2017

Analytical Business Modelling (MIS40520)

ASSIGNMENT 3

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Introduction

The problem of how to minimise cost while meeting basic nutrient requirements was originally posed by economist George Stigler in 1945 who used heuristics and manual calculations to estimate a minimum cost. The diet problem was famously solved using the Simplex Algorithm in 1947 (Garner Garille, S, 2001).

We are going to use this approach to attempt to minimise the weight of food required to feed a trekking group climbing Mount Everest. AdventureTrek, a relatively new travel company based in Amsterdam, are planning on adding a new expedition to Mt. Everest to their growing list of tour packages. As part of these expeditions, the tour company must hire Sherpas to act as guides and assist carrying food up the mountain for the trekkers. AdventureTrek have hired us to create an initial report minimising the weight of food that will be required for group of 10 trekkers so that they still meet their minimum daily nutritional requirements.

The following report first will review Stigler's original paper and other related papers to understand the approaches taken in solving this problem. We then plan to use Xpress-IVE to model the original Stigler diet problem, to serve as a way to build a correct, functioning model that can be validated. Once we are satisfied the model is working, we will adapt it for the business problem posed above.

The Cost of Subsistence

Stigler first posed the diet mix problem in his paper titled The Cost of Subsistence in 1945. He examined the minimum amount of US dollars required for an average male to sustain a healthy diet in the years 1939 and 1944. To calculate this, he obtained the minimal nutritional requirements, found the nutritional content of widely available foods and their cost and then used heuristics to minimise the cost of sustaining this diet.

At the time of writing the paper, Stigler noted that nutrition was still a developing science and was a complex issue. He wrote that there were over 20 known types of nutrients such as vitamins and minerals that were considered vital to health however many of these are required in such minute amounts that any natural diet should cover these needs (Stigler, 1945). Stigler used the National Research Councils recommended daily allowance from 1943 as the basis for a healthy diet. For this project, we will also use these requirements even though nutritional science has moved on since his publication. 9 nutrients and their quantities are shown in the table below.

Nutrient	Allowance
Calories	3,000 calories
Protein	70 grams
Calcium	.8 grams
Iron	12 milligrams
Vitamin A	5,000 International Units
Thiamine (B_1)	1.8 milligrams
Riboflavin (B_2 or G)	2.7 milligrams
Niacin (Nicotinic Acid)	18 milligrams
Ascorbic Acid (C)	75 milligrams

Figure 1 - Nutrient Requirements (Stigler, 1945)

Next, Stigler examined the quantity of each nutrient in widely available foods at this time. He tabulated 77 foods in his paper with the caveat that nutrient content varies for reasons such as non-homogeneous structure, seasonality and genus, maturity, preparation and cooking methods. Stigler used an updated table for the 1944 calculation and he normalised the nutrient content per dollar of that food type. For this project, we have used the same food tables including 1939 and 1944 pricing. This input data can be seen in the accompanying input files.

The methodology Stigler used was heuristic in nature. Simplifications were made here to enable one result for the average American - seasonal pricing was omitted, and food availability and quantity purchased for a given amount was assumed constant in various locations. The data Stigler obtained to create the tables was from the US Bureau of Labor Statistics and he selected a small subset of all information available. Stigler noted that a lower cost diet was entirely possible with a larger food selection and that cheap food produced locally could also be exploited (Stigler, 1945).

Commodity	Price Aug. 15, 1944 (cents)	Calories (1,000)	Protein (grams)	Calcium (grams)	Iron (mg.)	Vitamin A (1,000 I.U.)	Thiamine (mg.)	Riboflavin (mg.)	Niacin (mg.)	Ascorbic Acid (mg.)
1. Wheat Flour	64.6	24.9	786	1.1	203		30.9	18.6	246	
3. Wheat Cereal	23.2	12.3	398	15.0	183		15.0	9.2	119	
5. Corn Meal	6.3	26.3	655	1.2	72	22.6	12.7	5.8	77	
8. Rolled Oats	9.9	18.1	651	3.7	245		26.6	6.4	46	
15. Evaporated Milk	10.0	5.6	283	10.1	6	17.4	2.0	15.7	7	40
46. Cabbage	4.9	2.0	94	3.0	27	5.4	6.8	3.4	20	4,054
51. Potatoes	80.1	6.1	143	.8	50	2.8	12.5	3.0	84	1,071
52. Spinach	11.6	.8	74	—	96	641.3	4.0	9.6	23	1,924
53. Sweet Potatoes	12.3	4.0	57	1.1	22	120.5	3.5	2.2	34	793
69. Navy Beans	10.8	14.7	924	6.2	433		21.0	13.4	119	
74. Sugar	67.0	26.9	—	—	—					
78. Pancake Flour[1]	12.2	16.0	479	18.1	46		3.7	1.9	41	
79. Beets[2]	7.3	2.2	85	1.1	70	132.3	2.9	6.3	29	895
80. Liver (Pork)[3]	21.9	2.7	408	.2	518	145.0	10.4	51.8	472	580

Figure 2 - Sample of Stigler Food Dataset (Stigler, 1945)

Stigler further reduced the dataset by removing inferior foods from the normalised list where another food had higher content for a lower price which resulted in a table of 9 foods. Stigler aimed to meet or exceed all requirements and our model uses the same constraint. Lastly, Stigler experimented with combinations of foods until a handful of possibilities had been examined. The results Stigler came up with are shown below.

Commodity	August 1939		August 1944	
	Quantity	Cost	Quantity	Cost
Wheat Flour	370 lb.	$13.33	535 lb.	$34.53
Evaporated Milk	57 cans	3.84	—	—
Cabbage	111 lb.	4.11	107 lb.	5.23
Spinach	23 lb.	1.85	13 lb.	1.56
Dried Navy Beans	285 lb.	16.80	—	—
Pancake Flour	—	—	134 lb.	13.08
Pork Liver	—	—	25 lb.	5.48
Total Cost		$39.93		$59.88

Figure 3 - Stigler Annual Diet Results (Stigler, 1945)

As we can see from the table above, the cost of subsistence increased during the period of the study. Stigler noted that the index of retail prices increased 47% between the years 1939 and 1944 which was reflected in the minimum cost (Stigler, 1945). Some of the foods have been replaced but we can observe that cabbage, spinach and beans remained in the diet and are still considered rich sources of nutrients to this day.

Stigler's diet was roughly three times cheaper than other conventional minimum diets at the time. This was most likely due to exclusion of any taste and variety constraints which most would agree was an oversimplification. Again, for this assignment we will replicate Stigler's constraints and omit any food type preferences from the study.

The Knapsack Problem

Another famous combinatorial optimisation problem that we will address in this project is the knapsack problem. The knapsack problem often deals with optimising the number of items to be placed within a certain volume, typically with weighted inputs. For our problem, along with looking at the minimal cost of an explorer surviving on mount Everest, we will calculate the minimum weight of foods required to sustain this explorer and contrast the results with the minimal cost output.

Linear Programming Model

To solve Stigler's diet problem using linear programming, a Mosel model was created in the Xpress-IVE software package. The model was created with flexibility in mind so that we could experiment with both variations of Stigler's original problem and our Everest problem. This section briefly describes the model which is attached.

Assumptions

The following assumptions were made:

1. The input files were created correctly to match the model.
2. We can purchase partial units of food, for example ½ lb of flour.
3. The simplifications mentioned in the review of Stigler's paper are applicable.
4. The dataset from Stigler's paper is sufficient for this project.

Algebraic Formulation

The model was first derived algebraically as follows. The abstract formulation of this problem was relatively simple.

Inputs:

- Type of nutrient requirement – minimum or exact match
- Number of days (d) to simulate (not required for algebraic model)
- Number of foods (n) to consider
- Number of nutrients (m) to consider
- Names of foods and nutrients (not required for algebraic model)
- Set of nutrients in each food (Y). Let $y_{ij} \in Y$.
- Set of weights per dollar of each food (Z). Let $z_i \in Z$.
- Set of nutrients required (W). Let $w_i \in W$.

Solution variable array:

- Dollar amount of each food input (X). Let $x_i \in X$.

Objective functions:

- Minimise: cost = sum of solution variables

$$\text{cost} = \sum_{i=1}^{n}(x_i)$$

- Minimise: weight = sum of solution variables * weight per \$

$$\text{weight} = \sum_{i=1}^{n}(x_i)\, z_i$$

Constraints:

- Meet the nutrient requirements exactly

$$\sum_{i=1}^{m}(\sum_{j=1}^{n}(y_{ij}\, x_i) = w_i$$

Or

- Meet/Exceed the nutrient requirements

$$\sum_{i=1}^{m}(\sum_{j=1}^{n}(y_{ij}\, x_i) \geq w_i$$

Mosel defaults to non-negativity constraints and so these were not included.

Mosel Model

The Mosel implementation of the algebraic model was significantly more complex and is described in this section. The model takes and input file name and initially only initialises the modelling parameters. Once this is complete, it can read the full data arrays from the input file and move on to solving the problem.

The modelling parameter "nutrient_requirement" has two options which allow the model to be used in diverse ways. If "exact" is selected, it will meet the nutritional requirements. If "minimum" is selected, it will meet or exceed the nutritional requirements. The model them optimises for both minimal cost and minimal weight and prints the results to screen.

Testing

The model was tested with three variations of the Stigler problem before trying our Everest scenario. A simplified version of Stigler's problem was also modelled in excel to verify the results.

Stigler_Full_77_1939

The input file "Stigler_Full_77_1939.dat" models Stigler's full list of foods before he removed the unlikely candidates from his tables. The default action is to meet or exceed all requirements.

Running this model to minimise costs gave the following output:

- Total cost for 365 days is: $39.66
- Daily cost is: $0.11
- Total weight for 365 days is: 353204 grams
- Daily weight is: 968 grams

Daily food breakdown results:

- Wheat Flour (Enriched): 371.94 grams = $0.030
- Liver (Beef): 3.20 grams = $0.002
- Cabbage: 100.36 grams = $0.011
- Spinach: 23.00 grams = $0.005
- Navy Beans, Dried: 469.19 grams = $0.061

Daily nutrient breakdown result/required:

- Calories: 3.000 / 3 = 100%
- Protein: 147.414 / 70 = 211%
- Calcium: 0.800 / 0.8 = 100%
- Iron: 60.467 / 12 = 504%
- Vitamin A: 5.000 / 5 = 100%
- Vitamin B1: 4.120 / 1.8 = 229%
- Vitamin B2: 2.700 / 2.7 = 100%
- Niacin: 27.316 / 18 = 152%
- Vitamin C: 75.000 / 75 = 100%

Stigler estimated an annual minimum cost of $39.93 and so our model has improved on his results. Examining the output in detail we can see that our recommended foods closely matched Stigler's conclusions.

Further tests were carried out on this model such as modelling for weight and cost along with varying the nutrient requirement. The following table shows the results.

Requirements	Minimum		Exact	
Optimise for	Cost	Weight	Cost	Weight
Results $/year	39.66	83.97	50.43	107.81
Results g/year	353,204	225,406	360,349	273,514

We can see that varying the optimisation equation and the constraint type, very different results are achieved. Test results are included in the appendix.

Stigler_Reduced_9_1939

The input file "Stigler_ Reduced_9_1939.dat" models Stigler's reduced list of foods after he removed the unlikely candidates from his tables. The default action is to meet or exceed all requirements.

Running this model to minimise costs gave the following output:

- Total cost for 365 days is: $39.66
- Daily cost is: $0.11

This result is identical to our first model and shows that Stigler's heuristic method of reducing his list was an effective method of pruning the potential combinations. Further results are shown below for different modelling parameters.

Requirements	Minimum		Exact	
Optimise for	Cost	Weight	Cost	Weight
Results $/year	39.66	109.76	Infeasible	Infeasible
Results g/year	353,204	333,338	Infeasible	Infeasible

The exact solution was infeasible with our limited range of foods. Test results are included in the appendix.

Stigler_Reduced_15_1944

The input file "Stigler_ Reduced_15_1944.dat" models Stigler's reduced list of foods after he removed unlikely candidates from his 1944 table. The default action is to meet or exceed all requirements.

Running this model to minimise costs gave the following output:

- Total cost for 365 days is: $59.90
- Daily cost is: $0.16

Requirements	Minimum		Exact	
Optimise for	Cost	Weight	Cost	Weight
Results $/year	59.90	81.10	Infeasible	Infeasible
Results g/year	354,793	326,123	Infeasible	Infeasible

Stigler's result was $0.02 cheaper annually than what the model output and this was most likely a minor error in the programming or input dataset. Again, the reduced dataset produced an infeasible solution for exact requirements. Test results are included in the appendix.

Everest Input

Now that Stigler's model has been explained, modelled using Express-MP and verified, we can modify the model constraints to minimise the weight a group of Sherpas should carry up Mt. Everest for an expedition group. Our model was created underpinned by the following assumptions:

Assumptions

- The nutritional requirements chosen are based on a male hiker between the ages of 19-30 years old
- As the travel company has yet to finalise their package itinerary, we will use a competitor's itinerary as a basic for time spent at each section of the mountain
- Food and cost are based on the original Stigler data. A more accurate model with foods from Nepal can be created in the future with our model when this data is provided by the travel company
- An average increase in calories assumed per day, this should be explored in more detail for future models
- The model assumes that a group of 10 hikers are attempting to climb Mt. Everest

Increase in Calories per Day

Due to the increased levels of physical activity, coupled with the low temperatures and reduced oxygen, climbers required far more calories per day when ascending Everest. Several sources (Peakfreaks.com, 2017) (Mount Everest The British Story, 2017) calculate that climbers require between 6000-8000 calories per day, and between 1000-15000 calories on summit day. These increases have and associated nutritional increases are included in our model below.

Expedition Length

As the travel company have yet to finalise their travel itinerary, we will use a competitor's itinerary (Berg Adventures) as a basis for our model: (Media, 2017)

Their schedule is outline here, along with the calories required for each section. Note that several sections of the itinerary do not have calorie requirements. This is because food will be supplied to hikers at villages along the route up. They will only be required to carry food themselves from Base Camp upwards.

As this table shows, we will require four separate models for the four trips to and from Base Camp. We can assume that each time returning to Base Camp, rucksacks can be restocked with food.

Schedule	Details	Food Required	Calorie Requirements
Day 1-6	Flights/ Time in Kathmandu/ Flight to Lukla	No Food Required	n/a
Day 7-16	Trek to Base Camp (BC)	Food provided at villages along route	n/a
Day 17-21	Rest Period at BC	Food provided at BC	n/a
Day 22-27	"First Rotation"—two nights at Camp I, three nights at Camp II, and the return to BC.	Food Required	30,000
Day 28-31	Rest days at BC.	No Food Required	n/a
Day 32-35	"Second Rotation" with nights at Camp I and Camp II, and a day trip to Camp III.	Food Required	32,000
Day 36-38	Rest at BC.	No Food Required	n/a
Day 39-42	"Third Rotation" including nights at Camp I and Camp II, and a night sleeping at Camp III.	Food Required	32,000
Day 43-48	Rest days.	No Food Required	n/a

Day 49-54	First chance for a summit attempt, includes two nights at Camp II, one night at Camp III, and a short night at the South Col before climbing	Food Required	54,000
Day 55-70	Descend	No Food Required	n/a
Total			**114,000**

The following tables show the results for each model:

First Rotation

Requirements	**Minimum**		**Exact**	
Optimise for	Cost	Weight	Cost	Weight
Results $/50 man-days	13.17	22.87	16.58	21.59
Results g/50 man-days	105168	69616	83088	70302

Second and Third Rotation

Requirements	**Minimum**		**Exact**	
Optimise for	Cost	Weight	Cost	Weight
Results $/80 man-days	27.62	48.60	34.91	45.90
Results g/80 man-days	219482	143811	174492	145268

Note: As the second and third rotations have similar calorie requirements, they are modelled together. I.e. They are two 40 man-day expeditions, so we will model for 80 man-days.

Summit Attempt

Requirements	**Minimum**		**Exact**	
Optimise for	Cost	Weight	Cost	Weight
Results $/40 man-days	23.31	41.01	29.49	38.77
Results g/40 man-days	185190	121348	147838	122533

Overall Trip

Requirements	**Minimum**		**Exact**	
Optimise for	Cost	Weight	Cost	Weight
Results $/170 man-days	64.10	112.48	80.98	106.26
Results g/170 man-days	509840	334775	405418	460636

Based on the results from Stigler's model in the earlier sections of this report, as expect, optimising for a minimum requirement as opposed to exact requirements gives more favourable results. The cheapest combination we found is $64.10, while the lightest weight combination was 334.775kgs. Considering that the Sherpas who will be carrying this food will be able to split this weight into several trips, i.e. all this weight won't have to be carried at once, we feel this is very favourable.

Model Review and Evaluation

Verification

The Stigler diet problem is well known and well documented which allowed us to compare our results to those in Stigler's and other literature. We were also able to create a crude excel solver model for a quick comparison. These cross-validation attempts verified that the model was providing the correct outputs before moving on to trial our main Everest problem.

Scalability
The model allows any number of input foods or nutrients within the software's capability which means it can be scaled for very large problems. As we have seen in some instances, a larger optimisation problem may lead to an optimum solution being found in comparison to a smaller problem where a feasible solution does not exist. To extend our model, we can easily add additional constraints and features to the Mosel code. One specific benefit of the scalability of our model is that if we were to obtain a full database of all foods on the market, we could re-run the model for improved and up to date results. Likewise, for our Everest scenario, we can re-run for a Nepal food database.

Goal Programming
So far in this project, we have optimised for cost or weight. Goal programming could have been implemented to find a balance between both cost and weight.

Development Environment
Some observations were made during the project.

- The Xpress-IVE suite provides a printout of where an error has occurred during model simulation. This was useful for debugging.
- The Xpress-IVE suite allows the user to experiment with different optimiser algorithms. This was not required in the model described above but is a useful feature for other problems.
- Xpress-IVE can report the solution status which was critical for this problem. We had two inputs which resulted in infeasible solutions and it was important to have this information.
- The stats output panel allows the user to see the algorithm being used along with the iterations and time taken. This was useful during debugging the model.
- Another useful feature that we experimented with was the sensitivity and duality features of Xpress-IVE. This gave us additional information as to the nature of our solutions.
- One variation of the model during the project included an integer constraint for the decision variable. While not relevant to the problem being considered, this resulted in a very time consuming problem for the software to solve and we were able to use the information panels to explore the progress of the algorithms. This will be useful for future projects.
- As Express-IVE is a closed source application, online solutions to code problems encountered were difficult to come by. In comparison, the open source programming language Python has a large thriving community online and as such if code problems are encountered, solutions or help can be easily found at sites such as stackoverflow.com.
- As Express-IVE implements all LP algorithms "out of the box", there was no need to code up and algorithms in the environment. This is a nice time saver but impedes deeper understanding of the algorithms themselves, that would have been achieved if we had to code up the algorithms from scratch.

Conclusions and Recommendations
The question, "In OR practice and research, software is fundamental. The dependence of OR on software implies that the ways in which software is developed, managed, and distributed can have a significant impact on the field.", was posed to us at the beginning of this assignment. Based on our research for this project and our work building several of these models, we wholehearted agree with this statement.

The calculations required to find an optimum solution took Stigler months, if not years, to complete by himself in the early 1940's, while in 1947, it took nine clerks, using hand-operated desk calculators, 120 clerk-days to solve the problem using the Simplex algorithm (Garner Garille, S, 2001). Without the

Express-IVE environment, we would certainly not have been able to complete any of the models outlined above.

The initial models developed provided confidence that our LP model was working correctly and could be used for our business problem outlined. With this, we developed a model based around a standard trip from Kathmandu right through to the summit of Everest and back down. All trekking days from Kathmandu to Base Camp were excluded as food would be supplied to the travellers at villages up to this point. This is an extra cost that will have to be addressed by AdventureTrek as part of the overall package cost. From Base Camp upwards, we've provide several optimised results, both for cost and weight.

As our model has used Stigler's data set for our model, it should be accepted that the numbers we've calculated are not practical for use by AdventureTrek. What these results do provide, however, is a proof of concept that our model will work and a view of the approach we would use to solve the problem for them. With updated food data, our model could be calibrated quickly to give very useful results.

With this in mind, the overall total minimum cost of $64.10 is not a true reflection of what a minimised model will provide for them. The overall minimum weight of 334.775kgs, however, is a lot more useful as while cost is effected by inflation, weight of food generally stays the same. With an updated list of foods, we feel this overall weight can reduce even further.

Another point to consider for future models is the knapsack problem, mentioned briefly above. While weight is of course very important, the volumes of the foods may not be practical for carrying up a mountain. As a result, we propose to add another optimised constraint for future models; the volume of each food in particular.

In conclusion, Stigler's diet mix problem continues to be a very important application of optimisation in operational research and business analytics. The foundational work of Stigler and Dantzig have allowed us to create models to minimise food weight and thus save money for the AdventureTrek company.

Following this project, we feel our model could also be deployed in areas where nutrition is the most important aspect of a diet. Some examples could include:

1. Developing world nutrition
2. Feeding livestock on a farm
3. Space Travel
4. Other expeditions

References

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Appendix

Results

"Stigler_Full_77_1939.dat" - Minimum requirement

Results for input file Stigler_Full_77_1939.dat:

Parameter nutrient_requirement: minimum
Parameter no_days: 365
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 365 days is: $39.66
Daily cost is: $0.11
Total weight for 365 days is: 353204 grams
Daily weight is: 968 grams

Daily food breakdown results:
Wheat Flour (Enriched): 371.94 grams = $0.030
Liver (Beef): 3.20 grams = $0.002
Cabbage: 100.36 grams = $0.011
Spinach: 23.00 grams = $0.005
Navy Beans, Dried: 469.19 grams = $0.061

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 147.414 / 70 = 211%
Calcium: 0.800 / 0.8 = 100%
Iron: 60.467 / 12 = 504%
VitaminA: 5.000 / 5 = 100%
VitaminB1: 4.120 / 1.8 = 229%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 27.316 / 18 = 152%
VitaminC: 75.000 / 75 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 365 days is: $83.97
Daily cost is: $0.23
Total weight for 365 days is: 225406 grams
Daily weight is: 618 grams

Daily food breakdown results:
Cheese (Cheddar): 79.80 grams = $0.043
Peanut Butter: 100.98 grams = $0.040
Lard: 193.33 grams = $0.042
Liver (Beef): 56.73 grams = $0.034

Pork Chops: 91.05 grams = $0.062
Cabbage: 95.67 grams = $0.011

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 70.000 / 70 = 100%
Calcium: 0.800 / 0.8 = 100%
Iron: 12.698 / 12 = 106%
VitaminA: 6.955 / 5 = 139%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 33.719 / 18 = 187%
VitaminC: 75.000 / 75 = 100%

"Stigler_Full_77_1939.dat" - Exact requirement

Results for input file Stigler_Full_77_1939.dat:

Parameter nutrient_requirement: exact
Parameter no_days: 365
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 365 days is: $50.43
Daily cost is: $0.14
Total weight for 365 days is: 360349 grams
Daily weight is: 987 grams

Daily food breakdown results:
Wheat Flour (Enriched): 227.96 grams = $0.018
Corn Meal: 167.84 grams = $0.017
Evaporated Milk (can): 272.79 grams = $0.045
Peanut Butter: 8.03 grams = $0.003
Lard: 112.91 grams = $0.024
Liver (Beef): 25.84 grams = $0.015
Cabbage: 82.48 grams = $0.009
Potatoes: 86.36 grams = $0.005
Spinach: 3.04 grams = $0.001

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 70.000 / 70 = 100%
Calcium: 0.800 / 0.8 = 100%
Iron: 12.000 / 12 = 100%
VitaminA: 5.000 / 5 = 100%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 18.000 / 18 = 100%
VitaminC: 75.000 / 75 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 365 days is: $107.81
Daily cost is: $0.30
Total weight for 365 days is: 273514 grams
Daily weight is: 749 grams

Daily food breakdown results:
Evaporated Milk (can): 51.12 grams = $0.008
Cheese (Cheddar): 54.15 grams = $0.029
Peanut Butter: 9.59 grams = $0.004
Lard: 97.72 grams = $0.021
Liver (Beef): 38.80 grams = $0.023
Ham - smoked: 226.45 grams = $0.137
Salt Pork: 67.61 grams = $0.024
Cabbage: 104.10 grams = $0.012
Cocoa: 99.81 grams = $0.038

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 70.000 / 70 = 100%
Calcium: 0.800 / 0.8 = 100%
Iron: 12.000 / 12 = 100%
VitaminA: 5.000 / 5 = 100%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 18.000 / 18 = 100%
VitaminC: 75.000 / 75 = 100%

"Stigler_Reduced_9_1939.dat" - Minimum requirement

Results for input file Stigler_Reduced_9_1939.dat:

Parameter nutrient_requirement: minimum
Parameter no_days: 365
Parameter no_foods: 9
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 365 days is: $39.66
Daily cost is: $0.11
Total weight for 365 days is: 353204 grams
Daily weight is: 968 grams

Daily food breakdown results:
Wheat Flour (Enriched): 371.94 grams = $0.030
Liver (Beef): 3.20 grams = $0.002
Cabbage: 100.36 grams = $0.011

Spinach: 23.00 grams = $0.005
Navy Beans, Dried: 469.19 grams = $0.061

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 147.414 / 70 = 211%
Calcium: 0.800 / 0.8 = 100%
Iron: 60.467 / 12 = 504%
VitaminA: 5.000 / 5 = 100%
VitaminB1: 4.120 / 1.8 = 229%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 27.316 / 18 = 152%
VitaminC: 75.000 / 75 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 365 days is: $109.76
Daily cost is: $0.30
Total weight for 365 days is: 333338 grams
Daily weight is: 913 grams

Daily food breakdown results:
Wheat Flour (Enriched): 313.34 grams = $0.025
Cheese (Cheddar): 460.08 grams = $0.246
Liver (Beef): 30.70 grams = $0.018
Cabbage: 109.13 grams = $0.012

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 152.643 / 70 = 218%
Calcium: 4.128 / 0.8 = 516%
Iron: 16.703 / 12 = 139%
VitaminA: 10.057 / 5 = 201%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 4.334 / 2.7 = 161%
Niacian: 18.000 / 18 = 100%
VitaminC: 75.000 / 75 = 100%

“Stigler_Reduced_9_1939.dat” - Exact requirement

Results for input file Stigler_Reduced_9_1939.dat:

Parameter nutrient_requirement: exact
Parameter no_days: 365
Parameter no_foods: 9
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Infeasible

Total cost for 365 days is: $96.10
Daily cost is: $0.26
Total weight for 365 days is: 299675 grams
Daily weight is: 821 grams

Daily food breakdown results:
Wheat Flour (Enriched): 337.70 grams = $0.027
Evaporated Milk (can): 37.19 grams = $0.006
Cheese (Cheddar): 424.00 grams = $0.226
Lima Beans, Dried: 18.05 grams = $0.004
Navy Beans, Dried: 4.09 grams = $0.001

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 146.415 / 70 = 209%
Calcium: 3.876 / 0.8 = 485%
Iron: 16.184 / 12 = 135%
VitaminA: 6.536 / 5 = 131%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 3.516 / 2.7 = 130%
Niacian: 13.237 / 18 = 74%
VitaminC: 0.370 / 75 = 0%

LP Solution for minimising weight:

Problem status: Infeasible

Total cost for 365 days is: $100.92
Daily cost is: $0.28
Total weight for 365 days is: 299554 grams
Daily weight is: 821 grams

Daily food breakdown results:
Wheat Flour (Enriched): 208.41 grams = $0.017
Evaporated Milk (can): 37.19 grams = $0.006
Cheese (Cheddar): 440.56 grams = $0.235
Lima Beans, Dried: 18.05 grams = $0.004
Navy Beans, Dried: 116.49 grams = $0.015

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 160.618 / 70 = 229%
Calcium: 4.167 / 0.8 = 521%
Iron: 24.185 / 12 = 202%
VitaminA: 6.784 / 5 = 136%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 3.625 / 2.7 = 134%
Niacian: 11.920 / 18 = 66%
VitaminC: 0.370 / 75 = 0%

“Stigler_Reduced_15_1944.dat” - Minimum requirement

Results for input file Stigler_Reduced_15_1944.dat:

Parameter nutrient_requirement: minimum
Parameter no_days: 365
Parameter no_foods: 15
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 365 days is: $59.90
Daily cost is: $0.16
Total weight for 365 days is: 354793 grams
Daily weight is: 972 grams

Daily food breakdown results:
Wheat Flour (Enriched): 663.39 grams = $0.094
Cabbage: 96.73 grams = $0.014
Spinach: 13.62 grams = $0.004
Pancake Flour: 166.91 grams = $0.036
Liver (Pork): 31.39 grams = $0.015

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 99.304 / 70 = 142%
Calcium: 0.800 / 0.8 = 100%
Iron: 29.476 / 12 = 246%
VitaminA: 5.000 / 5 = 100%
VitaminB1: 3.324 / 1.8 = 185%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 32.251 / 18 = 179%
VitaminC: 75.000 / 75 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 365 days is: $81.10
Daily cost is: $0.22
Total weight for 365 days is: 326123 grams
Daily weight is: 893 grams

Daily food breakdown results:
Wheat Cereal: 54.98 grams = $0.016
Rolled Oats: 685.99 grams = $0.150
Spinach: 100.87 grams = $0.031
Liver (Pork): 51.65 grams = $0.025

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 116.364 / 70 = 166%
Calcium: 0.800 / 0.8 = 100%

Iron: 55.561 / 12 = 463%
VitaminA: 23.793 / 5 = 476%
VitaminB1: 4.609 / 1.8 = 256%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 21.295 / 18 = 118%
VitaminC: 75.000 / 75 = 100%

“Stigler_Reduced_15_1944.dat” - Exact requirement

Results for input file Stigler_Reduced_15_1944.dat:

Parameter nutrient_requirement: exact
Parameter no_days: 365
Parameter no_foods: 15
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Infeasible

Total cost for 365 days is: $72.47
Daily cost is: $0.20
Total weight for 365 days is: 402221 grams
Daily weight is: 1102 grams

Daily food breakdown results:
Wheat Flour (Enriched): 260.04 grams = $0.037
Corn Meal: 148.39 grams = $0.021
Evaporated Milk: 290.02 grams = $0.072
Cabbage: 106.94 grams = $0.016
Sugar: 268.14 grams = $0.040
Liver (Pork): 28.45 grams = $0.014

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 70.000 / 70 = 100%
Calcium: 0.840 / 0.8 = 105%
Iron: 16.976 / 12 = 141%
VitaminA: 3.791 / 5 = 76%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 18.000 / 18 = 100%
VitaminC: 75.000 / 75 = 100%

LP Solution for minimising weight:

Problem status: Infeasible

Total cost for 365 days is: $85.90
Daily cost is: $0.24
Total weight for 365 days is: 349765 grams
Daily weight is: 958 grams

Daily food breakdown results:
Wheat Cereal: 182.45 grams = $0.053
Corn Meal: 73.69 grams = $0.010
Rolled Oats: 224.42 grams = $0.049
Evaporated Milk: 107.64 grams = $0.027
Cabbage: 63.40 grams = $0.009
Spinach: 25.00 grams = $0.008
Navy Beans: 116.40 grams = $0.028
Sugar: 440.09 grams = $0.065
Liver (Pork): 74.60 grams = $0.036

Daily nutrient breakdown result/required:
Calories: 3.000 / 3 = 100%
Protein: 70.000 / 70 = 100%
Calcium: 1.415 / 0.8 = 177%
Iron: 44.216 / 12 = 368%
VitaminA: 10.969 / 5 = 219%
VitaminB1: 1.800 / 1.8 = 100%
VitaminB2: 2.700 / 2.7 = 100%
Niacian: 18.000 / 18 = 100%
VitaminC: 75.000 / 75 = 100%

'Everest_trip1.dat" – Minimum Requirement

Results for input file Everest_trip1.dat:

Parameter nutrient_requirement: minimum
Parameter no_days: 50
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 50 days is: $13.17
Daily cost is: $0.26
Total weight for 50 days is: 105168 grams
Daily weight is: 2103 grams

Daily food breakdown results:
Wheat Flour (Enriched): 122.79 grams = $0.010
Cabbage: 389.10 grams = $0.043
Spinach: 35.93 grams = $0.008
Navy Beans, Dried: 1555.53 grams = $0.202

Daily nutrient breakdown result/required:
Calories: 6.000 / 6 = 100%
Protein: 362.159 / 140 = 259%
Calcium: 2.500 / 2.5 = 100%

Iron: 166.450 / 20 = 832%
VitaminA: 7.500 / 7.5 = 100%
VitaminB1: 8.745 / 3 = 292%
VitaminB2: 5.606 / 3.25 = 172%
Niacian: 49.592 / 40 = 124%
VitaminC: 255.000 / 255 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 50 days is: $22.87
Daily cost is: $0.46
Total weight for 50 days is: 69616 grams
Daily weight is: 1392 grams

Daily food breakdown results:
Cheese (Cheddar): 259.97 grams = $0.139
Peanut Butter: 189.80 grams = $0.075
Lard: 369.57 grams = $0.080
Liver (Beef): 12.72 grams = $0.008
Pork Chops: 141.81 grams = $0.096
Cabbage: 289.38 grams = $0.032
Spinach: 129.07 grams = $0.028

Daily nutrient breakdown result/required:
Calories: 6.000 / 6 = 100%
Protein: 140.000 / 140 = 100%
Calcium: 2.500 / 2.5 = 100%
Iron: 20.000 / 20 = 100%
VitaminA: 31.234 / 7.5 = 416%
VitaminB1: 3.000 / 3 = 100%
VitaminB2: 3.250 / 3.25 = 100%
Niacian: 46.137 / 40 = 115%
VitaminC: 255.000 / 255 = 100%

"Everest_trip1.dat" – Exact Requirement

Results for input file Everest_trip1.dat:

Parameter nutrient_requirement: exact
Parameter no_days: 50
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 50 days is: $16.58
Daily cost is: $0.33
Total weight for 50 days is: 83088 grams
Daily weight is: 1662 grams

Daily food breakdown results:
Wheat Flour (Enriched): 351.70 grams = $0.028
Wheat Cereal (Enriched): 38.40 grams = $0.012
Evaporated Milk (can): 89.07 grams = $0.015
Cheese (Cheddar): 208.58 grams = $0.111
Peanut Butter: 119.03 grams = $0.047
Lard: 295.92 grams = $0.064
Cabbage: 360.30 grams = $0.040
Potatoes: 180.69 grams = $0.011
Spinach: 18.07 grams = $0.004

Daily nutrient breakdown result/required:
Calories: 6.000 / 6 = 100%
Protein: 140.000 / 140 = 100%
Calcium: 2.500 / 2.5 = 100%
Iron: 20.000 / 20 = 100%
VitaminA: 7.500 / 7.5 = 100%
VitaminB1: 3.000 / 3 = 100%
VitaminB2: 3.250 / 3.25 = 100%
Niacian: 40.000 / 40 = 100%
VitaminC: 255.000 / 255 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 50 days is: $21.59
Daily cost is: $0.43
Total weight for 50 days is: 70302 grams
Daily weight is: 1406 grams

Daily food breakdown results:
Cheese (Cheddar): 250.64 grams = $0.134
Peanut Butter: 142.69 grams = $0.056
Lard: 382.15 grams = $0.083
Liver (Beef): 22.85 grams = $0.014
Pork Chops: 129.09 grams = $0.087
Cabbage: 407.83 grams = $0.046
Spinach: 5.38 grams = $0.001
Peas, Dried: 60.27 grams = $0.010
Lima Beans, Dried: 5.14 grams = $0.001

Daily nutrient breakdown result/required:

Calories: 6.000 / 6 = 100%
Protein: 140.000 / 140 = 100%
Calcium: 2.500 / 2.5 = 100%
Iron: 20.000 / 20 = 100%
VitaminA: 7.500 / 7.5 = 100%
VitaminB1: 3.000 / 3 = 100%
VitaminB2: 3.250 / 3.25 = 100%
Niacian: 40.000 / 40 = 100%
VitaminC: 255.000 / 255 = 100%

"Everest_trip2_trip3.data" – Minimum requirement

Results for input file Everest_trip2_trip3.dat:

Parameter nutrient_requirement: minimum
Parameter no_days: 80
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 80 days is: $27.62
Daily cost is: $0.35
Total weight for 80 days is: 219482 grams
Daily weight is: 2744 grams

Daily food breakdown results:
Wheat Flour (Enriched): 150.05 grams = $0.012
Cabbage: 451.85 grams = $0.050
Spinach: 48.18 grams = $0.010
Navy Beans, Dried: 2093.44 grams = $0.272

Daily nutrient breakdown result/required:
Calories: 8.000 / 8 = 100%
Protein: 484.685 / 187 = 259%
Calcium: 3.330 / 3.33 = 100%
Iron: 223.274 / 26.7 = 836%
VitaminA: 10.000 / 10 = 100%
VitaminB1: 11.630 / 4 = 291%
VitaminB2: 7.467 / 4.33 = 172%
Niacian: 66.000 / 53.3 = 124%
VitaminC: 300.000 / 300 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 80 days is: $48.60
Daily cost is: $0.61
Total weight for 80 days is: 143811 grams
Daily weight is: 1798 grams

Daily food breakdown results:
Cheese (Cheddar): 349.49 grams = $0.186
Peanut Butter: 252.09 grams = $0.099
Lard: 492.72 grams = $0.106
Liver (Beef): 17.38 grams = $0.010
Pork Chops: 194.91 grams = $0.132
Cabbage: 321.20 grams = $0.036
Spinach: 169.85 grams = $0.037

Daily nutrient breakdown result/required:
Calories: 8.000 / 8 = 100%
Protein: 187.000 / 187 = 100%
Calcium: 3.330 / 3.33 = 100%
Iron: 26.700 / 26.7 = 100%
VitaminA: 41.229 / 10 = 412%
VitaminB1: 4.000 / 4 = 100%
VitaminB2: 4.330 / 4.33 = 100%
Niacian: 61.452 / 53.3 = 115%
VitaminC: 300.000 / 300 = 100%

"Everest_trip2_trip3.data" – Exact requirement

Results for input file Everest_trip2_trip3.dat:

Parameter nutrient_requirement: exact
Parameter no_days: 80
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 80 days is: $34.91
Daily cost is: $0.44
Total weight for 80 days is: 174492 grams
Daily weight is: 2181 grams

Daily food breakdown results:
Wheat Flour (Enriched): 472.50 grams = $0.038
Wheat Cereal (Enriched): 50.35 grams = $0.015
Evaporated Milk (can): 118.19 grams = $0.020
Cheese (Cheddar): 281.77 grams = $0.150
Peanut Butter: 156.57 grams = $0.062
Lard: 392.02 grams = $0.085

Cabbage: 403.44 grams = $0.045
Potatoes: 282.24 grams = $0.017
Spinach: 24.06 grams = $0.005

Daily nutrient breakdown result/required:
Calories: 8.000 / 8 = 100%
Protein: 187.000 / 187 = 100%
Calcium: 3.330 / 3.33 = 100%
Iron: 26.700 / 26.7 = 100%
VitaminA: 10.000 / 10 = 100%
VitaminB1: 4.000 / 4 = 100%
VitaminB2: 4.330 / 4.33 = 100%
Niacian: 53.300 / 53.3 = 100%
VitaminC: 300.000 / 300 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 80 days is: $45.90
Daily cost is: $0.57
Total weight for 80 days is: 145268 grams
Daily weight is: 1816 grams

Daily food breakdown results:
Cheese (Cheddar): 337.20 grams = $0.180
Peanut Butter: 189.39 grams = $0.075
Lard: 509.54 grams = $0.110
Liver (Beef): 30.88 grams = $0.018
Pork Chops: 178.15 grams = $0.121
Cabbage: 477.05 grams = $0.053
Spinach: 7.01 grams = $0.002
Peas, Dried: 80.85 grams = $0.014
Lima Beans, Dried: 5.77 grams = $0.001

Daily nutrient breakdown result/required:
Calories: 8.000 / 8 = 100%
Protein: 187.000 / 187 = 100%
Calcium: 3.330 / 3.33 = 100%
Iron: 26.700 / 26.7 = 100%
VitaminA: 10.000 / 10 = 100%
VitaminB1: 4.000 / 4 = 100%
VitaminB2: 4.330 / 4.33 = 100%
Niacian: 53.300 / 53.3 = 100%
VitaminC: 300.000 / 300 = 100%

“Everest_summit.dat” – Minimum Requirements

Results for input file Everest_summit.dat:

Parameter nutrient_requirement: minimum
Parameter no_days: 60
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 60 days is: $23.31
Daily cost is: $0.39
Total weight for 60 days is: 185190 grams
Daily weight is: 3087 grams

Daily food breakdown results:
Wheat Flour (Enriched): 166.02 grams = $0.013
Cabbage: 508.34 grams = $0.057
Spinach: 54.21 grams = $0.012
Navy Beans, Dried: 2357.95 grams = $0.307

Daily nutrient breakdown result/required:
Calories: 9.000 / 9 = 100%
Protein: 545.581 / 210 = 260%
Calcium: 3.750 / 3.75 = 100%
Iron: 251.393 / 30 = 838%
VitaminA: 11.250 / 11.25 = 100%
VitaminB1: 13.086 / 4.5 = 291%
VitaminB2: 8.402 / 4.875 = 172%
Niacian: 74.232 / 60 = 124%
VitaminC: 337.500 / 337.5 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 60 days is: $41.01
Daily cost is: $0.68
Total weight for 60 days is: 121348 grams
Daily weight is: 2022 grams

Daily food breakdown results:
Cheese (Cheddar): 393.57 grams = $0.210
Peanut Butter: 281.19 grams = $0.111
Lard: 555.54 grams = $0.120
Liver (Beef): 20.05 grams = $0.012
Pork Chops: 219.95 grams = $0.149
Cabbage: 363.88 grams = $0.041
Spinach: 188.29 grams = $0.041

Daily nutrient breakdown result/required:
Calories: 9.000 / 9 = 100%
Protein: 210.000 / 210 = 100%
Calcium: 3.750 / 3.75 = 100%
Iron: 30.000 / 30 = 100%
VitaminA: 45.882 / 11.25 = 408%
VitaminB1: 4.500 / 4.5 = 100%
VitaminB2: 4.875 / 4.875 = 100%
Niacian: 68.797 / 60 = 115%
VitaminC: 337.500 / 337.5 = 100%

"Everest_summit.dat" – Exact Requirements

Results for input file Everest_summit.dat:

Parameter nutrient_requirement: exact
Parameter no_days: 60
Parameter no_foods: 77
Parameter no_requirements: 9

LP Solution for minimising cost:

Problem status: Optimum found

Total cost for 60 days is: $29.49
Daily cost is: $0.49
Total weight for 60 days is: 147838 grams
Daily weight is: 2464 grams

Daily food breakdown results:
Wheat Flour (Enriched): 524.06 grams = $0.042
Wheat Cereal (Enriched): 58.54 grams = $0.018
Evaporated Milk (can): 139.51 grams = $0.023
Cheese (Cheddar): 314.73 grams = $0.168
Peanut Butter: 176.53 grams = $0.070
Lard: 441.73 grams = $0.095
Cabbage: 450.24 grams = $0.050
Potatoes: 331.55 grams = $0.020
Spinach: 27.08 grams = $0.006

Daily nutrient breakdown result/required:
Calories: 9.000 / 9 = 100%
Protein: 210.000 / 210 = 100%
Calcium: 3.750 / 3.75 = 100%
Iron: 30.000 / 30 = 100%
VitaminA: 11.250 / 11.25 = 100%
VitaminB1: 4.500 / 4.5 = 100%
VitaminB2: 4.875 / 4.875 = 100%
Niacian: 60.000 / 60 = 100%

VitaminC: 337.500 / 337.5 = 100%

LP Solution for minimising weight:

Problem status: Optimum found

Total cost for 60 days is: $38.77
Daily cost is: $0.65
Total weight for 60 days is: 122533 grams
Daily weight is: 2042 grams

Daily food breakdown results:
Cheese (Cheddar): 379.99 grams = $0.203
Peanut Butter: 213.92 grams = $0.084
Lard: 573.37 grams = $0.124
Liver (Beef): 34.49 grams = $0.020
Pork Chops: 201.44 grams = $0.136
Cabbage: 536.73 grams = $0.060
Spinach: 7.97 grams = $0.002
Peas, Dried: 84.79 grams = $0.015
Lima Beans, Dried: 9.52 grams = $0.002

Daily nutrient breakdown result/required:
Calories: 9.000 / 9 = 100%
Protein: 210.000 / 210 = 100%
Calcium: 3.750 / 3.75 = 100%
Iron: 30.000 / 30 = 100%
VitaminA: 11.250 / 11.25 = 100%
VitaminB1: 4.500 / 4.5 = 100%
VitaminB2: 4.875 / 4.875 = 100%
Niacian: 60.000 / 60 = 100%
VitaminC: 337.500 / 337.5 = 100%