Estimating benefits by improving the reliability on travel times

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Abstract

This paper presents a probabilistic model for estimating benefits by improving the reliability on travel times. Normally road network planners only consider benefits of decreasing travel times by constructing new expressways in estimating time related economic benefits. However, it has become more important to evaluate the reliability of road networks since there are increasing needs to reduce the risk of arriving late at the destination. The model incorporates the probabilistic characteristics of travel times associated with the designated arriving time. An example of applying the model to the Kyoto-Osaka area is also demonstrated.

1 Introduction

The reliability of road network has become more important, since the time value of people increased in business and other activities. There are three types of reliability of road network; connectivity reliability, time reliability and capacity reliability (Bell and Cassir [1]). This paper focuses on the time reliability of network that is related to the uncertainty of travel times within the network.

Normally constructing new road or implementing transport demand management measures can reduce the travel times. The benefits generated by the reduction of
travel times are estimated in the traffic planning. However, the measures can contribute to decrease the variation of travel times as well as the reduction of mean travel times. This leads to the reduction of risk to arrive late at the destination, which is beneficial to drivers. This type of benefits should be incorporated in estimating economic benefits by implementing some measures for improving the road traffic conditions. It becomes essential in information oriented society, since the trips on road network increasingly associated with the designated arrival time. Typical example can be seen in the Just-In-Time delivery system for freight transport.

Some researchers presented models for identifying the optimal starting time and route of a driver by minimising the travel cost under the uncertainty of travel times (e.g. Hall [2], Chang and Mahmassani [3], Ben-Akiva [4]). This paper presents a probabilistic methodology for estimating benefits by improving the reliability on travel times generated by some measures including new road construction and regulating traffic flow.

2 Methodology

2.1 Overview

The method employs modelling the drivers' behaviour to minimise their disutility due to delay at the destination. It is assumed that drivers have the designated time for arriving at the destination. If they arrived late, the penalty cost would be incurred and if they arrived earlier, they had to wait until the designated time and also the time cost would be incurred. The model involves finding the optimal starting time of travel and optimal route for drivers by minimising the disutility. It incorporates the probabilistic characteristics of travel times that can be provided by the traffic simulation.

2.2 Adjustment of starting time of a driver

First, a model can be formulated for the adjustment of starting time of a driver to minimise the expected disutility with the probabilistic variation of travel times. A simple one link with one-OD is taken. It is assumed as follows for modelling:

(a) The recurrent traffic behaviour of a driver is modelled such as commuting
(b) The designated arrival time is fixed
(c) Penalty is incurred for delay arrival at the destination
(d) Time cost is incurred for waiting in early arrival at the destination
(e) A driver fully recognises the distribution of travel times (mean and variation) of the route he/she uses
(f) The distribution of travel times do not change during the driver travels
Under these conditions, let us formulate a model for identifying the optimal starting time of a driver considering the reliability of travel times. Suppose that the probability density function \( f(t) \) of travel time \( t \) for each link can be given. Assume that a driver starts the origin at time \( t_0 \) and arrives at the destination at time \( t' \). If the driver arrives later at the destination than the designated time \( t_d \), the penalty would be incurred. If the driver arrives earlier at the destination than the designated time \( t_d \), the time cost would be incurred. The cost \( C_p(t', t_0) \) relating to the delay and early arrival penalty can be expressed by the following equation.

\[
C_p(t', t_0) = \begin{cases} 
(t_d - t') \cdot c_f & \text{if } t' \leq t_d \\
(t' - t_d) \cdot c_d & \text{if } t' > t_d 
\end{cases}
\]  

(1)

where,

\( c_f \): coefficient for time cost due to early arrival (yen/min.)

\( c_d \): coefficient for delay penalty (yen/min.)

The cost \( C_m \) incurred by increasing the travel time in moving from the origin to the destination can be represented by

\[
C_m = \int_{-\infty}^{+\infty} c_m \cdot t \cdot f(t) \, dt \\
= c_m \cdot E(f(t))
\]  

(2)

where,

\( c_m \): coefficient for time cost due to the increase of travel time (yen/min.)

Then the expected disutility (or cost) can be expressed by the sum of the penalty cost and travelling cost. (Figure 1)

\[
EDU(t_0) = \int_{-\infty}^{+t_0} c_f \{t_d - (t_0 + t)\} f(t) \, dt + \int_{t_0}^{+\infty} c_d \{t_0 + t - t_d\} f(t) \, dt + C_m
\]  

(3)

Note that the arriving time \( t' \) can be replaced by \( t' = t_0 + t \), where \( t_0 \) and \( t \) represent the starting time and travel time, respectively.
The optimal starting time $t^*_0$ can be identified by minimising the expected disutility of equation (3).

$$t^*_0 = \min_{t_0} EDU$$ (4)

If the distribution of travel times and the coefficients for various costs are given, the optimal starting time can be determined using equations (1) – (4).

Figure 1: Identification of expected disutility using the distribution of travel times and penalty function
2.3 Starting time and route choice model for commuters

The model described in the previous section can be extended to one-OD and multiple link network. The extended model can simultaneously identify the optimal starting time and optimal route for a driver. As this study deals with commuters by private cars, the commuting path can be selected from a limited number of paths on the road network. The procedure for identifying the optimal solution is as follows.

(a) Estimate the distribution of travel times of the past days until the previous day for a number of designated paths using dynamic traffic simulation
(b) Calculate the minimum expected disutility by equation (3) for each path with the distribution of travel times, the coefficients for costs and the designated time for arrival
(c) Select the path that indicates the minimum value of expected disutility
(d) The starting time of the selected path gives the starting time of the day for the driver

This procedure contains the day-to-day choice of the starting time and path of a driver. A driver is not expected to change the path during travelling.

2.4 Dynamic traffic simulation model

The dynamic traffic simulation model is based on a BOX model that was originally developed by Fujii et al. [5]. The BOX model is essentially a macroscopic model but because the origin and destination of each vehicle is defined, it is actually a hybrid macroscopic/microscopic model. Vehicles are assumed to choose the shortest path when they arrive at a node using an estimated average travel time. The BOX model consists of two components, flow simulation and route choice simulation as shown in Figure 2. A sequence of boxes is used to represent each link. Groups of vehicles flowing out of a box and into the next box during the scanning interval represent the flow on links. There are two assumptions for modelling links; (a) the maximum flow during a scanning interval is the same for all sections on links, (b) no inflow and outflow is allowed in the middle of links. A consequence of assumption (a) is that only the last section of a link can be a bottleneck, where a congestion queue starts. Two states of flow; congested flow and free flow are represented.

In this study two types of drivers are taken: commuting drivers and other drivers. The commuting drivers are to choose the starting time and route using the starting time and route choice model for commuters that was described in section 2.3. To identify the optimal starting time and route, a commuting driver should recognise the distribution of travel times for each path. The distribution of travel times can be estimated by collecting the travel times for a path at an interval of
one minute that is provided by flow simulation of BOX model. Other drivers are to choose the shortest route when arriving at each node of network. This procedure is included in the BOX model.

![Diagram](image)

**Figure 2: Structure of BOX model**

### 2.5 Evaluation index of benefits by improving reliability on travel times

There are four evaluation indices relating to the benefits by reducing the travel times and improving the reliability on travel times:

(a) Expected disutility for early arrival and delay
(b) Expected travel time cost
(c) Real disutility for early arrival and delay
(d) Real travel time cost

Figure 3 shows these indices. The expected disutility for early arrival and delay and the expected travel time cost were already given by equations (3) and (2), respectively. The real disutility for early arrival and delay can be expressed by

\[ RDU(t) = c|t_a - t_d| \]  

(5)
where,
\[ c = \begin{cases} 
  c_d & (t_d \leq t_a) \\
  c_f & (t_d > t_a) 
\end{cases} \]  
(6)

\( t_a \): real arriving time

![Diagram of travel times](image)

Figure 3: Evaluation indices for benefits by improving the reliability on travel times

The real travel time cost \( C_m' \) can be represented by

\[ C_m' = c_m(t_a - t_0) \]  
(7)

This study takes (c) the real disutility for early arrival and delay and (d) the real travel time cost as indices for evaluating benefits by improving the reliability on travel times and benefits by reducing the travel times, respectively.
3 Case study

The model described in the previous section was applied to the real road network of Kyoto-Osaka area for evaluating benefits for commuters by building new expressways.

![Road network in Kyoto-Osaka area after constructing 2nd Keihan Expressway and other expressways](image)

Figure 4: Road network in Kyoto-Osaka area after constructing 2nd Keihan Expressway and other expressways
Figure 4 shows the future road network of Kyoto-Osaka area in 2010 that was used for the simulation study. The 2nd Keihan Expressway is now under construction. Benefits of constructing this new expressway and other new expressways, which are indicated by dotted line in Figure 4, were evaluated in terms of the reduction of travel times and improvement of the reliability on travel times.

The O-D matrix data were given based on the road traffic census in 1994. The total traffic volume in this region in 2010 was assumed to be 1.5 times of that in 1994. The coefficients required for the calculation was assumed as shown in Table 1.

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Value (yen/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_d$</td>
<td>300</td>
</tr>
<tr>
<td>$c_f$</td>
<td>30</td>
</tr>
<tr>
<td>$c_m$</td>
<td>65</td>
</tr>
</tbody>
</table>

We considered commuting drivers (1700 vehicles) who go to Hirakata from Kyoto (see Figure 4). The designated time for arriving at Hirakata was assumed to be 9:00 a.m. Typical three paths were taken for the candidate paths that drivers may choose.

Table 2 shows an example of the results of estimating benefits. Two cases are taken:

Case 1: 2nd Keihan Expressway and other expressways shown by dotted line in Figure 4 were constructed.

Case 2: Case 1 plus reducing the capacity of national highway route 1 near Hirakata by 50% due to traffic impediment

<table>
<thead>
<tr>
<th>Case</th>
<th>Benefits by improving reliability on travel times (yen/day)</th>
<th>Benefits by reducing travel times (yen/day)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>347,723</td>
<td>6,786,936</td>
<td>5.1</td>
</tr>
<tr>
<td>2</td>
<td>594,176</td>
<td>4,069,649</td>
<td>14.6</td>
</tr>
</tbody>
</table>
In case 1 benefits by improving reliability on travel times by building new expressways are estimated about 5% of the benefits by reducing travel times. Improving the reliability on travel times increased the percentage of benefits to 14.6% in case 2 in which the traffic condition was more uncertain. This demonstrates the importance of alternative route to allow drivers to avoid the traffic impediment.

4 Conclusions

This paper presented a model for estimating the benefits by improving the reliability on travel times within road network. The model takes into account the probabilistic characteristics of travel times. The model was applied to the road network in Kyoto-Osaka area. The result indicated that the benefits by improving the reliability of travel times by building new expressways are relatively small compared with the benefits by reducing the travel time itself. However, it can be increased if the traffic impediment often generates heavy congestion on existing highways.

References