SYSTEMS ANALYSIS IN NUTRITION AND HEALTH PLANNING: APPROXIMATE MODEL RELATING BIRTH WEIGHT AND AGE TO RISK OF DEFICIENT GROWTH

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SUMMARY

This paper summarizes the initial phase of an effort to develop semiquantitative methods for nutrition and health planning. The general approach is to utilize the methods of systems analysis and operations research where appropriate, but the emphasis is on developing a simplified, approximate analysis that government planning groups could conveniently apply in evaluating various potential programs for attaining specific nutrition and health objectives, while satisfying certain constraints (e.g., budget, facilities, personnel).

An essential element of the analysis is a model that provides an approximate description of malnutrition (inadequate growth, as indicated by weight for age) and mortality in terms of those variables that can be affected by

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intervention programs. We have concentrated initially on using the results of two INCAP longitudinal studies to develop models relating the incidence of malnutrition (second and third degree on the Gómez scale) to age and previous growth, including birth weight. The two studies cover rural Guatemalan communities with considerable variability in ethnic, socioeconomic, and ecological conditions. Because they are tentative, the resulting models are discussed only qualitatively and not quantitatively.

The models may serve as baselines to estimate the consequences of potential programs aimed at different target groups, such as pregnant women and children whose weights at birth or thereafter fall below prescribed levels. The possible benefits of using models of this nature in nutrition and health planning are discussed.

INTRODUCTION

Within the developing countries there is an increasing recognition of the need for health planning methodologies that are more systematic and more quantitative than those now employed [1,2]. Improved methodologies are essential to insure that planning groups will be able to utilize more effectively the limited resources that are available for raising the health status of the population. But health planning is an extremely complex process involving many possible goals and variables, a wide variety of potential programs, interrelations with other sectors (e.g., agriculture, education, economics), political considerations, and cultural factors.

There have been several attempts to develop detailed mathematical methodologies [6] [(3)]. These generally are too complicated for most planners, and they usually require data that are unavailable and extremely costly to obtain. This severely restricts their usefulness to the health planner of a developing country. On the other hand, even the critics of these analyses would agree that some steps must be taken to develop a more quantitative planning methodology.

The long-range objective of our project is to develop a health planning methodology that is sufficiently simple to be readily understood and applied by planners, while at the same time being sufficiently detailed to provide useful semiquantitative results for guiding the selection of the most effective programs. Although we propose to employ the concepts and techniques of

6. For references to these attempts, see p. 105 of Hilleboe *et al.* [2]; also see articles in PAHO [4].

systems analysis [7] where appropriate, the primary emphasis is on simplicity. As a consequence of this emphasis, we realize that the resulting methodology will not be completely comprehensive or highly accurate; however, it will hopefully include many of the most important aspects of the problem.

We suggest that the planning process may be described conveniently in terms of the components shown in Fig. 1:

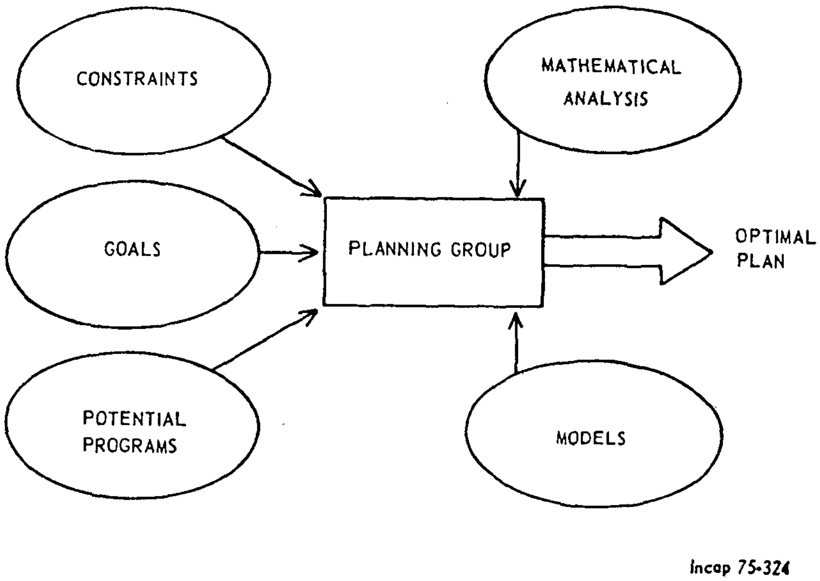

Fig. 1

Schematic diagram of the principal components of a planning process.

1. *Goals.* It is generally agreed that a planning group cannot proceed without having a clearly-defined set of goals, described in quantitative terms and to be reached in a given period of time (e.g., to reduce infant mortality by 50% within 10 years) [5]. These goals are selected at a higher government level, but it is the planners responsibility to see that the goals are reasonable and clearly defined. The definition of quantitative goals is at the same time the very first decision to be taken in the process of health planning, and the most important one.

7. The term "systems analysis" is used here in its most general sense; i.e., it includes operations research, simulation techniques, decision analysis, econometrics, and mathematical optimization methods.

One of the roles of the planner —and of the analyst— is to provide adequate information to assist the political decision-maker *in making* the best choice of goals.

2. *Constraints.* The possible means for attaining these goals are restricted by various constraints, such as those relating to availability of resources (funds, facilities, trained personnel, supplies) and availability of adequate technologies, as well as constraints relating to political and cultural factors. These constraints are classically separated into "intra-sectorial constraints", i.e., those within the health system, and "extrasectorial" ones. The planner must decide which constraints are most important and how they can be included in the decision process, either explicitly or implicitly.

3. *Potential Programs.* Since there are a vast number of potential programs that could be considered as possible candidates for attaining the prescribed goals, the group must limit its considerations to a reasonable number of programs. This elimination process is influenced by the nature of the goals and the constraints, and also requires the group to make qualitative estimates of which programs appear to be most promising.

The three components commented upon so far (goals, constraints, and potential programs) can be expressed in terms of variables which, in principle, can be interconnected by means of equations representing their mutual interplay. This is the role of the other two components of Fig. 1 (models and mathematical analysis).

4. *Models.* In order to compare the relative attributes of the various potential programs, the planners must be able to estimate the expected performance of each program (i.e., the level of contribution of each program to the prescribed goals for different levels of inputs of resources). These estimates require the development of "models", i.e., approximate mathematical descriptions, of: (a) the dependence of the outputs of a program on the inputs (investments of resources); and (b) the influence of these programs outputs (e.g., lower risk of malnutrition) on the prescribed goals (e.g., reduce infant mortality by 50% within 10 years).

5. *Mathematical Analysis.* A principal objective of the planner is to design an "optimal plan", i.e., a specific combination of programs that has the highest probability of meeting the prescribed goals, while minimizing expenditures of the most scarce resources and also being consistent with the other constraints. Generally, this design step is most conveniently accomplished with a mathematical analysis that interrelates the

models, goals, and constraints in terms of an evaluation parameter that may involve costs, effectiveness, efficiency, number of persons affected, or other measures of performance. The analysis might be linear programming or a simulation method. Clearly, the practical implementation of the analysis would be greatly facilitated if analytical results for a wide range of variables could be presented in terms of generalized graphs and tables, thereby minimizing the necessity of complex computations by the planner.

Although it might appear from this description that each of these five components should be considered separately in the order given above, this would not be the most effective approach in an actual planning process. Instead, some aspects of the components should be considered simultaneously because of strong interrelationships (e.g., constraints and mathematical analysis); furthermore, we expect that the planning group will decide to modify the initial details of the components after other components are developed and a more accurate view of the overall problem evolves.

In previous studies we have considered various aspects of the application of systems analysis to the planning of nutrition-related programs in developing countries [6-8]. One of our recent studies [9] illustrates how a simple model of malnutrition and mortality for children below 4 years of age could be utilized in an approximate analysis of the expected consequences of nutrition intervention programs. This preliminary illustration motivated the present study to develop a more satisfactory model of malnutrition, i.e., of inadequate growth as expressed by the weight of children at various ages. Specifically, we have attempted to develop models that would help the planner to see more clearly the consequences of intervention programs that affect the growth of children in different age intervals (including the prenatal period) or that are restricted to children with low birth weight. The models are based on available results of detailed long-term prospective (longitudinal) studies conducted by INCAP [10-12] in rural Guatemala. For thorough discussions of these data, publications by Mata *et al.* [10, 11] and Lechtig *et al.* [12] may be consulted. In the present paper we concentrate on the modeling procedures and several illustrative applications, since the models are not yet sufficiently refined to warrant detailed interpretation and application.

Although malnutrition is only one of the many health problems encountered in developing countries, it is considered to be among the most important and serious problems for children during the first two or three years of life [13]. We expect that the modeling procedures developed for malnutrition will prove to be useful in studies of other health problems.

DESCRIPTION OF MALNUTRITION MODEL

The primary purpose of the models in this study is to illustrate the potential usefulness of such models in the planning of programs for improving the growth of preschool children. With this purpose defined, the next step is to determine what choice of variables appears to be most meaningful.

Dependent Variables

One of the most widely accepted indicators of inadequate growth of preschool children is the Gómez classification of the prevalence of malnutrition [14]. The PAHO Interamerican Study of Mortality in Infancy and Childhood [13] has shown that children in specific age intervals whose weight falls below 75% of the mean weight of children of the same age and sex in an economically advanced area (i.e., children in the second or third degree of malnutrition according to the Gómez classification) have higher risk of death than those with adequate growth. It is recognized that growth depends on morbidity as well as on diet, but is relatively independent of genetic differences in the first few years of life [15].

We shall adopt the percentage of children with weight below 75% of the standard as a dependent variable of the model although it has certain deficiencies, especially for children over 2 years of age[16]. The mean weights of children in Denver [17] will be used as the standard because of the large size of the sample and the convenient form of the published data.

The prevalence of babies with low birth weights ($\leqslant$2.5 kg) will be adopted as the second dependent variable because of its proven value as an indicator of unfavorable prenatal conditions that result in higher risks of malnutrition, morbidity, and mortality in the postnatal period [11]. Low birth weight is an indicator of fetal malnutrition resulting from inadequate health and nutrition of the mother before and during pregnancy [11, 12]; it is recognized that there are many non-nutritional problems that can also lead to low birth weight [18].

Deaths were not included as dependent variables because it would have complicated considerably a model aimed mainly for illustration, and also because the data available do not include a sufficient number of deaths to allow for safe conclusions. In a previous study, however, we have described a very approximate way of including this factor[9], and we plan to develop an improved mortality model that may be combined with the present model to remove this limitation.

Independent Variables

Selection of the independent variables is extremely difficult because there are so many factors that strongly influence the dependent variables (prevalence of malnutrition and low birth weight), and many of these factors can be changed by intervention programs. At present, the data available are not sufficient for adopting independent variables relating to the detailed causes of malnutrition (e.g., duration of breast feeding, nutrient content of supplemental diets, incidence of infectious diseases, social stimulation). Therefore, we will adopt the following gross variables: (1) risk of low birth weight; i.e., the probability of an infant having a birth weight of 2.5 kg or less; (2) risk of malnutrition in any age interval; i.e., the probability of a child's weight falling below the prescribed "malnutrition level" during a specific age interval; and (3) the probability of recovery; i.e., the probability of a child's weight rising above the prescribed "malnutrition level" during the age interval considered. As will be described later, the magnitude of each of these variables may be changed by various types of intervention programs.

Structure of Model

The choice of variables suggests that the structure of the model should include the following characteristics: (1) two classes of children, one with birth weights of 2.5 kg or less (the "low birth weight class", denoted by LBW), and the other with birth weights above 2.5 kg (the "acceptable birth weight class", denoted ABW); (2) two nutritional states of the children in each age interval, one corresponding to weights equal to or below the 75% level of the reference population (the "malnutrition state", denoted by M), and the other to weights above this 75% level (the "acceptable nutritional state", denoted A); (3) several age intervals within the period 0 to 2 years of age.

The model is based on these characteristics together with the following simplifying assumptions:

1. The nutritional status of a child at a particular age depends only on the child's birth weight class (LBW or ABW) and

nutritional status at the immediately-preceding age (*i.e.*, *not on* the child's nutritional status at any earlier ages). This is the assumption of a Markov process [19], and it greatly simplified the model by having only two nutrition states in each age interval, rather than numerous states corresponding to different histories (sequences of previous nutritional states). We are unable to test the validity of this assumption with the available data because there are not enough cases in many of the different histories.

2. The removal of children from the model due to deaths is being neglected at this moment, as already mentioned.

The mathematical development of the model is presented in the Annex. For the sake of illustration, and in order to avoid the use of mathematical symbols, we will use actual figures based upon the INCAP studies.

MODEL OF GUATEMALAN INDIAN VILLAGE

During the past 10 years INCAP has conducted a detailed longitudinal study of the growth and health of young children in a Guatemalan highland community, Santa María Cauqué. The data indicate that the birth weights and subsequent growth of the children are extremely poor, and morbidity, especially diarrheal diseases, is severe. Consequently, the infant mortality rate is high, being about 100 per 1,000 births. (For a more detailed description of the nature of the community, the study, and the data, see Mata *et al.* 1967 and 1974 [10, 11]).

We have analyzed the data for Santa María Cauqué to obtain estimates of the independent variables of the malnutrition model. As of February, 1972, there were 438 children with birth weights recorded, and 185 of these had low birth weights. Therefore, the risk of low birth weight is 185/438=0.42, while the probability of having acceptable birth weights is 0.58. (See Fig. 2). The number of LBW infants having data available on their weights at 3 months of age is 145, and 40 of these have weights that classify them as being malnourished. Consequently, the corresponding risk of malnutrition is, in this case, 40/145=0.28. The chance that a LBW infant will have an acceptable nutritional status at age 3 months is therefore 0.72. The corresponding probabilities for children born with an acceptable weight (ABW) were found to be 0.03 and 0.97, respectively. As can be seen, the probabilities of being malnourished at 3 months vary widely according to the birth weight.

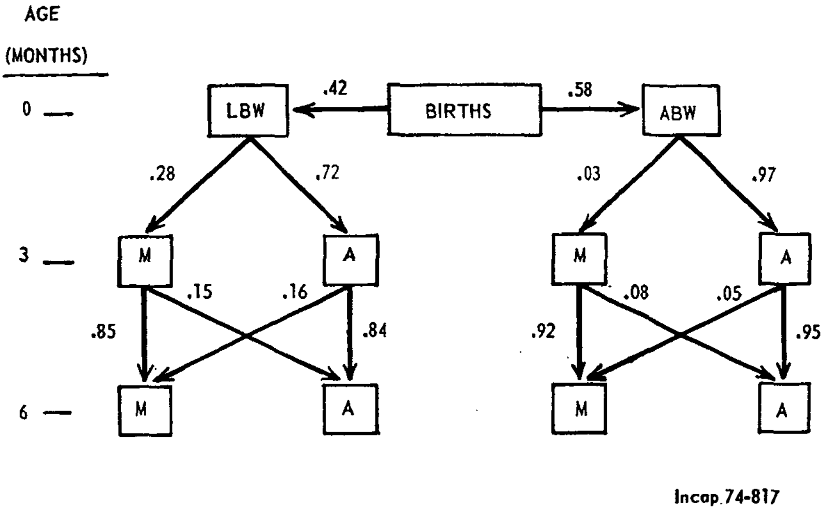

Fig. 2

Malnutrition model (0 to 6 months) with variables evaluated from the longitudinal data for Santa María Cauqué.

Some of the LBW children who are malnourished at 3 months will recover and attain acceptable nutritional status at 6 months (0.15 of them, while 0.85 will remain malnourished). Similarly, 0.16 of the children with LBW who are adequately nourished at 3 months will be found malnourished at 6 months. The corresponding figures for the children born with an acceptable weight are 0.08, 0.92, 0.05, and 0.95, respectively, as shown in Fig. 2.

The same is obtained for all other age intervals (see Fig. 3 for the fully developed model for Santa María Cauqué). The final result is that we have a sufficient set of equations to calculate the dependent variables (prevalence of malnutrition at various ages, and the prevalence of low birth weight children) if the values of the independent variables are known.

The two birth weight models (LBW and ABW) shown in Fig. 3 can be combined into one malnutrition model. The result is presented in Fig. 4.

MODEL OF LADINO COMMUNITIES

INCAP also is conducting a longitudinal study of four rural Guatemalan communities [12] in which the people are predomi-

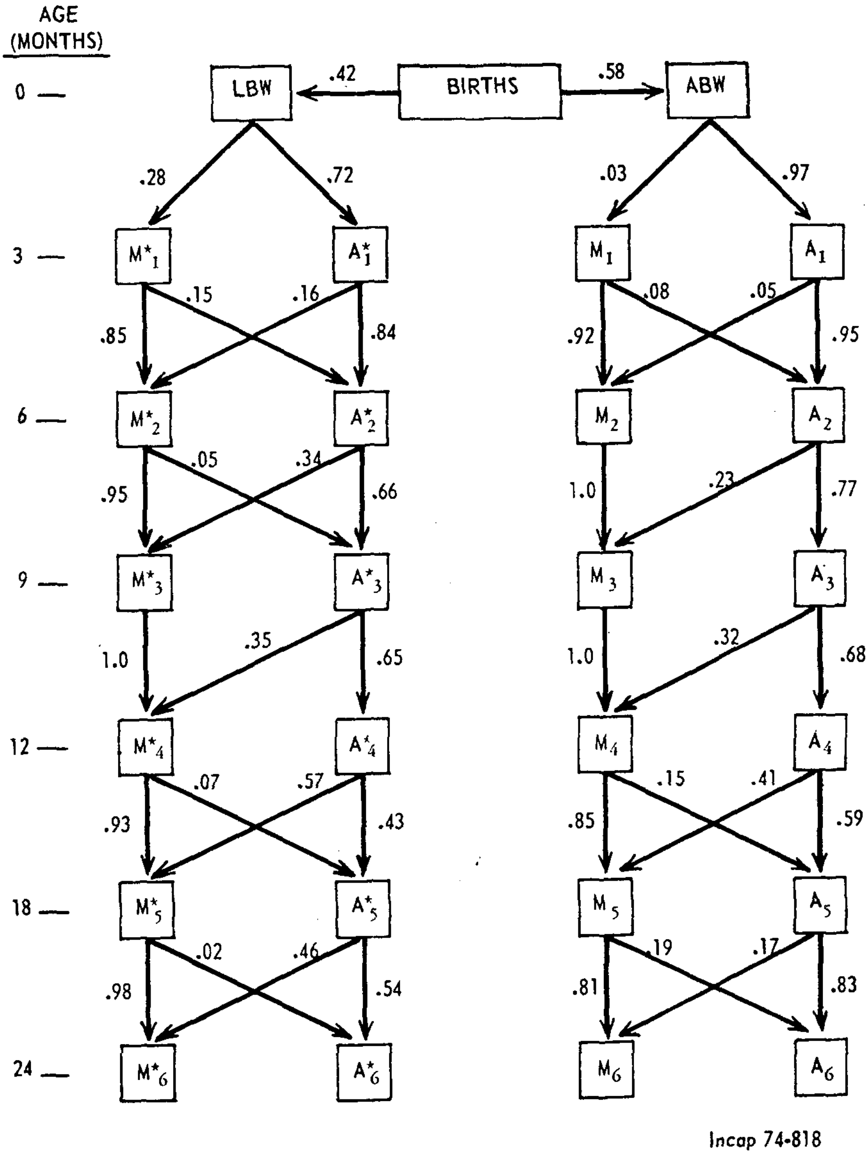

Fig. 3

Malnutrition model (0 to 24 months) with the variables evaluated from the longitudinal data for Santa María Cauqué.

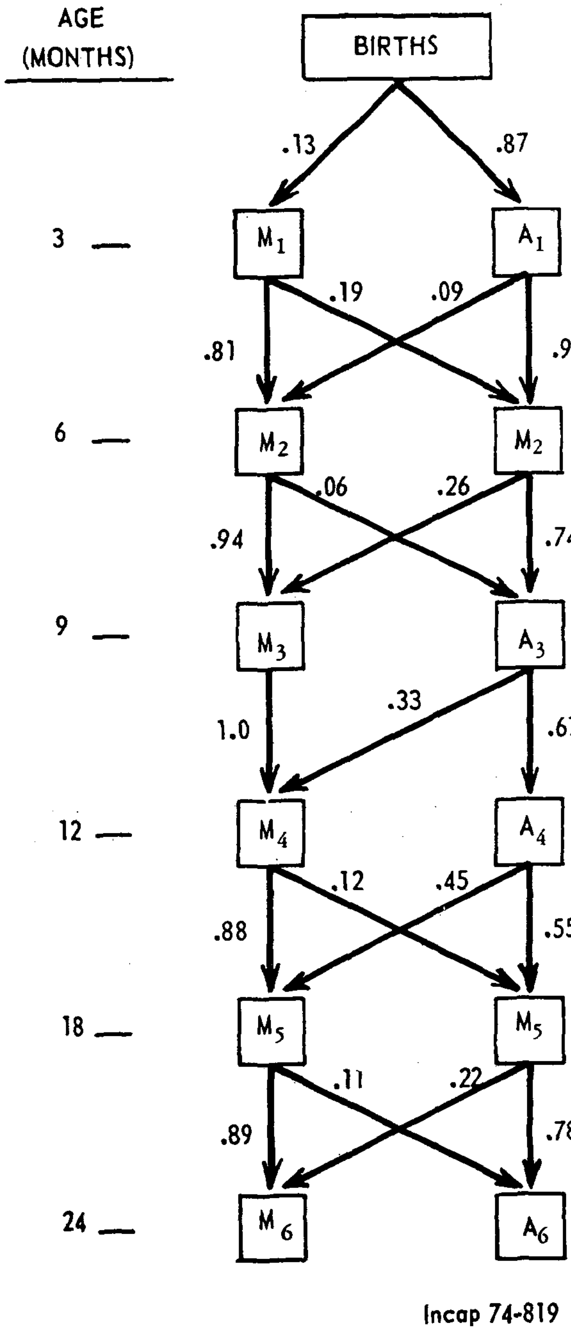

Fig. 4
Malnutrition model formed by combining the two birth weight models shown in Fig. 3.

nantly "ladinos", that is, people who do not use Indian dress and languages and do not follow Indian traditions. These communities provide a valuable contrast to Santa María Cauqué because their socioeconomic condition is higher, with the consequences being much lower prevalences of low birth weight babies (0.14 vs. 0.42) and of malnutrition (0.21 vs. 0.69 at age 2 years), plus a lower infant mortality rate (approximately 50/1,000 vs. 100/ 1,000 live births). Because of these differences between the ladino and Indian communities, it is expected that the respective models for these communities will aid in developing a more general model that, with minor adjustments based on cross-sectional data, will provide an approximate description of communities for which such detailed data are not available. A general model of this nature would be valuable in government planning efforts in which a variety of communities are considered. Although we have not yet attempted to formulate a general model, we are encouraged by the observation that the dependence of prevalence of malnutrition on age is qualitatively similar for the ladino and Indian communities (Fig. 5), although there are substantial quantitative differences. This observation suggests that it may be possible to formulate a general model in terms of several "similarity parameters" that could be evaluated for any community in terms of data that are either presently available or readily measured.

In the longitudinal study of the ladino communities, several different interventions have been implemented and monitored [20]. Consequently, the longitudinal data are a potential basis for developing models of these interventions. As a first step, we have concentrated on modeling only the intervention of reducing the prevalence of low birth weight babies by means of a caloric supplement to women during pregnancy. Since the details of this intervention are described and analyzed in previous publications [12], we will go directly to the preliminary model in Fig. 6 that has been developed by a procedure similar to that described in Section 3 and in the Annex. At present, this model extends only to 6 months of age because other interventions complicate the situation after that point.

The pregnant women are, for reasons explained elsewhere [12], divided into two groups:

AS ("acceptable supplementation") = women who have consumed 20,000 or more supplementary calories during pregnancy

IS ("inadequate supplementation") = women who have consumed less than 10,000 supplementary calories during pregnancy

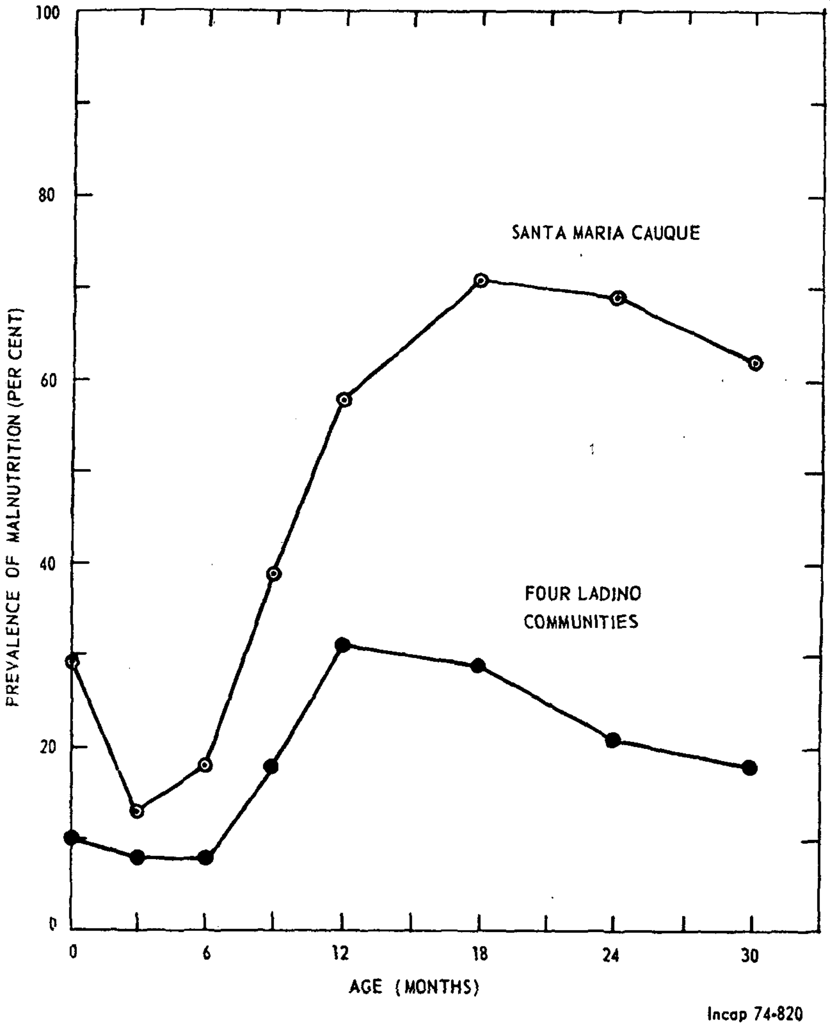

Fig. 5

Comparison of the age dependence of the prevalence of malnutrition in ladino and Indian Guatemalan communities.

The IS group is taken as the reference group, since their average consumption of supplement is sufficiently low to be essentially negligible relative to that of the AS group. The variable C_e in Fig. 6 represents the effective coverage of the supplementation program, i.e., it is defined as the fraction of pregnant women who consume 20,000 or more supplementary calories.

As may be seen in Fig. 6, the effect of the supplementation program is to reduce the risk of low birth weight from 0.176 to 0.107. Although the intervention produces a substantial change in birth weight, analysis of the existing longitudinal data indicates that supplementation during pregnancy does not have a statistically significant effect on the postnatal growth of children of comparable birth weights during the first 6 months. This result is consistent with the assumption of a Markov process described previously, and it allows us to disregard the supplementation category of children's mothers after birth weight has been determined. This represents a considerable simplification

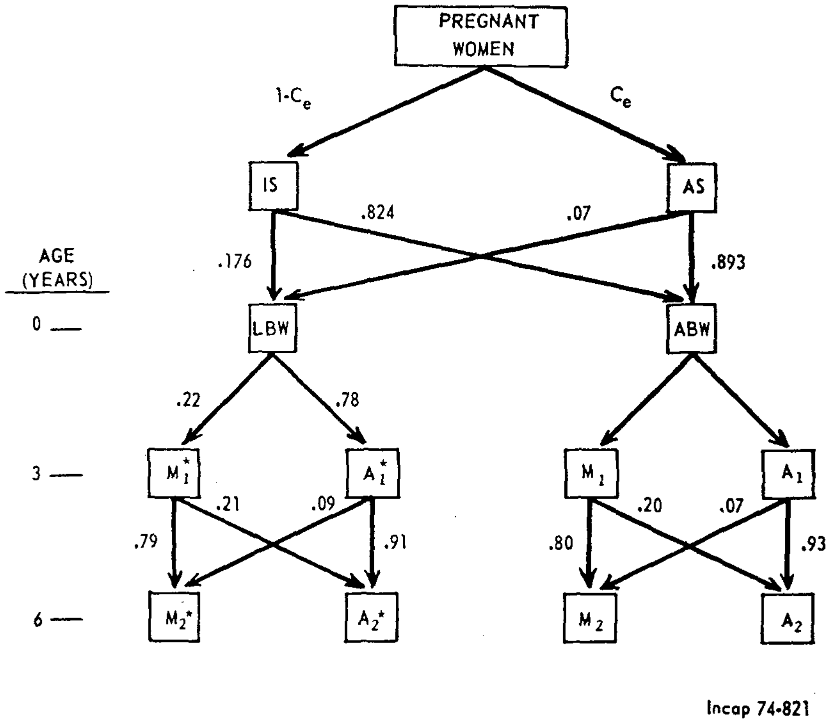

Fig. 6

Malnutrition model with variables evaluated from longitudinal data for ladino communities in Guatemala. Included is an intervention that provides a fraction (C_e) of the pregnant women with 20,000 or more supplementary calories during pregnancy. AS: 20,000 Cal. IS: 10,000 Cal.

in the model, since it would be necessary to have four states at birth (i.e., LBW+IS, LBW+AS, ABW+IS, ABW+AS) if there were a significant dependence of postnatal growth on supplementation during pregnancy.

Although the model in Fig. 6 is very preliminary, it does serve as an example of the possible role of modeling in nutrition planning. Specifically, with a model of this type it would be possible to compute the prevalence of low birth weight and the prevalences of malnutrition at 3 and 6 months of age for different levels of effective coverage, C_e. These results, together with an estimate of the dependence of the cost of the program on the level of C_e, would enable a planning group to perform a cost-benefit or cost-effectiveness analysis of the intervention.

ILLUSTRATIVE APPLICATION OF MODEL

We now consider an oversimplified illustration of the potential use of malnutrition models in health planning efforts. Although numerical values will be used in this illustration in order to prevent it from being too abstract, these values should not be considered to be accurate or realistic since the present model ignores several important factors, such as the loss of children by deaths.

Consider a hypothetical situation in which a planning group is attempting to compare the relative benefits of the following three potential intervention programs for a population similar to that of Santa María Cauqué.

1. *Birth Weight Intervention* that reduces the risk of low birth weights by 50%, i.e., from 0.42 to 0.21, without influencing significantly the values of any other variables in the model (Fig. 2). A supplemental feeding program for pregnant women is a possible example of this type of intervention [12], although we would expect that it might also affect the values of other variables in the model.

2. *Risk Intervention* in which the risk of becoming malnourished is reduced by 50% for children between 0 and 24 months of age, while the chances of becoming or remaining well nourished are increased correspondingly as described in the Annex. Possible examples of the type of intervention are programs that reduce diarrheal disease (e.g., improved water supply) or that improve the weaning diet (e.g., nutrition education, supplementary feeding). However, for both examples we would expect that there might also be changes in other variables, such as the recovery probabilities.

3. *Rehabilitation Intervention* that results in the recovery of 50% of those malnourished children who would have otherwise continued to be malnourished in the particular age interval. An example of this type of intervention is feeding plus nutrition education through nutrition rehabilitation centers [21], but we expect that such a program might also affect the risk of malnutrition. Since these centers usually do not accept children below 9 months of age, we will only consider the intervals between 9 and 24 months.

The results shown in Fig. 7 were calculated by modifying the models in Figs. 3 and 4 in the manner described above. The

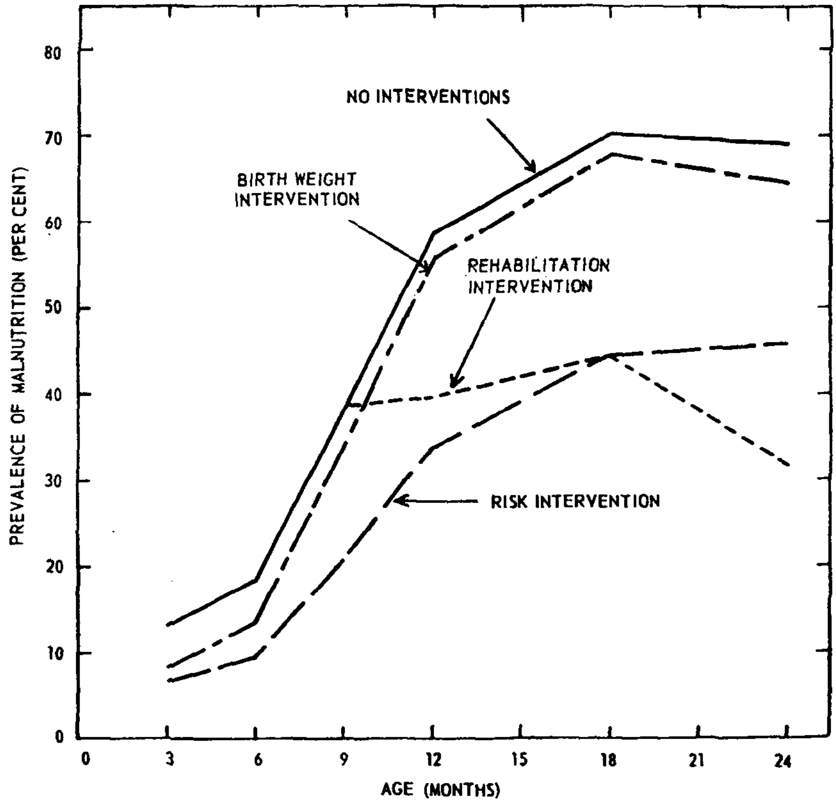

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Fig. 7

Illustration of the effects of three hypothetical interventions on the prevalence of malnutrition for 0 to 2 —year— old children. (Calculations based on the preliminary model of Santa María Cauqué).

average prevalence of malnutrition for a particular intervention is proportional to the area under the corresponding curve in the age range being considered. By measuring these areas, we have calculated the degree to which each intervention reduces the prevalence of malnutrition. The results are presented in Table 1

TABLE I

REDUCTION OF THE PREVALENCE OF MALNUTRITION BY THREE HYPOTHETICAL INTERVENTION PROGRAMS

Type of intervention	Percent reduction of malnutrition for three age ranges		
	3 to 12 months	12 to 24 months	3 to 24 months
Birth weight	14	5	7
Risk of malnutrition	46	37	39
Rehabilitation	10	40	32

for three age ranges: 3 to 12 months, 12 to 24 months, and 3 to 24 months. Results of this type would be useful to a planning group because they indicate the relative benefits of the potential interventions in different ranges of age. We will not attempt to draw definite conclusions from these results, since they are based upon a very preliminary model and therefore serve only to illustrate the procedure. Furthermore, a meaningful comparison of the interventions would require that we include program costs in the calculation to obtain results in terms of a cost-benefit or cost-effectiveness ratio. An additional need is to include mortality in the model so as to be able to compare the interventions on the basis of both malnutrition and mortality; in this case, the true value of the birth weight intervention would be more apparent.

DISCUSSION AND CONCLUSIONS

This preliminary study describes a possible method for developing simple models for health planners. In the particular case considered, a tentative model was developed of the dependence of the risk of malnutrition on birth weight and on age of children below two years of age.

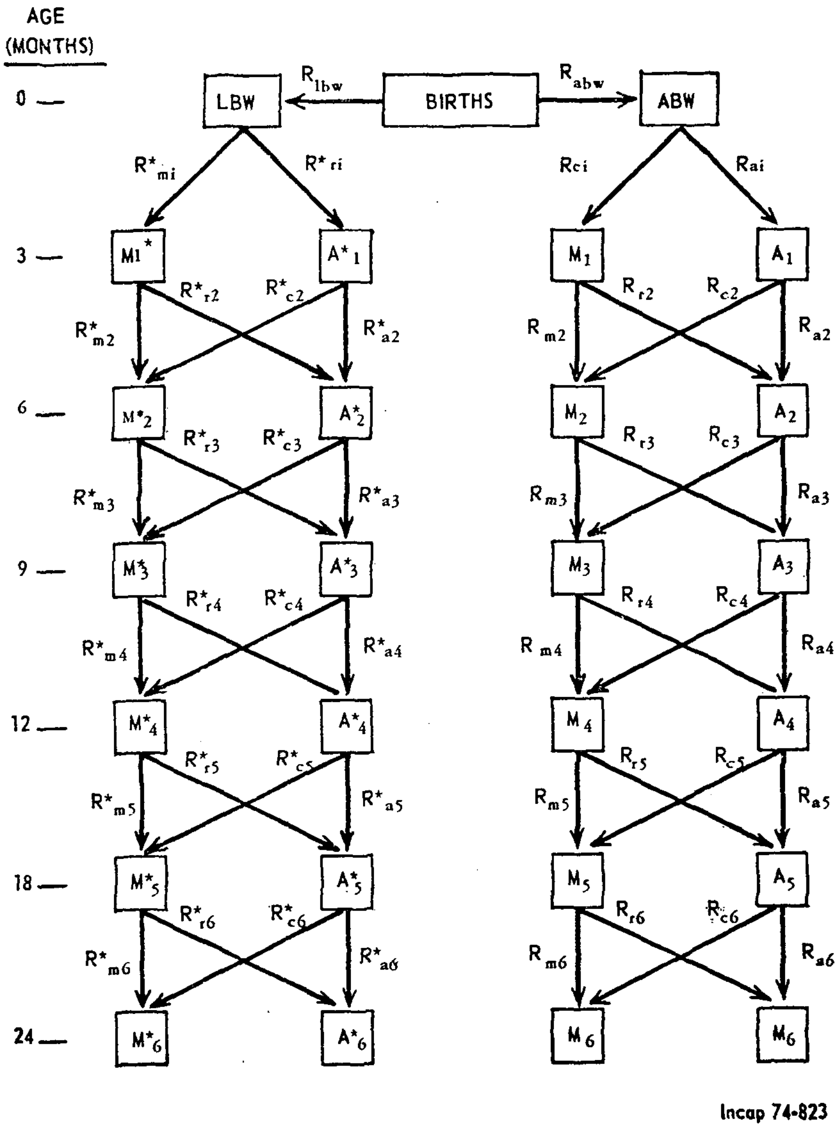

Fig. 8

Malnutrition model for children with low birth weight (LBW) and acceptable birth weight (ABW).

Although the quantitative details of the models are not expected to be highly accurate, we believe that the study serves to illustrate several points:

1. Models of this type can provide a clear view of the epidemiology of malnutrition in the population under consideration. For example, the present results for Santa María Cauqué clearly show: (a) the important role of low birth weight [11]; (b) the relatively high probability of low birth weight babies attaining acceptable weights by 3 months of age [8] (10); (c) the high risk of malnutrition for children between 6 and 18 months of age, independent of whether or not they had low birth weights.

2. In a very preliminary manner we have illustrated how the models may be used by health planners to evaluate, on a semi-quantitative basis, the relative benefits of different potential interventions.

3. Data obtained through long-term prospective studies are extremely important to the development of planning models.

We believe that attempts to develop simple models will lead to more effective communication between research groups and planners by indicating which factors are most influential. A likely consequence is that such attempts will provide a useful feedback that will guide future research efforts by indicating the type of the information that is most essential to planning.

Our future plans are to refine these models by more thorough analysis of a larger collection of data, and to attempt to develop a general model that can be applied to communities for which longitudinal data do not exist. We also plan to include an approximate model of the dependence of child mortality on malnutrition. The combined model of malnutrition and mortality would then be utilized in an analysis involving cost-benefit or cost-effectiveness ratios. A final step would be to test the utility and accuracy of the models by applying them in a real situation that begins with selection of interventions and continues through the final evaluation of the performance of these interventions.

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8. To a small extent this high recovery probability is influenced by the fact that, for the Denver standard used herein, the definition of low birth weight ($\leq$2.5 kg) is more severe that the definition of malnutrition. Specifically, 2.5 kg corresponds to 78% of the Denver mean birth weight, rather than 75%.

ACNOWLEDGEMENTS

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ANNEX

MATHEMATICAL DEVELOPMENT OF THE MALNUTRITION MODEL

The properties of the model will be described by proceeding step by step through part of Fig. 8. R_{lbw} represents the risk of children being born with low weights ($\leqslant$2.5 kg), while R_{abw} is the probability of them having acceptable birth weights ($>$2.5 kg). Since the sum of these two probabilities is 1, they are not independent and we may therefore express one in terms of the other; e.g.,

$$R_{abw} = 1 - R_{lbw} \qquad (1)$$

The risk of LBW (low birth weight) children being malnourished at 3 months of age is denoted by R^*_{ml}, where the subscript ml signifies malnutrition during the first age interval, and the superscript * is added to distinguish the risks of the LBW class from those of the ABW class, since these may differ substantially. The remainder of the LBW children will have acceptable nutritional status at 3 months, and this is represented by the probability

$$\overset{*}{R}_{rl} = 1 - \overset{*}{R}_{ml} \qquad (2)$$

The fraction of births that result in LBW children who are then malnourished at 3 months is simply equal to the product of the risks for each of these steps:

$$\overset{*}{M}_1 = R_{lbw} \quad \overset{*}{R}_{ml} \qquad (3)$$

This fraction corresponds to the prevalence at 3 months of age of malnourished LBW children based on the total number of births (LBW + ABW).

By similar reasoning, the prevalence at 3 months of acceptably nourished LBW children is

$$A^*_1 = R_{lbw} \, R^*_{r1} \tag{4}$$

With the help of Eqs. (2) and (3), this may be rewritten in the form

$$A^*_1 = R_{lbw} - M^*_1 \tag{5}$$

which may also be derived from the fact that the sum of A^*_1 and M^*_1 must equal R_{lbw}, corresponding to the fractions of births that are in the LBW class.

Some of the LBW children who are malnourished at 3 months will recover and attain acceptable nutritional status at 6 months, with the probability being denoted by R^*_{r2}; the others will be malnourished at 6 months also, with the risk being

$$R^*_{m2} = 1 - R^*_{r2} \tag{6}$$

Therefore, the prevalence of malnourished LBW children at 6 months is

$$M^*_2 = M^*_1 \, R^*_{m2} + A^*_1 \, R^*_{c2} \tag{7}$$

where $A^*_1 \, R^*_{c2}$ represents the contribution to M^*_2 of children who were acceptably nourished at 3 months but become malnourished by 6 months of age, with R^*_{c2} denoting the risk corresponding to this step. By substituting Eqs. (5) and (6) into Eq. (7) we obtain

$$M^*_2 = M^*_1 \, (1 - R^*_{r2}) + (R_{lbw} - M^*_1) \, R^*_{c2} \tag{8}$$

which is a more convenient form because we prefer to express all equations in terms of the three input variables we selected in the text, or in terms of quantities, such as M^*_1, which represent a combination of the independent variables (e.g., see Eq. (3)). The same form of equation is obtained for M^*_i at all other age levels, so it is convenient to rewrite Eq. (7) in a generalized notation,

$$M^*_i = M^*_{i-1} \, (1 - R^*_{ri}) + (R_{lbw} - M^*_{i-1}) \, R^*_{ci} \tag{9}$$

where i may be any of the age levels, and i - 1 denotes the preceding level. The generalized expression for A^*_i is simply

$$A^*_i = R_{lbw} - M^*_i \qquad (10)$$

A similar set of equations may be derived for the class of children with acceptable birth weights, the only difference being that R_{lbw} is replaced by R_{abw}. The result is that we have a sufficient set of equations to calculate the dependent variables (prevalence of malnutrition at various ages, and the prevalence of low birth weight children) if the values of the independent variables (R_{lbw}, R_{ci}, and R_{ri}) are known.

The procedure for using longitudinal data to estimate the values of R_{lbw} and R_{ci} was described in the text. A different procedure was used to calculate the recovery probabilities, R_{ri}, because the number of children recovering is so small in some age intervals that the results are not statistically significant. This procedure utilizes Eq. (9), which may be rewritten in the following form by solving for R^*_{ri}:

$$R_{ri} = 1 - \frac{1}{M^*_{i-1}} \left[M^*_i - R^*_{ci} \left(R_{lbw} - M^*_{i-1} \right) \right] \qquad (11)$$

(Note: this equation applies also for R_{ri}, the probability for ABW children, if R_{lbw} is replaced by R_{abw} and the asterisks (*) are omitted). R_{lbw} and R^*_{ci} are evaluated by the procedure described before, and we obtain M^*_i and M^*_{i-1} from a cross-sectional analysis of the longitudinal data to determine the prevalence of malnutrition at each of the age levels in the model. The principal advantage of this approach is that it insures that the values of the dependent variables (prevalences of malnutrition) of the model will be equal to the cross-sectional results of the longitudinal study when the values of the independent variables (R_{lbw}, R^*_{ci}, R^*_{ri}, R_{ci}, and R_{ri}) are set equal to those calculated by the foregoing procedures.

After evaluating the independent variables by these procedures, the values of the other variables (e.g., R_{mi} and R_{ai}) in the model may be calculated by means of the equations derived before. The resulting values based on the longitudinal data for Santa María Cauqué are shown in Fig. 3. The arrows for the recovery step have been omitted in several age intervals because the values of R_{ri} were zero.

In the case of interventions that do not influence birth weight nor use it as an indicator of high-risk children, it is unnecessary to have a model consisting of separate sub-models of the LBW and ABW classes. In such cases it is far more convenient to use a single model (e.g., Fig. 4) that combines both the LBW and ABW children.

In the text we illustrate how the independent variables may be estimated for two types of rural Guatemalan communities from available data.

RESUMEN

ANALISIS DE SISTEMAS EN LA PLANIFICACION DE SALUD Y NUTRICION: UN MODELO APROXIMADO QUE RELACIONA PESO AL NACER Y EDAD, CON RIESGO DE CRECIMIENTO DEFICIENTE

El presente trabajo resume la fase inicial de un esfuerzo por desarrollar métodos semicuantitativos para el planeamiento de programas de nutrición y de salud. Su enfoque general es utilizar, cuando se considere conveniente, métodos de análisis de sistemas y de investigación de operaciones. Principalmente, sin embargo, se hace énfasis en el desarrollo de un análisis aproximado simplificado, que los sectores gubernamentales de planificación podrían aplicar fácilmente en la evaluación de varios programas potenciales para lograr objetivos específicos en nutrición y salud, satisfaciendo a la vez ciertas restricciones (por ejemplo, presupuesto, facilidades, personal).

Un elemento esencial del análisis es un modelo que aporte una descripción aproximada de la desnutrición (crecimiento inadecuado, como el que indica el peso para la edad) y mortalidad en términos de las variables susceptibles de ser afectadas por programas de intervención. Inicialmente los esfuerzos en este campo se han concentrado en utilizar los resultados de dos estudios longitudinales del INCAP para desarrollar modelos que relacionen la incidencia de la desnutrición (segundo y tercer grados según la escala de Gómez) a la edad y al crecimiento previo, incluyendo peso al nacer. Los dos estudios cubren comunidades guatemaltecas que varían considerablemente en cuanto a condiciones étnicas, socioeconómicas y ecológicas. Puesto que son tentativos, los modelos propuestos se comentan sólo cualitativa y no cuantitativamente.

Los modelos pueden servir como base para estimar las consecuencias de programas potenciales dirigidos hacia diferentes grupos, tales como mujeres embarazadas y niños cuyo peso al nacer o después del nacimiento caen por debajo de los niveles prescritos. Se comentan los posibles beneficios que pueden derivarse del uso de modelos de este tipo en la planificación de salud y nutrición.

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