A detailed study of Food Bank's resource allocation and optimisation of nutrition using linear programming

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* : Order is solely alphabetical and does not reflect the level of contributions

Abstract

Food banks play a crucial role in addressing food insecurity by providing emergency relief to those in need. However, recent studies have raised concerns about the nutritional quality of these food parcels [1]. This nutritional imbalance can have serious implications for the health of food bank users, who are already vulnerable due to their economic status. Primary data also revealed inefficiencies in food bank allocation methods; they often distribute standardized sheets of data that fail to account for either inventory levels or specific nutritional needs. An algorithm was then developed that can take into account factors such as the stock of a specific branch of a food bank and the details of the specific recipient (e.g., likes, dislikes, allergies, weight) to produce a tailored parcel that is both affordable and nutritionally balanced.

Data Collection

To create an effective comparison point for our "optimal parcel," an accurate estimate of the composition of parcels most frequently allocated was identified. This was achieved by visiting the local Trussell Trust Woking food bank, observing their allocation methods, and obtaining primary data on parcel composition. This food bank uses a food allocation form to ration out supplies, including both food and other essentials; however, this study focuses solely on food supplies. The average frequency of each food item chosen was calculated. To construct the parcel, the nutritional values were documented for each food item on the allocation form, matched to the Tesco brand equivalent, as the Trussell Trust food bank has a long-standing partnership with Tesco, a leading multinational retailer of affordable groceries and general merchandise, and the largest in the UK.

Figure 1: Food Allocation Form Trussell Trust

Item	Allocation	Amount given
Soup (can / packet)	2 standard	46 cans
Beans / spaghetti in sauce	2 small	41 beans, 5 spaghetti
Tinned tomatoes / pasta sauce	2 small	8 tomatoes, 36 sauce
Tinned Vegetables	2 small	46 cans

Potatoes: tinned / mash / fresh	1 small	19 tinned, 4 mash
Pasta / Rice / Noodles / Couscous / Lentils	500g	10,500g pasta, 500g rice, 500g noodles
Tea / Coffee / Hot Chocolate	40 bags/small jar	70% tea, 17% coffee
Tinned Fruit	2 small	46 cans
Tinned Meat OR vegetarian (pulses)	2 small	39 meat, 7 cans
Tinned Fish	1 small	17 fish,
Rice pudding / sponge pudding / Custard	1 standard	21 rice pudding, 1 sponge pudding
Cereal	1 small packet	23 packets
Biscuits	1 small packet	23 packets
Milk UHT (Dairy / Plant based)	1 liter	23 liter dairy
Long-life juice / squash	1 liter	15 liter squash, 8 liter juice
Fresh: Eggs / cheese / bread	1 of each	23 bread, 19 cheese, 18 eggs
Jam/ peanut butter/honey/ marmite/chocspread/marmalade/ketchup/brown sauce/ chutney/ mayo/gravy/ oil	1 or 2	11 jam, 10 peanut butter, 1 marmite, 13 ketchup
Snacks / Crisps / chocolate/ sweets	1 or 2	13 crisps, 10 sweets, 15 chocolate

Methodology

Our process of optimization is done through utilizing the pulp linear programming library in python and applying the simplex method to these variables to satisfy minimum nutritional constraints. The algorithm will be applied to our data bank of foods and their nutrition to produce the optimum parcel. The objective function of this algorithm is to minimize price while satisfying the constraints to provide both a nutritionally balanced and affordable parcel.

The formula used for calculating the minimum caloric intake is based on the Harris-Benedict Basal Energy Expenditure (BEE) equation [2]. This considers variables such as weight, height, age, and gender to accurately estimate the Basal Energy Expenditure (BEE) for any given parcel recipient. Minimum calorie intake is calculated as this BEE value, which is determined by the equations below for each corresponding gender.

- $Men: BEE = 66.5 + 13.8(Weight) + 5.0(Height) - 6.8(Age)$
- $Women: BEE = 655.1 + 9.6(Weight) + 1.9(Height) - 4.7(Age)$

The daily caloric constraints from the equation are then multiplied by the amount of days that the parcel should last in order to show the total amount of calories required in the parcel. Furthermore, the maximum calorie intake is set to 1.2 and 1.5 times the calculated minimum calorie intake if the recipient does or does not partake in frequent rigorous exercise, allowing flexibility in the caloric range.

Protein intake is constrained to be no less than 0.75 grams per kilogram of body weight per day, aligning with the British Heart Foundation's recommendation [3] to ensure that the food parcel meets basic protein requirements for the individual's weight.

Fat intake is constrained to lie within 20% and 35% of the total calories, a range recommended by an article from the University of California at Davis [4]. This ensures a balanced proportion of fats within the overall caloric intake whilst also maintaining nutritional balance. The calories from fats are determined by multiplying the total grams of fat by 9 (since fats provide 9 calories per gram).

Carbohydrate intake is constrained to fall between 45% and 65% of the total caloric intake. This satisfies standard dietary recommendations [2] and ensures a sufficient intake of carbohydrates to fuel daily activities.

Saturated fat intake is also restricted to be 6% of the total caloric intake, following health guidelines [5] aimed at minimizing the risk of cardiovascular diseases associated with high levels of saturated fats.

Sugar intake is limited to 10% of total calories, adhering to standard recommendations [6] to minimize excessive sugar consumption and its associated health risks.

Fiber intake must exceed 90 grams, which is consistent with recommendations [7] for maintaining digestive health and preventing complications such as constipation and other gastrointestinal disorders.

Salt intake is constrained to fall between 1.3 grams and 6 grams per day. Ensuring that sodium consumption is kept within a healthy range, preventing both deficiency and excess, which could lead to health issues like high blood pressure. The American Heart Association states that a maximum of 2500 mg and a minimum of 500 mg of sodium compose a healthy range [8]. Translated into salt mass this leads to a range of about 1.3 to 6g of salt.

In addition to the nutritional constraints, a specific minimum requirement for fish consumption of at least 40g of fish per day was added. Abiding to the NHS Eatwell Guide [9], which recommends regular fish intake for its omega-3 fatty acids, rich micronutrient density, and other significant health benefits.

Finally, the food parcel must conform to the 5-a-day recommendation by the NHS Eatwell Guide [9]. This means that the parcel has to contain a variety of fruits and vegetables, totaling at least five portions per day, in order to promote a balanced intake of vitamins, minerals, and fiber.

Parcel Details and Comparison

Figure 2 : Average Parcel Nutrient Composition

Nutrient	Average Parcel Value
Calories	17230 kcal
Fat	402 g
Saturates	178 g
Carbohydrates	2596 g
Sugars	920 g
Fiber	284 g
Protein	622 g
Salt	41 g
Price	£26.52

Figure 3 : Optimal Parcel Composition for Median Male Respondent for 9 days

Item	Units
soup	1
beans	3
tinned vegetables	1
potatoes (tinned)	1
pasta	1
tinned fruit	1
pulses	2
tinned fish	3
cereal	1
biscuits	2
bread	1
mayo	1

Figure 4 : Optimal Parcel Nutritional Details for Median Male Respondent for 9 days

Nutrient	Optimal Value
Calories	17723
Fat	556.3
Saturates	117.2
Carbohydrates	2276
Sugars	400
Fiber	570.5
Protein	620.1
Salt	26.25
Price	12.03

Figure 5 : Parcel Composition Comparison Between Average Male 9 day Optimal Parcel and Average Observed Parcel

Nutrient	Average Parcel Value	Variable Parcel Value	Deviation (%)
Calories	17230	17723	2.86
Fat	402	556.3	38.38
Saturates	178	117.2	-34.16
Carbohydrates	2596	2276	-12.33
Sugars	920	400	-56.52
Fiber	284	570.5	100.88
Protein	622	620.1	-0.31
Salt	41	26.25	-35.98
Price	26.52	12.03	-54.64

Figure 6 : Parcel Composition Comparison Between Average Female 10-day Optimal Parcel and Average Observed Parcel

Nutrient	Average Parcel Value	Variable Parcel Value	Deviation (%)
Calories	17230	16511	-4.17
Fat	402	617.5	53.61
Saturates	178	153.8	-13.6
Carbohydrates	2596	1902.8	-26.7
Sugars	920	349.8	-61.98
Fiber	284	505.9	78.13
Protein	622	582.9	-6.29
Salt	41	50.49	23.15
Price	26.52	12.51	-52.83

Results and analysis

The following comparative analysis demonstrates the potential inefficiencies in the current food bank allocation system at Trussell Trust. The average parcel also exhibits a range of nutritional concerns that warrant further examination.

The average parcel observed from the Trussell Trust Woking contained approximately 17,230 calories, suitable for 9 to 10 days of consumption by men and women respectively. To enable a fair comparison with the optimal parcels, 9-day and 10-day versions for both men and women were constructed, yielding results within 2.86% and 4.17% of the calories in the average parcel. The median height, weight and age for men and women (assuming no food preferences or frequent rigorous exercise) were entered to match the expected demographics of a respondent at a food bank.

The findings presented in Figures 3 and 4 indicate that the optimal parcels generated by the algorithm for both genders exhibit minimal caloric deviation compared to the average parcel, facilitating a robust and equitable basis for comparison.

The optimal parcel contained 34% less saturated fat but 38% more total fat for men, while for women, it included 13.6% less saturated fat and 53.61% more total fat overall, indicating an increased amount of unsaturated fats. The paper ‘Dietary Fat Intake on Metabolic Health: An in-Depth Analysis of Epidemiological, Clinical, and Animal Studies' by Samuel A. Ofori et Al [11] shows that consumption of saturated fatty acids has been associated with negative metabolic effects whereas mono-unsaturated fatty acids and polyunsaturated fatty acids are associated with improved metabolic profiles. This increased profile of unsaturated fats therefore leads to significant improvements in metabolism.

Meeting the sugar constraint, the optimal parcels for men and women showed substantial decreases in sugar content by 56.2% and 61.98% respectively. The paper "Relationship between Added Sugars Consumption and Chronic Disease Risk Factors: Current Understanding" by James M. Rippe et. Al [12] highlights the increased risk of "obesity, cardiovascular disease, diabetes and non-alcoholic fatty liver disease as well as cognitive decline and even some cancers" associated with increases in added sugar consumption. Though the algorithm does not make a distinction between total and added sugars due to limited data, such significant decreases in sugar consumption must include a significant decrease in added sugar intake.

To meet the NHS 5 a day guidelines [13], the optimal parcels include five unique portions of 80g of fresh, canned, or frozen fruits and vegetables; 30g of dried fruit; 150ml of fruit or vegetable juice, or smoothie; or 80g of beans, lentils, or pulses.

According to the study "Fruit and Vegetable Intake and Mortality: Results From a Prospective Cohort Study" by Zhuang et al. [14], incorporating the five-a-day diet has significant health benefits. Increasing fruit intake by 100g lowers the risk of ischemic heart disease by 14% (RR 0.86) and the risk of ischemic stroke by 35% (RR 0.65). Similarly, a 100g increase in vegetable intake also reduces the risk of ischemic heart disease by 14% (RR 0.86) and ischemic stroke risk by 13% (RR 0.87). Moreover, reducing red meat consumption by 100g decreases the risk of colorectal cancer by 14% (RR 0.86) and type 2 diabetes by 20% (RR 0.80). Additionally, cutting down on processed meat by 50g reduces the risk of ischemic heart disease by 44% (RR 0.56) and colorectal cancer by 15% (RR 0.85).

Finally, the optimal parcels were 54.64% cheaper and 52.83% cheaper for men and women respectively. This can encourage food banks to increase their outreach theoretically allowing them to double their output through optimisation of their operations using linear programming - assuming that they do not experience significant diseconomies of scale.

Conclusion

This research identifies significant inefficiencies in the food bank allocation system of Trussell Trust and uses linear programming to produce an optimal food parcel that is both nutritious and affordable. By developing optimal parcels, improvements were achieved in nutritional quality whilst also demonstrating substantial cost savings—54.64% cheaper for men and 52.83% cheaper for women.

As food banks increasingly serve as long-term resources to the ongoing cost of living crisis, the lack of nutritional balance in their offerings poses serious health risks for economically vulnerable populations. Chronic consumption of excessive saturated fats, sugars, and salt can lead to significant health issues, including cardiovascular disease and diabetes.

Future applications of this research may include a website or an app to streamline the allocation process and provide tailored nutritional support to a multitude of UK food banks, thereby enhancing both efficiency for these organizations and the health outcomes for their users.

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