1. INTRODUCTION

In cold regions, winter weather poses a significant hazard to road transportation. Snow and ice reduce pavement friction, and this can cause traffic delays and increase the risk of traffic accidents. For example, up to 23% of all accidents in the US can be considered winter related (Federal Highway Administration), and a study conducted in the US found that winter precipitation is associated with a 19% increase in traffic crashes and a 13% increase in injuries compared to dry conditions (Black and Mote, 2015). A study conducted in Sweden found that road surface slipperiness was a factor in 50% of all accidents in winter (Norrman et al., 2000). In Japan’s northernmost island of Hokkaido, skidding accidents account for 90% of the winter-type traffic accidents (Takahashi et al., 2014).

Although vehicles are widely equipped with technologies designed to improve driving stability under winter road conditions, such as the anti-lock braking system (ABS) and electronic stability control (ESC), and these technologies do contribute to reductions in winter accidents, drivers’ visual assessment of road surface conditions still remains a critical element of safe winter driving. Road administrators conduct winter maintenance operations to provide road surfaces that are safe for the driving public. Although various friction-measuring devices have been developed and utilized, a number of road administrators still use visual inspection to assess winter road conditions (World Road Association, 2014). However, this visual determination is thought to be problematic, because it is a subjective measure of road safety that can be easily affected by experience and visibility conditions (Al-Qadi et al., 2002). If drivers mistakenly determine a slippery surface as “not slippery”, there is a risk of skidding and subsequent accident from unexpected loss of traction.

This study investigated the accuracy of visual assessment of winter road conditions through comparative tests between visual determinations of winter road conditions and friction values.

2. STUDY METHOD

2.1. Experimental site and test vehicle

The roadways selected for this study are the national highways Route 5 and Route 274, which are typical urban arterial roadways running through the northern part of the City of Sapporo. The total length of the test section was 21 km. In this study, a locked-wheel friction tester (LWFT), which is used as the standard friction measuring device in Japan (Tokunaga et al., 2008), was used as the test vehicle.
The LWFT has a measuring wheel that is installed on the left wheel path in the travel lane. The operator applies the brakes, measures the torque for one second after the measuring wheel fully locks, and then determines the corresponding friction value ($\mu$).

![Figure 1: Locked-wheel friction tester (LWFT).](image)

### 2.2. Procedure
The LWFT carrying the test subject ran on the test section at 40 km/h, and visual assessment of the road surface conditions and friction measurement were simultaneously conducted. A non-professional driver in his 30’s who regularly commutes to work by car was recruited as the test subject. The test subject has 10 years of driving experience and wears eyeglasses. The measurements were conducted during daytime and nighttime to obtain data under various road conditions and driving environments. Road conditions were classified into 6 categories by referring to the classification applied by road managers in Japan: dry surface, wet surface, slush, loose snow, compacted snow and ice.

### 3. STUDY RESULTS
Road conditions determined visually and friction values obtained at the time of visual assessment are shown in a side-by-side boxplot (Figure 2). The basic statistics and occurrence of outliers for each surface condition are shown in Table 1 and Table 2, respectively. The bottom and top of each box are the first and third quartiles of friction values, and the line inside the box is the median. The ends of the whiskers represent 1.5 interquartile ranges. Outliers are defined as data outside the whiskers.

Measurements (i.e., visual assessment and friction measurement) were conducted 3,982 times in total. The most numerous road surface visual assessment was “wet”, accounting for 2,844 (71%) of the measurements. With regard to the occurrence of outliers, cases where the friction value was low even though the surface condition was visually assessed as “dry” or “wet” and those where the friction value was high even though the surface condition was visually assessed as “ice” were frequently seen. 8.8% of road surfaces that were visually assessed as “dry” and 7.3% of road surfaces that were visually assessed as “wet” were determined as outliers.
This means that the test subject mistakenly evaluated very slippery surfaces as being safe. The formation of black ice might be a cause of the erroneous assessment. Black ice is thin, new ice that forms when water freezes on the road, appearing dark in color because of its transparency (American Meteorological Society). Therefore, drivers sometimes find it difficult to distinguish between black ice and wet road by the naked eye. The result indicates that there is a risk of skidding and subsequent accident from unexpected loss of traction due to the difficulty of distinguishing black ice from dry and wet surfaces by the naked eye.

In contrast, 11% of road surfaces that were visually assessed as “ice” were determined as outliers. Although the risk of skidding is lower in the case where dry or wet surfaces are mistakenly assessed as icy surfaces than in the case where slippery road surfaces are mistakenly assessed as dry or wet, these results indicate the difficulty of distinguishing icy surfaces from dry and wet surfaces by the naked eye.

![Figure 2: Road surface conditions determined by visual assessment and friction values determined by LWFT.](image)

<table>
<thead>
<tr>
<th>Road condition (visually assessed)</th>
<th># of data</th>
<th>Average</th>
<th>Median</th>
<th>Max.</th>
<th>Min.</th>
<th>25%tile</th>
<th>75%tile</th>
<th>Standard deviation</th>
<th>Dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>113</td>
<td>0.81</td>
<td>0.84</td>
<td>0.99</td>
<td>0.26</td>
<td>0.79</td>
<td>0.90</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>Wet</td>
<td>2,844</td>
<td>0.74</td>
<td>0.78</td>
<td>1.05</td>
<td>0.14</td>
<td>0.69</td>
<td>0.84</td>
<td>0.15</td>
<td>0.02</td>
</tr>
<tr>
<td>Slush</td>
<td>337</td>
<td>0.40</td>
<td>0.37</td>
<td>0.85</td>
<td>0.21</td>
<td>0.32</td>
<td>0.48</td>
<td>0.13</td>
<td>0.02</td>
</tr>
<tr>
<td>Loose snow</td>
<td>59</td>
<td>0.37</td>
<td>0.36</td>
<td>0.68</td>
<td>0.21</td>
<td>0.31</td>
<td>0.43</td>
<td>0.09</td>
<td>0.01</td>
</tr>
<tr>
<td>Compacted snow</td>
<td>353</td>
<td>0.37</td>
<td>0.38</td>
<td>0.58</td>
<td>0.17</td>
<td>0.33</td>
<td>0.41</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Ice</td>
<td>276</td>
<td>0.48</td>
<td>0.44</td>
<td>0.97</td>
<td>0.14</td>
<td>0.37</td>
<td>0.53</td>
<td>0.18</td>
<td>0.03</td>
</tr>
</tbody>
</table>
In this study, the appearance frequency of friction values for each surface condition determined by visual assessment was also calculated. Although a few of the visual assessments are incorrect, it can be said that snowy/icy surfaces can be basically distinguished from non-snowy/icy surfaces. In addition, analyses of data obtained during nighttime and daytime were conducted. During the daytime, although outliers are observed for the wet, slush and icy surfaces, outliers are rarer in daytime than at nighttime. There are surface conditions that were more rarely observed in daytime than at nighttime, but the results suggest that it is easier for drivers to distinguish road surface conditions by the naked eye in daytime than in nighttime. Further analyses and results described above will be discussed in the full paper.

4. CONCLUSIONS

In this study, a field experiment was conducted in which visual assessment of road surface conditions and friction measurements were simultaneously performed in order to investigate the accuracy of visual assessments of winter road conditions. The study found erroneous determinations, with slippery road surfaces being mistakenly assessed as dry or wet surfaces and dry or wet surfaces being mistakenly assessed as slippery. These erroneous determinations were observed more frequently at night, when the driver’s surroundings are difficult to see, than during the daytime. Despite some erroneous visual assessments, the study also found that snowy/icy surfaces can be basically distinguished from non-snowy/icy surfaces.

The erroneous assessment of winter road conditions, especially when icy surfaces are mistakenly assessed as dry or wet surfaces, can increase the risk of skidding and subsequent accident from unexpected loss of traction. Since human error is found to be a contributing factor in over 90% of traffic accidents (Treat et al., 1979., Rumar, 1985), it is necessary to avoid drivers’ erroneous determinations which occur under winter driving conditions in order to further reduce the number of traffic accidents and traffic injuries. To this end, the development and utilization of remote sensing technologies for road surface conditions and autonomous driving technologies that can work effectively even under winter conditions is required.

REFERENCES


