QUANTITATIVE EVALUATION OF THE RELATIONSHIP BETWEEN THE ROAD SURFACE CONDITIONS MEASURED BY CONTINUOUS TESTING VEHICLES AND THE RATE OF WINTER TRAFFIC ACCIDENTS

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1. BACKGROUND AND PURPOSE OF THE STUDY

Snowy cold regions account for 60% of Japan's land area. These regions see many traffic accidents that stem from weather conditions peculiar to winter (hereinafter: “wintry accidents”). Typical examples include skidding accidents on snow-covered or icy roads and run-off-road accidents involving snowstorm-induced poor visibility. As the majority of those wintry accidents are skidding accidents, elucidating the impact of winter weather and winter road surface conditions on traffic accident occurrence may be useful in selecting priority sections for measures against wintry accidents and in appropriately identifying the sections and the times of day that necessitate road management, including snow removal and anti-icing-agent application.

Many studies have addressed the influence of wintry weather conditions on traffic accidents. Andreescu and Frost\(^1\) surveyed the relationship between wintry weather conditions and traffic accident occurrence in Montreal, Canada, revealing that average temperature and rainfall/snowfall greatly influence traffic accident occurrence. Qiu and Nixon\(^2\) conducted a meta-analysis of 34 papers published between 1967 and 2005 on the relationship between traffic accidents and weather conditions, and concluded that the rate of traffic accidents was 84% higher when there was snowfall than when there was no snowfall. Other studies have similarly explored the influence of winter weather conditions on road traffic, suggesting that the number of accidents is likely to increase under adverse weather in winter.

More recently, methods for measuring and forecasting index values that quantitatively show road conditions, such as road surface temperature and slipperiness, have been developed for practical use. These indexes are thought to be directly related to skidding and other wintry accident occurrence, and are expected to help make measures against wintry accidents more sophisticated, such as by supporting appropriate snow removal and anti-icing agent application through the use of measured and estimated values of road surface conditions. However, the relationship between indexes for road surface conditions and wintry accidents is currently unidentified. Under this situation, the measured and estimated index values of road surface conditions cannot lead to the calculation of the risk of traffic accident occurrence, and it is difficult to apply the measurements of road surface conditions to traffic accident countermeasures.
In this study, we aimed to verify the relationship between indexes that represent road surface
conditions and traffic accident occurrence, which is essential for improving measures against wintry
accidents through the use of measured and estimated values of those road surface conditions.

2. VERIFICATION METHOD

In winter, road surface conditions vary by time and road section. To appropriately estimate the
relationship between road surface conditions and traffic accident occurrence, it is necessary to obtain a
road surface condition value that was measured at the time and location of an accident. Measurements
obtained by fixed-point monitoring equipment, which is normally used for traffic accident analysis, may
consistently provide data for every point in time during a given period, but fixed-point monitoring
equipment cannot measure road surface conditions where the equipment is not installed, and it cannot
intensively provide data of a traffic accident linked to the road surface condition associated with that
accident. This study focused on road surface condition data measured by a continuous road surface
condition test vehicle (“the test vehicle”) to link the measurement data to the data of corresponding
traffic accidents. The test vehicle stores recently accumulated data on road surface conditions taken in
the travel direction.

Figure 1 shows the test vehicle that was used for recording the data on road surface conditions. An
infrared radiometer and a thermometer are installed at the front of the vehicle to measure road surface
temperature and temperature distribution in the travel direction. The continuous road surface friction measurement device is installed at the rear of the vehicle. As shown in Figure 2, the continuous road surface friction measurement device consists of a measuring wheel that is skewed about the yaw axis relative to the vehicle’s travel direction and an axle sensor. The sensor in the device determines the lateral force generated by the wheel while the vehicle is traveling and converts that to a Halliday friction number (HFN). The HFN varies from 0 to 100 in accordance with the slipperiness of the road surface. On slippery roads, the HFN is low.

The correlation between HFN and friction coefficients ($\mu$) is expressed by the following equation.

\[ \mu = 0.009822 \cdot HFN - 0.019804 \]

The Japanese road structure ordinance defines $\mu$ for a snow-and-ice-covered surface as 0.15 (where the HFN is approximately 35), and this value is used to calculate stopping distances on such roads after hard braking and to determine the gradients and curve radii of such roads. Additionally, we verified the relations between HFN measurements and road surfaces by using a continuous road surface friction measurement device. We clarified that the HFN ranges between 60-70 on wet road surfaces, 50-60 on slushy road surfaces, 30-50 on compacted snow or black ice, and less than 30 on other icy roads. Taking these findings into consideration, we examined the relationship between slipperiness on roads, the conditions of snow and ice on roads and traffic accident occurrence.

In this study, we extracted the traffic accidents that occurred on a road section where the surface conditions were measured (“the verification section”) during the period 90 minutes before and after the measurement time, and tagged the data on road surface condition with the data on each accident. This enabled us to sum up the number of traffic accidents for each class of index: road surface temperature and HFN. Then, we calculated road surface temperatures and occurrence frequencies of HFN in the verification section during the verification time period by using the road surface condition measurements. We added the data on daily traffic volume to the aforementioned data in order to calculate the rate of traffic accident occurrence for road surface temperature, HFN and other indexes. The rate of traffic accident occurrence for each index can be obtained by the following equation.

\[ R_j = \frac{10^8 f_j}{365.25 P L Q} \]

Where, $R_j$: the rate of traffic accident occurrence when the road condition index is $j$ (accidents/100 million vehicle per km), $f_j$: the number of traffic accidents when the road surface condition index is $j$ (accidents), $P$: the period of analysis (years), $L$: the length of the section where the road surface condition index is $j$ (km), and $Q$: the average daily traffic volume for the section where the road surface condition index is $j$ (vehicles/day).

In this study, we surveyed a 45-km section on National Highway 230 in Sapporo, Hokkaido Prefecture, and studied the traffic accidents that occurred on weekdays in January and February of 2014 and 2016 to determine the relationship between the road surface condition indexes and the rates of traffic accident occurrence. The measured data on road surface conditions and traffic accidents were linked for this study. The data were from property-damage-only accidents, which are eight times as frequent as injurious accidents in winter. Daily traffic volume, which is needed in order for us to obtain the rate of traffic accident occurrence, was obtained from the 2010 Road Traffic Census.
3. VERIFICATION RESULTS AND DISCUSSION

Figure 3 shows the relationship between road surface temperature ($T$) and the rate of traffic accident occurrence ($R_T$) at the verification section during the measurement time period. $R_T$ was normalized as 1 for traffic accidents that occurred when the road surface temperature was higher than 6 degrees Celsius and was regarded as being neither icy nor snow-covered. $R_T$ was the greatest when $T$ was approximately 0 degrees Celsius. When $T$ rose higher than 0 degrees Celsius, $R_T$ decreased with increase in $T$. $R_T$ also fell when $T$ dropped below 0 degrees Celsius. When $T < -4^\circ C$, $R_T$ was less than the $R_T$ at $T > 6^\circ C$ without snow cover or icy road surface. When $T$ became approximately 0 C during snowfall, the road surface may have been wet or frozen, depending on the amounts of sunlight, long-wave radiation and vehicle heat. $R_T$ was likely to be great when $T$ was approximately 0 degrees Celsius, probably because the road surface condition changes quickly.

![Figure 3: Relationship between the road surface temperature and the rate of traffic accident occurrence at the verification section](image)

$R_T$ was normalized as 1 for traffic accidents occurring when the HFN is greater than 80, a value that indicates a dry road. The $R_{HFN}$ became 1.6 times the $R_{HFN}$ for dry road surface when the HFN increased from 65 to 75, values that indicate a wet road surface. And the $R_{HFN}$ became 1.7 times greater than that.
of the dry road surface when the HFN increased from 55 to 65, values that indicate a slushy road surface. When the HFN rose from 45 to 55, the $R_{HFN}$ decreased to 1.3. However, the $R_{HFN}$ greatly increased to 5.0 times the $R_{HFN}$ of the dry road surface when the HFN changed from 25 to 35, the values that indicate a compacted-snow surface. When the HFN decreases further, the $R_{HFN}$ also decreases. When the HFN is lower than 25, the $R_{HFN}$ became 2.5 times to 4.5 times the $R_{HFN}$ on the dry road surface. This is probably because drivers easily recognize the risk and drive with great care when the HFN is very low, or the driving speed becomes low as the road surface conditions become poor.

As discussed above, it was verified that road surface temperature and HFN influence the rate of traffic accident occurrence. By applying the relationship between the road surface temperature/HFN and the rate of traffic accident occurrence, it is possible to estimate the sections and time periods in which traffic accidents are highly likely in winter from the data obtained by test vehicles, the road surface temperatures obtained from the Road Weather Information System (RWIS), and the HFN measurements.estimates. This may allow road administrators to implement efficient winter road management and traffic accident countermeasures, such as intensive snow removal and anti-icing-agent application on sections and at time periods in which there is a high risk of traffic accident. Under the conditions shown in Figure 4, they may remove snow or apply anti-icing agent to raise the HFN to 40 or higher when the measured HFN is less than 40, and they may minimize such administration when the HFN rises between 50 and 60.

4. CONCLUSION AND FUTURE ISSUES

This paper reported on the verification of the relationship between values of road surface conditions measured by test vehicle and the rate of traffic accident occurrence. It was found that the rate of traffic accident occurrence is great when the road surface temperature is approximately 0°C and when the HFN is below 40. We will continue studies to increase the accuracy of the relationship between road surface conditions and the rate of traffic accident occurrence by collecting more data on road surface conditions and traffic accidents.

REFERENCES

