CATASTROPHIC BEHAVIOUR IN SYSTEM DYNAMICS MODELS FOR BLOOD BANK MANAGEMENT

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ABSTRACT

This paper explores the advantages of System Dynamics as an enquiry method for analysis of blood bank management systems which exhibit far reaching social implications. Causal loop diagrams are developed connecting various system components. The integration of individual causal loops is presented in the form of an influence diagram representing the 'dynamics' of a blood bank.Simulation model is built on the basis of causal loop diagrams. The system response to exogenous disturbances or policy changes are analyzed. The catastrophe model of blood bank system is developed and the parameters forming the control surface and behaviour surface are correlated with those of the System Dynamics model.

INTRODUCTION

For the past three decades blood bank management has been a formidable problem for all kinds of system enquiry methods. The need for a simple and compact description technique is essential for any approach to system enquiry especially when that system exhibits far reaching social implications as in the case of blood transfusion services. Studies conducted in India by the authors reveal that despite advancements in Immuno-Haematology and transfusion therapy there has been little improvement in blood bank management techniques. The ever increasing gap between demand and availability of blood, and the unique dependence of patient safety on transfusion service in the face of alarming rise in seropositive detection of AIDS among donors further aggravate the cause for concern.

The management problems in blood banking is chiefly due to the outdating of blood after its life period. A major part of the literature published so far suggesting policies for blood bank management is in reality mere academic exercises especially so under the present conditions of sophistication and complexity.Though simulation techniques yield solutions to complex inventory situations they ignore or fail to identify the time varying fluctuations in measures describing the system states and the decisive roles of exogenous elements in the inter dependant back loops. To cite an example the demand for blood originates outside the simulated system and hence cannot be treated as an internally generated variable. It is purely exogenous and hence the mechanism generating demand for blood is understood in a probabilistic sense only. 'Replenishment', 'leadtime', 'ordering' etc are conceptual parameters which are indiscriminately applied to blood bank inventory models. In reality they are variables outside the inventory set up over which the blood bank administrator has least control. Thus simulation studies confine themselves to constructing and operating dynamic models either disregarding exogenous elements influencing the system states or regarding them as controllable internal parameters. The generalizability of these studies are limited too.

This article explores the usefulness of System Dynamics simulation modelling for the analysis of blood bank inventory system. The problem is looked upon from an integrated vantage point.

DYNAMICS OF A BLOOD BANK

Most systems are dynamic in nature i.e they change their states with time. Even systems normally considered static turn out to be dynamic when perceived through a magnified time frame. System Dynamics is primarily a philosophy, a way of looking at organizations and systems, a methodology for the study of complex systems and the interaction of system variables. Its conceptual frame work integrates knowledge of the real world with the concept of how feed back structures cause observed changes, through time.(Forrester,J.W.,1973).It focuses on policies and how policies determine behavior.

The complexity of operations in a blood bank make the task of policy selections a formidable problem.(England and Roberts.,1978).The policy issues to be considered are multi objective in nature. Obviously an analytical model has to solve for several simultaneous equations with non linearities arising from interaction of these objectives and variables.

The starting point of system modelling exercise is identification of objectives which arise from an observed cause for concern of behaviour of one or more variables. Such a thinking towards problem definition leads to causal loopdiagrams. The role of causal loop diagrams in representing the structural relationships in a system is significant. (Nancy Roberts et.al 1983).

Some SD practitioners prefer such causal loops introduced by Maruyama in 1963 for the display

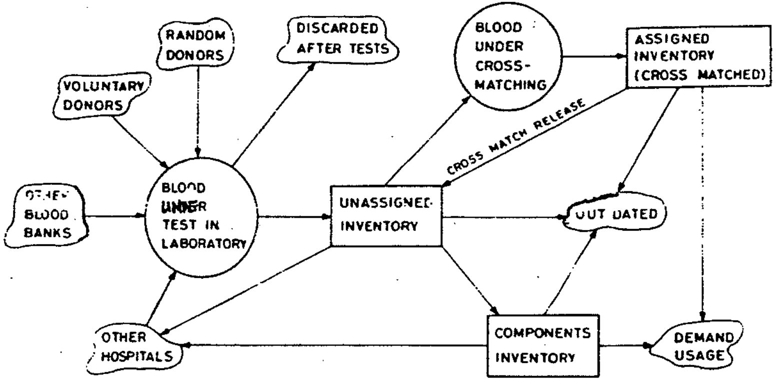

FIG 1 MODIFIED BLOOD BANK INVENTORY MODEL

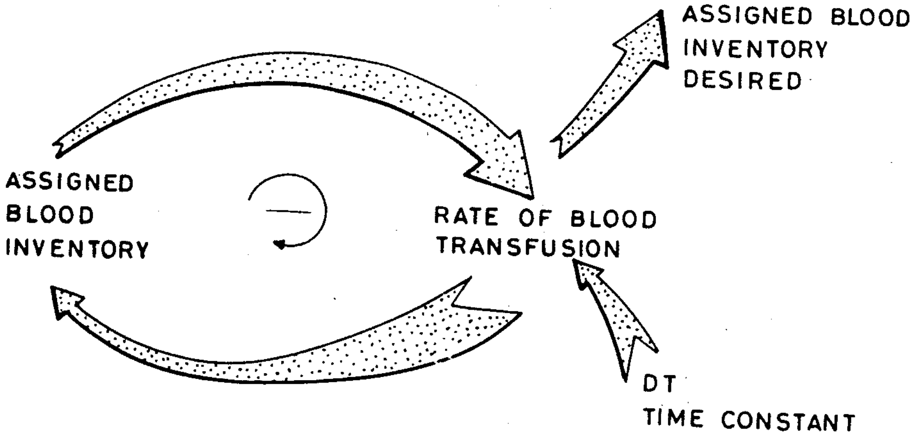

FIG.2 . SIMPLE C-L DIAGRAM

of relationships between variables, while Forrester consistently opposed the use of such diagrams because he believed that they can give a misleading impression of the feed back properties of the system. He suggested the well known flow diagramming approach based on providing clear cut rules for development of system models.

While in agreement with Forrester's reservations about causal loop diagrams it is to be remembered that the reasonably large collection of meaningful operating data required for the causal loop diagrams prevents erratic conclusions about feed back properties of the system. Besides,the computer software tools of SD ranging from DYNAMO, DYSMAP, STELLA etc have a strong affinity for information inputs in sizable quantities. Therefore in this work the authors have used C-L diagrams as building blocks for the development of the cumbersome SD flow diagram.This method adds to the modeller's insight into the behaviour exhibited by the system over a specified length of time.

The dynamic behaviour within a system is essentially generated by two types of mechanisms, namely positive feed back and negative feed back. The former promotes growth while the latter is goal seeking tending to move the system towards a desired level of operation. The underlying concept of this model building approach is based on the resource-state transformations in natural dynamic systems.(Wolstenholme and Coyle,1983).The blood bank inventory model of Jennings (Jennings, 1973) exhibits these resource-state transformation and can be considered as a dynamic system. (Shoukath Ali and Ramaswamy, 1991). A modified version of this classical model is given in Fig (1) with the addition of more state changes namely blood components and outdating. Such state changes are affected either through natural processes or by human decisions.

The dynamics of the system are highlighted through time dependant variations of the quantities and presence of substantial feed back relationships. Fig(2) is a simple causal feed back loop of the second type.

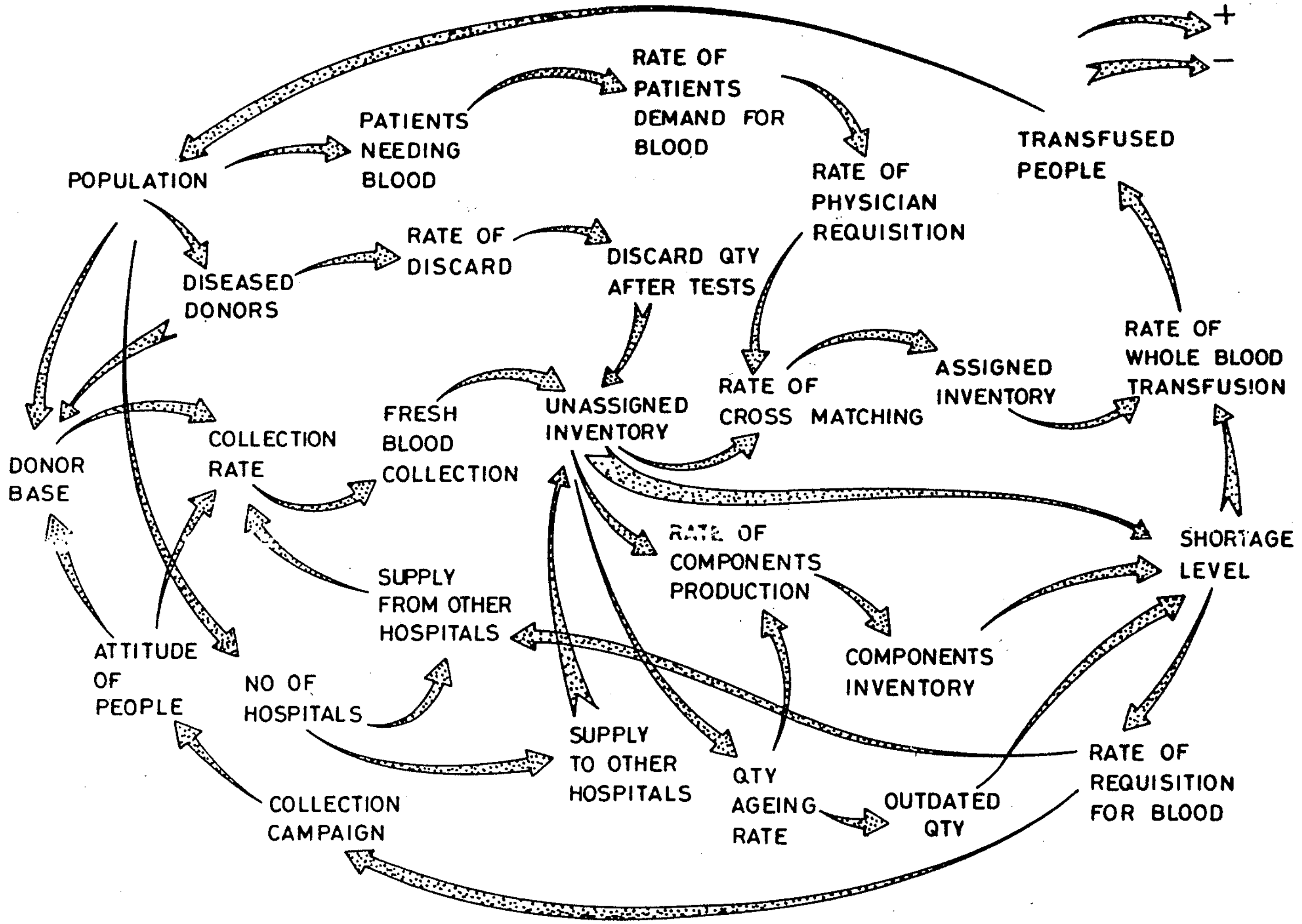

FIG. 3. BLOOD BANK DYNAMICS

The flow in the system is triggered through positive or negative feed back loops. The model exhibits a goal seeking behaviour tending to move the system to a desired level of operation. Thus transfusion rate is proportional to the difference between the desired level and the actual level while the rate over the time period determines the actual level. Thus the simple first order difference equation for the causal loop is obtained as,

$$L = \int R * DT$$

$$R = (1 / DT) * (L_D - L_{A'})$$

Integrating the individual causal loops connecting various system components the entire structural relationship may be obtained in the form of an influence diagram which represents the dynamics of a blood bank.(Fig 3.)

SIMULATION MODEL

As causal loop diagrams do not use specific symbols for representing rates and levels care should be taken while switching over to SD simulation flow diagrams. The simple causal loop of Fig (2) may be redrawn using SD symbols as shown in fig (4).

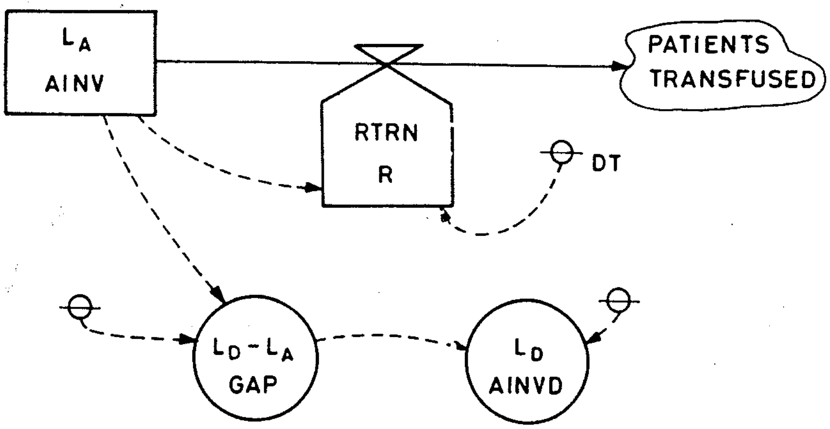

FIG.4. SIMPLE SD SIMULATION FLOW DIAGRAM

The DYNAMO equations may be written as follows:,

L AINV.K = AINV.J + DT * (RCMB.JK- RTRN.JK),
NOTE Assigned INVentory (Units of blood),
N AINVN = AINVD,
NOTE Assigned INVentory iNitial value,
R RTRN.KL = SHTGB.K DFPTDB,
NOTE Rate of TRansfusioN (Units of blood per day),

where,

RCMB = Rate of Cross Matching Blood(Units per day),
SHTGB = SHorTaGe of Blood (Units of blood),
DFPTDB = Delay in Filling PaTients' Demand for Blood,
AINVD = Assigned INVentory Desired.

The key elements considered in the simple flow diagram of fig (4) are assigned blood inventory level,shortage level, rate of cross matching etc. Introducing the state changes of blood from donor level to cross matched and components level,flow of requisitions for blood from other banks and hospitals, and exogenous elements influencing the bank operations, the SD simulation flow diagram for the whole system may be developed.

The conservative system part of the flow diagram has two major components namely flow of blood from the donor base to the demand usage point and the flow of requisitions from physicians to the donor base routed through the banks.

The nonconservative system part is constituted of the delays, constants and auxiliary variables estimated from the data collected on the blood bank operations. Some of these estimates are results of qualitative assessments made by the authors. Nevertheless the lack of precision that may have to be tolerated does not in any way destroy the value of such studies (Gordon,1990).

The graphs shown in figures 5 and 6 are the plotted output from the simulation run of the model. At the equilibrium state the model is initialized with,

AINV= 50 units of blood,
UAINV= 100 units of blood and
RPTDB= 50 units of blood (Rate of PaTients' Demand for Blood)

On the 15th day a sudden hike in RPTDB (might be due to accidents etc.) for 100 units occurs. This hike is injected into the model in the form of a PULSE function. The system responds with transient fluctuations which are characteristic of such systems. A sudden catastrophic rise in shortage level is observed.

When a STEP input is injected similar transients are generated. The system steadies itself after a period of about 100 days. The second graph shows the effect of sudden rise in blood collection injected as a PULSE function, on outdating quantity, OUTQ. An initial value of zero is assumed for OUTQ and this suddenly rises upto 20 units or more.A STEP input also produces similar pattern of outdating.

One of the significant weakness of DYNAMO is the primitive and less precise integration scheme i.e Euler's method. Even so modelling of complex information feed back systems can effectively be done with fair accuracy and precision. The process by which the SD equation structure is obtained is rather different and on the whole superior to most other modelling methods (Sharp and Price,1984).

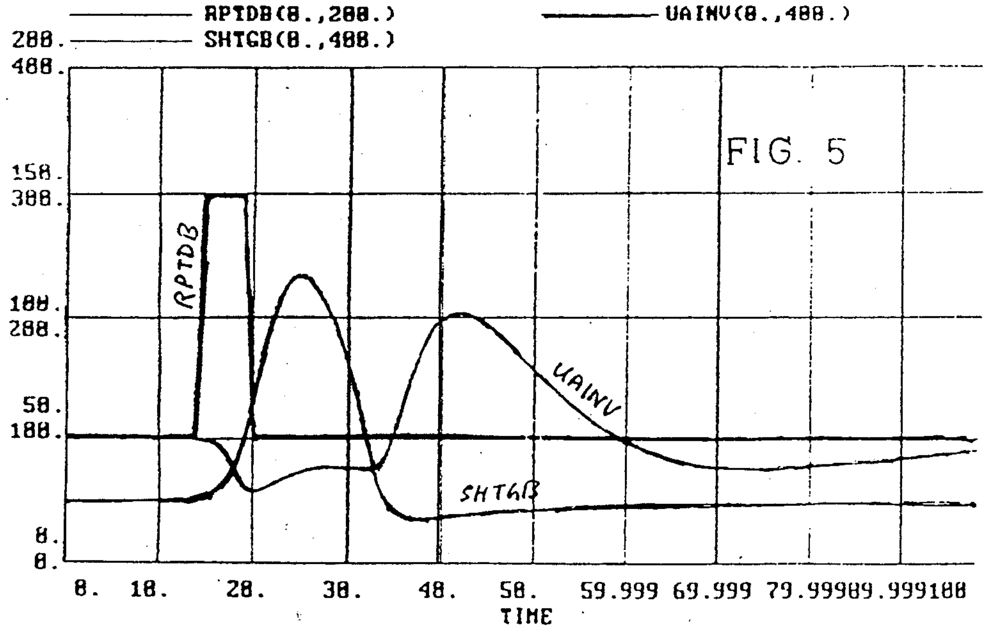
RPTDB(0.,200.)
SHTGB(0.,400.)
UAINV(0.,400.)
200.
400.
150.
300.
100.
200.
50.
100.
0.
0.
0. 10. 20. 30. 40. 50. 59.999 69.999 79.99989.999100
TIME
RPTDB
UAINV
SHTGB

FIG. 5

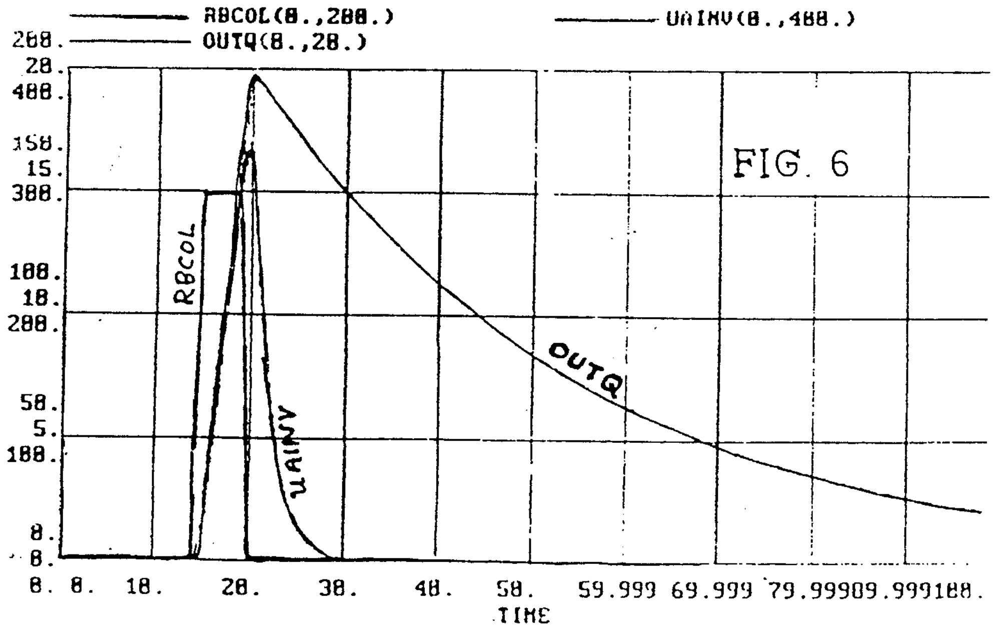
RBCOL(0.,200.)
OUTQ(0.,20.)
UAINV(0.,400.)
200.
20.
400.
150.
15.
300.
100.
10.
200.
50.
5.
100.
0.
0.
0. 0. 10. 20. 30. 40. 50. 59.999 69.999 79.99909.999100.
TIME
RBCOL
OUTQ
UAINV

FIG. 6

CATASTROPHIC BEHAVIOUR

System Dynamics and Catastrophe theory deal with nonlinear dynamic systems and it is natural that one resembles the other in many ways.

In 1974, Thorm, R classified elementary catastrophes describing discontinuities and cataclysmic changes in nature into seven groups, each of which is controlled by not more than four factors controlling the processes. The mathematical equations associated with these archetype forms along with their proof are presented by Golubitsky (1978).

The cusp Catastrophe model of a blood bank system is shown in fig (7). In blood banking the most significant elements over which the administrator has least control and that influence the optimum operating conditions, are outdating and shortage. The system swings between these two behavioural states.

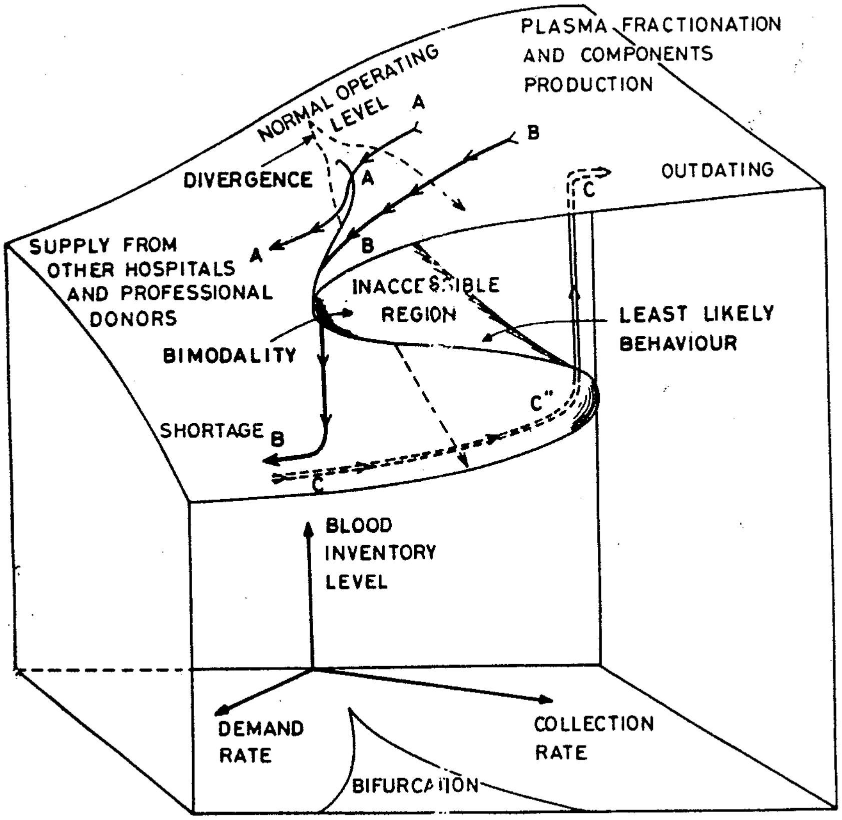

FIG.7. CATASTROPHE MODEL OF BLOOD BANK INVENTORY SYSTEM.

The single dimension which characterizes the behaviour surface is the blood inventory level. The parameters forming the control surface are demand rate and fresh blood collection rate. The behaviour surface is in fact a plot of points where the first derivative of the energy function is equal to zero. The unstable middle plate and the inflection points where catastrophes occur are formed by the maxima and the stable top and bottom sheets are formed by the minima. (Zeeman,1976).

It can be seen from the diagram that normal inventory levels are associated with mild catastrophes while large stock levels end up in severe catastrophes as indicated by the lines A-A-A and B-B-B respectively. Blood donation campaigns quite often yield good results in raising the inventory levels of blood banks. But as can be seen from the figure, if the collection rate is not rationally fixed based on shortage and preservation limitations large quantities of blood get outdated catastrophically. Acute shortage of blood is felt during times of major accidents, wars etc. Such unforeseen and sudden hikes in demand rate result in shortage catastrophes, the degree of which vary depending on the urgency of the requisitions for blood.

The bimodality of the model is indicated by an increase in the normal inventory level resulting in either shortage or outdating. This constitutes the bifurcation set of the model.

CONCLUSION

A scientific computer based model development is suggested for policy making in the management of blood banks. The set of DYNAMO equations developed for the conservative and non conservative systems were initialized using data collected through a survey conducted by the authors in 1991 on blood banking operations in India.

The survey revealed that out of about 1000 small and large blood banks in India only less than 150 banks are operating under licensing regulations stipulated by authorities. In the year 1990, there was a shortage of blood to the tune of 3.5 million units. In all the 1000 and odd banks the total quantity of blood collected was 19.5 million units against a demand for about 23 million units. This shortfall is reflected world wide. Donation campaigns alone do not serve the purpose because despite elaborate screening procedures as many as 10% recipients of transfusion developed Hepatitis virus C and about 1000 donors were detected as seropositive for AIDS.

The simulation results presented bring forth these points in a revealing manner and upholds the need for major changes in the management style of blood banks in India.

REFERENCES

1. ENGLAND, W and ROBERTS, S.D.(1978), Application of Computer Simulation to Health Care, *Proceedings of Winter Simulation Conference*, 1978, 665-677.

2. FORRESTER, J.W.(1973), *Industrial Dynamics*, MIT Press, Cambridge, Massachusetts.

3. GOLLUBITSKY, M.(1978), An Introduction to Catastrophe Theory and its applications , *Siam Review*, Vol,20, No.2, 352-387.

4. GORDON, (1990), *System Simulation*, Prentice Hall India, Ltd, New Delhi.
5. JENNINGS, B (1973) Blood Bank Inventory Control, *Management Science*,Vol. 19, 637-647.

6. MEIER, R.C., NEWELL, W.T and PAZER, H.L.(1969) *Simulation in Business and Economics*, Prentice Hall.

7. NANCY ROBERTS et.al (1983), *Introduction to Computer Simulation - The System Dynamics Approach*, Addison Wesley.

8. PAULRE,B.E (1981), Editor, *System Dynamics and Analysis of Change*, North Holland.

9. SHARP, J.A and PRICE, D.H.R (1984), System Dynamic and Operations Research- An Appraisal, Invited Review, *European Journal of Operations Research*, Vol.16, 1-12.

10.SHOUKATH ALI,K and RAMASWAMY,N. (1991), Setting Inventory levels for a Centrally Located Blood Bank of a Metropolis - A Simulation Approach, *Proceedings of Int.System Dynamics Conference*, 1991.

11.THORM,R.(1974). *Structural Stability and Morphogenesis*, Addison Wesley.

12.WOLSTENHOLME,E.F and COYLE R.G.(1983). Development of System dynamics as a Methodology for System Description and Qualitative Analysis. *Journal Of O.R.Society*, Vol.34, 569-581.

13.WOLSTENMOLME, E.F.(1983), Modelling National Development Programmes, *Journal Of O.R.Society*, Vol.34, No.12, 1133-1148.

14.ZEEMAN,E.C.(1976), Catastrophe Theory, *Scientific American,* Vol.234, No.4, 65-83.