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### 2013 Mathematical Contest in Modeling (MCM) Summary Sheet

The healthy level of Earth is vital to the survival of human beings. It's important for us to assess the healthy level of the Earth. To solve the problem, we build two models .One is Global Ecosystem Network Model, the other is Earth Health Level Evaluation Model .We design a simulation that replicates the interaction between impact factors which may have effect on the healthy level of the Earth. We select eight significant variables such as population, world forest cover, etc. Using weighted graph, we can figure out the variation of the factors related, once a bit change happen on any of the factors concerned in the ecosystem.

The second model is based on the BP neural network. We use the model to solve the problem of measuring how healthy the Earth is. We set a measure index based on living planet index for the evaluation. Besides, we build two correlation matrixes to show policy effects and uncertainty influences to inform the decision makers whether the decisions they made is helpful to the Earth. Ultimately, we use 12 groups of data to test the accuracy of the model. It shows fairly good rationality and reliability.,

It can be obviously seen that the model we build is easy to understand and has a high degree of flexibility.

According to the model we built previously, population is the critical node in the biosphere. Besides, we forecast that if we don't take any measure to save the Earth, the Earth will reach its limit by 2050.

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# To be or not to be

## I .Introductions

### *1. Problem Restatement*

The objectives in our study are:

- Establish a appropriate network model to show how can one factor change influence Earth's Health. The model influence factors should considered human behaviors .
- According to the model, set measures to predict future Earth's health .
- Calculate the accuracy and find out the critical node of the network.
- Discuss the strength and weakness of the model.
- Try to make the model useful to decision makers.

With this in mind:

- We investigate large scale of data including world population, global total fish production, world average temperature, world forest cover, number of threatened species every year , atmospheric carbon dioxide concentration, remained freshwater amount and world wetland cover.
- We review current methods used to measure the health level and make predictions about a certain region.
- We figure out the weight between each pair of related factors in the network.
- We calculate how the value of Earth's health change with the impact factors by tracking and penalizing the different types of interferences that occur during the simulations.
- We make recommendations regarding the algorithms that proved most efficient for decision makers to make appropriate policies.

### *2. Problem Background*

Most of the researches established do not take complex global factors and

provincial government policies into account. Besides, Earth's tipping point is still unknown so no one can tell exactly whether Earth is nearing its limit. Thus, the health level of a certain kind of an ecosystem can be predicted. An article in *Nature* magazine provides two quantitative models with following ideas: to improve global models and consider local conditions carefully; to identify factors that could influence Earth's health.

## II. Model Overview

To figure out Earth's health condition, two models are used to solve the problem. One is called Global Ecosystem Network Model. It's based on the graph theory which can quantitatively figure out how can one factor change react on the other factors related. The other is called Earth Health Level Evaluation Model. It is based on BP neural network which can show the Earth's health index and tell if it's in the healthy level, sub-healthy level, or some else. If we aim to predict the healthy level in the future, we need to use the Global Ecosystem Network Model to calculate the values of the impact factors, and then it's the Earth Health Level Evaluation Model's duty to figure out the index and tell its healthy level.

Ultimately, use the predict results to inform the decision makers whether they have make the right decision and how it can influence the earth.

## III. Assumptions of Model

The Earth's Health evaluating is far too unpredictable to be modeled accurately. To make our model more tractable, we make the following simplified assumptions:

- No energy revolution would happen within a short period of time. In other words, natural exploitation rate is regarded as a constant value.

- All the planets in the universe orbit regularly, no severe cosmic disasters such as meteorites hit on earth would happen.
- Weather plays a small part in the evaporated quantity of water. And water evaporate is not taken into account.
- Accidents caused by human behaviors including building collapse, crude oil leak, etc. can recover itself, so such kinds of activities can be ignored.
- World population is only limited by the total amount of global freshwater.
- Human activities in industry, agriculture and some other aspects can form a linear model as population increase.
- The change of atmospheric carbon dioxide concentration doesn't have impact on world forest cover.
- All the statistics data in the report is reliable.

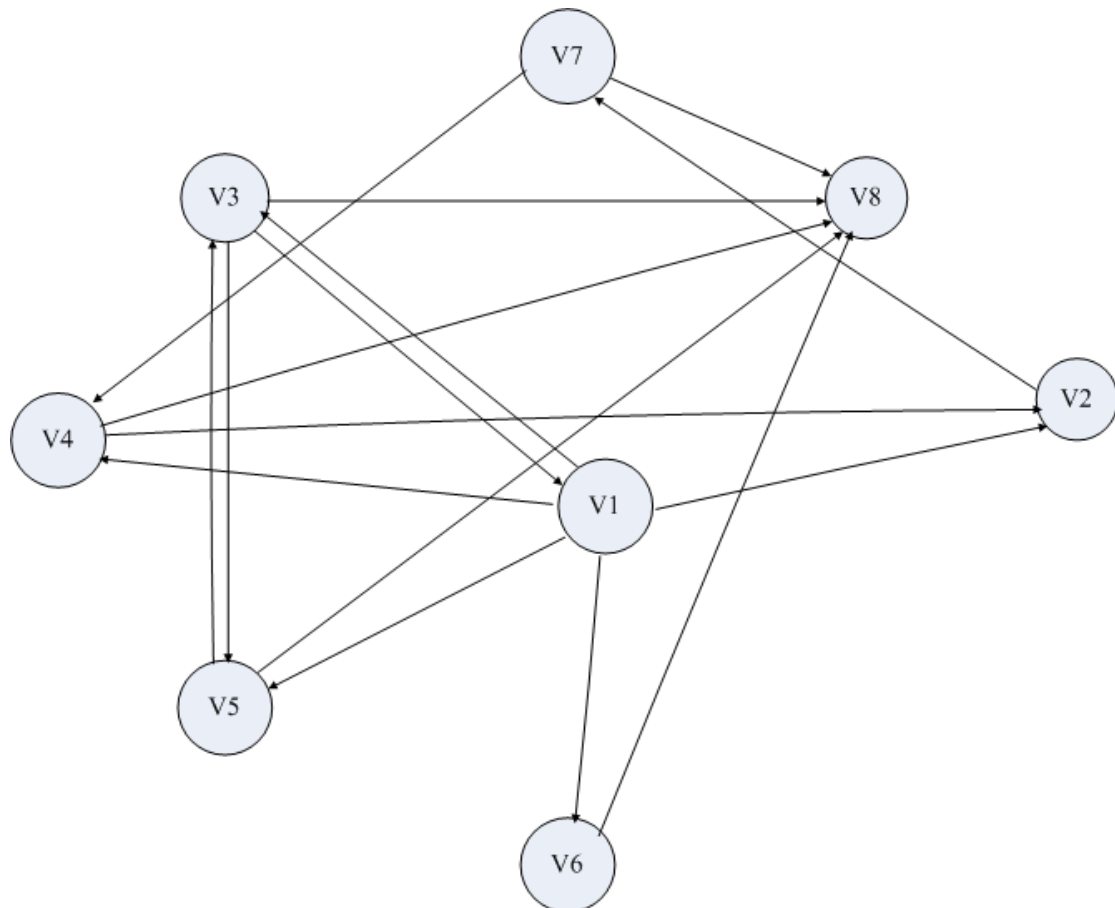
## **IV. Solutions**

### **Requirement 1**

Aiming to build a network model to measure Earth's health, we make the problem simplified. We translate the problem into calculating the effects on other factors. To solve this problem, we use a directed graph to show the interactions among impact factors. Through further analysis, we select 8 main impact factors among all aspects which have huge effect on global biosphere balance: world population, world average atmospheric carbon dioxide concentration, world freshwater remained amount, global forest cover, world wetland cover, global total fish production, world average

temperature and number of threatened species (can represent biodiversity). As the recent research shows, human behavior plays an extremely important part in Earth's health, so human must be considered in the impact factors. Greenhouse effect is rather influential to the Earth's health. In this way, world average atmospheric carbon dioxide concentration and world average temperature should also taken into account. Biodiversity is the most significant index in measuring ecosystem stability. Regarding the data we have found on the Internet, we use the number of threatened species to indicate this factor. Forest and wetland are called the cleansing organs of the Earth, therefore, their cover are indispensable to the model.

According to the analysis we made, the graph can be shown as follows:



In the graph, the nodes represent the impact factors which can influence Earth biosphere nature balance. To be exact, the nodes can stand for the following significations:

- V1: world population

- V2: world average atmospheric carbon dioxide concentration
- V3: world freshwater remained amount
- V4: global forest cover
- V5: world wetland cover
- V6: global total fish production
- V7: world average temperature
- V8: number of threatened species

Here, we want to emphasize that global total fish production represents the sum of wild fish catch amount and planted fish amount.

The links represent the environmental influences among nodes. For example, when world average atmospheric carbon dioxide concentration rises, world average temperature rises due to the greenhouse effect. Therefore, a link can be established between the two nodes.

We need to make several declarations about the links in the directed graph displayed above since it might be a little confusing on its existence. The declarations are as follows:

- The link between V7 and V4 represents temperature has a direct impact on world forest cover. According to the research<sup>[2]</sup>, if temperature rises, the world forest cover would be reduced in a large scale, so the relationship between the two factors is rather important.
- The link between V7 and V8 represents temperature has a direct impact on world threatened species. According to the research<sup>[3]</sup>, if temperature rises, the biodiversity would be largely influenced, so the link between the two factors is necessary.

In order to build the model, an appropriate weight for each link is essential. The weight can show how much the factor influence others. To have further research, a large scale of statistics data is essential.

From the data we get, we can establish a functional relationship for each couple of nodes related in the graph. To make the functional relationship useful to the model, we make data processing before the analyzing part. The data processing method is aimed at making the data with no unit. To achieve this, we find the biggest value in

each row, other data in the row divided by the selected data to make a series of new data which will be later used to generate the weight we want.

Based on the graph we already made, take the functional relationship between population and Atmospheric Carbon Dioxide Concentration for example, the original data is as followed: (data resources:[7,8,9,10,11,12,13])

Population	Billion	3.0	3.1	3.2	3.2	3.3	3.3	3.4	3.5	3.5	3.6
Atmospheric Carbon Dioxide Concentration	Parts Per Million by Volume	316.91	317.64	318.45	318.99	319.62	320.04	321.38	322.16	323.04	324.62

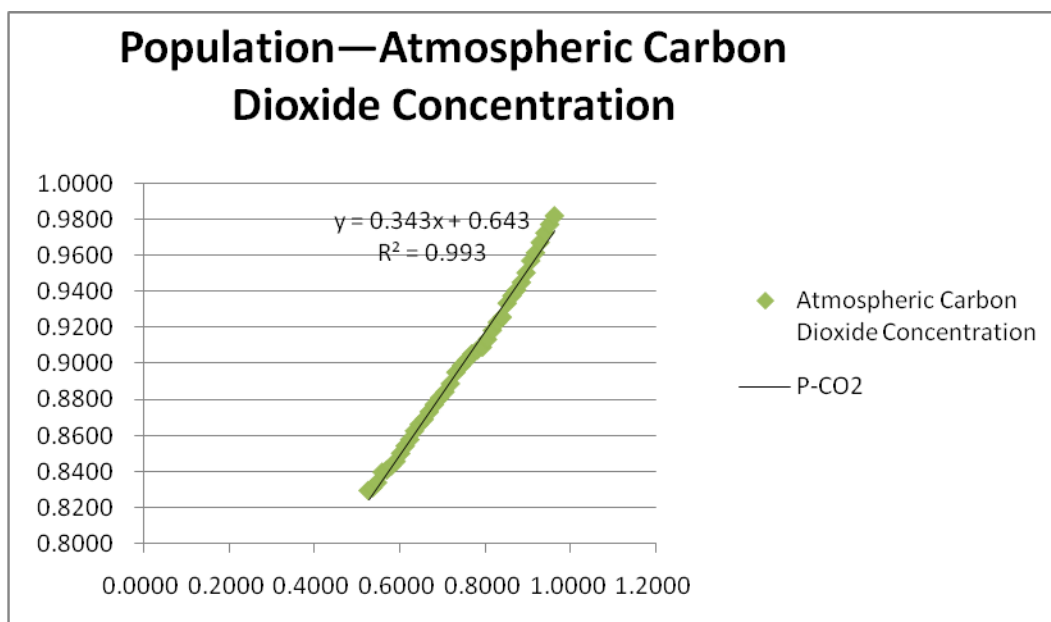
(partial)

After the data processing part , the data can be shown as followed:

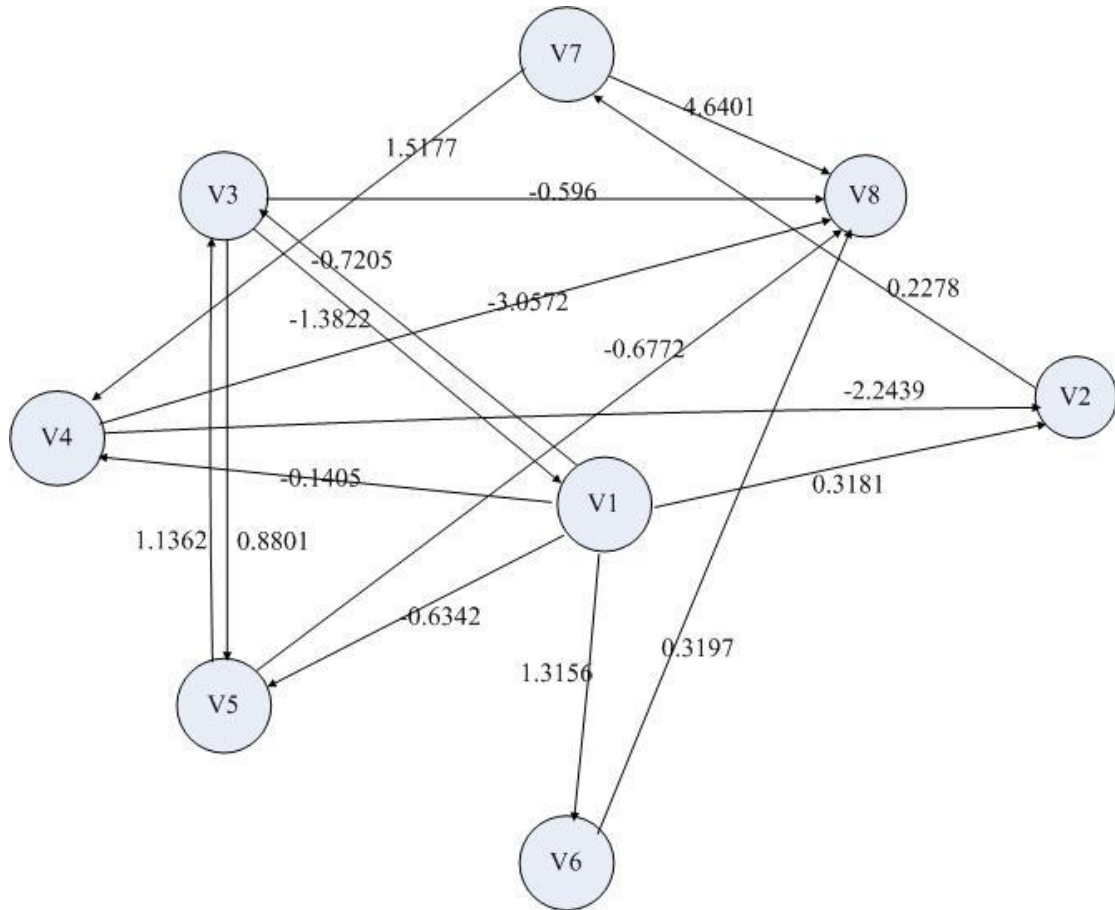
Population	0.4341	0.4420	0.4500	0.4583	0.4670	0.4761	0.4858	0.4960	0.5065	0.5172
Atmospheric Carbon Dioxide Concentration	0.8070	0.8089	0.8109	0.8123	0.8139	0.8150	0.8184	0.8204	0.8226	0.8266

(partial)

After the data processing part, we establish a linear model to simulate the functional relationship. From the equation we get, we can easily know how much atmospheric carbon dioxide concentration would change when population vary a bit . In the equation, the slope can accurately shown it quantitatively. We use the slope in the linear function as the weight between the two impact factors.



In this way, we can define the weight for each link in the directed graph and make it a weighted graph. The final network can be shown below:



In this model, we can easily calculate the value of other impact factors once any value of the factors change. The influence coefficient can be shown below:

$$W = \begin{pmatrix} 0 & 0.3181 & -0.7205 & -0.1405 & -0.6342 & 1.3156 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.2278 & 0 \\ -1.3822 & 0 & 0 & 0 & 0.8801 & 0 & 0 & -0.596 \\ 0 & -2.2439 & 0 & 0 & 0 & 0 & 0 & -3.0572 \\ 0 & 0 & 1.1362 & 0 & 0 & 0 & 0 & -0.67728 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.3197 \\ 0 & 0 & 0 & -1.5177 & 0 & 0 & 0 & 4.6401 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

In the following calculating process, we define  $w_{ij}$  to represent the effect  $V_i$  work on  $V_j$  for the next period of time. In order to study the changing process

once a sudden change reflect on the whole system in the next period , we define  $V_i(t)$  to stand for the value of  $V_i$  at  $t$  time,  $P_i(t)$  stand for the variation of  $V_i$  at  $t$  time. According to the implication of  $w_{ij}$  , it's obvious that

$$V_i(t+1) = V_i(t) + P_i(t+1) \quad , i=1,2,\dots,n, t = 0,1,2,\dots \quad (1)$$

$$P_j(t+1) = \sum_{i=1}^n w_{ij} P_i(t) \quad , j = 1,2,\dots,n, t = 0,1,2,\dots \quad (2)$$

We define row vector  $V(t) = (V_1(t), V_2(t), \dots, V_n(t))$  ,  $P(t) = (P_1(t), P_2(t), \dots, P_n(t))$  ,

the formula above can be shown as follows:

$$V(t+1) = V(t) + P(t+1) \quad (3)$$

$$P(t+1) = P(t)W, t = 0,1,2,\dots \quad (4)$$

If we only consider the variation based on the initial state, we can simply set

$$V(0) = P(0) \quad (5)$$

Then, once  $P(0)$  is given in the initial state, we can calculate the value of  $P(t)$  and  $V(t)$  at any time using the formula (3) ~ (5). In other words, we can forecast the system evolution.

As for verifying the correctness of the model, we can use the data we have to see how it can react to another year's factor data.

## Requirement 2

### 2.1 Model Overview

In the previous model, we can solve the problem of the interactions among impact factors that affect earth health considering uncertainties and other aspects. Therefore, we have a Global Ecosystem Network Model. We can easily show the condition of every factors referred. But we cannot tell directly how healthy the earth is. So in this part, we established a Earth Health Level Evaluation Model based on BP neural network. Using this model, we can get quantitatively value of the earth health and find which level it is.

According to the report [Living Planet Report 2012]<sup>[1]</sup>, we can get Living Planet

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