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# SYSTEMS APPROACH TO NUTRITION PLANNING: PRELIMINARY CONSIDERATIONS

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## 1. INTRODUCTION

In the past five years the problem of malnutrition in developing countries has received increasing attention because the consequences of malnutrition appear to be even more severe than previously recognized[1]*, and the number of persons affected by malnutrition has not been reduced significantly in many countries[2]. The occurrence and severity of malnutrition are particularly high for children ranging approximately from six months to three years of age[3]. During this period of life, the normal rate of growth of a child is extremely high, and this rate cannot be achieved unless the diet provides adequate amounts of calories, protein, vitamins, and minerals. It is difficult to insure adequate nutrition during this crucial period because the milk provided by the mother is no longer sufficient by itself to satisfy all of the nutritional needs of the child, but the child is not yet able to digest the same diet as the older members of the family. In low income families, the foods prepared for young children often have such low concentrations of nutrients that the child's limited capacity for food intake does not allow him to consume a sufficient quantity to provide adequate nutrition. The problem is compounded by the high occurrence of diarrhea during the weaning period; in addition to reducing the extent to which nutrients are absorbed in the child's digestive system, diarrhea is generally treated by adopting a diet having an extremely low nutrient content. The nutritional status of a child is also influenced detrimentally by many other factors, such as the economic and educational status of the family, dietary traditions, agricultural production, sanitation and medical care[4].

There is increasing evidence that malnutrition may result in permanent defects in the physical and mental development of children. For example, there are results showing that school-age children who have suffered from severe malnutrition during their infancy tend to have below-average heights, weights, and I.Q.[3].

Although adults are not affected as severely or irreversibly as children, there is ample evidence that malnutrition seriously reduces the ability of the body to perform physical work and to resist infection and disease. Consequently, the malnourished adult is trapped in a cycle where an inadequate diet may result in reduced productivity which contributes to low income and, therefore, to a poor diet for both the adults and children in the family. This cycle passes on from one generation to the next if the children's physical and mental capabilities are severely handicapped as a result of malnutrition. Since the most important resource of a country is its people, malnutrition is most certainly a problem of national development[1], as well as a long-standing humanitarian problem.

As a result of these facts and others, the United Nations commissioned a panel to recommend a program for alleviating malnutrition[5]. Other programs have been considered recently by various panels[6] and conferences[7], as well as in a number of books and journals. Recognition of the importance of combatting malnutrition has grown to the point that nutrition has recently been included as a campaign issue in elections in several countries (e.g., India, Chile, and Jamaica). Furthermore, many of the developing countries are now expanding their nutrition efforts, and some are attempting to integrate their nutrition program into the overall national development program. The World Bank has just recently indicated that it now considers nutrition as a vital aspect of national development[8].

Many of these considerations of nutrition programs conclude that a "systems approach" should be utilized in nutrition planning because the task of evaluating the alternative strategies is complicated by the large number of variables, objectives, and constraints. Although several excellent discussions of the basic steps and procedures of nutrition planning have recently been presented[9,10], these efforts have not attempted to develop a quantitative systems approach.

As members of the newly-established International Nutrition Planning Program at M.I.T., we are now attempting to develop a nutrition planning methodology that utilizes, where appropriate, the

* Superior numbers refer to similarly-numbered references at the end of this paper.

various techniques that are included within the broadest definition of the field of systems analysis. The tentative framework of the proposed methodology is outlined in Section 2, and two preliminary exercises are summarized in Section 3. Various problems and limitations are mentioned in Sections 2 and 3, and we discuss the current directions of our work in Section 4.

## 2. NUTRITIONAL PLANNING METHODOLOGY

Although systems analysis is an exceedingly powerful approach which, when properly applied, can yield useful information on complex systems, it has characteristics and limitations that can lead to incomplete and inaccurate results. This problem exists for all branches of knowledge that have developed methodologies, but the consequences are particularly serious for systems analysis because it is often difficult to verify the validity of the model or to check for computational errors. In a case as complex as nutrition planning, it is essential to guard against tendencies to develop a methodology that will be too rigid or specialized to be applicable to the exceedingly wide range of situations met in practice, or to over-emphasize the computational techniques to the degree that the possible inputs from human intuition and experience are sacrificed. Since some of the essential influences on nutrition planning (e.g., food acceptability governed by cultural traditions) cannot be modeled in a realistic manner, the methodology must incorporate human judgment into various steps of the procedure in a manner that encourages interaction and makes best use of the different attributes of the computer and of the human mind. That is, systems analysis should be treated as a limited tool to aid and extend human reasoning and experience.

A first step of a systems approach to nutrition planning is to adopt a tentative outline of principal steps to be included. The outline is tentative because it is expected that improvements will evolve as a result of the insight gained by attempting to develop the detailed analyses associated with these steps and by attempting to apply the resulting methodology. Therefore, the preliminary outline provides an initial perspective of the overall framework which is to be developed into a coherent, quantitative program by employing the techniques of system analysis. The outline that we have adopted as our first attempt is described briefly below*.

1. Problem Identification and Assessment. The initial task is to determine the principal causes and effects of malnutrition in the particular region or country being considered. The existing methods for accomplishing this task include the food balance sheet, the consumer expenditure survey, the food consumption survey, and the medical survey. The food balance sheet provides: (a) a tabulation of the food supplies that are available to the country in a particular year; (b) a calculation of the available quantities of nutrients (calories, protein, etc.) associated with these food supplies; (c) a comparison of the available quantities of nutrients with the quantities that are necessary to fulfill the nutritional requirements of the total population of the country. The results of the food balance sheet indicate if the present food supplies are deficient in certain nutrients in the hypothetical ideal case of equitable distribution of the supplies. Since distribution is not equitable in practice because of income differences and other factors, the results provide an unrealistically conservative estimate of the actual nutrient deficits of the population. Consumer expenditure surveys provide a more realistic view by gathering data on the quantities of foods purchased by families. However, the nutrient deficits calculated from such data are conservative estimates because they do not account for the loss of nutrients during cooking, the pattern of food distribution within the family, and the influence of health on the ability of the human body to absorb and utilize the available nutrients. To account for these factors, it is necessary to perform both a food consumption survey and a medical survey. In the food consumption survey, data are obtained on the kinds and quantities of foods actually consumed by the various members of families representing specific socio-economic segments of the population. These data are used to calculate the nutrient deficits for the different age groups and socio-economic levels. Furthermore, with the aid of additional data, these results are useful in attempts to determine what factors are primarily responsible for the various nutrient deficiencies. The principal disadvantages of food consumption surveys are the time and expense associated with interviewing an adequate number of households, the limited accuracy of the responses of the interviewees, and the omission of the influence of health on the utilization of the available nutrients. The latter factor is covered by performing a medical survey of families representing the same segments of the population. In addition to identifying the incidence of intestinal parasites or other health problems that reduce the absorption of nutrients, medical surveys provide information on the frequency and severity of the most common nutritional problems (e.g., marasmus, kwashiorkor, iron-deficiency anemias, etc.) and on the general nutritional status of the population as indicated by athropometric measurements (e.g., height and weight) of the various age groups. Although the results of medical surveys generally are the most reliable of the four methods, they are time-consuming and costly, and they require highly trained personnel. Since each survey has certain shortcomings, it is desirable to have the results of all four methods available to the nutrition planner.

2. Preliminary Analysis. The design of the above-mentioned surveys requires a preliminary analysis of the region or country being considered. In its simplest form, this analysis provides an intuitive estimate of the general nature of the nutrition problem, and this estimate is used as the basis for selecting the target groups, the survey items and techniques, and the sample sizes. In its highest form, the analysis will also include quantitative (but approximate) considerations of the available data and of potential objectives and strategies.

* For more detailed discussions of nutrition planning methodology, see references 9 and 10.

(Two examples are presented in Section 3.) When the surveys are completed, a detailed analysis of the resulting data leads to a more exact formulation of the objectives of the nutrition planning effort.

3. Formulation of Objectives. An essential step in developing a nutrition policy is the selection of the specific objectives or goals. Since the objectives are based upon the results of a careful analysis of the data provided by nutritional and medical surveys, their validity depends in part upon the accuracy and scope of the surveys and associated analysis. The objectives should be consistent with the overall development plan of the country, with the political, economic, and sociological constraints, and with the priorities expressed by the persons experiencing the most serious nutritional problems. If the objectives are set too high, the program will be doomed to fail; if the objectives are too low, the program will not lead to significant reductions of nutritional problems. The objectives should be stated in a manner that minimizes the difficulty of designing the nutrition program (i.e., selecting the most effective strategies) and of evaluating the program at a future date*. Clearly, the important task of formulating meaningful objectives is an extremely complex process that would benefit by adopting a systems approach that would assist human intuition and experience.

4. Comparative Analysis of Alternative Strategies. After the objectives of the nutrition policy have been stated, the next task is to design a program that will achieve these objectives in the most effective manner while satisfying a number of constraints arising from various factors (economic, political, cultural, etc.). Since there are a wide variety of alternative strategies** that must be considered for inclusion in the program, one might expect that the techniques of systems analysis would prove to be extremely useful in comparing the alternatives and determining an optimal combination. However, the analysis is complicated by the fact that some of the most important factors of the problem cannot be described accurately in terms of mathematical models. [An example of one such factor is the reluctance of people to accept new foods having unfamiliar tastes and odors.] Therefore, the systems analysis must be designed to allow for constructive interaction between the quantitative portion of the analysis, which will be performed by computer, and the nonquantitative portion, which will involve the input of questions and decisions based on the planner's experiences and/or intuition. [A simple illustration of this point will be described in Section 4.] The systems analysis would most probably utilize a wide variety of techniques, such as econometrics to assist in the formulation of models, mathematical programming methods to search for the most effective strategies, marginal and sensitivity analysis to guide the program design and to examine the solutions, decision analysis to assess the influences of risk and uncertainty, welfare economics to improve the perspective of the cost-benefit and cost-effectiveness considerations, and simulation techniques to estimate the possible consequences of various strategies. It should be emphasized that although there will be cases where a comprehensive analysis of the total planning activity may prove to be impractical because of time and cost limitations, useful results may be obtained in those cases by applying systems techniques to some components of the activity.

5. Recommended Program. The purpose of the preceding steps is to lead to the design of a nutrition program to meet the specified objectives of a particular country's nutrition policy while being compatible with the economic, political, cultural, and technological constraints. The basic elements of the program are: (1) the objectives; (2) the strategies selected for attaining these objectives; (3) preliminary tests to determine costs, consumer acceptability, etc.; (4) program implementation and administration; (5) methods for evaluating the effectiveness of the strategies and for introducing improvements; (6) estimated time schedule, budget, equipment and personnel. Ideally, the program should be an integral part of the overall development plan of the nation, and it should indicate the possible influences of improved nutrition on the objectives and performance of other sectors.

## 3. PRELIMINARY STUDIES

In this section we present a brief summary of our preliminary efforts to explore the potential benefits and limitations of applying systems analysis to nutrition planning. Our goal is to concentrate on the utilization of the simple existing techniques of systems analysis rather than to attempt to develop new techniques or to adopt the most elegant methods of mathematical programming or optimization theory. Consequently, we have concentrated initially on one of the best known and most widely used techniques, linear programming. We should also point out that, for simplicity, our initial studies have been approximate analyses of hypothetical limiting (extreme) cases rather than detailed analyses of actual cases, and we have considered isolated subsystems rather than the total nutrition system. Therefore, our results must not be interpreted as a realistic description of the subsystems under actual conditions. Instead, we believe that these results, when viewed from the proper perspective, provide useful information on the nature of the bounds or extreme solutions associated with the limiting cases. Knowledge of the approximate magnitudes of the bounds can prove to be valuable in a preliminary screening of a problem to estimate the ranges of the parameters and to identify the most influential factors and

* For example, the objective of improving the nutritional status of children may be stated more effectively by specifying measurable changes to be achieved by a definite date[10] (e.g., to achieve by 1980 a 50% reduction in the number of cases of third-degree malnutrition of children under 5 years of age in region X).

** Examples of the various possible strategies are changes in: agricultural methods and production patterns; food price policies; dietary customs (e.g., weaning practices); food fortication, supplementation, and substitution; water purification and sanitation; health care; education; employment and income distribution.

promising strategies.

### 3.1 EXPLORATORY ANALYSIS OF AGRICULTURAL STRATEGIES

Agriculture is one of the many sectors that should be considered in nutrition planning, and in this section we present an exploratory analysis of agricultural strategies. This study may be viewed as an extension of the food balance sheet technique, described in Section 2, to include considerations of the following questions. What changes in the present food production pattern of a particular country will lead to significant reductions in both the cost and the resources (land, water, and fertilizer) required to provide the population with the recommended amounts of the essential nutrients? From this viewpoint, what foods are most attractive (and least attractive)? Are the estimated reductions of costs and resources sufficiently large to be interesting to the development planner?

The question of providing a nutritious diet at low cost is especially important in countries where malnutrition is severe as a result of low income. Effective use of the resources required for food production is of primary concern in countries where population growth and traditional agricultural practices have lead to scarcities of arable land and water for irrigation. Fertilizer production in the developing countries has consistently lagged behind the demand, and the introduction of the new high-yielding grains is leading to substantial increases in the demand.

Our approximate analysis of these questions consists of the following steps: (1) Formulation of a simple linear model of the nutrient production, consumption, and requirements of a country; (2) Construction of a food balance sheet for estimating the deficits and excesses of nutrients provided by the present food production and consumption patterns; (3) Linear programming analyses* to determine what combinations of foods will satisfy the nutritional requirements of a country at minimum cost and for minimum usage of land, water, and fertilizer; (4) Examination of alternative agriculture strategies on the basis of their costs, resource requirements, and probable acceptability relative to the present agricultural and dietary practices.

Although our objective is to develop modeling and analytical techniques that will be useful to nutrition planners in developing countries, we chose the U.S.A. as the country for our initial study because the necessary data were more accessible, thereby freeing us to devote a greater portion of our time to the modeling and computation steps, which would be similar for all countries. Based on available data[11], we obtained estimates of the nutrient contents, prices, and quantities of land, water, and fertilizer associated with one kilogram of the principal foods of the U.S.A. By assuming linearity and additivity, these values were used to formulate a simple model for estimating the quantities of essential nutrients provided by any choice of food mix (i.e., combination of foods), as well as the cost and quantities of resources (land, water, and fertilizer) required to obtain these nutrients. This model was used to compute the food balance sheet shown in Table 1 for the U.S.A. in the year 1968. The nutrients provided by the following two food mixes were computed: (1) The production food mix, which includes all foods produced in the U.S.A. in 1968, even those foods that were used as animal feed or were exported; (2) The consumption food mix, which includes only those foods that were directly utilized for human consumption. The results of these mixes are listed in Table 1, and we see that nutrient production greatly exceeds nutrient consumption. The primary reason for this excess is that a large fraction of the agricultural production is fed to animals. Also included in the table is an estimate of the national nutritional requirements (NNR), i.e., the quantities of nutrients required in 1968 to provide all members of the United States population with annual nutrient intakes equal to the levels recommended by the NAS-NRC Food and Nutrition Board[12]. [Since the NAS-NRC Board did not provide values for the essential amino acids*, we have adopted the recommendations of FAO[13].] The ratios presented in the last two columns indicate that, as would be expected for a developed country, the nutrient production and consumption levels are substantially higher (40% in the lowest case) than the estimated nutrient requirements. Notice that the nutrients having the lowest excesses are calcium and calories in the case of consumption and ascorbic acid and calcium in the case of production. Both the quantity and quality** of the protein are high, with the sulfur amino acids being the essential amino acid having the lowest excess and with lysine being the one with the greatest excess in the case of consumption.

The next step was to utilize the model in a linear programming analysis of the optimal food mixes determined by separately minimizing cost, land, water, and fertilizer while satisfying the nutritional constraints (NNR) listed in Table 1. The results presented in Table 2 correspond to three different choices of bounds:

1. Unbounded (UB): In this case no bounds (limits) were placed on the quantities (activities) of the foods in the optimal mixes. As a consequence, the resulting mixes have unacceptably large quantities of some foods (e.g., soybeans, celery, onions) and did not include a sufficiently wide variety of foods to be palatable. To remedy this problem, we introduced the bounds described below.

2. Production Bounded (PB): The second choice of

* Although linear programming has been employed in numerous analyses of agriculture, the objective has generally been to maximize profit rather than to minimize the price of food to the consumer; furthermore, most analyses have not included the nutritional needs of the country as constraints.

* Protein is composed of many different amino acids, but only eight are essential to human nutrition because the body is incapable of synthesizing them from other amino acids. These eight are called the "essential amino acids".

** The quality of a protein supply is judged on the basis of its content of each essential amino acid relative to a reference[4].

bounds corresponds to the limit where the quantity of each food in the optimal mix is not permitted to exceed the 1968 level of production of the food in the U.S.A. Although the resulting mixes are far more palatable in this case because they include a greater variety of foods than in the unbounded case, several of the mixes have unacceptably high quantities of soybeans and sorghum but low quantities of sugar (since the production level of sugar is smaller than the consumption level because of large sugar imports).

3. Consumption Bounded (CB): In this case the bounds are designed to prevent the quantity of any food from exceeding the 1968 level of consumption of the food in the U.S.A. An advantage of this choice of bounds is that the resulting food mixes are closer to the actual consumption mix; a serious disadvantage is the fact that the stringent bounds eliminate some important strategies, such as increased consumption of soybeans.

The results for all three bounds are included in Table 2 because they correspond to different limiting cases, with the unbounded case yielding the most radical food mix and the consumption bounded case yielding the most conservative mix. For example, the unbounded mix corresponds to the hypothetical limiting case where foods are selected solely on the basis of maximum effective use of resources (i.e, without considering the constraints of existing dietary preferences or production capabilities). The consumption bounded mix corresponds essentially to the opposite limit where the existing consumption food mix is adopted as an upper bound, and the results indicate which combination of items in the present mix are most effective with respect to cost and resource usage.

Table 3 shows the cost and resource usages computed for each of the food mixes in Table 2. For ease of comparison, each cost and resource usage has been divided by the values estimated in Table 1 for the cost and resource usages corresponding to the consumption food mix of the U.S.A. in 1968. The results indicate that the cost and resource usages may be reduced approximately by a factor of five or more in the unbounded cases, by a factor of four or more in the production bounded case, and by more than a factor of three in the consumption bounded case. Notice that substantial reductions in the cost and usages of all resources are obtained by optimizing the food mix with respect to the cost or to any one of the resources. This result is a consequence of the fact that the costs and the water and fertilizer usages of many agricultural crops are closely related to the area of land required to grow a unit amount of the crop.

The sensitivity of the different optimal food mixes to the nutritional constraints is illustrated by the shadow prices given in Table 4. In this case, the shadow price of a particular nutrient requirement (constraint) is defined as the per centage change in the objective function (cost, land, water, or fertilizer) that occurs when the optimal mix is recalculated with a 10% change in the magnitude of that constraint from the NNR value given in Table 1. Since an optimal food mix will exactly satisfy some of the nutrient constraints (the "binding constraints") and will more than satisfy the remaining (non-binding) constraints, it follows that the shadow prices will have non-zero values for the binding nutrients and will be zero for the non-binding nutrients. The results in Table 4 show that calcium and calories were binding in all the cases considered here, and they usually were the most binding of the nutrients. Protein is not binding in any of these cases, and the only essential amino acids to be binding are the sulfur amino acids. [It is interesting to recall that calcium and calories had the lowest excesses of all nutrients in the food balance sheet for 1968 U.S. consumption (Table 1), and the excess of sulfur amino acids was lower than for the other essential amino acids.]

Using Tables 3 and 4 as sources of auxiliary information, we may now return to consider in more detail the optimal food mixes given in Table 2. Soybeans are included in all mixes because of their high concentrations of calcium and protein together with their relatively low cost and resource usages. At present, the majority of the U.S. soybean production is used as animal feed and is produced by large-scale farming based on the latest methods for increasing the yield and decreasing the cost. A similar statement can be made regarding several of the grains (e.g., sorghum, maize, and barley) that are included in the optimal mixes. Milk is utilized in some mixes because, in addition to being an effective source of calcium (which is the most binding nutrient in many of the cases), it also provides calories, protein, and other nutrients*. The principal contributors to meeting the calorie, protein, and essential amino acid constraints are soybeans, various grains, milk, and potatoes; sugar is another important source of calories. A variety of vegetables and fruits provide the balance of the vitamins and minerals. Absurdly large quantities of celery appear in several of the unbounded cases because, from the viewpoint of resource usage, celery is a very effective (but expensive) source of calcium and ascorbic acid.

Although the quantitative details of the results of this analysis are not expected to be entirely reliable because of the weaknesses of the food balance sheet method (see Section 2) and the approximations and simplifications associated with the model, we do believe that the results provide valuable approximate information to the nutrition planner. For example, the present results indicate that substantial reductions in cost, land, water, and fertilizer could be achieved in the U.S.A. if the population would decrease its consumption of animal products and substitute those foods that are now used primarily as animal feed (e.g., soybeans, sorghum, and maize)**. Since an animal is relatively inefficient in converting plant protein to animal

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* It should be emphasized that milk would not appear in the optimal mixes if the calcium constraint were less binding; that is, milk is not one of the most effective sources of nutrients other than calcium.

** There are various possible strategies for encouraging this change, such as nutrition education and the development of meat analogs (e.g., soybean products having meat-like texture and taste.

Table 1. Extended Food Balance Sheet for the U.S.A. in 1968.

A Comparison of the Nutrient Production (NP) and Nutrient Consumption (NC) with an Estimate of the National Nutritional Requirements (NNR)

| Nutrients | Units | NP | NC | NNR | NP/NNR | NC/NNR |
|---|---|---|---|---|---|---|
| Calories | $10^{15}$ Kcal. | 0.93 | 0.26 | 0.16 | 5.82 | 1.63 |
| Protein | $10^{10}$ Kg. | 3.74 | 1.02 | 0.40 | 9.42 | 2.57 |
| Essential Amino Acids: | | | | | | |
| Tryptophan | $10^{9}$ Kg. | 0.45 | 0.13 | 0.05 | 8.96 | 2.65 |
| Leucine | $10^{9}$ Kg. | 3.62 | 0.84 | 0.26 | 13.95 | 3.21 |
| Isoleucine | $10^{9}$ Kg. | 1.86 | 0.52 | 0.19 | 9.78 | 2.70 |
| Lysine | $10^{9}$ Kg. | 1.83 | 0.62 | 0.19 | 9.59 | 3.25 |
| Valine | $10^{9}$ Kg. | 2.05 | 0.58 | 0.22 | 9.36 | 2.59 |
| Threonine | $10^{9}$ Kg. | 1.44 | 0.40 | 0.15 | 9.07 | 2.67 |
| Sulfur Amino Acids | $10^{9}$ Kg. | 1.24 | 0.36 | 0.16 | 7.72 | 2.26 |
| Aromatic Amino Acids | $10^{9}$ Kg. | 2.98 | 0.83 | 0.30 | 9.96 | 2.77 |
| Vitamin A | $10^{15}$ I.U. | 0.99 | 0.41 | 0.17 | 5.79 | 2.38 |
| Ascorbic Acid | $10^{7}$ Kg. | 0.86 | 0.79 | 0.39 | 2.22 | 2.03 |
| Niacin | $10^{6}$ Kg. | 7.90 | 2.70 | 1.08 | 7.30 | 2.50 |
| Riboflavin | $10^{6}$ Kg. | 0.49 | 0.20 | 0.11 | 4.46 | 1.78 |
| Thiamin | $10^{6}$ Kg. | 1.19 | 0.25 | 0.08 | 14.85 | 3.16 |
| Calcium | $10^{8}$ Kg. | 1.94 | 0.84 | 0.66 | 2.94 | 1.40 |
| Phosphorous | $10^{8}$ Kg. | 7.83 | 2.11 | 0.66 | 13.10 | 3.21 |
| Iron | $10^{6}$ Kg. | 9.37 | 1.91 | 0.99 | 9.37 | 1.93 |
| Magnesium | $10^{8}$ Kg. | 3.26 | 0.65 | 0.23 | 14.18 | 2.83 |
| **Cost and Resources** | | | | | | |
| Cost | $10^{10}$ $ | 2.84 | 2.52 | | | |
| Land | $10^{7}$ Ha. | 9.30 | 6.57 | | | |
| Water | $10^{7}$ Ha.-M | 4.80 | 3.30 | | | |
| Fertilizer | $10^{10}$ Kg. | 3.25 | 2.61 | | | |

Table 2. Optimal Formulations of Food Mixes Corresponding to Minimization of Four Objective Functions (Cost, Land, Water, and Fertilizer) for Three Different Bounds on the Foods [Unbounded (UB), Production Bounded (PB), and Consumption Bounded (CB)]. Food quantities are reported in millions of metric tons.

| Foods | Least-Cost Formulations | | | Least-Land Formulations | | | Least-Water Formulations | | | Least-Fertilizer Formulations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UB | PB | CB | UB | PB | CB | UB | PB | CB | UB | PB | CB |
| **Grains** | | | | | | | | | | | | |
| Wheat | + | + | 17.08* | | | 9.64 | | | 6.69 | | + | 15.80 |
| Rye | + | + | 0.15* | | | + | | | + | | | |
| Barley | 2.37 | 3.74 | 1.15* | + | + | 1.15* | | | 1.15* | | + | 1.15* |
| Oats | + | + | 1.38* | | | 1.38* | | | 1.38* | | | + |
| Maize | | + | 5.71 | + | 26.24 | 7.36* | 26.55 | 28.75 | 7.36* | | + | 7.36* |
| Rice | | | | | + | 0.79* | | | 0.79* | | 2.10 | 0.79* |
| Sorghum | 8.71 | 12.96 | 0.27* | + | + | 0.27* | | | 0.27* | | 13.85 | 0.27* |
| **Legumes** | | | | | | | | | | | | |
| Dry Beans | | | | | | + | | | 0.53* | | + | + |
| Soybeans | 25.24 | 25.50 | 3.10* | 14.90 | 2.09 | 3.10* | 5.29 | 2.41 | 3.10* | 14.55 | 26.35 | 3.10* |
| Peanuts | | | | + | | 0.71* | | | 0.71* | | | |
| Nuts | | | | | 0.25* | 0.47* | | | 0.47* | | | |
| **Animal Products** | | | | | | | | | | | | |
| Beef | | | | | | | | | | | | |
| Lamb | | | | | | | | | | | | |
| Pork | | | | | | | | | | | | |
| Poultry | | | | | | | | | | | | |
| Lard | | | | | | | | | | | | |
| Fish | | | | | | + | | | 0.83* | | | |
| Veal | | | | | | | | | | | | |
| Milk | | | 38.74 | + | 44.82 | 37.95 | 23.70 | 45.04 | 39.18 | + | + | 38.59 |
| Eggs | | | | | | | | | | | | |
| **Vegetables** | | | | | | | | | | | | |
| Peas | | | | | | | | | | | | |
| Green Beans | | | | | | | | | | | | |
| Cabbage | | 1.07* | 1.07* | + | 1.07* | 1.07* | | | | | 1.07* | 1 07* |
| Carrots | | 0.07 | | + | 0.88* | 0.88* | | + | + | + | 0.69 | + |
| Lettuce | | | | + | 4.21* | 4.18* | 10.67 | 4.21* | 4.18* | | + | 4.18* |
| Onions | | | | | | | | | | | | |
| Tomatoes | | 7.20* | 7.11 | + | 7.20* | 7.44* | + | 7.20* | 7.44* | | 7.20* | 7.44* |
| Asparagus | | | | | | | | | | | | |
| Broccoli | | 0.14* | + | | + | | | + | | | + | + |
| Brussell Sprouts | | + | | | + | + | | | | | + | + |
| Kale | | 0.01* | 0.01* | + | 0.01* | 0.01* | + | 0.01* | | + | 0.01* | 0.01* |
| Peppers | | 0.06 | + | | | | | | | | 0.22* | + |

(cont.)

Table 2 (con't)

| Foods | Least-Cost Formulations | | | Least-Land Formulations | | | Least-Water Formulations | | | Least-Fertilizer Formulations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UB | PB | CB | UB | PB | CB | UB | PB | CB | UB | PB | CB |
| Spinach | 8.15 | 0.18* | 0.18* | 19.04 | 0.18* | + | + | 0.18* | | 2.00 | 0.18* | 0.18* |
| Cauliflower | | | | | | | | | | | | |
| Celery | | | | 49.40 | 0.70* | 0.70* | 63.46 | 0.70* | | 75.15 | 0.70* | 0.70* |
| Cucumbers | | | | | | | | | | | | |
| Eggplant | | | | | | | | | | | | |
| Garlic | | | | | + | 0.04* | | | 0.04* | | | |
| **Fruits and Berries** | | | | | | | | | | | | |
| Apples | | | | | | 2.49* | | | 2.49* | | | |
| Peaches | | | | | | + | | | | | | |
| Pears | | | | | + | 0.55* | | | 0.55* | | | |
| Grapes | | | | | | | | | | | | |
| Oranges | | 4.75* | 4.48* | | + | 4.48* | | 3.70 | 4.48* | | 3.07 | 1.71 |
| Grapefruit | | + | + | | + | 1.42* | | | + | | 1.52* | 1.42* |
| Watermelon | | | | | | | | | | | | |
| Canteloupe | | | | | | | | | | | | |
| Cherry | | | | | | + | | | + | | | |
| Plum | | | | | | + | | | + | | | |
| Apricot | | | | | + | 0.14* | | | 0.14* | | | |
| Fig | | | | | 0.05* | 0.05* | | | + | | | + |
| Olive | | | | | 0.08* | 0.10* | | | + | | | |
| Nectarine | | | | | + | 0.06* | | | 0.06* | | | |
| Avocado | | | | | | 0.07* | | | 0.07* | | | |
| Tangerine | | | | | 0.08* | 0.08* | | 0.08* | 0.08* | | 0.08* | 0.08* |
| Lemon | | | | | 0.60* | 0.50* | | 0.60* | 0.50* | | 0.60* | 0.50* |
| Lime | | | | | 0.03* | | | 0.03* | + | | | |
| Tangelo | | | | | | 0.04* | | + | 0.04* | | + | + |
| Cranberry | | | | | | + | | | | | | |
| Strawberry | | | | | | | | | | | | + |
| **Other** | | | | | | | | | | | | |
| Buckwheat | + | + | 0.01* | | | 0.01* | | | 0.01* | 26.94 | 0.02* | 0.01* |
| Potato | | | | 53.27 | 13.38* | 9.10* | + | + | 9.10* | | | |
| Sweet Potato | | 0.63* | | | + | 0.49* | | | 0.49* | | | |
| Sugar | 10.55 | 4.78* | 0.46* | 17.52 | 4.78* | 9.46* | 6.11 | 4.78* | 9.46* | 3.17 | 4.78* | 9.46* |

* These quantities are at the upper limit set by the bounds on the foods.

\+ Indicates those products that would have been used in the formulation if their cost or resource usage for that particular objective function were slightly lower (less than 30% lower).

Table 3. Costs and Resource Usages of the Optimal Formulations

(Values reported are the ratios of the resource usage of the optimal formulation to the corresponding values for U.S. consumption in 1968.)

| Resource | Least-Cost Formulations | | | Least-Land Formulations | | | Least-Water Formulations | | | Least-Fertilizer Formulations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UB | PB | CB | UB | PB | CB | UB | PB | CB | UB | PB | CB |
| Cost | 0.13 | 0.16 | 0.27 | 0.46 | 0.35 | 0.36 | 0.49 | 0.31 | 0.35 | 0.42 | 0.17 | 0.29 |
| Land | 0.30 | 0.33 | 0.33 | 0.21 | 0.25 | 0.30 | 0.23 | 0.25 | 0.30 | 0.38 | 0.32 | 0.32 |
| Water | 0.27 | 0.31 | 0.37 | 0.20 | 0.21 | 0.32 | 0.19 | 0.20 | 0.30 | 0.45 | 0.30 | 0.35 |
| Fertilizer | 0.22 | 0.25 | 0.28 | 0.29 | 0.30 | 0.30 | 0.26 | 0.29 | 0.31 | 0.20 | 0.24 | 0.27 |

Table 4. Binding Nutritional Constraints in Optimal Formulations

(Values reported are the per centage change in the objective function for a 10% change in the nutritional constraint.)

| Nutrients* | Least-Cost Formulations | | | Least-Land Formulations | | | Least-Water Formulations | | | Least-Fertilizer Formulations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UB | PB | CB | UB | PB | CB | UB | PB | CB | UB | PB | CB |
| Calories | 0.01 | 0.01 | 2.40 | 0.34 | 4.40 | 12.80 | 0.52 | 3.20 | 19.20 | 0.38 | 4.02 | 4.18 |
| Sulfur Amino Acids | 0 | 0 | 0 | 0.52 | 0 | 0 | 3.16 | 0 | 0 | 0.80 | 0 | 0 |
| Vitamin A | 0 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.05 | 0.41 | 0.40 |
| Ascorbic Acid | 0.25 | 2.01 | 0.99 | 0 | 0 | 0 | 0.04 | 0.18 | 0 | 0 | 0.55 | 0 |
| Niacin | 0.24 | 0 | 0 | 1.10 | 0 | 0 | 1.04 | 0 | 0 | 0 | 0 | 0 |
| Riboflavin | 4.35 | 3.55 | 0 | 1.42 | 0 | 0 | 1.38 | 0 | 0 | 2.97 | 0.52 | 0 |
| Calcium | 3.30 | 2.54 | 8.70 | 1.78 | 5.03 | 2.35 | 3.74 | 5.75 | 0.20 | 5.42 | 5.11 | 6.50 |
| Iron | 0 | 0 | 0 | 0 | 1.10 | 0 | 0 | 1.05 | 0 | 0 | 0 | 0 |

* Only nutrients which were binding in at least one formulation are included in this table.

protein, it seems logical to adopt the view that now prevails in most developing countries; i.e., that animal products are a luxury to be used sparingly to enhance main dishes composed of grains and legumes.

The same modeling and analytical methods could be applied equally well to a developing country. In such cases, however, we would expect to find some nutrient deficits, and the present analysis could be used to compare the various alternative agricultural strategies for eliminating the deficits at low cost and with effective use of resources.

### 3.2 PRELIMINARY ANALYSIS OF ALTERNATIVE DIETS FOR SPECIFIC TARGET GROUPS

Since the severity of malnutrition in a country generally is found to be far greater for some segments of the population (e.g., young children) than it is for the overall population, nutrition planners will usually find that it is more economical to concentrate on programs that are designed specifically for the most critical segment ("target group") rather than for the population as a whole. In this case, the food balance sheet method described in Sections 2 and 3.1 is not adequate by itself because the specific needs and pecularities of the target group may be overshadowed by the general characteristics of the total population. For example, in situations where the diet of the target group depends either on low income or on erroneous feeding practices rather than on inadequate food production, the nutrient deficiencies of the target group may be completely unrelated to the nutrient deficits indicated by the food balance sheet. To provide a more accurate view of the target group, it is necessary to move from the level of the food balance sheet to the level of the consumer expenditure and food consumption surveys. Linear programming is often employed in analyses at this level[14], and we have attempted to increase the value of these analyses by adding two constraints that often are omitted: (a) the requirement for essential amino acids; (b) a limitation on the total bulk (volume) of food that a person is capable of consuming daily. The bulk constraint is extremely important in the case of young children because in many countries their traditional diets are based on foods and mixtures having nutrient concentrations that are so low that it is physically impossible for a child to consume the large quantity required to provide adequate amounts of calories and protein[15].

Although the analysis can be applied to any target group, we have chosen to concentrate initially on young children (the approximate age range being 1 to 5 years), since they often are the most critical group with respect to malnutrition. The general objective of the analysis is to assist the nutrition planner in designing and comparing alternative nutrition strategies that will provide children with adequate quantities of the essential nutrients at low cost and at sufficiently low bulk. Our initial goal was to explore the attributes of the analysis by considering children's diets in five regions representing different staples: Northern Nigeria (millet and sorghum), Southern Nigeria (yams and cassava), Mexico (maize), India (rice), and Turkey (wheat). Three segments of the population were studied: (1) a child weighing 20 kg (age approximately 9 to 18 months); (2) a child weighing 20 kg (age approximately 5 to 6 years); (3) an adult weighing 60 kg. The adult was included as a standard for comparison. The necessary inputs to the linear programming analysis are: (1) data on the costs, bulk*, and nutrient contents of the principal foods for each of the countries: (2) the recommended nutrient intakes for each group (see Table 5); (3) the bulk limitation of each group (estimated to be 900 and 1250 ml/day for the 10 and 20 kg children, respectively). Since malnutrition of children is predominantly associated with calorie and protein deficiencies, we have chosen to simplify the present analysis by neglecting the vitamin and mineral requirements.

A summary of the results of this analysis is presented in Table 6. In the present case a least-cost diet is defined as a particular combination (mix) of regional foods that meets the nutritional and bulk constraints of the target group while minimizing the cost. The analysis considered a greater number of foods than listed in the table (which includes only those foods appearing in at least one of the formulations). Foods that were not considered in the analysis for a particular region are denoted by the entry of a dash in the table; the entry of a zero denotes foods that were considered but were not selected as components of the least-cost formulation.

At this point we should mention that it is apparent from the results in Table 6 that the least-cost diets obtained in this preliminary stage are unrealistic for actual consumption because the variety of foods in any diet is too limited and the quantities of some foods (e.g., oil and cowpeas) are absurdly large for children to digest. The analysis would yield more realistic diets if vitamins and minerals were added to the nutritional constraints (this would increase the variety) and if reasonable bounds were placed on the quantities of certain foods. As an example of the use of bounds, we found in the present study of Southern Nigeria that the principal regional staples, yams and cassava, would not be included in the least-cost diets unless forced in by means of a lower bound. We are now developing a program (Section 4) that will enable us to introduce bounds more easily and thereby observe their consequences.

In spite of the unrealistic aspects of the least-cost diets in Table 6, we believe that these results do provide some useful approximate information. To illustrate the main features of the analysis and the results, we will discuss the least-cost diets for Northern Nigeria in considerable detail. The analysis considered seven of the most commonly consumed foods of Northern Nigeria, but the solution shown in Table 6 utilizes only three of these: millet, oil, and cowpeas. It is of interest to point out that a diet composed solely of millet (804 g) would also fulfill all of the nutrition constraints of the adult, but its cost would be higher than that of the present solution because oil and cowpeas are cheaper

* Since water is added to many foods to obtain a consistency that is acceptable to children, our values for the bulk of each food include an estimate of the added water.

Table 5. Nutritional Constraints for children weighing 10 kg and 20 kg (abbreviated C10 and C20, respectively) and for an adult weighing 60 kg (A60).

| Nutrient | Units | C10 | C20 | A60 |
|---|---|---|---|---|
| Calories [a] | kcal/day | 1150 | 1775 | 2750 |
| Total Protein [b] | g/day | 14 | 20 | 36 |
| Essential Amino Acids [c] | | | | |
| Isoleucine | mg/day | 760 | 1030 | 930 |
| Leucine | mg/day | 1010 | 1375 | 1240 |
| Lysine | mg/day | 735 | 1000 | 900 |
| Aromatic Amino Acids | mg/day | 1150 | 1560 | 1405 |
| Sulfur Amino Acids | mg/day | 630 | 855 | 770 |
| Threonine | mg/day | 580 | 790 | 715 |
| Tryptophan | mg/day | 180 | 250 | 225 |
| Valine | mg/day | 830 | 1130 | 1015 |

[a] Based on Caloric Requirements, FAO, Rome, 1957.

[b] The required protein per unit body weight is assumed to be 1.4, 1.0, and 0.6 g/kg for C10, C20, and A60, respectively. [Protein Requirements, WHO, Geneva, 1965.]

[c] Based on the assumption that E/T is 42% for C10, 40% for C20, and 20% for A60. [E/T represents the required proportion (percent by weight) of essential amino acids in the total protein.] The amino acid requirements follow the recommendations of Munro [in Parenteral Nutrition (A. Wilkinson, ed.) Balliere, Tindall and Cassell, London (in press)].

Table 6. Least-cost diets calculated for children weighing 10 kg and 20 kg (abbreviated C10 and C20, respectively) and for a 60 kg adult (A60). The foods are expressed in g/day.

| | Northern Nigeria (Millet & Sorghum) | | | Southern Nigeria (Yams & Cassava) | | | Mexico (Maize) | | | India (Rice) | | | Turkey (Wheat) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foods | A60 | C20 | C10 | A60 | C20 | C10 | A60 | C20 | C10 | A60 | C20 | C10 | A60 | C20 | C10 |
| Millet and/or Sorghum[a] | 362 | 201 | 148 | - | - | - | - | - | - | - | - | - | - | - | - |
| Yams | 0 | 0 | 0 | 700[1] | 140[1] | 100[1] | - | - | - | - | - | - | - | - | - |
| Cassava | 0 | 0 | 0 | 400[1] | 70[1] | 50[1] | - | - | - | - | - | - | - | - | - |
| Maize | - | - | - | 2 | 142 | 95 | 772[c] | 260 | 191 | - | - | - | - | - | - |
| Rice | - | - | - | - | - | - | 0 | 0 | 0 | 755 | 233 | 166 | - | - | - |
| Wheat | - | - | - | - | - | - | 0 | 20 | 11 | 0 | 45 | 35 | 983[d] | 301 | 217 |
| Oil | 169 | 110 | 63 | 160 | 90 | 49 | 0 | 80 | 42 | 0 | 78 | 41 | 0 | 88 | 48 |
| Cowpeas | 4 | 35 | 25 | 75 | 80 | 68 | - | - | - | - | - | - | - | - | - |
| Dry Beans | - | - | - | - | - | - | 0 | 23 | 17 | 0 | 0 | 0 | 0 | 1 | 2 |
| Chickpeas | - | - | - | - | - | - | - | - | - | 0 | 24 | 18 | 0 | 0 | 0 |
| Shadow Prices[b] | | | | | | | | | | | | | | | |
| Calories | .84 | .80 | .75 | .45 | .56 | .53 | 1.0 | 1.25 | 1.33 | 1.0 | 1.05 | 1.09 | 1.0 | 1.26 | 1.28 |
| Sulfur Amino Acids | 0 | .05 | .05 | .12 | .77 | .82 | 0 | 0 | 0 | 0 | .16 | .18 | 0 | 0 | 0 |
| Lysine | .09 | .17 | .18 | 0 | 0 | 0 | 0 | .07 | .08 | 0 | .07 | .08 | 0 | .15 | .18 |
| Tryptophan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .13 | .14 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Protein | .07 | 0 | 0 | .07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bulk | 0 | 0 | 0 | 0 | .54 | .57 | 0 | .44 | .50 | 0 | .30 | .33 | 0 | .40 | .46 |

a Although the amounts shown here are for millet, equivalent amounts of sorghum could replace part or all of the millet at small incremental cost.

b The shadow price of a constraint is the percent change in the cost of the least-cost diet when the level of the constraint is changed by 1 per cent.

c The required amount of maize increases when we assume that a portion of the maize is prepared as tortillas.

d To account for the loss of nutrients occurring when wheat is prepared as bread, it is assumed that only 100 g of wheat are consumed in unprocessed forms while the remainder is consumed as bread.

1 The amount of this food is equal to the lower bound selected to insure that at least a minimal amount would be present in the formulation.

sources of calories and lysine, respectively, than is millet. Since the typical level of consumption of millet and sorghum in Northern Nigeria is above 400 g/day, the amount of millet (362 g) in the present solution appears to be reasonable. On the other hand, the amount of oil in the solution is unreasonable because it is approximately twelve times the typical consumption. When oil is constrained to a more reasonable quantity by introducing an upper bound, the amount of millet in the solution increases sufficiently to fulfill the calorie constraint, and the diet cost becomes slightly higher.

The shadow prices given in Table 6 show that, in the case of the least-cost diet for the adult in Northern Nigeria, only three of the constraints are binding: calories, lysine, and protein. Since the shadow price is greatest for calories, we may conclude that the cost of the present solution depends most strongly on the level of the calorie constraint (2750 kcal) and on the costs of the foods that are the major contributors to the fulfillment of this constraint.

The solution for children's diets in Northern Nigeria include the same three foods that appeared in the adult diet, but cowpeas are utilized to a greater degree because the nutritional constraints require a considerably higher protein quality for children than for adults. Although calories continue to be the predominant binding constraint, the requirement for high protein quality causes lysine and the sulfur amino acids to also be binding. To illustrate the contributions of each food to these binding constraints we have calculated the following contribution percentages from the results shown in Table 6 for the 10 kg child: Calories - oil 49%, millet 44%, cowpeas 8%; lysine -cowpeas 53%, millet 47%; sulfur amino acids - millet 84%, cowpeas 16%. Oil and cowpeas play important roles because they are very concentrated sources of calories and lysine, respectively. Our analysis shows that if we were to limit oil and cowpeas to more reasonable quantities, millet would increase to the degree that the bulk constraint would become binding, thereby forcing other foods to appear in the formulation and resulting in a substantial increase in the cost.

Calculations of least-cost diets for Northern Nigeria presented an unusual problem because the regional staples, yams and cassava, have very low concentrations of calories and protein. The least-cost diets that we obtained initially were unacceptable because the regional staples were completely excluded and maize was utilized to a far greater extent than its actual level of consumption in the region. The solution shown in Table 6 was obtained for the adult diet when constraints were added to force the staples to be utilized at levels that are approximately equal to their typical consumption levels. In the case of the children's diets, the bulk constraint severely limits the quantities of yams and cassava that may be forced into the diet. Even the moderate quantities shown in Table 6 are sufficiently large to cause the bulk constraint to be binding, and yet their nutritional content is sufficiently low that the quantities of maize, oil, and cowpeas appearing in the solutions are unreasonably high relative to the typical consumption pattern. This problem emphasizes the difficulties associated with formulating children's diets based on yams and cassava.

The least cost diets for the adult in Mexico, India, and Turkey were extremely simple because in each case they contain only a single food, the regional staple. The explanation for this result is that the staple is the cheapest source of calories, and the amount required to fulfill the calorie constraint provides enough protein and essential amino acids to surpass the corresponding constraints. The children's diets do not exhibit such simplicity because additional foods are included as a result of the bulk constraint and the requirement for high protein quality. Oil is utilized as a supplementary source of calories in all cases, and the amino acid pattern of the regional staple is supplemented by the addition of legumes (e.g., dry beans and chickpeas) and, in some cases, a second grain (wheat). Notice that the shadow prices indicate that the binding constraints are calories, bulk and several amino acids.

The results of the present study show that the formulation of least-cost diets for children may be influenced to a great degree by the bulk constraint, i.e., the limit on the bulk of food that a child may consume daily. This result is consistent with recent statements by Nicol[15]. As indicated by the shadow prices in Table 6, the bulk constraint frequently is as influential as the nutritional constraints. This suggests that it would be worthwhile to determine if changes in food preparation and/or feeding schedules are feasible and would result in an increase in the amount of low nutrient density foods that a child may consume without discomfort. It also points out the need for more accurate data on the bulk consumed by children of various ages.

In Table 6 we see that all of the least-cost diets computed for children contain large quantities of oil because of its high caloric concentration. Furthermore, the shadow prices show that in all cases calories are among the binding constraints, and in most cases calories are more binding than the amino acids. These results indicate that child nutrition programs should not concentrate on protein to the extent that calories are neglected, especially since diets deficient in calories result in some waste of protein as metabolized energy. We also note that, for the particular cases considered in Table 6, the shadow prices show that the sulfur amino acids and lysine generally prove to be the most binding amino acid constraints.

In considering the possibility of utilizing new foods, the planner benefits from data on the <u>competitive prices</u> of the foods, i.e., the price at which the food will appear in a least-cost diet having exactly the same cost as the reference least-cost diet (e.g., the diets in Table 6). The present analysis provides these data, but we will not attempt to present the details. It is of interest to point out, however, that in all of the cases covered in Table 6 the competitive prices indicate that oil seed meals would be more economic choices than animal products (milk, eggs, chicken, lamb, beef, goat, and fish).

## 4. CONCLUDING REMARKS

There is wide-spread agreement that malnutrition is one of the most critical problems of the developing countries, and there are increasing expectations that systems analysis will contribute significantly to the planning and evaluation of programs for combatting malnutrition. At this time, however, the application of systems analysis to nutrition planning is in its infancy, and therefore the form of the analysis has not been established and the benefits and limitations are unresolved. In an attempt to provide an initial perspective of the problem, we have described (Section 2) a tentative outline of the nutrition planning process, indicating where systems analysis may prove to be useful.

In Section 3 we summarized our preliminary studies of the potential utilization of systems analysis in two aspects of the nutrition planning process. Although both studies involve drastic oversimplifications, we believe that they illustrate some of the benefits and limitations of a popular technique, linear programming. For example, these studies clearly demonstrate that the analysis depends critically on the availability and accuracy of inputs from persons representing a wide range of fields, including nutrition, medicine, agriculture, social anthropology, economics, and food technology. Without the proper inputs, the analysis yields results that are unrealistic and, therefore, of limited value (or even detrimental if not interpreted correctly).

Based on the experience gained in these preliminary studies, we are now developing a computer-aided analysis that will: (a) perform basic calculations that are useful to the nutrition planner (e.g., calculations of the nutrient deficiencies of present diets and the cost-effectiveness of various strategies for improving these diets; and calculations of least-cost diets); (b) allow for the input of human knowledge and judgment, thereby correcting for the limitations of the analytical model and ensuring more realistic results; (c) enable various members of the planning team (nutritionists, doctors, economists, etc.) to examine quickly a wide variety of possible conditions and strategies. The computer memory will contain the necessary data on the nutrient requirements and bulk limitations of different target groups, as well as data on the costs, nutrient compositions, and bulk of various foods. Our ultimate objective is to have the analysis available at a time-sharing console with a simple instruction manual so that it may be used easily by persons having no knowledge of computer programming. The operator would type in the necessary input data (e.g., country, target group, present diet) and then specify different nutritional strategies (e.g., introduce a food or food mixture that is not presently consumed in the country). After examining the results, the operator would try other strategies and/or introduce bounds to obtain more acceptable diets. Although this project is more a problem of computer-aided design than of systems analysis, it utilizes the systems approach to determine what calculations and parameters are most valuable.

The next level of this work must be done in the context of a real case because we believe that the specific details of the application of systems analysis to nutrition planning will vary substantially with the nature of the particular country, target group, available resources, and the national nutrition policy. Therefore, we are now arranging to participate in a nutrition planning project in a developing country. This experience will hopefully provide an informative case study of the systems approach to nutrition planning.

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