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Multi-Agent Competition Simulation of Integrated Transportation System

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Abstract

Transportation networks have been developed during the recent decades with the rapid growth of economy. At the same time, the conflicts between different transportation modes were getting more and more intense. To describe the competition relationship in integrated transportation system, a multi-agent competition model was presented. It is important to provide decision support for regulators to lead more reasonable distribution of resources for planning and operating the integrated transportation network. Thus, a simulation program was developed to implement the proposed model and provide computer-aid decision support. Finally, several experiments were conducted to illustrate the effectiveness of this technique.

Keywords*: agent-based modeling; integrated transportation system; multi-agent; swarm*

1. Introduction

Transportation is indispensable to the economic development of human society in agricultural, industrial, or even knowledge-economy based on post-industrial society. The significance of transportation grows along with economic and social development. To enhance the efficiency of intermodal transportation for large quantities of goods, transportation networks have been developed during recent decades with the rapid growth of economy. With the rapid development of transportation system, the conflicts between different transportation modes (railway, highway, civil aviation etc.) is getting more and more intense, the role of government macroeconomic regulation is getting more and more important. Thus, it is important to provide more reasonable distribution of resources for planning and operating integrated transportation networks by computer-aided decision systems. Recently, much work was carried out in the application of exiting studies for transportation systems considering competition relationships. Zhou [1] considered pricing and competition in a transportation market with empty equipment repositioning. Xie [2] proposed an integrated sea–land transportation system model and its theory. A theoretical framework for modeling sales-service relationships in transportation industry was presented by Suzuki [3]. Forkenbrock [4] compared the external costs of rail and truck freight transportation. Kulak [5] provided a fuzzy multi-attribute selection method among transportation companies using axiomatic design and analytic hierarchy process.

Agent based simulation has become an attractive computational methodology in recent years. Its popularity results from the fact that it allows for complex systems to be simulated in a relatively straightforward way. Unlike traditional mathematical simulation tools, agent-based simulation based on components called agents and defines rules to determine the interactions of agents. Swarm is a multi-agent software platform for the simulation of complex adaptive systems, which was developed by the Santa Fe Institute [6]. Macal [7] proposed the basic concept for Agent-based modeling and simulation. Messie [8] set up a swarm simulation of multi-agent fault mitigation in large-scale, real-time embedded systems. Itami [9] simulated the complex interactions between human movement and the outdoor recreation environment. Axelrod [10] discussed simulation in the social sciences. Hirth [11] presented a simulation framework that allows the simulation of human-robot interaction including the simulated interaction partner and its dynamics. Seman [12] established an improved optimization model of

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internet charging scheme in multi service networks with new improved charging scheme with base price, quality premium and QoS networks involved and proposed that ISP also can set up their base price and quality premium based on ISP preferences.

This paper focused on the conflicts among different transportation modes (railway, highway, civil aviation etc.) and presented a computer-aided analysis model and simulation for multimodal transportation networks based on swarm simulation. A hierarchical model is developed to characterize multimodal transportation networks and a simulation is realized to analysis the relationship in integrated transportation system. Simulation programs are developed to implement the proposed model, and experiments are conducted to provide decision support.

2. Research Method

Traditionally, different transportation modes form a nexus of mutually reinforcing, which have different transportation service providers and customers, such as high-speed of civil aviation, low price of train, flexible of highway etc. Since the rapid development of transportation system, especially the improvement of the civil airport network layout and the construction of rapid transit railway, the target customers of different transportation modes is getting overlap. The coordination between different transportation modes and the optimal allocation of transportation resources become more and more urgent to the government. The proposed model is developed for the simulation of competition relationship between different transportation modes in the integrated transportation system. Each consumer has his/her value for the transportation product provided by different transportation company and their selection will determine the Business performance of different transportation modes.

Determining the competition relationship among different transportation modes in a market unavoidably is a complex problem which is difficult to describe using traditional mathematical modeling methods. The difficulty arises in modeling the act of different customers, and the inter-act of different companies. Therefore, the relationship between different transportations modes and customers is considered to be a complex adaptive system. Complex adaptive systems theory and agent based modeling are bottom-up approaches for analyzing and understanding such complex adaptive systems. We focus on a particular implementation of agent-based model, which is modeled as agents whose behavior mimics that of real entities. Agents act according to their rules/schema. The actions and interactions of the agents in the system result in an aggregate behavior of the system [13]. Agents in the model are the actual players in the system, which include firms and consumers. The agents interact with their neighbors and are guided by few simple rules and act locally [14].

The primary inter-action between passengers and transportation companies happens, if the following prerequisites are needed:

1) The transportation mode means to be able to satisfy the needs of customers (start-time, arrival-time etc.);
2) Affordable price.

There is a probability that he/she may prefer the transportation service, which depends on the utility function of several factors including the passengers' income levels, travel distance, travel time, convenience and comfortableness etc.

In applying the model to simulate the competition relations between different transportation modes, or any other similar problems, one must first identify the agents in the system and their rules. Agents in this problem include some transportation service provider (or transportation companies) of different transportation modes and many consumers (or passengers). Usually, a passenger will take a bus through highway when his/her travel distance is less than 400km, take a plane when travel distance is more than 800km, and otherwise take a train. With the development of traffic infrastructure construction, the traditional boundaries of different transportation modes began to be broken. The competition relationships between three kinds of transportation companies (highway, high speed rail, civil aviation) are studied in this research.

The IF/THEN rules are used to describe an agent's inter-action with other agents - the IF part of the rule is the condition or state, and the THEN part is the action. Agents need not to be homogenous and each agent has its own rules. To transportation companies, the

effectiveness of the pricing and service strategy is measured using its profit and market share. To describe the integrated transportation system, the following assumptions are made:

1. There are some civil aviation companies in the transportation system.
2. There is one High-speed Railway company in the transportation system.
3. There are many highway passenger transport companies in the transportation system.
4. The goal of the companies is to maximize their profits and market shares.
5. A passenger estimates his utility function to determine which transportation service provider to select.
6. Each passenger has his own income level according to the GPD of china and is assumed to be normally distributed.
7. With the development of economics, consumers' spending power will increase at the same time.
8. The transportation companiescalculate its State of operation according to their profit every period and take action.

To describe the transportation model, the following notations are used:

1. t 1, 2, 3… T, a period index.
2. X_t Total profit of high speed railway transportation for period t.
3. Y_t Total profit of highway passenger transportation for period t.
4. Z_t Total profit of civil aviation transportation for period t.

All variables indexed by t are dynamic in terms of being recalculated each period in the simulation. Every consumer (or passenger) has a certain amount of wealth, and will pay for their selected transportation service. At the end of each period, the consumers detect the state of surrounding transportation companies and take an action - choose a service provider or not. The transportation company is chosen probabilistically based on the utility function of passenger with parameters assigned to each aspect of service.

To simulate the integrated transportation system the following rules are used:

1. If the profit decreases for continually 10 periods, then the service provider will adapt its price to gain more market share.
2. If a service provider's market share decreases for more than continually 50 periods, then it will adapt its service and price strategy.
3. If a certain number of customers do not get service, then a new transportation company will be set up to meet the passenger's need.
4. If a civil aviation company's profit decreases, then it will compare the price with other service provider and decide to adapt its price or improve its service (it will increase the company's cost).
5. If a highway passenger transportation company's profit decreases, then it will improve its service.
6. If the high speed rail company's profit decreases, then it will improve the transportation network and expand its service scope.

The integrated transportation simulation system was developed using eclipse on a PC with an Intel processor. Swarm was first released in 1995 by SFI, which allows researchers to construct discrete event simulations of complex systems with heterogeneous agents. The newest version of Swarm is 2.2. A swarm simulation system is composed of four parts: Model Swarm, Observer Swarm, agents and the environments. Figure 1 shows the UML chart of the simulation which explained the structure of the simulation program. All the consumers and service providers were initialized in the same space, which was called the Consumer Space which mimics the environment. Every period, consumers make decisions on which service provider to select around them based on a probability function which is positive correlation with their travel utility function. At the end of each period, Observer Swarm evaluates the service providers' profit and display the state of simulation. Model Swarm controls the simulation process and builds all objects and actions. Service Provider implements the action of transportation service providers, which can fulfill the consumers' needs all around. Consumer Space is the collection of all consumers, which stores all users' state and distributes wealth to each consumer according consumers wealth probability function.

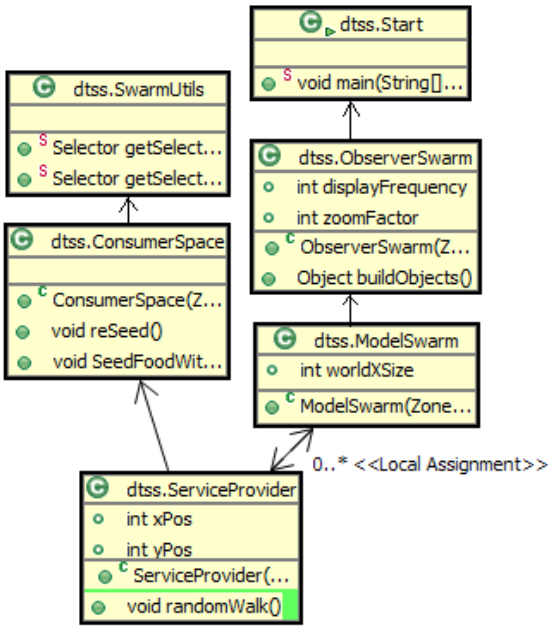

Figure 1. UML of the implementation program

3. Results and Analysis

Several experiments were conducted to describe the integrate transportation system in China and provide decision support for the regulators. In the last decade, China's economy growth has maintained close to 8%, therefore the growth of passengers in the future is assumed to be 8% per year. In China, there are one high-speed rail operator, 16 civil aviation companies in mainland and hundreds of Highway passenger transport companies. So the number of transportation service provider agents is generated according to the amount of transportation companies in China.

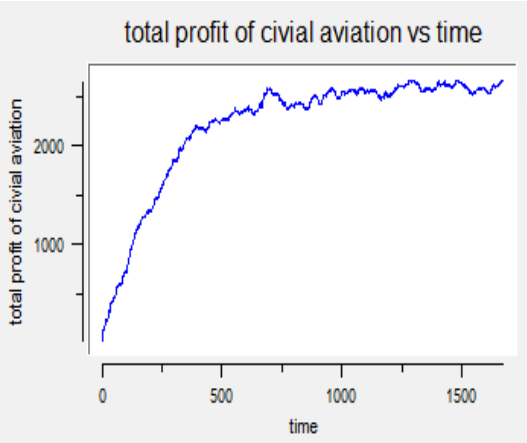

Figure 2. Total profit of civil aviation vs. time

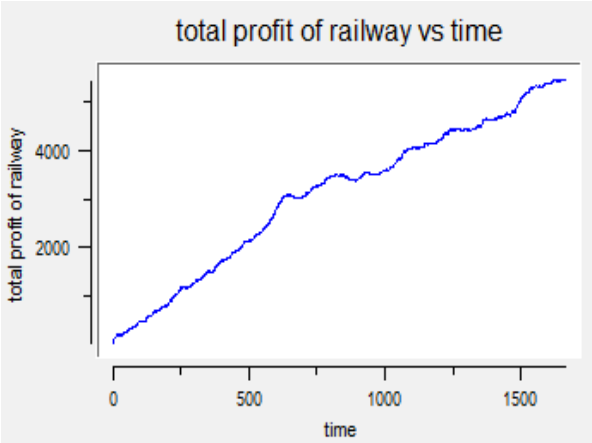

Figure 3. Total profit of railway vs. time

When the simulation starts, each passenger agent chooses a transportation service provider agent and pay for the transportation service provided by the transportation company. Figure 2, Figure 3 and Figure 4 shows the changing tendency of X_t, Y_t and Z_t with time, respectively.

From the figures we can see that the total profit of each transportation mode increases with the development of China's economy. However, as the curve shows, different transportation modes have different growth rates and total profits. Civil aviation starts with a high speed growth and reaches a steady state after 400 periods. It explains that the reform of civil aviation in China started in 1992, civil aviation in China made a rapid great-leap-forward development. As China is known for her massive land, the process of the construction of the China Railway High-speed (CRH) is relatively slower than civil aviation and highway. So, the total profit of railway continued to grow and gradually get slowly after 1500 periods. The total profit of highway reaches a high level after 700 periods and tends to be slowly growth. It indicates that with the development of other faster transportation modes passengers tend to choose the more comfortable transportation modes.

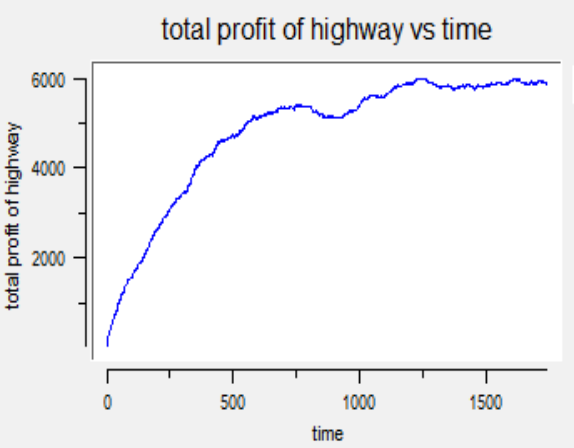

Figure 4. Total profit of highway vs. time

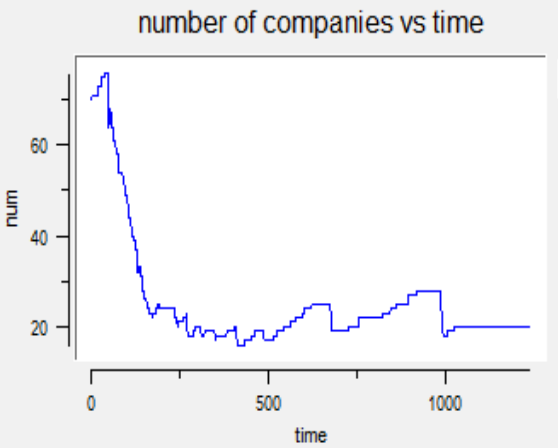

Figure 5. Number of companies vs. time

Figure 5 describes that the number of highway passenger transportation companies in the market. As the figure shows, there is an increase in the number of companies at the beginning and a significant decrease in a while. Then, the integrated transportation system will be steady and tends to be concentrate. While the market size is growing according to Figure 4, the number of highway transportation companies is decreasing. Highway is the first high speed passenger transportation mode in China. In the start stage, the market enters a rapid development period. The next, market enters resources disposition stage. The high efficiency company gain more advanced development while low efficiency ones began to disappear. Finally, the market enters the mature stage. The transportation resource tends to be concentrate and the competition relationships and market position gradually become stable. The market concentration is helpful to optimize the resource distribution among transportation companies. But, in the other hand, the government should take the appropriate regulation to avoid monopoly of the transportation market.

As the regulator of transportation market, the government should lead the resource to be reasonable allocation among different transportation modes. Excessive competition will cause the waste of transportation resources, while insufficient competition will hurt the interests of the consumer.

According to Figure 2 – 4, the market share of different transportation modes become stable when the market is getting mature. When consumer demand can be fully satisfied, the energy conservation and travel comfortable advantage of railway is rising. From the sustainable development point of view, the government should lead more transportation resource transfer to the construction of railway, especially the construction of China Railway High-speed (CRH). In addition, the coordination between various transportation modes should also strengthen to improve system efficiency.

4. Conclusion

In this paper, the competition relationship between different transportation modes was discussed. For the complexity of integrated transportation system, a multi-agent competition model is presented to describe the system. We take advantage of agent based modeling and swarm simulation platform and give out a multi-agent simulation based on swarm. A simulation program was developed to implement the complex transportation system simulation model. Several experiments were conducted to describe the system and provide decision support. The changing tendencies of market are presented. Simulation results imply that the market will be further centralization and government should regulate the social resource to rational allocation and avoid monopoly.

Finally, experiments indicate that the multi-agent simulation model is a useful tool for the analysis of integrated transportation system and can be used to make decision support. The result of simulation implies that the government should lead the resource to be reasonable allocation among different transportation modes. The construction of railway, especially the China Railway High-speed (CRH) should be further developed. In addition, the coordination between various transportation modes should also strengthen to improve the transportation system's efficiency.

Acknowledgements

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