DEVELOPMENT OF DYNAMIC FREEWAY SIMULATION MODEL FOR INCIDENT MANAGEMENT

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Abstract: ITS Technology may be the key for effective traffic management such as predicting change of congested traffic flow caused by incident or by sudden increase of traffic volume. The Freeway Traffic Management System (FTMS) of Korea contains incident detection algorithms and traffic incident certification modules. However, the function of predicting change of traffic flow condition in non-recurring congestion such as incident is not yet provided. Research on which this paper is based on, has developed dynamic highway traffic simulation model for prediction of future traffic condition. This model used real time TCS (Toll Collection System) and VDS (Vehicle Detection System) data, while the CA (Cellular Automata) model was used as traffic flow simulator. From the field test, in and out traffic volume of freeway, split ratio of each direction, length of delay caused by incident and traffic condition after occurrence of incident were predicted. The predicted results were expressed two-dimension graphics by an animator developed in this research and evaluated by comparing with field traffic data.

Key Words: Incident management, Integrated CA Model, Dynamic simulation model

1. INTRODUCTION

Congestion caused by rapid increase of demand produces huge personal and social cost. To avoid this serious transportation problem, ITS (Intelligent Transport Systems) provide a complementary means to maximize the efficiency and safety of transportation infrastructure.

Freeway traffic management system (FTMS) that is one of various system of the ITS is
automated traffic management system at expressway. Incident management to minimize the congestion caused by incident is important technology of FTMS. It is core technology of ITS for effective traffic management that predicting change of congested traffic flow caused by incident.

Predicted traffic information is much more valuable than real time traffic information in fluctuating traffic condition. Especially, predicting change of congested traffic flow caused by incident or sudden increase of traffic volume is core technology of ITS for effective traffic management. Because incident can serious congestion on freeway that has restricted entering and leaving facilities, it is very important function that verifying traffic flow state and predicting the extend and end of congestion.

Current FTMS verified incident by VDS(Vehicle Detection System), CCTV(closed circuit TV) and information of the highway users, but it dependent on experience of TOC staff about how traffic is processed after incident. Therefore we needs to predict the state of traffic flow for minimizing the congestion and continuing time of incident. If we can predict the affect of incident, we can compute the affected areas and recovering time of traffic flow. So we can establish traffic management strategies such as the space range of information providing and of alternate routes.

The Freeway Traffic Management System(FTMS) of Korea contains incident detection algorithm and incident certification module. However, the function of predicting change of traffic flow condition for more effective traffic management and accurate traffic information in non-recurrent congestion such as incident is not provided yet. FTMS decides current traffic condition by VDS, CCTV, other information, but FTMS has not real-time unification function of this information.

In this research, a dynamic highway traffic simulation model for prediction of future traffic condition was developed. The model used real time TCS(Toll Collection System) and VDS(Vehicle Detection System) data and CA(Cellular Automata) model was used as traffic flow simulator.

2. LITERATURE REVIEW

We study research and application cases of FTMS, incident response system and traffic flow model for analyzing the properties of incident on freeway.

2.1 The Research of Freeway Incident Analysis System

Traffic congestion is divided into recurrent congestion and nonrecurrent congestion. Recurrent congestion occurs when traffic demand exceeds highway capacity. It is often the case during morning traffic peaks in urban network. An incident is defined as at non-recurring event that causes a reduction of highway capacity or an abnormal increase in demand. Such events are divided into predictable events that are traffic crashes, disabled vehicles, highway maintenance and unpredictable events that are special non-emergency events(e.g. concerts, sports game) and sudden changes of weather.

We can establish preparation by providing related information for predictable incident. Because it is impossible to predict the occurrence and affect of incident for unpredictable
events, however, it is difficult to establish incident response.

Total incident time consists of detection time, verification time, response time, management time. Incident detection is the process by which an incident is brought to the attention of the agency responsible for maintaining traffic flow and safe operation on the highway. Incident verification entails confirming that an incident has occurred, determining its exact location, and obtaining as many relevant details about the incident as possible. Incident response includes dispatching the appropriate personnel and equipment, and activating the appropriate communication links and motorists information media as soon as there is reasonable certainty that an incident is present.

Incident detection and verification is managed rapidly by mobile phone of driver and by information of patrol car. The response time is different at incident site, but we can look upon that response time as fixed by rapid response of tractor car or related agencies.

The Freeway Traffic Management System (FTMS) of Korea contains incident detection algorithm and incident certification module. However, the function of predicting change of traffic flow condition for more effective traffic management and accurate traffic information in non-recurrent congestion such as incident is not yet provided.

Incident response is divided site management of the incident site and traffic management of the preceding highway section that is areas affected by an incident. Traffic management involves the application or traffic control measures in areas affected by an incident. Traffic management in the context of an incident may include managing the highway space, actively managing traffic control devices in affected areas, and operating alternate routes. Typical operational responsibilities of the Traffic Operation Center (TOC) include providing motorists information, determining incident clearance and highway repair needs, and operating alternate routes.

When incident is occurred, staff at TOC decides the method and the level of incident response according to future traffic condition by incident affect. In this point, the most important element is to predict the congestion time by incident. Therefore, to support determining management action of TOC staff and to upgrade the performance of incident response, we need simulation model that analyses the state of traffic flow after incident and its affects.

### 2.2 Review of Traffic Simulation Model

Traffic simulation models could be classified into macroscopic models and microscopic models according to its simulating detail. Microscopic model is based on individual vehicle movement and it could simulate activities of entities, interactions among entities and system entities in detail. However, due to difficulty of observation and validation in real situation it is hard to develop this type of simulation model. On the contrary, the activities and interactions of entities are treated very simply and aggregated variables of vehicles are used in macroscopic models. Although macroscopic model has a merit of high efficiency, its application range is restricted in simulating traffic management strategy like transit/HOV lane and decision making process performed by individual vehicle level due to its macroscopic analysis unit (traffic volume, velocity, density).

Despite of that there have been developed many traffic simulation models, it is considered that almost all models are not proper to analyzing ATMS (Advanced Traffic Management Systems) strategies.
System) and ATIS (Advanced Traveler Information System) related effect. Therefore, recently, many researches are having been performed for the purpose of analyzing ITS (Intelligent Transportation System) effect by modifying existing models or developing new models in the world. However, despite of these efforts, it is considered that there are still a lot of shortcomings related to capability and reliability of the model.

In order to analyze ITS effect, the simulation model that including traffic control facilities, information providing devices, strategies of traffic control and information provision is needed. In addition, the model should simulate on the basis of individual vehicle or passenger analysis unit. However, existing traffic simulation models are considered having shortcomings in simulating system, simulating detail and simulating dynamic traffic flow and passenger activities. Furthermore it is considered that parameters those are used existing simulation models are not developed under sufficient field survey and the accuracy of the models are not proved.

The model considered in this research should include function of estimating the effect caused by incident and function that could reflect the change of traffic situation induced by traffic information providing like ITS. To this purpose, the detail of the model is important. Therefore, in this research, the CA (Cellular Automata) model that has merit in simulation run time as microscopic model is selected.

### 3. DEVELOPMENT OF DYNAMIC SIMULATION MODEL FOR INCIDENT MANAGEMENT

#### 3.1 Particle Hopping Model With Parallel Computing

Cellular Automata (CA) is an artificial approach to simulation modeling based on movement rules to describe intelligent decision-making behavior of automata. Nagel and Schreckenberg (1992) analyzed freeway traffic behavior with a CA car following model called as NaSch model. The NaSch model is being used in the traffic modeling of the TRANSIM planning suites, and describes the variable phases of the traffic flow dynamics with the very high-speed computational performance of the micro simulation that is crucial to provide real-time analysis. NaSch (car-following) model is in parallel with noise mechanism. The movement rules are as following four steps:

**Speed update step**

- **Acceleration:** IF \((v_i < g_i)\) THEN \(v_{i+1} = \min[v_{max}, v_i + 1]\)
- **Deceleration:** IF \((v_i \geq g_i)\) THEN \(v_{i+1} = \min[v_i, g_i]\)
- **Randomization:** IF \((p_{noise} > \text{random value})\) THEN \(v_{i+1} = \max[v_{i+1} - 1, 0]\)

**Movement step**  
\[x_{i+1} = x_i + v_{i+1}\]

Where, \(v_i\) \((0 \leq v_i \leq v_{max}\), cell/time step\) is a particle’s velocity at time step \(t\), and \(g_i\) is the number of unoccupied cells to the leading particle at time step \(t\), and \(p_{noise}\) is random noise parameter \((0 \sim 1)\).

\(p_{noise}\) take a key role in describing stochastic flow dynamics, and describes free flow speed
and maximal flow, capturing acceleration noise, and the acceleration of stopped vehicles in a jam and the acceleration rate of vehicles to escape from a jam. The jam dynamics of NaSch model are similar to those of second-order fluid models. But second-order fluid models describe deterministic jam dynamics, whereas NaSch model does stochastic jam dynamics with fluctuation differences.

Slow-To-Start rule (STS), based on NaSch model and introduced by Barlovic(2002), more realistically captures the breakdown flow behavior, called as the reversed \( \lambda \) shaped flow-density relationship. To describe the acceleration rate of stopped vehicles, STS rule uses random noise parameter (\( p_s \)) that has higher value than \( p_{\text{noise}} \). If \( p_s >> p_{\text{noise}} \) then drivers escaping out of a jam will hesitate so that a jam grows and moves backward. STS rule is directly added to NaSch model, and an integrated NaSch model with STS rule is called as the modified NaSch model. And if \( p_s = p_{\text{noise}} \) then the modified NaSch model has the same function as the NaSch model.

Precedent works show that the modified NaSch model explains the uninterrupted traffic flow phases such as stop-and-go traffic, synchronized flow, a moving jam, and a stationary jam in the bottleneck. But mentioned-above CA models have following common shortcomings in view of microscopic behaviors:

a. Unrealistic braking capability to avoid back collision in one time step, generally 1 second, from \( v_{\text{max}} \) to 0.

b. Not distinguished drivers’ behavior between staying in a jam and escaping from it.

3.2 Additional Movement Rules For More Realistic Behaviors

In this paper, two additional movement rules, Stopping Maneuver Rule (SMR) and Low Acceleration Rule (LAR), will be introduced to tackle explained-above two defects and to capture velocity quantities more realistically under heterogeneous traffic flow conditions. SMR is to describe a decelerating vehicle to arrive and stop in the tail of a jam, and LAR is to capture an accelerating vehicle, which follows a stopped leading vehicle in a jam. And the two rules are easily and directly added into the modified NaSch model.

An approaching vehicle, with velocity \( v_i > 0, \text{cell/sec} \), to the back of a stopped leading vehicle can’t help slowing down to protect itself from a rear end collision or a crash, and needs enough Stopping Distance (SD) to accomplish a smooth safe stop. Let us assume the following:

\[
SD = \sum_{i=1}^{\nu} i + v_i \quad \text{for all vehicles with } v_i > 0
\]

NUC stands for the Number of Unoccupied Cells to the first stopped vehicle.

Using SD and NUC, SMR is applied with random noise (\( p_{\text{sm}}, p_{\text{noise}} \leq p_{\text{sm}} \leq 1 \)) as following:

\[
\text{IF (SD} \geq \text{NUC) THEN or IF (} v_i - 1 \geq v_{\text{lead}} \text{ and } v_i \geq g_i \text{) THEN \ IF (} p_{\text{sm}} > \text{random value) THEN } v_{i+1} = \min [v_i - 1, g_i] \ ELSE \ \text{the speed update step of the modified NaSch model}
\]
Where, \( v_{lead} \) is the velocity of the leading vehicle.

In the modified NaSch model, noise parameter values, namely \( p_{noise} \) and \( p_s \), are used for both the acceleration of stopped vehicles in a wide moving jam \((1-1/(v_{max} +1) << \rho \leq 1)\) and the acceleration of escaping vehicle from a jam. But an aggressive accelerating maneuver with high acceleration rate to escape a jam is different from accelerating maneuver in a jam. Because, in a jam, an accelerating maneuver is physically accomplished with low acceleration rate and drivers psychologically hesitate about accelerating. To describe a low acceleration rate in a jam, LAR is introduced. Let us make assumption about followings:

1. A stopped vehicle with \( g_i = 1 \), following a stopped vehicle, stays in a jam.
2. A stopped vehicle with \( g_i = 1 \), following a running vehicle, escapes from a jam.

And then LAR are modeled with random noise \((p_{la}, p_{noise} \leq p_{la} \leq 1 \text{ or } p_s \leq p_{la} \leq 1)\) as following:

\[
\text{IF (} v_i = \text{0) THEN} \\
\text{IF (} g_i = \text{1 AND } v_{lead} = \text{0) THEN} \\
\text{IF (} p_{la} \text{>} \text{random value) THEN } v_{i+1} = 0 \\
\text{ELSE } v_{i+1} = 1
\]

SMR and LAR are directly integrated into the modified NaSch model as following.

Velocity update step

\[
\text{IF (} v_i > \text{0) THEN} \\
\text{IF (} SD \geq NUC \text{) THEN or IF (} v_i \text{-}1 \geq v_{lead} \text{ and } v_i \geq g_i \text{) THEN SMR} \\
\text{ELSE the speed update step of the modified NaSch model} \\
\text{IF (} v_i \text{=} \text{0) THEN} \\
\text{IF (} g_i = \text{1) THEN} \\
\text{IF (} v_{lead} = \text{0) THEN LAR} \\
\text{ELSE the speed update step of the modified NaSch model} \\
\text{ELSE the speed update step of the modified NaSch model}
\]

Movement step

\[
x_{i+1} = x_i + v_{i+1}
\]

Above the integrated model, the modified NaSch model with SMR and LAR, has the convertibility. If \( p_{noise} = p_s = p_{sm} = p_{la} \), then SMR and LAR have the same function as the NaSch model, and if \( p_{noise} \ll p_s, \ p_{noise} = p_{sm}, \ p_s = p_{la} \), then as the modified NaSch model.

3.2 Traffic Flow Phenomena in the Modified NaSch Model with SMR and LAR

The random noise parameter \((p_{sm})\) is used with very higher values, because the deceleration of a vehicle, arriving to the end of a jam, is mandatory and more or less deterministic. And to describe low deceleration rate in a jam, the random noise parameter \((p_{la})\) is considered with...
high values, for example if $p_{la}=0.8$ and cell length 7.5 then acceleration rate is $1.5 \approx 7.5 \times (1-0.8)$. For heterogeneous flow ($\rho > \rho_c$), in figure 2, NaSch model shows a more or less convex flow-density relationship, but the integrated model does a concave flow-density relationship according to increasing the values of $p_{sm}$ and $p_{la}$.

**Figure 1.** Vehicle trajectories on a 1-lane periodic system with parallel update: dots represent vehicles that move to the right. The horizontal direction is discrete space to the right and the vertical direction to the down is discrete time. Left: NaSch model ($p_{noise}=0.135$, $v_{max}=5$). Right: the integrated model with SMR and LAR ($p_{noise}=0.135$, $v_{max}=5$, $p_{sm}=0.8$, $p_{la}=0.8$).

**Figure 2.** Fundamental diagram of the NaSch model VS the integrated model (NaSch+SMR+LAR): 5-min polling average. NaSch model with $p_{noise}=0.135$, $v_{max}=5$, and the integrated model with $v_{max}=5$, $p_{sm}=0.8$, $p_{la}=0.8$. $q$ is (veh/3600sec), so $1/q$ values are from 0 to 1.
The modified NaSch model explains the reversed $\lambda$-shaped flow-density curve with two maximum flow, $q_{\text{max}}$ and $q_{\text{min}}$, and the integrated model generates the same relationship. The modified NaSch model describes heterogeneous flow as straight-line relation, whereas the integrated model does as concave-curve relation according to increasing the values of $p_{\text{sm}}$ and $p_{\text{la}}$.

Figure 3. Fundamental diagram of the modified NaSch model vs. the integrated model: 5-min polling average. The modified NaSch model with $p_{\text{noise}}=0.135$, $p_s=0.5$, $v_{\text{max}}=5$, and the integrated model with $p_{\text{noise}}=0.135$, $p_s=0.5$, $p_{\text{sm}}=0.8$, $p_{\text{la}}=0.8$, $v_{\text{max}}=5$.

4. CASE STUDY

4.1 Input Data

In this research, 30 seconds unit VDS (Vehicle Detection System) data and 15 minutes unit TCS (Toll Collection System) data are used. The VDS data are used to estimate initial link density and turn movement ratio of flow at IC (Intersection). TCS data are used to make pattern for predicting future traffic volume. The data of VDS are composed of volume, occupancy, and average speed of each lane and TCS data are composed of in and out traffic volume of each tollbooth.

Figure 4. Data Adjustment: Axis X is 30-sec time series data num, and Y is volume (veh/30sec)
VDS data was adjusted to eliminate outlier and to supplement missing data. In this research moving average method was used and data was adjusted to time and space. Figure 4 shows the result of data adjustment.

4.2 Traffic Volume Forecasting

The method that was used to predict traffic volume is that of pattern recognition. In this research, the method that weight latest data was used. The result of volume forecasting by pattern recognition method is presented in Table 1 and Figure 5. The result shows the forecast data and observed data of Chungwon IC which located in analysis section. And from this result, the predicted traffic volume is considered as reasonable value.

Table 1. Result of Traffic Volume Forecasting

<table>
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<th>Classification</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
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<tbody>
<tr>
<td>Predicted</td>
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<td>150</td>
<td>179</td>
<td>175</td>
<td>159</td>
<td>150</td>
<td>149</td>
<td>140</td>
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<tr>
<td>Observed</td>
<td>165</td>
<td>156</td>
<td>174</td>
<td>174</td>
<td>174</td>
<td>174</td>
<td>151</td>
<td>151</td>
</tr>
</tbody>
</table>

Figure 5. Result of Traffic Volume Forecasting

4.3 Result of Simulation

To analyze the effect caused by incident, simulation was performed with the model that was developed in this study. And for validation, the result was compared with result of INTEGRATION at same conditions. The condition of incident, traffic and road is presented in Figure 6 and Table 2.

The simulation results are presented in Figure 7 and Figure 8. In Figure 7 and Figure 8, path travel time in time interval (t) is calculated by using cumulative travel time of each time slice. The main freeway trunk line is one direction and is composed of a series of freeway sections, and two freeway routes don’t meet.
The simulation results of INTEGRATION shows maximum accumulated travel time is about 720 second about 17-min simulation runtime, and the simulation results of the developed simulation model does show maximum accumulated travel time is about 900 second about 20-min simulation runtime.

These differences occurred, because each macroscopic relationship characteristics differ especially on the conditions of congested flows. In INTEGRATION out flow is calculated by using time headway that is determined by Speed-Flow and Flow-Concentration Model. On the other hand, in the developed model in this study out flow is affected by lane changing of vehicles. Furthermore, in INTEGRATION, available capacity in congested flow and on incident section occurred are over estimated. Thus, the model developed in this study is interpreted as more powerful model, because the developed simulation model with breakdown mechanism can better reflect real traffic conditions than INTEGRATION.
5. CONCLUSION

When incident is occurred, staff at TOC decides the method and the level of incident response according to future traffic condition by incident affect. In this research, dynamic highway traffic simulation model for prediction of future traffic condition was developed. The model used real time TCS(Toll Collection System) and VDS(Vehicle Detection System) data and CA(Cellular Automata) model was used as real time traffic flow simulator.

The CA model used as simulator in this research is link-based micro model. The CA model has a lot of advantages such as speed of simulation run time, range and applicability in various geometric designs and traffic conditions. In this research, the adaptive CA model that improve existing CA model was developed. The adaptive CA model could simulate congested traffic flow more elastically, could simulate breakdown, with STS rule, on bottleneck section like merging area and could simulate stop and go phenomena more realistically.

The simulation model developed in the research was tested for some freeway sections and times. Through field test, in and out traffic volume of freeway, split ratio of each direction, length of delay caused by incident and traffic condition after occurrence of incident were predicted. The predicted results were expressed 2 and 3 dimension graphics by animator developed in this research and evaluated by comparing with field traffic data.

The model developed in the research focus on providing a tool to freeway operator for decision making not to driver such as ramp metering, traffic information providing in case of non-recurrent congestion. And if functions related to dynamic traffic assignment are added to the model, it could be used for providing optimal path to the driver in the near future.

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