Safety Assessment of the Level Crossing in Cold, Snowy Regions

Naoki HATAKEYAMA
Safety Analysis Laboratory, Human Science Division

Yumeko MIYACHI

Yasushi KURIHARA
Meteorological Disaster Prevention Laboratory, Disaster Prevention Technology Division (Former)

In cold snowy regions, the number of level crossing accidents in winter is higher than in other seasons, therefore weather conditions, such as snow showers, are considered to have a large influence on accident occurrence. Previous studies have assessed the safety of level crossings solely from equipment data with no consideration of weather conditions. The purpose of this study, therefore, is to develop a method for assessing level crossing safety which takes into account weather condition factors. The method was applied in a case study and its assessment precision was improved.

**Keywords**: level crossing accident, safety assessment, cold, snowy region, weather factor, traffic environment

1. Introduction

The number of level crossing accidents - including train accidents such as train collisions, derailments and fires associated with level crossing accidents - have decreased by half over the 20 years from 1993 to 2012. This trend however has leveled off in recent years (Fig. 1(a)). And yet the proportion of level crossing accidents – not including the train accidents associated with level crossing accidents - in 2012 fiscal year accounted for nearly 40 % of all railway accidents which totaled 811 (Fig.1(b)). These facts show that level crossing accidents are still a key problem for railway companies.

The safety of level crossings can be assessed statistically, and through understanding factors which threaten safety, which can then help to determine the priority for countermeasures to prevent level crossing accidents. Previous studies on level crossing safety assessment [2-5], analyzed the safety of level crossings based on accident data and equipment data, without taking sufficient account of weather conditions (railway accident data contains train delays which occur at level crossings, and the same definition is used in the present paper). At the same time, the number of level crossing accidents each month in cold, snowy regions (Fig.2), increases in winter whereby it has been deemed that wintry conditions – such as snowfall, snow coverage etc. – must have some influence on the occurrence of level crossing accidents. This study therefore sets out to develop a method for analyzing the safety assessment of level crossings in cold, snowy regions, considering snowfall or snow coverage as a weather factor in addition to accident or equipment data [6] (Fig. 3). The traffic environment around a level crossing was also taken as a factor in railway accidents because it was found that the distance from a level crossing to the nearest road intersection and the amount of car traffic at the intersection had a large influence on the occurrence of level crossing accidents (Fig.3).
2. Characteristics of cold, snowy regions

2.1 Meteorological data

The influence of weather conditions on level crossing accidents was examined by analyzing winter weather data (December to March each year) over three years (2007 - 2009 fiscal year). Data for analysis was collected from weather stations of the Japan Meteorological Agency closest to each level crossing. Values were therefore approximate because it was not possible to obtain weather data specifically for each level crossing.

Four weather condition data indices were used - average temperature, cumulative rainfall, cumulative hours of sunshine and maximum snow depth. Cumulative rainfall also contained the amount of water from melting snow.

2.2 Analysis of weather conditions

The indices - average temperature, cumulative rainfall, cumulative hours of sunshine and maximum snow depth - were applied to the following three conditions and the cumulative relative frequency of for each item of data was calculated for each condition.

1. Weather data for the 24 hours preceding an accident around each level crossing for one month (hereinafter referred to as “24 h data prior to accident”).

2. Daily weather data for each month around each level crossing (LC) where the accident occurred (hereinafter referred to as “daily data around accident LCs”).

3. Daily weather data for each month around all level crossings (hereinafter referred to as “daily data around all LCs”).

For example, Fig. 4 shows the cumulative relative frequency of average temperatures in March in “24 h data prior to accident,” “daily data around accident LCs” and “daily data around all LCs.” The cumulative relative frequency for “24 h data prior to accident” is 72% at 0 degree, which means that there was an average temperature of 0 degree or less in 72% of accident weather conditions. On the other hand, the cumulative relative frequency of 0 degree or less in “daily data around accident LCs” weather data prior to accident” was 47.6% and in the “daily data around all LCs” it accounted for 55%. These facts show that level crossing accidents are more likely to occur if the average temperature is 0 degree or less on just one day, whereas if an area has a high rate of average temperatures of 0 degrees or less, then there is less likelihood of an accident.

The data was used to abstract conditions under which level crossing accidents occur easily. To do this, the relative frequency was calculated between “24 h data prior to accident” and “daily data around accident LCs” and between “daily data around accident LCs” and “daily data around all LCs” in order to identify the conditions which produced the largest difference value. Figure 5 shows the difference between “24 h data prior to accident” and “daily data around all LCs” (● in Fig. 5) and that between “daily data around accident LCs” and “daily data around all LCs” (▲ in Fig. 5).
in Fig. 5), taken from Fig. 4. The difference between “24 h data prior to accident” and “daily data around all LC’s” reaches its maximum at 0 degree or less, and the difference between “daily data around accident LC’s” and “daily data around all LC’s” reaches its maximum at 1 degree or less, so that in March level crossing accidents tend to occur on days when the average temperature is 0 degree or less and they tend to occur in areas where the average temperature frequently exceeds 1 degree.

These results were used to produce the Weather Condition index as follows: first, the largest difference values in the cumulative relative frequencies between “24 h data prior to accident” and “daily data around all LC’s” or between “daily data around accident LC’s” and “daily data around all LC’s” were sought. The days on which the largest differences occurred were then added together for each month from December to March at each level crossing. This process was applied to data from a cold, snowy region from FY 2007 to FY 2009 which produced the indices shown in Table 1.

### 3. Other factors other than cold, snowy conditions

After applying the method to data from a cold, snowy region for 3 years (FY 2007 – 2009) large differences appeared between actual and estimated values for a number of level crossings (Fig. 6). Field investigations were therefore conducted around those level crossings to identify other influencing factors aside from equipment data, such as traffic volumes for those level crossings, existence of parking lots or side roads, distance to the level crossing, etc. This investigation showed that for level crossings where a large difference had been found, there were other factors such as the large width of the crossing, short distance between the level crossing and the nearest intersection and high volumes of traffic at the nearest intersection.

An analysis was made of the relationship between the number of accidents and “the distance between the level crossing and the nearest road intersection” by using the equipment data.

It was found that level crossings at a distance to the nearest road intersection of less than 10 meters had significantly higher accident rates than other level crossings (Fig. 7).

Since it is not possible to obtain data on “traffic volume for the nearest road intersection” from LC equipment data, level crossings with a distance of less than 10 m to

![Fig. 6 Result after applying previous method [5] to level crossings in cold, snowy regions](image)

### Table 1 Weather factor index

| No. | Weather factor                        | Time frame       |
|-----|---------------------------------------|------------------|
| ①  | Daily rain fall                       | Dec.-Mar. Days more than 0mm |
| ②  | Daily average temperature             | Dec. Days less than 2℃  |
|     |                                       | Jan. Days less than 1℃  |
|     |                                       | Feb. Days less than -3℃  |
|     |                                       | Mar. Days less than 0℃  |
| ③  | Daily cumulative hours of sunshine    | Dec. Days less than 5h |
|     |                                       | Jan. Days less than 1h |
|     |                                       | Feb. Days less than 3h |
|     |                                       | Mar. Days less than 7h |
| ④  | Daily maximum snow depth              | Dec. Days more than 5cm |
|     |                                       | Jan. Days more than 25cm |
|     |                                       | Feb. Days more than 65cm |
|     |                                       | Mar. Days more than 60cm |
| ⑤  | Daily average temperature             | Dec. Days more than -3℃  |
|     |                                       | Jan. Days more than -5℃  |
|     |                                       | Feb. Days more than -5℃  |
|     |                                       | Mar. Days more than 1℃  |
| ⑥  | Daily cumulative hours of sunshine    | Dec. Days less than 4h |
|     |                                       | Jan. Days less than 6h |
|     |                                       | Feb. Days less than 3h |
|     |                                       | Mar. Days equal to 0h |
| ⑦  | Daily maximum snow depth              | Dec. Days equal to 0cm |
|     |                                       | Jan. Days less than 50cm |
|     |                                       | Feb. Days less than 30cm |
|     |                                       | Mar. Days less than 25cm |

① stands for both conditions for “24 h prior data to accident” and “daily data around all LC’s”
②, ③ and ④ stand for conditions for “one-month daily LC weather data prior to accident”
⑤, ⑥ and ⑦ stand for conditions of “daily data around all LC’s”
the nearest intersection were divided into three groups: “LC leading directly onto a main road with no space for evacuation,” “LC leading directly onto a main road with space for evacuation” and “LC leading onto a minor road” and compared these conditions with the average of the number of accidents. Results showed that “LC leading directly onto a main road with no space for evacuation” had a significantly higher average number of accidents than other types of LC (Fig. 8).

Based on the above outcome, it was decided to use the following three conditions as the nearest road intersection less than 10 meters, “LC leading straight onto main road” and “no space for evacuation” (Fig. 9) as traffic environment factors.

4. New method for the assessment of level crossing safety

4.1 Weather factors in cold, snowy regions from previous research

Weather factors in cold, snowy regions do not influence level crossing safety in the same way all year round. A study was conducted to identify the periods of the year where the method from previous research did not function, in order to identify the times of the year when cold, snowy region related factors could be applied. First, LC accident data from a 3-year survey in cold, snowy regions (FY2007 – 2009) was divided into monthly units, to which the method from previous research was applied. Comparison of the correlation coefficients for accidents and the real values showed that they were as low as 0.49 from December to January and 0.37 from February to March. The year was thus split into three periods – April to November (hereinafter referred to as “spring to autumn”)), December to January (hereinafter referred to as “winter I”) and February to March (hereinafter referred to as “winter II”). The weather factors were to be added to the data in winter I and winter II.

4.2 Method based on Poisson regression analysis

Poisson regression analysis was applied, which is a process commonly applied for the analysis of rare events, to the level crossing safety assessment in this study. The number of railway accidents was used as the objective variable and the accident factors as the explanatory variables as shown in (1).

\[
y = \sum \exp \left( \sum W_i \times F_j \right)
\]

(1)

where \( y \) is the estimated value of the number of railway accidents, \( W_i \) represents the values weighted by Poisson regression analysis, and \( F_j \) is the accident factor. Meanwhile, \( i \) stands for seasons (“spring to autumn,” “winter I,” “winter II”), \( j \) stands for the different accident factors. Accident factors were chosen by stepwise selection using AIC criteria [7] because the explanatory variables are not always effective for explaining the railway accidents.

In addition to the extracted equipment related data, other information was included among the possible factors causing the accident, such as amount of snowfall and other meteorological conditions and traffic data for the area around the crossing. Table 2 shows the degree of influence of each of the accident factors selected as a cause for the accident after applying the method.
### 4.4 Observations about the new method

Table 2 reveals a tendency for accidents to occur more on days with less hours of sunshine, i.e. winter I, and on days with heavy snowfall, in areas where the average temperature is not extremely low, i.e. winter II. Regarding non-meteorological factors, Table 2 shows a quantitative decrease in the estimated number of accidents when an alarm is installed on the crossing, especially with a crossing gate or lifting barrier. Results also illustrate that accidents occur more frequently at level crossings located at less than 10 meters from the intersection of a national road with no space for evacuation at any time of year, although the problem is worse in winter. The latter results therefore indicate that the two conditions “LC at less than 10 m from the intersection of a main road” and “no space for backing or evacuation” – are in fact influenced by the season.

Consequently, it is deemed that the results of this research can be applied to the following three domains:

(A) Safety assessment of level crossings;
(B) Diagnosis of accident factors at level crossings;
(C) Estimation of countermeasure effectiveness on decreasing the number of accidents.

The safety of each level crossing can thus be assessed (A) by inputting the values of both accident factors for each level crossing and their weighted values from Table 2 into the safety assessment equation shown as (1). This allows a statistical assessment of the level crossing. It is assumed that this approach can be used to identify change in LC safety due to installation of new facilities or alteration of its environment.

Diagnosis of accident factors for each level crossing (B) is achieved by obtaining values for each accident factor using the LC safety assessment equation, thereby ascertaining their influence on accident occurrence. For example, this analysis can show whether the cause of a railway accident is a large amount of car traffic or pedestrian traffic etc. Figure 10 (a) and (b) shows the results of the diagnosis for each accident factor.

Estimation of countermeasure effectiveness on decreasing the number of accidents (C) makes it possible to estimate quantitatively the impact of a countermeasure on level crossing accidents in the future. Figure 10 (a) shows the influence of each accident factor on the number of accidents at each level crossing which is assumed alternately to be equipped with a crossing alarm, located less than 10 meters from a main road intersection and without space for evacuation in cold, snowy regions. Following this method, the number of level crossing accidents is estimated at 52.6 over 10 years. On the other hand, Fig. 10 (b) shows the case where a LC is equipped with a gate or lifting barrier with alarm, and with a space for evacuation. The results show that the estimated number of level crossing accidents falls to 2.5. Utilizing this method allows prior estimation of impact of a countermeasure on the decrease in number of level crossing accidents.

### 5. Conclusion

This study proposed a method for assessing the safety of level crossings in cold, snowy regions by considering winter weather factors. This method was applied to level crossings in cold, snowy regions, producing a correlation coef-
sufficient between estimated and real values of 0.81. Although the proposed method does not offer a complete explanation of the factors underlying LC accidents in cold, snowy regions, it does give adequate insight into these causes. The proposed method can be employed to assess LC safety, diagnose LC accident factors in all kinds of regions including cold, snowy regions, be applied to estimate the effectiveness of measures to improve LC safety.

References

[1] Ministry of Land, Infrastructure, Transport and Tourism, “Information Relating to The Safety of the Railway Transport (FY2012),” 2013 (in Japanese).
[2] Ikeda, T., Ootake, H., "A Study of Countermeasure of Level crossing Accidents (9) – An Approach of Prior Assessment of Accident Risk in Railway Crossings with Crossing Bars and without Security Guards -," Bulletin of Railway Labor Science Research Institute, No. 35, pp. 95-114,1981 (in Japanese).
[3] Fukuda, H., "A Study for Evaluation Criteria of Railway Crossing Hazard," RTRI Report. Vol. 3, No. 6, pp.9-16, 1989 (in Japanese).
[4] Matsumoto, S., "An Assessment Method of Risk and Countermeasure in Railway Crossing," proceedings on 207th RTRI monthly symposium, 2007 (in Japanese).
[5] Hatakeyama, N., Matsumoto, S., "A Safety Assessment of Railway Crossing by Using the Frequency of the Event That Automobiles/Pedestrians Exist near the Crossing Gate during Shut of Crossing Gate," The 24th Fall Reliability Symposium in Reliability Engineering Association of Japan, pp.7-10, 2011 (in Japanese).
[6] Hatakeyama, N., Miyachi, Y., Kurihara, Y., Kaburaki, T., "A Safety Assessment of Railway Crossing in Consideration of Winter Weather Condition in Snowy Cold Region," The 21th Spring Reliability Symposium in Reliability Engineering Association of Japan, pp.43-46, 2013 (in Japanese).
[7] Akaike, H., "Information theory and an extention of the maximum likelihood principle," proceedings of the 2nd International Symposium on Information Theory, Petrov, B. N., and Caski, F., pp. 267-281, 1973.

Authors

Naoki HATAKEYAMA, Dr. Eng.
Assistant Senior Researcher, Safety Analysis Laboratory, Human Science Division
Research Areas: Human Factors

Yumeko MIYACHI, Dr. Eng.
Senior Researcher, Safety Analysis Laboratory, Human Science Division
Research Areas: Applied Psychology, Management Engineering

Yasushi KURIHARA
Researcher, Meteorological Disaster Prevention Laboratory, Disaster Prevention Technology Division (Former)
Research Areas: Disaster Prevention