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# Redesigning Road Network in the Era of Decreasing Population by Traffic Simulation

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## Abstract

In light of an aging society in which the number of expressway users declines while infrastructure maintenance costs remain high, we propose a new method for evaluating whether expressway routes should be closed when their cost-benefit ratios become unfavorable owing to reduced usage. Moreover, we conducted a case study in which this method was applied to analyze the Kawasaki route (Kanagawa No. 6, Kawasaki route, a metropolitan expressway in Japan). The analysis results projected the cost-benefit ratio of this route to fall below 1 by 2025 owing to the reduced number of users. However, closing the Kawasaki route would lead to significant congestion on its alternative route, National Route 409. Restoring the congestion rate of National Route 409 to its previous level requires its expansion to 10 lanes, making the closure of the Kawasaki route impractical.
*Keywords*: road network, cost-benefit analysis, congestion, traffic simulation

## 1 Introduction

The decline in Japan's population has affected various economic activities, including a reduction in expressway users. This decrease may result in lower toll revenue for expressway operators. For example, in the fiscal year 2020, Metropolitan Expressway Co., Ltd. [1] reported operating revenues and expenses of 498.3 billion yen and 497.7 billion yen, respectively. The costs of new road construction were transferred to the Japan Expressway Holding and Debt Repayment Agency. Revenue from completed road assets was recorded as operating revenue and their costs as operating expenses (234.5 billion yen). Excluding these, the operating revenue was 263.8 billion yen and the operating expense was 263.2 billion yen. Toll revenue, amounting to 263.5 billion yen, comprised approximately the entire operating revenue. From the operating expenses, 190.1 billion yen were allocated for road asset rent payments (to cover construction costs) and 72.9 billion yen for expressway management, accounting for 72.2% and 27.6% of the expenses, respectively. Toll revenue is generally intended to cover repayment and maintenance costs incurred during road construction. The other expressway companies have similar profit structures.

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Therefore, if toll revenues decrease, maintenance costs can surpass income, potentially necessitating the closure of expressways [1]. However, expressways serve the public interest and are crucial for daily life and logistics. Therefore, their closure should be carefully considered, weighing user benefits as well as costs.

This study introduces a new method for evaluating whether expressway routes should be closed in the context of a shrinking population and decreasing number of users. The proposed method involves a comparison of maintenance and management costs, considering user benefits. If future benefits are found to be lower than the costs, route closure is considered. Potential congestion on alternative routes following closure was assessed through simulations.

The remainder of this paper is structured as follows. Section 2 reviews related research, Section 3 outlines the analysis objectives of this study, Section 4 explains the analysis method, Section 5 presents the analysis results, and Section 6 summarizes the findings. This study extends our previous conference paper [2].

## 2 Related Work

Analyzing a road in terms of costs (such as construction and maintenance) and benefits to users is known as a cost-benefit analysis. As demonstrated in [3-8], cost-benefit analyses are commonly employed in decisions about new road construction and in evaluating existing road projects.

Some studies have extended the traditional cost-benefit analysis methods. For instance, in [9-11], cost-benefit analyses were conducted considering the environmental impacts. Another study retrospectively evaluated road construction projects using a cost-benefit analysis. The studies in [12-14] compared the results of cost-benefit analyses before and after the operation of routes. Although these studies used cost-benefit analysis to evaluate both new and existing roads, they did not consider route abolition based on their analysis results.

To assess the closure of expressways, it is essential to consider the impacts of such closures in addition to performing cost-benefit analyses. The most significant effect is the traffic congestion on nearby roads. When a particular road becomes congested, vehicles diverting to alternative routes can cause congestion on the surrounding roads.

Several studies focused on traffic congestion. In particular, [15] analyzed the causes of traffic congestion, and [16] examined methods for reducing congestion on expressways. [17] introduced a macroscopic fundamental diagram (MFD) as an index for measuring congestion, with the horizontal axis representing the average density of vehicles in a road section and the vertical axis representing the average traffic volume in the same section. Generally, traffic volume increases with density; however, once a road is congested, traffic volume decreases as density increases. Studies [18] and [19] utilized MFDs to analyze urban road networks. Additionally, [20] evaluated traffic congestion using an MFD that included both expressways and general roads.

# 3 Purpose of Analysis

As Japan's population shrinks, the number of expressway users is also expected to decline. This reduction in users will inevitably lead to decreased toll revenue for expressways, necessitating the consideration of potential route abolitions in the future. We chose a specific expressway route as a case study, conducted a cost-benefit analysis under conditions of reduced traffic volume, and investigated the possibility of abolishing this route based on our findings. As mentioned earlier, abolishing one expressway route is expected to cause congestion on neighboring roads. Therefore, we assessed the congestion levels on surrounding roads to evaluate the potential impact.

# 4 Research Methodology

## 4.1 Methodology

The analytical approach employed in this study is illustrated in Figure 1. First, a road network was constructed using a traffic simulator. Subsequently, a specific route was selected for analysis, and a cost-benefit assessment was conducted under conditions of reduced user traffic on that route. The analysis aimed to determine whether the projected cost-benefit ratio would fall below 1 in the future. Typically, this ratio is computed by dividing benefits by costs. If the ratio is less than 1, it indicates that the benefits do not outweigh the costs, prompting the consideration of route abolition.

When considering route abolition, it is crucial to identify alternative routes for vehicles that currently use the target route. Origin-destination (OD) data, which recorded the start and end points of vehicle trips without intermediary stops, were utilized. To ascertain the routes taken by the vehicles, a traffic simulator was employed because the OD data did not include intermediate stops. Vehicles traveling along the target route were identified using this process. Subsequently, the target route was removed from the map of the simulation model, and another simulation was conducted to identify alternative routes for these vehicles.

Through simulation, the congestion levels on alternative routes were estimated. Consequently, the effect of route abolition was evaluated in terms of congestion. Additionally, if congestion rates were projected to increase, we considered measures to restore congestion levels to those observed prior to the abolition of the route.

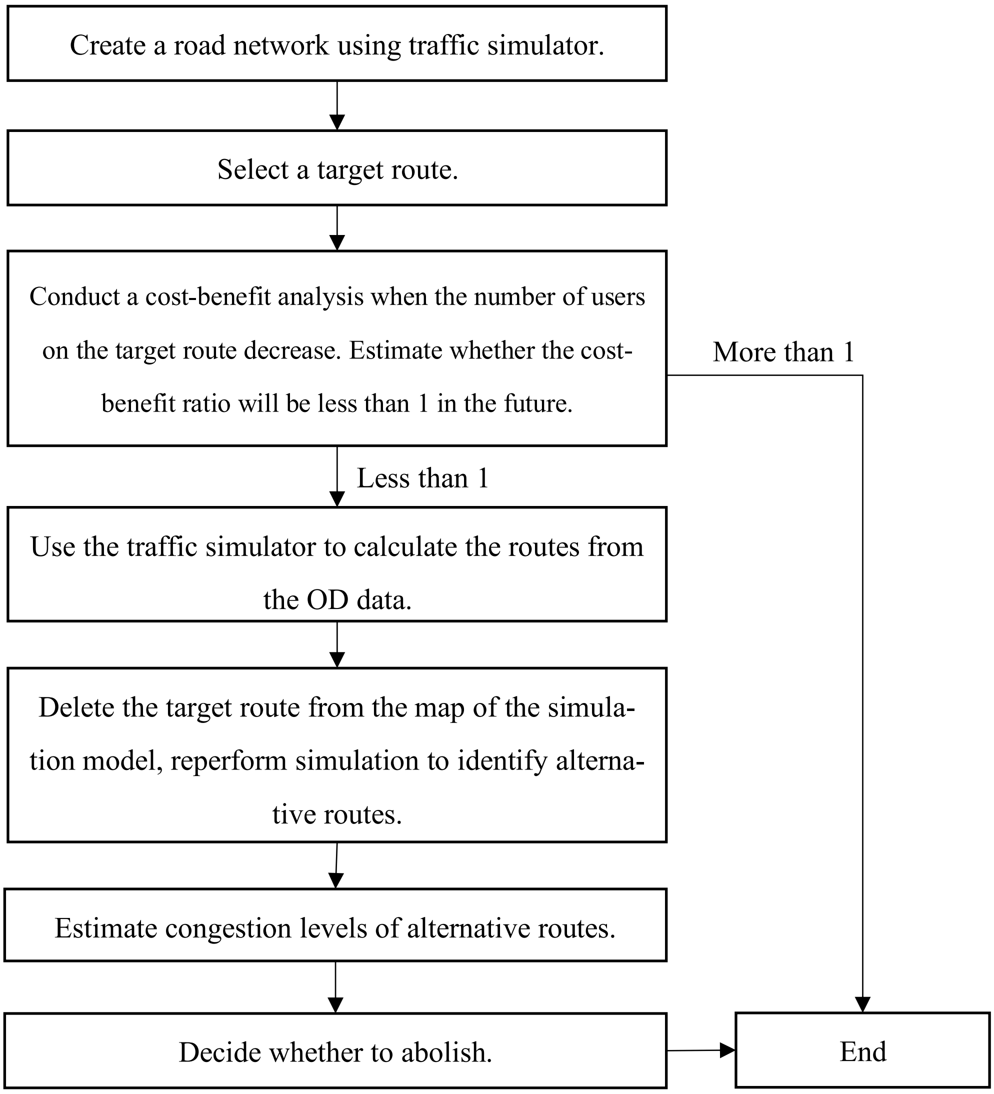


Figure 1: Research Methodology.

## 4.2 Cost-benefit ratio

The cost–benefit ratios for the target routes were calculated according to [21], which is published by the Ministry of Land, Infrastructure, Transport, and Tourism. The cost-benefit analysis is based on a certain year, and the benefits and costs are calculated for cases with and without the existence of the target routes as follows:

The benefits are as follows: (A) shortened travel times, (B) reduced running costs, and (C) reduced traffic accidents. The sum of these benefits is called the total benefit.

In addition, the sum of (D), the project cost required for road construction, and (E), the cost required for road maintenance, is called the total cost.

The equations for (A), (B), and (C) are as follows: $i$ denotes the state of existence or non-existence of a road using two symbols: $W$, indicating its existence, and $O$, indicating its non-existence. $l$ denotes a link and $j$ denotes a vehicle type.

(A): Benefits of shortened travel times

Benefit of reduced travel time: $BT = BT_O - BT_w$

Total travel time cost: $BT_i = 365 \sum_j \sum_l (Q_{ijl} T_{ijl} \alpha_j)$

$BT$: Benefit of shortened travel time over one year.

$BT_i$: Total travel time cost per year for existence $i$.

$Q_{ijl}$: Traffic volume per day of vehicle type $j$ for link $l$ and existence $i$.

$T_{ijl}$: Travel time (min) per day of vehicle type $j$ for link $l$ and existence $i$.

$\alpha_j$: Time value of a vehicle of type $j$ per min, as defined in Table 1.

Table 1: Time value basic unit by vehicle type $\alpha_j$.

| Vehicle Type | Time Value |
|---|---|
| Passenger Car | 40.10 |
| Bus | 374.27 |
| Small Freight Car | 47.91 |
| Ordinary Freight Car | 64.18 |

(B) Benefits of reduced running costs

Benefits of reduced running costs: $BR = BR_O - BR_w$

Total running cost: $BR_i = 365 \sum_j \sum_l (Q_{ijl} L_l \beta_j)$

$BR$: Benefits of reduced running expenses.

$BR_i$: Total running cost for existence $i$.

$Q_{ijl}$: Traffic volume per day of vehicle type $j$ for link $l$ and existence $i$.

$L_l$: Length (km) of link $l$.

$\beta_j$: Driving cost of a vehicle of type $j$ as defined in Table 2; the unit is the cost per vehicle km.

Table 2: Driving cost of vehicle type $j$ ($\beta_j$).

| Speed (km/h) | Passenger Car | Bus | Small Freight Car | Ordinary Freight Car |
|---|---|---|---|---|
| 30 | 11.00 | 41.19 | 15.04 | 35.25 |
| 35 | 10.51 | 39.88 | 14.55 | 33.22 |
| 40 | 10.15 | 38.85 | 14.14 | 31.50 |
| 45 | 9.87 | 38.05 | 13.82 | 30.11 |
| 50 | 9.67 | 37.46 | 13.58 | 29.04 |
| 55 | 9.54 | 37.08 | 13.41 | 28.28 |
| 60 | 9.46 | 36.90 | 13.32 | 27.85 |
| 65 | 9.44 | 36.91 | 13.30 | 27.75 |
| 70 | 9.47 | 37.10 | 13.35 | 27.97 |
| 75 | 9.55 | 37.49 | 13.48 | 28.52 |
| 80 | 9.69 | 38.08 | 13.69 | 29.41 |
| 85 | 9.89 | 38.86 | 13.97 | 30.65 |
| 90 | 10.15 | 39.84 | 14.34 | 32.25 |

(C) Benefit of reduced traffic accidents

Benefit of reduced total annual accidents: $BA = BA_O - BA_w$

Social loss of traffic accidents for existence $i$: $BA_i = \sum_l AA_{il}$

$AA_{il}$: Social loss of traffic accidents for link $l$ and existence $i$, calculated as

$AA_{il} = 360Q_{il}L_l$.

$Q_{il}$: Traffic volume per day for link $l$ and existence $i$.

$L_l$: Length of link $l$.

$BA_i$ is assumed to be the same as the annual traffic volume for links $l$ and existence $i$.

The project cost for road construction (D) includes construction, land, security, and indirect costs. In addition, the costs required for road maintenance (E) include those for the inspection and repair of road structures such as bridges and tunnels, patrols and cleaning, and snow removal.

Assuming that the total benefits and costs obtained using (A)–(D) continue for 50 years from the time of evaluation, these values are calculated with a social discount rate of 4% for discounting the present value. Then, the present value of the total benefits is divided by the present value of the total costs to obtain the cost-benefit ratio. In this study, the data for the target route were based on [22]. In addition, it was assumed that traffic volume would change at the same rate as the population decline in Japan since 2005. It is estimated that the number of vehicles will decrease because the number of road users and logistics needs will decrease as the population decreases. Road abolition was considered when the cost-benefit ratio of the target route fell below 1.

### 4.3 Congestion rate

If a route is closed, it is expected that vehicles using this route will divert to surrounding roads. Therefore, we examined how the congestion levels on these alternative routes changed depending on whether the target route was closed. The congestion rate was determined by dividing the traffic volume on the target route by the traffic capacity. Furthermore, if closing the target route increases congestion on surrounding roads, measures to mitigate congestion are necessary. This analysis considered expanding the number of lanes on the surrounding roads. Increasing the number of lanes increases the traffic capacity, thereby reducing congestion rates. Hence, we calculated the additional number of lanes required to return the congestion levels to those observed before the closure of the target route.

## 5 Results

### 5.1 Road network

MATSim [23] was used as a traffic simulator with Simunto Via [24]. MATSim is an open-source mesoscopic traffic simulator, and Simunto Via is an analysis and visualization tool for MATSim. We used MATSim to read OpenStreetMap to obtain information such as the coordinates of the nodes on the expressway and main road, the number of lanes, and the maximum speed of the links connecting the nodes. Subsequently, a road network was created using this information. We used the area surrounded by latitude 35.801711 and longitude 139.657827 in the northwest and latitude 35.541027 and longitude 139.881277 in the southeast of OpenStreetMap to create the road network, as shown in Figure 2.

Figure 2: Road network obtained using MATSim.

### 5.2 Selection of target routes

Metropolitan Expressway Co., Ltd. published the results of business evaluations for certain routes and the corresponding cost-benefit ratios from cost-benefit analyses. Table 3 shows the cost-benefit ratios for certain routes. The cost-benefit ratio of the Metropolitan Expressway Kanagawa No. 6 Kawasaki route (hereafter referred to as the Kawasaki route) is the lowest at 1.1. In this study, we analyzed the Kawasaki route as the target line for the case study.

Table 3: Metropolitan expressway cost-benefit ratio.

| Route | Investigation Year | Cost-Benefit Ratio |
|---|---|---|
| Kawasaki route | 2015 | 1.1 |
| Yokohama North Route | 2018 | 1.5 |
| Harumi Route | 2016 | 1.6 |
| Saitama Shintoshin Route | 2011 | 2.1 |
| Shinjuku Route | 2014 | 2.2 |
| Shinagawa Route | 2011 | 4.0 |

### 5.3 Kawasaki route cost-benefit analysis results

In this subsection, we present the results of a cost-benefit analysis of the Kawasaki route based on future expectations. We assumed that the change in the number of vehicles along the Kawasaki route was equal to the rate of change in the Japanese population. Figure 3 presents the results of estimating the future number of vehicles on the Kawasaki route by calculating the rate of change in the Japanese population according to [25]. As shown, approximately 60,000 vehicles used the Kawasaki route in 2005. However, by 2060, this number is expected to decrease to approximately 44,000.

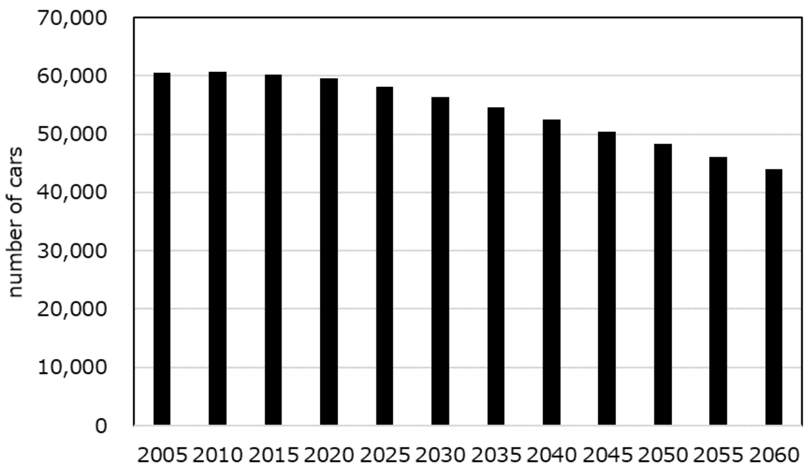


Figure 3: Number of vehicles on the Kawasaki route.

Next, we analyzed the cost-benefit of the Kawasaki route after 2005. The cost-benefit ratio in 2005 is based on data provided in [22]. For (D), the project cost required for road construction, and (E), the cost required for road maintenance, we used data from [26] and assumed that they were constant during the analysis period.

The cost-benefit ratio for each year was calculated, and its values are plotted in Figure 4. The cost-benefit ratio is expected to reduce to less than 1 in 2025. Moreover, the cost-benefit ratio is expected to deteriorate with the number of vehicles.

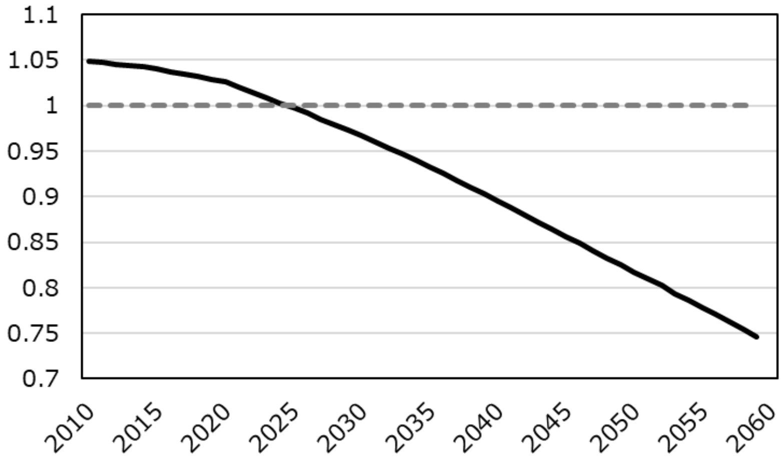


Figure 4: Cost-benefit ratio.

## 5.4 Impact of abolishing the Kawasaki route

Based on the results of the cost-benefit analysis, we considered the case of abolishing the Kawasaki route. For the OD data, we used the results of a person trip (PT) survey conducted in 2018 and published by the Tokyo Metropolitan Area Transportation Planning Council. A PT survey is a survey of people. It records each trip: from where, to where, at what time, and by what means of transportation.

Intermediate routes were calculated from the OD data using MATSim to extract only the travel data via the Kawasaki route. We found that vehicles traveling on the Kawasaki route started from or went to one of the following seven areas: Yokohama-Shi Tsurumi-Ku, Kawasaki-Shi (Saiwai-Ku), Kawasaki-Shi (Kawasaki-Ku), Kawasaki-Shi (Nakahara-Ku), Yamato-Shi, and Shinagawa-Ku. Therefore, we only need to consider the vehicles running to or from these seven areas.

Table 4: Origin-Destination (OD) data for vehicles using the Kawasaki route.

| Origin | Destination | Number of Vehicles |
|---|---|---|
| Isumi-shi | Kawasaki-shi Kawasaki-ku | 86 |
| Kamogawa-shi | Yokohama-Shi Tsurumi-ku | 95 |
| Kamogawa-shi | Kawasaki-shi Kawasaki-ku | 75 |
| Kamogawa-shi | Ōta-ku | 138 |
| Kimitsu-shi | Kawasaki-shi Kawasaki-ku | 336 |
| Kimitsu-shi | Ōta-ku | 95 |
| Ichihara-shi | Kawasaki-shi Kawasaki-ku | 375 |
| Ichihara-shi | Yokohama-Shi Tsurumi-ku | 118 |
| Ichihara-shi | Ōta-ku | 359 |
| Katsuura-shi | Yokohama-Shi Tsurumi-ku | 96 |
| Ōtaki-machi | Yokohama-Shi Tsurumi-ku | 77 |
| Ōtaki-machi | Ōta-ku | 264 |
| Chōnan-machi | Ōta-ku | 198 |
| Mutsuzawa-machi | Ōta-ku | 290 |
| Mobara-machi | Ōta-ku | 123 |
| Kisarazu-shi | Kawasaki-shi Kawasaki-ku | 222 |
| Kisarazu-shi | Yokohama-Shi Tsurumi-ku | 96 |
| Kisarazu-shi | Kawasaki-shi Kawasaki-ku | 193 |
| Kisarazu-shi | Kawasaki-shi Nakahara-ku | 128 |
| Kisarazu-shi | Ōta-ku | 111 |
| Yokohama-shi Tsurumi-ku | Kamogawa-shi | 95 |
| Yokohama-shi Tsurumi-ku | Ichihara-shi | 213 |
| Yokohama-shi Tsurumi-ku | Katsuura-shi | 96 |
| Yokohama-shi Tsurumi-ku | Sodegaura-shi | 303 |
| Yokohama-shi Tsurumi-ku | Ōtaki-machi | 173 |
| Kawasaki-shi Saiwai-ku | Kamogawa-shi | 75 |
| Kawasaki-shi Saiwai-ku | Sodegaura-shi | 91 |
| Kawasaki-shi Saiwai-ku | Kisarazu-shi | 193 |
| Kawasaki-shi Kawasaki-ku | Isumi-shi | 86 |
| Kawasaki-shi Kawasaki-ku | Kimitsu-shi | 336 |
| Kawasaki-shi Kawasaki-ku | Ichihara-shi | 375 |
| Kawasaki-shi Kawasaki-ku | Sodegaura-shi | 114 |
| Kawasaki-shi Kawasaki-ku | Chosei-mura | 156 |
| Kawasaki-shi Kawasaki-ku | Kisarazu-shi | 124 |
| Kawasaki-shi Kawasaki-ku | Ichihara-shi | 128 |
| Ōta-ku | Isumi-shi | 170 |
| Ōta-ku | Kamogawa-shi | 138 |
| Ōta-ku | Kimitsu-shi | 95 |
| Ōta-ku | Ichihara-shi | 263 |
| Ōta-ku | Ōtaki-machi | 264 |
| Ōta-ku | Chōnan-machi | 198 |
| Ōta-ku | Mutsuzawa-machi | 290 |
| Ōta-ku | Mobara-machi | 123 |
| Ōta-ku | Kisarazu-shi | 232 |
| Yamato-shi | Isumi-shi | 95 |
| Yamato-shi | Sodegaura-shi | 95 |
| Shinagawa-ku | Kisarazu-shi | 145 |

To evaluate the abolishment of the Kawasaki route, we deleted it from the road network map, as shown in Figure 2. OD data extracted from the seven areas listed in Table 4 were used. Simulations were conducted using MATSim with an updated map and OD data. It was found that National Route 409, which is parallel to the Kawasaki route, became an alternative route for all the OD data.

Figure 5 shows the congestion rates for National Route 409 after the Kawasaki route is abolished. According to [22], the Kawasaki Line has four lanes with a congestion rate of 1.13. Figure 5 shows that the congestion rate was approximately four times higher when the Kawasaki route was abolished. This congestion rate is expected to decrease in the future with the number of users, but it will at least remain approximately 2.7 times the initial value. Accordingly, the effect of abolishing the Kawasaki route is expected to be significant.

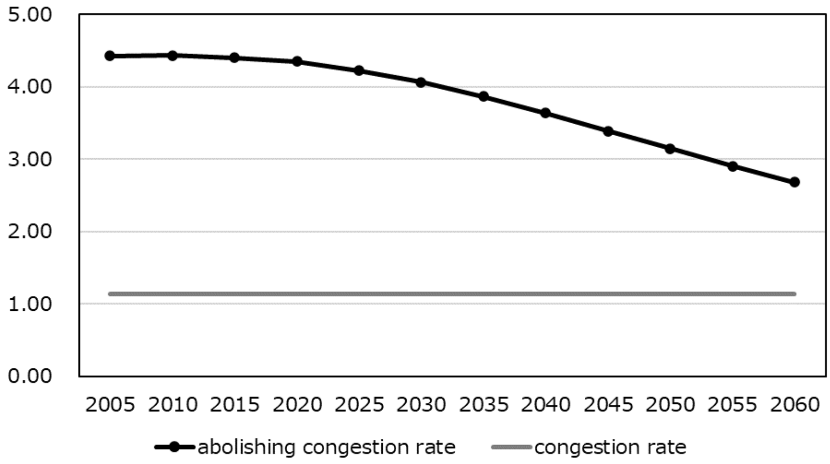


Figure 5: Cost-benefit ratio.

We considered increasing the number of lanes to reduce congestion on route 409. Increasing the number of lanes increases the traffic capacity, which reduces the congestion rate. According to [22], the traffic volume for 24 h on weekdays was 20,769 vehicles, and the congestion rate was 1.13; therefore, the traffic capacity was calculated as 765 vehicles. National Highway 409 has four lanes. If expanded to lanes 6, 8, and 10, the traffic capacity would be 1,149, 1,532, and 1,915 vehicles, respectively.

Using these data, we calculate the congestion rates until 2060. Figure 6 shows whether the congestion rate would fall below its value before the Kawasaki Line was abolished. The results showed that the number of lanes will be lower than that in 2060 when the number of lanes is assumed to be 10. Roads with 10 lanes include those with right-turn lanes and left-turn lanes at intersections and those with 10 lanes in intersections, but no roads have 10 lanes outside intersections. In addition, there is a problem that the number of accidents increases when there are many lanes, so it is difficult to abolish them.

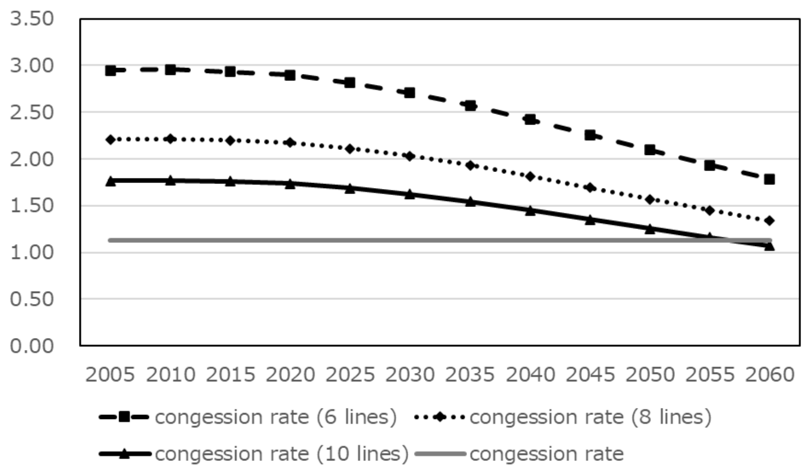


Figure 6: Congestion rate of 6, 8 and 10 lanes.

# 6 Conclusion

In this study, we addressed the issue of declining expressway users by proposing a method to determine whether a route should be closed when its cost-benefit ratio deteriorates.

The cost–benefit analysis of the Kawasaki route indicated that its ratio would fall below 1 by 2025. Our simulation of origin-destination (OD) data revealed that vehicles on the Kawasaki route either originated from or were destined for seven specific areas: Yokohama-Shi Tsurumi-Ku, Kawasaki-Shi Saiwai-Ku, Kawasaki-Shi Kawasaki-Ku, Kawasaki-Shi Nakahara-Ku, Yamat-Shi, and Shinagaw-Ku.

Then, we assessed the impact of closing the Kawasaki route by examining alternative routes. The simulation shows that National Route 409, which runs parallel to the Kawasaki route, serves as the primary alternative. By comparing the congestion rates on National Route 409 before and after the closure of the Kawasaki route, we found that congestion significantly increased despite the overall decrease in drivers. To mitigate this, we considered expanding Route 409 and determined that ten lanes would be required, making the closure of the Kawasaki route impractical.

This case study focuses on the Kawasaki Route. Future research will extend this analysis to other routes by considering the elimination of multiple lines using macroscopic fundamental diagrams (MFDs). In addition, we aim to explore the impact of extending the Kawasaki route to the Tomei Expressway, a project currently under consideration. Further research topics include seasonal traffic fluctuations, toll fee effects, safety and accident issues, integration with other transportation modes, long-term policies, and stakeholder analyses.

# Acknowledgement

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# References

[1] Metropolitan Expressway Co., Ltd., "IR Report July 2020", 2020.

[2] S. Higashikawa, A. Shoko, I. Kazuhiko, T. Tomoaki, Z. Jieshuo, O. Tomoyuki, and H. Hayashi, "Towards Sustainable Road Network in the Era of Shrinking Population: Case Study Using MATSim", 12th International Congress on Advanced Applied Informatics, pp. 535-539, 2022.

[3] D. B. Lee, "Methods for evaluation of transportation projects in the USA, Transport Policy", Transport Policy, vol. 7, No. 1, pp. 41-50, 2000.

[4] K. G. Willis, G. D. Garrod, and D. R. Harvey, "A review of cost–benefit analysis as applied to the evaluation of new road proposals in the U.K.", Transportation Research Part D: Transport and Environment, vol. 3, No. 3, pp. 141-156, 1998.

[5] Y. Hayashi and H. Morisugi, "International comparison of background concept and methodology of transportation project appraisal", Transport Policy, vol. 7, No. 1, pp.73-88, 2000.

[6] S. Damart and B. Roy, "The uses of cost–benefit analysis in public transportation decision-making in France", Transport Policy, vol. 16, No. 4, 2009.

[7] S. Chi and J. Bunker, "An Australian perspective on real-life cost-benefit analysis and assessment frameworks for transport infrastructure investments", Research in Transportation Economics, vol. 88, 2021.

[8] E. D. A. A. Amjad, "Cost Benefit Analysis for Construction Projects. Petrokenya Industrial City Jubai Saudi Arabia", IEP-SAC Journal 2004-2005, pp. 85-90, 2005.

[9] D. Pearce, "Cost benefit analysis and environmental policy", Oxford Review of Economic Policy, vol. 14, No. 4 , pp. 84–100, 1998.

[10] S. Manzo and K. B. Salling, "Integrating Life-cycle Assessment into Transport Cost-benefit Analysis", Transportation Research Procedia, vol. 14, pp. 273-282, 2016.

[11] J. D. Harford, "Congestion, pollution, and benefit-to-cost ratios of US public transit systems", Transportation Research Part D: Transport and Environment, vol. 11, No. 1, pp. 45-58, 2006.

[12] J. Odeck and A. Kjerkreit, "The accuracy of benefit-cost analyses (BCAs) in transportation: An ex-post evaluation of road projects", Transportation Research Part A: Policy and Practice, vol.120, pp.277-294, 2019.

[13] A. E. Boardman, W. L. Mallery, and A. R. Vining, "Learning from ex ante/ex post cost-benefit comparisons: the Coquihalla highway example", Socio-Economic Planning Sciences, vol. 28, No. 2, pp. 69-84, 1994.

[14] C. Kelly, J. Laird, S. Costantini, P. Richards, J. Carbajo, and J. Nellthorp, "Ex post appraisal: What lessons can be learnt from EU cohesion funded transport projects?", Transport Policy, vol. 37, pp. 83-91, 2015.

[15] C. Chen, Z. Jia, and P. Varaiya, "Causes and cures of highway congestion", IEEE Control Systems Magazine, vol. 21, No. 6, pp. 26-32, 2001.

[16] P. Varaiya, "Reducing Highway Congestion: An Empirical Approach", European Journal of Control, vol. 11, No. 4–5, pp. 301-309, 2005.

[17] C. F. Daganzo, "Urban gridlock: Macroscopic modeling and mitigation approaches", Transportation Research Part B: Methodological, vol. 41, No. 1, pp. 49-62, 2007.

[18] N. Geroliminis and C. F. Daganzo, "Existence of urban-scale macroscopic fundamental diagrams: Some experimental findings", Transportation Research Part B: Methodological, vol. 42, No. 9, pp. 759-770, 2008.

[19] A. Loder, L. Ambühl, M. Menendez, and K. W. Axhausen, "Understanding traffic capacity of urban networks", Scientific Reports, vol. 9, 2019.

[20] C. Buisson and C. Ladier, "Exploring the impact of homogeneity of traffic measurements on the existence of macroscopic fundamental diagrams", Transportation Research Record Journal of the Transportation Research Board, vol. 2124, pp.127-136, 2009.

[21] The Ministry of Land, Infrastructure, Transport, and Tourism, Road Bureau, City Bureau, "Cost-Benefit Analysis Manual (Draft) , (2008) , https://www.mlit.go.jp/road/ir/kihon/26/2-1_b.pdf, (accessed February 1st 2022).

[22] Road Traffic Census 2005, https://www.ktr.mlit.go.jp/road/shihon/road_shihon00000023.html (accessed February 1, 2022).

[23] A. Horni, K. Nagel, and KW Axhausen, "The Multi-Agent Transport Simulation MATSim" , Ubiquity Press, London, 2016.

[24] "Simunto Via User Manual", Version 1.8, 2018.

[25] Cabinet Office, Japan, "Annual Report on the Ageing Society", 2021.

[26] Metropolitan Expressway Co., Ltd., "Business evaluation", https://www.shutoko.co.jp/company/enterprise/road/committee/ (accessed February 1, 2022).