1981 Winter Simulation Conference Proceedings
T.I. Ören, C.M. Delfosse, C.M. Shub (Eds.)

POLICY ANALYSIS AND EVALUATION OF GONORRHEA CONTROL PROGRAMS: A SIMULATION APPROACH

Ramesh K. Shukla, Ph.D., Associate Professor
Yaşar A. Özcan, M.B.A., Research Associate
Department of Health Administration
Medical College of Virginia
Virginia Commonwealth University
Box 203, MCV Station
Richmond, Virginia 23298

ABSTRACT

A simulation model is developed to study the dynamics of transfer and detection of gonorrhea in a population. Alternative policy issues are developed and studied by changing controllable parameter values in the model. The alternative policies are evaluated based on the sensitivity of the parameters in controlling the disease. The parameters studied are: Percentage of females Using Pills (PUP), Percentage of males Using Condoms (PUC), efficiency (delays) in the self-detection process, and efficiency (delays) in the system-detection process. The analyses indicate that reducing the use of pills and increasing the use of condoms, as birth control practices, will also be highly effective in controlling gonorrhea. The efficiency of self-detection seems to be more sensitive to the prevalence of the disease than the efficiency of the system detection. It is suggested that consumer education regarding birth control practices and the self-detection process may be more effective than the present emphasis on the system-detection process.

1. OBJECTIVES

A computerized simulation model is developed to study alternative policy decisions in controlling gonorrhea in a community. This simulation model studies the effectiveness of controlling gonorrhea by:

a) changing the levels of usage of condoms and pills in a community through consumer education;
b) increasing the efficiency of self-detection process through consumer education; and,
c) increasing the efficiency of system-detection process through the application of management sciences.

The literature suggests that the use of condoms or pills significantly affect the probability of transfer of the disease. However, the relationships between the percentage of people using these birth control devices and the prevalence of the disease is not clear. The relative effectiveness of controlling gonorrhea by manipulating the preferences for birth control practices is explored here. It is also suggested that increasing the efficiency of self-detection process through consumer education is more effective than increasing the efficiency of case-investigation process (system-detection process).

2. MODEL

The simulation model developed to study the foregoing policies is based upon Forester's dynamic simulation technique. The simulation model captures the dynamics of transfer from homosexual and heterosexual contacts (Figure 1). Disease transfer probabilities, given the use of pills and/or condoms, were subjectively assessed by a panel of experts consisting of a physician, nurse, case investigator and program director. The model also considers delays in self- and system-detection processes. The cure rate of the treatment (penicillin injection) is assumed to be 100%.

Figures 1, 2 and 3, describing conceptual models are provided and described on the next three pages. The conceptual model of the dynamics of transfer and detection are described in Figure 1. Figure 2 and 3 presents the relationships between various factors involved in the calculation of the rates of transfer (RTM and RTF) and the rates of detection (RDMN, RDFN, RDMC and RDFC) respectively. In Figure 1, NHM (NHF) NMIU (NFIU) and NMID (NFID) are the Numbers of Healthy Males (Females), Males (Females) Infected and Undetected, and Males (Females) Infected and Detected respectively. RTM (RTF) is the rate of transfer of the disease to males (females) from homosexual as well as heterosexual contacts. RDMN (RDFN) is the rate of

81CH1709-5/81/0000-0641$00.75

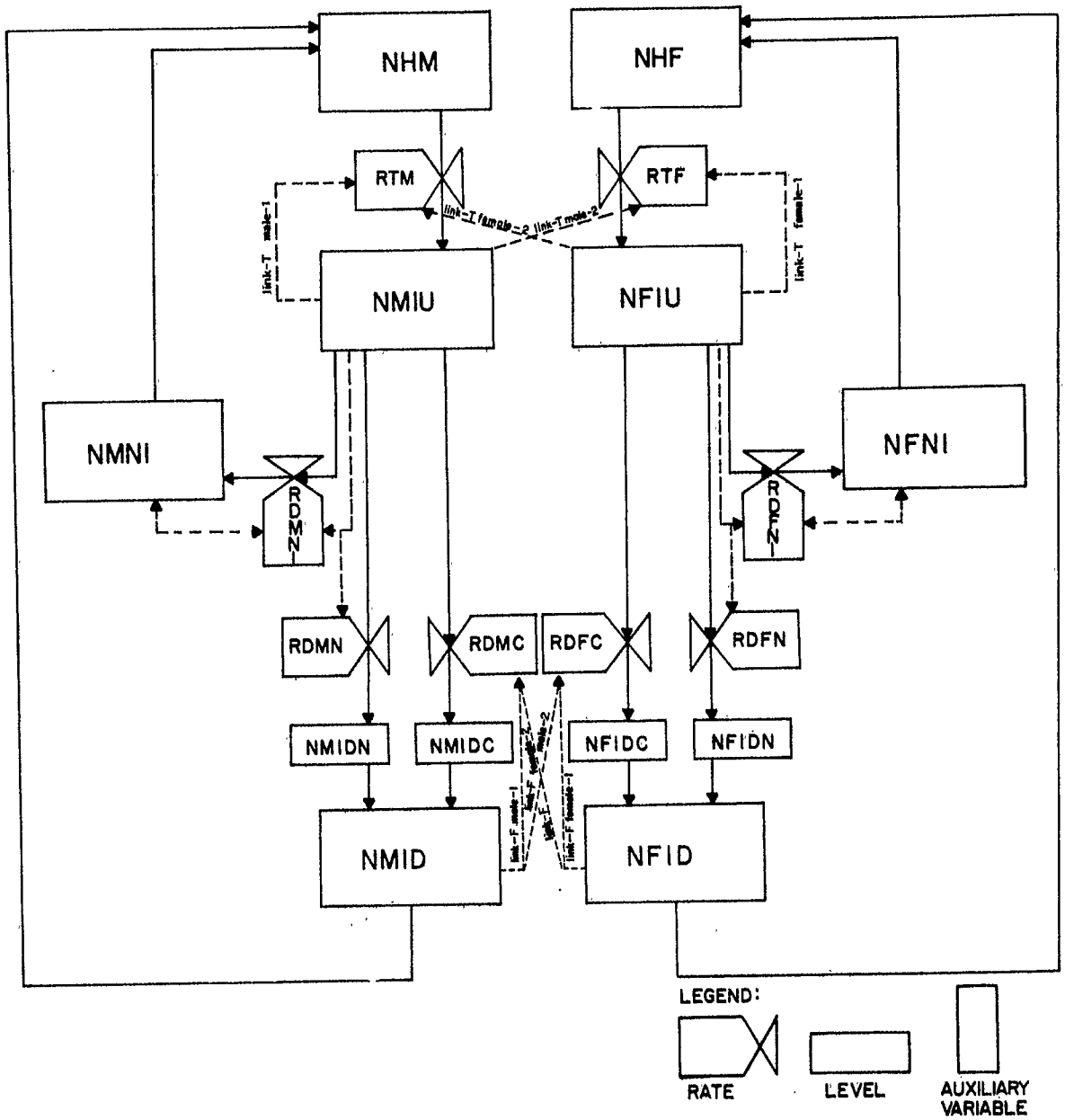

Fig. 1

CONCEPTUAL MODEL OF TRANSFER AND DETECTION OF GONORRHEA

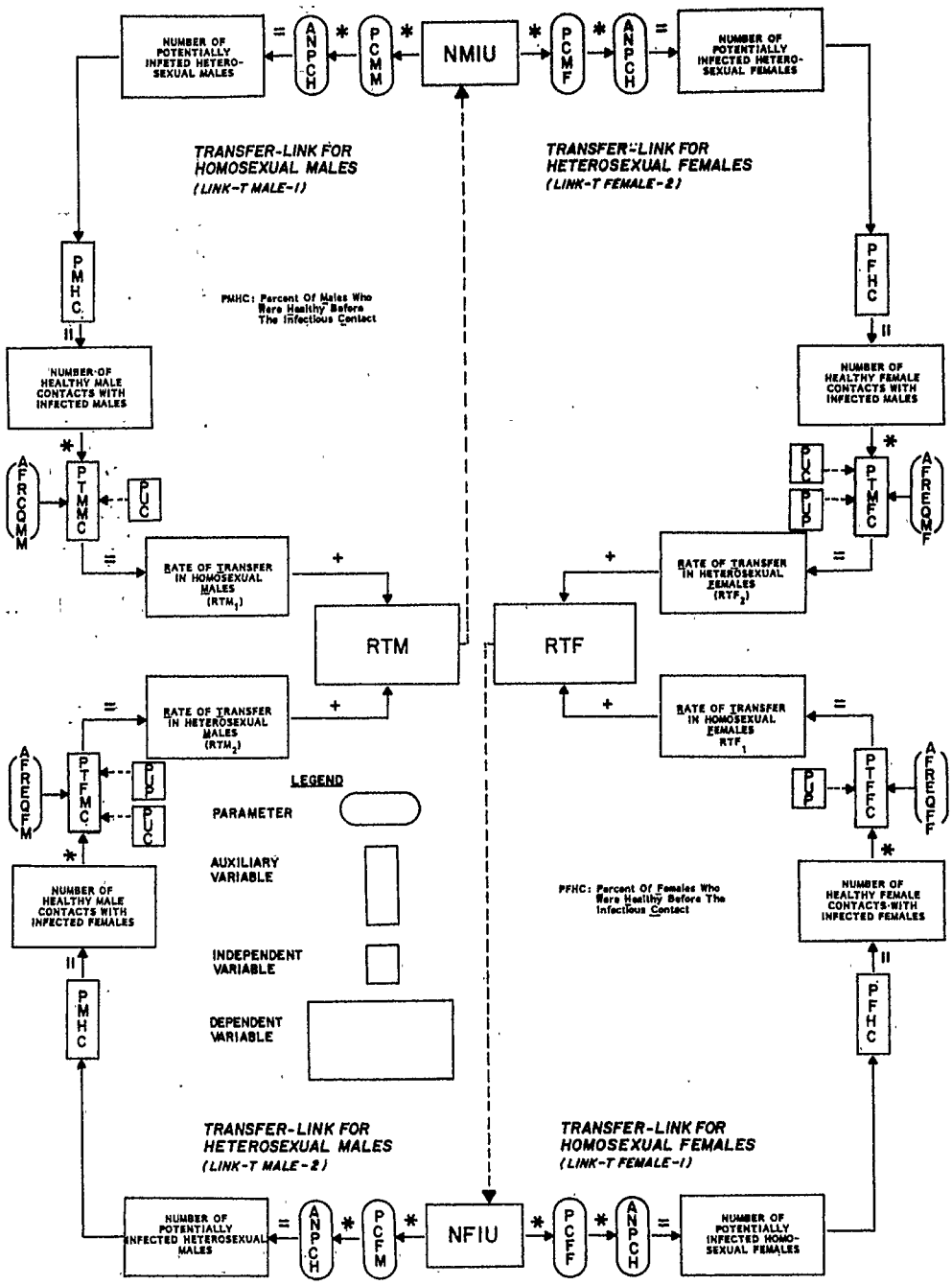

Fig. 2

A MODEL FOR DETERMINING RATES OF TRANSFER--RTM and RTF

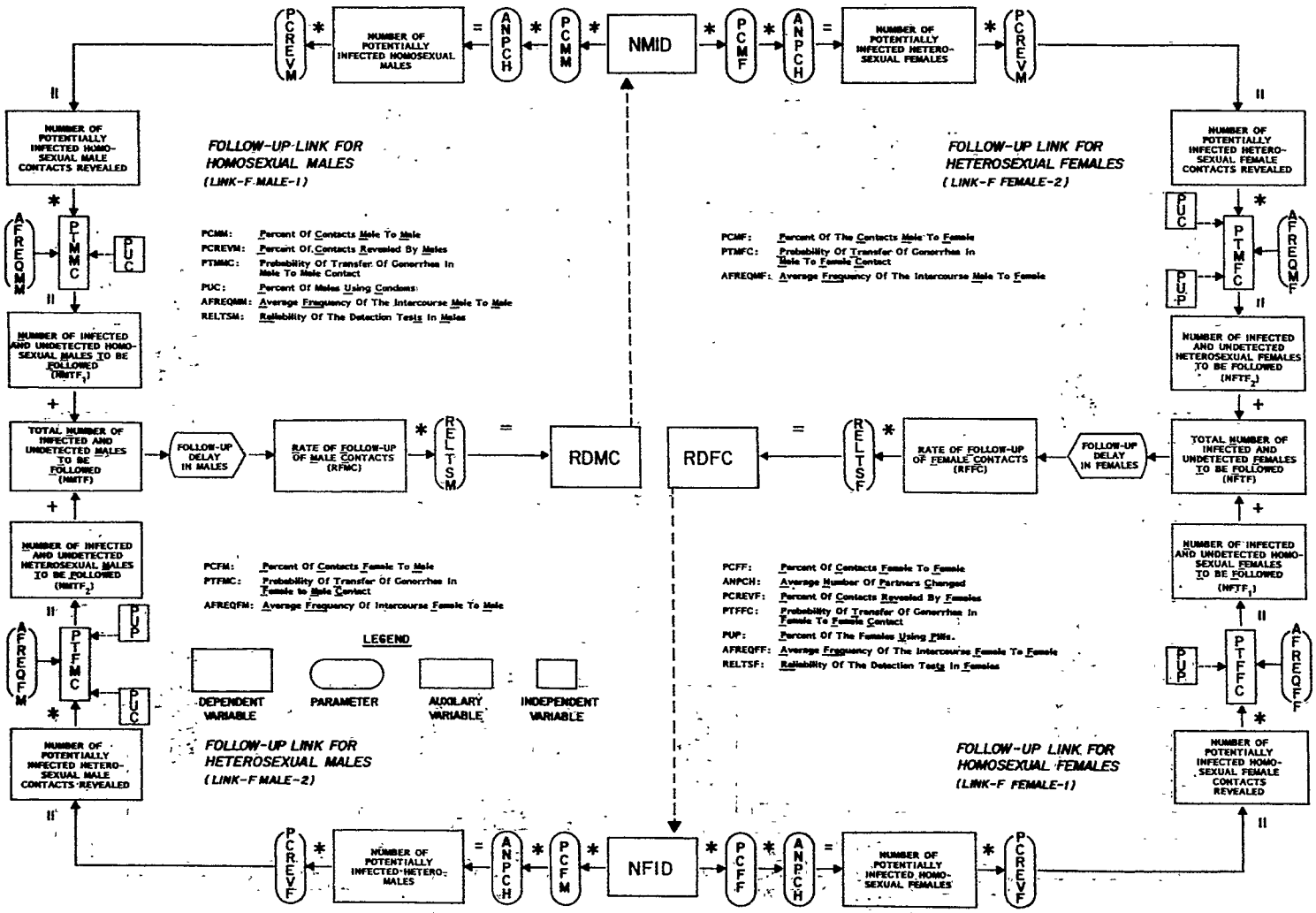

Fig. 3

A MODEL OF DETERMINING RATES OF DETECTION--
RDMC and RDFC

detection of the disease from the natural (self) detection process for males (females). RDMNI (RDFNI) is the Rate of Detection of Males (Females) who are Not found Infected. This rate represents the error in the detection process. NMNI (NFNI) represents the Number of infected Males (Females) who are Not found Infected and become the source of infection for the healthy population. The reliability of the detection process was set high and therefore RDMNI (RDFNI) and NMNI (NFNI) were very low and did not affect RTM or RTF.

In the self-detection process, there is a delay between the time a person gets infected and he or she detects himself or herself. This delay can be described by a delay function, $ND(X) = I(X) + D(X)$. The delay function has a deadtime I(X), (the minimum time during which no person in the group detects himself or herself), and the delay time, D(X), (the minimum time period in which the cumulative detection of people has peaked). The dead time represents the incubation time period for the disease when the symptoms of the disease are not observable and detectable. The average incubation periods for males, I(M), and females, I(F), are about three and seven days respectively. In the model presented here, the detection delay functions will be considered as controllable parameters to study their sensitivity in reducing the total number of infected population in a community. Similarly, there is a delay function between the time an infected person reveals his (or her) sexual contacts and the contacts are actually followed and detected by the system, the department of health. This delay can also be represented by a similar delay function which has a dead time and a delay function. The dead time is the minimum time period for processing information from a source to the department of health. After the initial delay in processing information, the rate of follow-up detection is higher in the beginning which decreases slowly to a steady state level. Both the delay functions are set as first order exponential functions where the number of persons detected increases with time at a decreasing rate until a steady state is reached. D(X) represents the time when the steady state is reached.

2.1 Dynamics of Transfer

Figure 2 describes the dynamics of transfer of the disease from homosexual and heterosexual contacts for males and females. For example, the rate of transfer of the disease to females (RTF) is affected by heterosexual proportion of NMIU (number of males infected and undetected) and the homosexual proportion of NFIU (number of females who are infected and undetected). The dynamics of transfer can be described as a "positive-loop." That is, greater the level variables (NFIU or NMIU) greater will be the rates of transfer of the disease; and greater the rates of transfer (RTM and RTF), greater will be the level variables (NMIU and NFIU). The extent to which NMIU and NFIU affect RTF and RTM are computed through a serious of logical stepwise calculations. Let us take an example of calculating RTF (RTF-1 + RTF-2) using NMIU and NFIU. RTF-1 and RTF-2 represent the homosexual and heterosexual contributions to the rate of transfer of the disease. The extent to which RTF-1 will be affected by NFIU will depend upon:

1. the proportion of NFIU that are homosexuals (PCFF),
2. average number of partners changed between the times a person is detected (ANPCH),
3. the proportion of the total sexual contacts between infected and healthy partners (PFHC),
4. the probability of transfer of the disease between infected female and healthy female (PTFFC).

The PTFFC will depend upon several factors such as the proportions of females using pills and probabilities of transfer in a single female to female contact, and the average frequency of sexual contacts. Similarly RTF-2, the rate of tranfer from males (NMIU) to females, can be computed. However, the posterior probability of transfer (PTMFC) will depend upon the use of pills and condoms both. The links for calculating RTM-1 and RTM-2 are very similar to the calculation for RTF-1 and RTF-2 (see Figure 2).

2.2 Dynamics of Detection

Victims of gonorrhea can be detected through:

1. self-detection by the victims, and
2. detection by the health care system:
   a. follow-up of the potential victims whose identities are revealed by confirmed gonorrhea cases, and
   b. screening programs.

In this paper the dynamics of self-detection and the system-detection processes are modeled. The dynamics of detection can be described as a negative loop. That is, greater the number of infected and undetected (NMIU, NFIU) persons, greater will be the rates of detection (RDMC, RDFC, RDMN and RDFN); and greater the rates of detection, lower will be the infected and undetected persons. The calculations of the rates of detection for the self-detection process and the system-detection processes are done differently. The RDMN and RDFN--the rates of detection through natural (self) detection is influenced only by the delays in the self-detection process. However, the RDMC and RDFC --the rates of detection through investigating contacts (case investigation by the system) are influenced by: proportion of the NMID (or NFID) revealing contacts, the proportion of revealed contacts followed, the probability that the contacts followed are infected, and delays in following (investigating) potential cases.

The rate of detection of male contacts (RDMC) is affected by the contacts revealed by the homosexual proportions of NMID and the heterosexual proportions of NFID. The RDMC (or RDFC) are calculated by determining the total Number of infected and undetected Males To be Followed (NMTF) and then applying the delay function in their detection (see Figure 3). The equations for calculating NMTF are given below:

NMTF = NMTF-1 (homosexual contacts to be followed + NMTF-2) (heterosexual contacts to be followed).

NMTF-1 = NMID * PCMM * ANPCH * PCREVM * PTMMC.

NMTF-2 = NFID * PCFM * ANPCH * PCREVF * PTFMC.

The logic of these equations can be more clearly followed in Figure 3.

The probability of transfer of gonorrhea from male to male contacts (PTMMC) depends upon the proportion of homosexual contacts using condoms (PUC), the average frequency of sexual contact (AFREQMM), and the probability of transfer in a single contact. Similarly PTFMC depends upon PUC, the proportion of females using pills (PUP), AFREQFM, and the probability of transfer in a single contact.

3. THE SIMULATION

The target population for the simulation was a hypothetical community of approximately 130,000 people with a sexually active population of 37,800 males and 40,000 females. In this community the percentages of male heterosexual and homosexual contacts were set at 80 and 20 percent respectively. For females, the corresponding figures were 95 and 5 percent. It was assumed that initially two percent each of the male and female populations were infected and undetected. These initially-infected percentages were varied in other runs of the model to test the sensitivity of the results to this parameter; the same results were obtained.

A key factor in the spread of the disease is, of course, the probability of transmission in a contact between infected and uninfected people. An uninfected male was assumed to have a 40 percent chance of infection without and zero chance with a condom. For females in homosexual contacts the probabilities were .20 if the receiver used pills and .10 if not. For heterosexual contacts the probabilities were higher. Contact with an infected male not using a condom had a 40 percent chance of transmission without and a 90 percent chance with pills. These probabilities were subjectively estimated by a group of physicians, social workers, and nurses.

Following detection, the cure rate (penicillin injection) was assumed to be 100 percent. Other system parameters--percent of cases asymptomatic, incubation period, detection delay, clinical follow-up delay, and rate of sexual contact--were all set at values consistent with previous studies and expert opinion.

The program was run with arbitrary initial values for the level and rate variables. The steady state values for these variables were reached in about 560 days. This initial run is termed as the basic run and the steady state value of the prevalence of the disease (percentage of the 77,800 people who were infected and undetected) was reached in 560 days (see Figure 4 on the next page). Alternate policies were tested by changing the appropriate parameter values. Table 1 below provides the parameters to values for the basic run and for alternate runs.

When the policies related to parameter(s) were tested, the other parameter values were kept constant at the values of the basic run.

Table 1

CONTROLLABLE PARAMETERS

PARAMETERS	DESCRIPTION	PARAMETER VALUES	
		Basic Run	Range
PUP	Percentage of females using pills	.5	0.0-1.0
PUC	Percentage of males using condoms	.15	0.0-.65
ID(M)	Dead time in natural detection for males	3 days	0-7 days
ID(F)	Dead time in natural detection for females	5 days	3-9 days
D(M)	Delay time in natural detection for males	4 days	0-8 days
D(F)	Delay time in natural detection for females	7 days	6-9 days
IDF	Dead time in follow-up delay	5 days	0-6 days
DELYF	Delay time in follow-up delay	16 days	4-20 days

The parameter values for the basic run were set to approximate the conditions in Virginia. The Simulation model was considered to be valid since the steady state prevalence (2.01%) of the disease from the basic run was very close to the actual prevalence (2.06%) in Virginia. The construct validity was tested by checking the direction of relationship between prevalence and the model parameters. The parameter values were changed only one at a time. All the directional relationships were found as expected. The dynamics of detection as modeled was considered valid since the data from Virginia department of health closely matched with that of the model (see Table 2). Table 2 breaks down the total number detected by the detection system. The self-detection process and the system-detection process detected 66% and 34% of the cases through the model as compared to 59% and 41% as indicated by the Virginia data.

Table 2

MODEL VALIDATION BY DETECTION PROCESSES

DETECTION PROCESS	MODEL RESULTS	ACTUAL DATA
Self-Detection	66%	59%
System-Detection	34%	41%
TOTAL	100%	100%

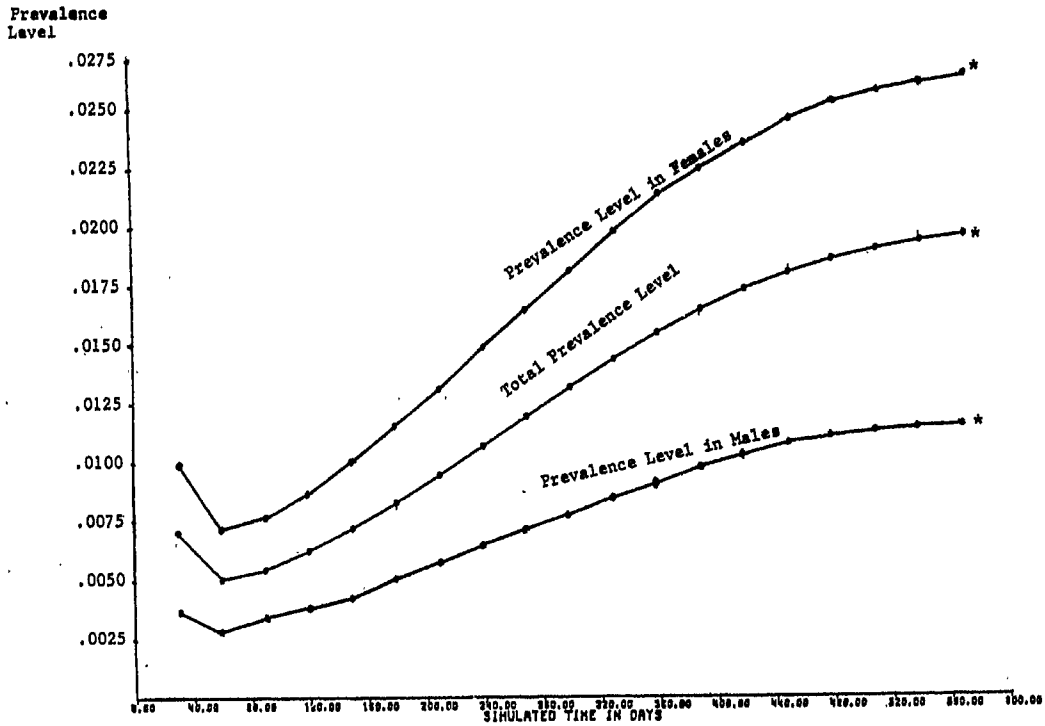

Figure 4: The Prevalence Levels in Basic Run *Steady State Values

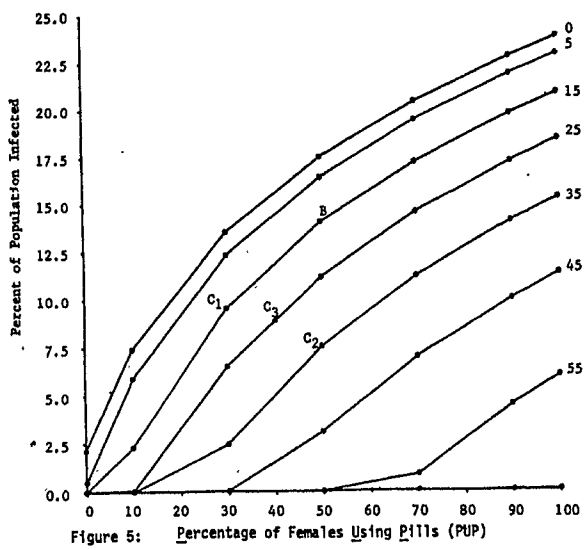

Figure 5: Percentage of Females Using Pills (PUP)

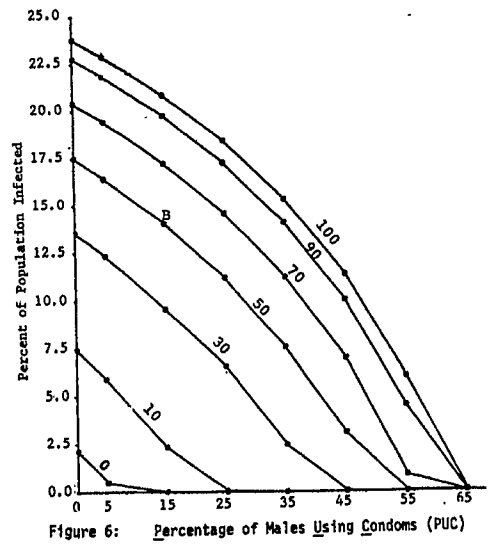

Figure 6: Percentage of Males Using Condoms (PUC)

4. RESULTS

4.1 Effects of PUP and PUC

The model was run for approximately 600 simulated days, tracing the movement of males and females within each set of groups. At that time it was determined that the group sizes had stabilized, the run was discontinued, and various system conditions were recorded. Of particular interest to us here is the percentage of infected but undetected sexually active adults. These percentages, for various combinations of condom and pill use, are shown in Figures 5 and 6, both of which present the same information. Figure 5 shows the effects of varying the percentage of females using pills, holding the percentage of males using condoms constant. Figure 6 reverses the orientation, holding pill use constant and varying the use of condoms.

An examination of these two graphs reveal patterns of infection consistent with our a priori expectations. At any level of pill use, increased use of condoms causes a decrease in the rate of infection. At any level of condom use, increased use of pills increases the rate of infection. The shapes of these two sets of curves are also quite interesting from a public health policy perspective. In both cases, the curves are essentially concave. That is, for a given level of condom use, the rate of infection increases, in general, less and less for constant increases in pill use; the marginal impact of increased pill use becomes less and less significant. Putting it another way, the marginal improvement in the infection rate becomes greater and greater with decreasing pill use. For fixed pill use and varying condom use the situation is just the opposite. The marginal effect of increasing condom use is, in general, more and more significant.

It is interesting to note that in the absence of both types of birth control practices 2.1 percent of the sexually active population is infected. Although the infection rates by sexes are not represented in these graphs, the breakdown is a 1.7 percent rate for men and a 2.6 percent rate for women. Of greater interest, however, are the effects of changes in birth control practices away from existing community norms.

The point labelled B in both Figures 5 and 6 is a base case considered by expert opinion to be representative of normal community practice, 50 percent pill use and 15 percent condom use. At these levels 14.5 percent of the sexually active population is infected, the rate for women being somewhat more than twice that for men (19.5 percent versus 9.2 percent).

What would it take to eliminate the infection entirely? Assuming no change in condom use, following the 15 percent condom use curve in Figure 5 until it reaches an infection rate of zero suggests that a total discontinuance of pill use would be required. Assuming this was an unrealistic expectation, alternative strategies can be proposed; for example, with no change in pill use (following the 50 percent pill use curve in Figure 6), an increase to 55 percent condom use would be necessary. Other combinations of behavioral changes that would achieve the desired result can also be determined from the graphs.

Other changes aimed at improving the situation within limited budget constraints can also be evaluated with the model, providing the benefit side of a cost-benefit analysis. For example, suppose that the costs of three different educational programs, each of which would accomplish a total 20 percent change in public behavior patterns, were the same. Program 1 leads to a 20 percent decrease in pill use; Program 2 leads to a 20 percent increase in condom use; Program 3 affects both, decreasing pill use and increasing condom use each by 10 percent. (This assumption is not realistic, but it is useful for illustrative purposes.)

Program 1 (condom use of 15 percent, pill use reduced to 30 percent) would lead to an infection rate of 9.9 percent, a reduction of 4.6 percentage points from the base case. This is shown in Figure 5 as point C_1. Program 2 (pill use of 50 percent and condom use increased to 35 percent), point C_2 in Figure 5, has an infection rate of 7.8 percent, a decrease of 6.7 points from the base case. Program 3 (pill use reduced to 40 percent and condom use increased to 25 percent), point C_3 in Figure 5, had an infection rate (estimated by interpolation on the graph) of 9.1 percent, a reduction of 5.4 points from the base case. Based solely on consideration of the decrease in the infection rate, Program 2, education to increase the use of condoms is the most effective, causing the greatest reduction in the rate of infection for the given expenditure.

For the more complicated and realistic situation in which the educational programs to be compared do not necessarily cost the same for a given change in population behavior, the model can be used to estimate, by appropriate choice of parameters, the effects on infection rates. This would then become part of the overall cost-benefit analysis, considering not only the infection rates and monetary costs but also the other, non-monetary system impacts, such as changes in birth rates.

4.2 Effects of Detection Efficiency

Table 3 provides the results regarding the impact of efficiency (in the detection processes) on the prevalence of gonorrhea. The prevalence level was calculated as (NMIU + NFIU)/77,800; and the efficiency of detection processes was changed by varying the delay functions. For the basic run the steady state prevalence was 2.01%. When the delay times were reduced by 2.5% and 5.0% in the self-detection process, the prevalence was reduced to 1.41% and .75% respectively. That is, by increasing the efficiency in the self-detection by 5% the prevalence was reduced by 63 %. On the other hand, the similar increase in the efficiency of the system detection process by 5% results in the prevalence at 1.88% or 6 % reduction. This result indicates that self-detection process is more sensitive to the prevalence than the system-detection (case investigation) process.

The computer runs were also made after changing only the dead time (incubation period) in the natural detection. The results showed that decreasing the time for incubation period reduces the number of incidence drastically. Unfortunately, at the

Table 3

IMPACT OF INCREASING EFFICIENCY ON THE PREVALENCE (%)

% Increase in the Efficiency of Detection Processes	Prevalence of Gonorrhea	
	Self-Detection	System-Detection
0 Basic Run	2.01	2.01
2.5%	1.41	1.91
5.0%	0.75	1.88

present time, we do not have the technology of reducing the incubation period. A breakthrough in technology in this area, whereby individuals can observe and detect symptoms sooner, will be very instrumental in controlling gonorrhea. Our findings showed that reducing the period in self-detection by 3 to 4 days had the same effect as the effects of reducing the incubation period by one day.

5. DISCUSSION

The results of this study indicate that consumer education may be more effective strategy in controlling gonorrhea than the present emphasis of increasing the efficiency of system-detection methods. The simulation model presented here studies only the degree of effectiveness of these two alternative policies. The actual policy decisions should be made based upon the cost-effectiveness criteria. In this model we have only examined the effectiveness of certain policies and strategies. Some changes would cost more than the others. For example, change of natural delay time through consumer education may be more expensive than increasing the efficiency of the follow-up system. Also, some other considerations must be made before deciding on the direction of change, like moral and social values involved and its impact on the life of the community.

REFERENCES

Forrester, J. W. (1969), Principles of Systems, Wright Allen Press, Cambridge, Mass., second edition, fourth printing.