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철도건널목으로의 안전관리체계 적용

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

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Abstract - 철도 운전사고의 대부분을 차지하는 철도건널목에 대한 기존의 사고예측식은 국외의 경우 Peabody Dimmick Formula, New Hampshire Index, National Cooperative Highway Research Program(NCHRP) report 50, U.S. Department of Transportation(DOT) 사고예측식 등을 이용하고 있었으며, 국내의 경우, U.S. DOT 사고예측식의 입력변수를 다변량 분석법을 이용하여 국내에 맞게 조정한 사고예측식을 이용하고 있다. 그러나 위에서 제시한 철도건널목 사고예측식은 철도건널목에서 발생하는 사고를 단순히 철도통행량, 도로통행량, 선로수, 도로수 등의 요인에 국한하여 분석한 것이고, 사고예측식 자체가 철도건널목에만 국한된다는 맹점을 안고 있어서 철도건널목장치라든지 철도건널목을 이용하는 사람들의 성향 등, 여러 인자를 고려한 철도건널목에서의 안전성분석 및 대책을 제시할 필요가 있다. 본 논문에서는 철도건널목장치를 포함하여 다른 시스템에도 범용적으로 적용할 수 있고, 제한된 변수에만 국한하지 않아 여러 사항을 고려할 수 있는 안전성분석 절차를 제시하였는데 이 안전성 분석 절차를 철도건널목에 적용함으로써 시스템의 위험요인을 분석하고, 이에 대한 원인 및 결과, 손실을 도출한 후 대책을 제시할 수 있었다.

1. Introduction

Because railway system is a mass transit system, the influences 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.

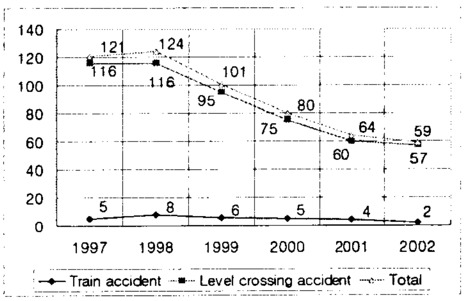


Fig. 1.1 Accidents for train and level crossing [5]

Until now, there are several equations to find the Level Crossing accident prediction such as Peabody Dimmick 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 I.

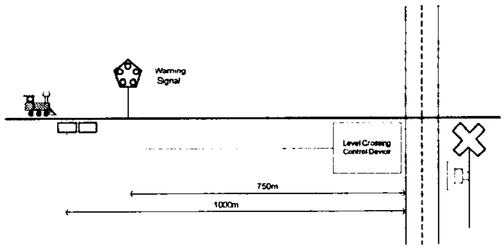


Fig. 2.1 Composition of Level crossing

Table 2.1 Types of level crossing in Korea railway network

Classification	Description
Class I	Barrier, alarm, and sign are operated day and night or operation staff observe the related Level Crossing
Class II	Alarm, and sign are just equipped and operated
Class III	Only sign is equipped

3. Accident prediction equation for level crossing

3.1 Level Crossing Accident Prediction Equations in Korean

Several indices and equations such as Peabody Dimmick 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. [6]

Table 3.1 Factors of accident prediction equations for level crossing in Korea

$$a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL$$

Category	Class I (Gates)	Class II (Flashing Lights)	Boundary
K	0.001088	0.003646	
EI	$\left[\frac{(c*t)+0.2}{0.2}\right]^{0.3116}$	$\left[\frac{(c*t)+0.2}{0.2}\right]^{0.2953}$	0~300
MT	$e^{0.2912mt}$	$e^{0.1088mt}$	1~6
DT	1	$\left[\frac{(d)+0.2}{0.2}\right]^{0.0470}$	1~1.3
HP	1	1	1
MS	1	1	1
HT	1	1	1
HL	$e^{0.1036(hl-1)}$	$e^{0.1380(hl-1)}$	1-3

where

a	= un-normalized accident prediction (accidents/year at the crossing)
K	= constant for initialization of factor values at 1.00
EI	= 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 highway 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 ①Hazard identification, ②Causal analysis, ③Consequence analysis, ④Loss analysis, ⑤Countermeasure analysis, ⑥Impact analysis, and ⑦Demonstrations 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.

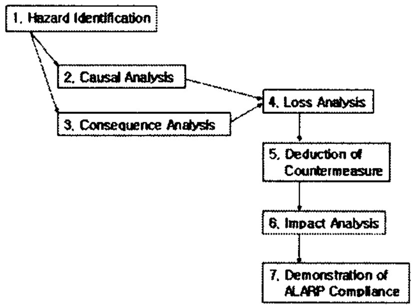


Fig. 4.1 Safety Analysis Process

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 4.1Proposed safety analysis techniques

	Hazard identification	Causal analysis	Consequence analysis
General	FMEA, HAZOP	FTA & FMEA FTA & Markov Markov & FMEA	ETA
Simple system	FMEA	FMECA	FMECA

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 4.2 Hazards of level crossing

No.	Hazard Description
1	Failure of Level Crossing to Protect Public from Train
2	Barrier Operates without being Caused by Train
3	Misuse of Level Crossing by Road User
4	Signal Passed at Danger(SPAD) at Signal Protecting Level Crossing

5	Poor Sighting of Level Crossing

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.

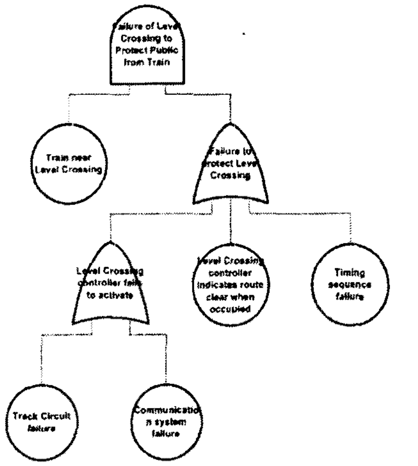


Fig. 4.2 FTA for causal analysis

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 = (90×74) / (3600×20) = 0.09

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

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

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

$((3.3\times10^{-2} + 8.4\times10^{-2}) + 9.7\times10^{-2} + 2.0) \times 0.09 =$ 0.2/year

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

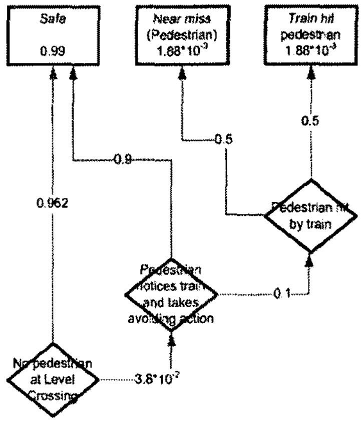
4.3.3 ETA for Consequence Analysis

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.

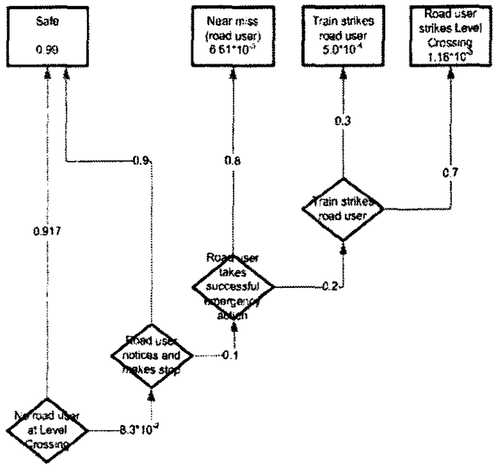
If we assumed that 300 pedestrian and 1,189 road user use a specific Level Crossing for 20 hours per day at a specific level crossing in Korea, taking 9 seconds and 5 second to traverse the crossing respectively, then the probability of the pedestrian and road user being present at the Level Crossing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

Probability $_{pedestrian}$ = (300×9) / (3600×20) = 3.8×10^{-2}

Probability $_{road\ user}$ = (1,189×5) / (3600×20) = 8.3×10^{-2}



(a) Pedestrian



(b) Road user

Fig. 4.3 ETA for consequence analysis

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.

Safety condition
Train hits pedestrian
Near miss (pedestrian, road user)
Train strikes road user
Road user strikes level crossing

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 4.3 Results of Loss Analysis for the hazard

Incident	Frequency (per annum)	Safety loss per incident (PEF)		Safety loss per annum(PEF)	
		Passenger	Public	Passenger	Public
Train hits pedestrian	3.8×10^{-4}	-	1	-	3.8×10^{-4}
Near miss (pedestrian)	3.8×10^{-4}	-	-	-	-
Near miss (road user)	1.35×10^{-3}	-	-	-	-
Train strikes road user	1.0×10^{-4}	10^{-2}	0.1	1.0×10^{-6}	1.0×10^{-5}
Road user strikes LC	2.4×10^{-4}	5×10^{-3}	0.1	1.2×10^{-6}	2.4×10^{-5}
		Total per annum		2.2×10^{-6}	4.2×10^{-4}

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.

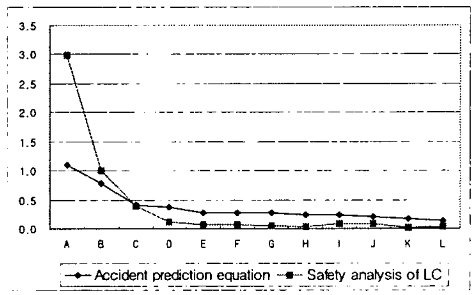


Fig. 5.1Comparison between accident prediction equation and safety analysis in Korea

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]

[1] IEC61508 parts 1-6, "Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related System" March, 1998

[2] CENELEC EN50126, "Railway application - The specification and demonstration of dependability, reliability, availability, maintainability and safety (RAMS)", March, 2000

[3] CENELEC EN50128, "Railway application - Software for railway control and protection system", June, 2000

[4] CENELEC EN50129, "Railway application - Safety related electronic systems for signaling", April, 2000

[5] "Analysis and counter measure for Railway accident in Korea", Korea National Railway, 2002

[6] Mark Mironer, Michael Coltman, Robert McCown, "Assessment of Risks for High-Speed Rail Grade Crossings on the Empire Corridor", Federal Railroad Administration, August, 2000

[7] Engineering Safety Management (Yellow Book) Issue 3", Railtrack PLC. October, 2003