System-dynamics-based the analysis for material scheduling capacity

Han Jin¹,²,³,a, Dai Er-fu⁴,⁵*
¹Faculty of Geomatics, Lanzhou Jiaotong University, Lanzhou, Gansu, China
²Gansu Provincial Engineering Laboratory for National Geographic State Monitoring, Lanzhou, Gansu, China
³National-Local Joint Engineering Research Center of Technologies and Applications for National Geographic State Monitoring, Lanzhou, Gansu, China
⁴Lhasa Plateau Ecosystem Research Station, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing, China
⁵University of Chinese Academy of Sciences, Beijing, China
aEmail: 0218387@stu.lzjtu.edu.cn
*Corresponding author’s e-mail: daief@igsnrr.ac.cn

Abstract. Emergency material scheduling is an essential part of disaster prevention and mitigation. This paper builds up materials scheduling model based on system dynamics, real-simulation the process of emergency material scheduling in disaster prevention and mitigation, exploring the main factors that affect a city's emergency capacity. The result shows that: the higher the scheduling capacity of government emergency material, the city's emergency capacity can reach its peak level faster. This model can predict materials scheduling speed in real-time and provide the government's emergency administrative department with a theoretical foundation to formulate reasonable disaster prevention and mitigation plans.

1. Introduction
The government usually needs to transport a large number of materials to carry out the early disaster prevention work before natural disasters happen, like earthquakes, typhoons, dry. Otherwise, it would aggravate the impact of disaster events and cause secondary disasters. The speed of transporting materials to afflicted areas directly affects the city’s disaster-prevention and emergency capacity. Therefore, improving the government’s material scheduling rate has significant implications for reducing disaster loss.

At present, research of disaster materials mainly focuses on site selection, materials prediction, et al. Emergency materials site selection usually uses a genetic algorithm, GIS, and other methods to choose the position of materials scheduling center during the disaster or pre-disaster¹, ². The demand forecasting of emergency material creates a model to predict the quantity demand of materials during the disaster based on the statistics data of historical disasters situations³, ⁴. Currently, most research directions get the optimization results of material transportation from one-sided, but various complex factors often influence the actual transportation. The system dynamics has its unique advantage in qualitative and quantitative research of complex systems, so people can study the materials...
transportation strategy through that method. Li et al. explored the main causes affecting the speed of materials transportation, built up the material transportation model, and ran materials transportation simulations\(^5\). Sugeng et al. aimed at the flood in Jakarta, built up a system dynamics model to explore the complicated dynamic relationship between the urban development of Jakarta and hydro-geomorphology\(^6\). Yu et al. took typhoon "Fitow" that causes a flood in Zhejiang Yuyao as an example, and they established multiple target dynamical models to simulate the level of citizen panic and disaster loss ratio\(^7\). This paper runs a dynamic simulation of materials transportation before the disaster happens, as well as introduces a city elastic model to real-time forecast and evaluate a city's emergency capacity, which provides technical support for government planning disaster reduction strategies.

2. System dynamics model

2.1. Causal loop diagram

The system model's causal relationship can be set up by establishing the logical relationship between variables and constants, based on Vensim software. The quantitative relation between each parametric variable was written in the model in the form of an equation. Then researchers can run the numerical simulation. System dynamics, mainly used in the field of the information feedback system, is a numerical simulation for structural functions, and it is suitable for studying the dynamic relationship between complex systems. Before a disaster happens, it is usually necessary to reserve a large amount of materials to reduce the threat of hidden dangers that cause disasters. If the demand for materials is too great, and the existing reserves are insufficient, there will be a demand gap. In order to make up for the shortage of materials, the government departments need to schedule disaster reduction materials urgently. In scheduling, government emergency material's scheduling capacity plays a significant role, affecting every step of emergency scheduling. The stronger scheduling capacity leads to shorter scheduling and transportation time, and the materials can be mobilized quickly. Finished scheduling a disaster reduction disaster, the emergency material inventory will increase and begin to go into service. The demand will gradually decrease, and the material gap will be narrowed. There are one-time use materials; the inventory will increase first and then decrease during the early and medium-term disaster; the amount of usage will increase gradually. Therefore, the total amount of material is the sum of the inventory and usage amount. The causal loop diagram of material scheduling is shown in Figure 1.

![Causal loop diagram](image)

2.2. Stock flow diagram

To a certain degree, the causal loop diagram only is a simple explanation of the internal mechanism of disaster prevention and mitigation work, without a dynamic quantitative description of the relationship between variables, and does not show the interaction result between variables. In order to simulate its quantitative relationship, people can use Vensim to establish the corresponding dynamic equation and simulate the real-time changes through system feedback and control. The Stock flow diagram is shown in Figure 2.
The main variables of the model are shown in Table 1. The urban emergency elastic models can reflect the change of the city's emergency capacity. People can use this model to measure the city's material emergency capacity. The following formula (1) is used to make a qualitative analysis of the city's emergency capacity.

\[ f_t = \alpha \sum_{i=1}^{m} \omega_i \frac{T_{it}}{R_i} \quad (0 < \alpha < 1, 0 < \omega_i < 1) \]  

\( f_t \) refers to the urban emergency capacity at the moment \( t \). \( \alpha \) means the weight of materials in the process of urban disaster prevention and reduction. \( \omega_i \) is the matching degree of material reserves. \( R_i \) presents the total demand for materials, and \( n_{it} \) means the number of materials that can be scheduled at the moment \( t \). Through the above material inventory, people can get real-time variations of the material emergency capacity to measure the city's disaster emergency capacity.

3. Analysis of simulation results

There are various types of emergency materials, including medical resources, protective devices, necessities of life, emergency equipment and disaster reduction equipment, which can be used for disaster prevention and mitigation as well as emergency rescue. The paper sets the demand for materials is 50000 sandbags used for dam protection and flood protection, without material re-usability. The scheduling capacity of government emergency material can affect the scheduling time and transportation time of materials. The stronger the scheduling capacity is, the shorter the scheduling and transportation time. When the scheduling capacity is 0.8, 0.6 and 0.4, the simulation results of the government's emergency capacity are shown in Figure 3.

Table 1. The main variables of the model

| Variable name                             | Type          | Equations                                                                 |
|-------------------------------------------|---------------|---------------------------------------------------------------------------|
| Scheduling inventory of emergency material| Level         | INTEG (Material scheduling rate-Material arrival rate, 0)                  |
| Emergency material inventory              | Level         | INTEG (Material arrival rate - Material used rate, 5000)                  |
| Usage of emergency material               | Level         | INTEG (Material used rate, 0)                                             |
| Material scheduling rate                  | Auxiliary     | IF THEN ELSE(Time>=Government information delay: OR: Time<=Government information delay + Material scheduling time, Shortage of emergency material/Material scheduling time, 0) |
| Material arrival rate                     | Auxiliary     | IF THEN ELSE (Shortage of emergency material>0, Scheduling inventory of emergency material/Material transportation time, 0) |
4. Conclusion

This paper builds up a disaster prevention and mitigation model for material scheduling based on material scheduling characteristics. It explores the key factors affecting a city's emergency capacity with limited resources, and provides theoretical support for the government to make disaster prevention and mitigation plans. The results show that: 1) In order to improve the work efficiency of disaster prevention and reduction, it is necessary to select a plan with high material scheduling capacity to conduct materials scheduling, to ensure sufficient reserves of emergency materials before the disaster occurs. 2) The government can quickly reach the peak of emergency capacity by improving the emergency material scheduling capacity. The simulated disaster prevention and reduction strategy in this paper has achieved good results. However, the research does not involve rescuing victims in disaster and restoration and reconstruction after disasters. Those parts will be further complemented in future studies.

Acknowledgments

This paper was supported by National key research and development program under grant number 2018YFC1508800, lzjtu (201806) EP support.

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