# Mathematical Simulation Model for the Study of the Transmission Dynamics of the Leishmaniasis Under a Systemic Approach

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## Abstract

This article present a model in System Dynamics, for the control of the Leishmaniasis. This proposal presents the interactions among the five subsystems that intervene in the transmission dynamics of the Leishmaniasis: insect population, human population, animal population, the environment and the control strategies. The parasite, the transmission personage, is defined as the element that determines the relationships among the subsystems that determines the epidemiological cycle. The indicated subsystems are separated at different levels and its dynamics is modeled through a set of 120 differential equations involving the different reported parameters in the scientific literature. The resulting model permits to simulate the transmission with and without controls and to observe the efficiency of applying of those control policies. The simulation is performed using a home made software called EVOLUTION, in two different conditions: natural conditions or without controls and with controls, obtaining quantitative and qualitative results which were considered plausible by the experts. The set conformed by the software and then model could be considered a valuable tool for epidemiology research.

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## INTRODUCTION

The tropical diseases as the yellow Fever, the Dengue, the Chagas disease and the Leishmaniasis among others, represent, for the tropical regions, one of the greatest sanitary problems registered in the last years (WHO, 1990). The Leishmaniasis appears as the sixth disease in frequency at world level; in the world about 350 million people are exposed to contract the Leishmaniasis (WHO, 1990) for 1990 the WHO made an estimate of 12 million of infected.

The Leishmaniasis in America is extended from the south of the United States until the north of Argentina (WHO, 1990). In Colombia due to its increase, since 1980, and as a product of the National program of Leishmaniasis, record of this disease, is mandatory. From 1981 to 1986 were reported 164 cases by each 100.000 inhabitants; in some small regions, 73 of each 100 persons are affected (TARAZONA, 1992).

The manifestations of the disease in its different modalities, vary from sores cutaneuos that evolve to severe forms of incapacity, mucous mutilates lesions up to visceral deadly disease.

The Leishmaniasis is endemic in four of the five continents, the disease has been informed in more than 100 countries, it occurs in altitudes below of the level of the sea (Valley of Jordan, Colombia) and above 3.000 on the level of the sea ( Peruvian Andean), it is found in the tropical wet forests of America, and in semiarid zones and yet in deserts regions of the world (Africa).

Studies on the disease transmission have been performed accomplishing under a partial view, resulting in a compendium of partial data. The main purpose of these studies is the detection of cases and the location of the affected regions for curative character.

The WHO in 1990 concludes: " Would be very useful to have epidemiological models for the elaboration of programs evaluation.". Systems Dynamics is a good tool for developing an epidemiological model because it understands the different feedback structures that determines the epidemiological cycle of the disease, the dynamics, and the complexity levels; all this under systemic approach, that permits to define, to apply and to evaluate control policies to the phenomenon in its whole.

The present work is in the frame of the investigation promoted by the Tropical Disease's Research Center, CINTROP, leader in health care investigations in the Colombian east assigned to the Industrial University of Santander (UIS), in agreement with the SIMON research group, who work in models and simulation at Systems Engineering School of the UIS, this group is pioneer in the use of the Systems Dynamics in the region.

This research constitutes a contribution for decision making in the tropical disease prevention through the model construction with a systemic methodology and its simulation in the computer.

This model covers the epidemiological cycle of the Leishmaniasis, underlining the population dynamics of the transmitting insect, the environment effect, the evolution of the disease in the human been, the participation of the animals as bearing in the transmission cycle and control policies application.

## STATEMENT OF THE PROBLEM

The control of the Leishmaniasis's transmission currently is guided to the passive detection of cases, to the development of case active detection campaigns, to the domestic animals control and to the insects control, being the last one the most used in Colombia. The complete application of these controls, has not been carried out, due to the fact that its costs surpass the budgets fixed for that purpose.

The use of this model in the transmission behavioral study in the event of not applying control policies, as well as in the planning, design and evaluation of the same, is converted into an optimum tool into the strategic plans development for the health care. saving costs and avoiding undesirable effects on the environment.

The working team that developed this model, does not know scientific reports of an integral model guided to the control the transmission; the reported models are guided to determine transmission indicators in static form. Example of these are the contributions of Belajev (1973) and Muench (1979).

## OVERALL STRUCTURE OF THE MODEL

The proposed model, by means of system analysis, a reference framework for the modeling including the interrelationships among the five subsystems that intervene in the transmission dynamics, insect population, human population, animal population, the environment and the control strategies.(See Figure 1).

The modeling process is developed through the disaggregation of each one of the subsystems indicated in the reference framework, until reaching the proposed model.

**Disaggregation levels.** At first, before disaggregation analysis, the subsystems that intervene in the transmission dynamics of the Leishmaniasis were identified: the insect subsystems, animal subsiystems, and human subsystems.

In the human population subsystem three groups are distinguished :

**The sane human .** Human group formed by all the resident persons of the place in study, who have not been stung by an infected insect.

**The infected human .** Belong to this group, persons that have been stung by the infected insect and are incubating the parasite.

**The sick human.** Infected human group, those infected people that developed the disease and present active lesions.

Of the animal subsystem three groups are defined :

**The sane animals.** Considered all the animals, wild as well as domestic, that are found within the area which do not carry the parasite.

**The infected animals.** Sane animals, that have been a stung by an infected insect.

**The reservoir animals .** Those animals bearing and developing the parasite. When one of those reservoir animals is stung by an insect, the last one get infected and become a transmitter agent.

Of the insect subsystem, are distinguished two large groups:

**The sane insects .** Those that they have not entered in contact with the parasite.

**The Infected insects**. To this group belong the insects that have developed the parasite.

With the previous conceptual platform were defined the three disaggregation levels developed in the proposed final model:

**1. Disaggregation of the subsystem insect Population.** It is analyzed the populational dynamics of the insect with the participation of the human and animal population, independent of the effect of the environment and of possible controls.

Considering the insect as the principal element that energizes the transmission of the Leishmaniasis, it is necessary to widen its study to exert greater control over the same. In this study, it is of great importance to know the different stages of the insect life cycle, particularly during the stunging stage.

In this disaggregation level is presented a nonlinear relationship among the insects density (DPTI) and the parities index (IP: Percentage of female insects that in fact put eggs), given by the expression

$IP = K \times EXP (a \times DPTI^3)$
where,
K: 0.95
a: $\ln (0.05 / 0.95) / 1 \times 10^6$

**2. Inclusion of the environment effect in the Populational Dynamics of the insect.** The effect of the environment to the previous model is added. The environment is defined by the altitude, the latitude, the rainfall level, the temperature and the relative dampness. The deleterious effect of the rainfall (ESCORSA, 1984) was taking into account by means of a multiplier.

**3. Disaggregation of the subsystem Human Population.** The contact of a person with the parasite, causative agent of the Leishmaniasis, the consequent infection and possible clinic apparition of the same, more known as disease, play a role preponderant in the transmission dynamics studied with this model. The human group is disaggregated according to there different stages. (SARAVIA, 1991).

**4. Application of the strategies of control to the general model.** The general Model facilitates the analysis of control strategies permitting to add variables that represent them and quantity the effect of the same on the transmission dynamics. The effect of fumigation is modelled using an additional auxiliar variable affecting the mortality of the winged insects. This effect of nonlineal character , is expressed in the equation of the mortality rate by fumigation:

$TMF = pmm \times EXP (a \times DIAS^2)$
where,
pmm: Maximum mortality percentage according to the insecticide concentration.
a: $\ln (1 \times 10^{-6} / pmm) / DIAS^2$

DIAS: Time elapsed among a t and a t+Dt

figure 2. present the general stock and flow diagram of the model proposal.

## MATHEMATICAL MODEL

The mathematical model consists of 120 linear and nonlinear differential equations that define the transmission dynamics of the Leishmaniasis as a function of the populational dynamics of the insect, of the evolution of the disease in the human and of the effect of bearing animals as parasites.

## SIMULATION

Simulation tool. The simulation of the model was accomplished in a microcomputer compatible IBM, using a software called EVOLUTION 1.0, which is a tool for modeling in Systems Dynamics in Windows environment, developed by the SIMON research group of the Industrial University of Santander (GELVEZ, 1994).

**Simulation conditions.** The spatial unity of the model is the focus area, given in square meters. The simulation temporary unity is the day, since the development time of the insect is of 45 days in average (WHO, 1990), unity "day" is understood as the smaller time range in which occurs a change in the population. It is defined a simulation period of two years (720 days).

**Initial conditions.** Based on bibliographical review and in field data reported by experts, the initial conditions and parameters were estimated.

## RESULTS

**Populational dynamics of the insect.** In the Figure 3, the observed behaviour for population density is presented, with and without fumigation and are compared with the real behavior obtained by the experts (ESCORSA, 1984). Qualitative correspondente was found between field data and simulation results.

**Transmission dynamic.** Human infected. (See Figure 4). During the first months of the year, an increase in infected human population in observed, due to the disease existance of a high density of trasmitter insects. Later on, the infected population level decrease due to the fact that some people go forward to other stages of the disease. During the final months of the year a new increase in infected population level is observed. The two infected population peaks correspond to the population dynamics of the insect which in turn, depends upon the climate cycle of the region. Figure 4 also shows that the dynamics of infccted human is about the same for the second year, but attenuated. This is due to the fact that a closed system was assumed for the simulation.

**Animal population.** Figure 5, shows the evolution of sane, infected and reservoir animal population. It can be observed how the number of sane animals reduces quickly, presenting a doble s shape of a curve, produced by the apparition of the two peaks in the population of insects. The peaks of infected animals corresponds to peaks in the dynamic of insect population. The animal population trend, corresponds to the typical behavior of insect spread.

## CONCLUSIONS

1. This work shows how the Systems Engineering, through the System approach and System Dynamics, wides its action field, integrating interdisciplinary groups for the study of complex phenomena and creating informatic environments that enhances the research capability, and contributes to the process of decisions making in the area of the health care.

2. The proposed model already constitutes a tool of academic use, providing to students of Epidemiology, a laboratory to study the transmission dynamics of the disease and allows the analysis of the results of controls application.

3. With this work, a general reference framework of the transmission dynamics of the Leishmaniasis was achieved , this reference framework will guide the next work field of CINTROP researchers.

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FIG. 1. GENERAL REFERENCE FRAMEWORK

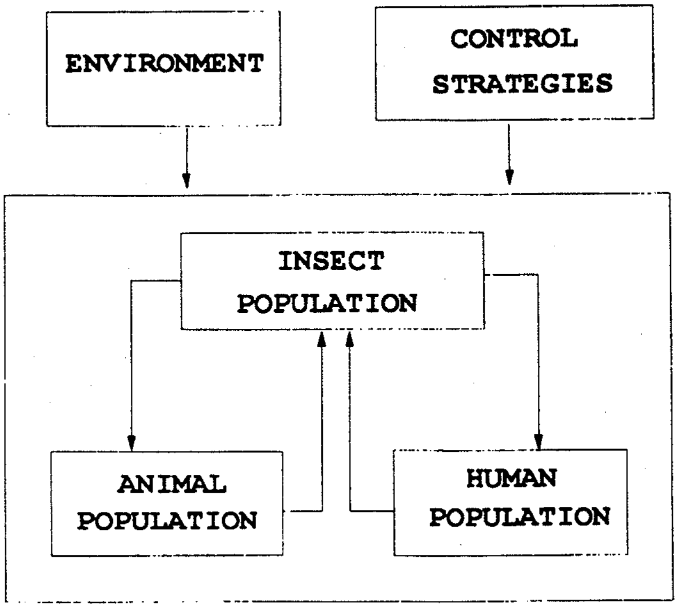
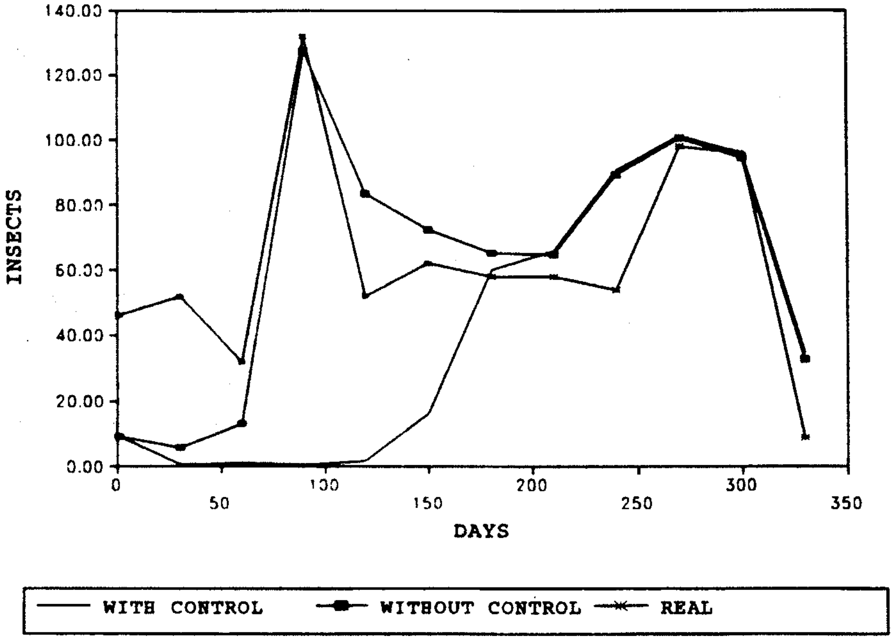


FIG. 3. POPULATIONAL DENSITY



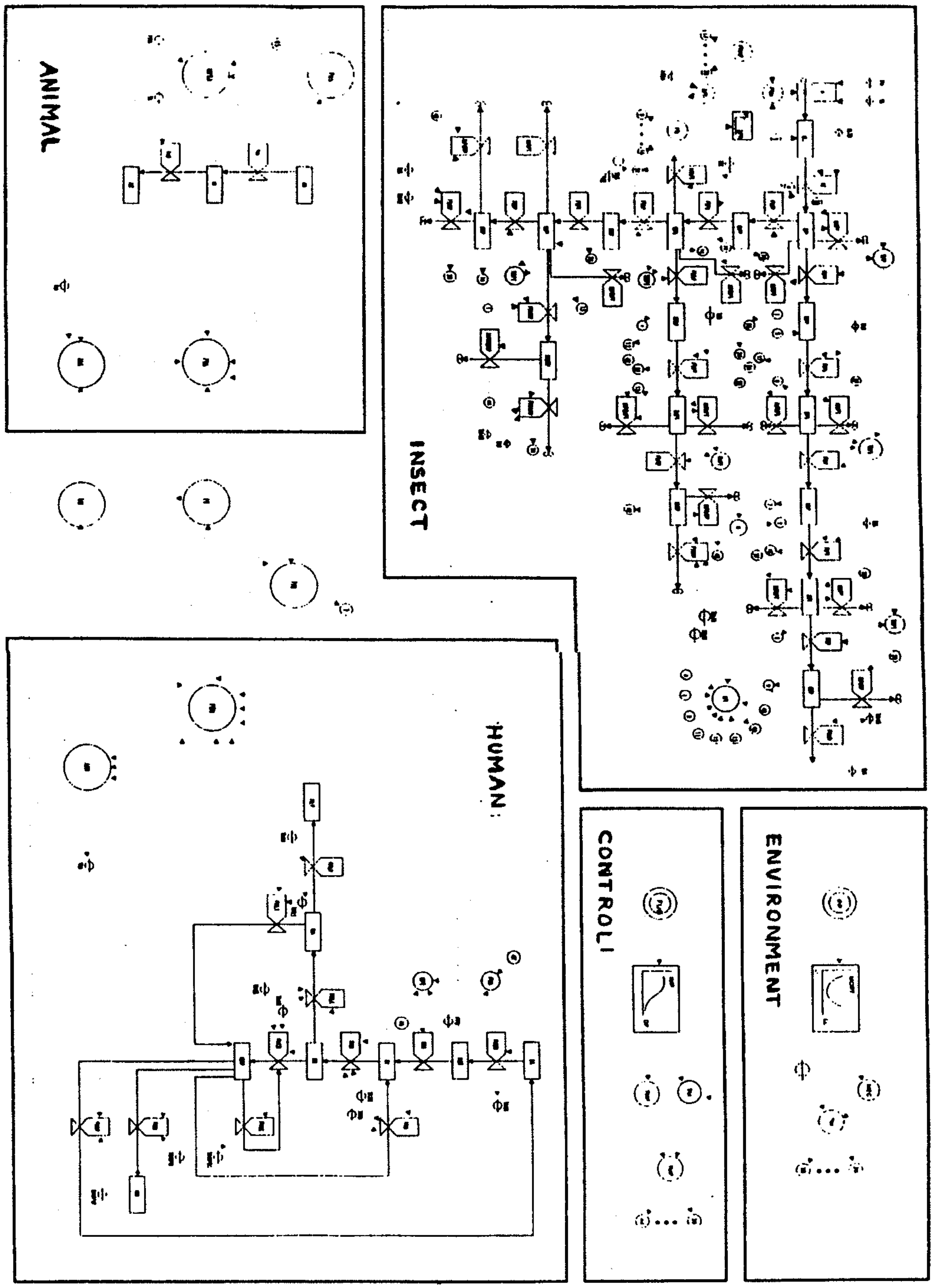


FIG. 2. GENERAL STOCK AND FLOW DIAGRAM OF THE MODEL

FIG. 4. INFECTED HUMANS

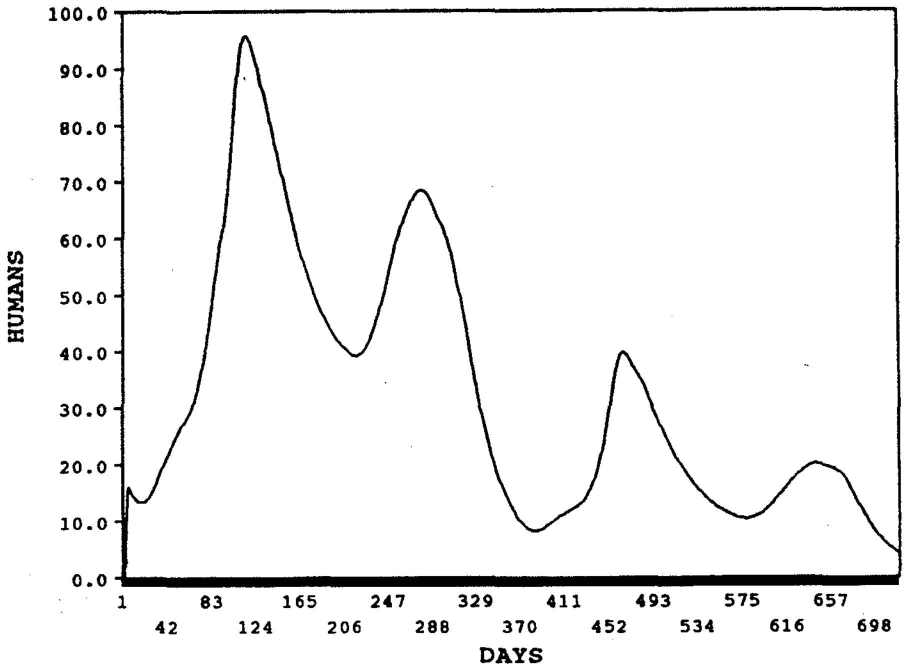


FIG. 5. ANIMAL POPULATION