TRANSPORT FORECASTING BASED ON ARTIFICIAL LIFE CONCEPT

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Abstract

A system dynamics model based on Artificial Life (AL) concept is proposed for transport forecasting. The proposed model focuses on the economic behaviour which emerges out of the interactions among individual local objects, i.e. economic units. That model is merely a large aggregation of simple programs which specify how the local objects react in the environment. Application examples are provided to illustrate the applicability of the proposed model.

1. Introduction

The forecasting should begin preparing a variety of pictures, herein called "rich pictures" (Checkland, 1981), for the future environment. The next step is analyzing the system behaviour of interest for individual rich picture. Basically, qualitative analysis is more preferable than quantitative analysis in long-term forecasts. The extrapolative forecasting, which depends on actual record of the past, does not cope with drastic changes in environmental conditions. In order to study the "future-as-it-can-be," we desire a system dynamics model which can adapt to those rich pictures.

Artificial life (AL) is the study of man-made systems that exhibit behaviour characteristics of natural living systems (Langton, 1988). The Artificial Life focuses on the system behaviour which emerges out of the interactions among micro/local objects. Thus, the AL is concerned with system dynamics. The system dynamics model based on the AL concept can flexibly adapt itself to the given environment, since that model is merely a large aggregation of simple programs which specify how the local objects react in the environment.

In this paper we propose a forecasting model based on the AL concept for transport network growth. This model is an artificial world where the local objects/units, i.e. people, resources developers, energy factories, products factories, transporters, traders, banks, and central/local governments, act for individual purpose. The AL-based model will present us a variety of scenarios in transport planning. Application example of East-Asia transport network growth is provided to illustrate the applicability of the proposed model.

2. System Dynamics

2.1. System dynamics model

The objective of system dynamics modelling is to obtain the mathematical description, i.e. state equations. A discrete time model can be written

$$\mathbf{X}(t+1) = \mathbf{f}(\mathbf{X}(t), \mathbf{I}(t)), \quad (1)$$

where **X**(t) denotes the state vector at time t, **I**(t) denotes the input vector, and **f** is a function vector. A continuous time model can be written

$$d\mathbf{X}/dt = \mathbf{f}(\mathbf{X}(t), \mathbf{I}(t)). \quad (2)$$

In general, the outputs from a system are related to the both variables of state and input, so that we may write

$$\mathbf{Y}(t) = \mathbf{g}(\mathbf{X}(t), \mathbf{I}(t)), \quad (3)$$

where **Y**(t) is the output vector, and **g** is a function vector. In this paper the both variables of **X** and **I** are called local variables or local objects.

When analyzing a system related economical, social, technological, and ecological issues, we usually employ a discrete time model, e.g. econometrics model, etc. System-Dynamics proposed by J.W. Forrester is one of the discrete time models (Forrester, 1961).

The process of the System-Dynamics modelling is: i) Extracting the causal relations in a system, ii) Preparing a causal-loop diagram, iii) Transforming the causal-loop diagram into a flow-diagram by identifying system levels, rates, auxiliaries, and parameters.

2.2. Classical system dynamics model

The interactions among local variables determine the model behaviour. In the System-Dynamics or in the econometrics, usually it is not so difficult to manipulate the model behavior of interest. Such manipulations in the model behaviour are possible under the following conditions:

a) The hierarchical differences among the output variables and the local variables are small.
b) The both functions of f and g in Eqs.(1)-(3) are explicit, especially linear.
c) The function f is not chaotic.

On these conditions we have a well-structured model whose behaviour may sometimes be explicitly operatable. This is the "classical model."

The interestingness of system dynamics analysis is to find unexpected behaviour which emerges out of the interactions among simple objects. For the "emergent behaviour," the system dynamics model should not be constrained by the conditions a)-c).

3. System Dynamics Based on Artificial Life Concept

3.1. Artificial Life

Natural life emerges out of the interactions of a great number of cells. Artificial Life (AL) employs the following synthetic approach to the study of life-as-it-could-be (Langton, 1988): i) Creating simple rule-governed objects, ii) Constructing a large aggregation of the objects, iii) Generating life-like behaviour as the result of the local interactions among individual objects.

The Artificial Life focuses on the problem of behaviour generating. Thus, the AL is concerned with system dynamics. For AL systems, the ongoing dynamics is the behaviour of interest rather than any final state. System dynamics models based on the AL concept have the following features:

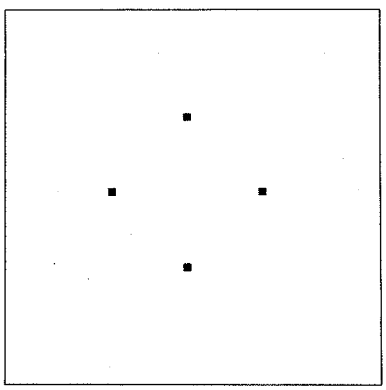
A) They are large aggregations of simple objects or programs.

B) Each program specifies how an object reacts in its environment, including interactions with other objects.

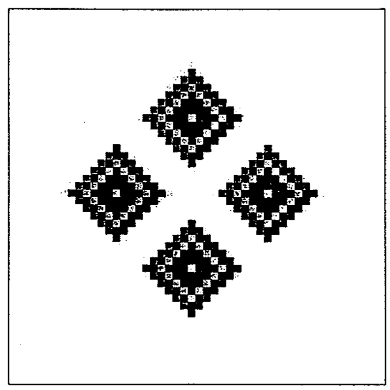
C) There are no programs which directly dictate the behaviour at levels higher than the individual program.

The AL-based system dynamics model will not satisfy the conditions of a) or b) in 2.2. Object-oriented programming is useful for AL systems. This computer-based modelling methodology positively requires "analysis by simulation."

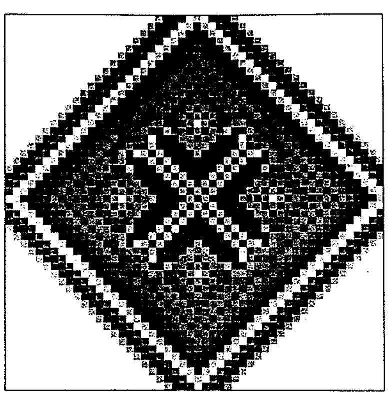
Cellular automata, which consist of cells arranged in a regular lattice, are models for AL (Tamayo, 1988). The state of each cell takes discrete values, and a discrete time model is introduced to the state transitions. The new state is defined as a function of its own previous state and the state of the neighbourhood. Figure 1 illustrates a sequence in the evolution of a simple two-dimensional model. We can see emergent patterns and the diffusion.



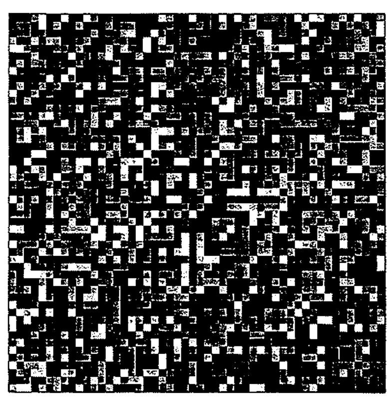
(a) t = 0



(b) t = 18



(c) t = 55



(d) t = 293

Figure 1 Evolution of a two-dimensional cellular automaton

3.2. Ricardian model based on AL concept

Classical school economists are the people of "analysis by thinking." We are surprised at their clear thinking. David Ricardo explained the doctrine of comparative advantage, which is the basis of the case for specialization and for freedom of trade, by means of the following example (Hartwell, 1971).

Suppose that Portugal has an absolute advantage in the production of both commodities of wine and cloth as shown in Table 1. If the post-trade exchange rate between the commodities is reasonable, then it would be advantageous for Portugal to employ her capital in the production of wine, and to export wine in exchange for cloth. Thus, England would import wine by the export of cloth despite her absolute inferiority. The both countries can simultaneously gain from trade.

Table 1 Productivity of commodities

	Labour hours required to produce	
	1 gallon wine	1 yard cloth
Portugal	80	90
England	120	100

Modern economics is not reliant on the Ricardo's theory any longer; however, his theoretical analysis does not lose its value. Even if it is difficult for us to tower above Ricardo in the theoretical analysis, we can rank beside him by taking a different approach, the analysis by simulation.

Simulation analysis can reveal the characteristics of an economical system. For example, the continuous time model, i.e. differential equations model, used to be introduced to illustrate the Ricardo's theory (Caravale, 1980). Now we present a Ricardian model based on the AL concept.

The AL-based model is an artificial world which consists of England and Portugal. Wine producers, cloth producers, traders, and consumers in both countries act pursuing individual profit. The producer wants to increase the production considering the demand for the products. The trader wants to increase the volume of business considering the supply and demand for the products. The trader has dealings with national producers and foreign traders. The consumer demands constant volume of wine and cloth for a given period of time. The consumer wants to buy cheaper products, i.e. national or imported goods.

Given the post-trade exchange rates between the commodities and the initial conditions, the behaviour of the Ricardian model can be simulated. Figure 2 shows a result. We recognize the specialization there.

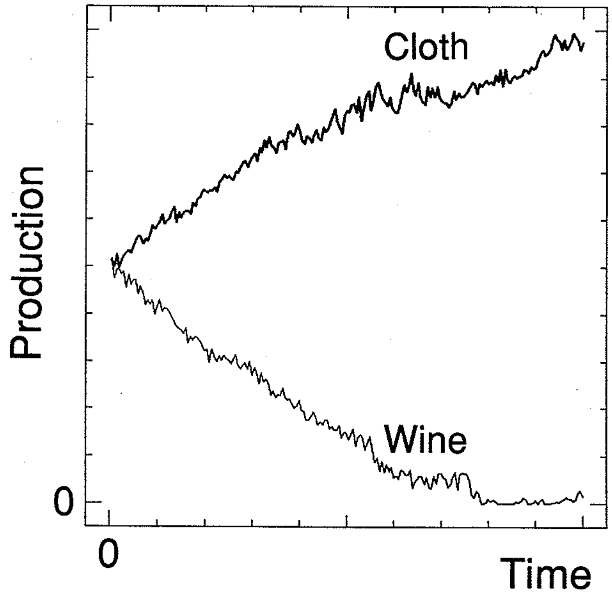


Figure 2 Products specialization in England

4. Transport Network Growth Model Based on AL Concept

4.1. Forecasting model

Since the transport depends on national/international economy, a demand forecasting model for transport should be coupled with an economic growth model.

Extrapolative forecasting models, which explicitly dictate global behaviour without considering the interactions among local objects, can not cope with drastic changes in environmental situations. Forecasting models considering the system structure possibly can adapt to the drastic change. Especially, the AL-based model can adapt itself to the given environment, since that model is merely a large aggregation of simple programs which specify how the local objects react in the environment.

AL-based system dynamics models, which generate global behaviour implicitly but not explicitly, will present us a variety of scenarios in transport planning.

4.2. Economic growth model

Production, distribution, consumption, and investment are the main activities in circular flow of economic system. Finance and government administration concern those activities.

The prototype model for economic growth based on the AL concept is an artificial world which consists of N countries. Figure 3 illustrates the model framework. In every country the local objects/units, i.e. people, resources developers, energy factories, products factories, transporters, traders, banks, and central/local governments, act for individual purpose as follows:

a) People (Pch) - People unit Pch (the subscripts c and h denote country and identification, respectively: c=1,...,N, h=1,...,NPc) is employed by an enterprise unit. It consumes energy and products for people. It can change its employment and/or residence for a large salary. Its expense is in proportion to its income. It wants to buy cheaper products. Its propensities to save and to change employment/residence are influenced by the people units' propensities in its immediate neighbourhood.

b) Resources developer (RDcri) - Resources developer unit RDcri (the subscript r denotes kind of resources, r=1: for energy, r=2: for products, and i denotes identification: i=1,...,NRDc) outputs resources by inputting labour, energy, and capital equipment. It supplies resources to factories. It wants to increase the profit. The substitution between capital and labour is possible.

c) Energy factory (EFcj) - Energy factory unit EFcj (the subscript j denotes identification: j=1,...,NEFc) outputs energy by inputting labour, energy, energy resources, and capital equipment. It supplies energy to people and enterprises. It wants to eliminate the deficit. The substitution between capital and labour is limitational.

d) Products factory (PFcpk) - Products factory unit PFcpk (the subscript p denotes kind of products, p=1: for people, p=2: for enterprises, and k denotes identification: k=1,...,NPFc) outputs products by inputting labour, energy, products resources, and capital equipment. It supplies products to people and enterprises. It wants to increase the profit. Its willingness to invest is influenced by the products factory units' willingness in its immediate neighbourhood. The capital equipment is composed of the products for enterprises. The substitution between capital and labour is possible.

e) Transporter (TPcl) - Transporter unit TPcl (the subscript l denotes identification: l=1,...,NTPc) conveys resources and products by inputting labour, energy, and capital equipment. It wants to eliminate the deficit. The substitution between capital and labour is limitational. See 4.3.

f) Trader (TDcm) - Trader unit TDcm (the subscript m denotes identification: m=1,...,NTDc) plays an intermediary role in the international/domestic trade of resources and products. It wants to increase the profit.

g) Bank (Bcn) - Bank unit Bcn (the subscript n denotes identification: n=1,...,NBc) takes care of money, i.e. receiving and lending. People and enterprises deposit money in it, and enterprises raise funds from it. It wants to adjust saving to investment by interest rates operation.

h) Local government (LGcq) - Local government unit LGcq (the subscript q denotes identification: q=1,...,NLGc) engages in local public services, i.e. giving subsidies to energy factories, and aiding poor people. It wants to eliminate the deficit financing. People and enterprises shall be liable to local taxation.

i) Central government (CGc) - Central government unit CGc engages in national public services, i.e. giving subsidies to transport liners, and aiding poor local governments. It improves ports and transport routes by inputting labour, energy, and products for enterprises. It wants to eliminate the both deficits of trade balance and financing. It imposes customs on imported products and resources. People and enterprises shall be liable to national taxation. The central government sometimes plays a centralized controller against AL concept, such as revaluing/devaluing foreign exchange rates, opening/closing ports/routes/economy, etc. The international exchange market is not considered at present.

In order to keep and increase the productivity, enterprise units invest in their capital equipment. Moreover, they have to invest against environmental pollution. Heavy pollution inactivates people units; so that the labour productivity will decrease. And, the local government unit will order the enterprise units to invest more against pollution or to stop operation.

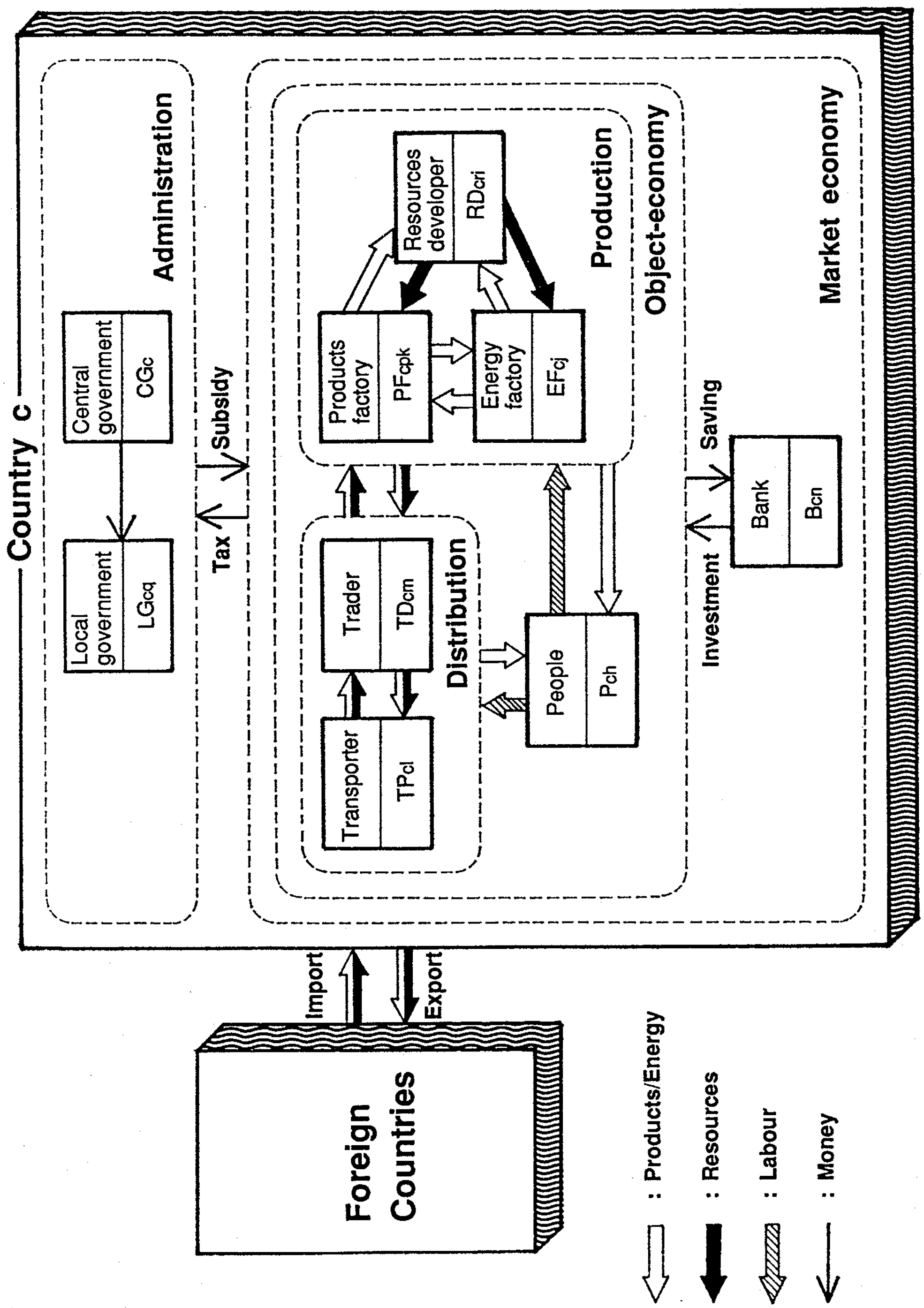


Figure 3 Framework of economic growth model

People units increase in population on a long time scale. Active enterprise units increase also in population, but on a short time scale. Each unit performs according to its own strategy. It is possible for the unit to change its strategy at every iteration stage. The poor unit follows the strategy of a rich unit in the neighbourhood; however, such a mimic habit does not necessarily guarantee success. Mutation is occasional random alteration of the strategy (Goldberg, 1989). Mutation rates are appropriately small. The mimicry and mutation are the built-in mechanism of the natural selection in this model.

4.3. Transport network growth model

Transport network should grow according to transport demands. A transport route consists of links. A link connects an origin node and a destination node, where the node means a port or a freight station in a production complex. The central government unit and transporter units want to invest in the link congested with cargoes. Barriers to entry into the congested link are open to outside transporters.

Trader units want to transport the commodity as economically as possible. Thus, the freight competition shall be inevitable. If a trader unit can not avail the direct freight between two nodes, the trader will search for an indirect and economical freight, if possible.

Time preference for commodities is not considered at present. However, if the commodities are classified more sophisticatedly, then trader units have to take into account the time preference of individual trade commodity. And transporter units have to provide rapid transport services. The mutation and mimicry will also play the important role in the distribution revolution.

5. Application to East-Asia

5.1. East-Asia model

The transport network growth in East-Asia is investigated. The market economies along the Asia-Pacific Rim have registered extremely rapid growth, and the pressure for improving the transport network is building up especially in China.

One of the sources of the economic growth is human resources development (Ogawa, 1993), e.g. population growth, higher standard of education, higher morale, etc. The population growth rates have been declining very rapidly in the past quarter century in East-Asia. Hence, we assume no demographic change in our model. Educational development is not considered here.

The artificial world is composed of China (the east side), South Korea, North Korea, and the outside. The countries trade with each other and also with the outside through the boundary; however, North Korea is closed to the other countries except for China.

Suppose that the countries can import resources and products from the outside as they wish, and that the international price of the outside commodity is fixed. On the other hand, exports to the outside are restricted within the limits.

5.2. Numerical example

Setting the initial conditions in consideration of the present state, the behaviour of the artificial world is simulated. A people unit corresponds to a population of million.

One of the current topics of East-Asia is the North Korea problem. It is highly probable that North Korea will open the country in the not very distant future. Although we have not yet realized an endogenous mechanism of the political revolution in our model, we can investigate the impact of the revolution by using the model, for example the impact upon the transport network. The trade amount between China and South Korea is rapidly growing, so that the transport modal shift from the Yellow Sea (Hwang Hai) route to the transit route via North Korea might occur after the revolution.

The AL-based model produces various simulation results. Figure 4 illustrates an interesting result. We recognize the transport development between the northeast China and South Korea via North Korea, as expected. Nevertheless, the Yellow Sea route does not decline. This means that the transport network growth recreates new demand for transport. At least it may be said that the AL-based model is more imaginative than the authors of this paper.

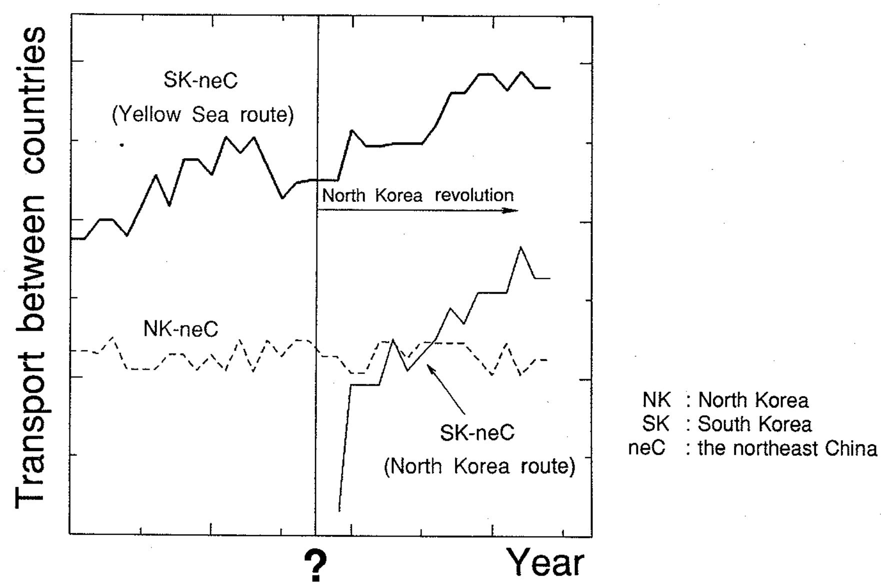


Figure 4 Impact of North Korea revolution

6. Conclusion

This paper is concerned with the transport forecasting model based on Artificial Life concept. The results are summarized as follows:

1) The system dynamics methodology based on the AL concept, which positively requires "analysis by simulation," is proposed.
2) The Ricardian model based on the AL concept is proposed, and the simulation example of the comparative advantage is provided.
3) The prototype model for transport network growth based on the AL concept is proposed, together with the economic growth model.
4) Application example of the transport network growth in East-Asia is provided to illustrate the applicability of the proposed model.

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