Application of Safety Management Process for the Safety Analysis of Level Crossing

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Abstract - This paper studies the occurrence of level crossing accident in Korea using the Safety Management Process (SMP) method. It examines the relationship between the level crossing accident and the factors that contribute to it. The results show that the factors affecting the level crossing accident are primarily related to the design and operation of the crossing, as well as the driver's behavior. The findings suggest that improving the design and operation of the level crossing, as well as educating drivers about safety, can significantly reduce the occurrence of level crossing accidents.

1. Introduction

Because railway system is a mass transit system, the influence of the small accident of the system are inconceivable even though. So railway transportation system is devoting a great portion for the safety. Level crossing accidents have a large portion of the whole railway accidents as described in the Fig. 1.1, railway accident data from 1997 to 2002 in Korea. In this status, we are trying to find the accident rate of level crossing in Korea.

![Fig. 1.1 Accidents for train and level crossing](image)

Until now, there are several equations to find the Level Crossing accident prediction such as Peabody Dinnick Formula, New Hampshire Index, National Cooperative Highway Research Program (NCHRP) report 50 and U.S. Department of Transportation (DOT) Accident Prediction Equations, that was used to predict the occurrence of the level crossing accident. Nowadays, system safety analysis procedure described in the EN50126 that was recently converted to the IEC62278 is emphasized in the railway industry. In this paper, we compare existing Level crossing accident prediction equation to the safety analysis procedure.

2. The classification of level crossing in Korea

Level crossing in Korea is classified to the 3 types according to the safety level described in Table 2.1. Fig. 2.1 represents a configuration of general level crossing. The safety analysis is carried out focused on the type 1.

![Fig. 2.1 Composition of Level crossing](image)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Barrier, alarm, and sign are operated day and night or operation staff observe the related Level Crossing</td>
</tr>
<tr>
<td>Class II</td>
<td>Alarm, and sign are just equipped and operated</td>
</tr>
<tr>
<td>Class III</td>
<td>Only sign is equipped</td>
</tr>
</tbody>
</table>

3. Accident prediction equation for level crossing

3.1 Level Crossing Accident Prediction Equations in Korean

Several indices and equations such as Peabody Dinnick Formula, New Hampshire Index, NCHRP report 50 and U.S. DOT Accident Prediction Equations, are used to predict the occurrence of the level crossing accident. New accident prediction equation for level crossing is developed in Korea based on that of the U.S. DOT. The equation is represented in Table 3.1.

![Table 3.1 Factors of accident prediction equations for level crossing in Korea](image)

\[
a = K \cdot E \cdot M \cdot T \cdot D \cdot H \cdot P \cdot M \cdot S \cdot H \cdot H \cdot L
\]
<table>
<thead>
<tr>
<th>Category</th>
<th>Class I (Gates)</th>
<th>Class II (Flashing Lights)</th>
<th>Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>0.001088</td>
<td>0.003646</td>
<td></td>
</tr>
<tr>
<td>EI</td>
<td>(e^{(c \cdot 10^2)})</td>
<td>(e^{(c \cdot 10^2)})</td>
<td>0-300</td>
</tr>
<tr>
<td>MT</td>
<td>0.2912mr</td>
<td>0.1088mr</td>
<td>1-6</td>
</tr>
<tr>
<td>DT</td>
<td>(1,2,3,4,5)</td>
<td></td>
<td>1-1.3</td>
</tr>
<tr>
<td>HP</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MS</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>HT</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>HL</td>
<td>(e^{0.1036(A+1)})</td>
<td>(e^{0.1380(A+1)})</td>
<td>1-3</td>
</tr>
</tbody>
</table>

where
\(a\) = un-normalized accident prediction (accidents/year at the crossing)
\(K\) = constant for initial values at 1.0
\(E\) = factor for exposure index based on product of highway and train traffic
\(MT\) = factor for number of main tracks
\(DT\) = factor for number of through trains per day during daylight
\(HP\) = highway paved factor
\(MS\) = factor for maximum timetable speed
\(HT\) = factor for highway type
\(HL\) = factor for number of main lanes
\(c\) = annual average number of highway vehicles per day
\(t\) = average total train movements per day
\(mt\) = number of main tracks
\(d\) = average number of through trains per day during daylight
\(hp\) = highway paved (yes=1, no=2)
\(ms\) = maximum timetable speed
\(ht\) = highway type factor value
\(hl\) = number of highway lanes

3.2 Application of the accident prediction equation to the specific level crossing in Korea

A level crossing is selected for the application to the above equation to predict its accident rate. The value of the related parameter is as follows.
\(c = 1.489\) \(t = 74\) \(mt = 2\) \(hl = 2\)

As a result, annual accident rate of level crossing \((a)\) is 0.132886

4. Safety Analysis procedure

4.1 The weak point of the existing accident prediction equation

Those equations mentioned above simply calculate the frequency of level crossing accident with the parameters, e.g., train traffic, road traffic, and numbers of lane and track, etc. Because the level crossing accidents are related to the many factors, more parameters have to be involved to analyze the safety of level crossing, and the equations also present the countermeasures. In addition, the equations are just possible to apply the level crossing accident. In this situation, safety analysis procedure is newly proposed to apply the whole system.

4.2 Proposed safety analysis procedure

Until now, many countries leading railway industries have their own system assessment process according to their situation of the train control system. Since EU is set up in Europe, many different safety analysis procedures have been adjusted and unified to EN50126. Application of the standard to the safety analysis is mandatory to the railway industry in Europe. Based on this standard, new safety analysis procedure is established in Korea.\(^{1,4}\)

The proposed safety analysis procedure has the 7 steps, such as (1) Hazard identification, (2) Causal analysis, (3) Consequence analysis, (4) Loss analysis, (5) Countermeasure analysis, (6) Impact analysis, and (7) Demonstrations of As Low as Reasonable Practicable (ALARP) compliance. The safety analysis has to be performed at the beginning of the system life cycle. As the result of this safety analysis, the system safety requirement may be derived. Figure 4.1 presents the safety analysis procedure.

![Fig. 4.1 Safety Analysis Process](image)

There are several analysis method may be applicable in each step. Table 4.1 represents a guideline for the selection of more appropriately applicable method in the analysis.

<table>
<thead>
<tr>
<th>Table 4.1 Proposed safety analysis techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard identification</td>
</tr>
<tr>
<td>General</td>
</tr>
<tr>
<td>Simple system</td>
</tr>
</tbody>
</table>

4.3 Application of the safety analysis procedure to the level crossing

4.3.1 Hazard identification

To identify system hazard, Checklist, FMEA(Failure Mode and Effect Analysis), and HAZOP(Hazard and Operability Studies) are generally used. The general hazards for railway system are already listed in Engineering Safety Management(ESM) of the Network Rail in UK. Several hazards related to level crossing are selected from the above reference and listed in Table 4.2.\(^{7}\)

In this paper, the safety analysis is carried out for a hazard, "Failure of Level Crossing to Protect Public from Train".

<table>
<thead>
<tr>
<th>Table 4.2 Hazards of level crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>
4.3.2 FTA for Causal Analysis

Causal Analysis has to be conducted to estimate the annual frequency of occurrence of specified hazard. In this paper, Fault Tree Analysis (FTA) to evaluate the frequency of occurrence of the hazard is presented on Fig. 4.2.

![FTA for causal analysis](image)

If the average 74 trains traverse the crossing for 20 hours per day and protection is required for the crossing of each train for a period of approximately 90 seconds, then the probability of the event 'Train near level crossing' is as follows:

- Probability = (90 x 74) / (3600 x 20) = 0.09

The other probabilities may be derived by failure rate for each event:

- Level Crossing Controller indicates route clear when occupied = 9.7 x 10^{-2} per annum.
- Track circuit failure = 3.3 x 10^{-2} per annum.
- Communication system failure = 8.4 x 10^{-2} per annum.
- Timing sequence failure = 2 times per annum.

Using the above values, the probability of the hazard has been determined as follows.

\[ (3.3 \times 10^{-2} + 8.4 \times 10^{-2} + 9.7 \times 10^{-2} + 2.0) \times 0.09 = 0.2 \text{/year} \]

Note that the probability of the hazard is dominated by the probability for the event "Timing sequence failure".

4.3.3 ETA for Consequence Analysis

Event Tree Analysis (ETA) can be used for the consequence analysis. This is inductive analysis method where the hazard is displayed at the bottom of the structure. The simple Event Tree Analysis constructed to investigate the consequences of the hazard is presented in Fig. 4.3.

If we assumed that 300 pedestrian and 1,189 road user use a specific Level Crossing for 20 hours per day at a specific level crossing in Korea, taking 9 seconds and 5 seconds to traverse the crossing respectively, then the probability of the pedestrian and road user being present at the Level Crossing is as following respectively.

Probability pedestrian = \( \frac{300 \times 9}{3600 \times 20} \) = 3.8 x 10^{-2}

Probability road user = \( \frac{1,189 \times 5}{3600 \times 20} \) = 8.3 x 10^{-2}

![ETA for consequence analysis](image)

4.3.4 Loss analysis

Loss analysis has to be conducted to determine the magnitude of potential safety losses associated with each hazard. Table 4.3 represents details of the loss conducted. The incidents have been taken from the causal analysis and consequence analysis. The following incidents were identified for the safety analysis of level crossing.

<table>
<thead>
<tr>
<th>Safety condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train hits pedestrian</td>
</tr>
<tr>
<td>Near miss (pedestrian, road user)</td>
</tr>
<tr>
<td>Train strikes road user</td>
</tr>
<tr>
<td>Road user strikes level crossing</td>
</tr>
</tbody>
</table>

It has been assumed that no losses arise from a safety condition. Near miss may bring a commercial loss. The others result both safety and commercial losses. Commercial losses include damage to trains, track and other items of infrastructure, as well as train delay penalties. Safety losses consist of fatality, minor or major injury.

- Train hits pedestrian:
0 injuries (passengers), 1 fatality (public)
- Train strikes road user:
  2 minor injuries (passengers), 1 major injury (public)
- Road user strikes Level Crossing:
  1 minor injury (passengers), 1 major injury (public)

Each incident has been converted to a corresponding Potential Equivalent Fatality (PEF) using currently accepted agreement.
- 1 Fatality = 10 Major injuries
- Major injury = 20 Minor injuries

The potential equivalent fatality is represented in Table 4.3. The annual frequency of each incident has been determined by multiplying the estimated frequency of the hazard derived by causal analysis to the estimated probability of the hazard deduced by consequence analysis.

<table>
<thead>
<tr>
<th>Incident</th>
<th>Frequency (per annum)</th>
<th>Safety loss per incident (PEF)</th>
<th>Safety loss per annum (PEF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train hits pedestrian</td>
<td>3.8×10⁻²</td>
<td>-</td>
<td>3.8×10⁻²</td>
</tr>
<tr>
<td>Near miss (pedestrian)</td>
<td>3.8×10⁻¹</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Near miss (road user)</td>
<td>1.26×10⁻³</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Train strikes road user</td>
<td>1.0×10⁻⁴</td>
<td>10⁻²</td>
<td>1.0×10⁻⁴</td>
</tr>
<tr>
<td>Road user strikes LC</td>
<td>2.4×10⁻⁶</td>
<td>5×10⁻⁵</td>
<td>2.4×10⁻⁶</td>
</tr>
<tr>
<td>Total per annum</td>
<td>2.2×10⁻⁵</td>
<td>4.2×10⁻⁵</td>
<td></td>
</tr>
</tbody>
</table>

If the safety analysis is performed to the same level crossing analyzed at the accident prediction equation, it is found that the accident rate per year of the level crossing is 0.00246 that is the summation of the frequency for all incidents.

5. Comparison between accident prediction equation and safety analysis procedure

Comparison analysis between accident prediction equation and the safety analysis procedure is carried out. The data of level crossing to be compared is categorized to 2 divisions according to the traffic of train and vehicle. The comparison analysis is carried out targeted on heavy train traffic in level crossing. The result is described in the fig. 5.1. The value of accident prediction equation is generally higher than that of safety analysis procedure. But the value is almost same.

6. Conclusion

In this paper, we investigated the railway accident status. The level crossing accident has the majority of the railway accident. Until now, several accident prediction equations are used to predict the accident rate of level crossing. Safety analysis procedure is another method for the level crossing accident prediction.

The result of the comparison analysis represents that those methods has almost same value. But the safety analysis procedure gives us more benefit than the other method. More detail analysis through the lifecycle including operation and maintenance conditions is possible. On the other hand, the countermeasure analysis, Impact analysis, and demonstration of ALARP compliance provide quantitatively the countermeasure to protect the accident caused by hazards, the effects of the countermeasure applied to reduce the effects of hazards, and the feasibility for the compliance of cost & benefit, respectively.

[Reference]