Simulation Analysis of Truck Automated Lanes on Intercity Expressways

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Background

Freight transportation

Dominant mode of intercity goods movement

Will keep playing an important role in the near future

However, many problems are also increasing

- Environment
- Accident
- Delay
- Labor force

*New transportation system is desired*

Truck automated lanes
Background

Truck automated lanes

• Dedicated lanes for freight traffic on intercity expressways
• Unmanned or manned control with ICT
• Effective use of lane by platooning

Dedicated lane (Ishizawa, 2006)
Investigation of change in whole road network

By using network data and OD demand

Objective

Previous studies including Nishida, et al. (1998) and Ishizawa (2006)

Examined the effects of truck automated lanes on New Tomei-Meishin Expressway

Assuming a fixed demand on the expressway

Not considered

Induced demand from other routes
Change in the traffic flow of whole road network
Study flow

- Link performance data
- OD demand data

Estimation of link performance function considering mixed traffic

Future dynamic OD demand

Future network data (truck automated lanes)

Dynamic traffic simulator

Examine the change in network flow by introducing truck automated lanes (Total traffic volume, speed, truck volume)
Estimation of link performance function

k-v function (density - speed)

- Non-linear model based on car-following theory by Gazis (1961)

\[ v = v_f \exp \left[ -\alpha \left( \frac{k_p}{C} \right)^{\frac{1}{l-1}} \right] \]

- \( k \) : density (veh./km)
- \( C \) : capacity
- \( v_f \) : free flow speed
- \( \alpha, l \) : parameters

PCE (passenger car equivalence)

\[ k_p = PCE \cdot k_T \]

\[ k_p = (1 - P) \cdot k_M + PCE \cdot P \cdot k_M \]

- \( k_M \) : density of mixed traffic
- \( P \) : truck ratio
Estimation of link performance function

**k-v function (density - speed)**

- Non-linear model based on car-following theory by Gazis (1961)

\[
v = v_f \exp \left[ -\alpha \left( \frac{k_P}{C} \right)^{l-1} \right]
\]

- Assumption: passenger car and truck have the same speed (Huber, 1982; Okura, et al., 1991)

\[
v = v_f \exp \left[ -\alpha \left( \frac{(1-P) \cdot k_M + P \cdot C \cdot P \cdot k_M}{C} \right)^{l-1} \right]
\]

Simultaneous estimation of \( v_f, \alpha, l, PCE \)

- \( k \): density (veh./km)
- \( C \): capacity
- \( v_f \): free flow speed
- \( \alpha, l \): parameters
- \( k_M \): density of mixed traffic
- \( P \): truck ratio
Link performance data

Road traffic census data
Year: 1997, 1999, 2005
Area: Aichi, Gifu, Mie, Shizuoka, Nagano

Traffic speed at peak hour
Density/Capacity

Speed decrease by truck is not obvious
Estimation results of link performance function

\[ v = f(k) = f((1 - P) \cdot k_M + PCE \cdot P \cdot k_M) \]

\[ f(k) = v_f \exp\left[-\alpha \left(\frac{k}{C}\right)^{l-1}\right] \]

<table>
<thead>
<tr>
<th>Free flow speed ( v_f ) (km/min)</th>
<th>( \alpha )</th>
<th>( l )</th>
<th>PCE</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expressway</td>
<td>1.032 + 0.283*speed limit (km/h)</td>
<td>0.217</td>
<td>2.616</td>
<td>1.733</td>
</tr>
<tr>
<td>Surface road (3+ lanes)</td>
<td>0.952</td>
<td>0.767</td>
<td>1.492</td>
<td>No good</td>
</tr>
<tr>
<td>Surface road (2 lanes)</td>
<td>0.756</td>
<td>0.339</td>
<td>1.654</td>
<td>No good</td>
</tr>
</tbody>
</table>

PCE at expressway is estimated at 1.73

Consistent to the literature

PCE could not be estimated for surface roads

Might be difficult to estimate with sample including various types of roads
Development of future OD demand

Current OD: Road traffic census OD data 1999

Future OD: OD data at 2030 by MLIT

→ Adjusted for target year 2020
  (New Tomei-Meishin expressway begins operation)

Distribution of current dynamic demand for each OD pair is applied to obtain future dynamic OD demand.
Future network data

Current network data  used for validation of simulation

Future network data  Year 2030 data by MLIT

→ Adjusted for year 2020

Network at 2020
**Dynamic traffic simulator**

**Meso-scopic**: One packet for 5 vehicles for each vehicle class

**Route choice**: dynamic user optimum → myopic link choice

**Congestion**: Point-queue + link capacity → spill back

**Vehicle movement**: Periodic scanning → 15 second time step

**Vehicle class**: passenger car, truck

**Value of time**: 68.7JPY/min. for passenger car

87.4JPY/min. for truck

**PCE**: 1.73 for both expressway and surface road
Validation of simulator

Observed and estimated link traffic volume

using OD demand data at 1999 and network data at 1999

Observed volume (veh./day)

Estimated volume (veh./day)

Total

Correlation coefficient: 0.773

Tomei-Meishin expressway

Not biased at expressway
Assumption for truck automated lanes

- **Lanes**: 2 lanes of 6 lanes at New Tomei-Meishin Expressway
- **Vehicle length**: 13.5m (Ishizaka, 2006)
- **Headway**: 13.5m
- **Speed**: 100km/h (Nishida et al. (1998): 100km/h, Ishizaka (2006): 110km)
  - Speed decrease is not considered up to the capacity
- **Capacity**:
  \[ C_{a,t} = 100 \times \left( \frac{1000}{27.0} \right) = 3703.7 \text{ (Veh./h)} \]

\[ \begin{array}{ccc}
\text{Capacity} & \nu & k \\
(\text{Veh./h}) & (\text{km/h}) & (\text{Veh./km})
\end{array} \]

Operation at on/off ramp is not considered in simulation
### Scenarios for New Tomei-Meishin Expressway

<table>
<thead>
<tr>
<th>Case</th>
<th>Normal lanes</th>
<th>Truck automated lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lanes</td>
<td>Speed limit</td>
</tr>
<tr>
<td>Base</td>
<td>4～6</td>
<td>100km/h</td>
</tr>
<tr>
<td>Case 1</td>
<td>6</td>
<td>100km/h</td>
</tr>
<tr>
<td>Case 2</td>
<td>6</td>
<td>120km/h</td>
</tr>
<tr>
<td>Case 3</td>
<td>4</td>
<td>100km/h</td>
</tr>
</tbody>
</table>
Truck ratio at base case

• High truck ratio at New Tomei-Meishin Exp.
• Change in Old Tomei-Meishin Exp. is small
Change in traffic volume compared to base case

Case 1: 6 lanes 100km/h

Case 2: 6 lanes 120km/h

Increase in speed to 120km/h (Case 2) → Induced demand from Chuo Exp.

Induced demand by automated truck lanes at the same level

Case 4: 4 lanes 100km/h + 2 truck automated lanes

※Normal lanes are shown for New Tomei-Meishin exp. in figure
Change in speed compared to base case

Case 1: 6 lanes 100km/h

Case 2: 6 lanes 120km/h

Nagoya JCT has speed decrease because of increased truck volume.

Increase in speed on other links is not significant.

Case 2 & 3 have the same speed increase for passenger car.

Nagoya JCT has speed decrease because of increased truck volume.

Case 3: 4 lanes 100km/h + 2 automated truck lanes

※ Normal lanes are shown for New Tomei-Meishin exp. in figure.
Change in truck ratio compared to base case

Case 1: 6 lanes 100km/h
Case 2: 6 lanes 120km/h
Case 3: 4 lanes 100km/h + 2 automated truck lanes

Significant decrease in truck ratio at normal lanes in Case 3

*Normal lanes are shown for New Tomei-Meishin exp. in figure
*Only expressways are shown in figures
## Comparison of vehicle-hours and benefit

### <Vehicle-hours>

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Tomei-Meishin</th>
<th>New Tomei-Meishin</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>6094</td>
<td>--</td>
<td>319</td>
<td>356</td>
</tr>
<tr>
<td>Case 1 (6 lanes 100km/h)</td>
<td>6075</td>
<td>-19</td>
<td>289</td>
<td>384</td>
</tr>
<tr>
<td>Case 2 (6 lanes 120km/h)</td>
<td>6044</td>
<td>-50</td>
<td>261</td>
<td>411</td>
</tr>
<tr>
<td>Case 3 (4 lanes + 2 truck automated lanes)</td>
<td>6055</td>
<td>-39</td>
<td>256</td>
<td>413</td>
</tr>
</tbody>
</table>

※Unit: 1000 veh. hour

- The size of decrease in veh.-hrs. is Case 2 > Case 3 > Case 1
- Decrease in veh.-hrs. is significant at routes other than New Tomei-Meishin Exp.

### <Benefit>

<table>
<thead>
<tr>
<th></th>
<th>Travel time decrease (100MJPY/Yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1 (6 lanes 100km/h)</td>
<td>340</td>
</tr>
<tr>
<td>Case 2 (6 lanes 120km/h)</td>
<td>884</td>
</tr>
<tr>
<td>Case 3 (4 lanes + 2 truck automated lanes)</td>
<td>706</td>
</tr>
</tbody>
</table>

Automated truck lanes doubles the benefit
Conclusion

- Introducing truck automated lanes has a better effect than mixed use of lanes in terms of veh.-hrs.
- Introducing truck automated lanes into New Tomei-Meishin Exp. causes significant flow change in whole networks → Assumption of fixed demand was not realistic

Future tasks

- Estimation of different speed in mixed traffic for each vehicle class
- Improvement of simulator including realistic route choice
- Estimation of CO2 reduction considering platoon effect