturated fat** contained in food **i** | Input variable (Constant) |
| $pf_i$ | **Poly unsaturated fat** contained in food **i** | Input variable (Constant) |

| | | |
|---|---|---|
| $m_i$ | **Monounsaturated fat** contained in food **i** | Input variable (Constant) |
| $c_i$ | **Carbohydrate** contained in food **i** | Input variable (Constant) |
| $fs_i$ | **Free sugars** contained in food **i** | Input variable (Constant) |
| $s_i$ | **Salt** contained in food **i** | Input variable (Constant) |
| $df_i$ | **Dietary fiber** contained in food **i** | Input variable (Constant) |
| $va_i$ | **Vitamin A** contained in food **i** | Input variable (Constant) |
| $ti$ | **Thiamin** contained in food **i** | Input variable (Constant) |
| $r_i$ | **Riboflavin** contained in food **i** | Input variable (Constant) |
| $ne_i$ | **Niacin** contained in food **i** | Input variable (Constant) |
| $vb_i$ | **Vitamin B6** contained in food **i** | Input variable (Constant) |
| $vb_{2i}$ | **Vitamin B12** contained in food **i** | Input variable (Constant) |
| $fo_i$ | **Folate** contained in food **i** | Input variable (Constant) |
| $vc_i$ | **Vitamin C** contained in food **i** | Input variable (Constant) |
| $vd_i$ | **Vitamin D** contained in food **i** | Input variable (Constant) |
| $I_i$ | **Iron** contained in food **i** | Input variable (Constant) |
| $ca_i$ | **Calcium** contained in food **i** | Input variable (Constant) |
| $ma_i$ | **Magnesium** contained in food **i** | Input variable (Constant) |
| $pot_i$ | **Potassium** contained in food **i** | Input variable (Constant) |
| $z_i$ | **Zinc** contained in food **i** | Input variable (Constant) |
| $cop_i$ | **Copper** contained in food **i** | Input variable (Constant) |
| $Io_i$ | **Iodine** contained in food **i** | Input variable (Constant) |
| $se_i$ | **Selenium** contained in food **i** | Input variable (Constant) |

| | | |
|---|---|---|
| $ph_i$ | **Phosphorous** contained in food **i** | Input variable (Constant) |
| $ch_i$ | **Chloride** contained in food **i** | Input variable (Constant) |
| $so_i$ | **Sodium** contained in food **i** | Input variable (Constant) |
| $x_{fj}$ | **Daily intake of fruit j** | Decision variable (Continuous) |
| $x_{vn}$ | Daily intake of **vegetable n** | Decision variable (Continuous) |
| $x_{rk}$ | Daily intake of **red meat k** | Decision variable (Continuous) |
| $x_{sl}$ | Daily intake of **staple food l** | Decision variable (Continuous) |
| $Id_{fj}$ | Indicator variable **of** $x_{fj}$ (to check if its daily intake is greater than **80g)** | Input variable (Binary) |
| $Id_{vh}$ | Indicator variable **of** $x_{vn}$ | Input variable (Binary) |

*Table 1 – Decision and Input Variables*

Our model contains **two** decision variables (**Food intake** and **price of the food**) and **30** input variables (**nutritional availability and indicators**), as listed in Table 1 above. The mentioned decision variable food intake is to find the optimal amount of food intake needed to achieve the recommended nutrient levels, and the decision variable price is to determine the cost required to purchase the food items. The nutritional constraints have a lower and upper bound limit to ensure that the respective Nutritional requirement is met without exceeding the recommended limit (Ross et al., 2011; National Academies of Sciences et al., 2019).

### *2.3 Constraints*

Objective function:

Minimize: $p=\sum_{i=1}^{41} x_i \cdot y_i$ $\quad$ $x_i$ The daily intake of food $i$ (100g)

$y_i$ The price of food $i$ ( £ per 100g)

1. $L \le X \cdot N \le U$ $\quad$ where $X=\begin{bmatrix} x_1 & \cdots & x_{41} \end{bmatrix}$,

$$N=\begin{bmatrix} e_1 & \cdots & so_1 \\ \vdots & \ddots & \vdots \\ e_{41} & \cdots & so_{41} \end{bmatrix}, \quad U=\begin{bmatrix} u_1 & \cdots & u_{30} \end{bmatrix}$$

$$L=\begin{bmatrix} l_1 & \cdots & l_{30} \end{bmatrix},$$

$u_n$: upper bound of nutrients,

$l_n$: lower bound of nutrients

2. $\sum_{j=1} x_{f_j} + \sum_{h=1} x_{v_h} \ge \frac{\sum_{i=1}^{41} x_i}{3}$ $\quad$ $x_{f_j}$: The amount of fruit $j$ (100g)

$x_{v_h}$: The amount of vegetable $h$ (100g)

3. $\sum_{k=1} x_{r_k} \le 70$ $\quad$ $x_{r_k}$: The amount of red meat $k$

4. $\sum_{l=1} x_{s_l} \ge \frac{\sum_{i=1}^{41} x_i}{3}$ $\quad$ $x_{s_l}$: The amount of staple food $l$

5. $\sum_{j=1} Id_{f_j} + \sum_{h=1} Id_{v_h} \ge 5$ $\quad$ where $Id_{f_j}=\begin{cases} 1 & if\ x_{f_j} \ge 0.8 \\ 0 & if\ x_{f_j} < 0.8 \end{cases}$

and $Id_{v_h}=\begin{cases} 1 & if\ x_{v_h} \ge 0.8 \\ 0 & if\ x_{v_h} < 0.8 \end{cases}$

6. $x_i, y_i, e_i, \ldots, so_i, x_{f_j}, x_{v_h}, x_{r_k} \ge 0$

These additional constraints were included to ensure that the solution includes a diverse range of healthy recommended foods instead of achieving the nutritional requirement through a single type of food, making the model balanced and realistic. The details of each constraint are listed below.

**Constraint 1:** These nutrition constraints ensure the recommended nutrition requirement is achieved; all 30 constraints are listed under the appendices.

**Constraint 2:** As recommended by Public Health England (2018) This constraint ensures that 1/3 of the total weekly food consumed are fruits and vegetables.

**Constraint 3:** Based on Public Health England (2018), this constraint ensures that the red meat consumption is less than 70gm per day.

**Constraint 4:** According to Public Health England (2018)'s recommendation, this constraint ensures that 1/3 of the total weekly food consumed is staple food such as rice, bread, pasta.

**Constraint 5:** This ensures more than five fruits and vegetables of more than 80gm are consumed daily as per Public Health England (2018).

### *2.4 Assumptions*

The following assumptions were made during the development of the model:

1. Spices and herbs have no nutritional or calorie content since they are negligible.
2. The food prices considered are based on the market values at a particular time (2024). We assume prices will remain the same over time.
3. We assume that the Absorption efficiencies of every person are the same.
4. Everyone has the same food preferences and goal of achieving recommended nutritional requirements.
5. The weight of the food item in solution is not a fixed value. It can be bought based on retail packaging and availability considering if it is over the mentioned optimal limit.

# 3. Prototype Demo & Solution:

## *3.1 Solution:*

Based on the variables and constraints outlined above, we obtained the optimal list of food items with their corresponding weights that university students need to consume to achieve recommended nutrition at a minimised cost of 24.26 pounds per week, as shown in Figure 1. Our cost for weekly grocery purchase is significantly lower than the average weekly grocery spending of 36 pounds among students across the UK (Jessica Murray, 2023).

```
Model Status: Optimal

Avocado,_Fuerte,_flesh_only,_weighed_with_skin_and_stone = 1160.77164 grams
Carrots,_old,_raw = 900.8905499999998 grams
Cheese,_hard,_average = 52.0949128 grams
Eggs,_chicken,_whole,_raw = 2182.6161 grams
Milk,_semi_skimmed,_pasteurised,_average = 1641.01098 grams
Oil,_sunflower = 122.410932 grams
Onions,_raw = 1946.09625 grams
Pasta,_wholewheat,_spaghetti,_dried,_raw = 602.095746 grams
Peas,_raw = 4.86513202 grams
Potatoes,_old,_raw,_flesh_only = 1488.59109 grams
Rice,_white,_long_grain,_raw = 1921.93673 grams
salt = 14.4906741 grams

Minimized Cost: 24.269116279860683 pound
```

*Figure 1: Food items per week*

The collective weight of the food items is around 12000 grams, with avocados, carrots, onions, and peas totaling approximately 4,000 grams, which satisfies the constraint of fruits and vegetables being at least one-third of the weekly total consumption. The MILP model has ensured a proportional mix of fruits and vegetables to ensure a balanced daily and weekly consumption of fruits and vegetables. Furthermore, we have pasta, potatoes, and rice, which collectively weigh around 4,000 grams approx., fulfilling the requirement that staple foods constitute one-third of the weekly total diet. Therefore, the list meets all essential nutritional requirements for energy, protein, fats, and other vital nutrients mentioned in the model development part, giving students a comprehensive guide to a balanced diet that promotes optimal health and well-being while being cost-effective.

### *3.2 Sensitivity Analysis:*

To determine the effect of change in food quantities on our optimal solution of the total cost, we performed sensitivity analysis, which is a crucial part of our study and provided us with key insights into how changes in food item quantity can affect the total cost. The table below presents the food items, their respective shadow prices (a measure of the impact of a unit change in the quantity of a food item on the total cost), and the range of quantities that maintain the optimal solution. This information, along with alternate food item suggestions, is beneficial for students in making cost-effective food choices while maintaining nutritional balance.

| Object Name | Final Value | Shadow Price | Lower Bound | Upper Bound | Substitute Option |
|---|---|---|---|---|---|
| Apples | - | 0.2 | -0.908g | 30.025g | Carrots |
| Avocado | 158.791g | -0.78791 | 156.575g | 163.943g | Cabbage |
| Bananas | 80g | 0.08944 | 79.167g | 107.478g | Cost-efficient |
| Blackberries | - | 1.4 | -1.765g | 59.634g | Carrots, Retinol |
| Blueberries | - | 1.333 | 1.017g | 33.732g | Carrots |
| Cherries | - | 0.9 | -0.632g | 20.806g | Carrots |
| Mangoes | - | 0.95 | -1.551g | 49.807g | Carrots |
| Oranges | - | 0.225 | -1.647g | 55.374g | Carrots |
| Strawberries | - | 1 | -1.632g | 55.061g | Carrots |
| Beans | - | 0.417 | -47.928g | 21.805g | Peas |
| Beetroot | - | 0.22 | -1.452g | 48.698g | Carrots |
| Broccoli | - | 0.219 | -48.1g | 25.950g | Peas |
| Cabbage | 80 g | 0.0173 | 77.557g | 130.819g | Peas |
| Carrots | 124.330g | -0.44330 | 9.147g | 125.57g | Bacon, Onions |
| Cauliflower | - | 0.25 | -4.481g | 39.02g | Peas |
| Garlic | - | 0.65217 | -149.339g | 19.965g | Pasta, Peas |
| Mushrooms | - | 0.297 | -102.340g | 4.414g | Peas |
| Onions | 80g | 0.095 | 80g | 132.436g | Onion |
| Peas | 29.731g | 0.15934 | -18.846 g | 30.953g | Cabbage, Bacon |
| Spinach | - | 0.51923 | -69.518g | 4.583g | Magnesium, Retinol rich food |
| Tomatoes | - | 0.05971-0.175 | -0.084g | 2.731g | Peas |
| Bacon | - | 0.00589-0.2 | -20.438g | 2.521g | Magnesium, Retinol rich food |
| Beef | - | 0.74612-0.85 | -18.252g | 1.925g | Magnesium, Retinol rich food |
| Lamb | - | 1.33335-1.5 | -21.661g | 2.365g | Magnesium, Retinol rich food |
| Bread | - | 5.287-16 | -3.436g | 117.402g | Carrots |
| Rice | 286.092g | 0.185 | 259.873 g | 287.450g | Bacon |
| Potatoes | 194.885g | 0.08 | 182.456 g | 297.259g | Cabbage |
| Pasta | 71.875g | 0.056 | 68.494g | 84.563g | Cabbage, Bacon |
| Cheese | 13.600 g | 0.775 | 10.466g | 49.578g | Cabbage |
| Eggs | 311.225 g | 0.42 | 310.943g | 316.512g | Bacon |
| Milk | 208.303 g | -0.12798 | 184.128g | 284.129g | Staple Food Options |

*Table 2: Sensitivity analysis(per-day)*

We observed that most food items selected by our model for the optimal solution have a minimal impact on the total cost, even when their quantities fluctuate. However, cheese—while rich in calcium and protein—exerts a higher influence on the overall cost, reflected by a shadow price of 0.775. Similarly, eggs are a significant source of protein but also carry a notable shadow price of 0.42, which is considerably higher than that of other food items chosen by our model. Therefore, it is essential to maintain a balanced proportion of these two food items to meet nutritional requirements without overloading the budget.

On the other hand, some cost-effective options included in the list, such as cabbage, potatoes, avocados, bananas, peas, milk, and pasta, exhibit negative or very low shadow prices. This indicates they have minimal impact on expenses, making them cost-efficient choices that help balance budget considerations with the nutritional needs of the diet.

In contrast, the food items not selected by our model possess high shadow prices, signaling their significant effect on overall costs.

### *3.3 Model Limitations:*

- One aspect to improve in our model is the inclusion of dietary preferences or restrictions, such as foods avoided due to religious, ethical, or health reasons, such as halal, kosher, gluten-free, vegan, or organic eating. By catering to these preferences, we can make it easier for students to plan their diet without compromising on their choices.
- By capturing the complexity of real-world situations, such as considering the specific dietary needs, allergies, or medical conditions of any individual, we can further improve the model output. Considering user-specific health profiles allows us to create individualized diet plans that will have a meaningful impact on any student with any specific nutritional deficiency.

## 4. Managerial Recommendations and Insights:

- Students who are frugal with their budgeting due to their financial challenges can benefit from the model by purchasing food items that are both nutritious and cost-effective. This avoids students to over purchase or under purchase food products while purchasing their groceries.

- Students with a nutrient deficiency can adjust or modify the model to find foods that can counter their deficiency of specific nutrition.

- To enhance accessibility, the model can be incorporated into the University resources, including pre-arrival guides and the mobile application. Furthermore, collaboration with student support services can facilitate its distribution and ensure students receive the necessary guidance. Partnering with local supermarkets can be very beneficial, such as providing discounts on the recommended food items for the students.

## 5. Conclusion:

Using mixed integer linear programming, our model effectively addresses the students' challenges in maintaining a healthy, balanced diet while being budget conscious. It gives them a list of food items to pick from and provides a practical framework to plan their weekly dietary requirements, making the students' lives much more manageable and healthier. This can help students develop healthy eating habits that can lead to long-term lifestyle changes that benefit them even after they graduate.

## References:


1. Institute of Medicine (US). (2011) *Summary tables: Dietary reference intakes: Tolerable Upper Intake Levels, Vitamins.* Available at: https://www.ncbi.nlm.nih.gov/books/NBK56068/table/summarytables.t7/?report=objectonly (Accessed: 16 November 2024)

2. National Academies of Sciences, Engineering, and Medicine. (2019) *Dietary reference intakes: Recommended Dietary Allowances and Adequate Intakes, Elements* Available at: https://www.ncbi.nlm.nih.gov/books/NBK545442/table/appJ_tab3/?report=objectonly (Accessed: 16 November 2024)

3. National Academies of Sciences, Engineering, and Medicine. (2019) *Dietary reference intakes: Tolerable Upper Intake Levels***,** *Elements (iron, etc.)*. Available at: https://www.ncbi.nlm.nih.gov/books/NBK545442/table/appJ_tab9/?report=objectonly (Accessed: 16 November 2024)

4. Office for National Statistics (ONS). (2023) *Family spending in the UK: April 2022 to March 2023*. Available at: https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/expenditure/bulletins/familyspendingintheuk/april2022tomarch2023 (Accessed: 16 November 2024)

5. Office of Dietary Supplements, National Institutes of Health. (n.d.) Nutrient recommendations and Databases. Available at: https://ods.od.nih.gov/HealthInformation/nutrientrecommendations.aspx#dri (Accessed: 16 November 2024)

6. Public Health England. (2016) *Government dietary recommendations: Government recommendations for energy and nutrients for males and females aged 19+ years*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/618167/government_dietary_recommendations.pdf (Accessed: 16 November 2024)

7. Public Health England. (2018) *A quick guide to government healthy eating recommendations*. Available at: https://assets.publishing.service.gov.uk/media/5ba8a087e5274a55c3407c38/A_quick_guide_to_govt_healthy_eating_update.pdf (Accessed: 16 November 2024)

8. Public Health England. (2021) *McCance and Widdowson's composition of foods integrated dataset 2021*. Available at: https://assets.publishing.service.gov.uk/media/60538e66d3bf7f03249bac58/McCance_and_Widdowsons_Composition_of_Foods_integrated_dataset_2021.pdf (Accessed: 16 November 2024)

9. Save the Student. (n.d.) *What do students spend their money on?* Available at: https://www.savethestudent.org/money/student-budgeting/what-do-students-spend-their-money-on.html (Accessed: 24 November 2024)

10. University of Bristol. (2023) *Facts and figures*. Available at: https://www.bristol.ac.uk/university/facts/ (Accessed: 12 November 2024).

\

# Appendix

## 1. MATHEMATICAL DERIVATIONS

The mathematical model is formulated as a **Mixed Integer Linear Programming (MILP) problem**, with the following structure:

### I. Objective Function:

Minimize: $$p = \sum_{i=1}^{41} x_i \cdot y_i$$

Were,

$x_i$ = The daily intake of food *i* (100g)

$y_i$ = The price of food *i* (௹ per 100g)

### II. Constraints:

Recommended Weekly Intake of Nutrients (for 19-64 years old males)

$$2500 \leq \sum_{i=1}^{41} x_i \cdot e_i \leq 2750$$

$e_i$ : Energy (kcal) in per 100g food *i*

$$55.5 \leq \sum_{i=1}^{41} x_i \cdot p_i \leq 138$$

$p_i$ : Protein (g) in per 100g food *i*

$$44 \leq \sum_{i=1}^{41} x_i \cdot f_i \leq 97$$

$f_i$: fat(g) in per 100g Fat food *i*

$$\sum_{i=1}^{41} x_i \cdot sf_i \leq 31$$

$sf_i$: Saturated fat (g) in per 100g food *i*

$$16.2 \leq \sum_{i=1}^{41} x_i \cdot pf_i \leq 19.8$$

$pf_i$: Polyunsaturated fat (g) in per 100g food i

$$32.4 \leq \sum_{i=1}^{41} x_i \cdot m_i \leq 39.6$$

$m_i$: Monounsaturated fat (g) in per 100g food *i*

$$\sum_{i=1}^{41} x_i \cdot c_i \geq 333$$

$c_i$: Carbohydrate (g) in per 100g food *i*

$$\sum_{i=1}^{41} x_i \cdot fs_i \leq 33$$

$fs_i$: Free sugars (g) in per 100g food *i*

$$\sum_{i=1}^{41} x_i \cdot s_i \leq 6$$

$s_i$: Salt (g) in per 100g food *i*

$$30 \leq \sum_{i=1}^{41} x_i \cdot df_i \leq 70$$

$df_i$: Dietary fiber (g) in per 100g food *i*

$$700 \leq \sum_{i=1}^{41} xi \cdot va_i \leq 3000$$

$va_i$: Vitamin A (μg) in per 100g food *i*

$$1 \leq \sum_{i=1}^{41} xi \cdot t_i$$

$t_i$: Thiamin (mg) in per 100g food *i*

$$1.3 \leq \sum_{i=1}^{41} xi \cdot r_i \leq 1.3$$

$r_i$: Riboflavin (mg) in per 100g food *i*

$$16.5 \leq \sum_{i=1}^{41} xi \cdot ne_i \leq 35$$

$ne_i$: Niacin equivalent (mg) in per 100g food *i*

$$1.4 \leq \sum_{i=1}^{41} xi \cdot vb_{1_i} \leq 100$$

$vb_{1_i}$: Vitamin B6 (mg) in per 100g food *i*

$$1.5 \leq \sum_{i=1}^{41} xi \cdot vb_{2_i}$$

$vb_{2_i}$:Vitamin B12 (μg) in per 100g food *i*

$$200 \leq \sum_{i=1}^{41} xi \cdot fo_i \leq 1000$$

$fo_i$: Floate (μg) in per 100g food *i*

$$40 \leq \sum_{i=1}^{41} xi \cdot vc_i \leq 2000$$

$vc_i$: Vitamin C (mg) in per 100g food *i*

$$10 \leq \sum_{i=1}^{41} xi \cdot vd_i \leq 100$$

$vd_i$: Vitamin D (μg) in per 100g food $i$

$$8.7 \leq \sum_{i=1}^{41} xi \cdot I_i \leq 45$$

$I_i$: Iron (mg) in per 100g food $i$

$$700 \leq \sum_{i=1}^{41} xi \cdot ca_i \leq 2500$$

$ca_i$: Calcium (mg) in per 100g food $i$

$$300 \leq \sum_{i=1}^{41} xi \cdot ma_i \leq 350$$

$ma_i$: Magnesium (mg) in per 100g food $i$

$$3500 \leq \sum_{i=1}^{41} xi \cdot pot_i$$

$pot_i$: Phosphorus (mg) in per 100g food $i$

$$9.5 \leq \sum_{i=1}^{41} xi \cdot z_i \leq 40$$

$z_i$: Zinc (mg) in per 100g food $i$

$$1.2 \leq \sum_{i=1}^{41} xi \cdot cop_i \leq 10$$

$cop_i$: Copper (mg) in per 100g food $i$

$$140 \leq \sum_{i=1}^{41} xi \cdot Io_i \leq 1100$$

$Io_i$: Iodine (μg) in per 100g food $i$

$$75 \leq \sum_{i=1}^{41} xi \cdot se_i \leq 400$$

$se_i$: Selenium (µg) in per 100g food $i$

$$550 \leq \sum_{i=1}^{41} xi \cdot ph_i \leq 4000$$

$ph_i$: Phosphorus (mg) in per 100g food $i$

$$2500 \leq \sum_{i=1}^{41} xi \cdot ch_i \leq 3600$$

$ch_i$: Chloride (mg) in per 100g food $i$

$$1500 \leq \sum_{i=1}^{41} xi \cdot so_i$$

$so_i$: Sodium (mg) in per 100g food $i$

### III. Daily Food Group Requirements

- The total amount of fruits and vegetables consumed daily should be greater than one third of the total daily food intake:

$$\sum_{j=1} x_{f_j} + \sum_{h=1} x_{v_h} \geq \frac{\sum_{i=1}^{41} x_i}{3}$$

$x_{f_j}$: The amount of fruit *j* (100g)
$x_{v_h}$ : The amount of vegetable *h* (100g)

- Red Meat Intake:

$$\sum_{k=1} x_{r_k} \leq 70$$

$x_{r_k}$: The amount of red meat *k*

- The amount of staple food should be greater than 1/3 of the total amount of foods

$$\sum_{l=1} x_{s_l} \geq \frac{\sum_{i=1}^{41} x_i}{3}$$

$x_{s_l}$ : The amount of staple food l

- There should be at least five types of fruits and vegetables included in the daily intake with each having more than 80g:

$$\sum_{j=1} Id_{f_j} + \sum_{h=1} Id_{v_h} \geq 5$$

Where $$Id_{f_j} = \begin{cases} 1 & if\ x_{f_j} \geq 0.8 \\ 0 & if\ x_{f_j} < 0.8 \end{cases}$$ and $$Id_{v_h} = \begin{cases} 1 & if\ x_{v_h} \geq 0.8 \\ 0 & if\ x_{v_h} < 0.8 \end{cases}$$

- **Positivity constraint:** $x_i, y_i, e_i, \ldots, so_i, x_{f_j}, x_{v_h}, x_{r_k} \geq 0$

## 2. CODES

### 1. Data Preparation

Splitting a multi-sheet Excel file into individual Excel files.
https://github.com/sayame3/MA-1/blob/main/dataset%20-%20preparation/prepare%20dataset%20part1.ipynb

Merging Multiple Data Sheets into a Single Dataset
https://github.com/sayame3/MA-1/blob/main/dataset%20-%20preparation/prepare%20dataset%20part2.ipynb

Data Cleaning, Transformation, and Feature Engineering
https://github.com/sayame3/MA-1/blob/main/dataset%20-%20preparation/prepare%20dataset%20part3.ipynb

Replacement of Placeholder Values in the Dataset
https://github.com/sayame3/MA-1/blob/main/dataset%20-%20preparation/prepare%20dataset%20part4.ipynb

### 2. Model Development and Sensitivity Analysis

Mixed Integer Linear Programming (part 1) -Male
https://github.com/sayame3/MA-1/blob/main/MILP/Part1_MILP_(per_day)%20Male%20(1).ipynb

Mixed Integer Linear Programming (part 2) with Sensitivity Analysis – Male
https://github.com/sayame3/MA-1/blob/main/Sensitivity%20Anlaysis/Part2_LP_%2B_Sensitivity_analysis_(per_day)_Male_(1)%20(1)%201.ipynb

Mixed Integer Linear Programming (part 1)- Female
https://github.com/sayame3/MA-1/blob/main/MILP/Part1_MILP_(per_day)%20Female.ipynb

Mixed Integer Linear Programming (part 2) with Sensitivity Analysis- Female
https://github.com/sayame3/MA-1/blob/main/Sensitivity%20Anlaysis/Part2_LP_%2B_Sensitivity_analysis_(per_day)_Female_(1)%201.ipynb

Sensitivity Report
https://drive.google.com/file/d/1JtUSEDhewM0SL-8dsteNGNzzAcr4bJTp/view?usp=sharing

**3. Nutrient Optimization Model**
https://github.com/sayame3/MA-1/blob/main/model/Modeling%20%20(2).ipynb