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A MATHEMATICAL MODEL OF RUMOR PROPAGATION FOR DISASTER MANAGEMENT

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Abstract – This paper focuses on the study of rumor propagation for possible application to disaster management. A conceptual mathematical model that simulates rumor spread was introduced in this study. The model simulates the mutation of information during the propagation using Monte Carlo method. This model reinforces some of the existing rumor theories and rumor control strategies.

Keywords: earthworms, diversity, density, sugarcane land, conventional soil management, annual rainfall and soil factors.

INTRODUCTION

Various theories about rumors, especially those pertaining to disasters, were already formulated by social scientists. Some of these theories are based on intuition and qualitative studies. Recently, an emerging field called *Mathematical Sociology* tries to investigate social phenomenon, such as rumor propagation, using mathematical and computational models. Experimental or statistical research on rumor propagation is impractical and usually infeasible, that is why rumor modeling using mathematics is used to mimic rumor spread. The main goal of this paper is to mimic the evolution of stories during the information propagation using Monte Carlo simulation.

The basic law of rumor states that rumor strength is directly proportional to the significance of the subject towards the individual concerned and to the uncertainty of the evidence at hand (Rosnow and Foster, 2005). A modified theory views rumor-mongering as a way of handling anxieties and uncertainties during chaotic times by creating and passing on stories, and attempting to provide an explanation for behavior and to address confusion (Rosnow 1991, 2001). Specifically, rumors take place when no clear link exists between people and the correct information, causing ambiguity (Bordia and DiFonzo, 2004). When people fail to find a plausible answer to their queries, they begin to interpret the situation and make use of the information at hand to come up with stories (Bordia and DiFonzo, 2004). Also, belief in a rumor depends on the degree of suggestibility and credulity of the rumormongers involved.

Two basic models on rumor propagation are the Daley-Kendall (Daley and Kendall, 1965) and Maki-Thompson Models (Maki and Thompson, 1973). Serge Galam (2003), the father of sociophysics, studied the dynamics of rumor spread originating from minorities regarding the September 11 Pentagon bombing. Galam (2005) and Suo and Chen (2008) investigated the dynamics of the formulation of public opinions. Dodds and Watts (2005) formulated a model for social and biological contagion.

Yu and Singh (2003) developed models for detecting deception using Dempster-Shafer Theory. Matos (2004) studied the relationship between information flow in the society and the volatility in financial markets. Lind et al (2007), Rabajante and Otsuka (2010), and Salvanica and Pabico (2010) investigated the spread of information, such as gossips, in social networks. Other researches about rumor spread were done by Moreno, Nekovee and Pacheco (2004), and Nekovee et al (2006).

There are various strategies in controlling spread of information such as (1) controlling the entry and exodus of people in the community, (2) regulating the media of

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communication, (3) influencing the belief system of people, and (4) introducing an antithesis of the circulating information.

Rumor control by introducing antithesis to the circulating information is also used in disaster management. From http://www.colorado.edu/ conflict/ peace / treatment/ rumorct.htm:

> "The key to effective rumor control efforts is an ability to perform three functions. First, some mechanism is needed for determining what rumors are actually circulating. Second, an effective strategy is needed for determining which rumors are true, and which are false. Finally, mechanisms are needed for correcting inaccurate rumors and replacing them with reliable information… Perhaps the best developed example of rumor control mechanisms is the crisis control centers developed during the heart of the Cold War to prevent incomplete information about the actions of opposing military forces from escalating into a violent and dangerous confrontation between the United States and the Soviet Union.
>
> At the local level, the United States Community Relations Service (an arm of the U.S. Department of Justice) empowered to intervene in racial conflicts) has utilized rumor control teams within communities in an effort to stop rumors that harm intergroup relations."

Also refer to Tierney, Bevc and Kuligowski (2006) regarding their discussion on disaster myths and media.

THE MODEL

Previous studies about information propagation, such as by Galam (2003, 2005), only consider a pair of conflicting information. As an extension to such researches, this model is formulated to observe the dynamics of multiple pairs of conflicting information. A Monte Carlo Simulation algorithm was formulated to mimic information propagation and mutation. The results showed the evolution of stories considering finite number of time periods and actors. The results are summarized using descriptive statistics.

Deterministic rules were integrated inside the formulated stochastic algorithm. The algorithm uses random numbers which make it prone to statistical errors. Perturbation analysis should be done to check the stability of the algorithm to the given initial values and parameters.

The algorithm was carried out using a Scilab program (version 5.3.0). Initial values were given by the user in order to run the program. A limitation of the algorithm is that a person cannot handle conflicting stories at the same time.

A community network is needed in the implementation of the algorithm. The simulation is applicable to any type of network. The nodes of the network are named as actors, while the edges represent the communication occurring among the actors. The circulating story is composed of n number of basic information.

For example, in the recent Ondoy typhoon, comments were circulating that damages could have been lesser if certain precautions were made. Hence, even if the typhoon was over, it left the question "Who is to be blamed about the unexpected but controllable damages brought about by Typhoon Ondoy?" Having the issue in mind, consider the following basic information (Mendoza, 2009; GMANews, 2009):

1) The Arroyo Administration is to be blamed;
2) The MMDA Chairman is responsible for the damages; and
3) Engineers of Angat Dam should be blamed.

In the given example, combinations of the three basic information compose the possible stories. One story could be, 'Arroyo administration is to be blamed, the MMDA chairman is not responsible, and the Engineers of Angat Dam should be blamed.' Another could be 'Arroyo administration is to be blamed, together with the MMDA Chairman and the engineers of Angat Dam.'

A story with n basic information is stored in an n-dimensional hypercube (Figure 1). In real life, this hypercube serves as the memory of the actor. The entire network may be illustrated as shown in Figure 2, where each actor is assigned a memory. The boxes represent the memories of the actors, where each memory is modeled by a hypercube.

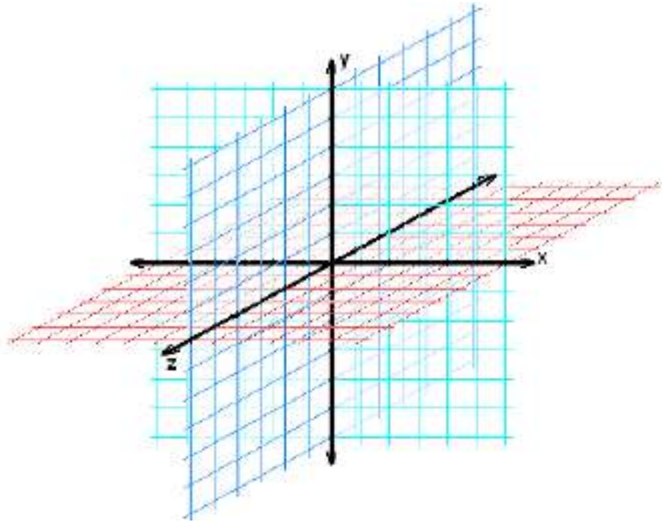

Figure 1: A Three-dimensional hypercube

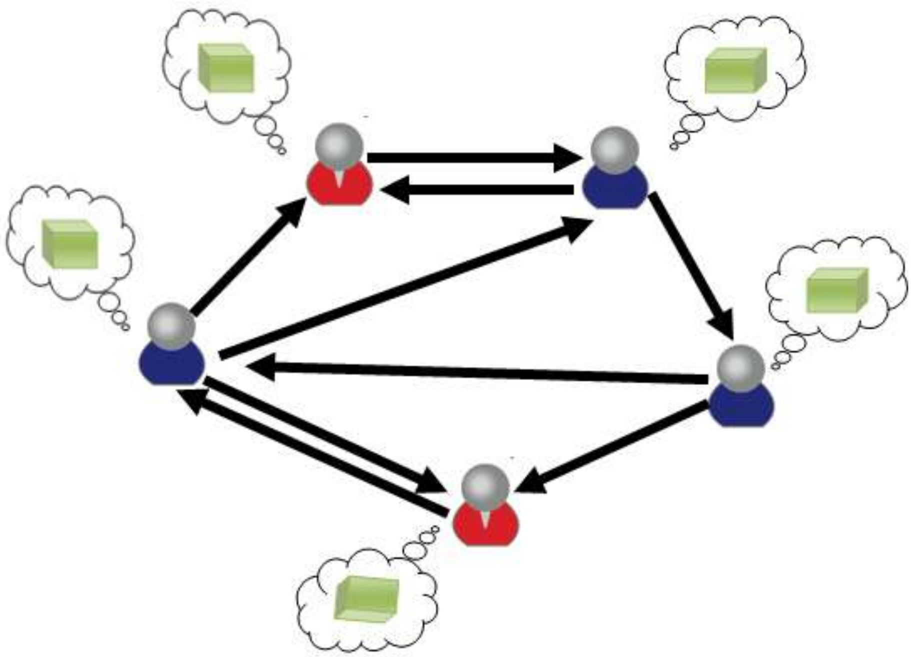

Figure 2: A Network with Actors and their Respective Memories

The axes of the hypercube represent the basic information. Each basic information is assigned with a positive or a negative value. For the given example, the three basic information correspond to the three axes, say $x, y,$ and z axes, respectively. The positive x-axis represents the information that Arroyo administration is to be blamed in the effects of the typhoon, while the negative x-axis represents the information that the Arroyo administration is not to be blamed. Similarly, the positive y-axis represents the information that the MMDA Chairman is to be blamed, while the negative y-axis represents the information that the MMDA Chairman is not to be blamed. Lastly, the positive z-axis represents the information that the engineers of the Angat Dam are to be blamed and the negative z-axis represents the information that the engineers of Angat Dam are not to be blamed.

The values assigned to the basic information are the degrees of belief of the actor. Each degree of belief is given a value from -2 to 2. The n basic information with their corresponding degrees of belief are stored in the memory (hypercube) of the actor using an n-tuple belief vector.

A positive degree of belief means that a person is a believer, while a negative value means that the actor is a non-believer. These states were further divided into two. A believer can further be classified as a believer but doubting, and a believer who is loyal; while a non-believer can further be classified as a non-believer but doubting, and a non-believer and loyal. The believers and loyal have a greater strength of belief, which is from 1 to 2 (or in the case of non-believers and loyal, -1 to -2).

For example, if the value of the basic information is 0.7, it means that the actor believes the basic information with the degree of 70%, but implying that the actor is still doubting with the information. While if the value of the basic information is -0.3 then the actor does not believe the basic information with the degree of 30% but his/her unbelief is weak.

Notice that, the range of belief of a believer but doubting has the same length of measure as compared to the range of a believer and loyal. These two are of equal length to give equal chances for an actor to be in these states.

Another group of actors are categorized to be in the neutral state. These are the actors having a zero (0) degree of belief because they have no knowledge of the story or they are simply indifferent. In this paper, it is assumed that an actor cannot have opposing beliefs at the same time. The values 2 and -2 are the extreme values that can be assigned to an actor's degree of belief or unbelief. This implies that each hypercube (memory) is bounded.

Figure 3, shows a summary of the possible states of the actors which can be found in the system.

Probabilities of communication are assigned for every actor. This probability is within the interval 0 to 1. This is denoted by P_{ij}, or the

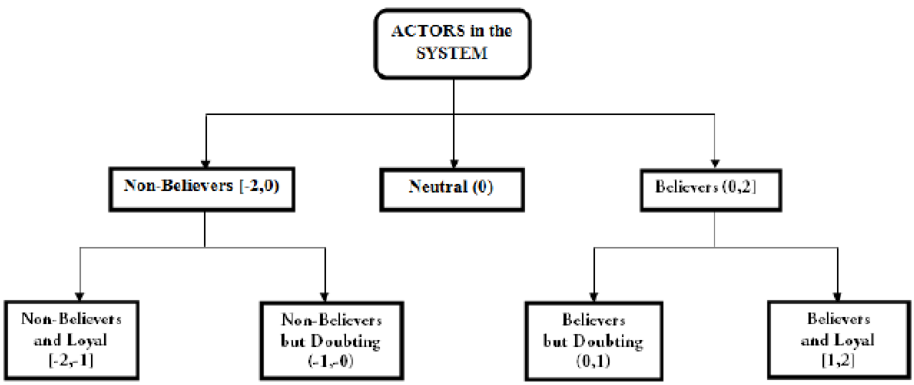

Figure 3: A Tree Diagram of all the Possible Actors in the System

probability that actor i will communicate with actor j (or the probability that actor i will share the story to actor j.) For example, $P_{13} = 0.8$, means there is an 80% probability that actor 1 will communicate with actor 3.

Degrees of influence are also assigned to each edge. It is denoted by I_{ij}, or the degree of influence actor j has over actor i. For example, $I_{21} = 0.3$, means actor 2 has 30% influence over actor 1.

Since a two-way network is being considered, it is assumed that, P_{ij} is not necessarily equal to P_{ji} and similarly, I_{ij} is not necessarily equal to I_{ji}. Also, $P_{ii} = 1$ and $I_{ii} = 1$, since a person has complete probability of communication and influence over him/herself, respectively.

community. This implies that the concept of time is discrete. Making the step size of each time steps smaller will make the algorithm approximate a continuous model.

Information evolves in the network through the mutation of the basic information through a simulation algorithm (Table 1). Mutation of the basic information will then affect the content of the story inside an actor's memory (hypercube). The algorithm is shown in Table 2.

Going back to the Ondoy issue, consider only the first two basic information: 1) Arroyo Administration is to be blamed; 2) The MMDA Chairman is responsible for the damages. Using the algorithm, the following results are obtained for five actors, six time periods, and 100 simulation runs:

Table 1. Evolved Stories after Six Time Periods

time	Actor 1		Actor 2		Actor 3		Actor 4		Actor 5	
	Basic info 1	Basic info 2	Basic info 1	Basic info 2	Basic info 1	Basic info 2	Basic info 1	Basic info 2	Basic info 1	Basic info 2
1	0.80	0.00	-0.50	1.00	0.00	-1.30	2.00	1.60	-2.00	-1.80
2	0.85	-1.22	-0.10	1.00	-0.40	-1.18	1.60	1.09	-0.80	2.00
3	-1.65	-0.80	-0.29	2.00	-0.08	-0.57	1.01	0.24	-0.47	1.45
4	-1.01	-0.18	-1.16	1.94	0.14	1.56	-0.49	0.94	-1.65	2.00
5	-2.00	2.00	-1.66	1.85	-2.00	2.00	-2.00	2.00	-2.00	2.00
6	-2.00	2.00	-2.00	2.00	-2.00	2.00	-2.00	2.00	-2.00	2.00

The stories within the system will then propagate after t number of time periods. In real life, this represents the number of days or years that the information will propagate within the

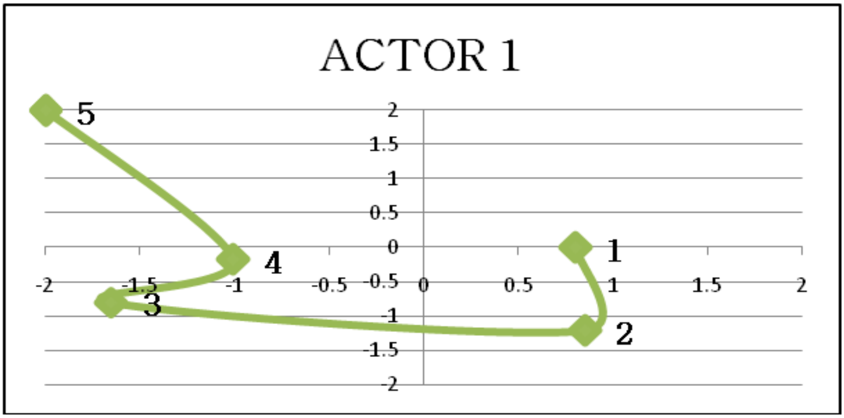

Figure 4.a. Two-dimensional Memory of Actor 1 with Evolving Stories

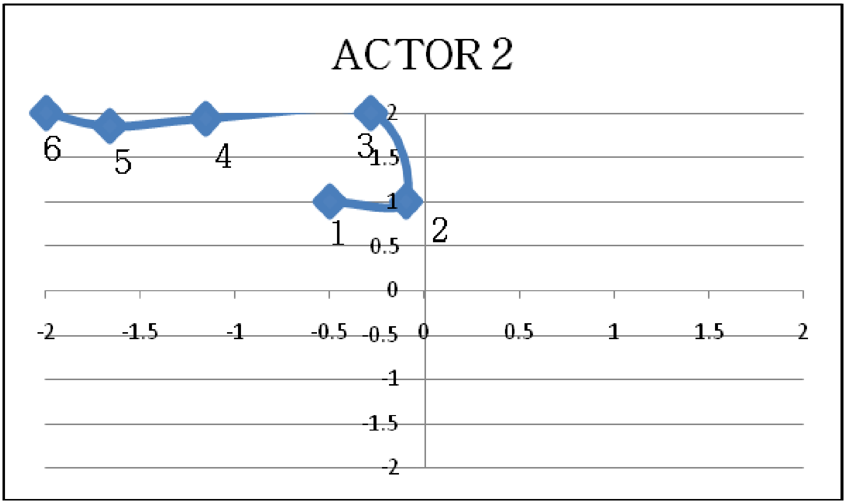

Figure 4.b. Two-dimensional Memory of Actor 2 with Evolving Stories

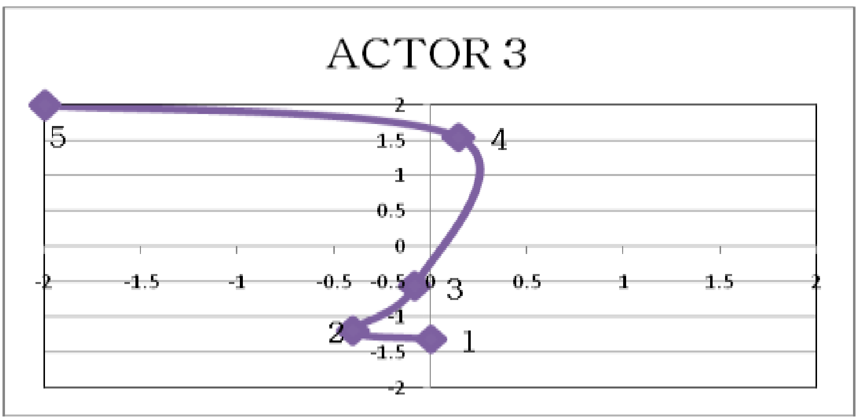

Figure 4.c. Two-dimensional Memory of Actor 3 with Evolving Stories

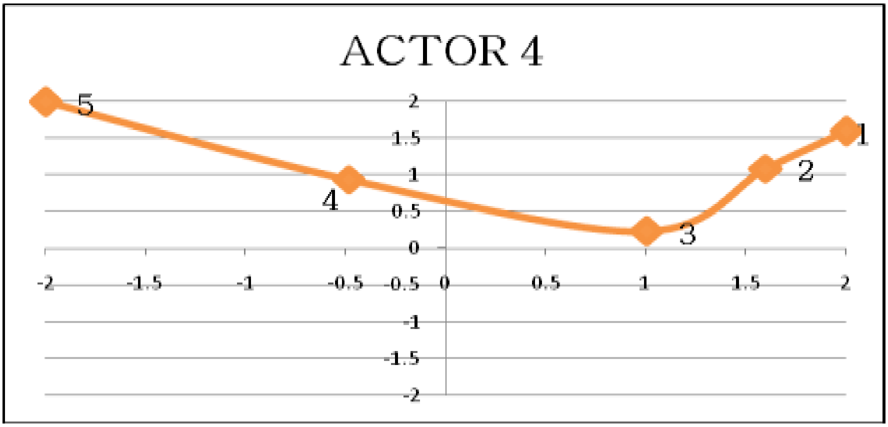

Figure 4.d. Two-dimensional Memory of Actor 4 with Evolving Stories

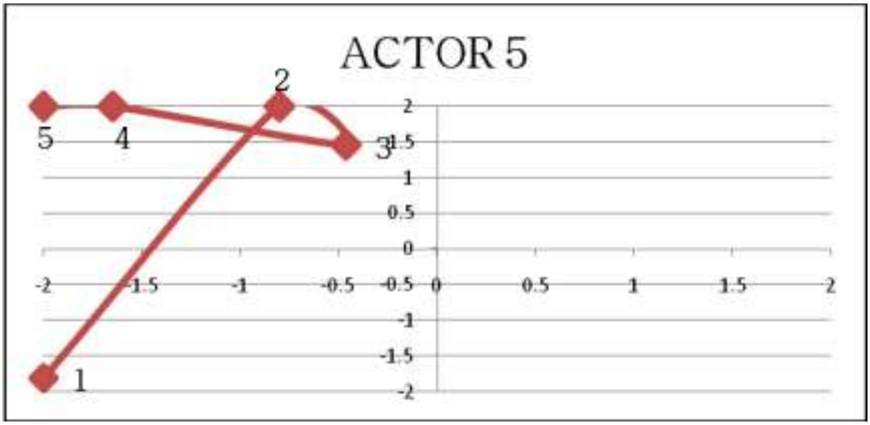

Figure 4.e. Two-dimensional Memory of Actor 5 with Evolving Stories

It can be observed from the results, that a loyal believer can eventually become a loyal non-believer, and vice-versa. Another observation is that from a neutral state, an actor can be a believer (or non-believer).

Also, the results were intuitively unpredictable. For example, Actor 1 is initially neutral for the second basic information. But after two time periods, and after interacting within the system, he/she becomes a non-believer with respect to the second basic information. But again, unexpectedly, after two time periods, he/she becomes a loyal believer (i.e. he/she strongly believes that the MMDA Chairman is to be blamed in Ondoy's aftermath).

The results from this prototype example mimic a certain real life scenario; for instance, people are indecisive on their stand in a particular issue. Modeling rumors can be helpful in controlling the spread of unwanted stories or to strengthen favorable stories. Particularly the model shows the behavior of the information propagation within a finite number of time periods for a specific social network, with a stochastic probability of connection. The standard deviation of the of the simulation runs should be analyzed to check how good the mean of the simulation can represent the phenomenon.

Table 2. Algorithm Written in Scilab Ver. 5.3.0 Code

```
clear

disp('Simulation of Information Mutation During Propagation')
disp('****************************************************')
disp(' ')


//input

n= input ('no. of actors:')
m= input ('no. of basic info:')
t= input ('no. of time periods:')
run= input ('no. of simulation runs:')

disp('--------------------------------------------------------------------')
disp ('row i represents memory of actor i', 'elements should be in [-2,2]')
disp(' ')
for i=1:n
 for k=1:m
  x(i,k)=input ('enter value of basic information:')
 end
 disp (x, 'the initial memory matrix is (at time period 0)')
end
A=x;

disp('--------------------------------------------------------------------')
disp('cell i,k represents communication from actor k to actor i', 'probability should be in [0,1]')
disp(' ')
for i=1:n
 for k=1:n
  if i~=k then
   p(i,k)=input ('enter probability of communication:')
  else
   p(i,k)=1;
  end
 end
 disp (p, 'probability matrix for communication')
end

disp('--------------------------------------------------------------------')
disp('cell i,k represents influence of actor k to actor i', 'value of influence should be in [0,1]')
disp(' ')
for i=1:n
 for k=1:n
  if i~=k then
   r(i,k)=input ('enter influence:')
  else
   r(i,k)=1;
  end
 end
 disp (r, 'influence matrix')
end


     end
    end
   end
  end
  disp (y, 'the memory matrix is', i, 'at time period', runi, 'for simulation run #', '------------------------')
  B(runi,i,:,:)=y(:,:)
  x=y;
 end
 x=A;
end
```

```
for l=1:t
 for i=1:n
  for j=1:m
   FMean(l,i,j)=mean(B(:,l,i,j));
   FStdev(l,i,j)=stdev(B(:,l,i,j));
  end
 end
end

for l=1:t
 disp('--------------------------------------------------------------------')
 disp('the following matrices are presented as transpose')
 disp (FMean(l,:,:), l, 'the mean of simulation runs for the memory matrix at time period')
 disp (FStdev(l,:,:), l, 'the standard deviation of simulation runs for time period')
end


//distance

disp('--------------------------------------------------------------------')
temp2=0
for i=1:n
 for k=1:m
  temp1(k)=(A(i,k)-FMean(t,i,k))^2;
  temp2=temp1(k)+temp2;
 end
D(i)=sqrt(temp2);
end
disp (D, 'distance between initial and mean final story')
```

CONCLUDING REMARKS

Even without performing an actual experiment to study information propagation, theoretical and conceptual modeling helps in understanding the general behavior of the propagation process. Through this research, the possible control spots and the possible mutation of stories can be determined. In addition, the parameters to be manipulated can be assessed. One of the difficult tasks in using the model is the determination of the actual values of the parameters and input values.

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