FEASIBILITY STUDY ON FRICTION MAPPING

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ABSTRACT   RÉSUMÉ

Northern Japan has cold winters with snowfall heavier than that typically seen at its latitudes. Since winter weather creates hazardous road conditions for road users, winter road maintenance is essential in these regions. To carry out winter road maintenance works appropriately, it is necessary for road managers to identify road sections where treatment is required. To this end, thermal mapping has been widely used. Thermal mapping is based on the fact that the pattern of road surface temperatures is reproducible under similar weather conditions. Thermal mapping develops a unique surface temperature pattern for each route (a “thermal fingerprint”). Another technique to clarify road surface conditions involves determining the slipperiness of the road surface. Although the recent development of a practical device that allows continuous measurement of road surface friction has expanded the application of slip indicators in winter road maintenance, it is impossible to constantly measure changing road surface friction. If, like road surface temperature, the distribution of road surface friction is reproducible, road managers can reduce the need to conduct road surface friction measurement. This study aimed to verify the reproducibility of friction data by using an expressway as a case study route.

1. INTRODUCTION

Japan lies between the latitudes of 20 and 45 degrees North. The climate is predominantly temperate, but it varies greatly from north to south because of the wide range of latitude. Northern Japan has cold winters with snowfall heavier than that typically seen at its latitudes. In this region, winter weather significantly affects traffic flow and creates hazardous road conditions. For this reason, studded tires were widely used in Japan from the 1960s, but they were banned in the 1990s to prevent the harmful environmental effects of the asphalt dust they produced. However, since the ban took effect, problems with extremely slippery road surfaces have frequently arisen in winter [1]. For example, on Japan’s northernmost island of Hokkaido, skidding is responsible for 90% of “winter-type” traffic accidents (Figure 1). Accordingly, measures against icy road surfaces have become a major part of winter road maintenance.

With tight budgets and strong public demand to keep roads clear of snow and ice, road administrators must find ways to carry out winter road maintenance effectively and efficiently. To this end, a correct understanding of road surface conditions is imperative, especially an understanding of whether the road surface is slippery. Although friction measurement is useful in terms of eliminating human error and supporting prompt and accurate decision-making, it is impossible to constantly measure changing road surface friction. If the distribution of road surface friction is reproducible, road authorities will be able to reduce the need to conduct friction measurement.

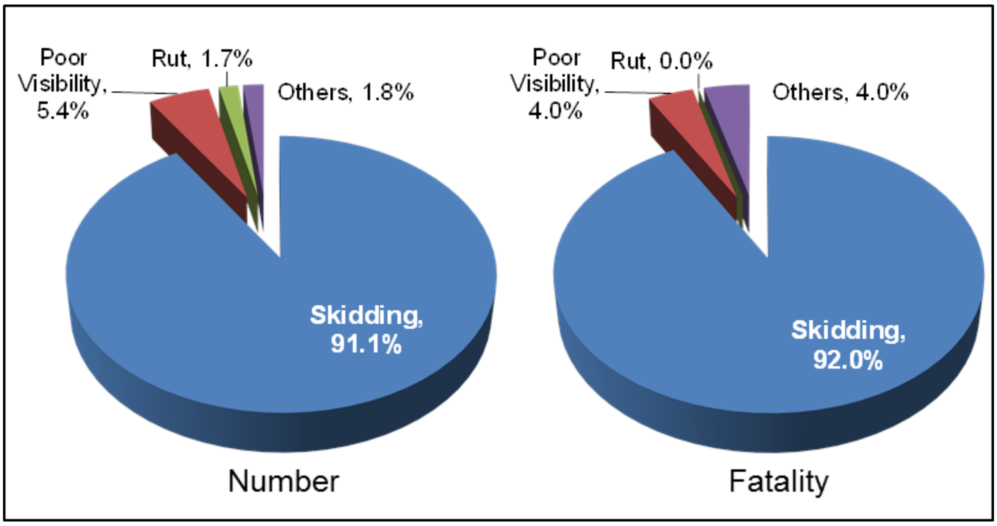

Figure 1 - “Winter-type” traffic accidents in Hokkaido (Nov. 2009 – Mar. 2010)

2. LITERATURE REVIEW

One of the most widely used tools for monitoring winter road surface conditions is the road weather information system (RWIS) [2], which is a collection of weather monitoring sensors located along the road network. At these stations, valuable road weather data such as road surface temperature, air temperature, wind velocity and snow accumulation are collected and provided via Internet to maintenance staff in order to support decision-making [3]. However, the amount of information provided by the RWIS is still limited. Technically, data are collected only at specific locations where sensors are installed [4].

To fill the resulting information gap, thermal mapping was developed, mainly in the United Kingdom and Sweden ([5], [6]), and it has been widely used to evaluate and refine chemical treatment strategies. Thermal mapping involves measuring the road surface temperature under a range of different weather conditions using high-resolution infrared thermometers fitted to a vehicle. Thermal mapping is based on the fact that patterns of road surface temperatures are reproducible under similar weather conditions [7]. In order for thermal mapping to be relevant on most winter nights, data collection is carried out under three defined weather conditions. Then, thermal mapping develops a unique surface temperature pattern for each route (a “thermal fingerprint”). The thermal fingerprints are categorised as “Extreme”, “Intermediate” or “Damped”. Extreme refers to data collected under clear calm conditions, Intermediate refers to clear windy conditions or calm conditions with extensive cover of medium-level cloud, and Damped refers to data collected under conditions of extensive low-level cloud cover.

Another approach to determining the state of the road surface involves the measurement of road surface friction. This method has been used in the field by a number of road agencies, and it is widely adopted by airport authorities [8]. Various friction-measuring devices have been developed and tested by road agencies and researchers [9]. In recent years, the development of practicable devices capable of continuously measuring road surface friction has expanded the use of friction indicators in winter road maintenance (e.g., [10], [11]). Although it is impossible to constantly measure changing road surface friction, Tokunaga et al. [12] indicated that the variation in friction value tends to be affected by various factors such as exposure, elevation and road structures.

3. STUDY METHOD

3.1. Continuous Friction Tester (CFT)

In this study, a continuous friction tester (CFT) was used to continuously measure friction values on roadways in real time (Figure 2). The device calculates friction by measuring the axial force created by a measuring wheel installed at a 1- to 2-degree skew from the direction of travel (Figure 3). A friction value computed in this way is referred to as a Halliday friction number (HFN). The HFN scale was set by the device's designer, and it usually ranges from 0 to 100. As shown in Figure 4, HFN values and axial force have a linear relationship. The HFN is 0 when there is no force between the tire and the road, and is 100 with lateral force between the tire and the road when the measuring wheel is run on dry pavement (fine and gap-graded asphalt concrete) at -17.8 degrees Celsius. HFN values can be converted to the friction coefficient (μ) that is measured using a standard device in Japan (Equation (1)) [13].

$$\mu = 0.008\mathrm{HFN} - 0.1294 \qquad (1)$$

Figure 2 - Continuous friction tester (CFT)

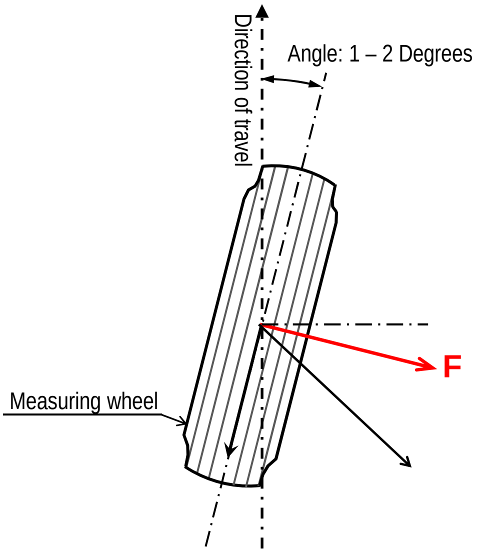

Figure 3 - CFT measurement principle

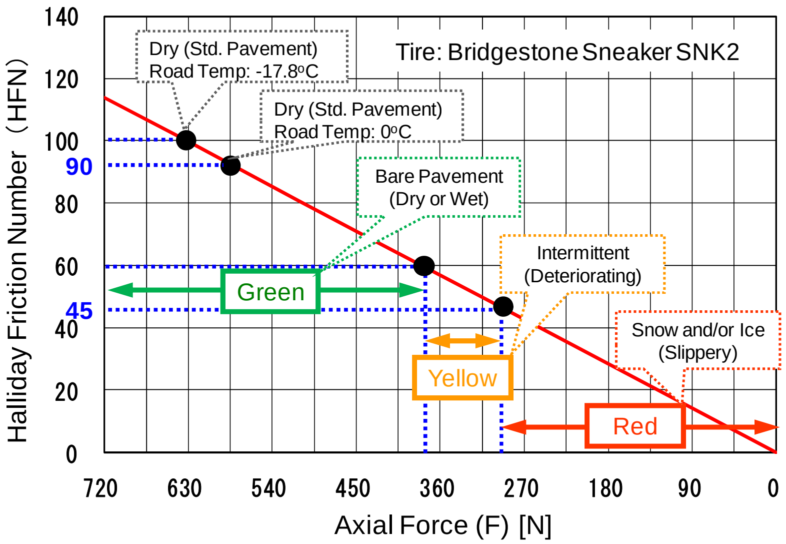

Figure 4 - Relationship between axial force and HFN

The CFT sampling rate is 10 Hz by default, and HFN values can be checked in real time via an on-board display inside the vehicle. Friction data are combined with information on the date, time, positioning, road surface temperature, weather conditions (sunny/ cloudy/ rainy/ snowy), road surface conditions (dry/ wet/ slushy/ compacted snow/ icy), vehicle ID, traveling speed and other information, and are stored on a recorder to enable various forms of analysis using the accumulated data.

3.2. Case Study

In the winter of 2011 to 2012, 90 friction measurements were taken on an 18-km-long section of expressway in Hokkaido as a case study route. To obtain data under various weather conditions and times of day, measurements were conducted for five days each in early winter (mid-December), mid-winter (late January) , and late winter (late February). Six friction measurements were conducted each day at intervals of approximately 4 hours.

Measurement start times were set at 9:30, 13:00, 17:00, 20:30, 00:00, 04:00 based on the road authority’s decision, and subject to change upon consultation with road administrators in relation to snow removal or other work. Measurement carried out in early winter, mid-winter, and late winter are referred to here as Run 1 – Run 30, Run 31 – Run 60, and Run 61 – Run 90, respectively.

4. STUDY RESULTS

4.1. Friction distribution in winter

Friction values fluctuate greatly with distance because of the influences of snow and ice. As an example, Figure 5 shows the measurement results from Run 1 and Run 41. Although the road surface friction is stable inside the tunnel, the distributions of road surface friction derived from both measurements are quite different.

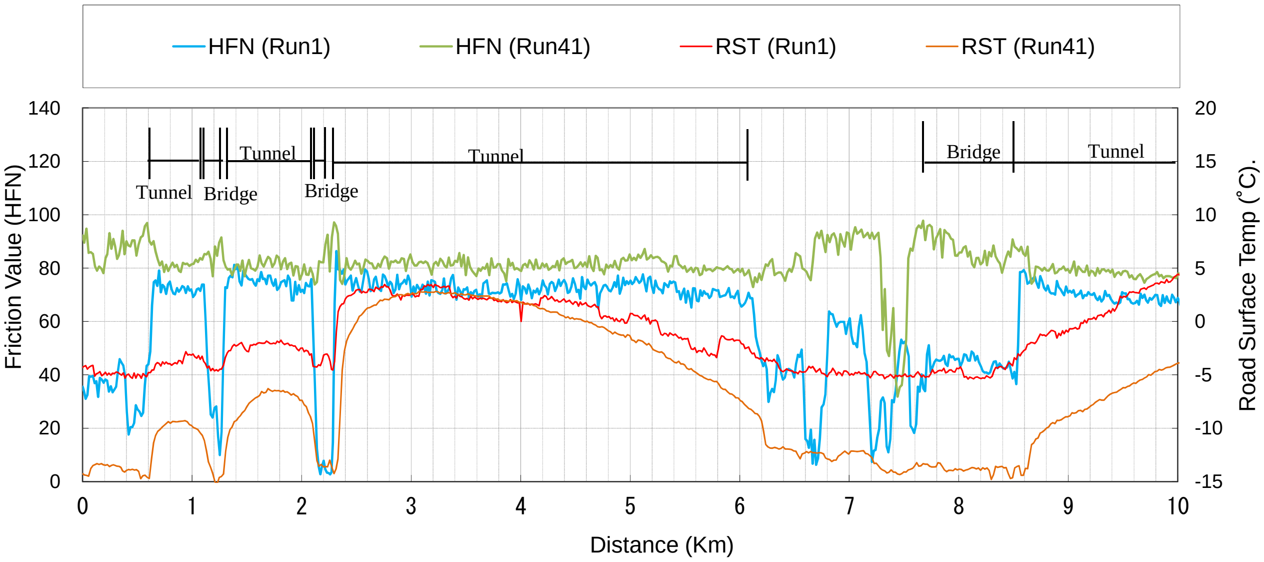

Figure 5 - Measurement results from Run 1 and Run 41

4.2. Reproducibility of the surface friction in consideration of the weather conditions

As shown in Figure 5, although the road surface friction varies greatly with distance in winter, determining the dependence of the road surface friction distribution on weather and other conditions makes it possible to identify sections at risk of freezing based on weather forecasts and other information and to implement preventive measures without continuously conducting friction measurements.

To evaluate the reproducibility of friction data collected in winter, the difference in friction distribution (Ei) at point i was introduced. Ei is found using Equation (2); the basic concept is diagrammed in Figure 6.

$$E_i = HFN_i(\mathrm{Run}_{std}) - HFN_i(\mathrm{Run}_x) - \left\{\overline{HFN(\mathrm{Run}_{std})} - \overline{HFN(\mathrm{Run}_x)}\right\} \qquad (2)$$

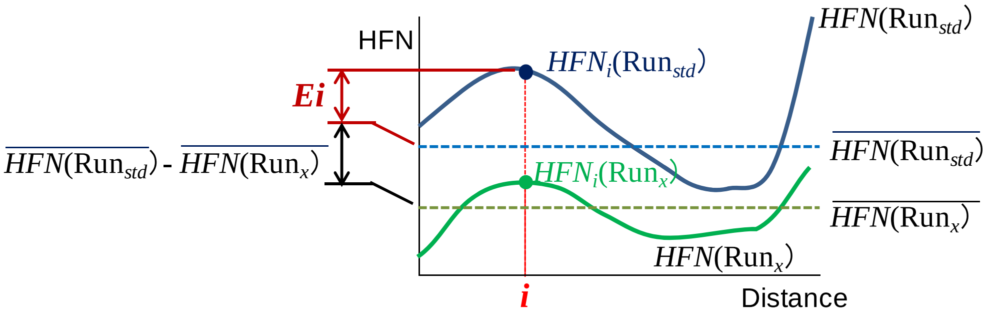

Figure 6 - Conceptual diagram of Ei

where Run_{std} is the standard measurement, Run_x is the control measurement, $HFNi\ (\mathrm{Run}_{std})$ is the friction at point i of Run_{std}, $HFNi\ (\mathrm{Run}_x)$ is the friction at point i of Run_x, $\overline{HFN(\mathrm{Run}_{std})}$ is the average friction of Run_{std}, and $\overline{HFN(\mathrm{Run}_x)}$ is the average friction of Run_x.

In this study, the results from three measurements under the same conditions were selected and one of them was taken as Run_{std}.

First, the reproducibility of friction data collected at night, to identify the potential for icing, is verified. Figure 7 shows examples of measurement results from cases where the weather was sunny and the road surface temperature was above zero during the daytime but dropped dramatically after sunset. The friction value decreased in a section with a length of approximately 400 m between around kilometer 7.2 and kilometer 7.6. Although this section has no bridge or other structures, it is presumed that snowmelt from the daytime when the road surface temperature rose flowed onto the road and partially froze with the drop in surface temperature after sunset.

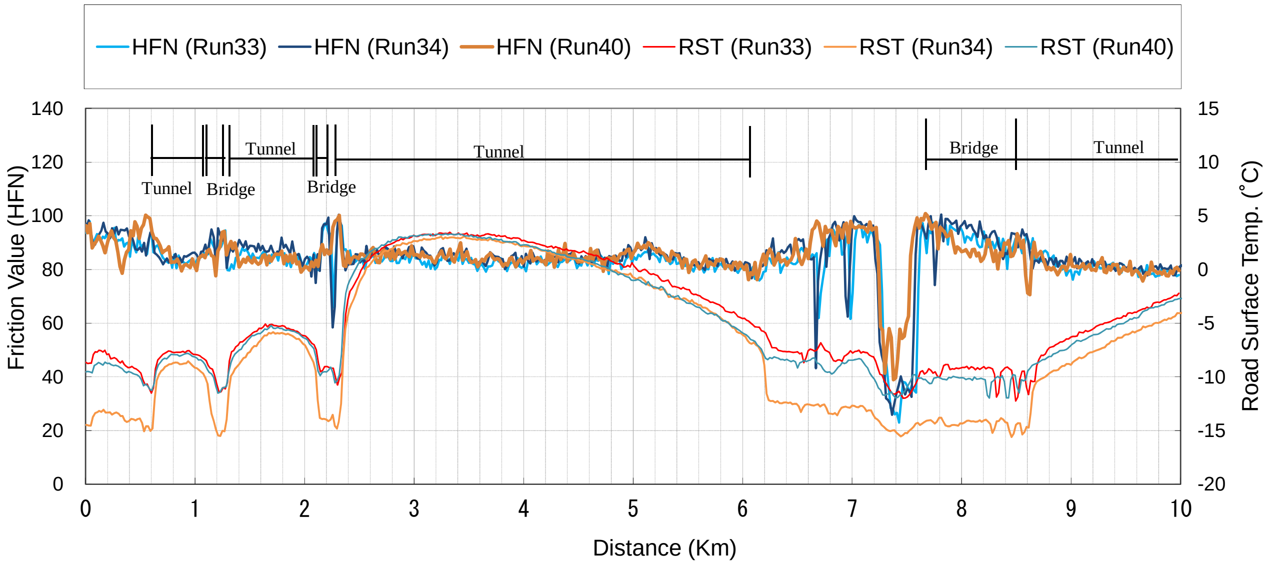

Figure 7 - Examples of measurement results from clear days when the road surface temperature dropped dramatically at night (Run 33, Run 34, and Run 40)

Table 1 shows basic error statistics obtained by taking Run 33 as Run_{std}. Friction value reproducibility was confirmed, as 83 to 91% of data were within a ±6 margin of error on the HFN scale (within ±0.05 in terms of the friction coefficient) and approximately 95% were within ±12 (within ±0.10 in terms of the friction coefficient). The large maximum and minimum error values were partly a result of differences of several to ten meters in points of sudden changes in friction. In road management, it is necessary to determine points where friction changes suddenly based on accumulated measurements.

Table 1 - Basic error statistics for clear days when the surface temperature dropped dramatically at night

	Date	Error(HFN)			Appearance Ratio (%)	
		Ave.	Max.	Min.	±6	±12
Run34	Jan. 30	0.0	44.3	-50.1	90.6	96.2
Run40	Jan. 31	0.0	32.0	-60.4	83.7	94.0

4.3. Production of Friction Fingerprints

Friction fingerprints are produced for conditions under which the reproducibility of friction data was confirmed in the previous section. Friction fingerprints are produced using friction data collected under same conditions by averaging the deviation from the average friction (HFN) for each measurement.

Figure 8 shows a friction fingerprint for cases where the weather is clear and the road surface temperature drops dramatically at night. The horizontal axis represents the travel distance, and the vertical axis represents the deviation from average friction (HFN) for each measurement.

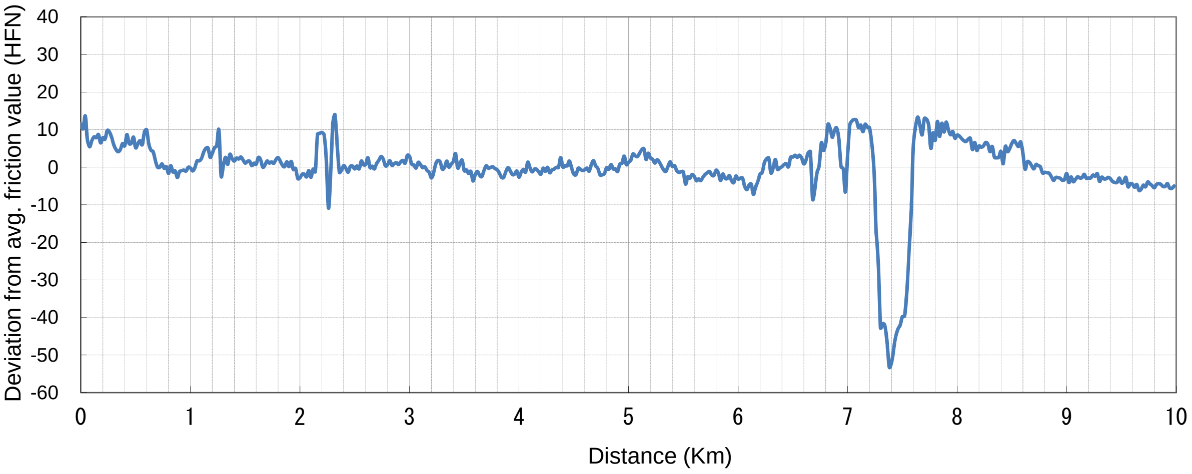

Figure 8 - Friction fingerprint for cases where the weather is clear and the road surface temperature drops dramatically at night (produced from Run 33, Run 34 and Run 40)

4.4. Reproducibility of the friction fingerprints

The reproducibility of the friction fingerprints produced in the previous section was verified by comparing the results with those of measurements conducted under the same conditions. First, the reproducibility of the friction value derived from the friction fingerprint for cases where the weather is clear and the road surface temperature drops dramatically at night was verified by comparing the results with those of Run 35 and Run 41, which were conducted under the same condition.

As an example, Figure 9 shows the friction measured from Run 35 and the friction calculated from the friction fingerprint for cases where the weather is clear and the road surface temperature drops dramatically at night. The calculated friction values were determined by superimposing the average friction value of Run 35 onto the friction fingerprint. As shown in Figure 11, although there are differences of several to ten meters at points of sudden changes in friction between around kilometer 7.2 and kilometer 7.4, friction values showed similar distributions.

Table 2 indicates basic error statistics obtained by taking the calculated friction values as Run_{std}. The friction values calculated from the friction fingerprint showed high reproducibility, as more than 85% of the data were within a ±6 margin of error on the HFN scale (within ±0.05 in terms of the friction coefficient), and more than 95% were within a margin of ±12 (within ±0.10 in terms of the friction coefficient).

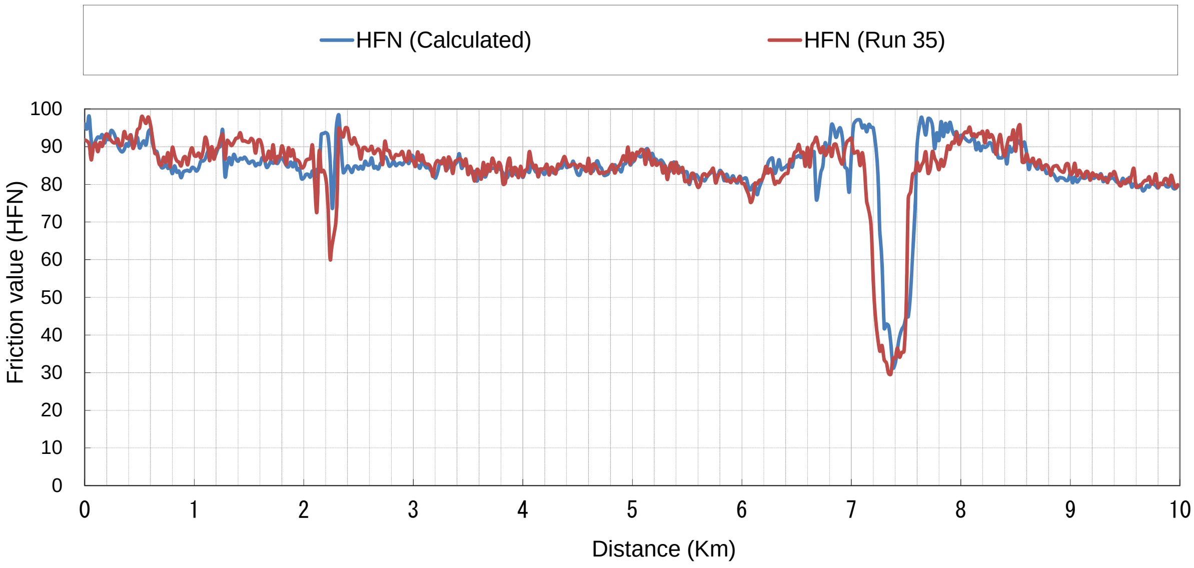

Figure 9 - Comparison between measured friction from Run 35 and calculated friction from the friction fingerprint for cases where the weather is clear and the road surface temperature drops dramatically at night

Table 2 - Basic error statistics for cases where the weather is clear and the road surface temperature drops dramatically at night

	Error(HFN)			Appearance Ratio (%)	
	Ave.	Max.	Min.	±6	±12
Run35	0.0	31.5	-45.8	86.0	95.8
Run41	0.0	35.4	-10.6	89.6	97.8

5. FUTURE STUDIES

In this study, the feasibility on friction mapping was verified. Although the reproducibility of friction data was confirmed only for one case, it is expected that creating friction fingerprints is effective in estimating the distribution of road surface friction. The authors plan to further accumulate and analyse friction data to clarify and schematize the conditions under which the distribution of friction data is reproducible.

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