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Lunch Crunch: Can nutritious be affordable and delicious?

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Summary:
As everybody acknowledges, school lunches are a vital component of schoolchildren's nutrition, providing a third of their caloric intake on a daily basis. Providing of healthy, well-balanced meals is therefore a major concern when determining the composition of school lunches. However, other, equally weighty factors, such as palatability and cost, must also be taken into account. A perfectly prepared nutritional masterpiece of a lunch is useless if it is too expensive to serve or too disgusting for students to touch. Likewise, cheap meals are simply expensive trash if they are discarded untouched, and a sublime entree cannot be served if it causes heart attacks.

All three variables must be met with at least a modicum of success for the lunch program as a whole to prevail. The dilemma of thus providing palatable, nutritious, and cost-effective school lunches to public school students presents a difficult compromise at best and wasted time, money, and food at worst.

Our team was tasked with determining several aspects of this multifaceted problem. First, we composed a linear regression model for the relationship between calorie intake and height, weight, and age. The Harris-Benedict equation, developed in 1918, provided a basis of our own model. Varying coefficients had to be employed in order to account for differing male and female basal metabolic rates. Our sample size consisted of 154 young individuals, 75 males and 54 females. The activity level, body mass index, and diseases/disorders were accounted for in sub-models of the first. Our end
model returned values slightly too high in relation to empirically obtained ones, but given that it was predicated on an equation that consistently did the same, such overestimates are understandable.

Our next model involved the calories and nutrients needed for high school students to qualify as adequately nourished. Using averages of age, height, and weight, we successfully determined the average required calories for both male and female students of high school age (13-19) to qualify as such. The results concluded that 31.8% of male and 77.8% of female students meet the specifications of "adequate nourishment" and thus gain their re quired nutrients from standard school lunches.

Our third model predicted the palatability of a school lunch based upon a budget of \$7 and \$6 per week, respectively. Students benefit only from the lunches they consume, so no matter how nutritious, a meal must also meet certain minimum standards of appeal for students to gain the nutritional benefits thereof. From a list of 100 potential food options we selected 44 based on an approval rating of at least 50%. Our results demonstrated that a healthy school lunch that remains under the budget consists of one entree containing meat and carbohydrates, such as

hamburgers and pasta with meatballs along with milk and a combination of three fruits and vegetables. We composed a lunch plan allowing $7/week, which permitted, for instance, a meal of a beef taco, strawberries, and skim milk, as well as two servings of green beans. For the $6/week we showed that a meal composition would simply remove the second serving of green beans, leaving a beef taco, strawberries, skim milk, and green beans.

Introduction:

School lunches are the most convenient and substantial means of providing nutrition to students in public schools. As such, some 31 million children partake of the National School Lunch Program daily.[1] It is therefore imperative that the dietary needs of schoolchildren be met by any lunch program adopted by the public school systems nationwide. Unfortunately, while 94% of schools served meals that met vitamin and mineral requirements, the same meals also exceeded federal limits for fat and saturated fat.[1] Furthermore, students supplement distasteful lunches with sugar-and-fat-laden snacks and drinks. Soda is the single largest source of of sugar in the diets of American adolescents. 20% of teenagers consume at least three sugar-sweetened beverages per day.[1] The health of American schoolchildren has suffered as a result of excessive fat, salt, and sugar consumption. Almost one-third (31.8%) of all US children aged 2-19 are overweight or obese.[2] First Lady Michelle Obama has called attention to nutrition reform in school meals with her “Let’s Move!” initiative, but results have been mixed since its inception in 2010.[3]

Moreover, school lunches are universally renowned for their unpalatability. Students respond to undesirable entrees by simply not consuming them. Significantly over 15% of school lunches were thrown away, in a study of Boston middle schools. A particular emphasis on health food waste was observed: 60 to 75 percent of the vegetables and 40 percent of the fruit was discarded. Extrapolated nationwide, over $1.2 billion is wasted annually on uneaten food.[4] The First Lady’s efforts to improve the nutritional content of school lunches have failed to impact this amount of squandered food.[5] In fact, students report that the lunch reforms have reduced the already-dismal palatability of the food.[6] Some 1.6 million students have ceased purchasing school lunches as a result of the reforms’ implementation.[7] Gustatory dislike of school lunches was cited as the most common reason for not purchasing school-provided meals.[8]

School lunches are naturally constrained by costs of preparation. Currently, the average cost of preparing a school meal is currently approximated at $3.00 per student, accounting for ingredient, labor and administrative costs.[12] The cost is roughly $2.58.[13] With a federal subsidy of only $0.26 per meal, providing lunches to students thus represents a significant financial liability to districts, and as such, one whose cost must be minimized. The mandated improvements to nutritional value only increase this liability, averaging an additional $0.25 per meal.[10] The aforementioned loss of students purchasing lunches cuts down on school revenue and increases the lunch deficits further.[11] Furthermore, federal regulations demand that the national average of school lunch prices be reduced to $2.46 by 2015.[13] This unviable financial situation greatly restrains the already-limited capability to incorporate taste and nutritional concerns into school lunches.

Providing nutritious lunches for students is a crucially important aspect of the public school system. A rise students’ academic performance is proven to be directly linked with healthy diets, of which school lunches are a major component.[14] However, the delicate balance between cost, nutrition and taste precludes any facile means of supplying cheap, healthy, and delicious meals to public school children.

Restatement of the Problem

The United States Department of Agriculture has asked our consulting firm to do the following:

1. Develop a mathematical model that takes as input a student's individual attributes, and outputs the number of calories that a student with those attributes should eat at lunch.
2. Create a model to determine the distribution of U.S. high school students among each input attribute for the first model.
3. Determine if every student eats the standard school lunch, what percentage of students will have their caloric needs met at lunch.
4. Develop a lunch plan that is within the weekly budget of $7 per student, meets the nutritional standards, and appeals to students.

Global Assumptions

1. According to previous research, breakfast has no effect on the calorie intake at lunch (NCBI #1). Hence we do not take breakfast into account when we determine proper lunch calorie intake.
2. We will further assume that students receive one-third of their daily caloric intake and nutrients from their school lunches.
3. The amount of calories that a student intakes is equal to the amount of calories expended for a healthy individual.

Part I:

Designing the Model

Harris and Benedict developed a model for energy expenditure. However, their model was created for populations at ages much higher than those of schoolchildren. As our study focuses on schools, we fixed the model to be more accurate at younger ages. We measured energy expenditures in kilocalories.

We modeled calorie intake as a function of age, weight, and height, and gender. In previous studies, the relationship between these factors is approximately linear.

Let *c* be the output recommended calorie value, *a* be the age in years, *h* be the height in centimeters, and *w* be the weight in kilograms. Our linear curve would therefore be

$$E = (A\mathrm{a} + B\mathrm{h} + C\mathrm{w} + D) \qquad (1)$$

where *A*, *B*, *C*, and *D* are constant coefficients.

We used a Java program to determine the values of the constant coefficients. Different sets of coefficients needed to be determined depending upon gender.

Similar models, such as the Harris Benedict equation, in other studies show that *A* is generally negative, while the *B*, *C*, and *D* are positive. *D* was sometimes very large, but the absolute value of the other three constants were generally less than 20.

As a result, we iterated *A*, *B*, and *C* from an absolute value of 0 to 20 by 0.1 each time. *D* was iterated from 0 to 500 by integer values.

In order to determine the best set of coefficients, we fit our iteratively projected curves onto all experimental data from Harris and Benedict of samples less than 25 years of age. The sample size of males was 75 people, and the sample size of females is 54 people.

The curve fitting was performed by summing the vertical distance between experimental energy expenditure and theoretical energy expenditure from the curve for each point.
For *n* people, we minimize

$$\sum_{i=0}^{n} |E_i - (A\mathrm{a}_i + B\mathrm{h}_i + C\mathrm{w}_i + D)| \qquad (2)$$

where E_n is the experimental energy expenditure, and a_i, h_i,, and w_i are the age, height and weight of person *i*.

We then expand upon the basic model in two ways.

First, energy expenditure depends upon human lifestyle as well as body shape. Harris and Benedict's sample population contained people of normal activity levels. We expanded the model by adding an activity level factor, δ. This was a standard practice in similar models. As activity level affects energy expenditure as a ratio of basal metabolic rate, it is reasonable to assume that age and body shape do not significantly affect the value of δ. Based upon other studies, we determined an activity level of approximately $\delta = 0.9$ for inactive students, $\delta = 1$ for moderately active students, and $\delta = 1.2$ for extremely active students.

Second, studies have shown that Harris and Benedict's model is not an accurate measure of energy expenditure for certain diseases, such as diabetes and eating disorders. We strive to include this by considering the impact of obesity of the model.

We assume that obese students desire to follow a fitness and diet plan to lose weight healthily. Studies show that a safe rate of weight loss is 8% of body weight over 6 months. Since burning 3500 calories equates to losing one pound, to lose the correct amount of weight, the calorie intake needs to be reduced by 3.42 times body weight.

We determined which students are obese using body mass indices.

$$BMI = W/H^2 \qquad (3)$$

We declare a person to be obese when his or her BMI is over 30.

We did not take into account geographic and socioeconomic demographics across the United States, since we do not believe that to be a major factor. Inner city schools will have different access to funds when compared to rural schools. In theory, costs would be slightly higher than our what our model predicts, meaning our developed school lunch menu may have more variability than what is realistic. Nonetheless, USDA prices and transportation costs will be similar, or at the least, have little impact on overall costs.

Thus, with the coefficients determined in the computer program and the additional two factors, we arrive at the following equation for energy expenditure:

For males:

If $W/H^2 < 30$,

$$E = (-19.9a + 15.5h + 6.3w)(\delta) \qquad (4)$$

If $W/H^2 > 30$,

$$E = (-19.9a + 15.5h + 6.3w)(\delta) - 3.42w \qquad (5)$$

For females:
If $W/H^2 < 30$,
$$E = (-1.1a + 10.7h + 2.2w + 453)(\delta) \qquad (6)$$
If $W/H^2 > 30$,
$$E = (-1.1a + 10.7h + 2.2w + 453)(\delta) - 3.42w \qquad (7)$$

Validation of the Model

We can evaluated our data by analyzing the percent error from randomly generated data points that we originally based our data from. Based on the Harris Benedict equation, multiplying an individual's basal metabolic rate by 1.3 if he or she does seated work but does no exercise (Harris Benedict Equation.) As a result, we multiplied all experimental heat produced (kcal) over 24 hours in Benedict and Harris's data by 1.3 since we assume that everyone's calorie expenditure is at least equal to living a lifestyle in the seated learning environment. The actual calories required may be higher in cases that an individual is more active.

Actual calories required (kcal)	Theoretical calories (kcal)	Percent Error
2604	2730	4.84%
2031	2301	13.29%
2067	2395	15.87%
2146	2352	9.60%
1852	2196	18.57%

Table 1: Table showing percent error of calculated calories for males under 25 using our modelled equation.

Actual calories required	Theoretical calories	Percent Error
2283	2383	4.38%
2068	2336	12.96%
2202	2375	7.86%

1924	2327	20.95%
2119	2241	5.76%

Table 2: Table showing percent error of calculated calories for females under 25 using our modelled equation.

Results of the Model

This model returned overall overestimates for the calorie intake as a function of age, height, and weight for both male and female cases. However, the Harris-Benedict counterpart, also returned general overestimates for caloric needs. As our model was predicated upon that earlier model, our recommendations for slightly too many calories are understandable.

Part II:

Assumptions:

1. We assume that the average values of heights and weights employed in this model represent the population. We may make this assumption because the sample size is large enough and this data is used often by other organizations
2. The number of people for each age is equal; we may make this assumption because approximately the same number of students attend each year of high school.
3. We assume that a school lunch contains 850 Calories ("School Lunch Showdown:...").
4. As previously assumed, lunch should account for ⅓ of daily calorie value.

Using data for age, average height, and average weight from the Centers of Disease Control (*Mean Body Weight, Height…*), we are able to calculate the calories from lunch needed on average by a person of an age between 13 and 19, the ages of high school students, using equations (4) and (6) for males and females, respectively. Since the weights and heights we enter are the average of the age group, δ is 1. We then calculate the standard deviation of the calories needed:

$$\text{Males: } \sigma_c = \sqrt{(6.3\overline{w})^2 + (15.5\overline{h})^2} * Age \qquad (8)$$

$$\text{Females: } \sigma_c = \sqrt{(2.2\overline{w})^2 + (10.7\overline{h})^2} * Age \qquad (9)$$

From this, we may find the probability that the number of calories needed are met by an 850 Calorie school lunch using the normal distribution cumulative probability calculator function.

Age	Average weight $\overline{w}$ (kg)	Standard deviation of weight σ_w(kg)	Average height $\overline{h}$ (cm)	Standard deviation of height σ_h(cm)	Calories needed from lunch μ (kcal)	Standard deviation of calories σ_c (kcal)	Probability that calories met
13	53.9	1.9	160.1	0.8	854.14	224.05	0.493
14	63.9	1.6	168.5	0.9	911.91	223.74	0.391
15	68.3	1.1	173.8	0.6	941.90	150.77	0.271
16	74.4	1.4	175.3	0.6	955.82	166.62	0.263
17	75.6	1.4	175.3	0.6	951.71	166.62	0.271
18	75.6	1.1	176.4	0.7	950.76	167.37	0.274
19	78.2	1.3	176.7	0.6	951.14	161.10	0.265

Table 3: Table showing percentage of males that receive the necessary amount of calories from school lunches

Age	Average weight $\overline{w}$ (kg)	Standard deviation of weight σ_w (kg)	Average height $\overline{h}$ (cm)	Standard deviation of height σ_h (cm)	Calories needed from lunch μ (kcal)	Standard deviation of calories σ_c (kcal)	Probability that calories met
13	57.7	1.4	159.1	0.6	756.00	92.57	0.845
14	59.9	1	161.8	0.6	766.88	95.01	0.809
15	61.1	1.7	162	0.6	768.11	111.44	0.769
16	63	1.2	161.9	0.5	768.78	95.45	0.802
17	61.7	1.2	163.2	0.6	772.09	118.01	0.745
18	65.2	1.5	163	0.5	773.58	113.15	0.750
19	67.9	1.2	163.1	0.7	775.55	150.89	0.689

Table 4: Table showing percentage of females that receive the necessary amount of calories from school lunches

Results of the Model

The percentage of males that get enough calories from lunch on average is 31.8%, while the percentage of females that get enough calories is a much larger 77.3%. These values make sense, because males have higher necessary calories, which means fewer males will meet their necessary calories from school lunches, while the females need fewer calories, therefore will more likely meet their necessary calories from school lunches.

Validation of the Model

The average weights and heights and average standard deviations represent those of the whole population and the distributions are approximately normal. We may make this assumption for our model because the sample sizes are large enough, all more than 250, and form an insignificant proportion of the true population, therefore by the Law of Large Numbers and the Central Limit Theorem, we assert our assumption.

Part III:

There’s no such thing as a free lunch. A sample school district has a weekly budget of $7 per student for the purchase of food only. Leverage math modeling to develop a lunch plan (using food categories) that stays within the budget, meets the nutritional standards and appeals to students. What changes would you make if your budget was decreased by $1?

Assumptions:

1. All schools purchase their raw-lunch materials from the USDA.
2. Food prices are consistent with those of 1997, adjusted for inflation.
3. The average student has a 2000 calorie diet.

A given school district has limited funds, thus, it must balance its budget with nutritional standards and appeal to students. We will create a model to develop a lunch plan for an ambiguous school with a budget of $7 or $6.Schools should not serve food that most students will not eat. We obtained food preference data from a survey conducted on 1,818 Ohio primary and secondary students to determine what lunch options are viable. From a list of 100 food options, we chose 44 that are representative of current school programs and were not unfavored by at least 50% of the students. We also included certain vegetarian options that may not have been above the threshold to account for cultural and vegetarian/vegan diets.

Options	Cost ($)	Calories	Fat	Sodium	Carb	Fiber	Protein	Calcium	Vitamin C
Cheese Pizza	0.524	0.3855	0.553846	0.435833	0.33	0.44	0.66	17	2
French Fries	0.14	0.4335	0.861538	0.2975	0.37	0.78	0.21	2	2
Chocolate Milk	0.096	0.084	0.017231	0.0325	0.1089	0.1	0.2052	12	0
Chicken Nuggets	0.56	0.07785	0.947692	0.448333	0.1624	0.14	0.8616	3.8	0
Beef Tacos	0.55	0.309	0.6	0.466667	0.2023	0.58	0.555	12.3	0
Mashed Potatoes	0.247	0.1695	0.258462	0.2775	0.169	0.3	0.12	2.1	17.5
Strawberries	0.2	0.048	0.018462	0.000833	0.077	0.4	0.0402	1.6	98
Hamburgers	0.47	0.4455	0.739077	0.275833	0.315	0.34	0.99	6.2	0
Orange Juice	0.35	0.081	0	0.001667	0.134	0.04	0.012	0.2	25
Watermelon	0.15	0.045	0.009231	0.000833	0.0755	0.08	0.0366	0.7	13.5
2%Milk	0.093	0.0645	0.059692	0.043333	0.0497	0	0.2088	12.8	1.6
Skim Milk	0.23	0.0525	0.011077	0.043333	0.0485	0	0.204	20.4	1.6
Baked Potatoes	0.21	0.297	0.006154	0.214167	0.46	1.58	0.2574	3.4	22.5
Grapes	0.13	0.1035	0.009846	0.001667	0.181	0.18	0.0432	1	5.3
Mac & Cheese	0.47	0.285	0.509538	0.281667	0.2393	0.24	0.2934	6.3	0
Fruit Yogurt	0.32	0.1425	0.012308	0.048333	0.19	0	0.264	15.2	1.2
Corn	0.124	0.5475	0.291692	0.029167	0.7426	1.46	0.5652	0.7	0
Blueberry Muffins	0.22	0.5655	0.975385	0.2825	0.5398	0.2	0.2724	4.6	1.5
Banana Bread	0.36	0.489	0.646154	0.251667	0.546	0.22	0.258	2.1	2.8
White Bread	0.32	0.3975	0.196308	0.409167	0.4906	0.54	0.549	26	0
Grilled Cheese Sandwich	0.39	0.525	1.169231	0.766667	0.3356	0.3	0.6624	28	0
Tossed Salad	0.21	0.0225	0.009231	0.016667	0.0314	0.22	0.0444	2	5
White Rice	0.09	0.1935	0.017231	0.304167	0.279	0.08	0.1596	1	0
Hot Dog	0.383	0.2625	0.916308	0.580833	0.0254	0	0.4332	2	0
Green beans	0.15	0.0885	0.190769	0.2575	0.0761	0.62	0.1092	4	16
Oranges	0.16	0.0705	0.007385	0	0.1175	0.48	0.0564	4	89
Bananas	0.137	0.1335	0.020308	0.000833	0.2284	0.52	0.0654	0	14
Pineapple	0.19	0.072	0.007385	0.000833	0.1263	0.28	0.0324	1	60
Carrot Sticks	0.34	0.078	0.019077	0.073333	0.1226	0.72	0.0714	4	13
Cantaloupe	0.2	0.051	0.011692	0.013333	0.0816	0.18	0.0504	1	61
Applesauce	0.12	0.114	0.011077	0.0025	0.1991	0.24	0.0108	0	3
Chicken Caesar Salad	0.45	0.1665	0.309538	0.288333	0.0346	0.252	0.7734	5.88	5.88
Peaches	0.19	0.0585	0.015385	0	0.0954	0.3	0.0546	1	11
Wheat bread	0.28	0.3885	0.252923	0.441667	0.4714	0.88	0.5478	10	0
Apple	0.25	0.108	0.014154	0.000833	0.1906	0.66	0.0216	1	10
PBJ	0.32	0.4905	0.875692	0.4025	0.4223	0.58	0.6192	9	0
Meat/Cheese/Egg/Salad	0.32	0.1095	0.257846	0.115833	0.0177	0.1	0.4158	6	4
broccoli	0.18	0.0465	0.020923	0.025	0.0604	0.48	0.1542	4	135
blueberries	0.23	0.0855	0.020308	0.000833	0.1449	0.48	0.0444	1	16
BBQ Sandwich	0.63	0.279	0.432615	0.516667	0.1925	0.22	0.6408	6	5
green peas	0.14	0.1755	0.035692	0.005833	0.2097	1.48	0.4716	4	97
celery sticks	0.13	0.027	0	0.073333	0.047	0.48	0.072	4.7	11.8
pears	0.21	0.087	0.007385	0.000833	0.1546	0.62	0.0228	1	7
Spaghetti	0.39	0.2205	0.273846	0.291667	0.1918	0.3	0.4656	13	6

Table 5 (Compiled in Word). Figure displaying nutrition information by percent of a 800 calorie lunch and costs associated with each serving

Results of the Model

This data was compiled and run through a linear algebra algorithm developed using Eclipse in order to yield a list of food combinations that meet a school budget of $7 per student per week.

In a multidimensional array, a list of foods shown above was recorded along with their price, calories, fat, sodium, carbohydrates, fiber, protein, calcium, and vitamin C.

We used only integer valued possibilities for the amount each food, as it is, for example, unrealistic to serve one third of a hamburger.

For each nutritional factor, we set as a constraint that the intake of that nutrient must be between 25% and 40% of the daily value intake of that nutrient based on the 2000 calorie diet, as this is a fairly close threshold around ⅓ of the daily intake that lunch occupies.

The intake of each nutrient is:

$$\sum_{i=0}^{n} |n_i * N_i| \qquad (10)$$

where n_i is the integer amount of each food i and N_i is the amount of the nutrient in a unit amount of food i.

Similarly, the total cost of the lunch is:

$$\sum_{i=0}^{n} |n_i * C_i| \qquad (11)$$

where C_i is the cost of a unit amount of food i.

To find the optimal school lunch we solved for all n_i such that cost is minimized:

$$\min\left(\sum_{i=0}^{n} |n_i * C_i|\right)$$

given the constraints:

$$\text{all } n_i \in Z$$

$$25\% < \sum_{i=0}^{n} |n_i * N_i| < 40\% \text{ for all nutrients } N.$$

For $7 a week, we determined the optimal food combination to be a single unit of each of beef taco, strawberries, and skim milk, as well as two servings of green beans, which results in a cost of $1.28 per day or $6.40 per week.

For \$6 a week, we determined the optimal food combination to be a single unit of each of beef taco, strawberries, skim milk, and green beans, which results in a cost of \$1.13 per day or \$5.65 per week.

Other options are available, but do not optimize cost and student taste preferences.

Part IV: Strengths and Weaknesses

In the first model, our data was compiled from two separate collections of data. Scholarly articles from both Henry[17] and Harris[16] both provided height, weight and basal metabolic rate information regarding subjects. Varying measurement techniques and equipment could have reduced the reliability our model, but as the means of measuring height, weight, and BMR have remained simple and consistent, this potential unreliability is largely negated.

Estimated recommended calorie intake value is less accurate at younger ages because the data available had a disproportionate number of samples with ages between 18 and 25 rather than younger students, which would decrease the slope of our linear curve and increase the constant, since weight and height tend to stabilize sometime between the said ages.

A persistent weakness in our model is dealing with data from multiple sources, as this error was repeated in the third model. Due to incomplete data in acquiring food prices while developing a lunch program, we were forced to scavenge, taking information from *Nutrition Standards and Meal Requirements for National School Lunch and Breakfast Programs,* which contained 1997 data, as well as from current USDA prices. However, we were able to factor the inconsistencies of inflation and Ohio state costs compared to a national level, meaning that an acceptable amount of consistency is present for all food prices.

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