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A SYSTEMS ANALYSIS MODEL FOR EPIDEMIOLOGIC DECISION MAKING: AN EXAMPLE OF TRYPANOSOMIASIS

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Trypanosomiasis, a pathogenic protozoan disease caused by infection with species of the genus Trypanosoma, affects both humans and livestock. It constitutes a major obstacle to economic development as well as posing health risks to the human population of tropical Africa (Anon 1979; Finelle 1973; Ford 1971; Jahnke 1974; Jordan 1974). The African name Nagana is used to describe tsetse transmitted animal infections, while sleeping sickness refers to tsetse-borne human infections with the Gambiense and Rhodesiense types of trypanosomes. The disease in livestock contributes to malnutrition, weight loss, reduced productivity, and increased mortality. In humans, it is responsible for high mortality and ill health in many parts of Africa.

An understanding of the epidemiology of African trypanosomiasis requires a qualitative and quantitative analysis of interactions among man, domestic animals, wild vertebrates, trypanosomes, tsetse flies, other vectors, and other variables such as those of ecological, climatic, and geographic nature. The study of the epidemiology of this disease must, therefore, be directed towards a quantitative analysis of these associations and interactions.

Both the vector (Glossina) and the disease (trypanosomiasis) are distributed over an estimated 10 million square kilometers (km^2) of productive land of Africa between the 15 N and 29 S latitudes (Ford 1971; Jahnke 1974). About 35 million people living in tropical Africa are thus at risk (Jahnke 1974). Because of this risk to humans and to their domestic animals, huge expanses of potentially productive land are uninhabitable (Finelle 1973; Ford 1971). In Ethiopia alone, an estimated 96,000 km^2 of land are classified as tsetse infested (Langridge 1976). The economic development of the

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natural, human, and livestock resourses of these areas could be hastened if only the obstacle of the trypanosomiasis-tsetse complex were removed, or at least drastically reduced.

In order to recommend appropriate control measures, the trypanosome-tsetse complex was studied using the systems approach. This paper presents a summary of the analytical methodology used to select the best method to control African trypanosomiasis in Ethiopia. The detailed aspects of the study are available elsewhere (Habtemariam 1979).

Methods

The overall methodology was one of problem solving and decision making within the context of set goals and constraints of time and resources. A program evaluation and review technique flow diagram (PERT chart) was developed (Fig. 1) to indicate the flow of tasks, the time allocation, and the integration of the diverse analytic methods including a) multivariate data analysis, b) systems analysis, c) simulation modeling, and d) economic analysis with emphasis on optimization. The PERT chart begins with the definition of the problem and ends with a goal: the best control method. It also includes background preparation to untangle the complex epidemiology of African trypanosomiasis and to identify determinants of major significance useful for quantitative analysis. This was followed by the collection of existing information on trypanosomiasis in Africa and particularly in Ethiopia, by quantifying and analyzing this information, and finally by integrating, evaluating, and interpreting the results in light of the objectives.

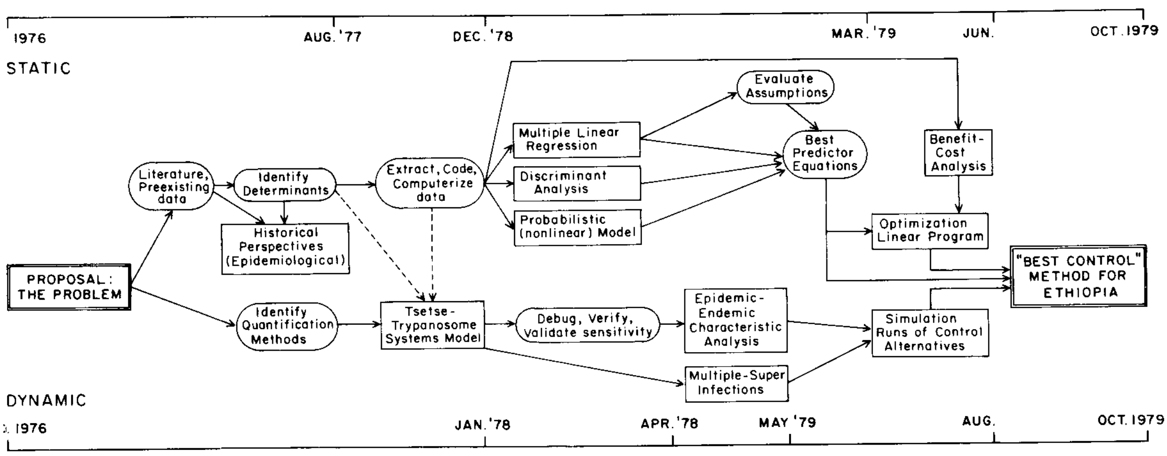

Fig. 1 Program evaluation and review technique (PERT) chart for the study of trypanosomiasis.

Multivariate type information about 28 predictor variables was obtained from Ethiopia; the dependent variable was prevalence of trypanosomiasis in cattle. A detailed description of how the data was gathered and processed, and how the variables were labelled is given elsewhere (Habtemariam 1979). Supplemental data from African countries lying on the same latitude or longitude as Ethiopia were also obtained and utilized in the various facets of the study.

To study the dynamics of trypanosomiasis infections, a systems analysis model was developed. Two important submodels were first prepared; one to simulate the realistic fluctuations of Glossina spp. population dynamics, the other to compute the effective transmission rate. After combining these submodels into a larger systems model, the appropriate mathematical relationships were set up based on classical mass action theory; differential equations described the dynamics of the system. A continuous system modeling program (CSMP) was utilized to computerize the model. Using this model, the most effective means of controlling trypanosomiasis were evaluated (Habtemariam et al 1982a; 1982b; 1982c).

A benefit-cost analysis of insecticidal spraying (manual) versus game reduction was examined to see if trypanosomiasis control could be justified from the standpoint of economics. Combining the results from benefit-cost analysis and multiple regression, a linear programming model was set up to include epidemiologic, ecologic and economic constraints. This multiperiod model included 126 equations and 81 activities (Habtemariam 1979).

Results and Discussion

The steps to be followed in selecting the best method to control trypanosomiasis were identified using diverse analytic techniques. Based on the multivariate analysis of the determinants of trypanosomiasis (Habtemariam 1979):

1. A region, designated an operational region, would be identified for control operations. To define such a region, data on geography, climate, and on human and livestock populations would be obtained; in addition, epidemiologic, economic and cultural factors would be considered.

2. The operational region would be classified into high or low trypanosome risk status, using the discriminant function for 10% prevalence as follows (Habtemariam 1979):

$$\text{Low risk (D1)} = 0.002X_7 + 0.094X_{24} - 0.188X_{29} - 3.168 \quad (1)$$

$$\text{High risk (D2)} = 0.46X_7 + 1.362X_{24} + 6.629X_{29} - 7.60 \quad (2)$$

where X_7 = forested areas in km^2,

X_{24} = human population density per cultivated km^2, and

X_{29} = indicator variable for fusca group tsetse flies.

Using the above functions, a case region could be assigned to the group with the largest value of the classification function. The probability of correct classification of high risk regions was 92.7%; for low risk regions, it was 54.5%.

The operational plan would be evaluated in light of high or low risk classification probabilities. In a region classified as low risk, disease control operations would be continued. In a region classified as high risk, the epidemiologic and economic implications of controlling the disease would be weighed against other developmental priorities since more capital, expertise, and time would be required to bring the disease under control in such a region.

3. The prevalence of trypanosomiasis in cattle in the operational region would be computed using the following multiple regression function (Habtemariam, 1979):

$$\hat{Y} = 0.43 + 1.388X_{25} + 4.21X_{29} + 4.16X_{26} - 0.0132X_{23} - 0.00468X_{20} + 0.0189X_{18} \quad (3)$$

where X_{25} = indicator variable for Bovidae family game animals,

X_{29} = indicator variable for fusca group tsetse flies,

X_{26} = indicator variable for Suidae family game animals,

X_{23} = human population density per km^2,

X_{20} = sheep and goat population (x 100,000)

X_{18} = number of rainy days per year.

If information on the presence or absence of Glossina and on the predominant group of Glossina in the operational region was lacking, the following non-linear (probabilistic) equation would be used:

$$\hat{Y} = \frac{1.0}{1.0 + e^{-(\theta_0 + \theta_1 X_2 + --- + \theta_6 X_{20})}}, \text{ where} \quad (4)$$

$$\theta_0 + \theta_1 X_2 + --- + \theta_6 X_{20} = 9.59 + 9.976X_2 + 0.22X_{14}$$

$$+ 0.334XI_{17} + 0.22X_{19} + 0.435X_{24} - 0.0088X_{20},$$

where X_2 = average latitude in degrees,

X_{14} = annual average temperature (C) for case area,

X_{17} = average total rainfall in mm per rainy day,

X_{19} = cattle population in case area (x 100,000),

X_{24} = human population density per cultivated km^2, and

X_{20} = sheep and goat population (x 100,000)

4. Once the risk status and prevalence of trypanosomiasis is established and the presence or absence of Glossina determined, the next step would be to select the best method for the control of the trypanosomiasis-tsetse complex. The multiple regression equation given earlier indicated that the best approach would be through vector control (X_{29}), game reduction (X_{25}, X_{26}), increasing human population density (X_{23}), e.g., by resettlement, and a proper balance of livestock population (X_{19}, X_{20}).

The systems analysis model and the simulation model, in contrast to the multivariate models discussed above, indicated a combined use of therapy and insecticide spraying, followed by resettlement, (Fig. 2) as the most effective route for the control of trypanosomiasis (Habtemariam et al 1982a; 1982b; 1982c). Inclusion of vegetation clearing -- thus game reduction.-- resulted in eradication of trypanosomiasis. Combination of the latter methods would allow farming and livestock raising under therapeutic protection. The practice of vegetation clearing would enhance farming and reduce the game population. Use of insecticides would kill the tsetse flies and other arthropods, an additional advantage for resettlement. Thus, a rational use of insecticides would be recommended.

Simulation models were useful in providing information about epidemic and endemic characteristics of trypanosomiasis infection status in terms of single, double, mixed, or super infections in the cattle population (Habtemariam et al 1982b). Such information could serve as a basis for implementing disease-vector control activities and for evaluating the consequences of such activities.

5. The decision to control trypanosomiasis would have to be economically justified; this was attempted through benefit-cost analysis. Using net present values (NPV) and benifit-cost (B-C) ratios as criteria for determining project feasibility and efficiency, insecticide application was found to be preferable to game control. The respective NPV were E$2,026,761.46 and E$227,134.28. The B-C ratios were, respectively, 1.14 and 0.98.

6. A policy for optimal allocation of scarce resources to the control of trypanosomiasis would have to be developed and evaluated. To this end, the results of the multiple regression equation and the benefit-cost study were incorporated into a linear programming (LP) model (Habtemariam 1979). The LP model indicated that the optimal method would require the combined and coordinated use of vegetation clearing, insecticidal spraying (using mechanized mist blowers), resettlement of the reclaimed land, and therapy of infected cattle at maximal levels. The net benefit (value of the objective function) over a period of five years was E$1.2 million during which time about 5,000 km^2 of tsetse infected land could be reclaimed and resettled.

In conclusion, integrating and applying multivariate techniques, systems analysis, and optimization methods to epidemiologic problem solving and decision making has been valuable. This approach could certainly be used in cattle trypanosomiasis control in Ethiopia and in other comparable African countries. Its potential application to other epidemiologic problems is an asset that should be exploited in future analytical studies.

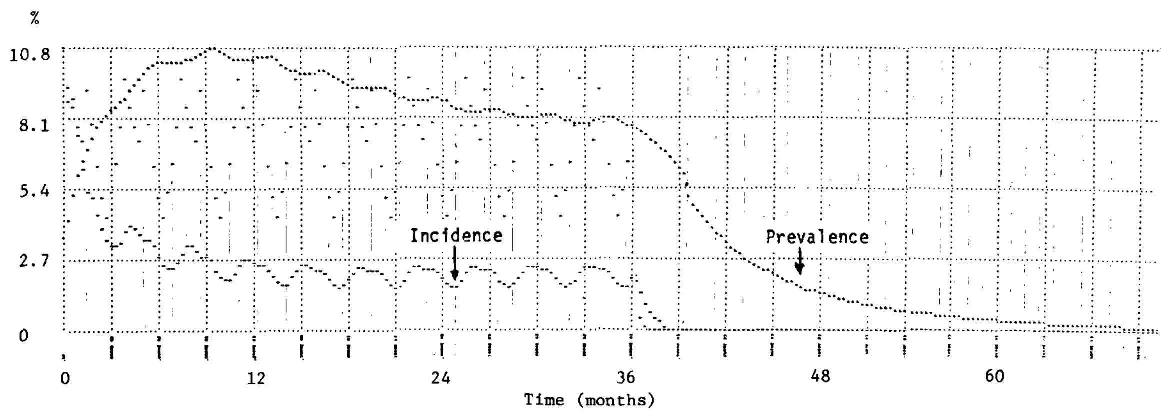

Fig. 2 Simulation of control of trypanosomiasis.

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