# Fixed Point Learning Based Intelligent Traffic Control System

**Wang Zongyao[1], Sui Cong[2] and Shao Cheng[3*]**

[1]Surrey International Institute and School of Tourism and Hotel Management, Dongbei University of Finance and Economics, Dalian, China.
[2]School of Finance and Laboratory of Experimental Economics, Dongbei University of Finance and Economics, Dalian, China
[3]Institute of Advanced Control Technology, Dalian University of Technology, Dalian, China

E-mail: *cshao@dlut.edu.cn

**Abstract.** Fixed point learning has become an important tool to analyse large scale distributed system such as urban traffic network. This paper presents a fixed point learning based intelligence traffic network control system. The system applies convergence property of fixed point theorem to optimize the traffic flow density. The intelligence traffic control system achieves maximum road resources usage by averaging traffic flow density among the traffic network. The intelligence traffic network control system is built based on decentralized structure and intelligence cooperation. No central control is needed to manage the system. The proposed system is simple, effective and feasible for practical use. The performance of the system is tested via theoretical proof and simulations. The results demonstrate that the system can effectively solve the traffic congestion problem and increase the vehicles average speed. It also proves that the system is flexible, reliable and feasible for practical use.

## 1. Introduction

With the increasingly rapid urbanization, traffic problem has become a big issue for many countries. Unreasonable road resource usage causes traffic congestion in almost every city around world. The governments make great efforts to develop public traffic system, integrate different types of traffic systems and constraint usage of personal vehicles. But these approaches cannot effectively solve the traffic congestion problem. Firstly, the traffic development is tightly constrained by the fixed urban layout. Secondly, the urban traffic developing speed cannot catch up with the increasing speed of vehicles [1]. So governments utilize intelligence technology to solve urban traffic congestion problems [2]. Intelligence traffic control technology focuses on maximizing the road resources usage rather than “constructing new roads”. This paper presents a multi-agent based intelligence traffic control system.

This system utilizes Fixed Point Theorem to adjust traffic flow density. This method can effectively maximize the road resources usage and avoid traffic congestion. As a distributed system, the intelligence traffic control is more flexible and more robust. No central control is needed to manage the system. The system applies a simple algorithm which is easy to build. And it can be easily integrated into existing traditional traffic control system.

## 2. Literature review

The traffic congestion commonly happens around road intersection. So controlling the traffic light signal at intersection is the key to solve the congestion problem. It has been proved that the traffic flow changing is a pseudo random process [3]. It is very difficult to setup a traffic light control model according to traffic flow. So traditional traffic lights often use fixed time period. Namely, the time periods of green light and red light are fixed. Furthermore, the traditional traffic lights are isolated individuals. The lack of communication and cooperation is also an important factor of traffic congestion. In recent years, researchers have developed many intelligence methods to improve the traffic light control. These intelligence methods are commonly used in small scale traffic network with few intersections [4, 5]. For large scale traffic network, multi-agent technology is commonly used to coordinate the traffic lights inside the network.

Multi-agent technology is a powerful tool to develop large scale distributed systems [6]. It divides a complex network system into a group of intelligence agents. The agents can cooperatively implement a global task which a single agent cannot implement. Multi-agent based traffic control system considers the traffic light controllers as agents. The agents can communicate with each other and cooperatively control the traffic flow according to real time traffic information. Roozemond presents a multi-agent based traffic network control system in paper [7]. The system can autonomously change control rules according to the traffic conditions. The system is composed of traffic light agents, road agents and management agents. The traffic light agents control the traffic flow with assistance of the road agents. The management agents implement global control of traffic light agents. Although the system can achieve cooperation control between agents, it does not clearly state the control rules. The paper [8] introduces an intelligence traffic control system with four kinds of agents: road agents, intersection agents, district agents and central management agents. Through the interaction between agents, the system can implement global optimization control and solve traffic congestion problem. But the centralized control increases the complexity of system and decreases the flexibility and robustness of system.

The main purpose of this paper is to solve traffic congestion caused by unbalanced road resource distribution. The main contributions of this paper are as follows. (1) The presented intelligence traffic control system uses distributed method to control the traffic network. The distributed configuration greatly alleviates the pressure of the large traffic system to the central control. (2) The intelligence traffic control system can autonomously adjust its control rules according to the real-time traffic information (traffic flow density). As applying a simple and practical algorithm (fixed point theorem), the complexity of the system do not increase with the expanding of traffic network. (3) The intelligence traffic control system uses a simple and efficient method to achieve intelligence control. So it is easy to realize and it effectively saves the cost of construction.

## 3. Traffic Network Control Model

### *3.1. Traffic Network Model*

The model of traffic network is built by using Graph theory [9]. At the intersections, the traffic lights of each direction can be considered as an agent. The agents are connected by roads between them. So topology of a traffic network can be represented by a graph $G = (V; \mathcal{E})$ where $V$ is set of agents and $\mathcal{E}$ is the set of edges. Any two agents can be considered as neighbours if they are connected by a road. If agent $j$ is a neighbour of agent $i$, we have $j \in N_i$ where $N_i = \{j_1, j_2, \cdots j_n\}$ is neighbour set of agent $i$.

In order to simplify and do not lose generality, all the roads are bidirectional roads with 6 lanes. When vehicles reach intersection controlled by agent $i$, vehicles on the right lane will turn to the right, vehicles on the left lane will turn to the left, and vehicles on the middle lane will go straight.

### *3.2. Traffic Network Model*

In actual traffic network, the lengths of roads are different. The number of "accommodated" vehicles is also different from road to road. In such case, the number of vehicles cannot reflect the crowdedness of the roads. So a parameter, **traffic flow density**, is defined to evaluate the level of congestion in traffic network. The traffic flow density of a road is defined as: number of vehicles on the road divided by the length of the road. The traffic flow density of road controlled by agent $i$ can be expressed as $x_i$.

The traffic flow density of agent $i$ is controlled by green light time period of agent $i$ ($T_i$). Obviously, the longer time period of the green lights can release more vehicles on the road. Accordingly, the traffic flow density will be decreased. The traffic flow density released by agent $i$ can be defined as $y_i = f(T_i)$. The proposed intelligence traffic control system aims to find the optimal released flow density for all agents based on real - time traffic information. If optimal released flow density of agent $i$ is determined, the green light time period of agent $i$ can be determined by $T_i = f^{-1}(y_i)$.

In matter of fact, the traffic congestions often happen at a few intersections in the traffic network. While these busy intersections often become bottlenecks of the entire traffic network. To solve the problem, we can maximize the usage of all the roads in the traffic network. To achieve the purpose, the proposed traffic control system will evenly distribute the vehicles to all the roads. Namely, the traffic flow density of each road will be controlled to reach a same value. Based on this idea, the purpose of optimization is to minimize $min(var(x))$, where $var(x)$ is variance of traffic flow densities of all the roads. Clearly, the best condition of the traffic network system is $var(x) = 0$. Namely, $x_1 = x_2 = \cdots = \bar{x}$ where $\bar{x}$ is the average traffic flow density of all roads in the traffic network.

In a traffic network with $n$ agents, the agent $j$ is one of the neighbours of agent $i$. $y_{ij}$ is traffic flow density transferred from agent $i$ to agent $j$. Consider all the neighbour pairs in the traffic network, a transferred traffic flow density matrix can be written as $Y$. The $(i,j)^{th}$ entry of matrix $Y$ can be expressed as

$$\begin{cases} Y_{ij} > 0 & (j \in N_i) \\ Y_{ij} = 0 & (j \notin N_i \ or \ i = j). \end{cases} \tag{1}$$

So the traffic flow density released by agent $i$ can be written as $y_i = \sum_{j \in N_i} y_{ij}$ . And $y = \{y_1, y_2, \cdots, y_n\}$ is traffic flow density vector of the entire traffic network. A weight matrix of traffic flow density is defined as $\Pi$. The $(i,j)^{th}$ entry of matrix $\Pi$ can be expressed as $\Pi_{ij} = y_{ij}/y_i$. Obviously, for any $i \in \mathcal{E}$, $\sum_{j \in N_i} \Pi_{ij} = 1$. According to the definition of traffic flow, we can write the traffic flow of agent $i$ as

$$\sum_{j \in N_i} \Pi_{ji} y_j + x_i - y_i. \tag{2}$$

The intelligence traffic control system aims to average the traffic flow density of all agents. For agent $i$, the goal of optimization is to keep the traffic flow density at an average value of the whole traffic network:

$$\sum_{j \in N_i} \Pi_{ji} y_j + x_i - y_i = \bar{x}. \tag{3}$$

According to equation (3), the optimal released flow of agent $i$ can be expressed as

$$y_i = max(\sum_{j \in N_i} \Pi_{ji} y_j + x_i - \bar{x}, 0). \tag{4}$$

In an intersection with four traffic lights (controlled by agent 1, agent 2, agent 3, agent 4), only one of the agents is the green light, and the others three are red light. The three agents with red lights have "incoming" traffic flow only. So the traffic flow density of red light agents will increase. The agent with green light has incoming traffic flow and released traffic flow. When the traffic flow density of each agent is equal to or close to the maximum limit (the traffic system is in a crowded state), the released flow of the green light agent will be greater than that of the "incoming" flow. According to equation (4), the traffic flow density of the green light agent $i$ will decrease ($\triangle y_i^1 > \sum_{j \in N_i} \Pi_{ji} \triangle y_j^1$).

Therefore, the optimal control strategy of a local intersection can be set as: first, the agent with maximum traffic flow density is set to green light. This rule reduces the maximum traffic flow density of agents. Traffic flow density of other agents will increase. Second, the released traffic flow density should be limited. The purpose of the local intersection control strategy is to reduce the traffic flow density variance among the agents. Third, the released traffic flow density should be equal to or close to the maximum limit. Namely, the algorithm will not take effect unless there are congestions in the traffic network. This strategy avoids the problems of the central control system. Furthermore, the algorithm is simple and easy to implement. It can be easily built based on traditional traffic network control system.

## 4. Simulation

In this paper, MATLAB is used to construct the simulation platform. The traffic map around the Forbidden City in Beijing is modelled as the experimental traffic network. The network contains 41 intersections (41*4 agents) and 63 roads. The longest north-south road is 3.7km and the longest east-west road is 6km. Each road is a bidirectional 6-lane road.

### *4.1. Equilibrium Traffic Network*

In the first experiment, we use the traditional traffic control system to control the vehicles. Green time period for each traffic light is set as 25 seconds. Initially, there is no vehicle in the traffic network. From t = 1 seconds, the vehicles randomly enter the traffic network. We define the number of vehicles entering the network per second as CI. In the first experiment, we set CI = 30cars/ seconds. This type of traffic network is also called equilibrium traffic network. Initially, only a small number of vehicles are randomly distributed in a few roads. As time goes by, more and more vehicles rush into the traffic network. Figure 1(a) depicts the traffic network state at t = 800 seconds. Due to the fixed time period of control signal, traditional traffic control system cannot effectively ease the traffic congestion. The vehicles are completely blocked at each intersection. The traffic network presents a paralyzed state. Furthermore, the traffic flow densities of roads are unbalanced. Some roads are idle, while others are congested.


(a) Traditional traffic network at t = 800s (b) Intelligence traffic network at t = 800s

**Figure 1.** Comparison of Traditional traffic network and intelligence traffic network

Meanwhile, we test the performance of intelligence traffic network control system. At the initial state, the traffic network condition is similar to that of the tradition traffic network. With the passage of time, no congestion happens in the traffic network. Figure 1(b) describes the traffic network in the state of t = 800 seconds. It can be seen that the vehicles are constantly "flooding" the whole traffic

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network. Although the traffic flow density is very high, there is no obvious congestion at any intersection. The traffic situation is significantly better than the traditional traffic network in figure 1(a).

*4.2. Disequilibrium Traffic Network*
In the second part of experiment, central area and the eastern area of the traffic network have higher CI (CI = 150cars/s). While the other roads have a lower CI (CI = 30cars/s). This type of traffic network is called disequilibrium traffic network. The disequilibrium traffic network is designed to simulate the real traffic congestion situation. In the real traffic network, traffic congestion commonly happens in certain special area (such as urban centres, downtown, etc). In the experiment of disequilibrium traffic network, the central area and the eastern area are set as crowded areas. We use intelligence traffic control system to control the disequilibrium traffic network. Figure 2 describes the traffic network state at t = 1000s. The figure 2 shows that the centres and eastern part of the traffic network is crowded. But under the control of the intelligence traffic network system, the vehicles can still move in an orderly way. In the surrounding part of the crowded areas, intelligence traffic control system effectively controls the vehicles to bypass the congestion area.

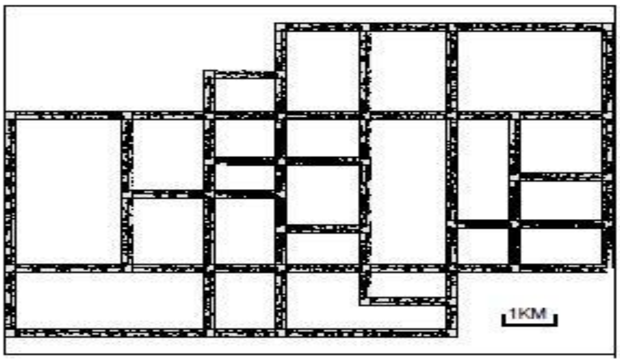
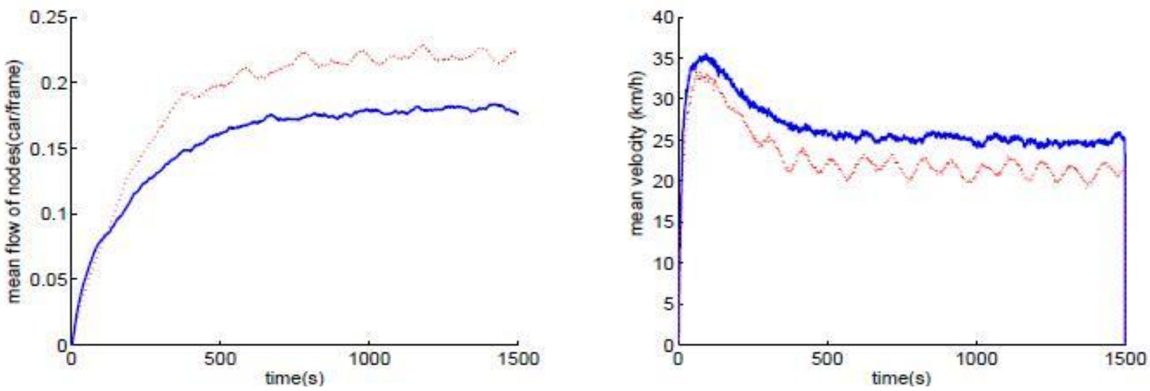



**Figure 2.** Traffic network status at t = 1000s

To prove the advantages of the intelligence traffic network, we use the traditional control method to control the same type of traffic network and compare the performances of the two control methods. Figure 3(a) and figure 3(b) illustrate the mean traffic flow density and average vehicle speed respectively. The dotted lines represent the traditional control method, and the solid lines represent the parameters of intelligence traffic network control system. The figures prove that the mean traffic flow density of intelligence traffic network is much smaller and more stable than that of traditional traffic network system. Under the control of intelligence traffic network, the vehicle average speed is faster and more stable as well.




(a) Traffic flow density comparison (b) Average vehicle speed comparison

**Figure 3.** Traffic network parameters

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## 5. Conclusion

In this paper, an intelligence traffic network control system is established by using multi-agent technology. The algorithm is designed based on fixed point theorem. Through the convergence property of fixed point theorem, the traffic flow density of each road is optimized. The fixed point theorem proves that the intelligence traffic control system can alleviate the traffic congestion and improve the usage of roads. This algorithm adopts the fully distributed structure, which improves the flexibility and robustness of the system. Furthermore, the intelligence system is simple, efficient and easy to implement. It greatly reduces the cost of construction and the complexity of the system.

In the experiment, the graph theory is used to construct the simulation platform of traffic system. In the experiment, we make a comparison between the traditional traffic control system and the proposed intelligence traffic control system. By comparing the parameters, we get conclusion that the intelligence traffic control system can effectively alleviate the traffic congestion and improve the average speed of the vehicles. It also proves that the feasibility of intelligence traffic control system in both equilibrium traffic network and disequilibrium traffic Network.

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