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Study on Opioids Diffusion Based on Improved SIR Model

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ABSTRACT

The abuse of opioids is harmful to the national economy and health. The U.S. government has spent a lot of time, energy and money to deal with this phenomenon. Based on the topic background and team discussion, we deeply excavated the data and information provided in the topic, determined the current use of opioids, and constructed an improved SIR model to determine the source of drug abuse, the mechanism of drug abuse diffusion and the origin of each state through reverse derivation, which provided guidance for the government in the context of opioid abuse. Based on the above results, we simulated and analyzed the improved SIR model and determined the accuracy and stability of the model in the data set.

1. Introduction

In recent years, the mortality rate of opioids abuse in the United States is much higher than that of other causes of death. At the same time, the opioids crisis is also eroding the U.S. economy, involving almost all sectors of the U.S. population, resulting in a series of problems in recent years, such as vacancies in corporate posts, social trust crisis, and the decline in the health-care-assisted economy in the United States^[1]. Effective and accurate judgment of the diffusion of opioids has become the key to controlling the abuse of opioids.

2. Data Preprocessing

2.1 Abnormal Value Processing

If the values in a set of data exceed twice the standard

deviation of the average value, we can call them outliers. In the data provided by NFLIS, we find some abnormal values and use the average value to replace them.

3. Model Construction

3.1 Establishing SIR Model

The SIR model is a propagation diffusion model and it is an abstract description in the process of information dissemination^[2].

Between the five states and their counties are similar to the spread of infectious diseases in the population^[3]. Therefore, SIR model simulation was constructed to study the spread of opioids and the characteristics of opioids and heroin time between the five states and their counties. The total number of people K is unchanged, and the residents of these five states can be divided into three categories:

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(1) There is no abuse of opioids and heroin, but it may be addicted to it, and it is recorded as a susceptible population S.

(2) Abuse of opioids and heroin, recorded as abuse of population I.

(3) The population recovered after abuse is recorded as the recovery population R.

When at time t, S(t) is the number of susceptible people, I(t) is the abused population, and R(t) is the population recovered after abuse. The total number K is constant.

$$K = S(t) + I(t) + R(t) \tag{1}$$

Among them, the infection rate α is the transmission rate of opioids and heroin, and the recovery rate β is the government governance rate.

The infection mechanism of the SIR model is as follows:

$$\alpha : S(i) + I(j) \rightarrow I(i) + I(j) \tag{2}$$

$$\beta : I(i) \rightarrow R(i) \tag{3}$$

When the moment of t+1, the differential equation of S_(t+1), I_(t+1), R_(t+1), propagation process is:

$$I_{t+1} - I_t = dI(t) / dt = \alpha I(t) S(t) - \beta I(t) = \alpha SI - \beta I \tag{4}$$

$$R_{t+1} - R_t = dR(t) / dt = \beta I(t) = \beta I \tag{5}$$

3.2 Determine Parameters

In this paper, the least square method is used to determine the parameters. Based on the known data, the square of the error is minimized and the best function matching of the data is found^[4].

Estimate the given new data, use the first-order Taylor formula to expand, compare the convergence conditions to fit the optimization, determine the distribution law of the parameters, and the sum of the squares of the error between the obtained data and the actual data. Get the parameter result when it is minimum: α : 0.031 and β : 0.87.

4. Application of the Model

4.1 Determining the Birthplace

In order to determine the origin of the use of opioids drugs, we use the 2010-2017 data provided by NFLIS to deduct the parameters of the calculated SIR model and obtain t-1, t-2, t-3, ... The proportion of the number of peo-

ple in the SIR model corresponding to the time, under the assumption of the model, the data of 2003 was obtained, which can be used as the birthplace of opioids abuse, combined with SIR model analysis, and the conclusion is shown in Figure 1.



Figure 1. Original place of abuse of opioids

In Figure 1, the red part represents the starting position for the broad diffusion of the opioids. According to the position of the latitude and longitude, the origin of the five states is shown in Table 1 and the probability of the origin.

Table 1. Probability of original place of use of opioids in five states

State	KY	OH	PA	VA	WV
County	ALLEN	CLAY	ERIE	CLARION	CLINTON
Probability	0.7912	0.6331	0.3687	0.5297	0.4107

5. Current Situation Analysis

Opioids are used in medicine to relieve pain in patients. They interact with opioids receptors in cells to increase the patient's pain threshold and reduce the body's perception of pain. They have a strong analgesic effect.

Although society has realized that opioids cause great harm to the human body, there are still many abuses of opioids that exist throughout the world. The main reasons for the analysis re shown in Figure 2 by analyzing drug efficacy and human needs for drugs.



Figure 2. Reasons for the abuse of opioids

6. Model Improvement

6.1 Grey Relational Analysis

The total population, family status, marital status, education level, and ancestral home are all social and economic indicators of the U.S. Census Bureau. We applied grey correlation analysis to study their relationship to the abuse of opioids^[5]. The results presented by the grey correlation analysis method are determined based on the development trend between the influencing factors.

We select the family status, education level and age composition as the research object. Set family status as $x_i(1)$, set education level as $x_i(2)$, set age composition as $x_i(3)$, the abuse of opioids is set as $x_i(4)$, $x_i(4)$ as a reference data column. The grey relational degrees of 2000-2005 and 2010-2015 were calculated respectively, and the changing trends of three influencing factors were analyzed, as shown in Figure 3.

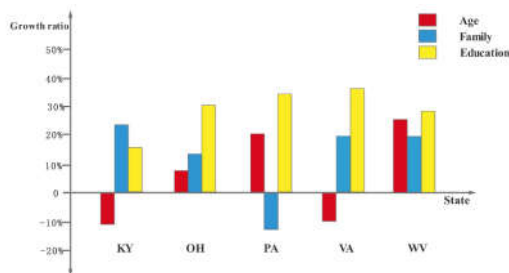


Figure 3. Change of grey relevance degree

According to Figure 3, we found the greatest correlation between opioids use and education. In the analysis of five states, the grey correlation of educational attainment increased.

6.2 Update Parameters

According to the results of grey relational analysis, the factors influencing family status, educational background, age composition and government policy are added to update the parameters of SIR model.

$$S_{t+1} - S_t = dS(t) / dt = -\alpha pI(t)S(t) = -\beta qSI \quad (6)$$

$$I_{t+1} - I_t = dI(t) / dt = \alpha pI(t)S(t) - \beta qI(t) = \alpha pSI - \beta qI \quad (7)$$

$$R_{t+1} - R_t = dR(t) / dt = \beta qI(t) = \beta qI \quad (8)$$

p is a factor influencing the combination of family status, educational background and age composition. Give

different weights, 0.2, 0.5 and 0.3. The calculated value of p is 0.863. q is the influence parameter of government policy. The calculated value of q is 1.748. Determining the parameters $\alpha*q$ and $\beta*q$ of the model is 0.026753, 1.52076.

7. Simulation and Analysis

For the simulation analysis of the improved SIR model, taking 2010 as the starting point, combined with the data provided by NFLIS, the simulation analysis of the model is carried out. Taking Ohio as an example, the results are shown in Figure 4.

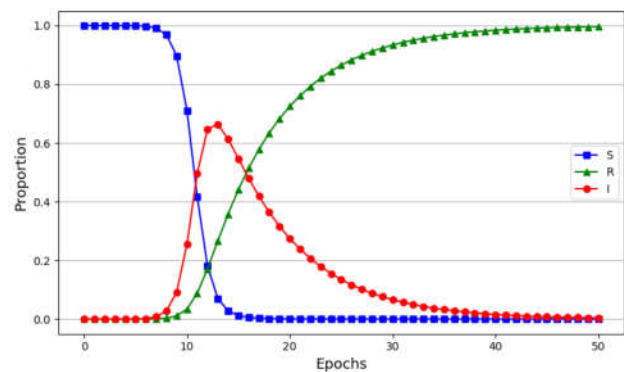


Figure 4. Ohio Model simulation results

According to the analysis in Figure 4, the number of abusers and recoverers of opioids maintained a low proportion at the beginning, and there was a significant increase after the 9th round of diffusion, while the number of people who had not been exposed to opioids also decreased significantly. When the spread reached the thirteenth round, the number of opioids abusers reached a maximum. After continuing to spread, the number of people who abuse opioids has declined, the number of people who recover has continued to increase, and the number of people who do not abuse opioids has dropped to a relatively stable level.

8. Conclusion

In this paper, we analyzed data on opioids abuse in five US states through data, identified the original place of opioids abuse in five US states through improved SIR models, predicted drug spreads, analyzed impacts and proposed improvements. We develop strategies to address the opioids crisis and use our proposed model to assess their effectiveness.

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