The Evaluation model for preliminary measures of stranded vehicles due to heavy snowfalls on the highway

Hayate ITOH[a], Hiroyuki ONEYAMA[b], and Masami YANAGIHARA[c]

[a,b,c] *Dept. of Civil Eng., Tokyo Metropolitan University, Minamiosawa 1-1, Hachioji-shi, Tokyo 192-0397, Japan*
[a] *E-mail: itohhayate.research@gmail.com*
[b] *E-mail: oneyama@tmu.ac.jp*
[c] *E-mail: yanagihara@tmu.ac.jp*

1. INTRODUCTION

In recent years, Japan has frequently experienced heavy snowfall, leading to large numbers of stranded vehicles and prolonged traffic disruptions that take several days to resolve. These incidents are not limited to regions with heavy snowfall but also occur in areas with relatively little snowfall.

On expressways, where the environment is enclosed, passengers trapped in large-scale vehicle strandings caused by heavy snowfall must endure long waits for rescue by the Self-Defense Forces and other organizations, relying on limited supplies of food, fuel, and other necessities. In harshly cold conditions, there is a risk to human life, making it essential to conduct efficient vehicle discharge operations for early resolution and to provide information on the estimated time required for clearance as part of crisis management.

The current winter expressway management policy is based on the fundamental principle of "prioritizing human life and thoroughly preventing large-scale vehicle strandings on major roads." Emphasis is placed on preventive measures such as planned and preemptive traffic restrictions and enhanced monitoring of high-risk areas. However, accurately predicting snowfall amounts is challenging, making it unrealistic to completely prevent vehicle strandings through preventive measures alone. Additionally, depending on the situation and operation after a stranding occurs, the duration of the stranding may be prolonged. Therefore, it is necessary to prepare for large-scale strandings and consider post-occurrence countermeasures.

When a vehicle stranding due to heavy snowfall is detected, nearby interchanges are promptly closed, and once the situation is assessed and exit routes are secured, snowplow teams begin vehicle discharge operations. The snowplow team moves upstream in the stranded lane, driving in the opposite direction toward the front of the stranded vehicles. They facilitate vehicle movement sequentially from the front by equipping chains, towing, and clearing snow between vehicles. Additionally, to shorten the discharge operation time, another method being considered and implemented involves snowplow teams entering through the median opening within the stranded section and enabling vehicles upstream of the opening to move. These vehicles are then discharged by making a U-turn into the opposite lane.

However, cases which U-turn discharge has been implemented are limited, and verification of its efficient use has not progressed. When performing U-turn discharge, the required time to discharge is expected to vary depending on the location of the median opening and the order in which it is used. Therefore, it is desirable to predict and compare the required time to discharge. However, research that predicts and estimates the required time to discharge is extremely limited.

This study aims to construct a method for estimating the required time to discharge vehicles stranded due to heavy snowfall and to analyze preliminary measures that can facilitate efficient operation after a stranding occurs.

2. MEHTODOLOGY

The analysis of preliminary measures using the predicted required time to discharge stranded vehicles is conducted in three steps, as shown in Figure 1.

Step 1 is "The estimation model," which estimates the required time from the start of the discharge operation to the completion of stranded vehicle clearance affected by heavy snowfall. By inputting variables related to "Infrastructural conditions," "Snowplow conditions," "Weather conditions," "Vehicle conditions," and "Operation of snowplows," the model calculates the required time to discharge until all vehicles can move and the total waiting time, which is the sum of the waiting time for all vehicles. Specifically, based on infrastructural conditions and vehicle conditions, the model determines the length and number of stranded vehicles in each section divided by the median openings. Then, it assigns the operation area for each snowplow team. Using the required time to discharge per stranded vehicle, which varies according to the amount of snowfall, the model calculates the required time to discharge and the total waiting time.

Step 2 is "The optimize operation model," which compares the outputs of Step 1 across all possible snowplow operation patterns and selects the operation that minimizes either the required time to discharge or the total waiting time as the optimal snowplow operation.

Step 3 is "The preliminary measures evaluation model." This step sets up the probability distribution of "Vehicle conditions" and "Weather conditions" and runs 1,000 simulations of Step 2 based on realistic conditions. The results are aggregated to calculate evaluation values for preliminary measures. Using the evaluation values, this model allows for the analysis of the effectiveness of pre-installed measures, such as the placement and number of median openings and snowplow bases.

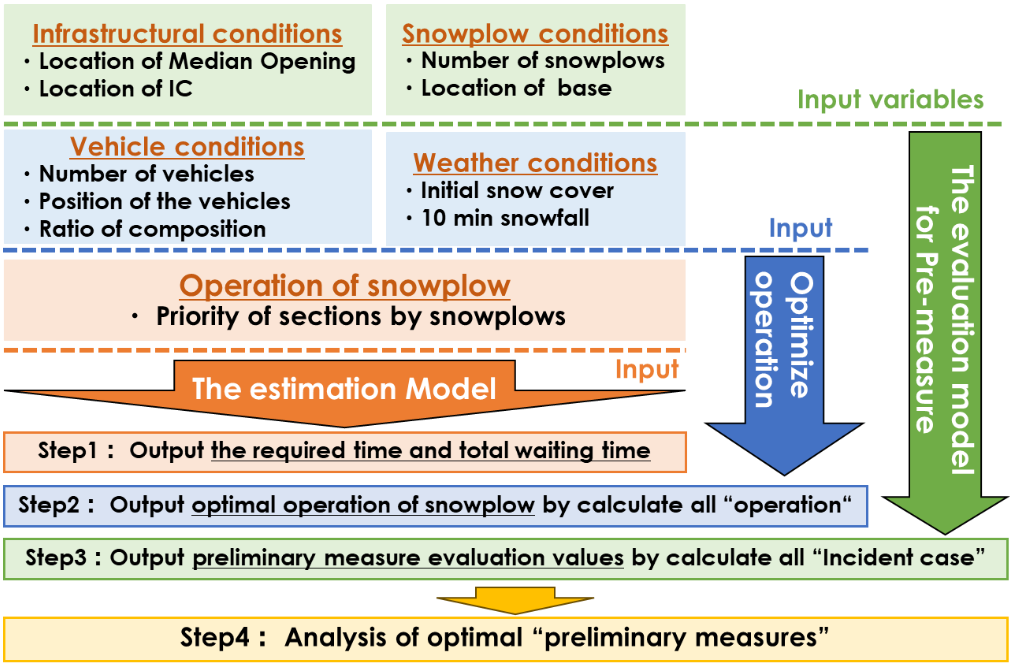

Figure 1. Framework of analysis

3. OVERVIEW OF ANALYSIS

In this study, the analysis focuses on the Kan-Etsu Expressway (upbound, Nagaoka JCT to Tsukiyono IC). Based on cases of stuck that occurred between 2016 and 2022, the distributions of "Vehicle conditions" and "Weather conditions" were aggregated, and new locations for median openings were analyzed. As candidates for new installations, midpoint locations between the 13 existing median openings were set, and analysis was conducted by varying both the number and placement of additional openings.

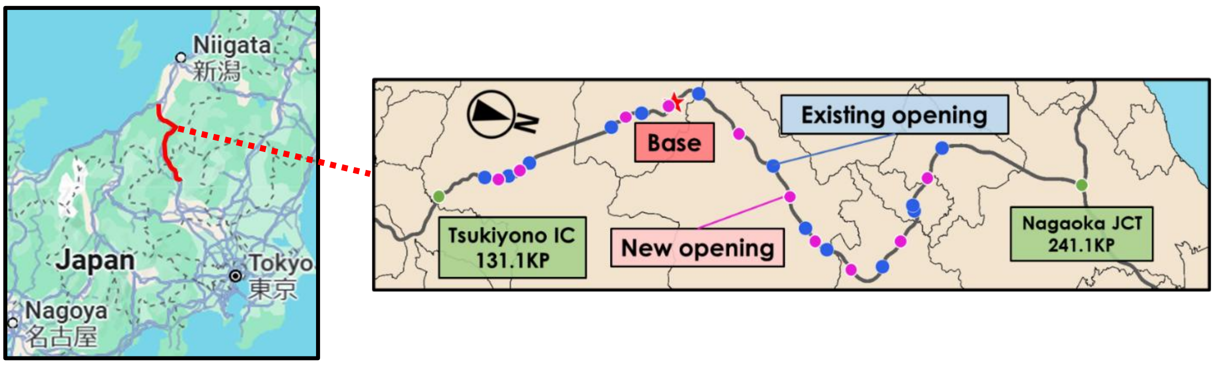

Figure 2. Target section (Kan-Etsu Expressway, Nagaoka JCT to Tsukiyono IC)

4. RESULTS

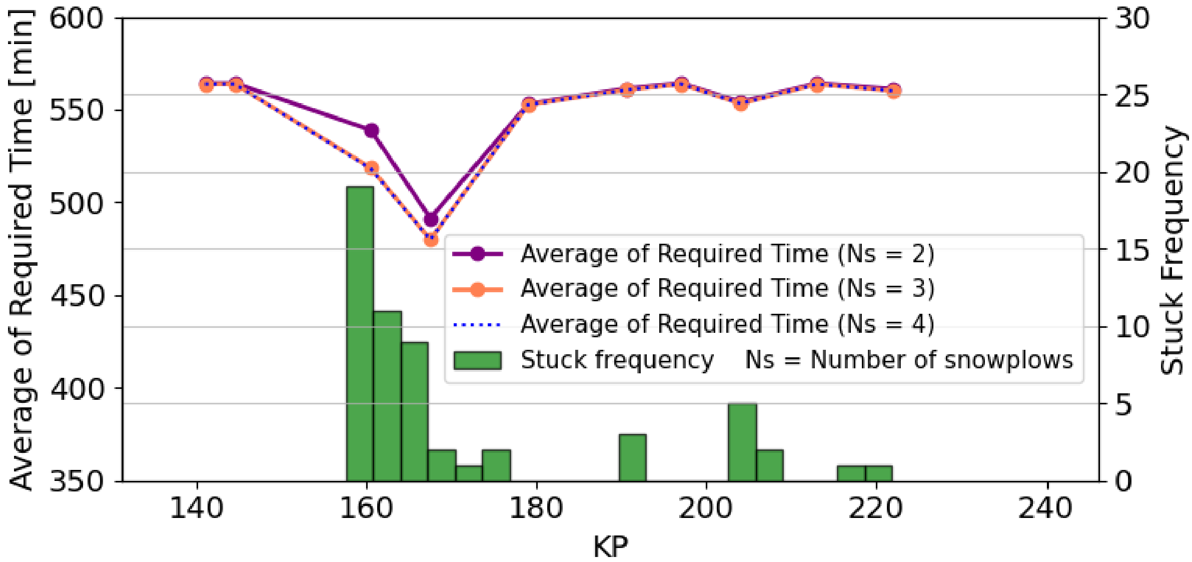

Figure 3. The comparison of new installation locations

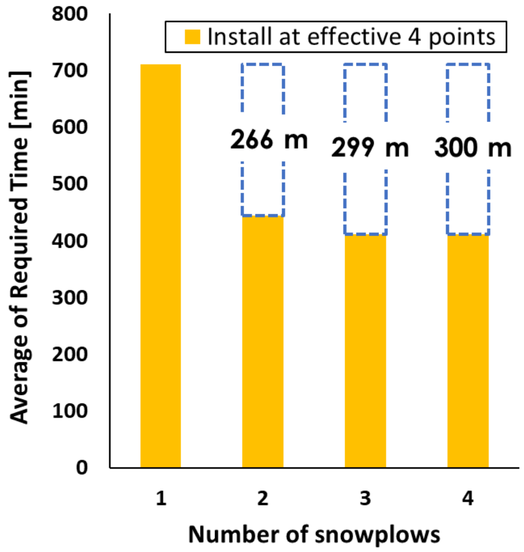

Figure 4. The comparison of snowplows

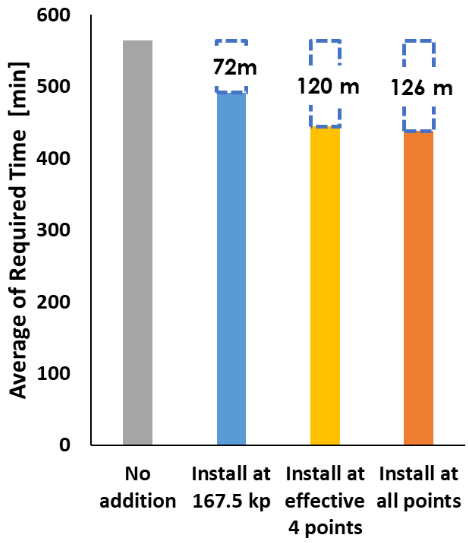

Figure 5. The comparison of installation patterns

Figure 3 shows the required time to discharge per case at each location when a new median opening is installed at a single point, along with the distribution of stuck occurrences. The reduction effect on the required time to discharge due to the installation of a new median opening is greater near locations where stuck frequently occur. This indicates that identifying high-risk stuck locations is important when installing a new median opening.

Figure 4 shows a comparison of the number of snowplow teams when median openings were installed simultaneously at four locations with significant effects. Increasing the number of snowplows from one to two resulted in a reduction of 266 min in the required time to discharge, demonstrating a significant reduction effect. However, increasing the number from two to three resulted in a reduction of 33 min. Although there is still a reduction effect, it is necessary to consider the trade-off with implementation costs.

Figure 5 compares three cases when the number of snowplow teams is two: (1) one point with the highest reduction effect, (2) simultaneous installation at four locations with significant effects, and (3) installation at all locations. Installing new median openings at all locations resulted in a 22.3% (126 min) reduction in the required time to discharge. However, even when installing at only the four locations with significant effects, a nearly identical reduction of 21.3% (120 min) was achieved.

5. CONCLUSIONS

When installing new median openings on the Kan-Etsu Expressway, it was found that the most efficient method, based on the analysis conditions in this study, is to organize two snowplow teams and install the median opening at the four most effective locations. Thus, this model is a useful method for quantitatively comparing and evaluating optimal locations for median openings. It can be used to analyze strategies for achieving efficient vehicle discharge operations during large-scale stranding on expressways during heavy snowfalls.

As a future prospect, by incorporating the relationship between slope, road conditions, and stuck risk, the model could be applied to other roads with fewer stuck cases, broadening its use in a wider range of scenarios.

ACKNOWLEDGMENT

This work was supported by NEXCO EAST and Nagaoka University of Technology.

REFERENCES

Ministry of Land, Infrastructure, Transport and Tourism (2021), Interim Summary of Road Traffic Assurance Measures During Heavy Snowfall

HOSODA H., TAKAHASHI T., YAMAMOTO Y., ‘Vehicle Guidance Training During Large-Scale Stranded Vehicle Incidents – Towards Supporting Passenger Protection in Snow Disasters –’, Proceedings of the 65th Hokkaido Development Technology Conference (FY 2021). 2021, pp490-493