Provisional chapter

Traffic-Congestion Forecasting Algorithm Based on Pheromone Communication Model

Satoshi Kurihara

Additional information is available at the end of the chapter

1. Introduction

The growth of **i**ntelligent **t**ransport **s**ystems (ITS) has recently been quite fast and impressive, and various kinds of studies on ITS from the viewpoint of artificial intelligence have also been done [1][2][3][4][5]. However, there are still many problems that need to be solved and alleviating traffic congestion is one of the main issues. Reducing traffic congestion is quite urgent because the amount of money lost due to congestion within only 1 km in Tokyo has reached as much as 400 million yen per year. To alleviate this situation, two traffic-control systems called the "Vehicle **I**nformation and **C**ommunication System (VICS)" and "the probe **c**ar **s**ystem (PCS)" are currently in operation in Japan.

VICS is a telecommunication system that transmits information such as that on traffic congestion and the regulation of traffic by detecting car movements with sensors installed on the road [6]. Information on car movements and that on forecasting traffic congestion are analyzed at the VICS center in real time and then the information from the center is displayed on equipment, such as car-navigation systems installed in individual cars (see Fig. 1).

Figure 1. VICS

PCS also provides information on car movements and that on forecasting traffic congestion to individual drivers the same as VICS does. Different from VICS, this system collects traffic information from all cars, which are considered to be movable sensor units. Each car has a telecommunication unit and transmits several kinds of information such as position, velocity, and the status of the car to the central server. Then, the calculated car-movement and traffic-congestion-forecasting information are analyzed and the information from the center is displayed on equipment, such as car-navigation systems.

Though these two systems are currently operated in Japan, the system structure of both systems is top down and centralized, so the reaction to dynamic changes in traffic congestion and occurrence of accidents is usually delayed and serious problems can occur when the central server is down. In other words, there is a lack of real-time features and of robustness in these systems.

On the other hand, traffic-control systems like ITS and PCS essentially have interesting features for the coordination mechanisms of multi-agent systems (MASs). The coordination mechanisms of MAS can generally be divided into two types: direct and indirect. In the former, precise coordination can be achieved, but when the number of agents becomes excessive the load of coordination becomes extreme. The coordination for the latter is usually called "stigmergy". Stigmergy is a generic name for mechanisms that provide spontaneous, indirect coordination between agents, where the influence in the environment left by the behavior of one agent stimulates the performance of a subsequent action of this agent or a different agent [7]. Since direct coordination is unnecessary in stigmergy, this mechanism can work in situations with massive numbers of agents. However, there is no guarantee that optimal coordination can be achieved. Therefore, how to create optimal coordination using stigmergy is an ambitious topic for research.

Moreover, traffic-control systems essentially have an interesting feature for the system architecture of MASs. Each agent in a MAS usually behaves to achieve a MAS goal regardless of its local or global views, and no agent behaves selfishly for its own gain. Of course, the goal of agents in a market-based environment is their own gain and basically they do behave selfishly. However, in the MAS for traffic-control systems, two competitive goals need to be achieved: the "goal of each agent" and the "goal of the MAS".

In the MAS for a traffic-control system each agent, which controls each car[1], wants to behave selfishly to achieve its goal, e.g., optimal-route navigation by considering the shortest route and the avoidance of congestion. Therefore, each agent in the ITS is in a competitive situation similar to the conventional game environment in a MAS. However, the goal for the MAS itself is stability and optimizing the traffic-control system. That is, eliminating traffic congestion and minimizing the average travel time of all cars to attain a smooth traffic flow. To achieve these goals, it may be necessary to restrict the behavior of each agent. Consequently, the goal of each agent and the goal of the MAS have a competitive relation, and ITS is a very interesting application for the MAS.

In the VICS and PCS currently operated in Japan, congestion information and congestion-forecasting information are updated every 5 min. In other words, VISC or PCS cannot forecast less than five minutes ahead. Since traffic data from sensors and cars are collected at the central server and calculations are done by using all the data, this process

[1] A system that interacts with a human driver to lead him to a destination as in a car-navigation system.

needs a certain amount of time. Therefore, we propose a new congestion-forecasting system that can react to dynamically changing traffic conditions based on a coordination mechanism using the pheromone-communication model. Its main feature is to be able to forecast short-term congestion one or two minutes ahead. There have been many studies on ITS [8][9][10], but there have been few on the forecasting of short-term congestion.

Section 2 discusses traffic-congestion information for car agents and proposes a method of forecasting congestion that uses a multi-agent coordination mechanism for road agents set up at intersections based on a pheromone-communications model, which adaptively responds to increasing amounts of congestion. Section 3 discusses our tests to verify the basic effectiveness of this method. Finally, we conclude this paper in Section 4.

2. Method of forecasting congestion based on pheromone-communications model

Congestion-forecasting technology is one of the main elements of ITS. Up to now, several methods have been proposed, two of which are classified below.

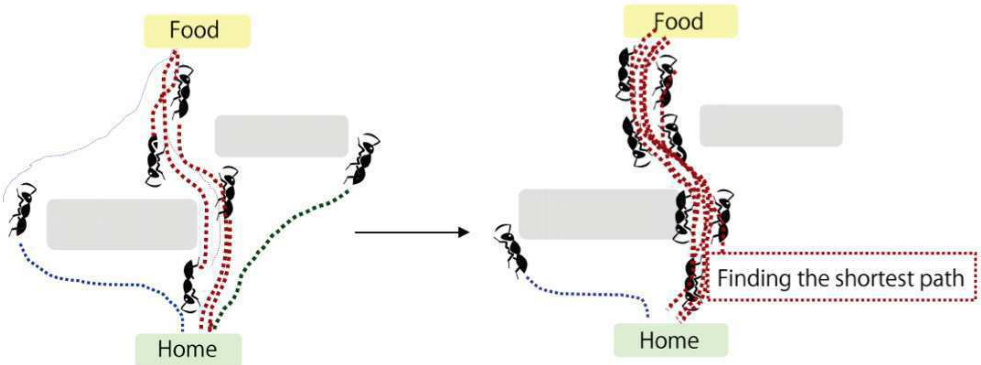
- Long-term forecasting of congestion: A method of statistically analyzing past traffic data, and discovering a pattern where congestion has occurred [13].
- Short-term forecasting of congestion: A method of forecasting congestion a few minutes ahead by using real-time information.

Although it can effectively make forecasts under regular-congestion conditions that have originated from car and road situations, a large amount of past data is necessary for analysis. Moreover, it has weaknesses in forecasting under irregular-congestion conditions, such as those experienced during the Golden-week holidays in Japan and the Christmas-holiday season in the U.S.

VICS and PCS essentially belong to the second classification, and is excellent at short-term forecasting of congestion. Yet, in the current VICS and PCS that is operating in Japan, data from each car is collected at the central server and all calculations are done there. Consequently, it is difficult to supply real-time information due to bottlenecks and time lags in communicating information and the centralized calculations.

For solving these problems, a short-term system of forecasting congestion based on distributed processing is adequate. This paper focuses on ”roads”, and we propose a MAS consisting of many road agents. These road agents are set up at every intersection, and they coordinate locally with one another to forecast congestion. In this research, we adopted the pheromone-communications model as the mechanism for coordination.

Pheromone communications are based on the behavior of social insects like ants and bees and are applied as a model that is used to adaptively respond to dynamic changes in the environment in various applications [12] (see Fig. 2). Our method is an effective way of forecasting congestion in which each road agent generates pheromone information on its own road unit and exchanges this information with its neighboring agents. In a related study, Ando et al. investigated the forecasting of congestion in a local area a short time after pheromones had evaporated and diffused [11]. However, all drivers need to have the same probe-car system installed in their vehicles. Even though there has been some discussion on



When one ant finds an advantageous path from the colony to food, others are more likely to follow that path, and positive feedback eventually leads all the ants to follow a single path.

Figure 2. Ant-colony optimization

information being shared, individual automobile manufacturers are currently developing their own probe-car systems and consequently the rate of diffusion of these probe-car systems is quite low. Therefore, we decided to develop a more realistic and universal system by focusing on the road and not the cars.

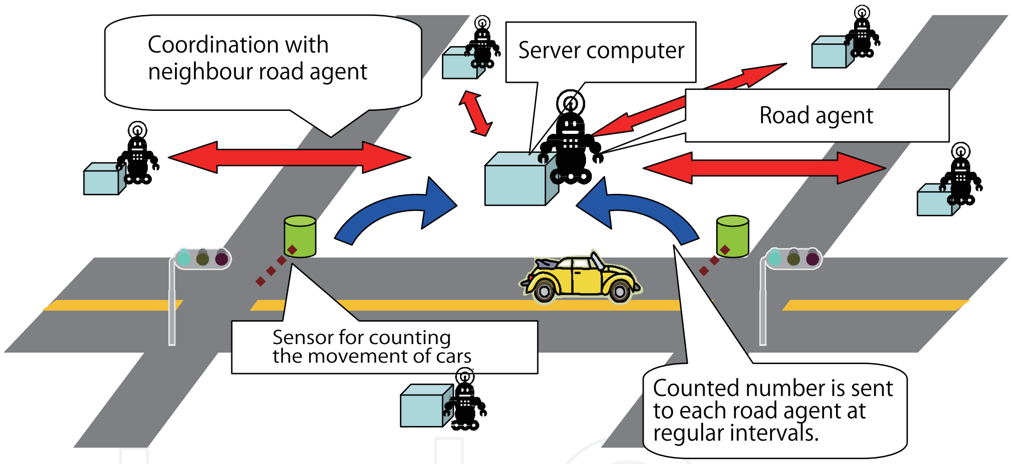


Figure 3. Structure of road environment

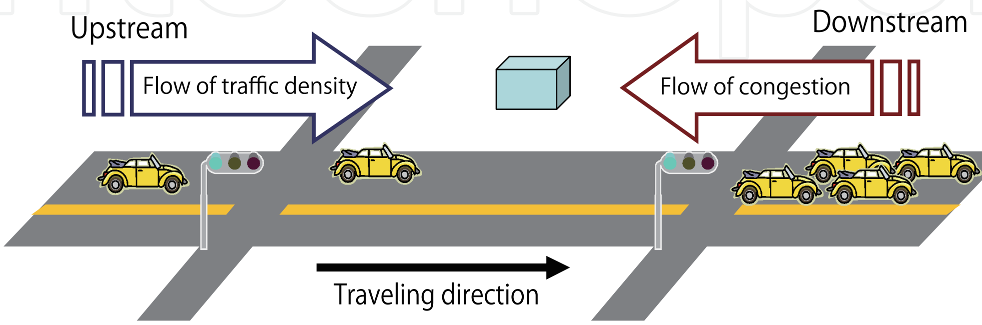


Figure 4. Two important flows in congestion dynamics

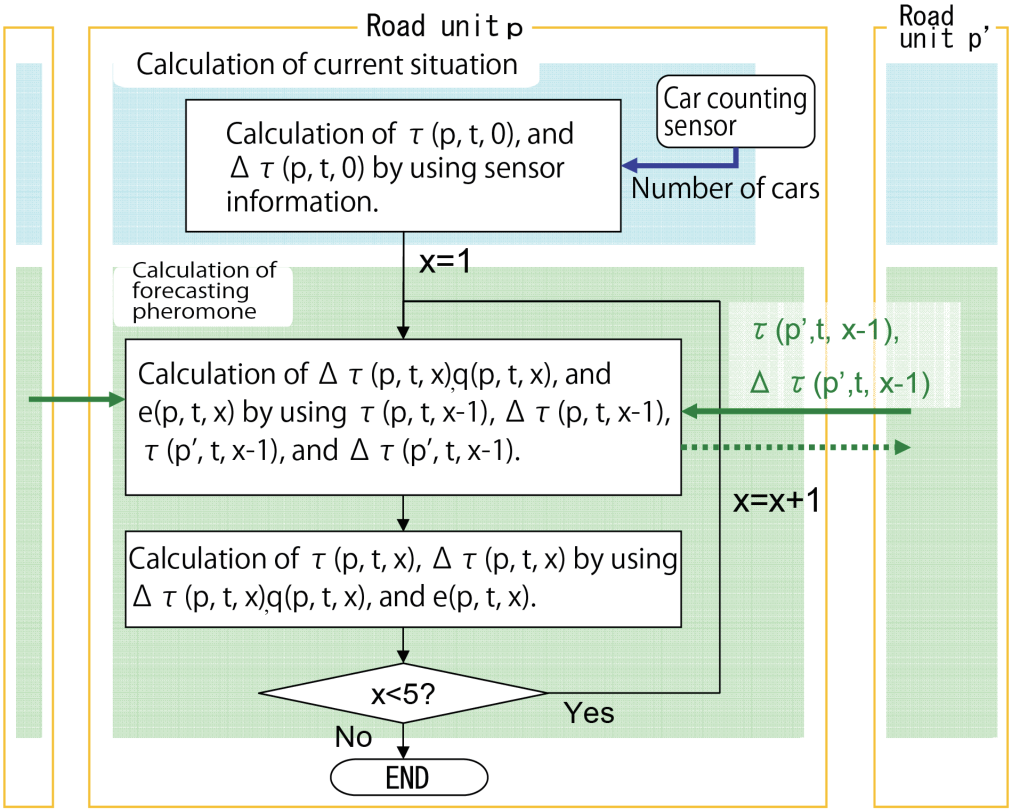


Figure 5. Flow chart for forecasting congestion

2.1. Congestion-forecasting algorithm

First, we will define the road environment as follows (see Fig. 3):

- A road unit is a section between two connected intersections. Each road unit consists of several lanes, usually in both directions, with no branching.
- The number of cars going through an intersection is counted by a sensor installed at each intersection, and this number is sent to each road agent installed on roadside server computers at regular intervals.
- The road agent installed in each roadside server computer calculates and forecasts the traffic congestion.

Therefore, central servers and probe-car systems are not necessary with our method.

A road unit on which a car is currently traveling is called "upstream", and a road unit that will be reached in the future is called "downstream". We focused on two important car-flow dynamics to investigate traffic congestion (see Fig. 4). The first was the flow in traffic density, which spreads from upstream to downstream, corresponding to the movement of cars. The second was the flow in traffic congestion, which spreads from downstream to upstream. At this point, the traffic congestion is defined as follows: a certain road unit becomes bottle-necked blocking the flow of cars. This blocking generates a queue of cars from downstream to upstream.

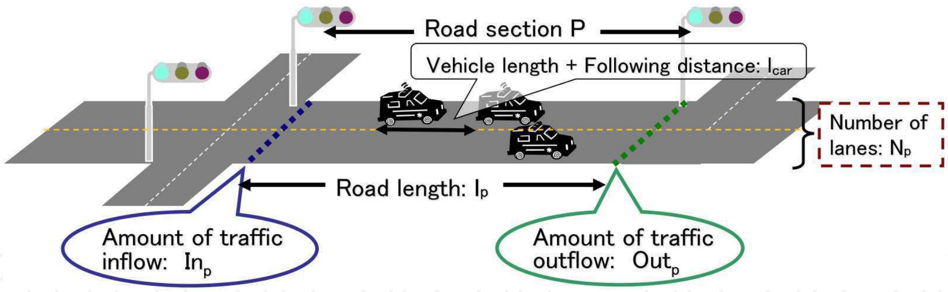


Figure 6. Calculation of current traffic situation

In this paper, we formulate the flow of traffic density using "traffic-density pheromones $\Delta\tau$" and formulate the growth of the queue using "congestion-diffusion pheromones q". To make forecasts more accurate, we introduce the "evaporation rate e", which indicates the change in congestion density from generation to dissolution.

Each road agent in our algorithm forecasts traffic congestion at one minute intervals, as shown in Fig. 5, where $\tau(p,t,x)$ is the forecasted traffic density of a road unit s at time t and $\Delta\tau(p,t,x)$ is the forecasted transition in traffic congestion of road unit s at time t. Even though the calculation interval for forecasting can be shortened further, this increases the load of communication between the sensor and road agent. The one-minute intervals are much shorter than the five minutes of VICS.

Forecasting one minute ahead is calculated through coordination between each agent and their adjacent neighbouring agents. And forecasting two or more minutes ahead is calculated through coordination between each agent and more dispersed neighbouring agents.

2.2. Calculation of the current traffic situation

The inflowing amount, $I(p,t)$, and outflowing number, $O(p,t)$, of cars at regular intervals t are measured with a sensor and are sent to road agents. $I(p,t)$ indicates how many cars flowed into a road unit, p, and $O(p,t)$ indicates how many flowed out of it. First, the road agent that receives this information calculates the traffic density as

$$N(p,t) = N(p,t-1) + I(p,t) - O(p,t) \tag{1}$$

$$d(p,t) = \frac{N(p,t) \times l_{car}}{l_p \times L_p} \tag{2}$$

where $N(p,t)$ is the number of cars, $d(p,t)$ is the traffic density at intervals t of a road unit, p, l_{car} is the length of a car[2], l_p is the length of the road unit, p, and L_p is the number of lanes of p (see Fig. 6).

[2] More precisely, the length of a car + the distance between two cars.

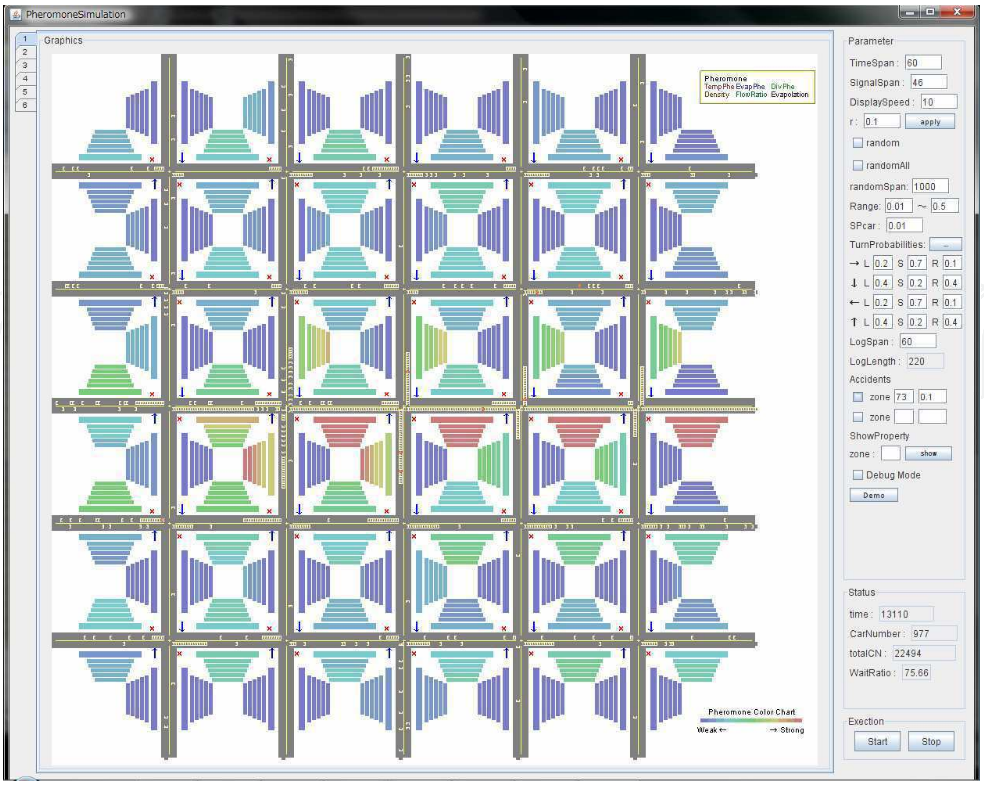


Figure 7. Traffic simulator

2.3. Calculation of congestion forecasting pheromone

Each road agent calculates the congestion forecasting pheromone, τ, which indicates the forecasted congestion density that will occur a few minutes ahead the current situation. $\tau(p,t,0) = d(p,t)$ and $\Delta\tau(p,t,0) = I(p,t) - O(p,t)$ are the initial values for this calculation. As Fig. 5 shows, the traffic-density pheromones $\Delta\tau(p,t,x)$, congestion-diffusion pheromones $q(p,t,x)$, and evaporation rate $e(p,t,x)$ are calculated using $\tau(p,t,x-1)$, $\Delta\tau(p,t,x-1)$, $\tau(p',t,x-1)$, and $\Delta\tau(p',t,x-1)$. At this point, $\tau(p',t,x-1)$ and $\Delta\tau(p',t,x-1)$ are given from the neighbouring road unit. Then, $\tau(p,t,x)$ is calculated.

(a) Calculation of traffic-density pheromones

As previously mentioned, the traffic density spreads from upstream to downstream, corresponding to the movement of cars. What is important is how fast this flow is transmitted, and we define the transmitting velocity of traffic density as $S(p,t,x)$.

$$S(p,t,x) = s_p \times bs_p \times jf(p,t,x) \tag{3}$$

Here, s_p is the distance that a car moves during a certain time span and this is calculated from the maximum legal speed limit of road unit p. bs_p is the proportion of time green lights are displayed in a signal cycle in the traveling direction of the car on this road. Moreover, $jf(p,t,x)$ is a congestion factor that shows the decreasing ratio of the transmitting velocity of traffic density due to the congestion.

$$jf(p,t,x) = \begin{cases} 1.0 & (\tau(p,t,x-1) < \alpha) \\ 1.0 - \tau(p,t,x-1) & (\tau(p,t,x-1) \geq \alpha) \end{cases} \tag{4}$$

α is a threshold where the congestion factor demonstrates the effect, and $\alpha = 0.5$ is used here. $S(p,t,x)$ indicates the transmission distance of the traffic density in the one time span, so the ratio of $S(p,t,x)$ and l_p is important.

$$\Delta\tau(p,t,x) = \sum_{p' \subset N_b} f(p,p') \times \Delta\tau'(p',p,t,x) \tag{5}$$

$$\Delta\tau'(p,t,x) = \begin{cases} \Delta\tau(p,t,x-1) \& (S(p,t,x) > l_p) \\ \frac{S(p,t,x)}{l_p} \times \Delta\tau(p,t,x-1) \& (S(p,t,x) \leq l_p) \end{cases} \tag{6}$$

where N_b indicates the set of upstream road units p and $f(p,p')$ is a parameter that changes based on the relation between p and p'. In this study, $f(p,p')$ was 0.7 when the road unit, $p' \to p$, was straight, 0.2 when it turned left, and 0.1 when it turned right.

(b) Calculation of congestion diffusion pheromones

As previously mentioned, traffic congestion spreads from downstream to upstream. Therefore, the congestion diffusion pheromones are defined based on the difference between the congestion level of the current road unit and the congestion level of the next road unit.

$$q(p,t,x) = \sum_{p'' \subset N_f} g(p,p'') \times q'(p'',p,t,x) \tag{7}$$

$$q'(p'',p,t,x) = \{\tau(p'',t,x-1) - \tau(p,t,x-1)\} \tag{8}$$

where N_f indicates the set of downstream road unit p, and $g(p,p'')$ is a parameter that changes based on the relation between p and p'', which is the same as $f(p,p')$.

	1 min ahead	3 min ahead	5 min ahead
Forecasting with pheromone method	0.98	0.94	0.91
Conventional forecasting	0.95	0.88	0.79

Table 1. Comparison of correlation coefficient between forecast and actual values due to changes in traffic density (forecasting 1 min ahead).

(c) Calculation of evaporation rate

As previously mentioned, the evaporation rate indicates the change in congestion density due to its generation and dissolution. That is, by referring to the degree of traffic change,

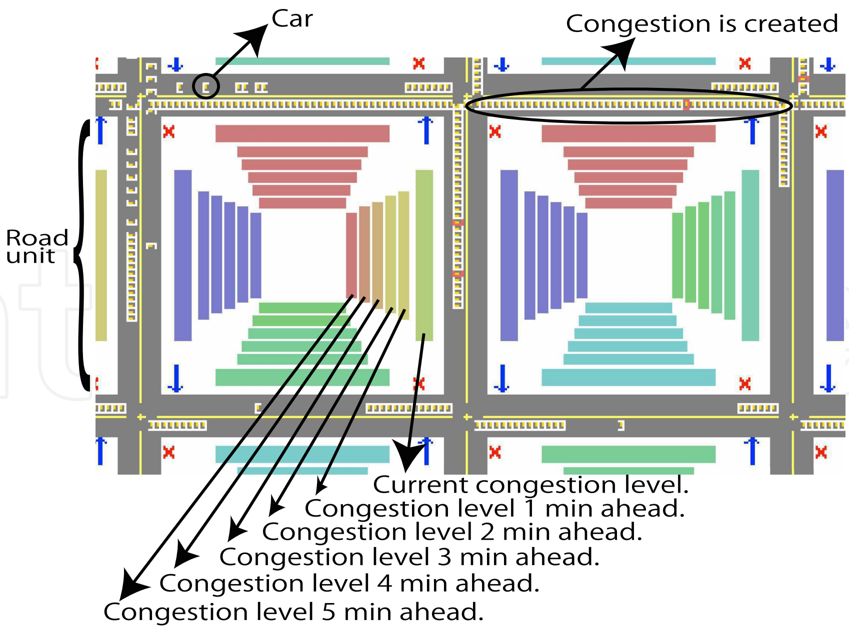


Figure 8. Forecasting scenario in simulator

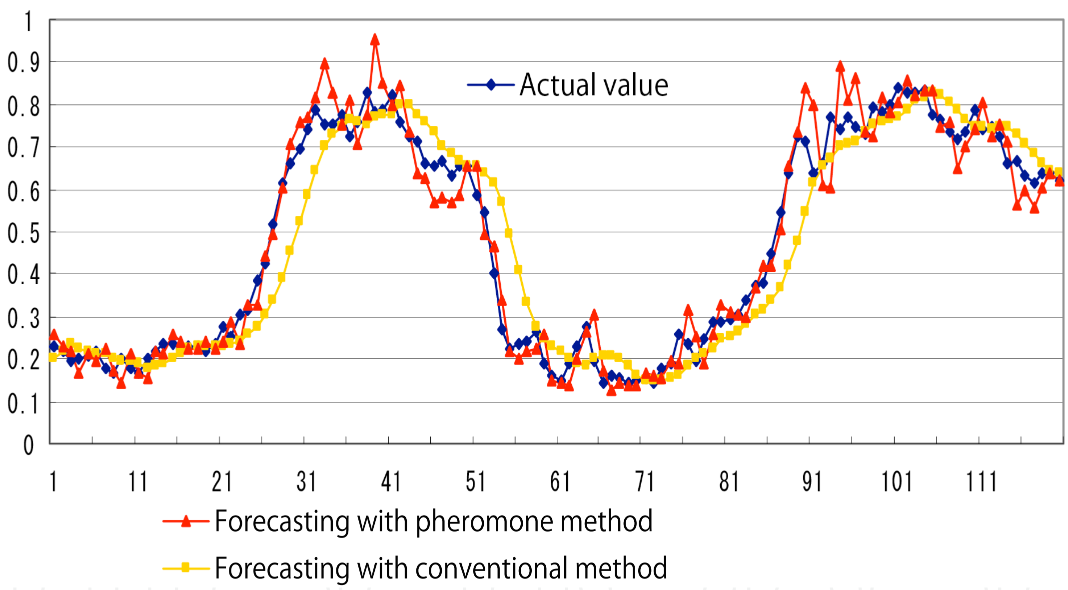


Figure 9. Comparison of congestion forecasting due to changes in traffic density (forecasting 1 min ahead).

$\Delta\tau(p,t,0) = I(p,t) - O(p,t)$, $\Delta\tau$ becoming larger than normal means that traffic congestion will occur. However, $\Delta\tau$ becoming smaller than normal means that traffic congestion is "evaporating". To determine the amount of normal traffic change on the road unit p, the decentralization, v_p, of this change is calculated using the data from a previous day.

$$e(p,t,x) = \begin{cases} \beta_1 \& (v(p,t,0) > x \times v_p) \\ 1.0 \& (-x \times v_p < v(p,t,0) < x \times v_p) \\ \beta_2 \& (v(p,t,0) < -x \times v_p) \end{cases} \tag{9}$$

The above expression shows that when the difference between the observed amount of traffic and the amount of traffic in normal conditions increases, the degree of congestion generation and congestion evaporation becomes big. β_1 and β_2 are parameters that indicate the degree of evaporation and in this study, β_1 is 1.1 and β_2 is 0.9.

(d) Calculating congestion-forecasting pheromones

The forecasting of congestion pheromones after x minutes is calculated from the above value as follows.

$$\tau(p,t,x) = e(p,t,x) \times \tau(p,t,x-1) + \Delta\tau(p,t,x) + q(p,t,x) \quad (10)$$

Each road agent forecasts short-term traffic congestion by sequentially and repeatedly calculating (a) to (d) from the above.

2.4. Simulations

To experimentally verify the basic effectiveness of our proposed forecasting model, we implemented a simple simulation environment and compared the accuracy of forecasting a few minutes ahead (i.e., one, three, and five minutes) with the proposed and a conventional method. We especially verified the effectiveness of our methodology in two respects, i.e.,

1. The forecasting accuracy of generation/dis-
   solution of congestion due to changes in traffic density and
2. The forecasting accuracy of generation/dis-
   solution of congestion due to sudden accidents.

The correlation coefficient of the actual measurements and the forecasting values was used for the evaluation, and the simulation environment shown in Fig. 7 was used for the experiment. This simple simulator had a 5 x 5 lattice structure with single-lane roads. There was one traffic signal at each intersection. The length of one road unit, i.e., the distance between two consecutive intersections, was 400 m.

In this experiment, we set $1 time-step$ to $1 sec$ and $1 time-span$ to $60 time-steps$. Each road agent calculated the traffic density on its own road unit every minute, and forecasted until 5 minutes ahead. To evaluate the effectiveness of the proposed method, we used a conventional method of short-term forecasting based on a statistical approach [8] and made forecasts 1, 3, and 5 min ahead.

This conventional forecasting approach was based on the assumption that the current congestion situation would generally continue for a few minutes. The current VICS and PCS update their congestion information every five minutes, so if we used this conventional method to forecast five minutes ahead, it could basically be thought of as using the same approach as VICS and PCS.

Fig. 8 is an expansion of part of the simulator used in executing the forecasts. We can see that one road agent forecasts congestion of its road unit that will not occur within 5 min but

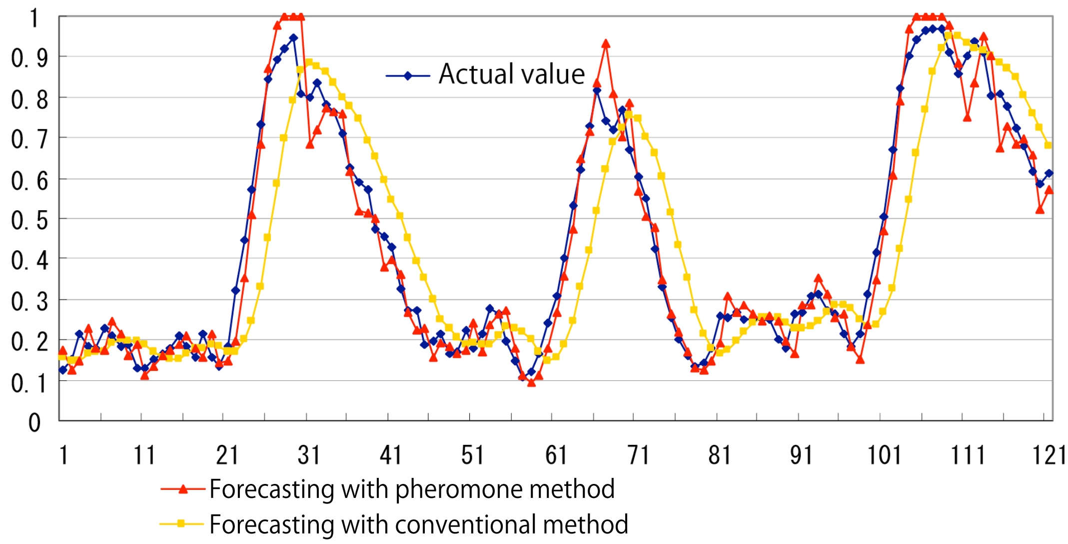


Figure 10. Comparison of congestion forecasts due to sudden accidents (forecasting 1 min ahead)

occur after this. On the other hand, we can also see that one agent forecasts congestion of its road unit that will continue for longer than 5 min.

	1 min ahead	3 min ahead	5 min ahead
Forecasting with pheromone method	0.98	0.94	0.86
Conventional forecasting	0.86	0.66	0.45

Table 2. Comparison of correlation coefficient between forecast and actual values due to sudden accidents

2.4.1. *Congestion due to changes in traffic density*

Traffic congestion is usually generated when more than the acceptable number of cars moves into a road unit. We carried out the simulation for about 2 hours and generated and evaporated congestion several times by changing the traffic density. We then compared our proposed method with the conventional approach by forecasting 1, 3, and 5 min ahead.

As a result, our proposed approach had a higher accuracy than the conventional method (Table 1). Fig. 9 shows the change in the actual traffic-congestion level (blue line) and the forecast congestion level 1 min ahead by using the conventional (yellow line) and our approach (red line). The change in the red line is similar to that in the blue line. The change in the yellow line, on the other hand, is delayed. Therefore, our proposed method can forecast congestion more accurately than the conventional approach.

2.4.2. *Congestion due to sudden accidents*

Next, we evaluated how accurately congestion could be forecast when sudden accidents occurred. This type of congestion does not happen based on changes in traffic density, but it occurs due to the decreased capacity of the roads to accommodate cars traveling along them. Since this decrease in capacity happens suddenly, the speed at which congestion is diffused is very rapid. In our simulation, we compared the effectiveness of our proposed method with that of the conventional approach by quickly changing the traffic density of a certain road unit. As Table 2 and Fig. 10 show, our proposed method is more accurate than the conventional scheme. Forecasting accuracy particularly worsened with the conventional method during long-term forecasts. However, we were able to maintain accurate forecasts with our method.

3. Conclusion

We proposed a method of forecasting congestion using a multi-agent coordination mechanism. A road agent installed at each intersection coordinates with its neighboring road agents based on the pheromone-communications model to adaptively respond to dynamically arising congestion and forecasts congestion a few minutes ahead. Here, we tested and verified the basic effectiveness of this method using simple simulation.

It is unnecessary in our approach to utilize a sufficient number of cars with the same probe system [8], or to upgrade the central server. At the very least, it needs to have simple sensors installed to count the number of cars moving through intersections, and small computers for road agents at these intersections. However, we have assumed that various kinds of computers, servers, and sensors will be installed in various locations to gather large amounts of information from the real world in about 5-10 years as part of urban scanning. Actually, small-scale real-world experiments are now being conducted in several locations throughout Japan [17]. These are based on the development of ubiquitous-information-communication technologies such as sensor-networks and wireless communication devices. In such situations, our method is expected to be quite practical. This evaluation was only done through simulation, and the road map used had a simple lattice structure. However, as we have already obtained detailed road data and VICS/PCS data throughout the entire country of Japan, we can shortly begin to evaluate our method using these real-world data.

As for traffic light control, all traffic lights need to react to dynamic changes in traffic in real time [14][15][16] in traffic-light-control systems, which are also the primary systems for controlling traffic. However, the current system cannot respond to dynamic changes in road conditions in real time even though some automatic control occurs according to the traffic flow. We also plan to develop a new traffic-light-control algorithm based on a MAS.

Author details

Satoshi Kurihara

Osaka University, Japan

References

[1] V. R. Tomás and L. A. Garcia: A Cooperative Multiagent System for Traffic Management and Control, The Fourth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS-06), 2006.

[2] T. Nakata and J. Takeuchi: Mining Traffic Data from Probe-Car System for Travel Time Prediction, KDD'04, pp. 22-25, 2004.

[3] X.-H. Yu and W. W. Recker: Stochastic adaptive control model for traffic signal systems, Transportation Research Part C 14, pp. 263-282, Elsevier, 2006.

[4] K. Tufte, J. Li, D. Maier, V. Papadimos, R. L. Bertini, and J. Rucker: Travel Time Estimation Using NiagaraST and latte, SIGMOD'07, pp. 1091-1093, 2007.

[5] J.-D. Schmocker, S. Ahuja, and M. G. H. Bell: Multi-objective signal control of urban junctions - Framework and a London case study, Transportation Research Part C 16, pp. 454-470, 2008.

[6] http://www.vics.or.jp/english/index.html

[7] "Definitions of stigmergy." From a special Issue of Artificial Life on Stigmergy. Volume 5, Issue 2 / Spring 1999.

[8] P. G. Balaji, G. Sachdeva, D. Srinivasan, Multi-agent System based Urban Traffic Management, IEEE Congress on Evolutionary Computation 2007, pp. 1740–1747, 2007.

[9] Ana L. C. Bazzan, Opportunities for multiagent systems and multiagent reinforcement learning in traffic control, Autonomous Agents and Multi-Agent Systems, Vol. 18, No. 3, pp. 313–341, 2009.

[10] J. J. Sánchez-Medina and M. J. Gálan-Moreno and E. Rubio-Royo", Traffic Signal Optimization in La Almozara District in Saragossa Under Congestion Conditions, Using Genetic Algorithms, Traffic Microsimulation, and Cluster Computing, IEEE Transaction on Intelligent Transportation Systems, Vol. 11, No. 1. pp. 132–141, 2010.

[11] Y. Ando, Y. Fukazawa, O. Masutani, H. Iwasaki, and S. Honiden: Performance of Pheromone Model for Predicting Traffic Congestion, The Fifth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS-06), 2006.

[12] M. Dorigo and G. di Caro: The ant colony optimization meta-heuristic, New ideas in optimization, McGrawHill, pp. 11-32, 1999.

[13] E. Chung: Classification of traffic pattern. Proceedings of the 11th World Congress on ITS, 2003.

[14] M. Wiering: Multi-Agent Reinforcement Learning for Traffic Light Control, Machine Learning, *Proceedings of the Seventeenth International Conference (ICML'2000)*, pp. 1151-1158, 2000.

[15] D. Oliveira, A. L. C. Bazzan, B. C. Silva, E. W. Basso, L. Nunes, and R. J. F. Rossetti, E. C. Oliveira, R. Silva, and L. C. Lamb: Reinforcement learning based control of traffic lights in non-stationary environments: A case study in a microscopic simulator, *Proc. of EUMAS06*, pp. 31-42, 2006.

[16] D. Oliveira, P. Ferreira, and A. L. C. Bazzan: Reducing traffic jams with a swarm-based approach for selection of signal plans, *Proc. ANTS 2004*, Vol. 3172 of LNCS, pp. 416-417, Berlin, Germany, 2004.

[17] http://uscan.osoite.jp/