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JUNK FOOD OR GENUINE NOURISHMENT: THE NUTRITIONAL VALUE OF SOME SOUTH AFRICAN FAST-FOOD CHAINS

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ABSTRACT

Integer programming is used to test the nutritional completeness of two fast-food chains operating in South Africa, McDonald's and Kentucky Fried Chicken. It is shown that a fully nutritional and varied daily diet can be made up from McDonald's menu items, but the same is not true for Kentucky Fried Chicken. This exercise is highly suited to introduce students to mathematical programming: skills learned include formulating mathematical programming problems, mastering linear programming software and exploring the Internet for relevant data.

1. INTRODUCTION

Fast-food restaurants are usually considered to be "junk food" restaurants, and to be avoided if one is serious about the nutritional content of one's diet. But how true is this? The world's most famous fast-food chain, McDonald's, has recently located into South Africa, and we set out to answer the question: is it possible to construct a daily diet which was nutritionally complete (in the dietary sense) and comprised only of items from the McDonald's South African menu? If this was so, what combinations of menu items would together constitute a nutritionally complete diet (i.e. could be considered "wholesome")? And how much would such a daily diet cost the consumer? A natural extension of this would be to compare the cost of a nutritionally complete diet across various fast-food chains.

The diet problem was one of the first linear optimisation problems to be studied back in the 1930s and 1940s. It was motivated during the World War II by the US Army's desire to meet the nutritional requirements of the field GIs at minimum cost. One of the early researchers to formally study this problem was George Stigler. In 1945 Stigler formulated a diet problem as a linear programming (LP) problem in which 77 food types were available (including wheat flour, cabbage, spinach, corn meal, evaporated milk, peanut butter and pork liver) and 10 nutritional requirements (vitamin A, vitamin C, and so on) had to be satisfied (see Stigler, 1945). Since Dantzig's simplex solution to the LP problem only appeared in 1947, Stigler had to resort to a heuristic approach to solve this problem. The optimal heuristic result had an estimated cost of $39.93 per year (1939 prices). In the fall of 1947, Jack Laderman of the Mathematical Tables Project of the National Bureau of Standards undertook solving Stigler's model with Dantzig's new simplex method. It was the first "large scale" computation in linear optimisation. The LP consisted of nine equations in 77 unknowns, and it took nine clerks using hand-operated desk calculators 120 man-days to solve for the optimal solution. The cost of the optimal diet was $39.69 per year - not far off Stigler's heuristic solution. The optimal "computer" solution yielded a rather bland diet, consisting of the items mentioned above, which would probably not meet a minimum standard of tastiness (Stigler required that the same diet be eaten each day). "Tastiness" was clearly not included in the model formulation.

Bosch (1993, 1995) revisited the diet problem, constructing nutritionally complete daily diets (in much the same way as Stigler did) for McDonald's, Wendy's and Burger King (the three largest hamburger chains in the US), and comparing them on a cost basis. Of the three chains, only McDonald's is represented in South Africa, and even then the menu has been adapted to suit local demand. Furthermore, the pricing structure of menu items appears to be completely different to the US menu, so a look at the McDonald's diet problem from a South African perspective is interesting. A comparison with a competing (non-hamburger) fast-food outlet offers insight into value for money amongst fast food vendors (where value for money is defined in terms of nutritional value offered per rand spent).

2. A "NUTRITIONALLY COMPLETE" AND REASONABLE DIET

Before a fast food diet problem can be constructed it is necessary to define what is meant by a "nutritionally complete" diet. *Recommended Dietary Allowances*, published by the US Food and Nutrition Board of the National Research Council, has appeared regularly since 1941. The 10th (and latest) edition, issued in 1989, is used by South African dieticians to provide standards for good nutrition. The recommended daily allowance (RDA) is defined in terms of intake of essential nutrients, and varies according to the gender, age, weight and height of the person concerned. For the purposes of this study the consumer was assumed to be a male, aged between 19 and 24 years, weighing 72 kg and 1.77 metres tall, and then the daily dietary requirements were such that this consumer had to obtain

- less than 30% of his total energy (calories) from fat
- less than 10% of his total energy from saturated fats
- between 55% and 60% of his total energy from carbohydrates

(Note that 1g of fat = 9 calories, and 1g of carbohydrates = 4 calories).

Furthermore the daily diet had to provide

- less than 300mg of cholesterol
- between 120mg and 2400mg of sodium
- at least 58g of protein
- between 2200 and 2600 calories.

A further goal in determining an optimal daily diet is that it should be divided into two interesting meals (lunch and dinner), each with a main meal and a beverage (this step was clearly omitted by Stigler!). Thus for this study it was assumed that a typical fast-food patron would find a daily diet "reasonable" if it contains

- at least two main meals, different from one another (to provide variety)
- exactly two beverages

Furthermore, constraints were added that ensured that the main meal at McDonald's was supplemented by at least one side dish - either chips or a dessert. (The reader may wish to add to this list of constraints, or reduce it). It should be stressed here that the constraints included cover nutritional value and variety, but *do not attempt to model a consumer's individual taste preferences.*

US-based fast-food companies are aware that their customers worry about nutrition, and so make the nutritional data of their menu items available. A publication *McDonald's Food: The Facts* is distributed in all McDonalds' US outlets, and is also available on their worldwide website **http://www.mcdonalds.com/a_food/nutritionmenus**; this offers nutritional information about all menu items. Whilst McDonald's makes no representation that this data is appropriate outside of the US, it was assumed unlikely that the data be affected to any great extent by the fact that suppliers in South Africa are not American-based companies (see Appendix 1).

Menu prices were obtained by visiting a McDonald's outlet (Appendix 2). Prices were those relevant in November 1997.

A competing fast-food chain was selected based on availability of nutritional information. This essentially limited choice to US-based companies; Kentucky Fried Chicken (nutritional information found in *KFC Nutrition Facts* at **http://www.kentuckyfriedchicken.com/nutrition** was chosen as an example of a competitor. Unfortunately other hamburger and fried chicken fast-food chains operating in South Africa do not make available nutritional information about their menu items, and this naturally eliminates them, and reduces the size of this study.

Several assumptions and approximations had to be made. Certain items on the South African menus were not contained in the official nutritional data, and so were omitted from the study altogether unless additional nutritional information could be obtained from alternative sources (e.g. beverage manufacturers). Furthermore serving sizes/quantities of some items on the SA menus were different to the official US serving sizes/quantities. In this case local nutritional values had to be calculated in the correct proportions based on the US data. In the case of Kentucky Fried Chicken, individual pieces consist of either a whole wing, a breast, a drumstick or a thigh. For meals that consist of a combination of pieces (e.g. a "Fiver" contains an assortment of 5 pieces) an average nutritional content was calculated assuming an equal amount of wing, breast, drumstick and thigh. Furthermore, menus change from time to time; the data for this study is relevant to menus as at October 1997.

The integer programming formulation for the McDonald's diet problem can be found in Appendix 3. A similar formulation can be derived for the Kentucky Fried Chicken (KFC) diet problem. The problem was solved using LINDO software.

3. RESULTS - BASIC DIETS

The optimal (cheapest) daily diet at McDonald's that satisfies all the nutritional and reasonableness requirements is given in Table 1.

Restaurant	Cost	Optimal Diet	Nutritional Information
McDonald's	R25-00	**Lunch:** Hamburger Medium McFries Medium Chocolate Milkshake	Calories 2320 29.09% from fat 9.50% from saturated fat 57.76% from carbohydrates
		Dinner: Filet-O-Fish Strawberry Sundae Large Sprite	Cholesterol 160mg Sodium 2365 mg Protein 60g

Table 1. Optimal daily diet for McDonald's

Bosch (1995) had an optimal McDonald's daily diet consisting of two hamburgers, a small McFries, a side salad with croutons and a lite dressing, a small orange juice and a small vanilla milkshake. It should be noted here that the South African McDonald's outlets do not serve salads (and a lot of other US menu items), and Bosch included a different range of "reasonableness" constraints, making an identical optimal diet not possible. The cost of Bosch's diet was $4-87; allowing for 2.8% US inflation per year and at an exchange rate of $1 = R4.85 (November 1997), this translates into a current optimal cost of R24-96!

A feasible diet satisfying all the nutritional requirements was not possible for KFC. On closer examination of the data it was evident that menu items at KFC had a relatively high total fat content, or were relatively low in caloric value. A near-optimal diet from KFC, which only violated the maximum percentage from fat constraint is shown in Table 2.

Restaurant	Cost	Optimal Diet	Nutritional Information
Kentucky Fried Chicken	R38-16	**Lunch:** Drumstick 2 Medium chips Large Chips Dinner Roll Liquifruit	Calories 2550 45.35% from fat 7.84% from saturated fat 55.61% from carbohydrates Cholesterol 213mg Sodium 2352 mg
		Dinner: Drumstick 2 Medium Chips Mini Loaf Liquifruit	Protein 58g

Table 2. Near-Optimal daily diet for Kentucky Fried Chicken

The daily diet in Table 2 appears to contain an excessive quantity of chips; these were obviously included in this solution to increase the caloric count. Even after allowing for the violation of the fat constraint, the KFC daily diet is vastly more expensive than the McDonald's daily diet (R38-16 compared to R25-00), making it clear that McDonald's offers better nutritional value for money than does KFC. Other near-optimal KFC solutions (violating the proportion of fat constraint *and* the total calorie count) are shown in Table 3.

Restaurant	Cost	Optimal Diet	Nutritional Information
Kentucky Fried Chicken	R25-38	**Lunch:** Breast Medium Chips Liquifruit	Calories **1604.5** 47.26% from fat 9.68% from saturated fat 59.77% from carbohydrates
		Dinner: Chicky Pack Medium Chips Liquifruit	Cholesterol 225 mg Sodium 2390.75 mg Protein 59.25 g
Kentucky Fried Chicken	R31-38	**Lunch:** 2 Drumsticks Medium Chips MiniLoaf Sprite 350 ml	Calories **1848.5** 44.43% from fat 8.40% from saturated fat 57.29% from carbohydrates Cholesterol 282 mg
		Dinner: Chicky Pack Medium Chips Liquifruit	Sodium 2367.75 mg Protein 59.25 g
Kentucky Fried Chicken	R33-97	**Lunch:** 2 Drumsticks 2 Medium Chips Coke 350 ml	Calories **2076.5** 40.42% from fat 7.69% from saturated fat 56.20% from carbohydrates
		Dinner: Chicky Pack Medium Chips Coke 350 ml	Cholesterol 240 mg Sodium 2348.75 mg Protein 60.75 g

Table 3. Other Near-Optimal daily diets for Kentucky Fried Chicken (at least 1600, 1800 and 2000 Calories)

An alternative way of seeing that the McDonald's optimal diet offers better nutritional value for money is to observe that the 1600 calorie KFC diet would cost R25-38, virtually the same as the McDonald's optimal diet, but would still violate two important constraints (low calorie count and excessive proportion of calories from fat). Other, still sub-optimal KFC diets, cost significantly more.

It may be argued that this comparison is a somewhat unfair, in that the main meals on KFC's menu are limited to chicken portions, whilst McDonald's includes ground beef, chicken and fish in its main meals (in fact the optimal McDonald's diet includes both ground beef and fish, but *not* chicken). To avoid this bias the McDonald's problem was re-solved after adding constraints to ensure that chicken was included in one, and then both, meals. The results of this exercise are found in Table 4.

Restaurant	Cost	Optimal Diet	Nutritional Information
McDonald's (at least one chicken meal)	R27-20	**Lunch:** Hamburger Medium McFries Large Coke	Calories 2220 27.41% from fat 8.80% from saturated fat 58.36% from carbohydrates
		Dinner: McChicken Strawberry Sundae Medium Strawberry Milkshake	Cholesterol 160mg Sodium 2215 mg Protein 64g
McDonald's (chicken in both meals)	R30-60	**Lunch:** McChicken Strawberry Sundae Medium Sprite	Calories 2200 26.18% from fat 9.61% from saturated fat 58.36% from carbohydrates
		Dinner: McNuggets (6 pieces) 2 Caramel Sundaes Regular Coke	Cholesterol 150mg Sodium 2090 mg Protein 66g

Table 4. Optimal daily diets for McDonald's (one and two chicken meals)

It is seen that the effect of forcing two chicken meals into the optimal McDonald's daily diet results in a price increase of 22.4% over the basic optimal diet, implying that chicken in a fast-food menu is a more expensive component than ground beef or fish. However the McDonald's two-chicken-meals diet is still significantly cheaper than the best near-optimal KFC diet (R30-60 versus R38-16).

4. RESULTS - OTHER DIETS

Since the KFC diet is "nutritionally incomplete", it was excluded from further study and discussion here. Whilst the optimal McDonald's diet presented in Table 1 is nutritionally complete and reasonable, it could be described by patrons at McDonald's as somewhat boring. After all, as far as the main meals are concerned it contains only the standard hamburger and the Filet O Fish. To satisfy customers who might be unhappy with the Table 1 diet, the mathematical model that was used to obtain the Table 1 diets were repeatedly modified, once for each main meal missing from Table 1. Each time the goal was to force a particular main meal into the diet, achieved by adding a single constraint to the basic mathematical model. The resulting diets are listed in Table 5.

The entries in the "Extra Cost" column of Table 5 indicate the extra cost to the consumer for those diets over and above the basic optimal McDonald's diet. (Alternatively, these costs can be interpreted as the amount by which McDonald's would have to reduce the cost of each main meal to have it included in the basic optimal diet).

Main Meal	Extra Cost	Optimal Diet	Nutritional Information
Cheeseburger	R1-50	**Lunch:** Cheeseburger 2 Strawberry Sundaes Regular Sprite	Calories 2500 22.32% from fat 9.72% from saturated fat 57.28% from carbohydrates
		Dinner: Filet-O-Fish Strawberry Sundae Large Sprite	Cholesterol 190 mg Sodium 2310 mg Protein 59 g
Big Mac	R1-80	**Lunch:** Big Mac Strawberry Sundae Large Coke	Calories 2260 28.08% from fat 9.56% from saturated fat 59.47% from carbohydrates
		Dinner: Filet-O-Fish Ice Cream Large Coke	Cholesterol 195 mg Sodium 2360 mg Protein 60 g
Quarter Pounder DeLuxe	R5-50	**Lunch:** Quarter Pounder DeLuxe Strawberry Sundae Medium Coke	Calories 2250 27.20% from fat 10.00% from saturated fat 57.78% from carbohydrates
		Dinner: McChicken Caramel Sundae Large Coke	Cholesterol 180 mg Sodium 2375 mg Protein 61 g
Quarter Pounder with cheese	R7-40	**Lunch:** Quarter Pounder with cheese Strawberry Sundae Small McFries Large Coke	Calories 2230 29.87% from fat 9.89% from saturated fat 57.22% from carbohydrates Cholesterol 185 mg
		Dinner: McNuggets (6 pieces) Small McFries Large Coke	Sodium 2225 mg Protein 59 g
McNuggets 6 Pieces	R2-70	**Lunch:** McNuggets (6 Pieces) Strawberry Sundae Large Sprite	Calories 2200 27.20% from fat 9.61% from saturated fat 58.73% from carbohydrates
		Dinner: Filet-O-Fish Ice Cream Caramel Sundae Regular Coke	Cholesterol 170 mg Sodium 2025 mg Protein 59 g

McNuggets 9 Pieces	R4-00	**Lunch:** McNuggets (9 Pieces) Strawberry Sundae Large Coke	Calories 2250 28.40% from fat 8.80% from saturated fat 57.78% from carbohydrates
		Dinner: Filet-O-Fish Ice Cream Medium Coke	Cholesterol 180 mg Sodium 2155 mg Protein 64 g
McNuggets 20 Pieces		Not Feasible	
McChicken	R2-20	**Lunch:** McChicken Strawberry Sundae Large Sprite	Calories 2200 27.41% from fat 8.80% from saturated fat 58.00% from carbohydrates
		Dinner: Hamburger Medium McFries Medium Chocolate Milkshake	Cholesterol 160 mg Sodium 2345 mg Protein 64 g

Table 5. Optimal daily diets that include particular McDonald's main meals

It is interesting to note that only one main meal - McNuggets 20 Pieces - could not be included in an optimal diet. The McNuggets 20 Pieces is essentially a family meal, meant for more than one person, and its size ensures that it has high cholesterol and sodium levels. When the model was adapted to allow a single McNuggets 20 Pieces to be considered as *both* the day's main meals in one, it too can be included in an optimal diet.

The above analyses make it abundantly clear that the McDonald's menu indeed offers wholesome and nutritious meals at a reasonable cost.

5. USING THE McDONALD'S EXAMPLE FOR TEACHING LINEAR PROGRAMMING

Bosch originally intended his model to be a teaching aid, rather than for commercial purposes. I have similarly used this example to stimulate first-time learners of operational research/management science into the ideas involved in formulating and solving real-world deterministic mathematical programming problems. Initially the students are simply asked if they think that eating at McDonald's is healthy and/or wholesome, and they are set the task of proving their answer using scientific methods. Advantages of this problem and this approach if used as a class project are several. Firstly, the problem is bigger (in terms of the number of variables and constraints) than most encountered in the typical classroom text book, so ensuring that students get the idea that in practice not all LP problems have 3 variables and 2 constraints, and can all be solved by hand graphically or by using the simplex technique by hand! Thus the student will have to be exposed to LP software to reach a solution. I have chosen the LINDO software here as the student version comes supplied with some modern textbooks in operational research/management science (and indeed the one that I typically use for the course). This package is extremely quick and easy to install and use, and is very user friendly. Furthermore the full commercial version of LINDO is one of the most widely-available and -used commercial LP software. Secondly, the setting is interesting to most students, who inevitably would have been exposed to the fast-food way of eating. This level of interest is often converted into an increased dedication to exploring the problem. Thirdly, it highlights the point that the input data for most OR problems is not always easily available, and needs to be actively sought out. Students are encouraged to go and visit the problem-area (and to sample the vendor's wares while they are about it, if they wish!). Almost all students today have access to the Internet to find the required nutritional information (I give students this hint after a few days if they have not worked it out yet); thus a further spin-off of a project of this nature is that it often presents students with their first opportunity to *constructively* "surf the net". Thus students learn a variety of techniques and tools in a single aggregated setting. Furthermore this setting is not restricted to the fast-food chains mentioned here: many products on supermarket shelves offer nutritional information on their packaging, and the problem could easily be adapted to construct optimal daily diets from a given set of products, using suitable constraints.

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APPENDIX 1: McDONALD'S NUTRITIONAL INFORMATION

Menu Item	Cal	Total Fat	Satur Fat	Choles-terol	Sodium	Carbo	Protein
Hamburger	260	9	3.5	30	580	34	13
Cheeseburger	320	13	6	40	820	35	15
Big Mac	560	31	10	85	1070	45	26
Quarter Pounder Deluxe	550	31	11	90	1010	39	20
Quarter Pounder with Cheese	530	30	13	95	1290	38	28
Filet-O-Fish	560	28	6	60	1060	54	23
McFries Small	210	10	1.5	0	135	26	3
McFries Medium	450	22	4	0	290	57	6
McFries Large	540	26	4.5	0	350	68	8
McChicken	440	20	3	60	1040	38	27
McNuggets 6 Pieces	290	17	3.5	60	510	15	18
McNuggets 9 Pieces	430	26	5	90	770	23	27
McNuggets 20 Pieces	960	60	10	200	1710	50	60
Apple Pie	260	13	3.5	0	200	34	3
Ice Cream	150	4.5	3	20	75	23	4
Caramel Sundae	360	10	6	35	180	61	7
Chocolate Sundae	340	12	9	30	170	52	8
Strawberry Sundae	390	7	5	30	95	50	7
Coffee	50	1.3	0.8	5	58	7	4
Tea	50	1.3	0.8	5	58	7	4
Orange Juice Small	80	0	0	0	20	20	1
Orange Juice Large	160	0	0	0	40	40	1
Coca Cola Classic Regular	150	0	0	0	15	40	0
Coca Cola Classic Medium	210	0	0	0	20	55	0
Coca Cola Classic Large	300	0	0	0	30	82	0
Diet Coke Regular	1	0	0	0	30	0	0
Diet Coke Medium	2	0	0	0	35	1	0
Diet Coke Large	3	0	0	0	45	1	0
Sprite Regular	150	0	0	0	55	39	0
Sprite Medium	210	0	0	0	70	56	0
Sprite Large	300	0	0	0	90	80	0
Chocolate Milkshake Medium	360	9	6	40	250	60	11
Chocolate Milkshake Large	720	20	12	80	500	120	22
Vanilla Milkshake Medium	360	9	6	40	250	59	11
Vanilla Milkshake Large	720	20	12	80	500	118	22
Strawberry Milkshake Medium	360	9	6	40	180	60	11
Strawberry Milkshake Large	720	20	12	80	360	120	22

APPENDIX 2: McDONALD'S MENU ITEMS PRICE LIST (NOVEMBER 1997)

Menu Item	Price
Hamburger	2.90
Cheeseburger	3.50
Big Mac	7.80
Quarter Pounder Deluxe	8.60
Quarter Pounder with Cheese	7.80
Filet-O-Fish	5.60
McFries Small	3.30
McFries Medium	4.50
McFries Large	5.90
McChicken	7.80
McNuggets 6 Pieces	6.60
McNuggets 9 Pieces	9.30
McNuggets 20 Pieces	18.00
Apple Pie	3.60
Ice Cream	2.00
Caramel Sundae	3.60
Chocolate Sundae	3.60
Strawberry Sundae	3.60
Coffee	2.70
Tea	2.70
Orange Juice Small	2.70
Orange Juice Large	3.90
Coca Cola Classic Regular	2.70
Coca Cola Classic Medium	3.30
Coca Cola Classic Large	3.90
Diet Coke Regular	2.70
Diet Coke Medium	3.30
Diet Coke Large	3.90
Sprite Regular	2.70
Sprite Medium	3.30
Sprite Large	3.90
Chocolate Milkshake Medium	4.50
Chocolate Milkshake Large	6.50
Vanilla Milkshake Medium	4.50
Vanilla Milkshake Large	6.50
Strawberry Milkshake Medium	4.50
Strawberry Milkshake Large	6.50

APPENDIX 3: THE McDONALD'S DIET PROBLEM FORMULATION

The decision variables are the items on the menu. In the McDonald's diet problem the decision variables are

hamburger = # of hamburgers in the daily diet
cheeseburger = # of cheeseburgers in the daily diet

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strawberry milkshake large = # of large strawberry milkshakes in the daily diet.

Since the decision variables are all integer-valued (it is not possible to order 0.5361 hamburgers!), the problem is an integer programming problem.

The objective is to minimise cost, so the objective function is

Minimise *cost* = 2.90 *hamburger* + 3.50 *cheeseburger* + ... + 6.50 *strawberry milkshake large*

There are constraints for each nutritional requirement:

calories = 260 *hamburger* + 320 *cheeseburger* + ... + 720 *strawberry milkshake large*
fat = 9 *hamburger* + 13 *cheeseburger* + ... + 20 *strawberry milkshake large*
saturated fat = 3.5 *hamburger* + 6 *cheeseburger* + ... + 12 *strawberry milkshake large*
cholesterol = 30 *hamburger* + 40 *cheeseburger* + ... + 80 *strawberry milkshake large*
sodium = 580 *hamburger* + 820 *cheeseburger* + ... + 360 *strawberry milkshake large*
carbohydrates = 34 *hamburger* + 35 *cheeseburger* + ... + 120 *strawberry milkshake large*
protein = 13 *hamburger* + 15 *cheeseburger* + ... + 22 *strawberry milkshake large*

$-0.3\ \textit{calories} + 9\ \textit{fat} \leq 0$

$-0.1\ \textit{calories} + 9\ \textit{saturated fat} \leq 0$

$-0.55\ \textit{calories} + 4\ \textit{carbohydrates} \geq 0$

$-0.6\ \textit{calories} + 4\ \textit{carbohydrates} \leq 0$

$\textit{cholesterol} \leq 300$

$120 \leq \textit{sodium} \leq 2400$

protein $\geq$ 58

2200 $\leq$ *calories* $\leq$ 2600

To ensure "reasonableness" of the diet we add to the model the following constraints:

mainmeal = *hamburger* + *cheeseburger* + ... + *McNuggets 20 pieces*

beverages = *coffee* + *tea* + ... + *strawberry milkshake large*

chips = *McFries small* + *McFries medium* + *McFries large*

dessert = *apple pie* + *caramel sundae* + ... + *ice cream*

mainmeal $\geq$ 2

beverages = 2

chips $\geq$ 1

dessert $\geq$ 1

hamburger $\leq$ 1

cheeseburger $\leq$ 1

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McNuggets 20 pieces $\leq$ 1

All decision variables $\geq$ 0 and integer-valued.