TRAVEL TIME RELIABILITY ON EXPRESSWAY NETWORK UNDER UNCERTAIN ENVIRONMENT OF SNOWFALL AND TRAFFIC REGULATION

Hiroshi Wakabayashi
Faculty of Urban Science, Meijo University, 4-3-3, Nijigaoka, Kani-City, Gifu 509-0261 Japan,
Tel: +81-574-69-0131, Fax: +81-574-69-0155,
E-mail: wakabaya@urban.meijo-u.ac.jp

ABSTRACT

Travel time reliability assessment model has been developed for an expressway network under uncertain environment of snowfall and traffic regulation after snowfall. The framework should consider the process that weather forecast affects implementation of traffic control and that the traffic control changes the travelled speed. Two types of dependency of traffic control schemes and traffic conditions between adjacent highway sections also should be considered. The former dependency is considered using correlation coefficient matrices of traffic control, and the latter is considered in the course of composition of probability distribution function in travel time. This framework is applied to the expressway network between Nagoya and Osaka, two major cities in Japan. Travel time reliabilities are calculated and compared for several routes, and for normal and abnormal period under the given weather forecast pattern.

1. INTRODUCTION

Conventional highway networks have been constructed based on the average traffic demand. However, traffic demand fluctuates day-to-day, and road capacity and speed limitation varies. Highway network should provide sure and unfluctuating traffic service, by offering drivers alternative routes even when a certain route is closed. This is the motivation for studying highly reliable transportation systems.

This paper proposes a framework of travel time reliability analysis under uncertain snowfall environment and presents its application to the actual expressway network. Travel time reliability is defined as the probability that the travel time between two given nodes is guaranteed within a certain travel time. It can also be treated as the maximum travel time required to arrive at the destination with a given probability.

2. STUDY FRAMEWORK

The framework reflects that traffic control scheme is affected probabilistically under weather
forecast, and that the provided traffic service varies probabilistically under traffic control. Traffic demand is also formulated as the probabilistic density function of travelled speed. The focused greater area is composed of many prefectural divisions and the weather forecast information is provided for every division or more divided fine division. Thus the framework has a structure that input is the distribution of weather forecast for the focused area and outputs are travel time reliability, i.e. the expected probability distribution function of travel time and the probability of availability between a pair of nodes.

Desired study framework should have the study structure that the input is the weather forecast and the output is the travel time reliability and the availability of traffic service. This study flow is demonstrated in Figure 1.

This study consists of the following sub topics:
1) the definition of travel time reliability and its significance,
2) the state of the traffic controls (i.e. regulations) such as “highway closed”, “snowplow operation”, and some kinds of “speed limitation” and available weather information,
3) the relationship between actually introduced traffic control and weather condition,
4) estimation of probability for each traffic control implementation under categorised snowfall probability,
5) consideration of dependent events of traffic control between adjacent highway sections,
6) formulation of vehicles speed distribution on the expressway under each traffic control through observation and estimation.
7) the overall procedure for calculating travel time reliability.

![Figure 1. Study Framework from “Snow Fall” to “Travel Time Reliability”](image-url)
3. PROBABILITY OF SNOWFALL AND TRAFFIC REGULATION

The traffic control on the expressway is carried out according to the actual weather, not to the weather forecast. However, the purpose of this study is to develop the estimating (normative) model not only for assessing existing network performance, but also for evaluating many alternatives such as a new route construction and its routing, and strategies of snow removing investment. Thus, the relationship between traffic control and weather forecast is used for the reliability analysis.

For example, Japan Highway Public Corporation applies five types of traffic control under snowfall environment: 1) “highway closed”, 2) “snowplough operation”, 3) 50 km/h speed regulation, 4) 80 km/h speed regulation, and 5) no regulation. “Snowplough operation” means that paralleled snowploughs remove snow at 50 km/h speed on each lane and vehicles follow them. These control schemes depend on the weather.

In this study, these control schemes and weather forecast are treated as discrete valuables. Here, the realized probability for traffic control level is defined as a conditional probability:

\[ p_{a,rj|wi} = \text{Prob(control level is } j \text{ on link } a \text{ | weather forecast is } i \), \]

where \( j \) is the traffic control level, and \( i \) is the snowfall probability of aggregated weather forecast.

4. TRAVEL TIME RELIABILITY

Let \( h_{a,rj}(t) \) be a probability density function of travel time at control level \( j \) on link \( a \), probability distribution function \( H_{a,rj}(t) \) is obtained as

\[ H_{a,rj}(t) = \int_0^t h_{a,rj}(t)dt . \]

Parameters for \( h_{a,rj}(t) \) are obtained by survey travelling including for maximum speed, minimum speed, and space mean speed under normal condition, and the obtained probability density functions of speed and travel time are tested by chi-square test.

Expected probability distribution function \( H_a(t) \) is given as

\[ H_a(t) = \sum_j p_{a,rj|wi} H_{a,ri} . \]
The overall travel time reliability is obtained by the composition of probability distribution functions of travel time along the route. In this procedure, dependency of traffic condition between adjacent highway sections can be considered.

This framework is applied to the expressway network between Nagoya and Osaka, two major cities in Japan. One of the route lengths is 188.6 km for Meishin route. Travel time reliabilities are calculated for several routes, and normal / abnormal period.

5. EXAMPLE OF CASE STUDY RESULTS

One of the case studies is shown in Table 1, 2 and Figure 2. Under the snowfall probability in Table 1, the availability between Nagoya and Osaka is calculated as Table 2. The probability distribution function for travel time is shown in Figure 1. This figure suggests that the Meishin route (one of the routes with the heaviest traffic in Japan) that located in the heavy snowfall area is much affected by the snowfall.

This framework can be employed for the benefit analysis of new route construction and snow removing facilities such as road heating.

<table>
<thead>
<tr>
<th>Weather Forecast District</th>
<th>Probability of Snowfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aichi Prefecture</td>
<td>0-20%</td>
</tr>
<tr>
<td>Gifu Prefecture</td>
<td>30-50%</td>
</tr>
<tr>
<td>Shiga Prefecture (North)</td>
<td>60-100%</td>
</tr>
<tr>
<td>Shiga Prefecture (South)</td>
<td>0-20%</td>
</tr>
<tr>
<td>Kyoto Prefecture (South)</td>
<td>0-20%</td>
</tr>
<tr>
<td>Mie Prefecture (North)</td>
<td>0-20%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Availability</th>
<th>Probability of &quot;Closed&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meishin Route</td>
<td>67.27%</td>
</tr>
<tr>
<td>Meihan Route</td>
<td>84.33%</td>
</tr>
<tr>
<td>2nd Meishin Route</td>
<td>82.87%</td>
</tr>
</tbody>
</table>
6. CONCLUSION

(1) This paper proposed the framework for assessing travel time reliability under uncertain environment of snowfall and traffic regulation.

(2) The model structure is as follows:
   (a) Input is weather forecast data.
   (b) Output is the Travel Time Reliability, and the probability of service closure.

(3) Two kinds of Inter-Dependency are considered.
   (a) Regulation between adjacent links is considered as “Grouping Links of the same regulation”, approximately, using correlation table of traffic regulation.
   (b) Inter-Dependency of traffic condition is treated using inverse travel time distribution function.

(4) Proposed framework is applied to the new route that runs through different area of snow fall.

(5) This framework is also applied to
   (a) towards the socio-economic,
   (b) provision of travel time information to the drivers,
   (c) the effect of snowfall snow removing facilities such as road heating.