Hybrid cellular automata model for Railway Transportation System and its implementation on GIS

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Abstract

This paper presents a new temporal-spatial process modeling methodology that uses a hybrid cellular automata model for the hybrid system with spatial property. The railway transportation system is a kind of this system, the simulation of its traffic flow distribution, based on this model over a GIS support, demonstrates its effectiveness.

1 Introduction

The operation mode of China railway today is high speed, high density, heavy haul and mixed traffic (passenger & freight)[1], so there exists the distinct conflict between transportation capacity and traffic volume. In order to further improve transportation efficiency and service quality, a systematic model and analysis method for railway transportation system must be developed. And based on this model, we can describe and analyze the railway transportation system's characteristics more scientific and figure out the reasons that restrict the transportation capacity.

The railway transportation systems is a kind of hybrid system and must use hybrid modeling methods such as hybrid Petri net, hybrid automata etc., these existing hybrid modeling methods analyze the system's state transformation just according to temporal dimension and omitted the influence of spatial factors[2]-[4]. However, differing from other hybrid systems, the railway transportation system has explicit spatial property. So a generalized cellular automata model method integrating hybrid system conception is put forward, and for the practical application of this advanced intelligent information technology, we also implements it based on GIS platform and demonstrates some simulation conclusions.

2 Analysis of the railway transportation system

The railway transportation system includes both continuous dynamics and many logic program operations and exists in an uncertain environment. This is a typical hybrid system characterized by interacting continuous and discrete dynamics[5], which can be described as a eight-tuple HA=(L,V,f,T,As,Inv,Ev,θ), where

- L is a finite set of discrete states called locations.
- V is a finite set of states of continuous variables at a given moment t, $V=\{x_1, x_2, \cdots, x_n, t\}$, x_i is the i-th real-valued continuous variable, and the state of a hybrid system includes both locations and continuous values, denoted by (l,v), where $l \in L, v \in V$.
- f is a function that assigns to each location $l \in L$, a function f(l) describes the evolution of variables in time at location l, usually is a differential function.
- T is a finite set of transitions. Each transition t=(l,l') joins a source location $l \in L$ to a target location $l' \in L$.
- As is a function that assigns to each transition t=(l,l'), a relation As_t called assignment. It is used to describe the discrete changing of the values of variables, As_t: x:=g(x).
- Inv is a function that assigns to each location $l \in L$, a predicate Inv_l is called the invariant of l, which usually describes the limited conditions

of the system variables.

- Ev is a function that assigns to each transition t=(l,l'), a predicate Ev_t called guard. The transition t=(l,l') may be fired if the guard Ev_t is satisfied.
- Θ is the initial states of the hybrid system.

Further, differing from other hybrid system, railway transportation system has inherent spatial property. However, the existing hybrid system modeling methods analyze system's dynamic just according to the temporal factor and omitted the influence of the spatial factor.

3 Hybrid cellular automata model

Cellular automata(CA) model is a bottom-to-top spatial-temporal dynamic discrete modeling frame, which is composed of a fourfold: cells, states, neighbors and rules[6]. The simplicity and flexibility make CA able to simulate a variety of behaviors of complex systems. A cellular automata is a four-tuple: $A=(L_d, N, S, f)$, *where* A is a cellular automata; d is a positive integrity describing the cellular space dimension, L is the cell, N is the neighbors, s is the state set of all cells, f is the local transformation function. CA is a discrete dynamical system because space, time and system states are discrete and these states change sequentially over time and space. Each point in a rectangular spatial grid, called a cell, can have any one of a finite number of states. The states of the cells in the lattice are updated according to a local rule, which depends on the cell state and the state of its neighbors at the previous time step. The state of the entire lattice is updated synchronously in discrete time steps.

However, because of the homogeneity and discreteness property, these restrict CA's modeling ability for hybrid system with nonlinear features and qualitative knowledge. So we utilize the hybrid system theory and intelligent technology to extend the traditional concept of cells, continuous and discrete states, neighbors relationship and transition rules, and a new hybrid cellular automata is put forward, which can meet the needs of spatial-temporal model for hybrid system and enhance the ability for describing complicated system structure including mobile cells and qualitative transformation rules, such as fuzzy rules.

So a hybrid cellular automata model for the railway transportation system can be described as formula (3-1):

$$\Gamma=\{X,U,Y,f,g,\beta, M_0\} \qquad (3\text{-}1)$$

Where $X=X_D \cup X_L$ is a finite set of states of discrete and continuous variables at a given moment t, and $X_D=(s_1,s_2,\cdots\cdots,s_n)=S_1\times S_2\times\cdots\times S_n$ denotes the states of n discrete variables in the transportation system, $X_L=(l_1,l_2,\cdots\cdots,l_m)$ denotes the states of m continuous variables in the system. U is the input space and can be defined as the adjustment of the traffic schedule etc. Y is the output space and can be used for describing the index of the system performance. f and g are the state transformation function, where f is the local transition function for the discrete variable, g is the transition function assigned to the continuous variables which describing the evolution of variables in time and usually is a differential function. $\beta: X\rightarrow P(Y)$ is the output function, and $M_0=(x_d(0), x_l(0))\in X_D\times X_L=(s_1,s_2,\cdots\cdots,s_n)\times(l_1,l_2,\cdots\cdots,l_m)$ is the initial states of this system.

According to the previously formula, the system dynamic is determined by the transition function f and g. For a discrete variable $x\in X_D$ it can be represented by:

$$x_{t+\Delta t}\in f(s_i(t), N_i(t), LMove_i(t), \Delta t) \qquad (3\text{-}2)$$

where $s_i(t+\Delta t)$ is the state of the i-th discrete variable at the moment $t+\Delta t$, f_m is the m-th local transition function, $N_i(t)$ is the state set of the neighbors of the i-th discrete variable. $LMove_i(t)$ is the state of the continuous variable(such as moving train etc.) located in the i-th discrete variable(such as station, line etc.) at the moment t.

For the continuous variable such as the location of the moving train, it can be represented by:

$$g(l,t)=d(LMove_i(t))/dt=v(t) \qquad (3\text{-}3)$$

where g is a differential function and denotes the velocity of the moving train.

Based on the previously mentioned hybrid cellular automata, the dynamic process of the railway transportation system can be represented as following :

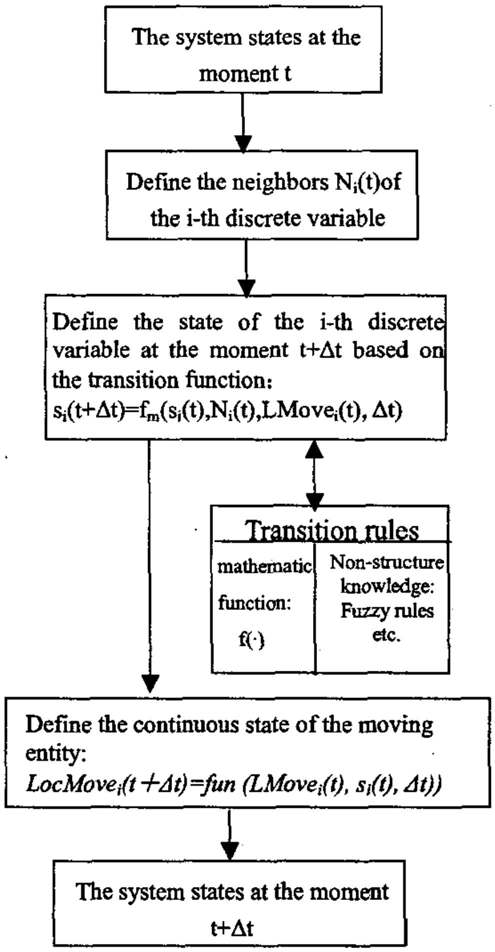

Fig. 1. hybrid cellular automata model for the railway transportation system

4 GIS implementation and example

Now, the Geographic Information System(GIS) technology is increasingly adopted by the users around the world to serve as the digital processing utility for the regions or networks problem[7]. So, in order to deal with its geographical distribution of the hybrid cellular automata model, we implement it on GIS.

We use the Object-Oriented(O-O) modeling method for the description of the hybrid cellular automata model, seeing Figure 2., and use the map to demonstrate the calculation output. The followings are the simulation conclusions for the analysis of the traffic flow distribution at the different time stage. Figure 3 demonstrates the traffic flow distribution of the railway system in the ordinary days. The green line means having low density of traffic, and the red line means having high density of traffic. Figure 4 demonstrates the traffic flow distribution of the railway system in the holiday days. Under the influence factors of holiday, travel sites, weather condition etc., the traffic flow distribution is distinct changed and demonstrates the high similarity with the practical situation.

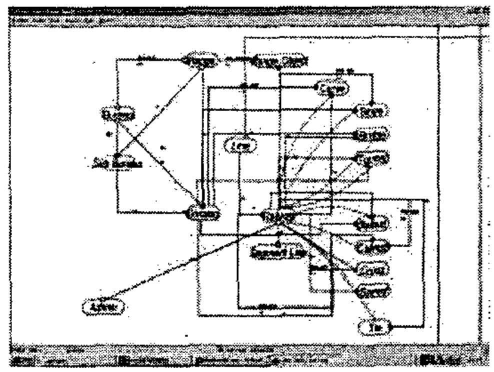

Fig.2. O-O Model for Hybrid Cellular Automata

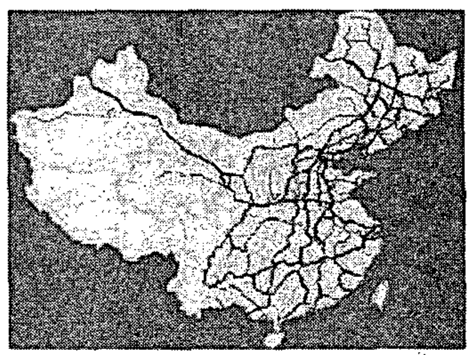

Fig.3. Map of traffic flow distribution in the ordinary days

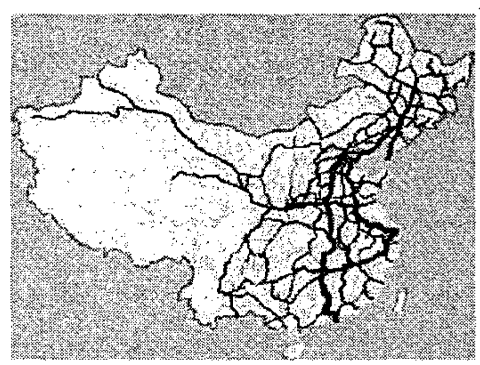

Fig.4. Map of traffic flow distribution in the holiday

5 Conclusions

This paper put forward a modeling method for hybrid system with spatial property integrating the hybrid system conception with cellular automata, which is very adaptive to describe the behavior of the railway transportation system. Moreover, under the support of GIS technologies, the system output with geographic distribution can be easily expressed by map.

The further work, but not limited, is to research the analytic method of the hybrid cellular automata.

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