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A System Dynamics Model of Flooding Emergency Capability of Coal Mine

Abstract. *Flooding emergency capability of coal mine is influenced by personnel's emergency quality, rescue equipment, rescue materials, rescue team and emergency management. This paper sets up a causal diagram and a flow chart model. With investigation on coal enterprises, a simulation model of flooding emergency capacity of coal mine is established using system dynamics. Results show: at the early stage of coal mine production, emergency input has hysteretic nature; increasing emergency input improves each factor's emergency level and flooding emergency capacity of coal mine; initial emergency level affects the time flooding emergency capacity reaches to desired level; the impact of each factor on flooding emergency capacity is different. The simulation model helps a sense of emergency input direction scientifically for coal enterprises. It is good for improving flooding emergency capacity of coal mine*

Streszczenie. *W artykule przedstawiono model matematyczny system ostrzegania przed powodzią w kopalniach. Przeprowadzono symulacje z uwzględnieniem dynamiki procesu. (**Dynamiczny model możliwości ostrzegania przed powodzią w kopalni**)*

Keywords: Flooding Emergency Capability; Personnel's Emergency Quality; Coal Mine
Słowa kluczowe: zagrożenie powodzią, kopalnie.

1. Introduction

At present, researches on coal mine flooding are made by domestic and foreign scholars. They are mostly concentrated on identifying factors, analyzing process, monitoring and warning. H. P. Zhang (2008) studied coal mine flooding caused by natural factors and human factors. X. F. Chen et al. (2007) proposed an interactive center of coal mine flooding and improved the flooding treatment process. J. T. Guo (2008) established a rescue-oriented logistics system model of coal mine flooding and assessed its reliability using matter-element extension method. On the emergency management, A. P. Li (2009) established a scheduling model of emergency resource for coal mine and set up a real-time monitoring mechanism. N. F. Yue (2009) evaluated emergency capacity of coal mine. Based on factor analysis of flooding emergency rescue of coal mine, a simulation model of flooding emergency capacity is established by system dynamics in paper. It simulates and analyzes flooding emergency capacity from initial emergency level and emergency input.

2. System dynamics model of flooding emergency capacity of coal mine

2.1. Factor Analysis

Based on human factors theory, factors influencing emergency capacity of coal mine flooding are personnel's emergency quality, rescue equipments, rescue materials, rescue team and emergency management, as shown in Fig.1.

Emergency quality is personnel's emergency capacity when facing coal mine flooding. Rescue equipments are mainly drainage equipments. Rescue materials refer to rescue stuff and facilities. Rescue team is a professional emergency team in coal enterprise. Emergency management mainly includes emergency management system, organization and culture.

Flooding emergency capacity of coal mine is influenced by emergency quality, rescue equipments, rescue materials, rescue team and emergency management. These factors are interrelated and interact on each other. There exist positive and negative feedback loops. Loop1: personnel's emergency quality→+flooding emergency capacity→+emergency benefit→+ emergency input→+personnel's emergency quality; Loop2: rescue equipments purchase→+ flooding emergency capacity→+emergency benefit→+emergency input→+ rescue equipments purchase; Loop3: rescue materials reserve→+ flooding emergency capacity→+emergency benefit→+emergency input→+ rescue materials reserve; Loop4: rescue team building→+flooding emergency capacity→+emergency benefit→+ emergency input→+ rescue team building; Loop5: emergency management→+ flooding emergency capacity→+emergency benefit→+emergency input→+ emergency management.

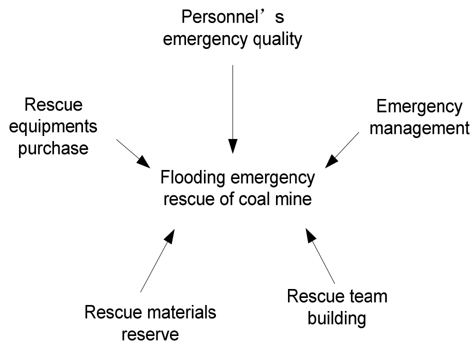

Fig. 1. Factor analysis of flooding emergency rescue

According to analyzing these positive and negative feedback loops, casual diagram is shown in Fig.2 by using Vensim.

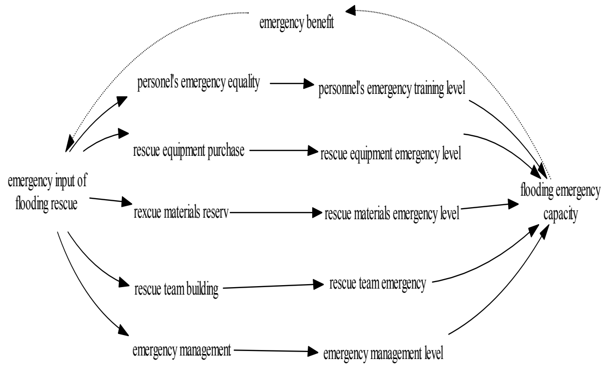

Fig. 2. Casual diagram of flooding emergency rescue

2.2. Flow Chart Model and Variable Definition

Flow chart model of flooding emergency capacity is shown as Fig. 3.

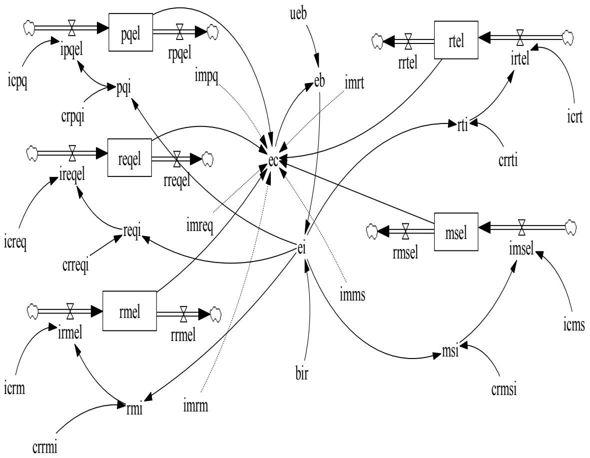

Fig. 3. Flow chart model of flooding emergency capacity

Model variables are defined as follows:

(1) State variables: personnel's emergency quality level *(pqel)*, rescue equipments emergency level *(req*el), rescue materials emergency level *(rmel)*, rescue team emergency level *(rtel)*, emergency management system level *(msel)*.

(2) Instrumental variables: emergency capacity *(ec)*, emergency benefit *(eb)*, emergency input *(ei)*.

(3) Rate variables: increased personnel's emergency quality level *(ipqel)*, increased rescue equipments emergency level *(ireqel)*, increased rescue materials emergency level *(irmel)*, increased rescue team emergency level *(irtel)*, increased emergency management system level *(imsel)*; personnel's emergency train input *(pqi)*, rescue equipments input *(reqi)*, rescue materials input *(rmi)*, rescue team input (*rti*), emergency management system input *(msi)*.

(4) Constants: influence coefficient of personnel's emergency quality *(icpq)*, influence coefficient of rescue equipments *(icreq)*, influence coefficient of rescues materials *(icrm)*, influence coefficient of rescue team *(icrt)*, influence coefficient of emergency management *(icms)*; change rate of personnel's emergency train input *(crpqi)*, change rate of rescue equipments input *(crreqi)*, change rate of rescue materials input *(crrmi)*, change rate of rescue team input *(crrti)*, change rate of emergency management system input *(crmsi)*; reduced personnel's emergency quality level *(rpqel)*, reduced rescue equipments emergency level *(rreqel)*, reduced rescue materials emergency level *(rrmel)*, reduced rescue team emergency level *(rrtel)*, reduced emergency management system level *(rmsel)*; impact of personnel's emergency quality on emergency capacity *(impq)*, impact of rescue equipments on emergency capacity *(imreq)*, impact of rescue materials on emergency capacity *(imrm)*, impact of rescue team on emergency capacity *(imrt)*, impact of emergency management system on emergency capacity *(imms)*; unit of emergency benefit *(ueb)*, benefit-input ratio *(bir)*.

3. System dynamics simulation of flooding emergency capacity of coal mine

3.1. Principles of System Dynamics Simulation

To simulate flooding emergency capacity of coal mine, emergency input is divided into emergency training, rescue equipment purchase, rescue materials reserve, rescue team building and emergency management. The proportions of each part accounting for emergency input are defined as change rate of input into personnel's emergency train, rescue equipments, rescue materials, rescue team and emergency management. By setting different values for change rate of input, we get simulation results of flooding emergency capacity and analyze it from initial emergency level and emergency input. After inviting safety management experts to analyze simulation results, we improve parameters in flow chart model to ensure a good coincidence between simulation results and actual values.

3.2. System Dynamics Equations

On the basis of practical investigation on a coal mine of coal industry group in Henan, values of parameters and constants in flow chart are determined by using flooding accident statistics of this coal mine and relative data about emergency input. Then system dynamics model of flooding emergency capacity is established. System dynamics equations are as follows:

(1) State equations

pqel_k=pqel_j+INTEG(ipqel-rpqel,20);reqel_k=reqel_j+INTEG(ireqel-rreqel,70);rmel_k=rmel_j+INTEG(irmel-rrmel,50);rtel_k=rtel_j+INTEG(irtel-rrtel,35);msel_k=msel_j+INTEG(imsel-rmsel,25)

(2) Auxiliary equations

*ec_k=pqel_k*impq+reqel_k*imreq+rmel_k*imrm+rtel_k*imrt+msel_k*immsr;eb_k=ec_k*ueb;ei_k=eb_k*bir*

(3) Rate equations

*ipqel_k=pqi_k*icpq;ireqel_k=reqi_k*icreq;irmel_k=rmi_k*icrm;irtel_k=rti_k*icrt;imsel_k=msi_k*icms; pqi_k=ei_k*crpqi;reqi_k=ei_k* crreqi; rmi_k=ei_k* crrmi;rti_k = ei_k*crrt;smi_k = ei_k*crmsi*

(4) Constants

icpq=0.04;icreq=0.08;icrm=0.06;icrt=0.05;icms=0.04;crpqi=0.1;crreqi=0.3;crrmi=0.25;crrti=0.2;crmsi=0.15;impq=0.1;imreq=0.3;imrm=0.2;imrt=0.2;imms=0.2;ueb=0.35;bir=0.2

4. RESULTS ANALYSIS

4.1. Simulation of Initial Emergency Level on Flooding Emergency Capacity

Taking the initial emergency level of each factor for 25%, 50%, 100%, we get the simulation on flooding emergency capacity of coal mine, as shown in Fig.4.

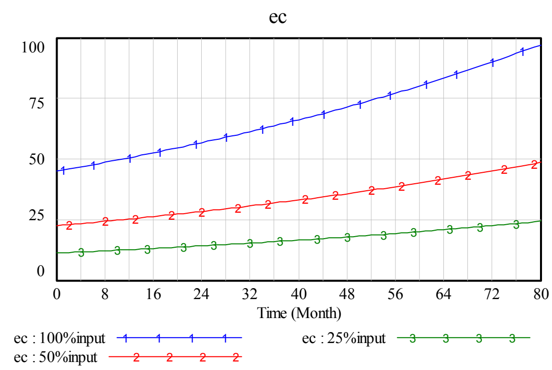

Fig. 4. Simulation of initial emergency level on flooding emergency capacity

As can be seen from Fig.4:

(1) Initial emergency level of each factor affects the time flooding emergency capacity to the desired level. The higher initial emergency level is, the faster flooding emergency capacity grows when increasing emergency input continually.

(2) Improving flooding emergency capacity of coal mine is a long process. As emergency input increases, each factor's emergency level and the whole flooding emergency capacity of coal mine are enhanced. At the early stage of coal mine production, emergency input into personnel's emergency training, rescue equipments, rescue materials and emergency management has hysteretic nature. Emergency capacity only has a small growth in January to April. With increased emergency input, flooding emergency capacity is significantly grown in the later months.

4.2. Simulation of Emergency Input on Flooding Emergency Capacity

Assume that incremental change of each factor's emergency input is 0.2. Flooding emergency capacity is simulated under six different conditions. Simulation results can be seen in Fig.5. Curve original is the initial emergency capacity under *ptip=0.1, reqip=0.3, rmip=0.25, rtip=0.2, smip=0.15.* Curve Δt-pqel represents the change rate of personnel's emergency train input changes from 0.1 to 0.3 with other conditions unchanged, that is *ptip=0.3, reqip=0.3, rmip=0.25, rtip=0.2, smip=0.15.* Similarly, curve Δt-reqel, Δt-rmel, Δt-rtel and Δt-msel respectively denote incremental input changing rate of rescue equipments, rescue materials, rescue team and emergency management.

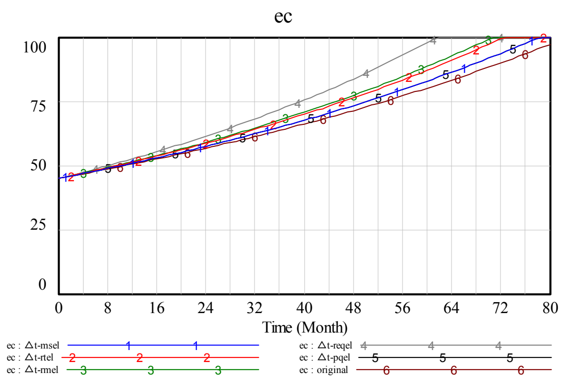

Fig. 5. Simulation of emergency input on flooding emergency capacity

As can be seen from Fig.5:

(1) Increasing each factor's emergency input improves flooding emergency capacity of coal mine. It reduces arrival time to the desired standard. Simulation results demonstrate increasing emergency input to achieve desired emergency capacity is faster than Curve original.

(2) The impact of each factor on flooding emergency capacity of coal mine is different. Under the same incremental change of each factor's emergency input, the most obvious is curve Δt-reqel. It shows rescue equipments have the greatest impact on emergency capacity, which shortens eighteen months to reach the desired standard. Curve Δt-rmel denotes rescue materials has a better impact on emergency capacity and shortens nine months. Curve Δt-rtel denotes rescue team shortens four months. Relatively speaking, emergency training and management have a weaker impact which only shortens two months.

(3) To realize better flooding emergency effect of coal mine, emergency input should be divided into rescue equipments, rescue materials, rescue team, emergency training and emergency management by a certain percentage. If increasing one factor's input alone, the effect at the early stage will be obvious. But when reach a certain level, it will be waste to increase input continually. For example, adjusting rescue equipments will obtain desired effect in the 62th month. If continuing to increase its input, flooding emergency capacity won't be grown, otherwise, it leads to resource waste.

5. Conclusions

In this paper we have developed a system dynamics model of flooding emergency capacity of coal mine. And this model has been simulated from initial emergency level and emergency input. Simulation results show that emergency input has hysteretic nature. It's a long process to improve flooding emergency capacity. And the higher initial emergency level is, the faster flooding emergency capacity grows. Moreover, the impact of each factor on flooding emergency capacity of coal mine is different. Emergency input should be divided into rescue equipments, rescue materials, rescue team, emergency training and emergency management by a certain percentage. These results help coal enterprises create a sense of emergency input direction scientifically and improve flooding emergency capacity. It is a new idea for safety management decision-making of coal mine.

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