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Activity analysis applied to menu planning

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I. INTRODUCTION

When the process of linear programming was first being developed in the 1940's, the so-called "diet problem" was formulated to test out this new procedure. Since the idea of linear programming was to find the solution(s) that would maximize (or minimize) a linear objective function subject to a system of linear (or nearly linear) constraints, the problem of designing a diet which would satisfy certain minimum nutritional requirements at least cost was particularly suitable for this type of analysis. Certainly, a human diet, any of various requirements, and the cost of such a diet can be expressed linearly. The expenditure on a particular food consumed summed over all of the foods present in the diet would be the cost. And the constraints on this problem can also be written in linear form: one set of constraints to insure that the resulting diet will contain as much or more than the required amounts of important nutrients and another set of nonnegativity constraints.

Even before the method of linear programming had been fully worked out, George Stigler (cited in Smith (20)) obtained a solution to a minimum cost diet by a sophisticated system of iterations. In 1941, Jerome Cornfield (cited in Smith (20)) became the first man to express the minimum cost diet problem mathematically, but he did not go on to work out the calculating procedures and did not publish his work. Dantzig and Laderman (cited in Smith (20)) finally solved the minimum cost diet problem with the use of linear programming in 1947. As an interesting sidelight, the minimun cost diet determined by Dantzig and Laderman was based on the problem formulated by Stigler and was only twenty-five cents less than Stigler's solution. Using August, 1939, prices, Stigler's annual subsistence diet for a moderately active adult male was $39.93; Dantzig and Laderman's solution, based on the same set of prices and assumptions, was $39.68.

Since that time, many other minimum cost diets (which are essentially blending problems) have been computed. Some of these included in their list of foods to be considered only those that were determined to be generally acceptable in the area on which the study was to be based. Some put no such limits on their list of foods. But, including the study by Victor Smith published in1964, all of the diets which have been computed had one feature in common: All contained basically few items, in bulk. The earlier studies and Smith's study made no allowances for how the food could be prepared and consumed.

A. The Electronic Computation of Human Diets: Smith

Smith's goal was to design a least cost diet which would take into consideration how foods would be used, either by themselves or in combination with other foods. As Smith expressed this, "The three models I am presenting illustrate the way in which 'conventional' restraints can be used in programming models to raise the level of palatability of the diet, unquantifiable as palatability may be" (21).

Smith utilized nutritional constraints alone to formulate the first of his diets, which he called his "Midget Model." The list of foods which he used was based on a study of those foods most commonly purchased by 176 families in the Lansing, Michigan area in 1955 (this list was also used in the calculation of his last two models). The resulting diet he obtained was reminiscent of Stigler's least cost diet of wheat flour, evaporated milk, cabbage, spinach, dried navy beans, pancake flour, and pork liver; Smith's "Midget Model" solution consisted of fresh milk, oleomargarine, carrots, potatoes, picnic ham, and white flour. Basically, the only difference between Stigler's approach and Smith's approach was that Smith restricted his list of foods to those that could be considered "popular."

Smith introduced the innovation of complementarity restrictions in his second, or "Small," model. The list of foods considered and the nutritional constraints remained as before (except that an upper limit was imposed on the total number of calories), but now he added what he called "explicit conventional restraints." These restraints were designed to insure that the foods which would appear in the solution could be combined in such a way that they could be used in a conventional manner. Note that in the "Midget Model," flour was present but none of the cooking accessories commonly used with flour were present (except for butter and milk, which could be combined with flour in a paste). The complementarity restrictions assured Smith that if flour appeared in the final solution, so would appropriate amounts of baking powder, yeast, baking soda, etc. These constraints covered the use of butter (or oleo) for bread, salad dressings for leafy green vegetables, several accessories for flour, and sauces for meat. Besides the complementarity conditions, Smith also "forced in" several cooking aides which could not be tied with the preparation of any one particular food: salt, pepper, spices, vinegar, prepared mustard, and coffee. Upper limits were placed on the amounts of ten other food groups due to the fact that they seemed to be quite economical and might therefore appear in the solution in excessive quantities.

As might be predicted, the composition of the "Small Model" was considerably different from the composition of the "Midget Model." Some foods reappeared but in smaller quantities due to either the complementarity constraints or the upper limit constraints. Other foods disappeared from the solution entirely because of the cost of their complements. But in general, the "Small Model" represented a diet with more palatability (twenty-two items in total) but at a greater cost. Whereas the "Midget Model" diet for a family of three for four weeks at May, 1955, prices in Lansing, Michigan, was $28.33, the "Small Model" diet under the same circumstances was $34.71 (21).

Smith's final formulation was his "Large Model." The list of foods considered here was the same as the one used previously with a few additions; the list was expanded to include foods bought by a smaller percentage of the sample population. The constraints used in the "Small Model" were followed, along with minimum level constraints on forty-one food groups that had been purchased by at least ninety percent of the sample. These minimum level constraints, in effect, "forced in" the most popular food items, in spite of the fact that had the constraints not been present, some of the foods would not have been included in the solution due to the cost of their complements. The "Large Model" included fifty-seven items at a higher total cost than the "Small Model" (the solution for the "Large Model" cost $43.58 (21)).

Smith calculated his three progressively more complex models to enable him to study the interaction between "habit and preference" and cost in the purchase of food. Obviously, he found that as the model was made to conform more and more to convention and palatability requirements, costs increased. Smith also studied the effects of varying the diet with minimum cost substitutions, varying the diet by making seasonal adjustments, and calculating the marginal cost of nutrients. But note that in all of his solutions, his foods appeared in bulk, leaving it to the ingenuity of the cook to combine and prepare them for actual meals.

In 1967, Joseph L. Balintfy of Tulane University used electronic computers to store food nutrient and cost information in the form of recipes.

B. Computerized Dietary Information System: Balintfy

Balintfy's study was not in a linear programming framework since he was not solving a least cost diet problem. However, he did utilize some of the ideas which had been presented in Smith's work and extended them to include the planning of actual menus.

Balintfy's job was to design a computerized dietary information system for the use of a group of hospitals in planning their meals (2). A recipe was entered into the computer's storage where it could be easily retrieved by calling on a subprogram. The information stored along with the recipe was quite detailed: nutrient content of each ingredient, the number of servings the recipe would make and the size of one serving, the projected cost of the recipe, etc. Balintfy worked out a system of "frequency ratings," one assigned to each recipe, that insured that a recipe could not be served with more than a certain number of meals during a specified length of time. The menu items were also coded according to the meal(s) at which the recipe could be served, the dominant color of the recipe, its flavor, texture, and temperature. The data in the computer provided menu planning information; the task of assigning the recipes to specific meals was left up to the dieticians and nutritionists who were to use the system. They would have to call on the computer to provide them with lists, say, of all hot breakfast dishes and all cold breakfast juices with the highest frequency ratings (these would be the most popular foods) and then decide what to serve and when.

Balintfy's work was similar to Smith's in a number of ways. Balintfy was concerned with providing sufficient nutritional information so that nutritionally adequate meals could be served. He provided for variety in the menus by the use of his frequency ratings (the number of foods in Smith's "Large Model" insured some measure of variety). He also catered to conventionality by assigning the highest frequency ratings to those foods which scored best in a survey taken of patients at the participating hospitals. But there were two important differences between the two studies. In the first place, Balintfy worked with recipes and not with bulk foods. In the second place, Balintfy did not utilize all of the information available to him in extending his problem to include using linear programming in formulating a least cost diet. In the institutional setting of his study, minimizing costs would not necessarily be of primary importance. What would be important, no doubt, would be to provide nutritious menus with variety, and this Balintfy accomplished by the use of his nutritional data and his frequency ratings.

C. The USDA Food Plans

At this point, the work of the United States Department of Agriculture in formulating food plans, that have been calculated and periodically revised, over the last forty years for different income groups should be mentioned. Basically, the plans were intended to be guides for economical food purchasing by families at different levels of income. The plans were typically designed at three levels which would cover the food expenditures of a majority of the population: the liberal plan, the moderate-cost plan, and the low-cost plan. However, the USDA also developed a "thrifty" food plan (previously called the "economy" plan) which would be relevant for those families with poverty-level incomes. The "thrifty" plan would have the most in common with a least cost diet since it was intended to be the most inexpensive of all of the plans, and as such has been used as a guideline in granting Food Stamp coupon allotments since January, 1976.

The "thrifty" plan was developed for several reasons (15): (1) the Recommended Dietary Allowances set by the National Academy of Sciences, National Research Council (which were used in the calculation of all USDA food plans) had been changed over the years for certain key nutrients, (2) the nutritive value of some foods had changed over the years, (3) the USDA's survey of foods consumed by both sexes at all age groups became available, (4) shifts in food prices had occurred, and (5) computerized techniques became available to aid in the development of food plans.

Instead of using linear programming, the development of the USDA diet was accomplished through the use of quadratic programming. The "thrifty" plans for each age-sex category were made to conform as closely as possible to actual food consumption patterns as determined by the USDA's 1965-1966 survey (17). The foods which were included in the list considered for the "thrifty" plan were those foods purchased by households spending from $5.00 to $6.99 per person per week, as determined by the USDA study. Constraints on the solution were nutritional requirements and a maximum allowable total cost for each plan. The resulting diets consisted of specified (by weight or by volume) amounts of seventeen different food groups. The "thrifty" plan "included larger proportions of the foods that were economical sources of nutrients than the other plans" (17).

As can be seen, this method of determining low cost diets had some similarities to Smith's procedure and some differences. The results of the "thrifty" plan were reported as bulk amounts and the USDA did not express their diet in terms of individual food items. The "thrifty" plan was made to conform to a measure of conventionality as was Smith's diet. However, the "thrifty" plan was not a least cost diet in the true sense of the word, since the problem as formulated was not one of minimizing costs but rather of staying within a cost limit. The objective function of the USDA quadratic program was to select that diet which represented as little change as possible from the 1965-1966 food consumption patterns, subject to nutritional constraints, a cost constraint, and limits on the quantities of each of the seventeen food groups that could enter the solution.

Some foods which did not appear in Smith's "Large Model" would no doubt appear feasible in the USDA's "thrifty" plan.

D. Objectives

The objective of this paper is to develop a model by which minimum cost diets that satisfy certain nutritional requirements and a degree of variety can be computed by using recipes instead of bulk food items. In a sense, this thesis will extend the type of work done by Balintfy to include the formulation of least cost diets. The studies done by Smith and the United States Department of Agriculture in their use of nutritional, variety, and conventionality conditions will be extended to include recipes.

E. Procedure

First will be expressed the problem of calculating a least cost diet as a Lagrangean function to minimize food expenditures subject to nutritional, utility, and nonnegativity constraints (utility here meaning a certain degree of conventionality). By using the Kuhn-Tucker conditions, this formulation will represent the nonlinear programming model of the problem. The dual to this nonlinear program will be examined next to arrive at "shadow" prices for nutritional elements.

Putting the model to an empirical use will involve the development of (1) conventionality criterion to determine which foods to include in the programming inputs and which recipes (or combinations of foods) to include, (2) the appropriate nutritional and price information, and (3) linear programming computer runs to calculate least cost diets and shadow prices. If initial runs provide what could be considered adequate variety to the diet, no further variety constraints will be necessary. Otherwise, additional variety conditions will be imposed to avoid monotony in the diet.

A further subject that will be examined is how adding an appropriate cost to each recipe or food item according to the energy used in food preparation might affect the solution.

II. ECONOMIC MODEL

A. Assumptions and Definitions

The first chapter contained such terms as "recipe" and "nutritional requirements." This chapter defines exactly how these terms will be used in the remainder of this paper and examines the relevant assumptions that will underly the rest of this work.

One basic assumption is that households (by which is meant any discrete unit that decides upon and carries out a food expenditure plan, whether that unit consists of one individual or a family of six) desire to minimize the cost of the foods they buy. Obviously, this assumption relates more to those households which would qualify for the USDA's "thrifty" or "low-cost" plans than to those in the "moderate-cost" or "liberal" plans. It is further assumed that in the group with which this thesis is concerned, lower-cost food items, such as hamburger, would be consistently chosen over higher-priced food items, such as steak. It is significant to note in this connection that the USDA determined that a majority of the United States' households would fall into the "low-cost" or "thrifty" categories (17). Based on the food consumption patterns of United States consumers as presented in the <u>1965-1966 Household Food Consumption</u> survey conducted by the USDA, forty-nine percent of all households fell into the "low-cost" or "thrifty" categories (spending less than $8.99 on food per person per week), while only forty-two percent of all households fell into the "moderate-cost" or "liberal" categories (spending between $9.00 and $15.00 on food per person per week). Those households spending more than \$15.00 on food per person per week were excluded from the survey (17).

Another assumption is that households base their food expenditure plans on both a "utility" consideration and on a "nutritional" consideration. As Becker (4) points out, people do not buy food for the utility of the individual food items purchased, but rather for the utility which they expect to enjoy from the meals which will be prepared using those foods. Individual foods themselves are an input into the meal-production process, as are required preparation time and the cost of using the necessary cooking equipment, such as a stove or a microwave oven. Therefore, the utility derived from the purchase of food will be assumed to consist of two parts: the use of standard, and supposedly popular, menu items, and some degree of variety in the menu. It is further assumed that the purchase of foods is also guided by whether or not the foods, considered as a group, provide basic nutritional requirements. Although Suvannunt (22) found that food prices can be linked primarily to just a few of all of the nutrients present in the foods, no weights will be placed on the nutrients in the theoretical model.

Further assumptions are that all nutrients have an equal weighting in the consumer's preference function, that the consumer chooses foods according to the combination of all nutrients that those foods have to offer, and that the consumer is a price taker (this rules out discounts given because of bulk purchases).

Definitions for the most important terms which will be used are:

1. "Food" (or "food item")--Any material of plant or animal origin consisting of essential body nutrients that may be used as an input into the meal production process.
2. "Recipe"--A formula for preparing a mixture of foods to be considered as the separate elements making up a menu. In a linear programming sense, a recipe is an activity. As it will be used in this study, a recipe may consist of either a number of foods in combination or one food which may be served without the addition of any other foods.
3. "Variety"--The introduction of different recipes into the menu plans over a specified period of time.
4. "Nutritional requirements"--Recommended dietary allowances of the essential body nutrients, such as iron, calcium, protein, etc., usually expressed on a weight-per-day basis.

B. Lagrangean Analysis

Since it is assumed that households wish to minimize the cost of their food expenditures and that the purpose in buying food is to utilize it in a form which may be served at a meal (in other words, into a recipe), the objective function may be expressed as:

$$\text{Minimize } G(g_1, g_2, \ldots, g_n) \tag{2.B.1}$$

where

$g_k = P_k Q_k \qquad k = 1, \ldots, n$

P_k = the cost of one serving of the k^{th} recipe, and

Q_k = the number of servings of the k^{th} recipe over a specified length of time.

The constraints on the problem, as indicated previously, are a "utility," or "variety," constraint, nutritional constraints, and nonnegativity constraints. The variety constraint may be written as:

$$Q_k \leq \overline{F}_k \qquad k = 1, \ldots, n \qquad (2.B.2)$$

where

$\overline{F}_k$ = the maximum allowed number of servings of the k^{th} recipe over a specified length of time.

The nutritional constraints will have the form:

$$\sum_{k=1}^{n} Q_k X_{jk} \geq \overline{X}_j \qquad j = 1, \ldots, m \qquad (2.B.3)$$

where

X_{jk} = the amount of the j^{th} nutrient per serving of the k^{th} recipe, and

$\overline{X}_j$ = the recommended dietary allowance for the j^{th} nutrient over a specified length of time.

And the nonnegativity constraints are:

$$Q_k \geq 0. \qquad k = 1, \ldots, n \qquad (2.B.4)$$

Transforming the inequality constraints into equality constraints by adding nonnegative slack variables gives:

$$\overline{F}_k - Q_k = s_k \qquad k = 1, \ldots, n \qquad (2.B.5)$$

and

$$\overline{X}_j - \sum_{k=1}^{n} Q_k X_{jk} = - s_j, \qquad j = 1, \ldots, m$$

so the problem may be written as:

$$\text{Min } G(g_1, \ldots, g_n) \tag{2.B.6}$$

subject to

$$Q_k + s_k = \overline{F}_k \qquad k = 1, \ldots, n$$

$$\sum_{k=1}^{n} Q_k X_{jk} - s_j = \overline{X}_j, \qquad j = 1, \ldots, m$$

all $Q_k \geq 0$, and

all s_k, all $s_j \geq 0$.

The nonnegativity requirements on the k + j slack variables insure that the inequality constraints of the original formulations will be met. Therefore, the Lagrangean function becomes:

$$J = G(g_1, \ldots, g_n) + \sum_{k=1}^{n} \lambda_k(\overline{F}_k - Q_k - s_k) + \sum_{j=1}^{m} \theta_j(\overline{X}_j - \sum_{k=1}^{n} Q_k X_{jk} + s_j). \tag{2.B.7}$$

The first order necessary conditions would be satisfied at the point where the first order partial derivatives with respect to Q, s, λ, and θ vanish. These first order conditions are:

$$\frac{\partial J}{\partial Q_1} = G_1 - \lambda_1 - (\theta_1 X_{11} + \ldots + \theta_m X_{m1}) \geq 0 \tag{2.B.8}$$

.
.
.

$$\frac{\partial J}{\partial Q_n} = G_n - \lambda_n - (\theta_1 X_{1n} + \ldots + \theta_m X_{mn}) \geq 0 \tag{2.B.9}$$

$$\frac{\partial J}{\partial Q_k} Q_k = 0 \qquad k = 1, \ldots, n \tag{2.B.10}$$

$$Q_k \geq 0 \qquad k = 1, \ldots, n \tag{2.B.11}$$

$$\frac{\partial J}{\partial \lambda_k} = \overline{F}_k - Q_k - s_k = 0 \qquad k = 1, \ldots, n \tag{2.B.12}$$

$$\frac{\partial J}{\partial \theta_j} = \overline{X}_j - \sum_{k=1}^{n} Q_k X_{jk} + s_j = 0 \qquad j = 1, \ldots, m \qquad (2.B.13)$$

$$\frac{\partial J}{\partial s_k} = - \lambda_k \leq 0 \qquad k = 1, \ldots, n \qquad (2.B.14)$$

$$\frac{\partial J}{\partial s_j} = \theta_j \leq 0 \qquad j = 1, \ldots, m \qquad (2.B.15)$$

$$\frac{\partial J}{\partial s_k} s_k = - \lambda_k s_k = 0 \qquad k = 1, \ldots, n \qquad (2.B.16)$$

$$\frac{\partial J}{\partial s_j} s_j = \theta_j s_j = 0 \qquad j = 1, \ldots, m \qquad (2.B.17)$$

$$s_k, s_j \geq 0 \qquad k = 1, \ldots, n \quad j = 1, \ldots, m \qquad (2.B.18)$$

evaluated at Q^*, s^*, λ^*, and θ^*, where the asterisk denotes the optimal solution. If the slack variables are eliminated by substituting in the transformed constraints, the result is a new set of first order conditions, the first four of which are identical to (2.B.8) through (2.B.11). Taking the place of (2.B.12) through (2.B.18) are:

$$\frac{\partial J}{\partial \lambda_k} = \overline{F}_k - Q_k \geq 0 \qquad k = 1, \ldots, n \qquad (2.B.19)$$

$$\frac{\partial J}{\partial \lambda_k} \lambda_k = 0 \qquad k = 1, \ldots, n \qquad (2.B.20)$$

$$\lambda_k \geq 0 \qquad k = 1, \ldots, n \qquad (2.B.21)$$

$$\frac{\partial J}{\partial \theta_j} = \overline{X}_j - \sum_{k=1}^{n} Q_k X_{jk} \leq 0 \qquad j = 1, \ldots, m \qquad (2.B.22)$$

$$\frac{\partial J}{\partial \theta_j} \theta_j = 0 \qquad j = 1, \ldots, m \qquad (2.B.23)$$

$$\theta_j \geq 0 \qquad j = 1, \ldots, m \qquad (2.B.24)$$

which are the Kuhn-Tucker conditions. Following Intriligator (10), these conditions are necessary and sufficient for a local minimum if the objective function is strictly convex and the constraint functions are concave. As stated by Lapan (13), however, quasi-convexity is generally satisfactory.

To be quasi-convex, the Lagrangean, which may now be written as:

$$J' = G(g_1, \ldots, g_n) + \sum_{k=1}^{n} \lambda_k(\bar{F}_k - Q_k) + \sum_{j=1}^{m} \theta_j(\bar{X}_j - \sum_{k=1}^{n} Q_k X_{jk}), \tag{2.B.25}$$

must be positive semi-definite. The successive bordered principal minors of the bordered Hessian must all have the same sign; that is, all of the principal minors must have the sign (9) of $(-1)^{n+m}$. For this problem, the bordered Hessian is:

$$\begin{vmatrix}
G_{11} & G_{12} & \cdots & G_{1n} & -1 & 0 & \cdots & 0 & -X_{11} & -X_{12} & \cdots & -X_{1m} \\
G_{21} & G_{22} & & G_{2n} & 0 & -1 & \cdots & 0 & -X_{21} & -X_{22} & \cdots & -X_{2m} \\
\vdots & & & & & & & & & & & \\
G_{n1} & G_{n2} & \cdots & G_{nn} & 0 & 0 & \cdots & -1 & -X_{n1} & -X_{n2} & \cdots & -X_{nm} \\
-1 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\
0 & -1 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\
\vdots & & & & & & & & & & & \\
0 & 0 & \cdots & -1 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\
-X_{11} & -X_{21} & \cdots & -X_{n1} & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\
-X_{12} & -X_{22} & \cdots & -X_{n2} & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0
\end{vmatrix} \tag{2.B.26}$$

$$\begin{vmatrix} \cdot \\ \cdot \\ \cdot \\ -X_{1m} & -X_{2m} & \ldots -X_{nm} & 0 & 0 \ldots 0 & 0 & 0 & \ldots & 0 \end{vmatrix}$$

C. Linear Programming Format

The linear programming layout of this problem is no different from what was derived using the Kuhn-Tucker conditions and Lagrangean analysis; the only alteration is in the form the equations take. Instead of one function encompassing both the objective function and the constraints, the objective function and the constraints are expressed separately. The problem discussed above is, in linear programming terminology, the primal, or original, problem. In general, following Ladd (12), the form of a linear programming minimization problem is:

$$\text{Minimize} \sum_{j=1}^{m} b_j y_j = G \qquad (2.C.1)$$

subject to

$$d_{11}y_1 + d_{12}y_2 + \ldots + d_{1m}y_m \geq d_{10}$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

$$d_{n1}y_1 + d_{n2}y_2 + \ldots + d_{nm}y_m \geq d_{n0}$$

$$y_j \geq 0. \qquad j = 1, \ldots, m$$

For this least cost diet model, the primal formulation is:

$$\text{Minimize} \sum_{k=1}^{n} P_k Q_k = C \qquad (2.C.2)$$

subject to

$$Q_k \leq \overline{F}_k \qquad k = 1, \ldots, n$$

$$\sum_{k=1}^{n} Q_k X_{jk} \geq \overline{X}_j \qquad j = 1, \ldots, m$$

and

$$Q_k \geq 0. \qquad k = 1, \ldots, n$$

Obviously, the objective function is still minimizing the food expenditure subject to utility ("variety") constraints, nutritional constraints, and nonnegativity constraints (of the choice variables, the Q_k's).

As pointed out by Chiang (7), for every minimization problem (in this case, of minimizing C), there is a related maximization problem (to maximize some new variable, C*), such that $\overline{C}^* = \overline{C}$. In other words, the optimal values of the objective functions in the primal and in the related maximization problem, called the dual, are always identical. Again following Ladd (12), the general form of the dual maximization problem is:

$$\text{Maximize} \quad \sum_{j=1}^{n} d_{j0} x_j = Z \qquad (2.C.3)$$

subject to

$$d_{11}x_1 + d_{21}x_2 + \ldots + d_{n1}x_n \leq b_1$$

.
.
.

$$d_{1m}x_1 + d_{2m}x_2 + \ldots + d_{nm}x_m \leq b_m$$

$$y_j \geq 0. \qquad j = 1, \ldots, m$$

To convert the minimization primal to its dual, follow the rules given by Chiang (7): (1) change "minimize" to "maximize"; (2) reverse the inequality signs of the primal constraints for the dual constraints (the nonnegativity restrictions are not changed, however); (3) the coefficient matrix for the dual constraints is the transpose of the coefficient matrix of the primal constraints; and (4) the column vector of constants in the dual constraints is the row vector of coefficients in the primal objective function. The first step in formulating the dual is to multiply the first constraint ($Q_k \leq \overline{F}_k$) by negative one, and so reverse the inequality sign (to $-Q_k \geq -\overline{F}_k$). This is not absolutely necessary, but does facilitate computing the dual constraints. So, the objective function of the dual becomes:

$$\text{Maximize} \quad \sum_{k=1}^{n} \overline{F}_k w_k + \sum_{j=1}^{m} \overline{X}_j u_j = C^*. \tag{2.C.4}$$

The transpose of the coefficient matrix of the primal constraints is:

$$\begin{vmatrix} -1 & 0 & 0 & \ldots & 0 & X_{11} & X_{21} & X_{31} & \ldots & X_{m1} \\ 0 & -1 & 0 & \ldots & 0 & X_{12} & X_{22} & X_{32} & \ldots & X_{m2} \\ \cdot & & & & & & & & & \\ \cdot & & & & & & & & & \\ \cdot & & & & & & & & & \\ 0 & 0 & 0 & \ldots & -1 & X_{1n} & X_{2n} & X_{3n} & \ldots & X_{mn} \end{vmatrix} \tag{2.C.5}$$

and is of dimensions [n X (n + m)]. Post multiplying this by the column vector of:

$$\begin{vmatrix} w_1 \\ \cdot \\ \cdot \\ \cdot \\ w_n \\ u_1 \\ \cdot \\ \cdot \\ \cdot \\ u_m \end{vmatrix} \tag{2.C.6}$$

which is of dimensions [(n + m) X 1], gives the (n X 1) column vector of constraints:

$$\sum_{j=1}^{m} X_{jk}u_j - w_k \leq P_k. \qquad k = 1, \ldots, n \qquad (2.C.7)$$

The u_j may be defined as the imputed (or "shadow") price of the j^{th} nutrient and w_k may be defined as the imputed price of variety. Symbolically, they are:

$$u_j = \frac{\Delta C_{min}}{\Delta \bar{X}_j} \qquad j = 1, \ldots, m$$

and $$(2.C.8)$$

$$w_k = \frac{\Delta C_{min}}{\Delta \bar{F}_k}$$

Therefore, each constraint contains a slack variable that may be interpreted as representing the change in the objective function that would result from either increasing a nutritional requirement by one unit or by increasing a variety constraint by one unit. In the optimal solution, the values of the u_j's and the w_k's should all be negative, or zero, indicating that any increase in either the nutritional constraints or the variety constraints can only lead to a decrease in the value of the objective function.

III. THE PROGRAMMING DATA

To apply the theoretical model, the first step was to secure the necessary data for the linear program. The data for this problem were in four basic areas: nutritional considerations, the "recipes," or food bundles, to be used, the prices for these recipes, and the energy necessary to prepare the different recipes and its associated cost. A fifth consideration was how to put this data into appropriate form for the linear program to be solved by a computer. Each of these five areas will be covered individually, with an explanation of what sources of information were used and why these were chosen.

A. Nutritional Considerations

The first question that might be asked is what a nutritional requirement is. According to the National Academy of Sciences, daily nutritional requirements, or "recommended dietary allowances," are "the levels of intake of essential nutrients considered, in the judgment of the Food and Nutrition Board on the basis of available scientific knowledge, to be adequate to meet the known nutritional needs of practically all healthy persons" (18). The NAS points out that since knowledge about the vitamin and mineral needs of healthy people are still incomplete, a varied and palatable diet is the best way to insure that one is receiving not only the adequate amounts of recognized nutritional elements, but also adequate amounts of nutritional elements that are still either being investigated or are as yet unknown (hence, the emphasis in this thesis on palatability and variety).

For the purposes of this thesis, the household (as defined in Chapter II) will consist of two adult parents, between twenty-three and fifty years of age, and two children, one boy and one girl, each between the ages of eleven to fourteen years old. The nutritional requirements for these four people, following those used by Smith (20), for one week is as follows (18):

Food energy	65,800.00 cal.
Protein	1,540.00 gr.
Calcium	29,400.00 mg.
Iron	448.00 mg.
Vitamin A	136,500.00 I.U.
Thiamine	33.60 mg.
Riboflavin	41.30 mg.
Niacin	441.00 mg.
Ascorbic acid	1,400.00 mg.

It may be noted that this list of nine nutritional elements corresponds to that used by Smith, but with three exceptions which Smith included that are not included here: fats, carbohydrates, and phosphorous. Except for phosphorous, no recommended allowances are given by the NAS for these elements. Phosphorous was not included because, quoting from the NAS book on the recommended dietary allowances,

> Phosphorous is present in nearly all foods, and dietary deficiency is not known to occur in man. Intake of this mineral in ordinary diets is almost always, if not invariably, higher than that of calcium, and is thought to be entirely adequate (18).

Because calcium had been included in the list of dietary requirements, it was redundant to include phosphorous, also. The NAS list of recommended dietary allowances does not include carbohydrates because they can be manufactured by the body, and does not include fats because they are present in many foods as the carriers of fat soluble vitamins, such as vitamins A, D, E, and K (18).

The National Academy of Sciences is not the only organization to have prepared a guide to adequate nutritional requirements--the United States Department of Agriculture also has nutritional guidelines. Most studies, this thesis included, have used the NAS dietary recommendations in preference to those of the USDA for two main reasons. The first reason is that the USDA requirements are not broken down into as many age/sex categories as are the NAS requirements and, accordingly, are not as precise. The second reason is that the USDA requirements were formulated primarily to be used by food processors and packagers in specifying the nutritional contents of their foods (one example of this kind of usage is where a food package states that that particular item contains 4% of the USDA Recommended Daily Allowance of some nutrient); the USDA requirements are nearly five percent higher on all nutritional elements than are the NAS requirements. The purpose of these overall generally higher recommendations is not the maintenance of a "higher" level of health than the NAS requirements provide (the NAS requirements are, as stated earlier, adequate for the maintenance of good health in nearly all people; there is even some doubt that a general overfulfillment of certain nutrients is beneficial and, in some cases, is known to be harmful (18)), but rather as a safeguard that if the consumer utilizes food labels as an indication of whether or not the household's nutritional needs are being met, the chances are good that the needs will probably be fulfilled if not overfulfilled. Remember, in this connection, that it was said above that a varied diet is the best guarantee of receiving sufficient amounts of all nutrients. It is interesting to note that the nutritional requirements for various age/sex categories that are listed in the back of USDA Handbook #8 and USDA Bulletin #72 (27) (see below) are the NAS dietary recommendations and not those of the USDA; also, studies by the USDA in formulating food plans for households at various income levels utilized the NAS dietary allowances.

Although all of the daily recommended dietary allowances of the various nutrients are expressed in bulk figures, it should be kept in mind that traditionally the requirements for certain nutrients are basically satisfied at one of the three main meals. For example, the requirement for ascorbic acid is generally satisfied at breakfast, with the intake of, say, a glass of orange juice or half a grapefruit, and/or at supper, with the intake of almost any vegetable. In the same manner, the allowance for vitamin A is usually satisfied at supper, where one would be most likely to eat such vitamin A-laden foods as beef liver or carrots. Also, although no distinction is made between the quality of the nutrients found in any one food, it should be remembered that gradations in quality do exist and may even be important nutritionally. For instance, there are several kinds of proteins, or amino acids, some of which the body cannot manufacture and so must be ingested with food that is eaten. But the requirements for protein are not broken down into the various amino acids; USDA Handbook #8 and USDA Bulletin #72 do not specify the makeup of the protein content in the different foods that precisely, either. Therefore, it is once again emphasized that variety in a diet is the best insurance of that diet being nutritionally satisfying.

Now that the recommended nutritional dietary allowances have been obtained for a hypothetical household, the next issue is the sources of the nutritional content of recipes that were included in the possible diet. As noted before in the definition of "recipe," a recipe can consist of either an individual food or a collection of foods. Therefore, it was necessary to secure the nutritional content for all foods present in the recipes. The sources for the amounts of nutrients present in the various foods were USDA Handbook #8, Composition of Foods, Raw, Processed, and Prepared (27), and USDA Bulletin #72 (23), which is an abbreviated and slightly different form of Handbook #8. Handbook #8 has two major sections: One gives the nutritional content of foods per one hundred grams and the other gives the nutritional content of foods per one pound. Bulletin #72 states its nutritional contents in terms of the quantity of the food that is either generally purchased or commonly used; for example, the nutritional composition is given for one apple and for one 10 1/2 ounce can of condensed cream of chicken soup.

No nutritional information was given by either of these sources for most spices (with the exception of iodized salt) or condiments (with the exception of tomato catsup). Accordingly, spices and condiments were assumed to have no nutritional value (with the exception of the two items previously noted) and were not included in any nutritional calculations.

B. Sources of Recipes ("Food Bundles")

Although the actual recipes that were included in the program were selected arbitrarily, several sources were used as indicators of the foods (of which the recipes should be constructed) that would be relevant to the study. Basically, eligible recipes would have to be (a) made up of "common" food items, (b) consisting of generally low-to-medium-priced food items, and (c) palatable in the sense of being familiar combinations and appearing frequently in either cookbooks or guides to low-cost cookery.

The first source consulted as a guide to those foods which should be considered was the study by Victor Smith on the electronic computation of human diets (20). Although this thesis works with food bundles, or recipes, and not with the bulk food items which Smith worked with, the individual food items which appeared in his solutions were good indications of those ingredients the recipes should consist of. Some of his individual food items were even conducive to being served alone and still satisfied the three conditions listed above. Smith's "Midget Model" solution was made up, as stated earlier, of milk, oleomargarine, carrots, potatoes, picnic ham, and white enriched flour. This list of foods immediately suggested such recipes as boiled potatoes, boiled carrots, mashed potatoes, baked ham, and creamed vegetables.

The next solution formulated by Smith, his "Small Model," consisted of essentially the same food items, with several additions. These additions were fresh oranges, extra large eggs, Wheaties cereal, and white or powdered sugar. From this solution came the idea to include fresh fruits, eggs in various preparations and alone, and a breakfast cereal. Smith also included different cooking aids in his solution, such as yeast, vinegar, and meat sauces. But since this thesis considered recipes, and not individual food items, if any cooking aids would be needed for any one recipe, they would be added directly to that recipe and not separately. Also, some of Smith's cooking aids which he required to be present in his solution due to his complementarity restrictions were not useful to this study; Smith did not include in his study any indication of how his food items would be used and so he needed to allow for more uses--hence, more cooking aids were required to stretch the food item's possible variations.

Smith's final solution, his "Large Model," had a greatly expanded list of foods. This formulation suggested the adding of cheeses, more kinds of vegetables such as cabbage, celery, lettuce, onions, and tomatoes, meats other than picnic ham such as hamburger, liver, chuck roast, bacon, pork chops, and sausage, chicken, more cereals such as oatmeal, prepared bread, and such pastes as spaghetti and macaroni, to the set of possible recipe ingredients.

The USDA "Thrifty Food Plan" diets were a second source for foods that should be considered for inclusion in the diet formulation. Once again, all foods were expressed in bulk amounts, not in terms of how they could be combined with other foods in recipes. One of the USDA's "Thrifty Food Plan" formats (17) contained dry beans, canned beans, citrus juice, canned snapbeans, canned green peas, vegetable soup, rice, and crackers. Another USDA publication, Your Money's Worth in Foods (16), suggested that beets, lima beans, lentils, and canned pork and beans might be appropriate foods. One additional USDA booklet, Family Fare: A Guide to Good

Nutrition (24), concerned itself with suggesting recipes that would not only be tasty but also thrifty for the nutrition and cost-conscious household. Out of the recommended recipes, condensed cream of mushroom soup, bouillion cubes, and fish fillets were useful in designing this household's diet.

Since palatability was a goal which any diet formulation should take into consideration, a method to check on how, generally speaking, palatable this collection of possible recipe ingredients would be to an average household needed to be devised. One measure of palatability would be how widely consumed these different food items are. The USDA's Report #11, Household Food Consumption Survey 1965-66 (25), studied the actual food intake patterns of individuals in the household. With this as a guide, the list of eligible recipe ingredients could be checked to see if these foods were frequently purchased by households and might therefore be considered palatable. In general, the list of foods for this thesis and the list of foods most often ingested by members of a household matched fairly well. This was a rather crude measure of palatability, since it would be difficult to assign a required percentage of households buying a particular food to say that that food is palatable, but the real goal of this exercise was to find the foods in the list bought by only a very small percentage of households--say, under ten percent of all households. About the only food in the list that was not widely purchased was beef liver. Beef liver was included in the diet anyway, however, because it was such a good source of proteins, vitamin A, riboflavin, and niacin. Items that were commonly purchased by the households in the USDA study but that had not yet been considered for inclusion in the list of eligible foods were catsup, chili sauce, green peppers, jelly, tuna, frankfurters, and salad dressing of the mayonnaise variety.

After compiling a group of food items that could logically be expected to be lower in cost than those that might be consumed by high income households and that seemed to be generally considered to be palatable, the next step was to put these foods together into recipes. Many of these foods could be prepared by themselves without any further additions, either by baking, frying, or boiling; these foods were basically the meats, poultry, vegetables, prepared flour products, fruits (both fresh and as juice), dairy products, and canned soups (those that are water-based). But others, such as flour and oleomargarine, needed to be mixed with other foods to be prepared for consumption. Plus, a diet of nothing but, for instance, fried foods would be boring; the hypothetical diet could be improved by allowing for the preparation of even those foods that could stand by themselves into further combinations with other foods.

Keeping all of this in mind, plus utilizing general knowledge of which foods seem to be economical, a standard cookbook was selected as the final source for the recipes used in the diet formulation. The cookbook selected was the Better Homes and Gardens Cookbook (5). Any of several other sources would have been just as valid, such as the Betty Crocker Cookbook or The Joy of Cooking. But all cookbooks seem to have their own biases (one might have a long list of ingredients for a recipe while another cookbook might have a much shorter list for a recipe of the same name), so all recipes were consistently drawn (ingredients, cooking times, etc.) from one source.

Going through the Better Homes and Gardens Cookbook, recipes were chosen that basically consisted of the foods already in the list. Most recipes were of "familiar" combinations, such as meatloaf, chili, pancakes, etc. Some of the recipes did not have familiar names, but were made up essentially entirely of foods in the list, for instance, "lentil-vegetable soup." The final list of recipes consisted of sixty-six recipes (keeping in mind that one recipe could be for raw, fresh oranges, for example). It included twelve meat dishes in which the meat was prepared individually, fifteen dishes in which a meat or seafood or poultry was prepared in combination with other foods, one dish consisting of cheese and a paste, seven vegetable-based soups, four variations on fruits (either as juice or fresh), eleven variations on vegetables (in juice, raw, boiled, creamed, etc.), milk, two dishes mainly egg-based, and thirteen dishes that would traditionally be considered as breakfast foods (such as oatmeal, cold cereal, pancakes, French toast, etc.).

For a complete list of the recipes and the pages in the Better Homes and Gardens Cookbook on which they were found, see Appendix A, Table A1.

C. Sources of Prices

Securing the appropriate costs for the various recipes was an involved but very vital part of the input-gathering process. The most difficult aspect of assigning a cost to each recipe was in dividing the costs of the various ingredients of that recipe into the correct amounts called for by that recipe. Obviously, two tablespoons of flour may be used in a recipe, but two tablespoons of flour could not be purchased in a grocery store--flour would be purchased in units of five or ten pound bags, probably. But this is really a question that should be discussed in the section on data manipulation. This section presents sources of price data for the quantities of the food items as they would typically be found in a grocery store.

Victor Smith used the survey method to ascertain the prices of his food items. His work was carried out at Michigan State University at Lansing; his survey for food prices was conducted in conjunction with a university "consumer panel" study participated in by families in the Lansing area (21). The purpose of the "consumer panel" was to determine what foods households actually purchased. Along with this, the 176 families participating in the study were asked to also note what price they had paid for each item they had bought. The prices that Smith finally used in his problem formulation were the average prices paid by the households for each item during May, 1955. For each week in May, Smith divided the total amount of money spent on each item by the total quantity of that item purchased to arrive at a weekly weighted average price. The average for the entire month of May was computed by calculating the unweighted average of the weekly prices. If an item was believed to be unavailable during any particular week, it was given a price of $10.00 per unit.

The United States Department of Agriculture food plans also called for quite detailed price information for the designing of their "thrifty," low-cost, moderate-cost, and liberal plans. For these prices, they relied on the prices given by the USDA's Household Food Consumption Survey 1965-66 as bases from which to compute more recent prices. The 1965-66 survey listed the average prices actually paid by households for almost 2,000 different items. Since the survey was nation-wide, these average prices reflected differences in package sizes, brands, quality, and general price levels between regions. To update this price information to 1974 levels (the year in which the most recent food plans were devised), the USDA used Bureau of Labor Statistics price data. The Bureau of Labor Statistics collects price information monthly on ninety-three carefully defined foods from representative grocery stores in selected cities across the country. A percentage change was calculated on these ninety-three items between those prices in the 1965-66 survey and the desired BLS figures. Then, to obtain the current prices for those foods not included in the BLS statistics, the same change that occurred to closely related foods was applied to the 1965-66 figures. For instance, if it was calculated that hamburger had increased in price 50% between 1965-66 and 1974, then the 50% change in price would also be used in calculating the current prices of low-cost cuts of meat included in the 1965-66 study but not in current BLS figures (17).

This thesis used a combination of BLS prices and survey prices. The ninety-three BLS price figures covered most of the foods needed. The remaining prices were determined by a survey of Ames, Iowa, grocery stores. The closest city to Ames for which individual BLS price information is published is Kansas City, Missouri; however, the United States Department of Labor office in Kansas City supplied a set of BLS prices for the ninety-three surveyed items for Cedar Rapids, Iowa (26). The prices were averages for the month of April, 1976.

The next problem was to fill in the prices for remaining ingredients by the use of a survey of Ames grocery stores. After eliminating "convenience" type stores that also handle grocery items (such as Quick Trip or Casey's General Store) and discount grocery wholesalers (such as Warehouse Market or the Carriage House meat outlet), Ames had seven retail grocery stores. Out of these seven stores, however, there were two Hy Vee's and two Ames Fruit and Grocery's, so only five different companies were represented. Three stores were surveyed to gather the input prices. All seven stores were entered on separate slips of paper and three slips were randomly selected. The stores thus chosen came from various parts of the city and represented three different companies: West Side Ames Fruit and Grocery, Fareway, and Hy Vee on Duff.

A list of the ingredients for which no prices had yet been secured was made up and then the three stores were surveyed every day for one week in September, 1976. The average price per week for each ingredient for each store was calculated; then at the end of the week the average weekly prices were again averaged between stores to arrive at one price per ingredient. The prices used in the program out of this survey method represented many different brands and container sizes. However, if different container sizes were involved, that food's cost was broken down into cents per ounce to arrive at a price based on identical quantities. For example, one brand of spaghetti noodles came in eight ounce packages and another brand came in ten ounce packages. So the ten ounce package's cost was broken down into cents per ounce and then multiplied by eight. Also, if there was a choice between a larger, more economical size container of some food and a smaller, more expensive-per-unit container of that same food, the amount called for by the recipe guided the choice as to which one to survey. For instance, it was more economical in terms of cost per ounce to buy a sixteen ounce can of green beans rather than an eight ounce can. But the recipe which called for green beans required eight ounces, so, since leftovers were not allowed for, the eight ounce can was chosen to base the cost of canned green beans on.

How the price information was made to conform to the amounts of the ingredients called for by the recipes and how the September survey prices were adjusted to correspond to the BLS prices from April will be discussed in the section of this chapter on data manipulation. A complete list of the prices used for each ingredient in the recipes and the container size and brands on which these prices were based can be found in Appendix A, Table A2.

D. Sources for Energy Costs

It would seem that adding the costs of the energy needed to prepare the recipes to the cost of the ingredients of those recipes would be an irrelevant exercise; after all, the public is constantly told on the TV and radio what a bargain electricity is. This may very well be true, however, the energy consumed by the average 30" electric range with a self-cleaning oven makes it the fourth largest appliance user of electricity in the average household--right after water heaters, refrigerators, and clothes dryers (3). And when the length of time that some of the recipes had to be baked or simmered was considered, the energy cost of preparing a presumedly low-cost dish might make it too expensive to enter into a least cost solution.

In 1973, some forty-six percent of all United States households owned an electric range (1). For the purposes of this study, a "typical" electric range for the hypothetical household needed to be decided on so that its wattage specifications could be used in calculating the costs of preparing the recipes. The medium priced electric range sold by the largest retailing company in the world, Sears and Roebuck, was the one chosen. This 30" range, model number 92061, had the following specifications:

	Watts/hour		Watts/hour
Left front burner	1250	Right front burner	2100
Left rear burner	1250	Right rear burner	1250
Oven (max. setting)	2700	Oven (broil)	3400

Each burner had nine settings and the oven had fifteen settings (plus "broil"). According to the appliances salesman consulted at Home Furnishings and Appliances in Ames, wattage specifications are given for the highest setting and decrease proportionately for all lower settings. Three basic burner settings, "high," "medium," and "low," were used for one of the 1250 watts-per-hour burners as the standard. The wattage used per hour for these three settings were 1250 on high, 833.3 on medium, and 416.8 on low.

Next was needed the cost of electricity as it is usually expressed: in terms of kilowatt hours (one kilowatt hour is one thousand watts of electricity used over the period of one hour). The city of Ames is one of the relatively few places that sells its own electricity--no one large region-wide utility company has the Ames electricity franchise. Therefore, the rate structure for Ames is unique in respect to the rate structure of companies supplying most of the area around Ames. So to obtain a rate structure for electricity more in keeping with the charges most people in this region would pay, the figures were secured from one of the major utility companies. The Iowa Electric Light and Power Company had an office in Ames, so their electricity rates were used. Their daily rates for electricity in the summer were (11):

First	0.658 KWH or less per day	$0.0477
Next	1.315 KWH/day	6.15 ¢/KWH
Next	1.972 KWN/day	4.80 ¢/KWH
Next	7.562 KWH/day	4.05 ¢/KWH
Next	8.219 KWH/day	3.65 ¢/KWH
Next	46.027 KWH/day	2.97 ¢/KWH
Over	65.753 KWH/day	2.09 ¢/KWH

More relevant, perhaps, would be the monthly rate for electrical use. The first twenty kilowatt hours would cost the consumer $1.45. From then on, the costs would be (11):

Next	40 KWH used per month @	6.15 ¢/KWH
Next	60 KWH used per month @	4.80 ¢/KWH
Next	230 KWH used per month @	4.05 ¢/KWH
Next	250 KWH used per month @	3.65 ¢/KWH
Next	1400 KWH used per month @	2.97 ¢/KWH
Over	2000 KWH used per month @	2.09 ¢/KWH

Combining the wattage specifications for running the "typical" stove for one hour and the monthly rate schedule, the following energy costs were calculated:

Setting	Time	Cost @ $0.05/KWH
Burner on low	1 hour	$ .02
Burner on medium	1 hour	.04
Burner on high	1 hour	.06
Oven (475 setting)	1 hour	.11
Oven (broil)	1 hour	.16

Next, this information needed to be combined with cooking times for all the recipes to arrive at the cost of the energy used in preparing each recipe. It had previously been decided to use the energy costs in two computer runs: One run would minimize only energy costs subject to the nutritional, variety, and nonnegativity constraints. The other run would minimize energy costs and ingredient costs added together subject to the same set of constraints. Therefore, for the first run, an energy cost of ten dollars was assigned to all recipes that required no cooking (such as fresh oranges, milk, tomato juice, etc.) to avoid their being free goods. In the second run, all cooking-free recipes were priced at the cost of their ingredients only. All other recipes were assigned energy costs on the basis of their cooking times; most recipes' cooking times had already been found in the Better Homes and Gardens Cookbook (as stated above). However, some recipes, such as canned green beans, canned bean soup, boiled potatoes, boiled cabbage, etc., were not explicitly discussed in this cookbook source. For these foods, the cooking times were based on the figures found in the USDA's Family Fare: A Guide to Good Nutrition (24). This publication gave the timetables for roasting meats, cooking fish, and boiling fresh vegetables. A list of all recipes, their cooking times, and their associated energy costs can be found in Appendix A, Table A4.

E. Data Manipulation

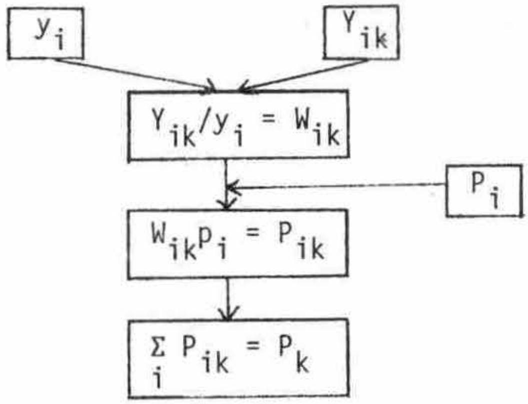
It was necessary to adjust the September prices of the surveyed foods to correspond to the April prices of the BLS statistics for Cedar Rapids. To do this, the "Seasonally Adjusted Food at Home" index number of consumer prices published in Economic Indicators (8) was consulted. The most recent index number available at the time was for August, 1976. To extrapolate the change of the consumer price index to September, the average change between the months of April to August was calculated and then added to the index number for August. Then the index number for April was divided by the extrapolated figure for September and multiplied to each of the September survey prices. The calculations were as follows:

Month	Index	Change
April	177.7	
May	179.5	+1.8
June	179.8	+0.3
July	179.8	0.0
August	180.3	+0.5

Average change = +0.65
Extrapolated price index for September = 180.95

$$\frac{\text{April}}{\text{September}} = \frac{177.70}{180.95} = 0.98 \text{ Adjustment factor}$$

Calculating the prices for each ingredient involved breaking down the prices for the foods as they were found in the grocery store into the prices for the quantities of those foods as they were used in the recipes. A flow chart type diagram (Figure 1) might help to explain how this was accomplished.



Where

y_i = the amount of ingredient i in each container or package as found in a grocery store

p_i = the price paid for the quantity y_i of ingredient i

Y_{ik} = the amount of ingredient i called for by recipe k = $W_{ik}y_i$

P_{ik} = the cost of Y_{ik} = $W_{ik}p_i$

W_{ik} = a conversion factor to convert the quantity of ingredient i as found in a grocery store to the quantity of ingredient i called for by recipe k

Figure 1. Calculating procedure for ingredient costs.

For example, recipe number twenty-four, hamburgers, consisted of the one ingredient, ground beef. The price of one pound of ground beef at the grocery store was 80¢. In this case, one pound of ground beef provided four servings, or hamburger patties. Therefore, y_i (1 lb.) = Y_{ik} (1 lb.), and p_i (80¢) = P_{ik} (80¢). Actually, the conversion factor would be 1 = W_{ik}. For most cases, a conversion ratio other than one would have to be used to calculate the P_{ik}. Recipe number thirty-two, scrambled eggs, was an example of this. The recipe, for four people (the hypothetical household), called for six eggs. Of course, eggs are typically purchased in cartons of one dozen. The price for one dozen eggs was found to be 72¢. The calculations to arrive at P_{ik} were:

$$W_{ik} = 1/2$$

$$(W_{ik})(y_i) = 1/2 \text{ X } 12 = 6 = Y_{ik}$$

$$(W_{ik})(p_i) = 1/2 \text{ X } 72¢ = 36¢ = P_{ik}.$$

The other ingredients for scrambled eggs--milk, salt, and margarine--had a total cost (P_{ik}'s) of 5¢. Therefore, P_k = 5¢ + 36¢ = 41¢.

Conversion factors could become very difficult, though, whenever it was necessary to change, say, a weight measure in pounds, ounces, or grams, into some other measure. For a simple example, recipe number nine, macaroni and cheese, called for two tablespoons of margarine. Margarine is usually bought in the grocery store in one pound packages. The labeling on the package of margarine states that one pound of margarine is equal to two cups. Two cups is equal to thirty-two tablespoons, so:

$$W_{ik} = 1/16$$

$$(W_{ik})(y_i) = 1/16 \text{ X } 32 = 2 = Y_{ik}$$

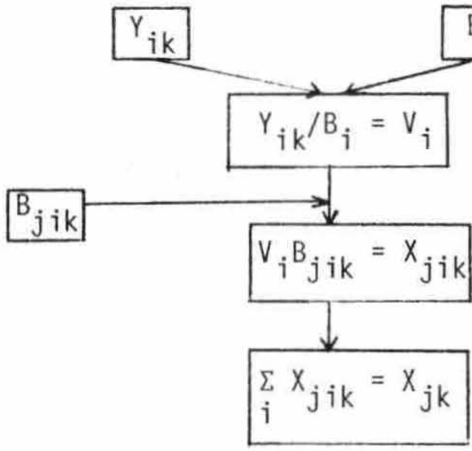
$$(W_{ik})(p_i) = 1/16 \text{ X } 40¢ = 2.5¢ = P_{ik}.$$

Many of the conversion factors were found in either the "Special Helps" section of the Better Homes and Gardens Cookbook (5), the "List of Common Conversions" section of The Joy of Cooking (19), or the "Servings and Pounds" section of the USDA's Family Fare: A Guide to Good Nutrition (24). In other cases, for instance in the margarine example given above, conversion information was given on the food's container. A list of the activities and their associated P_k's can be found in Appendix A, Table A5.

The next issue was to figure the nutritional contribution of each recipe ingredient to the total nutritional value of that recipe. This was where the USDA Bulletin #72 was of special help. USDA Handbook #8 gave the nutritional composition of a food per one pound of that food. This was useful for only a limited number of foods; the meats, poultry, fish, and pastes usually were required in terms of pounds or ounces by the recipes, but that was the extent of the cookbook measurements given by weight. The rest of the measurements were by volume, such as cups, tablespoons, or teaspoons, or by number, such as four slices of bread, one egg, one onion, etc. In most cases, Bulletin #72 provided the appropriate nutritional information for these volume or number type measurements. Once again, a flow chart type diagram might be helpful to illustrate the calculation of the nutritional contributions (Figure 2).

For example, recipe number eleven, meatballs, required one-half pound of ground beef. Handbook #8 gave the nutritional elements for one pound of ground beef, so V_i in this case would be equal to 1/2. The amount of protein in one pound of ground beef was 81.2 grams. The amount of protein in one-half pound of ground beef would then be $(V_i)(B_{jik}) = 1/2 \times 81.2 =$ 40.6 grams. A list of the nutritional composition of the sixty-six activities can be found in Appendix A, Table A6.

After the X_{jk}'s and P_k's were computed, the linear programming format could be set up. The rows of the linear program were the nutritional constraints, or $\overline{X}_j$'s (see page 23), plus the cost minimization function, or



where

B_i = the unit of measurement for ingredient i from either Handbook #8 or Bulletin #72

X_{jik} = the mount of the j^{th} nutrient in the amount of the i^{th} ingredient called for by the k^{th} recipe = V_iB_{jik}

B_{jik} = the amount of the j^{th} nutrient in the i^{th} ingredient of the k^{th} recipe as given by either Handbook #8 or Bulletin #72

V_i = a conversion factor to convert the quantity of ingredient i in recipe k as given by either Handbook #8 or Bulletin #72 to the quantity of ingredient i in recipe k as called for by that recipe

Figure 2. Calculating procedure for ingredient nutritional values.

objective function. The columns in the program were the recipes, or the sixty-six activities. The only bounds in the program were the variety constraints, or upper limits on how many times any one activity could enter into the optimal solution. These variety constraints changed among the different computer runs and will be discussed in the next chapter.

IV. APPLICATION OF THE MODEL

Now that the inputs for the linear program had been collected, the next decision that had to be made was how many different forms of the basic problem to solve. It had already been decided that the differentiation between the runs would initially lay in changing the variety constraints. In this respect, the aim of the different runs would be a varied diet with all negative reduced costs at a minimal level (if an activity that had entered into the solution was allowed to enter at a higher level, the resulting decrease in the cost of the diet would be very, very small).

To begin the process, the first diet formulation was somewhat analagous to Smith's "Midget Model." The problem formulation did not include any variety constraints whatsoever. Obviously, this first run resulted in a very inexpensive diet, but also one with hardly any variety. For the next run, all activities (or recipes) had an upper bound of two; in other words, no activity could enter into the solution more than twice. This restriction added a great deal of variety to the diet, but at a cost more than twice that of the first run. Also, many of those activities which had entered into this second solution had relatively large negative reduced costs, indicating that considerable cost savings could be realized if the upper bounds on these activities were raised. For the third run, the variety constraints (upper bounds) were changed only for those activities which had high negative reduced costs in the second solution. This formulation lowered the level of variety in the diet (if variety would be measured simply by the number of activities in the solution), but also significantly lowered the cost of the diet. In this third solution, all negative reduced costs were very small, pointing to very little if any more cost savings to be realized if the variety constraints were further altered.

For the next three computer runs, the variety constraints were left the same as they had been for the third problem formulation. The fourth run was a cost minimization problem of a slightly different emphasis: Instead of minimizing the cost of the recipes, this run minimized the cost of the energy necessary to prepare the recipes. The purpose of this run was to determine if any particular cooking method might be, in general, the most economical. Naturally, this formulation was also subject to the nutritional and nonnegativity constraints which had been present in all previous runs. The fifth problem formulation attempted to minimize the food costs of the activities plus the energy costs. In essence, this run consisted of simply adding together the food costs as represented in the third run with the appropriate energy costs from the fourth run and then minimizing the combined costs. The purpose of this run was to see whether or not an energy-expensive but low-food-cost (and vice versa) activity might still enter into the final solution. In other words, would the energy cost of preparing a dish that must be simmered/baked/boiled for a long time be significant enough to delete it from the solution, even if its food cost was relatively low?

The sixth, and final, computer run was a range analysis of the third previous solution. Subject to several qualifications that will be discussed later, the purpose of this run was to study the stability of the solution (how sensitive the solution would be to changes in prices) and what initial changes in the solution would occur if a price changed for any of the sixty-six activities.

Each of these six computer runs (which will be designated as runs A through F) will be covered separately. For each of the first five runs, the cost of the solution, to what extent the nutritional constraints were fulfilled or overfulfilled, the activities and ingredients making up the diet, and the dual variable coefficients will be discussed. A summary of the results of the first five runs, A through E, can be found in Appendix B, Table B1. For the final run, the results of the range analysis as they relate to the stability of the solution, which foods would change first in the event of a price increase or decrease, and the problems of interpreting the analysis for this particular model will be studied.

A. Results from the Problem Formulation A

The first solution, it may be remembered, was for an unbounded model--any of the activities could enter into the solution at any level. The minimum value of the objective function for this first run was $18.97 (to feed four people for one week). This was greatly higher than the $28.33 (1955 prices) necessary to feed three people for four weeks in Smith's "Midget Model." Of course, not only were Smith's prices those of the pre-high-inflationary 1960's and early 1970's, but also buying in bulk separate food items would be less expensive than pricing the small quantities of ingredients called for in recipes.

Of the nine nutritional constraints, five were fulfilled exactly at their lower bound and the other four were overfulfilled by various percentages. It was not surprising that calcium or iron would be among the

Table 1. Summary of the status of the nutritional value of Diet A

Nutrient	Quantity in the diet	Lower limit	Slack activity
Food energy	65,800.00	65,800.00	0.00
Protein	1,925,77	1,540.00	385.77
Calcium	29,400.00	29,400.00	0.00
Iron	448.00	448.00	0.00
Vitamin A	345,611.80	136,500.00	209,111.80
Thiamine	40.82	33.60	7.22
Riboflavin	66.89	41.30	25.59
Niacin	441.00	441.00	0.00
Ascorbic acid	1,400.00	1,400.00	0.00

"scarce" elements of this diet, but it was a bit surprising that protein (which is frequently referred to as being one of the most common of deficiencies) was abundant and food energy, or calories, was scarce. The protein constraint was overfulfilled by 125%. For the other three abundant nutritional elements, vitamin A was overfulfilled by 253%, thiamine by 121%, and riboflavin by 162%.

A total of five activities entered this first solution. Macaroni and cheese would be served 7.48 times, orange juice would be served only 1.07

times, pancakes would have a serving frequency of 2.61 times, beef liver would be served barely once (.99), and most of the time toast and margarine would be eaten. This last activity entered the solution at the 68.26 level. If a one-pound loaf of bread cut into eighteen slices is used as a base, this translates into 30.34 loaves of bread and 4.74 pounds of margarine. Each member of the hypothetical family of four would have to eat nineteen and one-half slices of bread per day, or just slightly over one loaf each. Once a day they could have a serving of macaroni and cheese; weekends would be very special because Saturday morning the family could have pancakes and orange juice, Sunday morning the family could have pancakes again and just a drop of orange juice, and Sunday noon they could really celebrate by sharing just less than one pound of liver among them.

If the division of foods into food groups as shown in the "A Daily Food Guide" section of <u>Family Fare: A Guide to Good Nutrition</u> (24) is followed, it can be seen just what special contributions each of these activities made toward satisfying the nine nutritional constraints. The meat food group (which included only the beef liver and the eggs from the pancakes, in this case) provided seventy percent of the vitamin A in the diet and over one-fourth of the riboflavin. The vegetable/fruit group (consisting of the orange juice and the onion from the macaroni and cheese) contained insignificant amounts of all of the nutrients except for ascorbic acid. Ninety percent of the diet's ascorbic acid was provided by this food group. The milk food group (made up of the milk from the pancakes and the milk and American cheese from the macaroni and cheese) accounted for fifty-six percent of the diet's calcium and over one-fourth of the protein and riboflavin. Not surprisingly, the bread/cereal food group (which contained the flour from the pancakes, the elbow macaroni from the macaroni and cheese, and the ubiquitous toast) provided sixty-three percent of the food energy, sixty-one percent of the protein, forty percent of the calcium, eighty-one percent of the iron, eighty-nine percent of the thiamine, forty-four percent of the riboflavin, and eighty-one percent of the niacin. Those foods which were covered under the "other foods" heading (salt, margarine, sugar, salad oil, and sirup) mostly contributed to food energy (twenty-seven percent) and vitamin A (twenty percent). Naturally, the bread/cereal group accounted for sixty-three percent of the cost of the diet, with the milk group second at eighteen percent of the total cost and the "others" group third at eleven percent.

The dual variable coefficients would appear only for those rows (or nutritional constraints) in which the "greater-than" requirement was effective, or, to put it another way, for the limiting processes. Accordingly, the dual activities for this solution were:

Row	Dual variable
Food energy	$.00009
Calcium	.00018
Iron	.01531
Niacin	.00205
Ascorbic acid	.00021

These figures may be interpreted as the shadow prices associated with a one-unit increase in the respective nutritional requirement. In other words, a one-calorie increase in the food energy requirement would cost less than one cent.

B. Results from the Problem Formulation B

The second solution, Diet B, was for a model which had an upper bound of two on all activities; no one activity could enter into the solution at a level exceeding two. The value of the objective function of this diet was 2.3 times greater than that for Diet A ($44.06 compared with the previous $18.97). The high negative reduced costs indicated on this run for several of the activities which had entered into the solution showed that many cost savings could be realized on this particular formulation; these high negative reduced costs were taken into account on the next run, Diet C.

The number of nutritional constraints which were exactly fulfilled dropped on this run from five to two: Protein was again an abundant nutrient while calcium and food energy remained scarce. And although

Table 2. Summary of the status of the nutritional value of Diet B

Nutrient	Quantity in the diet	Lower limit	Slack activity
Food energy	65,800.00	65,800.00	0.00
Protein	2,486.48	1,540.00	946.48
Calcium	29,400.00	29,400.00	0.00
Iron	500.75	448.00	52.75
Vitamin A	212,008.42	136,500.00	75,508.42
Thiamine	44.52	33.60	10.92
Riboflavin	53.56	41.30	12.26
Niacin	486.38	441.00	45.38
Ascorbic acid	4,300.83	1,400.00	2,900.83

niacin and ascorbic acid and iron had been scarce previously, the new variety constraints on the second solution had the effect of turning them into abundant nutrients. One additional change that held for two of the previously abundant nutrients was that their nutritional requirements were not as generously overfulfilled in the second solution as they had been in the first, with the exceptions of protein and thiamine. Protein was overfulfilled by 161% (compared to 125% in Diet A) and thiamine was over-fulfilled by 132% (compared to 121% in Diet A). The other abundant nutrients and the percentages by which they were overfulfilled were: iron--112%; vitamin A--155%; riboflavin--13-%; niacin--110%; and ascorbic acid--307%.

The number of activities in Run B more than quadrupled from Run A; Diet B consisted of thirty-six activities. If the recipes are examined, it would be found that those recipes which entered the solution leaned heavily to those which could be traditionally considered as breakfast dishes and to the vegetable based dishes. Actually, only eight of the recipes contained any meat--meatballs, tuna noodle casserole, hash, lazy day lasagne, tuna rice casserole, salmon loaf, lentil-vegetable soup, and split pea soup--and three of those contained fish. Macaroni and cheese again appeared in the solution. Five recipes were for soups--chicken noodle, lentil-vegetable, minestrone, split pea, and canned bean soup. Orange juice also repeated, along with fresh oranges--no doubt due to their excellent stores of ascorbic acid. Those foods which might be thought of as typical breakfast dishes and that entered the solution were scrambled eggs and fried eggs, pancakes, toast, waffles, popovers and popovers with grape jelly, blueberry muffins and blueberry muffins with margarine, cold cereal, oatmeal with brown sugar, cream of wheat and cream of wheat with sugar, and French toast. The vegetables that appeared in the solution were boiled potatoes and mashed potatoes, creamed onions, cabbage, carrots, canned peas, and canned green beans. The only drink to appear rather than orange juice was milk. Of all of the activities in the solution, only two entered below the upper bound of two: split pea soup (which entered at the .87 level) and tuna rice casserole (which entered at the 1.82 level). All of the other thirty-four activities entered at the level of two, or at their upper limit.

Once again, the solution diet should be considered in terms of the ingredients which made up the activities, or, in other words, how the various food groups were represented in the diet. The meat food group, which included eggs, fish, and pork besides the usual beef, accounted for thirty-six percent of the protein, twenty-four percent of the iron, twenty-two percent of the riboflavin, and forty-four percent of the niacin. The vegetable/fruit food group was the food group with the most individual members present. It supplied thirty-two percent of the iron, fifty percent of the vitamin A, thirty-eight percent of the thiamine, twenty-three percent of the niacin, and virtually all (ninety-seven percent) of the ascorbic acid. The milk food group made its most notable contributions by supplying twenty-six percent of the protein, sixty-one percent of the calcium, and forty-two percent of the riboflavin. The bread/cereal food group lost much of the prominence it had held in Run A. This time it accounted for twenty-four percent of the calories, twenty-five precent of the iron, forty-three percent of the thiamine, twenty percent of the riboflavin, and thirty percent of the niacin. The "others" category made a sizable contribution only to calories, where it added thirty percent of the diet's food energy. The most expensive food group was the meat group, making up forty percent of the cost of the entire diet. The second most expensive was the vegetable/fruit group at twenty-four percent of the total cost. The milk group and the bread/cereal group tied for third most expensive food group, comprising thirteen percent of the $44.06.

As mentioned earlier in Run B, only food energy and calcium were limiting processes. The dual activities for this solution were:

Row	Dual variable
Food energy	\$.00013
Calcium	.00320

Note that both of these figures represented an increase over the same comparable figures for Run A. As the makeup of the diet was constrained, higher shadow prices of the two apparently most scarce nutrients resulted.

C. Results from the Problem Formulation C

For the third solution, Diet C, the upper bounds on each activity were determined by examining the reduced costs of the activities in Diet B. Those foods which had positive reduced costs were left with upper bounds of two--these were the activities which had not entered the solution at all. Also left with upper bounds of two were those activities which had entered the solution but had very small negative reduced costs. For those activities which had entered the solution and that had significant negative reduced costs, the upper limits were adjusted. The upper limits for macaroni and cheese, tuna noodle casserole, hash, lentil-vegetable soup, lazy day lasagne, salmon loaf, pancakes, waffles, popovers, cold cereal, French toast, mashed potatoes, and creamed onions were doubled from two to four. The upper limits on orange juice and toast were increased from two to seven so that they could conceivably be served daily. With the same idea in mind, the upper bound on milk was raised from two to fourteen. The result of these changes was that the activities that made up Diet C had very low negative reduced costs (the largest of which was beef liver, with a negative reduced cost of $1.33; the second largest was popovers, with a negative reduced cost of $0.18. The beef liver variety constraint had not been increased from two due to the fact that having beef liver twice a week would no doubt be more than enough for most families). The minimum value of the objective function of Diet C fell from the $44.06 of Diet B to $25.23, only $6.26 more than the first solution, which was unbounded.

The nutritional constraints that were limiting increased from the two of Run B to three. Those constraints which were exactly fulfilled were for food energy, calcium, and niacin. Once again, protein was an abundant nutrient, but not as plentiful as it had been previous (2486.48 grams in Diet B). Actually, the amount of protein in this diet was only 60.04 grams more than in the first solution. The quantity of iron in this diet fell between the amounts in Diets A and B. The requirements for vitamin A and ascorbic acid were hugely overfulfilled (440% and 640%, respectively), while the requirements for thiamine and riboflavin were

Table 3. Summary of the status of the nutritional value of Diet C

Nutrient	Quantity in the diet	Lower limit	Slack activity
Food energy	65,800.00	65,800.00	0.00
Protein	1,985.81	1,540.00	445.81
Calcium	29,400.00	29,400.00	0.00
Iron	489.61	448.00	41.61
Vitamin A	600,666.37	136,500.00	464,116.37
Thiamine	44.36	33.60	10.76
Riboflavin	86.59	41.30	45.29
Niacin	441.00	441.00	0.00
Ascorbic acid	8,917.37	1,400.00	7,517.37

generously overfulfilled (132% and 210%, respectively). Niacin fell from being a plentiful nutrient in Diet B to being a limiting nutrient in Diet C.

The number of activities in Diet C fell by more than half from the thirty-six present in Diet B to sixteen. This time, emphasis in the diet again centered on those foods which might be considered to be breakfast foods. Although fewer activities entered the solution, many of those that did enter did so at or near their raised upper bounds of four or seven. Of those activities containing meat, the ones that appeared in the diet were hamburgers, beef liver, and lentil-vegetable soup. The number of soups fell from five in Diet B to two: chicken noodle soup and lentil-vegetable soup remained. Macaroni and cheese again stayed in the diet, and again at its new upper limit of four. Orange juice entered the solution at the level of seven. Of the so-called breakfast foods, pancakes, toast, waffles, popovers, cold cereal, and French toast appeared at their new upper limits of four (with the exception of an upper limit of seven for toast). Milk was present in the solution, but only at the 4.58 level (out of an upper bound of fourteen). Popovers with grape jelly also entered the diet, but at the 1.83 level (out of an upper limit of two). Diet C was rounded out with two vegetable dishes, boiled potatoes and mashed potatoes, which both entered at their upper limits. The hypothetical family of four could have either a soup or a meat and vegetable dish every night; for breakfast and lunch they would eat breakfast-type foods. This diet would be a vast improvement over the almost continuous diet of toast in Diet A.

In terms of the distribution of the activities' ingredients into food groups, each of the five food groups in general contributed to each nutritional requirement, with some groups providing almost the entire requirements of certain nutrients. The meat group accounted for a majority of both the vitamin A (eighty-four percent of the total amount in the diet--probably due to the presence of the beef liver) and the riboflavin (fifty-one percent). The meat food group also provided thirty percent of the protein, thirty-one percent of the iron, and forty-four percent of the niacin. The vegetable/fruit food group had again cornered the supply of ascorbic acid, containing ninety-six percent of the total. The vegetable/fruit group contributed forty-three percent of the thiamine and twenty-three percent of the niacin. The milk food group provided, as would be expected, seventy-five percent of the calcium. It also contributed thirty-six percent of the protein and thirty-two percent of the riboflavin. The bread/cereal food group gave significant amounts of food energy (twenty-five percent), protein (twenty-one percent), iron (twenty-seven percent), thiamine (thirty-eight percent), and niacin (thirty-one percent) to the diet. The "others" category provided more calories (food energy) to the diet than any other group, with thirty-one percent of the total. This group also accounted for twenty-six percent of the iron. The most expensive food group in terms of a percent of the total food bill was the milk food group at twenty-six percent of the total $25.23. Second was the meat group, at twenty-two percent, and third was the vegetable/fruit group, at twenty percent.

The dual activities for the limiting processes (food energy, calcium, and niacin) were:

Row	Dual variable
Food energy	$.00025
Calcium	.00019
Niacin	.02601

This could be interpreted as meaning that it would be less expensive to increase the requirement for calcium in this diet than it would have been in Diet B. Conversely, one additional unit of food energy would be more expensive in this diet than in Diet B. The cost of requiring one more unit of niacin was considerably higher in this diet than it had been in Diet A.

D. Results from the Problem Formulation D

Since the activities of solution C had very small negative reduced costs, the diet had probably been as finely tuned as possible to fulfill the nutritional requirements yet be at a minimum cost and avoid monotony. So from solving the problem from a least "food" cost angle, the problem was next solved from a least "energy" cost angle. As discussed in the third chapter, each activity was assigned an appropriate energy cost according to the temperature and the length of time it had to be baked or boiled or fried or simmered, etc. Diet D was the result of minimizing only the total energy cost, subject to the same nutritional, variety, and nonnegativity constraints as in Diet C. The minimum value of the objective function of Run D was $1.22. This would seem like a truly insignificant amount until it is realized that at the rate of five cents per kilowatt hour, $1.22 worth of electricity means that 24,400 watts of electricity in one week was used for cooking. This same 24,400 watts of electricity, to put it into another perspective, would be enough to run a one-hundred watt light bulb 244 hours, or 10.17 days. It is interesting to note in comparison that the energy cost for Run C (allowing noncooked activities to have energy costs of zero instead of $10.00) was $1.16.

The number of limiting processes remained at three; however, these three were not the same three as in Diet C. Food energy (calories) and calcium stayed at their lower limit, but in Run D, thiamine was the third limiting process in place of niacin. Protein remained an abundant nutrient, more plentiful in this diet than in any of the three preceding ones. The requirement for protein was overfulfilled by 202%. The

Table 4. Summary of the status of the nutritional value of Diet D

Nutrient	Quantity in the diet	Lower limit	Slack activity
Food energy	65,800.00	65,800.00	0.00
Protein	3,117.88	1,540.00	1,577.88
Calcium	29,400.00	29,400.00	0.00
Iron	651.49	448.00	203.49
Vitamin A	583,567.64	136,500.00	447,067.64
Thiamine	33.60	33.60	0.00
Riboflavin	89.71	41.30	48.41
Niacin	700.31	441.00	259.31
Ascorbic acid	1,468.89	1,400.00	68.89

level of iron, too, was higher in Diet D than in Diets A, B, or C; the lower limit for iron was exceeded by 145%. The amount of vitamin A had fallen from that in Diet C, having its requirement overfulfilled by 428% in the present solution as compared to Diet C's 440%. The quantity of riboflavin in Diet D was very close to the quantity in Diet C--only 3.12 milligrams larger in Diet D (the riboflavin requirement was exceeded by 217%). The niacin level went from the lower limit in Diet C to having its requirement overfulfilled by 159% in Diet D. The amount of ascorbic acid fell immensely from the 8,917.37 milligrams in Diet C to the 1,468.89 milligrams in Diet D--a quantity only 5% higher than the required 1,400.00 milligrams. This extreme drop could easily be accounted for, however.

Most of the ascorbic acid in previous solutions had come from either orange juice or fresh oranges. Since these did not require any cooking time, and therefore had no associated energy costs, they had been given, along with all other uncooked recipes, an energy cost of $10.00 in Run D so that they would not be "free" goods. This effectively priced them out of the solution, and the requirement for ascorbic acid had to be met by recipes less endowed with it.

The number of activities which entered Diet D increased to twenty-two from the sixteen of Diet C. For the first time, the number of breakfast-type foods fell in relation to the lunch and dinner foods. Some foods, especially those that needed only short frying times, appeared for the first time. These included roundsteak and onions, fried fish, and pork sausage. The number of soups stayed at two--chicken noodle soup (at the 1.32 level out of an upper limit of two) and canned bean soup. Chili con carne appeared in the diet for the first time. The tomato sauce, canned tomatoes, onion, and green pepper in the chili made a significant contribution toward filling the ascorbic acid requirement that had previously been the domain of the orange juice. Once again, macaroni and cheese entered the solution at its upper bound of four. One noteworthy aspect of this diet is that it included three canned foods that, being precooked, would need only to be heated up on the stove. Besides the canned bean soup, these were canned green beans and canned peas. The other nonbreakfast foods that did show up in the solution were tuna noodle casserole, hash, hamburgers, salmon loaf, beef liver, and creamed onions. Those breakfast foods that did show up in the solution were scrambled eggs and fried eggs, pancakes, waffles, oatmeal with brown sugar, cream of wheat with sugar (at the .099 level out of an upper limit of two), and French toast. Other than those foods already so mentioned, the only other food that entered the solution at a level less than its upper bound was tuna noodle casserole. Macaroni and cheese had the highest negative reduced cost at five cents.

As the ingredients of these activities broken down into their associated food groups are examined, it is seen that the meat group had gained in nutritional importance, especially at the expense of the vegetable/fruit group. The meat group provided thirty-eight percent of the calories, sixty-three percent of the protein, twenty-three percent of the calcium, forty-eight percent of the iron, eighty-nine percent of the vitamin A, thirty-nine percent of the thiamine, sixty-four percent of the riboflavin, and seventy-six percent of the niacin. The vegetable/fruit group contributed significantly only to the ascorbic acid requirement, accounting for seventy-seven percent of the total (down from ninety-six percent in Run C). Again the milk group gave the diet a majority of its calcium (fifty-six percent). This group also provided twenty-two percent of all riboflavin. The bread/cereal food group accounted for thirty-eight percent of the thiamine. The "others" food category was mainly important for two nutrients: twenty-nine percent of the calories and twenty-one percent of the iron. How the five food groups contributed to the overall cost of the diet would be meaningless since energy costs were only assigned to entire activities and could not be further divided down to individual ingredients. But, in general, those dishes that were basically meat-based (chili con carne, roundsteak and onions, tuna noodle casserole, hash, hamburgers, fried fish, salmon loaf, pork sausage, and beef liver) accounted for forty-seven percent of the total energy cost of the diet. The soups took two percent of the total energy cost. The breakfast dishes (see the list above) represented eighteen percent of the total, and the rest of the foods (macaroni and cheese, canned peas, canned green beans, and creamed onions) accounted for the final thirty-three percent of the total cost.

The dual activities for the limiting processes were:

Row	Dual variable
Food energy	$.00001
Calcium	.00005
Thiamine	.00110

E. Results from the Problem Formulation E

The next question investigated was how a solution for a minimum total cost diet (the energy cost plus the ingredient cost) would differ from the diets computed before. In most cases, the total cost of an activity was arrived at by simply adding together the food cost as used in Runs A, B, and C and the appropriate energy cost from Run D. For those foods that had been given energy costs of $10.00 in Run D, the total cost was the ingredient cost alone. The minimum value of the objective function of Run E was $26.28, only $1.05 greater than the cost of Run C. The composition of Diet E was considerably different from that of Diet C, however. If the energy costs alone were to be computed for Diet E (using the energy cost figures of Run D), the total would be $227.47, due to several of the activities which had been assigned energy costs of $10.00 entering at or near their upper limits. The "total" cost of Run C (using the energy cost figures of Run E) would have been $26.39. The energy cost of Run E was $1.05, which represented a cost savings of approximately ten percent over the energy cost of Run C.

The limiting factors of Run E represented a return to Run C; those nutrients whose requirements were exactly fulfilled were food energy, calcium, and niacin (instead of thiamine, as in Run D). Protein stayed

Table 5. Summary of the status of the nutritional value of Diet E

Nutrient	Quantity in the diet	Lower limit	Slack activity
Food energy	65,800.00	65,800.00	0.00
Protein	1,965.98	1,540.00	425.98
Calcium	29,400.00	29,400.00	0.00
Iron	482.73	448.00	34.73
Vitamin A	599,537.02	136,500.00	463,037.02
Thiamine	44.08	33.60	10.48
Riboflavin	86.66	41.30	45.36
Niacin	441.00	441.00	0.00
Ascorbic acid	8,899.30	1,400.00	7,499.30

abundant, but was not as plentiful in this diet as it had been in Diet D (protein was overfulfilled by 128% in Diet E as compared to 202% in Diet D). The amount of iron in the diet was down from that in Diet D, too, from being overfulfilled by 145% to 108%. The quantity of vitamin A in this diet fell between the quantities in Diet C and Diet D; the vitamin A requirement was surpassed by 439% in Diet E as compared to 440% and 428% in Diets C and D, respectively. The requirement for riboflavin was slightly less abundantly overfulfilled in this diet (210%) than it had been in Diet D (217%). Ascorbic acid was considerably more plentiful in this run (8,899.30 milligrams) than it was in Run D (1,468.89 milligrams) due to the noncooked, ascorbic acid-rich activity, orange juice, appearing in the solution again. Thiamine went from being a limiting process in Diet D to being overfulfilled by 131% in Diet E. This, also, was partly due to orange juice returning to the solution.

In this solution, the number of activities which entered the diet was seventeen, only one more than Diet C but five less than Diet D. Most of the activities in this solution were not for breakfast-type recipes; still, many more of the breakfast-type dishes were present in Diet E than in Diet D. Once again, macaroni and cheese entered at its upper limit of four. Spaghetti appeared for the first time at the .094 level out of a possible upper bound of two. Two soups remained in the diet--chicken noodle soup (at its upper bound of two) and lentil-vegetable soup (at the .775 level out of an upper bound of four). The only other dinner or lunch-type dishes were hamburgers (at its upper limit of two), beef liver (at its upper limit of two), boiled potatoes (at its upper limit of two), and mashed potatoes (at its upper limit of four). Orange juice reappeared in the diet, again at its upper bound of seven. Another drink, milk, also appeared in the diet at the 4.641 level out of an upper bound of fourteen. The breakfast-type activities in the solution were pancakes, toast, waffles, popovers, popovers with grape jelly, cold cereal, and French toast, all of which entered the diet at their upper limits. The highest negative reduced cost for this solution was $1.15 for beef liver (see the discussion of beef liver's reduced cost on page 54). The second highest negative reduced cost was twenty-eight cents for pancakes.

In this computer run, the meat food group had lost much of the prominence it had held in Run D. This group still provided the bulk of the vitamin A in the diet (eighty-three percent of the total), however, due to the beef liver. The meat group also accounted for twenty-eight percent of the protein, thirty-two percent of the iron, forty-nine percent of the riboflavin, and forty-four percent of the niacin. The vegetable/fruit food group continued to provide most of the diet's ascorbic acid (ninety-six percent of the total), but also gave the diet forty-two percent of all of its thiamine and twenty-two percent of all of its niacin. The milk food group contributed significant amounts of several nutrients: protein (forty-one percent), calcium (seventy-eight percent), and riboflavin (thirty-five percent). The bread/cereal food group provided twenty-five percent of the diet's food energy (or calories), twenty percent of its protein, twenty-seven percent of its iron, thirty-nine percent of its thiamine, and thirty-two percent of its niacin. The "others" food category was important for two nutrients; this group accounted for thirty-one percent of the food energy and twenty-six percent of the iron. The lunch and/or dinner-type dishes (spaghetti, macaroni and cheese, chicken noodle soup, lentil-vegetable soup, hamburgers, beef liver, boiled potatoes, and mashed potatoes) took up thirty-one percent of the total cost of the diet. But the most expensive group of activities was the breakfast-type recipes (see the list on page 64), which accounted for fifty-one percent of the total $26.28. The remaining eighteen percent of the food expenditure went for the two beverages, milk and orange juice.

The dual activities for the limiting processes were:

Row	Dual variable
Food energy	$.00033
Calcium	.00015
Niacin	.02242

F. Results of the Range Analysis, Run F

The range analysis that was run was a straightforward analysis of the solution to Diet C. As stated before, this solution represented the possibly best diet that not only conformed to the various constraints at least cost, but also had a measure of variety (only "food" costs are being considered here, not "energy" costs or "total" costs in the sense of food costs plus energy costs). Because the range analysis was conducted on the activities of this model, one big problem presents itself to any interpretation of the range analysis' results. A range analysis basically studies the stability of a solution in relation to how the prices of the activities can change without altering the initial solution (14). Studying how the prices of the diet's activities could change without altering the solution is not strictly a true picture of how changes in prices would affect this model, for the price of any one activity (with a couple of exceptions) could not change without several other activities changing, also. The "price" of an activity is actually the summation of all of the individual prices of the ingredients in that recipe. A price change would occur for an activity if the price changed for any one or more of the ingredients in that activity. But, for most cases, several different recipes share numerous ingredients; therefore, a price change for, say, flour, would change not only the price of the activity "pancakes," but also the activities "waffles," "popovers," "creamed onions," etc. This kind of inter-relationship between activities was not taken into account in the range analysis; so, this limitation should be kept in mind when examining the results of the range analysis.

The first question, therefore, is how stable the solution for diet C is. Quite simply, this solution is extremely sensitive to changes in price. For many activities, a slight decrease in cost might have been enough to alter the solution. For example, fried chicken, at an input cost of $1.47, did not enter the diet. But if the price of fried chicken had dropped to $1.44, the solution for Diet C would have been different. Also, hamburgers, at an input cost of 80¢, had entered the solution at its upper limit of two. But if the cost of hamburger were to rise to 81¢, the quantity of hamburger in the diet would have decreased. For those activities which had not appeared in the solution, obviously, the price could increase to an "infinite" amount without altering the solution. And for those foods which had entered the solution, generally, the price could have fallen to zero without altering the solution. But in many instances, it would not have taken either much of a decrease in the former's cost or an increase in the latter's cost to change the makeup of the diet.

For all of the activities, a range was indicated within which the price of each activity could vary without specific changes in that activity's level occurring. If that range was exceeded on either the high or the low side, the range analysis indicated which activities would change initially and how these activities would change (whether they would leave the diet, come in at their upper limit, and so on). For instance, the reduced unit cost of macaroni and cheese was 16¢. The input cost of macaroni and cheese was 52¢. The price of macaroni and cheese could vary anywhere from 36¢ to 68¢ and the activity, macaroni and cheese, would enter the solution anywhere from the 4.50 level to the zero level, respectively. But if the price of macaroni and cheese were to drop more than 16¢, popovers with grape jelly would enter the solution at its upper limit. Conversely, if the price of macaroni and cheese were to increase to more than 68¢, it would drop out of the solution entirely and milk would enter at its upper limit.

Those activities which seemed to be the "marginal" activities (i.e., those recipes which would be the first to change due to a price change of another activity either above or below its upper or lower cost limits) were relatively few: lentil-vegetable soup, popovers with grape jelly, milk, spaghetti, hamburgers, and beef liver. In Diet C, it may be remembered, the first three of these had entered the solution at a level below their upper bounds. Spaghetti had not appeared in the solution at all. And the last two were already in the solution and at their upper bounds.

For many of the activities, a price drop of nearly fifty percent would have had to have occurred for these recipes to have become eligible for inclusion in the solution diet. For example, the input cost of chili con carne would have had to have dropped from \$2.19 to \$1.29 before it would have been economical to include. And Swiss steak would have had to have dropped from \$2.40 to \$1.21 before it might have entered the solution. But for most of the activities, a price change of about 10¢ to 20¢ either way would have been enough to have perhaps placed these activities into the running for inclusion in the diet.

All of the results from the range analysis have been couched in fairly vague, general terms. This is because the limitations of this kind of analysis as applied to this kind of problem, as stated earlier, make only the general, and not the specific, findings important. Then, in general, the important findings of this range analysis were (1) that the solution to this formulation was especially price sensitive and therefore (2) the particular solution for Diet C was not very stable. Also, (3) those activities which seemed to be the first to change upon the change of any other activity's price were usually those whose actual input prices and the indicated upper and/or lower costs were put pennies apart.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

In all cases, food energy and calcium were limiting nutrients. It might be expected that calcium would be a scarce nutrient, for its requirement is usually satisfied by the intake of milk and cheeses, which are relatively high priced food stuffs. But the fact that food energy, or calories, is scarce, also, comes as a bit of a surprise. The American consumer is constantly subjected to TV and radio campaigns whose message is that Americans eat too much, that what is needed are cutting down on calories and increasing the consumption of either low calorie substitutes or vitamin preparations. Although it is indeed widely accepted that overeating seems to be a major health hazard in the United States, this study indicates that the problem of ingesting too many calories is an issue of wealth, and not of satisfying the other nutritional requirements. For, since calories were scarce, they had an associated shadow price other than zero. If what is sought is a diet to use as a guideline for "thrifty" food expenditures, such high-priced foods as sirup and other fats and oils should be considered for inclusion in the diet simply due to the calories they contain. The problem of ingesting too many calories arises when a diet is not varied, i.e., the individual's menus are heavily oriented to the breads and cereals and/or the milk and milk products, for example. If, however, the distribution of foods is such that each food group contributes significantly to one or more of the nutritional requirements, the problem shifts from that of consuming enough vitamin A, ascorbic acid, or riboflavin, for instance, to one of consuming enough calories. And as the amount of money spent on food is decreased, the cost of adding one more calorie to the diet increases. A "poor person's" food expenditure plan should emphasize such calorie-laden foods as mentioned above; it should not be taken for granted that any individual's food energy requirements is always being met. In a least cost, varied diet, this is especially important.

This thesis also sheds doubt on the conclusions of a common TV commercial. This ad claims that for women to ingest the recommended dietary allowance for iron, they "would probably have to overeat, and that's not good." The solution for this dilemma, they claim, is to take one Femiron tablet per day to insure that the iron requirement is being met. For all problem formulations except the first, the requirement for iron was overfulfilled, in one case by as much as 145%. And this was in those diets with degrees of variety, not in the diet which consisted primarily of toast! Plus, the problem of "overeating" (by which is assumed to be meant ingesting more than the daily recommended allowance of calories) was not present in these diets for, as mentioned above, in all diets food energy entered at its lower limit. So the claim of the commercial is not strictly true. Actually, it would be more accurate to advertise that eating a balanced diet (including beef liver, eggs, ground beef, and orange juice) would provide anyone with adequate amounts of iron, with few, if any, excess calories.

Perhaps the most important conclusions that can be drawn from examining the nutritional information of each diet are (1) that a varied diet is especially vital to fulfilling the nutritional requirements and (2) that each of the various food groups do indeed contribute significantly to meeting particular nutritional requirements. Both of these conclusions have been put forward before by many different studies; this study, utilizing recipes instead of bulk food items, also confirms them. In all cases except for the first, unbounded, solution, the diet contained some activities considered to be lunch dishes, some considered to be dinner dishes, and some considered to be breakfast dishes; not only did breakfast-type recipes appear, but also vegetables, meat-based recipes, fruits, and milk. The food energy requirement was fulfilled primarily, in three out of five diets, by the "other" food category, i.e., the fats, oils, sugars, etc. The protein requirement was fulfilled primarily, in four out of the five diets, by either the meat food group or by the milk food group. In the two diets perhaps the closest to real-life constraints, Diets C and E, the protein requirement was mainly filled by milk or by milk products, leading to the conclusion that for the average consumer, the milk food group would be the most important as far as protein is concerned. In all five diets, calcium was provided primarily by the milk food group, also. This indicates that eating cheeses, ice cream, drinking milk, etc., is indeed as important as nutritionists and mothers have always claimed. The requirement for iron was usually satisfied mainly by the meat food group (in three out of the five diets). In four out of the five diets, vitamin A was provided especially by the meat food group; actually, eating one-half pound of beef liver per person per week would provide all needed vitamin A value all by itself. In two cases thiamine was filled mostly by the bread/cereal group and in two cases thiamine was filled mostly by the vegetable/fruit food group. In three out of the five diets, riboflavin was provided primarily by the meat food group. In four out of the five diets, niacin was provided primarily by the meat food group, also. And in all five diets, ascorbic acid was overwhelmingly accounted for by the vegetable/fruit food group. In the case of ascorbic acid, drinking a juice glass of orange juice each morning would provide more than enough ascorbic acid by itself. The point of all of this is that a varied diet is vital; although it might seem that one food group predominates over the others in providing nutrients, each plays an important part in assuring that all nutritional requirements are met and each should be included in any diet.

There were several individual recipe ingredients that occurred over and over and that therefore might be considered as low cost and nutritious foods to make a special point to include in a diet. Most of these ingredients were common foods: flour, salt, onion, margarine, milk, orange juice, ground beef, eggs, sugar, and bread. Other foods that appeared often that perhaps would not be so common were elbow macaroni, American cheese, salad oil, sirup, and beef liver. Usually, breakfast-type dishes are thought of as being calorie-laden foods that should not be eaten too often. This study indicated that, within the balanced framework of the other recipes in the diets, breakfast dishes should be included relatively extensively. Such recipes as pancakes, waffles, French toast, oatmeal with brown sugar, popovers, and cold cereal entered the solution again and again. These foods no doubt are important for a balanced diet due to the fact they contain ingredients from several different food groups. For example, pancakes contain eggs from the meat food group, milk from the milk food group, flour from the bread/cereal food group, and salt, sugar, salad oil, and sirup from the "others" food group. Another recipe, not of the breakfast type, included in every diet, macaroni and cheese, exhibited this same quality. Its ingredients, too, come from several different food groups: flour and elbow macaroni from the bread/cereal food group, onion from the vegetable/fruit food group, milk and American cheese from the milk food group, and salt and margarine from the "others" food group. For a low cost, nutritionally satisfying diet, therefore, it seems safe to conclude that recipes which consist of foods from various food groups should especially be emphasized as compared to those recipes made up mainly of foods from one food group, for instance, chuck roast. The only exception to this general rule would be those basically one-food activities which provide especially generous amounts of certain nutrients, for example, orange juice and ascorbic acid, beef liver and vitamin A, and milk and calcium.

Another conclusion that could be drawn from the recipes included in the diets is that different sources of nutrients should be included along with those traditionally thought of first. For instance, it is usually considered that protein should be provided by the meats. Although it is true that proteins coming from meats are of a different "quality" than those from other sources, it should be kept in mind that such foods as dried beans, lentils, flour, bread, and pastes such as elbow macaroni can and should be utilized to provide this requirement, also.

If energy conservation is particularly important to the household, foods that can be fried quickly or merely heated through should find a place in their diet. This study found that when the cost of energy alone was considered, foods such as round steak and onions and pork sausage entered the solution diet for the first time. Actually, this diet, Diet D, leaned rather heavily to the meats food group, including not only the usual eggs, beef liver, and ground beef, but also round steak, tuna, cooked beef, fish fillets, canned salmon, and pork sausage. Also, canned foods such as canned green beans and canned peas should be added to a low energy cost diet. If baked foods are desired, the ones chosen should be baked for no more than moderate lengths of time, say up to around thirty minutes, at a low to medium temperature oven. A low energy cost diet should also include breakfast dishes that require relatively little cooking time, for instance, instant oatmeal, scrambled eggs, fried eggs, and pancakes.

All of these conclusions may be summarized fairly simply. Food energy (or calories) may be scarce in a low cost diet, and therefore special care must be taken to insure this requirement being met. Calcium, too, may be scarce, so a low cost diet cannot ignore the need for such relatively high priced foods as cheeses in the menu. In a "thrifty" food expenditure plan, the requirement for iron may be easily satisfied by the periodic consumption of beef liver, oranges, and other iron rich foods without the need of a vitamin supplement for iron. No one food group can provide all nutritional requirements--at least, certainly not in a least cost formulation. Menu items should consist of recipes representing as many food groups as possible. Some food items are especially rich in certain nutrients (for example, orange juice and ascorbic acid) and should definitely be included in a diet. There are food items that are low cost and may be used in many different recipes. Although some of these may be traditionally considered too fattening if used in quantity, in the framework of a least cost diet their contributions to calories are important. Nontraditional but nutritious and low cost foods, such as lentils, should definitely be worked into a low cost diet. And if energy conservation is a primary consideration, those recipes that may be prepared quickly on the stove or baked for only short periods of time should be emphasized. But most of all, behind all of these conclusions, is the very important, basic, idea of variety. Variety in a diet would insure, better than any other single factor, that nutritional needs are being met.

B. Recommendations for Future Research

It might seem as if the diet problem has been followed about as far as it could be, yet, there are several areas that might be profitable for future research.

Although this thesis considered both the cost of the recipes' ingredients and the energy cost associated with cooking the recipes, these are not the only two costs involved in meal preparation. One cost that could be studied is the cost of preparing the ingredients for inclusion into the recipes and then combining the ingredients together, i.e., slicing the carrots, peeling potatoes, beating some ingredients together, etc. If it is agreed that a housewife's time is worth money, then it might be interesting to study the effects of minimizing preparation costs along with ingredient costs and energy costs. This would probably involve a "time and motion" study, since currently available figures for recipe preparation times are based on institutional cooking and are not, therefore, directly applicable to the household.

Another source for future study would be how seasonal price changes could affect a least cost diet solution. For example, in this study, fresh oranges appeared in almost every solution at their upper limit. If, however, the price for fresh oranges was an August price or a January price, they might possibly have entered the solution at different levels. The makeup of a least cost diet using recipes could be extensively altered to conform to seasonal buying habits, for example, recipes using fresh tomatoes could be emphasized in a least cost diet for either August or September.

A final area that would be interesting to pursue is how a least cost diet formulation utilizing recipes, as in this thesis, might be extended to actually planning menus. This could involve several factors. The first would be assigning each recipe a meal code, depending on whether that recipe is a breakfast, lunch, or supper dish. Of course, some recipes that can be served at more than one meal, for instance, chili con carne for lunch or supper or pancakes for breakfast or lunch, would be assigned multiple meal codes. Then perhaps it could be required that the computer program design one week's menu, consisting of three meals per day, each meal made up of those foods typically served at that time. Such a menu plan would want to conform to nutritional constraints and variety constraints, also. Each recipe could be assigned a "difficulty" index, too, in case it was important that the meals not consist entirely of recipes that would be time consuming to prepare. In the same way, it might be required that each meal be basically an "oven" meal or a "burner" meal by giving each recipe a "cooking method" code. So several variations might be made to this least cost diet formulation, making it conform increasingly to real-life considerations. Actually, by varying the constraints in the above mentioned ways, the problem would approach Balintfy's work--extended to linear programming.

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VIII. APPENDIX A: SUMMARY OF THE DATA USED IN THE LINEAR PROGRAM

Table A1. Recipe "activities" and the sources for these recipes

Activity	Location of recipe in Better Homes and Gardens Cookbook (5) Page	Activity	Location of recipe in Better Homes and Gardens Cookbook (5)
Fried chicken	282	Tomato soup	339
Meat loaf	240	Ham	252
Franks & boiled potatoes	355[a]	Orange juice	---[b]
		Tomato juice	---[b]
Chili con carne	196	Scrambled eggs	306
Round steak & onions	237	Bacon	250
Broiled fish	296	Pork sausage	250
Family goulash	291[c]	Pancakes & sirup	106
Spaghetti	42	Fried eggs	305
Macaroni & cheese	208	Toast & butter	---[b]
Baked beans & franks	357[a]	Milk	---[b]
		Waffles & sirup	107
Meat balls	241	Popovers	103
Tuna noodle casserole	204	Popovers with grape jelly	103
Hash	198	Blueberry muffins	100
Beef stew	238	Blueberry muffins with margarine	100
Bean soup	337	Cold cereal	---[d]
Chicken noodle soup	340	Oatmeal	---[d]

[a]Frankfurters were added to the basic recipe.

[b]Size of serving and cooking instructions (if any) taken from Family Fare: A Guide to Good Nutrition (24).

[c]Taken from Betty Crocker's Cookbook (6).

[d]Size of serving and cooking instructions (if any) taken from food container.

Table A1. (Continued)

Activity	Location of recipe in Better Homes and Gardens Cookbook (5) Page	Activity	Location of recipe in Better Homes and Gardens Cookbook (5)
Lentil-vegetable soup	336	Oatmeal with brown sugar	---[d]
Minestrone	338	Cream of Wheat	---[d]
Split pea soup	335	Cream of Wheat with white sugar	---[d]
Swiss steak	237	French toast	94
Lazy day lasagne	42	Apples	---[b]
Tuna rice casserole	46	Bananas	---[b]
Weiner bean bake	45	Carrots	354
Hamburgers	241	Canned peas	---[d]
Chicken cacciatore	284	Canned green beans	---[d]
Fried fish	296	Sliced tomatoes	---[b]
Salmon loaf	298	Lettuce	---[b]
Oranges	---[b]	Canned beets	---[d]
Chuck roast	231	Canned bean soup	---[d]
Beef liver	259		
Pork chops	249		
Boiled potatoes	355		
Mashed potatoes	362		
Creamed onions	352		
Cabbage	353		

Table A2. Information secured by the Ames grocery store survey

Ingredients	Ingredient price (all adjusted to April, 1976, levels)	Container size (by weight or by volume)	Brands surveyed
Shortening	$1.32	48 oz.	Makeright Hy Vee Crisco Bake-rite Richtex Light Spry Fluffo
Tomato sauce	.22	8 oz.	Contadina Hy Vee Hunt's Del Monte Stokely
Red kidney beans	.31	15-15 1/2 oz.	Hy Vee Joan of Arc Tendersweet Richelieu Mrs. Grimes Union
Tomato juice	.66	46 oz.	Libby's Hunt's Hy Vee Musselman's Del Monte Stokely Campbell's
Spaghetti noodles	.36	10 oz.	American Beauty Martha Gooch
Parmesan cheese	.64	3 oz.	Kraft
Elbow macaroni	.65	24 oz.	American Beauty Martha Gooch
Dry navy beans	.40	1 lb.	Brown's Best
Brown sugar	.34	1 lb.	C & H
Molasses	.88	12 oz.	Grandma's Brer Rabbit
Egg noodles	.53	12 oz.	American Beauty

Table A2. (Continued)

Ingredients	Ingredient price (all adjusted to April, 1976, levels)	Container size (by weight or by volume)	Brands surveyed
Salad dressing	$ .65	16 oz.	Kraft Miracle Whip Hy Vee Hellman's Spinblend Mrs. Clark's
Cream of celery soup	.22	10 1/2 oz.	Campbell's
Stew meat	1.17	1 lb.	
Chicken bouillion	.32	15 cubes	Wyler's
Lentils	.36	1 lb.	Brown's Best
Canned green beans	.22	8 oz.	Dulany Hy Vee Tendersweet Del Monte
Dry green split peas	.33	1 lb.	Brown's Best
Lasagne noodles	.43	8 oz.	American Beauty Creamette
Cottage cheese	.57	12 oz.	Anderson-Erickson Hy Vee
Mozzarella cheese	1.02	8 oz.	Hy Vee Kraft
Frozen lima beans	.42	10 oz.	Hy Vee Bird's Eye Flav-R-Pac Everfresh
Canned pork and beans	.32	1 lb.	Van Camp's Hy Vee Campbell's Showboat
Chili sauce	.60	12 oz.	Del Monte Heinz Hunt's Old Southern

Table A2. (Continued)

Ingredients	Ingredient price (all adjusted to April, 1976, levels)	Container size (by weight or by volume)	Brands surveyed
Dry onion soup mix	$ .61	2 1-7/8 oz. pkts.	Wyler's Lipton's
Mushrooms	.52	4 oz.	Richelieu Mrs. Grimes Pennsylvania Dutch
Sirup	.56	16 oz.	Karo
Frozen blueberries	.92	16 oz.	Mott's Flavorland
Instant oatmeal	.55	18 oz.	Quaker
Cream of Wheat	.82	28 oz.	Nabisco

Table A3. Information secured by the Bureau of Labor Statistics figures for Cedar Rapids, Iowa

Ingredients	Ingredient price (BLS price for April, 1976)	Container size (by weight, volume, or number)
Flour	$ .84	5 lb.
Corn flakes	.45	12 oz.
Rice, short or medium	.35	1 lb.
Bread, white	.35	1 lb. loaf
Round steak	1.58	1 lb.
Chuck roast	.98	1 lb.
Hamburger	.80	1 lb.
Beef liver	.89	1 lb.
Pork chops	1.78	1 lb.
Pork sausage	1.31	1 lb.
Ham, whole	1.12	1 lb.
Bacon	1.55	1 lb.
Frankfurters	.78	1 lb.
Frying chicken	.58	1 lb.
Haddock	1.38	1 lb.
King salmon	3.67	1 lb.
Tuna fish	.61	6 1/2 oz.
Milk, white (store)	.77	1/2 gal.
Cheese, American	.83	8 oz.
Apples	.28	1 lb.
Bananas	.23	1 lb.
Oranges	1.24	1 doz.
Orange juice	.54	1 quart
Potatoes	1.49	10 lbs.
Onions, yellow	.25	1 lb.
Cabbage	.16	1 lb.
Carrots	.26	1 lb.

Table A3. (Continued)

Ingredients	Ingredient price (BLS price for April, 1976)	Container size (by weight, volume, or number)
Celery	$ .33	1 lb.
Lettuce	.44	1 head
Green peppers	.97	1 lb.
Tomatoes	.72	1 lb.
Canned beets	.35	#303 can
Canned peas	.34	#303 can
Canned tomatoes	.32	#303 can
Dried beans	.38	1 lb.
Eggs	.75	1 doz.
Margarine	.39	1 lb.
Salad or cooking oil	.96	24 oz.
Sugar	1.07	5 lbs.
Grape jelly	.56	10 oz.
Canned bean soup	.28	11 1/2 oz. can
Canned spaghetti	.26	15 1/2 oz. can

Table A4. Recipe activities, cooking instructions, and their associated energy costs

Activity	Cooking instructions Burner	Oven	Energy costs
Fried chicken	20 min. high 40 min. med.		$.05
Meat loaf		1 1/4 hrs. 350°	.09
Franks 'n boiled potatoes	30 min. med.		.02
Chili con carne	15 min. med. 1 hr. low		.03
Round steak and onions	30 min. med.		.02
Broiled fish		15 min. broil	.04
Family goulash	30 min. med. 45 min. low		.04
Spaghetti	45 min. med.		.03
Macaroni & cheese	15 min. med. 30 min. low	40 min. 350°	.07
Baked beans & franks		1 1/2 hrs. 325°	.09
Meat balls	45 min. low 15 min. med.		.02
Tuna noodle casserole	15 min. med.	20 min. 425°	.07
Hash		30 min. 350°	.03
Beef stew	1 1/2 hrs. low 35 min. med.		.05
Bean soup	15 min. med. 3 hrs. low		.07
Chicken noodle soup	15 min. med.		.01
Lentil-vegetable soup	2 hrs. low		.04
Minestrone	15 min. high 3 hrs., 25 min. on low		.08
Split pea soup	15 min. high 2 hrs. low		.05

Table A4. (Continued)

Activity	Cooking instructions: Burner	Cooking instructions: Oven	Energy costs
Swiss steak	15 min. high 1 3/4 hrs. low		$.05
Lazy day lasagne	15 min. med.	30 min. 375°	.05
Tuna rice casserole		25 min. 359°	.03
Weiner bean bake		1 1/2 hrs. 350°	.10
Hamburgers	15 min. med.		.01
Chicken cacciatore	30 min. med. 45 min. low		.04
Fried fish	15 min. med.		.01
Salmon loaf		40 min. 350°	.05
Tomato soup	5 hrs. low		.10
Ham		1 hr. 325°	.06
Orange juice	---	---	---
Tomato juice	---	---	---
Scrambled eggs	10 min. med.		.01
Bacon	8 min. low		.00(3)
Pork sausage	20 min. 10w		.01
Pancakes & sirup	30 min. med.		.02
Fried eggs	15 min. low		.01
Toast & butter	---	---	---
Milk	---	---	---
Waffles & sirup		20 min. 350°	.02
Popovers		15 min. 475° 30 min. 350°	.06
Popovers with grape jelly		15 min. 475° 30 min. 350°	.06
Blueberry muffins		25 min. 400°	.04
Blueberry muffins with margarine		25 min. 400°	.04
Cold cereal	---	---	---

Table A4. (Continued)

Activity	Cooking instructions Burner	 Oven	Energy costs
Oatmeal	10 min. med.		$.01
Oatmeal with brown sugar	10 min. med.		.01
Cream of Wheat	10 min. med.		.01
Cream of Wheat with white sugar	10 min. med.		.01
French toast	15 min. med.		.01
Apples	---	---	---
Bananas	---	---	---
Oranges	---	---	---
Chuck roast		3/4 hr. 325°	.04
Beef liver	5 min. high		.01
Pork chops	30 min. med.		.02
Boiled potatoes	30 min. med.		.02
Mashed potatoes	30 min. med.		.02
Creamed onions	15 min. low 15 min. high		.02
Cabbage	20 min. high		.02
Carrots	30 min. high		.03
Canned peas	10 min. med.		.01
Canned green beans	10 min. med.		.01
Sliced tomatoes	---	---	---
Lettuce	---	---	---
Canned beets	10 min. med.		.01
Canned bean soup	15 min. med.		.01

Table A5. Recipe activities "food" costs and "total" costs

Activity	Combined cost of all ingredients (P_k)	Cost of ingredients plus energy cost
Fried chicken	$1.47	$1.52
Meat loaf	.85	.94
Franks 'n boiled potatoes	.93	.95
Chili con carne	2.19	2.22
Round steak and onions	2.62	2.64
Broiled fish	1.85	1.89
Family goulash	2.06	2.09
Spaghetti	1.55	1.58
Macaroni and cheese	.52	.59
Baked beans and franks	1.10	1.19
Meat balls	.58	.60
Tuna noodle casserole	1.67	1.75
Hash	1.06	1.09
Beef stew	1.49	1.54
Bean soup	.85	.92
Chicken noodle soup	.22	.23
Lentil-vegetable soup	.45	.49
Minestrone	.69	.77
Split pea soup	1.01	1.06
Swiss steak	2.40	2.45
Lazy day lasagne	1.15	1.20
Tuna rice casserole	1.01	1.04
Weiner bean bake	1.78	1.88
Hamburgers	.80	.81
Chicken cacciatore	2.77	2.81
Fried fish	1.49	1.50
Salmon loaf	3.96	4.01
Tomato soup	1.55	1.65

Table A5. (Continued)

Activity	Combined cost of all ingredients (P_k)	Cost of ingredients plus energy cost
Ham	$1.12	$1.18
Orange juice	.44	.44
Tomato juice	.37	.37
Scrambled eggs	.41	.42
Bacon	.48	.48
Pork sausage	1.31	1.32
Pancakes and sirup	.55	.57
Fried eggs	.38	.38
Toast and butter	.18	.18
Milk	.40	.40
Waffles and sirup	.80	.82
Popovers	.31	.37
Popovers with grape jelly	.65	.96
Blueberry muffins	.92	.96
Blueberry muffins with margarine	.96	1.00
Cold cereal	.30	.30
Oatmeal	.34	.35
Oatmeal with brown sugar	.39	.40
Cream of Wheat	.14	.15
Cream of Wheat with white sugar	.16	.17
French toast	.57	.58
Apples	.37	.37
Bananas	.35	.35
Oranges	.44	.44
Chuck roast	.95	.99
Beef liver	.89	.89
Pork chops	1.57	1.59
Boiled potatoes	.17	.19

Table A5. (Continued)

Activity	Combined cost of all ingredients (P_k)	Cost of ingredients plus energy cost
Mashed potatoes	$ .22	$ .24
Creamed onions	.35	.37
Cabbage	.10	.12
Carrots	.17	.20
Canned peas	.36	.37
Canned green beans	.44	.45
Sliced tomatoes	.63	.63
Lettuce	.22	.22
Canned beets	.38	.39
Canned bean soup	.56	.57

Table A6. Nutritional composition of the activities

Activity	Food energy (cal.)	Protein (gr.)	Calcium (mg.)	Iron (mg.)	Vitamin A(I.U.)	Thia-mine (mg.)	Ribo-flavin (mg.)	Niacin (mg.)	Ascorbic acid (mg.)
Fried chicken	1095.00	147.50	116.44	15.86	5650.00	.67	3.02	44.05	0.00
Meat loaf	1121.47	70.26	81.51	10.84	1757.02	.39	.84	15.98	20.94
Franks 'n boiled potatoes	1600.00	62.00	45.00	8.20	0.00	.97	1.00	15.40	60.00
Chili con carne	1939.66	122.50	308.46	26.16	7044.22	1.12	1.49	29.04	254.81
Round steak and onions	1451.50	138.95	190.50	21.75	325.00	.71	1.33	32.75	42.00
Broiled fish	602.00	106.40	75.86	2.41	611.00	.36	.44	13.33	12.00
Family goulash	1888.32	106.70	253.65	19.60	6836.00	1.79	1.81	33.69	117.58
Spaghetti	2137.11	113.15	162.37	23.43	6535.00	2.50	1.90	37.87	104.00
Macaroni and cheese	856.10	82.67	2130.68	4.05	4420.40	.34	2.40	2.17	6.33
Baked beans and franks	1975.60	72.00	261.71	16.08	20.00	.96	1.07	12.73	5.50
Meat balls	878.00	54.60	236.47	8.40	790.00	.35	.69	10.95	0.00
Tuna noodle casserole	1489.34	109.58	1139.41	9.28	2774.09	.63	1.64	28.70	44.26
Hash	991.00	63.10	503.95	8.75	1085.00	.54	1.12	14.39	44.00
Beef stew	1681.43	131.43	209.82	21.77	24125.00	1.02	1.37	34.18	80.40
Bean soup	934.00	52.65	180.78	12.05	40.00	1.89	.57	9.94	11.00

Table A6. (Continued)

Activity	Food energy (cal.)	Protein (gr.)	Calcium (mg.)	Iron (mg.)	Vitamin A(I.U.)	Thia-mine (mg.)	Ribo-flavin (mg.)	Niacin (mg.)	Ascorbic acid (mg.)
Chicken noodle soup	515.00	18.26	101.62	4.02	125.00	.74	.41	5.78	0.00
Lentil-vegetable soup	895.37	61.87	246.29	17.34	3897.50	1.04	.63	7.02	49.87
Minestrone	895.25	26.36	329.31	9.45	10100.00	.99	.59	7.71	102.00
Split pea soup	1766.70	109.19	242.93	21.99	8707.00	3.88	1.37	18.20	34.00
Swiss steak	1452.61	122.74	260.32	19.70	4069.25	.71	1.19	31.01	76.89
Lazy day lasagne	1491.13	85.06	649.63	11.48	2831.90	1.87	1.72	14.62	10.89
Tuna rice casserole	828.32	73.57	281.45	7.01	1470.27	.34	.73	25.39	5.03
Weiner bean bake	2238.01	94.47	393.69	22.01	18503.30	1.28	1.35	18.48	143.22
Hamburgers	1216.00	81.20	45.00	12.20	160.00	.35	.72	19.50	0.00
Chicken cacciatore	1515.40	165.99	278.91	22.55	12446.15	1.34	3.90	53.18	232.56
Fried fish	626.50	91.30	116.25	4.51	590.00	.50	.62	11.70	9.00
Salmon loaf	1601.00	118.85	1529.72	11.43	2280.00	.76	1.49	38.12	2.38
Tomato soup	1376.42	123.19	139.22	20.26	10693.40	.78	1.24	32.10	82.80
Ham	1188.00	61.30	35.00	9.30	0.00	2.98	.72	16.00	0.00
Orange juice	1147.20	16.64	240.00	2.88	5152.00	2.18	.34	8.32	1147.20
Tomato juice	137.60	6.56	51.20	6.56	5808.00	.38	.21	5.44	116.80
Scrambled eggs	733.30	39.00	272.97	6.63	4596.67	.32	1.04	.07	.67

Table A6. (Continued)

Activity	Food energy (cal.)	Protein (gr.)	Calcium (mg.)	Iron (mg.)	Vitamin A(I.U.)	Thia-mine (mg.)	Ribo-flavin (mg.)	Niacin (mg.)	Ascorbic acid (mg.)
Bacon	270.00	15.00	6.00	1.50	0.00	.24	.15	2.40	0.00
Pork sausage	2259.00	42.60	23.00	6.40	0.00	1.95	.76	10.40	0.00
Pancakes & sirup	2015.00	30.00	490.47	18.12	940.00	.76	.94	5.20	2.00
Fried eggs	680.00	36.00	168.00	6.60	4480.00	.30	.90	0.00	0.00
Toast & butter	760.00	16.00	174.00	4.80	940.00	.48	.40	4.80	0.00
Milk	640.00	36.00	1152.00	.40	1400.00	.28	1.64	.80	8.00
Waffles & sirup	2643.37	39.50	645.97	19.37	1311.70	.93	1.27	6.30	3.00
Popovers	1265.00	33.00	380.97	5.60	3410.00	.68	1.01	4.20	2.00
Popovers with grape jelly	1865.00	33.00	428.97	9.20	3410.00	.68	1.13	4.20	14.00
Blueberry muffins	1846.70	34.75	308.96	8.36	992.50	1.03	1.06	7.75	21.50
Blueberry muffins with margarine	2246.70	34.75	320.96	8.36	2872.50	1.03	1.06	7.75	21.50
Cold cereal	630.00	22.00	586.00	1.00	700.00	.46	.86	2.00	4.00
Oatmeal	172.90	6.65	47.20	1.87	0.00	.25	.07	.27	0.00
Oatmeal with brown sugar	443.50	6.65	108.91	4.35	0.00	.26	.09	.40	0.00
Cream of Wheat	58.80	1.68	91.29	.39	0.00	.07	.04	.56	0.00
Cream of Wheat with white sugar	218.80	1.68	91.29	.39	0.00	.07	.04	.56	0.00

Table A6. (Continued)

Activity	Food energy (cal.)	Protein (gr.)	Calcium (mg.)	Iron (mg.)	Vitamin A(I.U.)	Thia-mine (mg.)	Ribo-flavin (mg.)	Niacin (mg.)	Ascorbic acid (mg.)
French toast	1620.00	28.50	472.48	18.65	1355.00	.50	.80	3.70	1.00
Apples	280.00	0.00	32.00	1.60	200.00	.16	.08	.40	12.00
Bananas	400.00	4.00	40.00	3.20	920.00	.24	.28	3.20	48.00
Oranges	260.00	4.00	216.00	2.00	1040.00	.52	.20	2.00	264.00
Chuck roast	1998.75	68.00	32.00	8.80	280.00	.20	.52	12.40	0.00
Beef liver	1040.00	120.00	48.00	40.00	242240.00	1.20	18.96	75.20	120.00
Pork chops	1040.00	64.00	32.00	8.80	0.00	2.52	.72	15.20	0.00
Boiled potatoes	479.00	7.70	49.94	2.21	940.00	.39	.14	5.40	73.00
Mashed potatoes	559.00	12.00	193.94	2.26	1115.00	.43	.34	5.50	74.00
Creamed onions	406.25	15.50	340.12	2.69	892.50	.24	.49	1.20	45.50
Cabbage	60.00	4.00	128.00	.80	380.00	.12	.12	.80	96.00
Carrots	90.00	2.00	96.00	1.80	30440.00	.16	.14	1.40	18.00
Canned peas	330.00	18.00	100.00	8.40	2240.00	.46	.26	4.40	44.00
Canned green beans	90.00	4.00	162.00	5.80	1380.00	.14	.20	1.40	20.00
Sliced tomatoes	80.00	4.00	48.00	1.80	3280.00	.22	.14	2.60	84.00
Lettuce	30.00	2.00	45.50	1.15	750.00	.14	.14	.65	14.50
Canned beets	170.00	4.00	68.00	3.00	40.00	.04	.10	.40	14.00
Canned bean soup	680.00	32.00	252.00	9.20	2600.00	.52	.32	4.00	12.00

IX. APPENDIX B: SUMMARY OF THE RESULTS OF LINEAR PROGRAMMING PROBLEM FORMULATIONS A THROUGH E

Table B1. Summary of the results of problem formulation A

Column	Activity	Upper limit	Reduced cost
Fried chicken	.[a]	None	$1.02
Meat loaf	.	None	.54
Franks 'n boiled potatoes	.	None	.61
Chili con carne	.	None	1.45
Round steak and onions	.	None	2.05
Broiled fish	.	None	1.72
Family goulash	.	None	1.46
Spaghetti	.	None	.88
Macaroni and cheese	7.48	None	.
Baked beans and franks	.	None	.61
Meat balls	.	None	.31
Tuna noodle casserole	.	None	1.12
Hash	.	None	.71
Beef stew	.	None	.89
Bean soup	.	None	.53
Chicken noodle soup	.	None	.08
Lentil-vegetable soup	.	None	.04
Minestrone	.	None	.37
Split pea soup	.	None	.43
Swiss steak	.	None	1.85
Lazy day lasagne	.	None	.70
Tuna rice casserole	.	None	.73
Weiner bean bake	.	None	1.11
Hamburgers	.	None	.46
Chicken cacciatore	.	None	2.09
Fried fish	.	None	1.32
Salmon loaf	.	None	3.30

[a]. indicates a value of 0.00.

Table B1. (Continued)

Column	Activity	Upper limit	Reduced cost
Tomato soup	.	None	$1.01
Ham	.	None	.84
Orange juice	1.07	None	.
Tomato juice	.	None	.21
Scrambled eggs	.	None	.20
Bacon	.	None	.43
Pork sausage	.	None	.99
Pancakes	2.61	None	.
Fried eggs	.	None	.19
Toast and butter	68.26	None	.
Milk	.	None	.13
Waffles and sirup	.	None	.15
Popovers	.	None	.04
Popovers with grape jelly	.	None	.26
Blueberry muffins	.	None	.56
Blueberry muffins with margarine	.	None	.56
Cold cereal	.	None	.12
Oatmeal	.	None	.29
Oatmeal with brown sugar	.	None	.26
Cream of Wheat	.	None	.11
Cream of Wheat with white sugar	.	None	.12
French toast	.	None	.05
Apples	.	None	.31
Bananas	.	None	.24
Oranges	.	None	.29
Chuck roast	.	None	.61
Beef liver	.99	None	.
Pork chops	.	None	1.31

Table B1. (Continued)

Column	Activity	Upper limit	Reduced cost
Boiled potatoes	.	None	$ .06
Mashed potatoes	.	None	.08
Creamed onions	.	None	.20
Cabbage	.	None	.04
Carrots	.	None	.11
Canned peas	.	None	.17
Canned green beans	.	None	.31
Sliced tomatoes	.	None	.56
Lettuce	.	None	.19
Canned beets	.	None	.30
Canned bean soup	.	None	.30

Table B2. Summary of the results of problem formulation B

Column	Activity	Upper limit	Reduced cost
Fried chicken	.[a]	2.00	$ .95
Meat loaf	.	2.00	.44
Franks and boiled potatoes	.	2.00	.58
Chili con carne	.	2.00	.95
Round steak and onions	.	2.00	1.82
Broiled fish	.	2.00	1.53
Family goulash	.	2.00	1.00
Spaghetti	.	2.00	.75
Macaroni and cheese	2.00	2.00	-6.41
Baked beans and franks	.	2.00	.00
Meat balls	2.00	2.00	-.29
Tuna noodle casserole	2.00	2.00	-2.17
Hash	2.00	2.00	-.68
Beef stew	.	2.00	.60
Bean soup	.	2.00	.15
Chicken noodle soup	2.00	2.00	-.17
Lentil-vegetable soup	2.00	2.00	-.46
Minestrone	2.00	2.00	-.48
Split pea soup	.87	2.00	.
Swiss steak	.	2.00	1.38
Lazy day lasagne	2.00	2.00	-1.12
Tuna rice casserole	1.82	2.00	.
Weiner bean bake	.	2.00	.22
Hamburgers	.	2.00	.50
Chicken cacciatore	.	2.00	1.68
Fried fish	.	2.00	1.04
Salmon loaf	2.00	2.00	-1.15

[a]. indicates a value of 0.00.

Table B2. (Continued)

Column	Activity	Upper limit	Reduced cost
Tomato soup	.	2.00	$ .92
Ham	.	2.00	.85
Orange juice	2.00	2.00	-.48
Tomato juice	.	2.00	.19
Scrambled eggs	2.00	2.00	-.56
Bacon	.	2.00	.42
Pork sausage	.	2.00	.94
Pancakes and sirup	2.00	2.00	1.28
Fried eggs	2.00	2.00	-.25
Toast and butter	2.00	2.00	-.48
Milk	2.00	2.00	-3.37
Waffles and sirup	2.00	2.00	-1.62
Popovers	2.00	2.00	-1.07
Popovers with grape jelly	2.00	2.00	-.97
Blueberry muffins	2.00	2.00	-.31
Blueberry muffins with margarine	2.00	2.00	-.36
Cold cereal	2.00	2.00	-1.66
Oatmeal	.	2.00	.17
Oatmeal with brown sugar	2.00	2.00	-.16
Cream of Wheat	2.00	2.00	-.16
Cream of Wheat with white sugar	2.00	2.00	-.16
French toast	2.00	2.00	-1.16
Apples	.	2.00	.23
Bananas	.	2.00	.17
Oranges	2.00	2.00	-.28
Chuck roast	.	2.00	.58
Beef liver	.	2.00	.60
Pork chops	.	2.00	1.33

Table B2. (Continued)

Column	Activity	Upper limit	Reduced cost
Boiled potatoes	2.00	2.00	$ -.05
Mashed potatoes	2.00	2.00	-.47
Creamed onions	2.00	2.00	-.79
Cabbage	2.00	2.00	-.32
Carrots	2.00	2.00	-.15
Canned peas	2.00	2.00	-.00
Canned green beans	2.00	2.00	-.09
Sliced tomatoes	.	2.00	.46
Lettuce	.	2.00	.07
Canned beets	.	2.00	.14
Canned bean soup	2.00	2.00	-.34

Table B3. Summary of the results of problem formulation C

Column	Activity	Upper limit	Reduced cost
Fried chicken	.[a]	2.00	$ .03
Meat loaf	.	2.00	.14
Franks and boiled potatoes	.	2.00	.13
Chili con carne	.	2.00	.90
Round steak and onions	.	2.00	1.37
Broiled fish	.	2.00	1.34
Family goulash	.	2.00	.67
Spaghetti	.	2.00	.01
Macaroni and cheese	4.00	4.00	-.16
Baked beans and franks	.	2.00	.23
Meat balls	.	2.00	.03
Tuna noodle casserole	.	4.00	.33
Hash	.	4.00	.34
Beef stew	.	2.00	.15
Bean soup	.	2.00	.33
Chicken noodle soup	2.00	2.00	-.08
Lentil-vegetable soup	1.39	4.00	.
Minestrone	.	2.00	.21
Split pea soup	.	2.00	.06
Swiss steak	.	2.00	1.19
Lazy day lasagne	.	4.00	.28
Tuna rice casserole	.	2.00	.09
Weiner bean bake	.	2.00	.67
Hamburgers	2.00	2.00	-.01
Chicken cacciatore	.	2.00	.96
Fried fish	.	2.00	1.01
Salmon loaf	.	4.00	2.28

[a]. indicates a value of 0.00.

Table B3. (Continued)

Column	Activity	Upper limit	Reduced cost
Tomato soup	.	2.00	$ .35
Ham	.	2.00	.40
Orange juice	7.00	7.00	-.10
Tomato juice	.	7.00	.18
Scrambled eggs	.	2.00	.18
Bacon	.	2.00	.35
Pork sausage	.	2.00	.48
Pancakes and sirup	4.00	4.00	-.17
Fried eggs	.	2.00	.18
Toast and butter	7.00	7.00	-.16
Milk	4.58	14.00	.
Waffles and sirup	4.00	4.00	-.14
Popovers	4.00	4.00	-.18
Popovers with grape jelly	1.83	2.00	.
Blueberry muffins	.	2.00	.20
Blueberry muffins with margarine	.	2.00	.14
Cold cereal	4.00	4.00	-.02
Oatmeal	.	2.00	.28
Oatmeal with brown sugar	.	2.00	.25
Cream of Wheat	.	2.00	.09
Cream of Wheat with white sugar	.	2.00	.07
French toast	4.00	4.00	-.02
Apples	.	2.00	.28
Bananas	.	2.00	.16
Oranges	.	2.00	.28
Chuck roast	.	2.00	.13
Beef liver	2.00	2.00	-1.33
Pork chops	.	2.00	.91

Table B3. (Continued)

Column	Activity	Upper limit	Reduced cost
Boiled potatoes	2.00	2.00	$-.10
Mashed potatoes	4.00	4.00	-.10
Creamed onions	.	4.00	.15
Cabbage	.	2.00	.04
Carrots	.	2.00	.09
Canned peas	.	2.00	.14
Canned green beans	.	2.00	.35
Sliced tomatoes	.	2.00	.53
Lettuce	.	2.00	.19
Canned beets	.	2.00	.31
Canned bean soup	.	2.00	.24

Table B4. Summary of the results of problem formulation D

Column	Activity	Upper limit	Reduced cost
Fried chicken	.[a]	2.00	$ .03
Meat loaf	.	2.00	.07
Franks and boiled potatoes	.	2.00	.01
Chili con carne	2.00	2.00	-.00
Round steak and onions	2.00	2.00	-.00
Broiled fish	.	2.00	.03
Family goulash	.	2.00	.01
Spaghetti	.	2.00	.00
Macaroni and cheese	4.00	4.00	-.06
Baked beans and franks	.	2.00	.06
Meat balls	.	2.00	.01
Tuna noodle casserole	1.06	4.00	.
Hash	4.00	4.00	-.00
Beef stew	.	2.00	.02
Bean soup	.	2.00	.05
Chicken noodle soup	1.33	2.00	.
Lentil-vegetable soup	.	4.00	.02
Minestrone	.	2.00	.06
Split pea soup	.	2.00	.02
Swiss steak	.	2.00	.02
Lazy day lasagne	.	4.00	.00
Tuna rice casserole	.	2.00	.01
Weiner bean bake	.	2.00	.06
Hamburgers	2.00	2.00	-.00
Chicken cacciatore	.	2.00	.01
Fried fish	2.00	2.00	-.00
Salmon loaf	4.00	4.00	-.05

[a]. indicates a value of 0.00.

Table B4. (Continued)

Column	Activity	Upper limit	Reduced cost
Tomato soup	.	2.00	$ .08
Ham	.	2.00	.05
Orange juice	.	7.00	9.98
Tomato juice	.	7.00	10.00
Scrambled eggs	2.00	2.00	-.01
Bacon	.	2.00	.00
Pork sausage	2.00	2.00	-.01
Pancakes and sirup	4.00	4.00	-.02
Fried eggs	2.00	2.00	-.01
Toast and butter	.	7.00	9.98
Milk	.	14.00	9.93
Waffles and sirup	4.00	4.00	-.03
Popovers	.	4.00	.03
Popovers with grape jelly	.	2.00	.02
Blueberry muffins	.	2.00	.01
Blueberry muffins with margarine	.	2.00	.01
Cold cereal	.	4.00	9.96
Oatmeal	.	2.00	.00
Oatmeal with brown sugar	2.00	2.00	-.00
Cream of Wheat	.	2.00	.00
Cream of Wheat with white sugar	.10	2.00	.
French toast	4.00	4.00	-.03
Apples	.	2.00	10.00
Bananas	.	2.00	9.99
Oranges	.	2.00	9.98
Chuck roast	.	2.00	.03
Beef liver	2.00	2.00	-.01
Pork chops	.	2.00	.01

Table B4. (Continued)

Column	Activity	Upper limit	Reduced cost
Boiled potatoes	.	2.00	$ .01
Mashed potatoes	.	4.00	.00
Creamed onions	4.00	4.00	-.00
Cabbage	.	2.00	.01
Carrots	.	2.00	.02
Canned peas	2.00	2.00	-.00
Canned green beans	2.00	2.00	-.00
Sliced tomatoes	.	2.00	10.00
Lettuce	.	2.00	10.00
Canned beets	.	2.00	.00
Canned bean soup	2.00	2.00	-.01

Table B5. Summary of the results of problem formulation E

Column	Activity	Upper limit	Reduced cost
Fried chicken	.[a]	2.00	$ .15
Meat loaf	.	2.00	.20
Franks and boiled potatoes	.	2.00	.07
Chili con carne	.	2.00	.88
Round steak and onions	.	2.00	1.40
Broiled fish	.	2.00	1.38
Family goulash	.	2.00	.67
Spaghetti	.09	2.00	.
Macaroni and cheese	4.00	4.00	-.06
Baked beans and franks	.	2.00	.21
Meat balls	.	2.00	.03
Tuna noodle casserole	.	4.00	.44
Hash	.	4.00	.36
Beef stew	.	2.00	.19
Bean soup	.	2.00	.36
Chicken noodle soup	2.00	2.00	-.08
Lentil-vegetable soup	.78	4.00	.
Minestrone	.	2.00	.25
Split pea soup	.	2.00	.03
Swiss steak	.	2.00	1.24
Lazy day lasagne	.	4.00	.28
Tuna rice casserole	.	2.00	.16
Weiner bean bake	.	2.00	.67
Hamburgers	2.00	2.00	-.04
Chicken cacciatore	.	2.00	1.08
Fried fish	.	2.00	1.01
Salmon loaf	.	4.00	2.40

[a]. indicates a value of 0.00.

Table B5. (Continued)

Column	Activity	Upper limit	Reduced cost
Tomato soup	.	2.00	$ .45
Ham	.	2.00	.42
Orange juice	7.00	7.00	-.16
Tomato juice	.	7.00	.19
Scrambled eggs	.	2.00	.14
Bacon	.	2.00	.34
Pork sausage	.	2.00	.34
Pancakes and sirup	4.00	4.00	-.28
Fried eggs	.	2.00	.13
Toast and butter	7.00	7.00	-.20
Milk	4.64	14.00	.
Waffles and sirup	4.00	4.00	-.29
Popovers	4.00	4.00	-.20
Popovers with grape jelly	2.00	2.00	-.05
Blueberry muffins	.	2.00	.13
Blueberry muffins with margarine	.	2.00	.04
Cold cereal	4.00	4.00	-.04
Oatmeal	.	2.00	.28
Oatmeal with brown sugar	.	2.00	.23
Cream of Wheat	.	2.00	.10
Cream of Wheat with white sugar	.	2.00	.07
French toast	4.00	4.00	-.11
Apples	.	2.00	.26
Bananas	.	2.00	.14
Oranges	.	2.00	.28
Chuck roast	.	2.00	.05
Beef liver	2.00	2.00	-1.15
Pork chops	.	2.00	.90

Table B5. (Continued)

Column	Activity	Upper limit	Reduced cost
Boiled potatoes	2.00	2.00	$ -.10
Mashed potatoes	4.00	4.00	-.10
Creamed onions	.	2.00	.16
Cabbage	.	2.00	.06
Carrots	.	2.00	.12
Canned peas	.	2.00	.15
Canned green beans	.	2.00	.36
Sliced tomatoes	.	2.00	.54
Lettuce	.	2.00	.19
Canned beets	.	2.00	.31
Canned bean soup	.	2.00	.22