A Mathematical Analysis on A Mathematical Model on Stress and Depression among Women

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Abstract: The aim of this research is to construct a model for Stress and Depression among women in India. The feasible values of the variables are obtained by the equilibrium analysis. The local and global stability of the model are analysed. The model is reconstructed with fuzzy parameters whose membership functions are formulated based on online survey of the stress and depression rate of Indian women. The local and global stability conditions are refined in fuzzy environment. Numerical simulations were shown to exhibit the flow of variables and to understand the impact of fuzzy parameter

Keywords: Stress, Depression, Fuzzy Environment, Survey Analysis.

1. Introduction

Stress is a feeling of emotional or physical tension. In the fast-paced world, stress is very common but, chronic stress is the one to avoid. Stress damages the health, mood, productivity, relationships which has to pay a high price to manage. The stress has symptoms such as inability to concentrate, constant worrying, making poor judgements, low thinking, reduces memory power. Depression is a mood disorder that causes a persistent feeling of sadness and loss of interest. Depression often begins in the teens, but it can happen at any age. Stress is not a mental health illness while Depression is a mental illness which requires a medical treatment such as medication, psychotherapy. The outcomes of depression are feelings of sadness, tearfulness, hopelessness and emptyness which leads to insomnia, fatigue and physical pain. The suicidal thoughts are the extreme level of depression. The main reasons for suicide are loneliness, experience of loss, financial problems, violence and abuse.

India is a country in which women has to play multiple roles at same time. So they have stress to sustain their goals in career, family and society. Globally, women suffer more depression than men. But men suicide rate is several times higher than that of women. Is this women’s true mental strength or our society brought up women to uphold everything in a balanced way?.

Formulation of mathematical model

The following system of four ordinary differential equations represents the Stress and Depression model,

\[
\begin{align*}
\frac{dS}{dt} &= \omega N - (\beta + \mu)S + \delta R \\
\frac{dI_S}{dt} &= \beta S - (\alpha + \mu + \gamma_1)I_S \\
\frac{dI_D}{dt} &= \alpha I_S - (\mu + \gamma_2 + d_s)I_D \\
\frac{dR}{dt} &= \gamma_2 I_D - (\delta + \mu)R + \gamma_1 I_S
\end{align*}
\]  

(1)

Where \( S(t), I_S(t), I_D(t), R(t) \) are the Susceptible, Infected by Stress, Infected by Depression and Recovery state respectively and \( \omega \) - Average birth rate, \( \mu \) - Average death rate, \( \beta \) - Stress rate, \( \gamma_1 \) - Recovery rate from Stress, \( \gamma_2 \) - Recovery rate from Depression, \( \alpha \) - Depression rate, \( \delta \) - Restress rate, \( d_s \) - Suicide death rate, \( N(t) \) - Female Population. Also \( S(t), I_S(t), I_D(t), R(t) \geq 0 \) and \( \omega, \delta, \mu, \alpha, \gamma_1, \gamma_2, \beta, d_s > 0 \).

The following figure shows the Stress and Depression model:

![Figure 1: Stress and Depression model](image)

Model in the Fuzzy environment

In this section, we reconstruct the model in fuzzy environment. Among the individuals there are different levels of stress and depression, so the susceptible, infectious by stress and depression are uncertain. The transition rate of stress and depression rate are considered as fuzzy numbers. The recovery from stress and depression are also uncertain. So we consider the recovery rate from stress \( \gamma_1 \) and recovery rate from depression \( \gamma_2 \) as fuzzy numbers. To describe the stress load on these parameters, we define the membership function \( \beta(v), \alpha(v), \gamma_1(v), \gamma_2(v) \) as in [2]:

\[
\beta = \begin{cases} 
0 & v < v_{\text{min}} \\
\frac{v - v_{\text{min}}}{v_M - v_{\text{min}}} & v_{\text{min}} \leq v \leq v_M \\
1 & v_M \leq v \leq v_{\text{max}}
\end{cases} \quad (2)
\]

\[
\alpha = \begin{cases} 
0 & v < v_{\text{max}} \\
\frac{v - v_{\text{min}}}{v_M - v_{\text{min}}} & v_{\text{min}} \leq v \leq v_M \\
1 & v_M \leq v \leq v_{\text{max}}
\end{cases} \quad (3)
\]

\[
\gamma_1 = \frac{\gamma_{10} - 1}{v_{\text{max}}} v + 1, \quad 0 < v < v_{\text{max}} \quad (4)
\]

\[
\gamma_2 = \frac{\gamma_{20} - 1}{v_{\text{max}}} v + 1, \quad 0 < v < v_{\text{max}} \quad (5)
\]
Then the system of fuzzy differential equations of the stress and depression model is given by

\[
\begin{align*}
\frac{dS}{dt} &= \omega N - (\beta(v) + \mu)S + \delta R \\
\frac{dI_S}{dt} &= \beta(v)S - (\alpha(v) + \mu + \gamma_1(v))I_S \\
\frac{dI_D}{dt} &= \alpha(v)I_S - (\mu + \gamma_2(v) + d_s)I_D \\
\frac{dR}{dt} &= \gamma_2(v)I_D - (\delta + \mu)R + \gamma_1(v)I_S
\end{align*}
\]

**Equilibrium Analysis**

The steady states are \(G_0(0,0,0,0)\), \(G_1(S,0,0,0)\), \(G_2(S,I_S,0,0)\), \(G_3(S',I_S',I_D',0)\) and \(G_4(S',I_S',I_D',R')\)

Case (1): Trivial steady state \(G_0(0,0,0,0)\) exists always.

Case (2): For \(G_1(S,0,0,0)\),

Let \(\bar{S}\) be the positive solutions of \(\frac{dS}{dt} = 0\).

From (1),

\[
\bar{S} = \frac{\omega N}{(\beta + \mu)}
\]

\[
G_1(S,0,0,0) = \left( \frac{\omega N}{\beta + \mu}, 0, 0, 0 \right)
\]

Case (3): For \(G_2(S,I_S,0,0)\),

Let \(\bar{S}, \bar{I}_S\) be the positive solutions of \(\frac{dS}{dt} = 0, \frac{dI_S}{dt} = 0\).

From (1),

\[
\bar{S} = \frac{\omega N}{(\beta + \mu)}
\]

\[
\bar{I}_S = \frac{\beta \omega N}{(\beta + \mu)(\alpha + \mu + \gamma_1)}
\]

\[
G_2(S,\bar{I}_S,0,0) = \left( \frac{\omega N}{(\beta + \mu)}, \frac{\beta \omega N}{(\beta + \mu)(\alpha + \mu + \gamma_1)}, 0, 0 \right)
\]

Case (4): For \(G_3(S',I_S',I_D',0)\),

Let \(S', I_S', I_D'\) be the positive solutions of \(\frac{dS}{dt} = 0, \frac{dI_S}{dt} = 0, \frac{dI_D}{dt} = 0\).

From (1),

\[
S' = \frac{\omega N}{(\beta + \mu)}
\]

\[
I_S' = \frac{\beta \omega N}{(\beta + \mu)(\alpha + \mu + \gamma_1)}
\]
When the Jacobian matrix for the system (1) is
\[
\begin{align*}
I_\text{D}' &= \frac{\alpha b N}{(\beta + \mu)\left(\alpha + \mu + \gamma_1\right)\left(\gamma_2 + \mu + d_\alpha\right)} \\
\end{align*}
\]
Therefore \(G_3(S^*, I_\text{S}, I_\text{D}', 0) = \left(\frac{\alpha N}{(\beta + \mu)} - \frac{b N}{(\beta + \mu)(\alpha N + \gamma_1)} \frac{\alpha b N}{(\beta + \mu)(\alpha + \mu + \gamma_1)\left(\gamma_2 + \mu + d_\alpha\right)} 0\right)\)

Case (5): For \(G_4(S^*, I_\text{S}^*, I_\text{D}', R^*)\),

Let \(S^*, I_\text{S}^*, I_\text{D}', R^*\) be the positive solutions of \(\frac{dS}{dt} = 0, \frac{dI_\text{S}}{dt} = 0, \frac{dI_\text{D}}{dt} = 0, \frac{dR}{dt} = 0\)

From (1),
\[
\begin{align*}
S^* &= \alpha N \left\{ \frac{1}{(\beta + \mu)} - \frac{(\beta + \mu)(\alpha + \mu + \gamma_1)}{\alpha b \gamma_2} \frac{(\delta + \mu)(\alpha + \mu + \gamma_1)}{\beta \gamma_1} \right\} \\
I_\text{S}^* &= \alpha N \left\{ \frac{\beta}{(\beta + \mu)} - \frac{(\delta + \mu)}{\alpha \gamma_2} \frac{(\delta + \mu)}{\beta \gamma_1} \right\} \\
I_\text{D}^* &= \alpha N \left\{ \frac{\beta}{(\beta + \mu)(\alpha + \mu + \gamma_1)(\gamma_2 + \mu + d_\alpha)} - \frac{(\delta + \mu)}{\gamma_2} \frac{(\delta + \mu)}{\beta \gamma_1} \right\} \\
R^* &= \frac{\gamma_2 I_\text{D} + \gamma_1 I_\text{S}}{\delta + \mu} \\
\end{align*}
\]

\[\therefore\text{the stress equilibrium is given by}\]
\[
\begin{align*}
G_4(S^*, I_\text{S}^*, I_\text{D}', R^*) &= (\alpha N \left\{ \frac{1}{(\beta + \mu)} - \frac{(\beta + \mu)(\alpha + \mu + \gamma_1)(\gamma_2 + \mu + d_\alpha)}{\alpha b \gamma_2} \frac{(\delta + \mu)(\alpha + \mu + \gamma_1)}{\beta \gamma_1} \right\}, \alpha N \left\{ \frac{\beta}{(\beta + \mu)} - \frac{(\delta + \mu)}{\alpha \gamma_2} \frac{(\delta + \mu)}{\beta \gamma_1} \right\}, \alpha N \left\{ \frac{\beta}{(\beta + \mu)(\alpha + \mu + \gamma_1)(\gamma_2 + \mu + d_\alpha)} - \frac{(\delta + \mu)}{\gamma_2} \frac{(\delta + \mu)}{\beta \gamma_1} \right\}, \frac{\gamma_2 I_\text{D} + \gamma_1 I_\text{S}}{\delta + \mu} ) \\
\end{align*}
\]

\[\therefore S^*, I_\text{S}^*, I_\text{D}', R^*\) are positive when,
\[
\frac{\beta}{(\beta + \mu)} > \max\{k_1, k_2, (\alpha + \mu + \gamma_1)k_1\}
\]

Where \(k_1 = \frac{\delta}{(\beta + \mu)}\) and \(k_2 = \frac{(\gamma_2 + \mu + d_\alpha)}{\alpha \gamma_2} + \frac{1}{\gamma_1}\)

**Local Stability**

By the Routh-Hurwitz criteria, we find the local stability of (6).

The Jacobian matrix for the system (1) is
\[
\begin{pmatrix}
-(\beta + \mu) & 0 & 0 & 0 \\
\beta & -(\alpha + \mu + \gamma_1) & 0 & 0 \\
0 & \alpha & (\gamma_2 + \mu + d_\alpha) & 0 \\
0 & \gamma_1 & \gamma_2 & -(\mu + \delta)
\end{pmatrix}
\]

When \(\frac{dS}{dt} = 0,\)
\[
-(\beta + \mu) = -\frac{\alpha N + \delta R}{S} \quad (8)
\]

When \(\frac{dI_\text{S}}{dt} = 0,\)
\[
-(\alpha + \mu + \gamma_1) = -\frac{\beta S}{I_\text{S}} \quad (9)
\]
When $\frac{dl}{dt} = 0$,

$$-(\gamma_2 + \mu + d_s) = \frac{a_Is}{I_D}$$  \hspace{1cm} \text{(10)}$$

When $\frac{dR}{dt} = 0$,

$$-(\mu + \delta) = \frac{\gamma_2 I_0 + \gamma I_S}{R}$$  \hspace{1cm} \text{(11)}$$

At the interior equilibrium (7) becomes

$$
\begin{pmatrix}
\frac{\alpha N + \delta R}{S} & 0 & 0 & 0 \\
\beta & -\frac{\beta S}{I_S} & 0 & 0 \\
0 & \alpha & -\frac{a_I S}{I_D} & 0 \\
0 & \gamma_1 & \gamma_2 & -\frac{\gamma_2 I_0 + \gamma I_S}{R}
\end{pmatrix}
$$  \hspace{1cm} \text{(12)}$$

The characteristic equation of (12) is given by

$$\lambda^4 + \frac{\alpha N + \delta R}{S} + \frac{\gamma_2 I_0}{R} + \frac{\gamma_1 I_S}{R} + \frac{\beta S}{I_S} + \frac{\alpha_I S}{I_D} \lambda^3
$$

$$+ \left(\frac{\omega N}{S} + \frac{\delta R}{S} + \frac{\gamma_2 I_0}{R} + \frac{\gamma_1 I_S}{R} + \frac{\beta S}{I_S} + \frac{\alpha_I S}{I_D}\right) \lambda^2
$$

$$+ \left(\frac{\omega N \gamma_2 I_0}{S} + \frac{\omega N \gamma_1 I_S}{S} + \frac{\omega N \beta}{I_S} + \frac{\omega N \alpha I_S}{S} + \frac{\omega N I_0}{I_D} + \frac{\omega N \alpha I_S}{I_D} + \frac{\omega N \beta}{I_S} + \frac{\omega N \alpha I_S}{I_D} \right) \lambda
$$

$$+ \left(\frac{\omega N \gamma_2 I_0}{S} + \frac{\omega N \gamma_1 I_S}{S} + \frac{\omega N \beta}{I_S} + \frac{\omega N \alpha I_S}{I_D} \right) + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D + \frac{\omega N \alpha I_S}{I_D} \beta \gamma_2 I_D = 0$$

(13)

Comparing (13) with $S^4 + AS^3 + BS^2 + CS + D = 0$

where

$$A = \frac{\omega N}{S} + \frac{\delta R}{S} + \frac{\gamma_2 I_0}{R} + \frac{\gamma_1 I_S}{R} + \frac{\beta S}{I_S} + \frac{\alpha_I S}{I_D}$$

$$B = \frac{\omega N \gamma_2 I_0}{S} + \frac{\omega N \gamma_1 I_S}{S} + \frac{\omega N \beta}{I_S} + \frac{\omega N \alpha I_S}{S} + \frac{\omega N I_0}{I_D} + \frac{\omega N \alpha I_S}{I_D} + \frac{\omega N \beta}{I_S} + \frac{\omega N \alpha I_S}{I_D}$$

$$C = \frac{\omega N \gamma_2 I_0}{I_S R} + \frac{\omega N \gamma_1 I_S}{I_S R} + \frac{\omega N \beta}{I_S R} + \frac{\omega N \alpha I_S^2}{I_D SR} + \frac{\omega N \beta}{I_S R} + \frac{\omega N \alpha I_S}{I_D}$$
\[ A > 0, \quad D > 0 \quad \text{as all the values positive}; \quad AB - C > 0, \quad \text{when} \quad 1 - S > 0; \quad C (AB - C) - A^2 D > 0 \quad \text{when} \quad \omega N < 1. \quad \text{Then by the Routh-Hurwitz criteria, the system (1) is locally stable.} \]

**Local Stability in Fuzzy Environment**

As \( \beta, \alpha, \gamma_1, \gamma_2 \) are the fuzzy numbers, \( \beta(v), \alpha(v), \gamma_1(v), \gamma_2(v) \) have different values. We proceed with the following three cases:

**Case (1):** When \( v < v_{\text{min}} \).
Here \( \beta = 0, \alpha = 0, \gamma_1 > 0, \gamma_2 > 0 \)

Then

\[
A = \frac{\omega N}{S} + \frac{\delta R}{S} + \frac{\gamma_2 I_D}{R} + \frac{\gamma_1 I_S}{R} + \frac{\beta S}{I_S} + \frac{\alpha I_S}{I_D}
\]

\[
B = \frac{\omega N \gamma_2 I_D}{SR} + \frac{\omega N \gamma_1 I_S}{SR} + \frac{\omega N \delta R}{SR} + \frac{\omega N \delta I_D}{SR} + \frac{\beta \gamma_2 I_D}{SR} + \frac{\alpha \delta I_S}{S} + \frac{\beta \delta R}{I_S} + \frac{\alpha \delta I_D}{I_S}
\]

\[
C = \frac{\omega N \beta \gamma_2 I_D}{I_S R} + \frac{\omega N \alpha \gamma_1 I_S}{I_S R} + \frac{\omega N \beta \gamma_1}{I_S} + \frac{\omega N \delta I_D}{I_S} + \frac{\omega N \delta I_D}{I_S} + \frac{\beta \gamma_2 I_D}{I_S} + \frac{\alpha \delta I_S}{S} + \frac{\beta \delta I_S}{I_D} + \frac{\alpha \delta I_D}{I_D}
\]

\[
D = \frac{\omega N \beta \gamma_2}{R} + \frac{\omega N \alpha \delta I_S}{R} + \frac{\omega N \delta I_D}{R}
\]

**Case (2):** For \( v_{\text{min}} \leq v \leq v_{\text{max}} \).

\( 0 < \beta < 1, 0 < \alpha < 1, \gamma_1 > 0 \) and \( \gamma_2 > 0 \)

Then

\[
A = \frac{\omega N}{S} + \frac{\delta R}{S} + \frac{\gamma_2 I_D}{R} + \frac{\gamma_1 I_S}{R} + \frac{\beta S}{I_S} + \frac{\alpha I_S}{I_D}
\]

\[
B = \frac{\omega N \gamma_2 I_D}{SR} + \frac{\omega N \gamma_1 I_S}{SR} + \frac{\omega N \beta I_S}{S} + \frac{\omega N \delta R}{S} + \frac{\omega N \delta I_D}{S} + \frac{\beta \gamma_2 I_D}{S} + \frac{\alpha \delta I_S}{S} + \frac{\beta \delta R}{I_S} + \frac{\alpha \delta I_S}{I_S} + \frac{\beta \delta I_D}{I_D} + \frac{\alpha \delta I_D}{I_D}
\]

\[
C = \frac{\omega N \beta \gamma_2 I_D}{I_S R} + \frac{\omega N \alpha \gamma_1 I_S}{I_S R} + \frac{\omega N \beta \gamma_1}{I_S} + \frac{\omega N \delta I_D}{I_S} + \frac{\omega N \delta I_D}{I_S} + \frac{\beta \gamma_2 I_D}{I_S} + \frac{\alpha \delta I_S}{S} + \frac{\beta \delta I_S}{I_D} + \frac{\alpha \delta I_D}{I_D}
\]

\[
D = \frac{\omega N \beta \gamma_2}{R} + \frac{\omega N \alpha \delta I_S}{R} + \frac{\omega N \delta I_D}{R}
\]

**Case (3):** For \( v_{\text{M}} \leq v \leq v_{\text{max}} \).

\( \beta = 1, \alpha = 1, \gamma_1 > 0 \) and \( \gamma_2 > 0 \)

Then

\[
A = \frac{\omega N}{S} + \frac{\delta R}{S} + \frac{\gamma_2 I_D}{R} + \frac{\gamma_1 I_S}{R} + \frac{\beta S}{I_S} + \frac{I_S}{I_D}
\]

\[
B = \frac{\omega N \gamma_2 I_D}{SR} + \frac{\omega N \gamma_1 I_S}{SR} + \frac{\omega N \beta I_S}{S} + \frac{\omega N \delta R}{S} + \frac{\omega N \delta I_D}{S} + \frac{\beta \gamma_2 I_D}{S} + \frac{\alpha \delta I_S}{S} + \frac{\beta \delta R}{I_S} + \frac{\alpha \delta I_S}{I_S} + \frac{\beta \delta I_D}{I_D} + \frac{\alpha \delta I_D}{I_D}
\]

\[
D = \frac{\omega N \beta \gamma_2}{R} + \frac{\omega N \alpha \delta I_S}{R} + \frac{\omega N \delta I_D}{R}
\]
Choosing \( l_1 = \frac{1}{\gamma_1}, l_2 = \frac{1}{\mu}, l_3 = \frac{1}{\gamma_2} \), we have

\[
(V(S, I_5, I_D, R)) = \left((S - S^*) \frac{\omega N + \delta R}{S} + (S - S^*) \delta \left( \frac{R}{S} - \frac{R^*}{S^*} \right) + l_1 (I_5 - I_5^*) \left( \frac{\beta S}{I_5} - \frac{\beta S}{I_5^*} \right) + l_2 (I_D - I_D^*) \left( \frac{\alpha I_5}{I_D} - \frac{\alpha I_5}{I_D^*} \right) + l_3 (R - R^*) \left( \frac{I_D}{R} - \frac{I_D}{R^*} \right) \right)
\]

Choosing \( l_1 = \frac{1}{\gamma_1}, l_2 = \frac{1}{\mu}, l_3 = \frac{1}{\gamma_2} \), we have

\[
(V(S, I_5, I_D, R)) = \left((S - S^*) \frac{\omega N + \delta R}{S} + (S - S^*) \delta \left( \frac{R}{S} - \frac{R^*}{S^*} \right) + l_1 (I_5 - I_5^*) \left( \frac{\beta S}{I_5} - \frac{\beta S}{I_5^*} \right) + l_2 (I_D - I_D^*) \left( \frac{\alpha I_5}{I_D} - \frac{\alpha I_5}{I_D^*} \right) + l_3 (R - R^*) \left( \frac{I_D}{R} - \frac{I_D}{R^*} \right) \right)
\]
We have the values of parameters as follows: \( \omega = 0.0234, \mu = 0.008, d_x = 0.024, \beta=0.36, \alpha=0.25 \). We assume \( \delta = 0.18, \gamma_1 = 0.18, \gamma_2 = 0.2 \)
Figure 2: Flow of variables with respect to time

Figure 2 shows the flow of variables with high recovery rate with respect to time when $\beta = 0.36 = 0.25$. Figure (3) shows the flow of individuals in susceptible class for the different values of $\beta$. When the transition rate of stress varies then the number of individuals in susceptible class move towards the infected by stress class with respect to time.

Figure 3: Susceptible class for different values of $\beta$

Figure (4) and figure (5) shows the flow of individuals in infected by stress class for different values of $\alpha$ and $\gamma_1$ respectively. From figure (4) for the various values of $\alpha$, the number of individuals in infected by stress class move towards the infected by depression class and figure (5) while increasing the recovery rate of infected by stress, we get high recovery rate with respect to time.
Figure 6: Infected by depression class for different values of $\alpha$

Figure 7: Infected by depression class for different values of $\gamma_2$.

Figure (6) and figure (7) shows the flow of individuals in infected by depression class for different values of $\alpha$ and $\gamma_2$ respectively. From figure (6) for the various values of $\alpha$, the infected by depression rate is high and figure (7) while increasing the recovery rate of infected by depression, we get high recovery rate with respect to time.

Figure 8: Recovered class for different values of $\gamma_1$

Figure 9: Recovered class for different values of $\gamma_2$.

Figure (8) and figure (9) shows the flow of individuals in recovered state for the different values of $\gamma_1$ and $\gamma_2$ respectively. If $\gamma_1$ and $\gamma_2$ value goes higher and higher then the recovery rate increases with respect to time.

Conclusion

A Stress and Depression model was constructed among the Indian women. The model was reexplored in the fuzzy environment with stress rate, depression rate, recovery rate from stress and recovery rate from depression were defined as membership functions. The equilibrium analysis was analysed for the model. The stability analysis were derived for the model. The stability analysis in the fuzzy environment was also discussed. The stress and depression rate were calculated by the survey taken. The numerical simulations were carried out to show the flow of variables.
References


