ICIC Express Letters
Part B: Applications
Volume **9**, Number **9**, September **2018**

ICIC International ©2018 ISSN 2185-2766
pp. **917–924**

A DEVELOPMENT OF INTELLIGENT TRAFFIC DISPATCHING AND PARKING SYSTEM WITH LIMITED PARKING LOTS: A CASE OF LOCAL CITY FESTIVAL APPLICATION

Youngho Cho[1] and Dae-Yul Jeong[2,*]

[1]Department of Cultural Convergence
Graduate School
[2]BK21+ Cultural Convergence Team
Department of Management Information Systems
Gyeongsang National University
501 Jinjudae-ro, Jinju City, Gyeongnam 52828, Korea
cyhhmh@gnu.ac.kr; *Corresponding author: dyjeong@gnu.ac.kr

Received February 2018; accepted May 2018

Abstract. *We developed an intelligent car dispatching and optimal available parking lot search system for the local festival with parking space constraints. We adopted LoRa (Long Range) network technology and Q-learning method to solve the parking bottleneck problem of the city wide distributed parking lots in the period of local festival. To develop the proposed system, we analyzed system requirements and designed the system architecture and general data processing flow. We assumed that most travelers have mobile phone. They use an App which can communicate with LoRa sensor network management server. We used Poisson distribution in the queueing theory to predict inbound traffics and to measure parking service performance. Q-learning algorithm is also used to find fastest routes and dispatch the vehicles efficiently to the available parking lots. The simulation results were good enough to verify the efficiency of the proposed method.*

Keywords: Traffic dispatching, Parking management, LoRa network

1. **Introduction.** During local festivals, each city has problem of limited parking space and traffic jam. Nevertheless, drivers from the other cities try to get the available parking lot as soon as possible. For this reason, a lot of vehicles rush in the same place at the same time that cause traffic congestion as well as social, environmental and economic problems. To handle the traffic jam and parking dispatching problems during a local festival, many traffic management staffs are engaged in the main road to guide tourist cars to available parking lots. Nevertheless, the traffic problems are more serious at the peak time of festival. Such local festival parking dispatching problems are very complex and hard to solve because it depends on the real-time traffic information [1,2].

Recently, there have been a lot of studies to control traffic resources in real time using IoT (Internet of Things) platforms and artificial intelligence algorithms. Methods of using the IoT platform have been proposed to solve this traffic congestion problem [3-6,11,18]. Of these IoT platforms, the LoRa (Long Range) network has features of low cost, low power, and wireless long distance communications. Because 'End node' browses the data wirelessly, there is no need to calculate it, therefore, it enables faster communication and the maintenance cost of battery-operated sensors is also low [8]. Based on the advantages of the LoRa network, we applied the research to controlling the traffic resources to the local festival.

The LoRa network is able to collect real-time information from distributed parking sites because it is browsed through the LoRa module of the end node. In this study, we propose a method to efficiently distribute traffics and solve the bottleneck problem with

DOI: 10.24507/icicelb.09.09.917

LoRa network. We used Q-learning algorithm and queuing theory to find the shortest distance to find shortest available parking space. The algorithm contributes to developing an intelligent traffic dispatching and parking allocation system that enables end-to-end solution in the case of suddenly increasing traffic during the local festival. To test the efficiency of the proposed method and algorithm, we simplified the problem with a few specific district parking lots as geographical reach from the 1 highway toll gates and 6 parking lots. Finally, we compared the efficiency of the proposed method with other methods.

2. Literature Review.

2.1. **Technology and network.** There are many different technologies for the intelligent parking systems [7]. Most of them use the Internet and sensor network, and they have some limitations such as time delays in the outdoors due to complicated operations. Also, there are many available technologies that are appropriate to the local distributed multiple outdoor parking lots in a specific area [8-10]. LoRa network with IoT sensors is the most prospect technology [8]. LoRa network adopts very economic sensor networks, which has advantages of low-cost, low-power, long-distance wireless networks because it uses the license-exempt band. It also can be developed by anyone with open sources. Really it can be a network-based platform capable of various services [7]. The LoRa network architecture uses Star-of-the-Star topology and connects low power devices for long distance wireless transmissions. Data obtained through LoRa module can be sent to one or more gateways. Gateway data are sent to LoRa WAN server. Since the server sends the data to the application server to which it responds, the LoRa network does not require complicated operations [8,11,14].

2.2. **Theory and algorithm.** Considering the actual local festival situation of widely distributed parking lots in a specific area and extreme traffic congestion by the rushing travelers, the problems are very difficult to solve compared with single parking lot allocation problem. The main purpose of the problem is effective dispatching waiting cars within a short time as well as efficient communications between sensors and server. To measure these atmospheric conditions and service time, we applied queueing theory. The queuing theory can be explained with three parts: content of arrival, service characteristics, and service policy. In the situation of local festivals, dispatching cars to the available parking lots subject to minimum time constraint is still a difficult problem [16]. The queuing model is easily applied to simulating traffic handling with random vehicle arrivals in the festival period. A queue of the traffic management system will be well synchronized with the waiting time and idle time of the server. Queuing model based simulation system is suitable to mimic LoRa network traffic dispatching system in a city because LoRa provides real-time communication based on IoT [12].

Recently, Q-learning algorithm with reinforcement learning has emerged as an alternative method to overcome the shortcomings of previous algorithms. The principle of the Q-learning algorithm is that an agent's future action is defined on the basis of the action in the current state plus the sum of the rewards for future actions [16]. It is an algorithm that performs reinforcement learning on the assumption that a single agent does not change a given finite condition [12]. To solve the actual parking situation problem with the dynamic environment is very difficult due to the change of the incoming and leaving vehicles continuously.

However, the Q-learning algorithm takes learning time when writing a Q-table, and this learning time depends on the size and complexity of the given environment. Also, it is an algorithm that performs reinforcement learning on the assumption that a single agent does not change a given finite condition [18]. Nevertheless, in the actual situation, the environment changes due to the change of the incoming and leaving vehicles. In this paper, we propose a Q-learning algorithm that can quickly allocate parking spaces by changing the learning policy based on the threshold value of a parking space based on a single agent.

3. **Requirements and Architecture.** To design a system architecture for the efficient traffic dispatching system on the platform of LoRa network with the distributed parking lot environment in a local city festival period, we need to assume following preconditions.

(1) In the local city, it is assumed that LoRa network range starts from highway tollgate entry. So users can receive real-time broadcasted information like text messages as he gets into the entry.
(2) The agent (user) is a member of the intelligent parking system. Each has its own unique ID.
(3) There are no legal considerations such as fines.
(4) Traffic signals operate normally and drivers do not waste time at the traffic signal stope line queue.
(5) The entries follow the Poisson distribution at the highway tollgate and parking lot.
(6) Only single agent responds at each time to reinforce Q-learning algorithm.

The general schematic view of the system can be configured as Figure 1. Until the highway IC entry, user accesses Internet using TCP/IP protocol. User (Actors) can

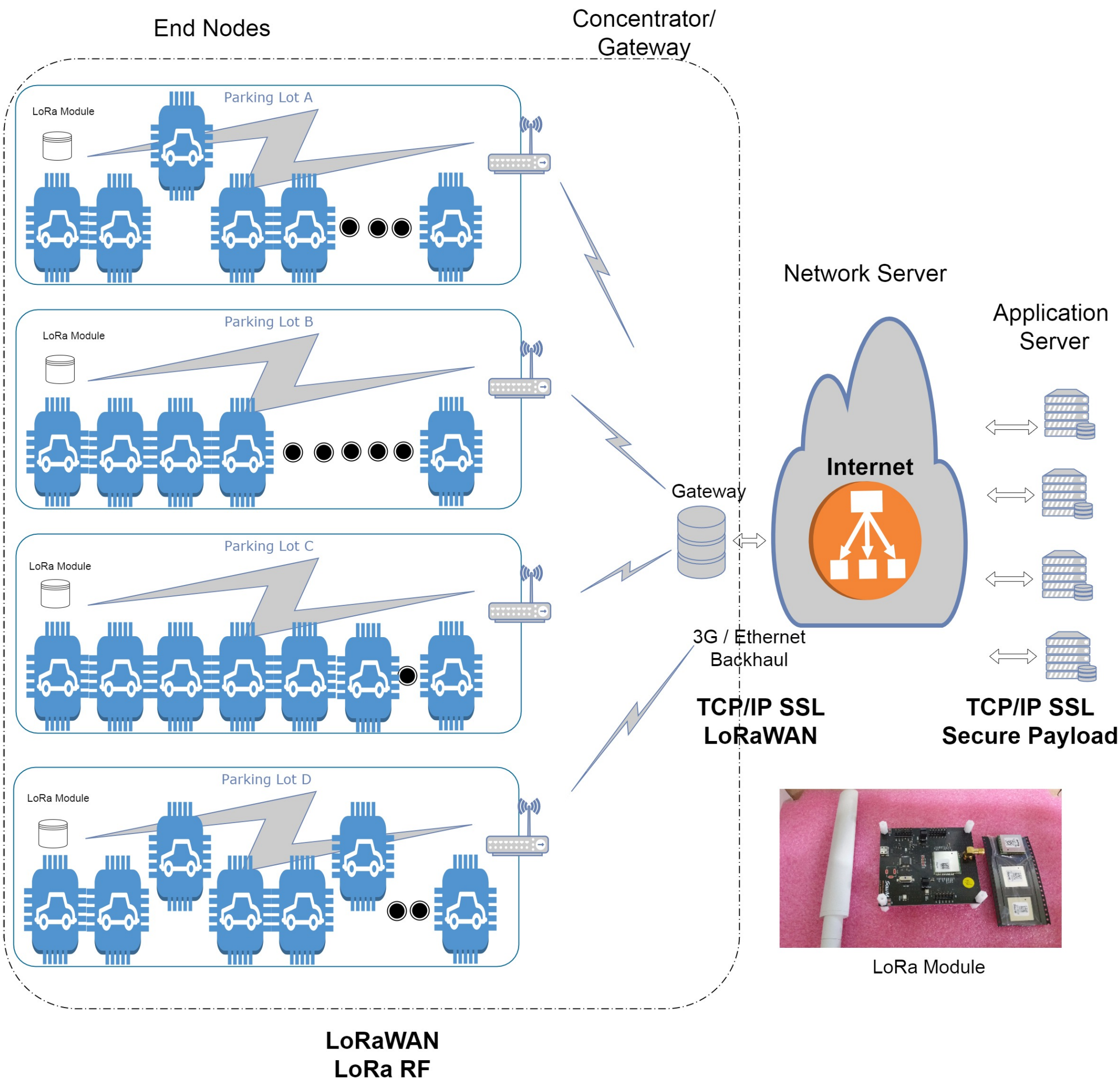

FIGURE 1. System architecture

access LoRa network service system after entering highway IC. In each parking lot, LoRa module is installed. The module consists of minimum size and low price with light sensor function. The LoRa network is configured as a star-of-star topology that is connected to an end device via a single-hop LoRa link connected to one or several gateways.

The proposed system is divided into three levels: LoRa service, data service, and application level. The parking status data are gathered from LoRa gateway, and serviced by the network server (NET SERVER) with the standard IP protocol. In the LoRa service section, the data obtained from the sensor are simply stored and updated. The data communication module which is connected to LoRa gateway performs data transmission and synchronization services. The information transmission layer transmits all information and serves as the interface with the parking management server which is the main server. This three layer access mode simplifies the management of all complex networks for accessing the end nodes. The parking data management module performs various application services such as user verification, access control and security, parking lot information service, and intelligent vehicle dispatching. To understand more specifically the logic of user identification and information update process, the system flow diagram will be more helpful as in Figure 2. To develop a prototype for the suggested system, we developed an efficient algorithm with the following variables and processing routines on the basis of queuing theory and Q-learning algorithm.

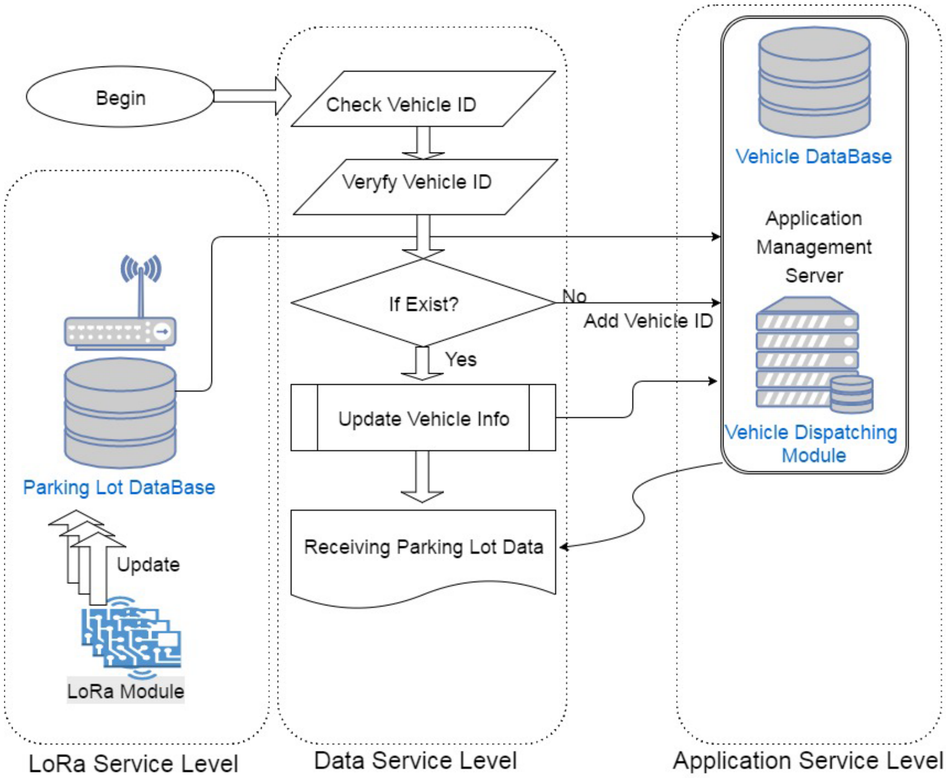

FIGURE 2. General processing flow

4. System Simulation.

4.1. Environment and network model. To simulate the traffic system in the period of the festival, we developed a simple network model (Figure 3). To simplify the problem, we assumed there are just only 6 parking lots in the city. Nodes represent parking lot with limited parking capacity, and the distance (km) between parking lots (nodes) is represented on the arc in the network. There are some additional assumptions. The total of parking capacity is 2,000, and the maximum incoming cars are 3,000 for 4 hours from 5:00 pm to 9:00 pm. The incoming direction starts from the N1 and there is no car leaving. In order to calculate the distance as cost, it is assumed that the number of vehicles flowing per hour is constant and the traveling speed between nodes is constant at 60 km/h. Since real-time traffic information is based on LoRa network, the parking status is broadcasted and updated in real time.

Definition of Variables:
C: Capacity of a car parking block; L: Number of levels in the car parking block;
U^t: Current utilization of the car parking block; P_i^l: Probability of the i^{th} car parking block; t_v: arrived time of vehicle v at parking block
Learning Rate (LR): The learning rate controls how fast we modify our estimates.
gamma: Discount Factor (discounted value of future rewards)

Pseudo code of proposed Q-learning algorithm:
//#Q-learning algorithm pseudo code: Q(state, action) = R(state, action) + gamma * Max[Q(next state, all actions)]//
//#Queuing theory: Compute P_i^l with t_v, U^t, L, C based on λ (average arrival rate), μ (average service rate)//
1. Set parameter and environment rewards in matrix R.
2. Initialize matrix Q to zero.
3. For each episode:
    Select a random initial state
    Do While the goal state has not been reached.
        (1) Select one among all possible actions for the current state.
        (2) Using this possible action, consider going to the next state.
        (3) Change state if Q-table was changed. //LoRa Network broadcasted//
        (4) Get maximum Q value for this next state based on all possible actions.
        (5) Compute: Q(state, action) = R(state, action) + gamma ∗ Max[Q(next state, all actions)] //learning step//
        (6) Set the next state as the current state.
    End Do
  End For

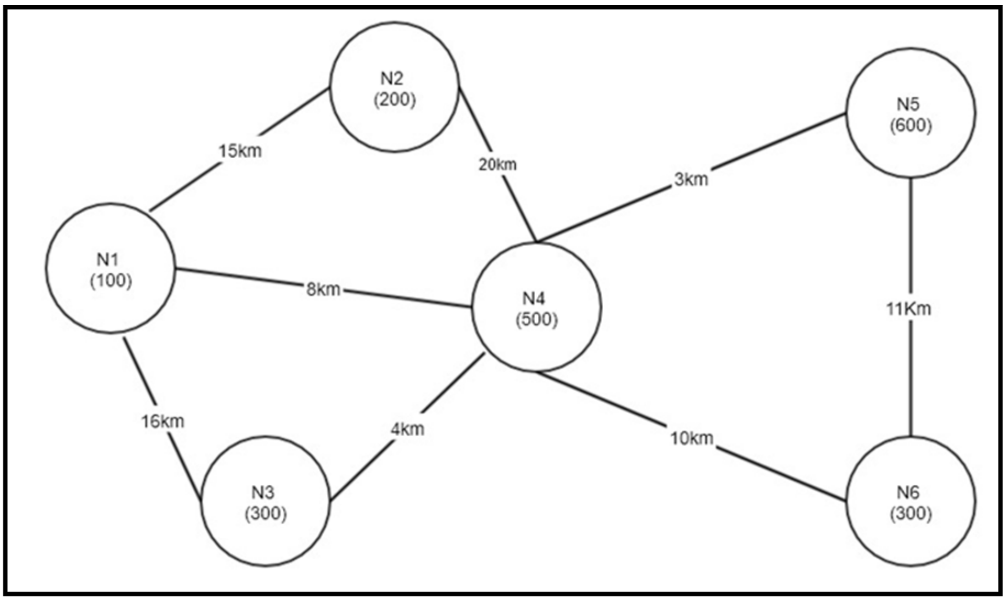

Figure 3. Simplified traffic system model

4.2. **Scenarios and algorithm test.** In the traffic queue, average arrival rates (λ) and service rate (μ) depend on the time period (30 minutes) from 5:00 to 9:00 pm. The inbound rate will increase to peak time. Table 1 shows the status of average inbound traffic and service rate for 4 hours. Also, all the average values are summarized in Table 1 to simulate the system.

Table 1. Average values in the queue

Time (pm)	Average arrival rate (namda)	Average service rate (mu)	Service rate	n-th car's probability in node: P(n)	Average cars in system: Ls	Average cars in queue: Lq	Average service time: Ws	Average waiting time in the queue: Wq
5:00	40	30	1.333333333	−0.444444444	−4	−5.333333333	−0.1	−0.133333333
5:30	50	40	1.25	−0.390625	−5	−6.25	−0.1	−0.125
6:00	60	90	0.666666667	0.098765432	2	1.333333333	0.033333333	0.022222222
6:30	70	120	0.583333333	0.048245403	1.4	0.816666667	0.02	0.011666667
7:00	80	240	0.333333333	0.002743484	0.5	0.166666667	0.00625	0.002083333
7:30	90	480	0.1875	3.53046E-05	0.230769231	0.043269231	0.002564103	0.000480769
8:00	80	300	0.266666667	7.03206E-05	0.363636364	0.096969697	0.004545455	0.001212121
8:30	70	180	0.388888889	0.000319687	0.636363636	0.247474747	0.009090909	0.003535354
9:00	60	120	0.5	0.000976563	1	0.5	0.016666667	0.008333333

To verify the performance of suggested algorithm, we compared three methods. Each method will be described as follows.

(1) SN#1: Without forecasting algorithm and information

The cars with random inbound will go to parking without any information. The car will try to park nearest parking site with trial and error method. There is a high probability that it will fail as time goes after.

(2) SN#2: Shortest route algorithm

It is very useful to find a destination based on the distance, but if the destination parking lot is full, it is necessary to search for another parking lot, so trial and error may occur several times. Parking success will not ensure because it is just based on distance only. The Dijkstra algorithm [9] is one of the most popular algorithms to find the shortest route. Nevertheless, since most of the multi-decker algorithms are used in the car navigation, in this study the shortest algorithm also uses the multi-decker algorithm.

(3) SN#3: Q-learning algorithm

The most promising location could be predicted by the pre-learned Q-table when the destination parking lot to visit is full. The Q-learning algorithm assumes that maximize stabilized state is a prerequisite, and therefore it is assumed that the number of queues is greater than zero. The state forwarding rule is to set the attenuation factor $r = 0.8$, $\alpha = 0.3$ when the destination value is reached and the queue values are subtracted from the previous behavior. Since the traffic conditions vary with each time frame, we calculate the distance as a function of the reward to complete the Q-table (Table 2). The success probabilities of each method are represented in Figure 4, SN#1 is randomly entered into Scenario 1 without any information, and SN#2 is applied to the shortest algorithm in

Table 2. Q(χ) update table

	Q(χ) update table						
	$N(i,j)$	1	2	3	4	5	6
PM 5:00	1	1	0.95	0.9	0.89	0	0
	2	0.58	1	0	1	0	0
	3	0.62	0	1	0.89	0	0
	4	0.8	0.68	0.78	1	0.92	0.8
	5	0	0	0	0.92	1	0.88
	6	0	0	0	0.8	0.88	1

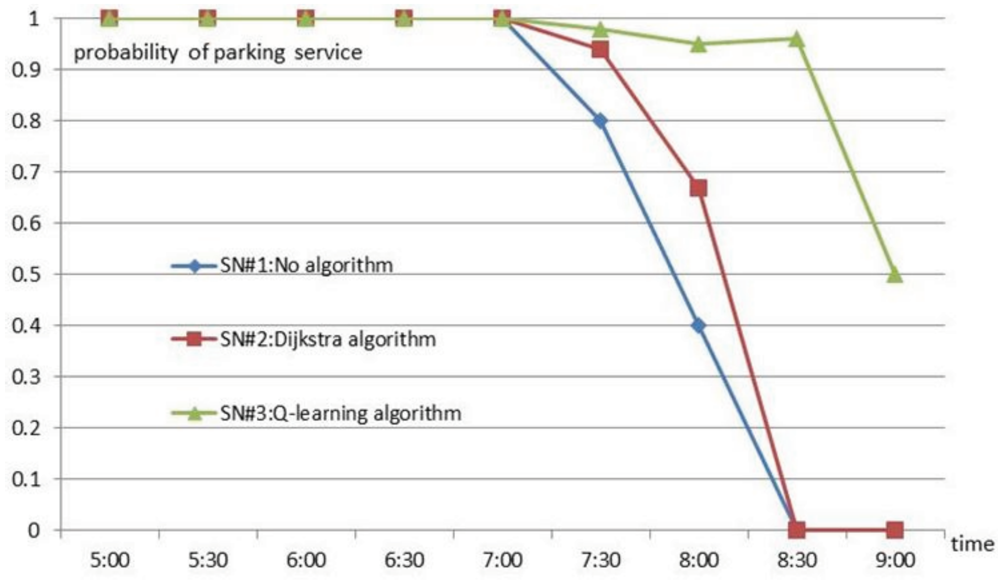

Figure 4. Probability of parking all the time

Table 3. Comparison of algorithms

Shortest route algorithm	Q-learning algorithm with LoRa network
(1) Because the distance is a weight and the loss is short, the calculation speed is considerably slowed when traffic overload is occurring and a lot of storage space is needed. (2) Provide the reason of causing the bottleneck by the shortest route from the user's point of view.	(1) Because it uses real-time communication of LoRa network using existing learned Q-Table, it does not need storage space and calculation speed is fast. (2) It is possible to select a policy to maintain the entire flow efficiently as intelligent forecasting algorithm is used. (3) The actors will be supported by the smart forecasting system as well as real-time parking status information system.

Scenario 2. SN#3 is the result of parking success probability over time when using Q-learning algorithm. As expected, excellent results were obtained when parking capacity was exceeded.

5. **Implications and Conclusion.** The main idea of this paper is to calculate parking rates simultaneously which will be important information to the actor's decision. To give the critical threshold of parking rate which informs the possible failure rate when a vehicle tries to get parking, the travelers will have chance of parking success with minimal travel time. To guide the shortest route for the traveler, the Q-learning algorithm will minimize trial and error to get the target destination.

The proposed Q-learning algorithm based on the queuing theory, which can obtain the shortest distance in a short time, will contribute to enhancing the efficiency of traffic management and dispatching vehicles on the right parking lots. The proposed system architecture and calculation method use real-time communication with LoRa network and reinforced Q-table, it does not need much storage space compared with the other real-time transaction processing system and also the calculation speed is fast. From the perspective of city traffic management agency, the dispatching efficiency of vehicles in the peak time has been increased. Therefore, the social costs can be much reduced such as waiting time due to the traffic jam and air pollution by the idle vehicle operation.

Nevertheless, there are some limitations in our research. Festival traffic is highly dependent on the number of travelers and festival program. Every traveler does not have the same behavior. To predict the behavior is very difficult. The actor's behavior patterns are considered. Also incoming roots are multiple in a city. We assumed only one agent at a time, but actually many agents will simultaneously interact with the system, especially in the peak time. Therefore, multi-agent situations from the many incoming roots (highway tollgate) are considered to solve the actual situation, especially in the large city.

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