# Exploring Risk Factors of Crash and Gate Breaking Frequency of Heavy Vehicle at Highway-railroad Grade Crossings Using a Three-Layer Hierarchical Approach

Shou-Ren HU [a], Jhy-Pyng LIN [b], Chi-Kang LEE [c]

[a] *Department of Transportation and Communication Management Science, National Cheng Kung University, Tainan City, 70101, Taiwan; E-mail: shouren@mail.ncku.edu.tw*
[b] *Department of Project Construction, Taiwan Railways Administration, MOTC, Taipei City, 10041, Taiwan; E-mail: tr453106@msa.tra.gov.tw*
[c] *Department of Marketing and Logistics Management, Southern Taiwan University of Technology, Tainan City 71005, Taiwan; E-mail: leeck@mail.stut.edu.tw*

**Abstract**: This study investigates the risk factors associated with heavy vehicle's crash and gate breaking frequency at highway-railroad grade crossings. Specifically, a three-layer hierarchical model of single and a set of combined risk factors is developed and evaluated to identify the most effective combinations of the factors that best explain the CCYs (number of crashes per 100 grade crossings per year) and BCYs (number of gate breakings per 100 grade crossings per year) . A 16-year crash and 7-year gate breaking dataset were collected for the empirical study. The numerical analysis results indicate that not only for the single factors such as number of heavy vehicles, number of daily trains, and highway width show a significant effect on the occurrence of a traffic collision(s) and/or gate breaking(s), but also specific combinations of these factors lead to a higher crash and/or gate breaking rate. Finally, policy implications based on the empirical study are discussed and future research directions are recommended.

*Keywords*: Crash Frequency, Gate Breaking, Heavy Vehicle, Highway-railroad Grade Crossing

## 1. INTRODUCTION

To avoid traffic collisions between train and heavy vehicle at a highway-railroad grade crossing (HRGX) is always the most important safety issue for a railway authority. Although the frequency of traffic collision between train and heavy vehicle is rarely low, the most severe tragedy among the rail incidents is that a train collides with a heavy vehicle at an HRGX. For example, a recent incident is that a serious collision between a train and a gravels truck on January 17, 2012 at Puxin crossing in the northern Taiwan area where a station and highway intersection are nearby, killed the locomotive engineer and injured 24 passengers. Hu and Lin (2012) concluded that cars and trucks are easily stuck on the track with a highway intersection(s) nearby and result in a significant number of crashes. Thus, to constrain heavy vehicle traffic seems to be a good solution to effectively reduce crash and/or gate breaking frequency at grade crossings, but there are still many difficulties faced and it remains to be discussed in the general public. According to past records in other countries, traffic collisions between train and heavy vehicle might be the most possible occurrence of derailed incidents and severe injury or fatality of a locomotive engineer at HRGXs. Davey (2005) depicted the main cause of concern was trucks and heavy vehicles, as breaches by trucks at grade crossings are common, and the potential crashes are likely to injure/kill the locomotive engineer and possibly derail the train.

Despite the risky driving behaviors at an HRGX are difficult to collect and comprehend the number of broken barrier gates and collisions between highway vehicles and trains in a given time period has been systematically collected in Taiwan for many years. The common finding is that high crash frequency at grade crossings in Taiwan is significantly associated with gate breaking frequency (e.g., the breaking of barrier gates by highway drivers). Figure 1 reveals that gate breaking incidents at HRGXs are positively proportional to the number of crashes. Thereby, many common factors are simultaneously responsible for crash and gate breaking frequency. In order to reduce the number of crashes, most grade crossings in Taiwan are equipped with three common active-type warning devices: a warning bell, auto-barrier gate, and flashing light. No matter how these warning devices are installed, the crash frequency each year at the grade crossings in Taiwan is still higher than those in the other compared countries (Hu and Lin, 2012). In addition, the improvement of all active-type countermeasures by traffic authorities cannot reach the expected effectiveness. Thereby, other advanced warning and/or control devices, such as law-enforcement cameras, videos, infrared obstruction detectors, LED train approaching indicators and so on, have been gradually employed, and some HRGXs with high crash risk are intensively installed in Taiwan since 2006. As a result, according to the statistics of the Taiwan Railways Administration (TRA), an apparently declining trend of the crashes and broken barrier gates were revealed in the past few years. In spite of a significant decreasing trend of gate breakings occurred at HRGXs, the TRA continuously dedicates to prevent the catastrophic traffic collision incidents between train and heavy vehicle at HRGXs. The heavy vehicles, including buses, trucks and trailers, are the vehicle groups which are also the most likely vehicles to break auto-barrier gates at HRGXs. In Taiwan, the largest number of highway vehicles traveling through HRGXs is constituted by small vehicles, including passenger cars (39.7%) and motorcycles (55.5%). The heavy vehicles are only accounted for 4.8% of total highway vehicular traffic. The statistics show that the gate breaking ratio by highway vehicles is proportional to the size of vehicles but inversely proportional to the traffic volume. Figure 2 reveals that more than 40% of the gate breakings at HRGXs are caused by heavy vehicles in the last five years. Similarly, an average of 14.7% of traffic collisions at HRGXs is attributed to heavy vehicles in the last 16 years, as shown in Figure 3. Due to its larger physical size and weight, heavy vehicle involved traffic collisions at an HRGX might result in severe consequence, thereby specific attention needs to be paid for those crashes and/or gate breaking caused by such vehicle type.

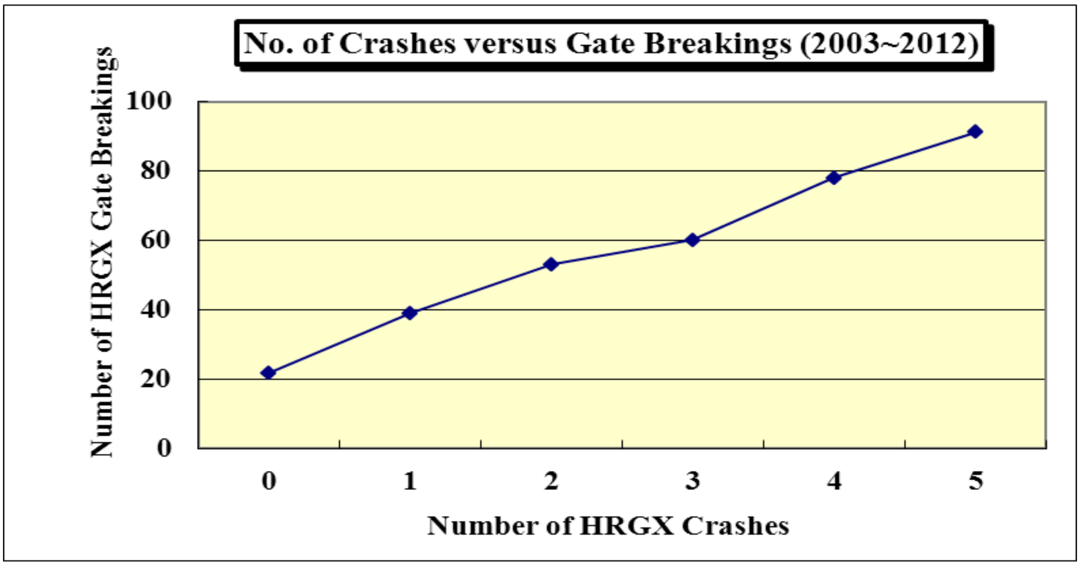


Figure 1. Average number of gate breakings versus average number of crashes

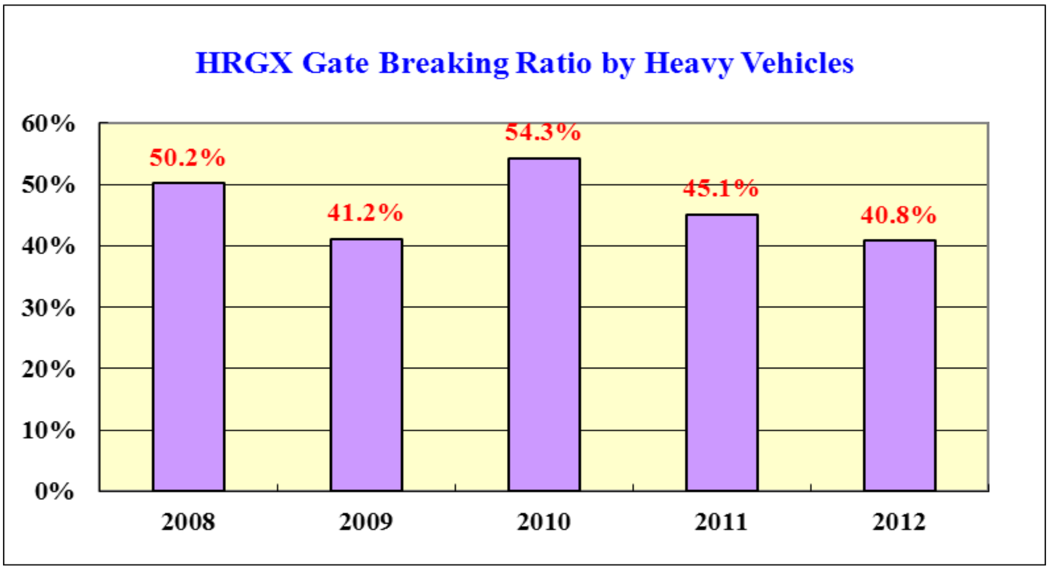


Figure 2. Yearly gate breaking ratios by heavy vehicles at grade crossings in Taiwan

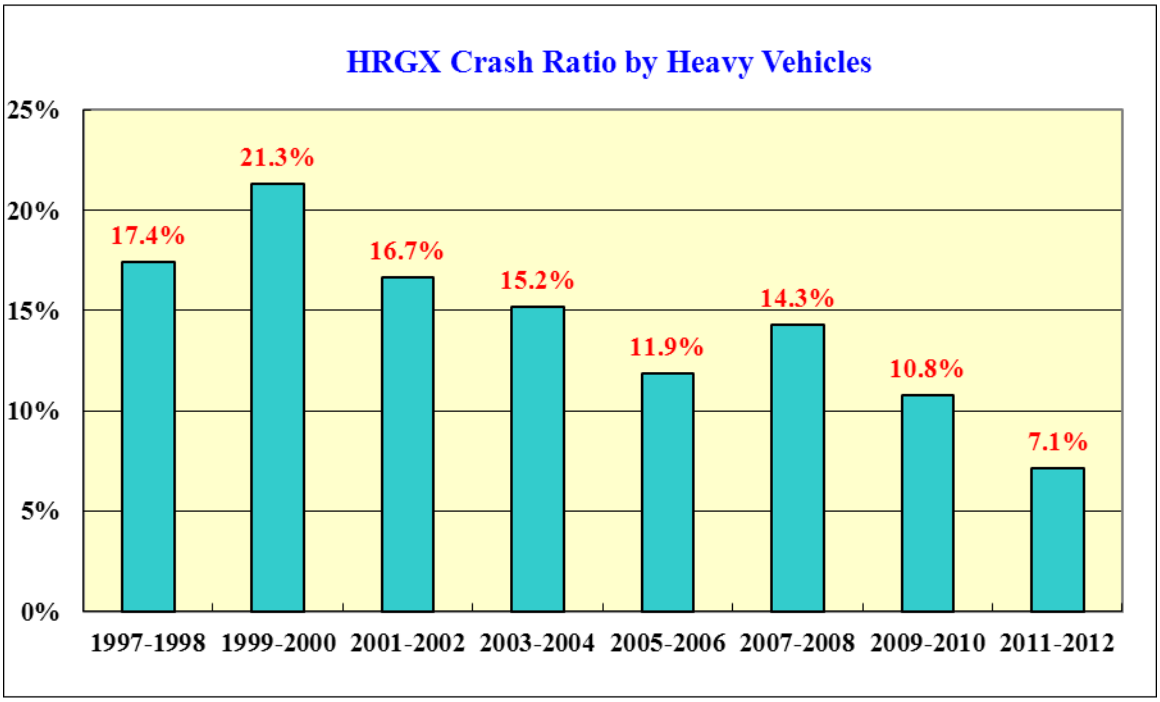


Figure 3. Two years crash ratios by heavy vehicles at grade crossings in Taiwan

Generally, a grade crossing collision would result in a serious body injury, vehicle damage, and traffic delay, traffic engineers ordinarily attempt to prevent or reduce this tragedy by actions labeled as three E's: engineering, education, and enforcement (Savage, 2006). In the past, the most relevant studies on crash/gate breaking prevention at a grade crossing focused either on the improvement of traffic warning/control devices or on the enhanced awareness of the risk caused by human errors. For the former, some statistical models were used to investigate the causal relationship among a set of countermeasures (the independent variables) and the crash/breaking frequency (the dependent variable). Many countermeasures of various highway geometric features and traffic warning/control devices were tested and evaluated for identifying the most relevant factors which are responsible for the occurrence of

HRGX crashes/breakings. Unfortunately, very few of them can be validated as true independent factors. Moreover, the collinearity problem generally confronted in regression based models is avoided by a stratified structure in the explanatory variables. Yan (2010) suggests that with given grade crossings' control types and attributes related to those significant factors, predictions can be obtained based on the 'if–then' rules found in the Hierarchical Tree Base Regression (HTBR) structure. In addition, it is important to identify potential interactions and non-additive effects among the explanatory variables for the assessment of a set of countermeasures. Such an issue can be effectively solved by some stratified collision prediction models (Park, 2007).

Based on relevant past research and empirical study findings, traffic collisions at HRGXs usually result from three potential causes: geographical features, traffic characteristics, and highway users' behaviors (Saccomanno *et al*., 2004; Millegan *et al*., 2009; Hu *et al*., 2010). In other words, uneven geographic features (e.g., gradient crossing or acute grade crossing), high traffic volume (represented by AADT and/or number of daily trains), and reckless or illegal driving behaviors contribute most to the occurrence of a traffic collision at a specific HRGX. The other studies similarly depicted the following findings: (1) rail traffic volume, road traffic volume, road visibility, road gradient, width of the crossing, and type of safety devices at a grade crossing all have been documented to have influence on the crash rate and the collective risk (Anandarao, 1998). (2) Number of daily trains, highway-to-rail separation, number of daily trucks, obstacle detection device, and (approaching) crossing markings affect crash severity at an HRGX (Hu *et al*., 2010). (3) The differences in the frequency of unsafe behaviors at HRGXs in two cities are attributed to a variety of factors, including the specific characteristics of the HRGXs (Khattak *et al*., 2009). We thereby believe that an HRGX with higher traffic exposure in terms of highway vehicular traffic and/or daily trains would be not only associated with a higher crash frequency but also a higher gate breaking frequency.

It is believed that the crash/gate breaking frequency will be higher at those HRGXs where the average vehicle speed is higher (Saccomanno *et al*., 2004); here, the "vehicle speed" refers to the posted speed, which takes into account the geometric factors affecting traffic collisions at HRGXs, such as number of lanes, sight distances, vertical and horizontal alignments, and so forth. Some factors affecting the speed of a vehicle are supposed as: (1) traffic flow volume, (2) a/some highway intersection(s) nearby, (3) width of highway, and (4) angle and gradient of a highway-railroad interface. The impacts of the first three factors on incident frequency will be explored later in this research. Traffic collisions at a specific HRGX usually occur when the crossing is located too close to a road intersection, such that when a vehicle enters the rail crossing zone it could not move away quickly because of many other vehicles in front of it (Anandarao, 1998). Saccomanno (2004) suggested that for active rail-road crossing zones (e.g., those with flashing lights) the significant risk factors are train speed, road surface width, traffic exposure, number of tracks, track angle and persons involved. Other influence factors affecting highway users' driving behaviors at HRGXs include sight distance, waiting time for a coming train(s), and where two trains meet near the grade crossing. The relative studies are as follows: (1) it reflects potential geometric factors affecting collisions at HRGXs, such as number of lanes, sight distance, vertical and horizontal alignments, and so forth (Saccomanno *et al*., 2004); (2) the most prominent motive for unsafe crossing is the desire to avoid a delay in order to save precious time (Davey *et al*., 2008); and (3) some countermeasures including angle of highway-railroad interface and double tracks of the railway will be also explored to identify the causal relationships between the risk factors and incident frequency. In addition, crash frequency increases proportionally as the number of tracks increases (Anandarao, 1998). Davey (2008) suggested that HRGX design should consider the off-limitation of the crossing zone to a large-size vehicle.

According to the previous studies, the exploration in terms of the crash and gate breaking frequency at an HRGX(s) by heavy vehicles would be fulfilled by using a similar hierarchical method with some possibly significant factors such as traffic volume of highway and/or railway traffic, number of track(s), width of highway, and highway intersection nearby. The research is organized as follows. Section two describes the dataset used for the empirical study where both crash and gate breaking historical data and grade crossing inventory data are collected and analyzed. Section three depicts the hierarchical model of combined factors adopted in the causal analysis. Section four provides the empirical study results and discussion on the policy implications. Finally, in section five, we summarize this paper with the research conclusions and future study directions.

## 2. DATA DESCRIPTION

### 2.1 HRGX Crash Data of Heavy Vehicle

The TRA has maintained a good HRGX crash database. Since 1997 every crash had been recorded by its geographical location, date, time, casualty, train number, highway user(s) involved and train delays. The crash dataset is monthly updated so that the most recent data were collected in December of 2012. From January 1st, 1997 to December 31th, 2012, a total of 75 traffic collisions caused by heavy vehicles at the 360 investigated HRGXs in Taiwan.

### 2.2 HRGX Gate (Barrier) Breaking by Heavy Vehicle

The TRA has also maintained more detailed information since 2006 for the first video camera installed at an extremely dangerous HRGX with the recorded data on the invading vehicle's license plate number and date/time of the offense. Beginning from September 1st, 2006 through December 31th, 2012, a total of 797 gate breaking incidents by heavy vehicles were reported and recorded at the same 360 HRGXs.

### 2.3 Heavy Vehicle Traffic Exposure and HRGX Inventory Data

At a highway-railroad interface, the relevant traffic volumes which include daily trains and heavy vehicle traffic volume were periodically surveyed and recorded by the TRA. The TRA operates a static daily train traffic approximately closed to 1,000 train trips per day. The daily train trips (DTTs) through every HRGX are estimated by the average of the train volume scheduled in the operation of timetable during the last 16 years. As to the highway volume including heavy vehicles, the heavy vehicle volume was estimated by the surveyed data in three 24-hour investigations respectively conducted in 2008, 2010 and 2011. Thereby, the traffic volumes of heavy vehicle obtained in the three filed surveys are averaged to represent the mean heavy vehicle volume for the corresponding HRGXs. Finally, highway widths were rarely changed in the HRGX areas according to the TRA's HRGX inventory database of three HRGX inventory handbooks released in 1998, 2003 and 2008. The widths of the HRGXs investigated are assumed to be remained constant because only 6 of the 557 existing HRGXs have been altered their highway widths since 2003.

### 2.4 Crossing Geographical Attributes

**Intersection:** the MUTCD (FHWA, 2000) suggests that preemption should be applied when the distance between a signalized intersection and an HRGX is less than 60 meters. However, if a signal preemption scheme is needed depending on the traffic situations, regardless the distance between an HRGX and the signalized highway intersection (Cho and Rilett, 2007). Therefore, a preempted HRGX with an intersection(s) nearby is defined as 'Intersection'. In all the 360 selected HRGXs, 289 HRGXs are defined as near "intersection" and the other 71 HGRXs are classified as "non-intersection".

**Track:** In Taiwan, the service lines in the eastern coastal rail corridor and the branch lines serve less passenger and freight volumes compared to those in the western main rail corridor; they are currently operating on a single-track rail infrastructure. According to the information provided by TRA, the ratio between the HRGXs located at single-track and double-track is 124:236.

## 3. HIERARCHICAL MODEL OF COMBINED FACTORS

### 3.1 Binary Variables

Three selected factors of the HRGX attributes for risk analysis including daily train trips (DTTs), truck volume and width of highway are converted into the binary variable of mutually exclusive categories by using the K-means approach. Other factors including intersection (near or not) and number of track (single or double) are two binary variables of mutually exclusive categories. Each binary variable will be presumably clustered into both high and low risk levels to the HRGXs and are marked by character of "H" and "L". First, an HRGX with high traffic volume in terms of railway or highway traffic might be assumed to be associated with a high incident frequency. Thereby, two implicative proxies DTT(H) and DTT(L) are assigned as high and low train traffic volume respectively. Similarly, the proxy Truck(H) and Truck(L) are the respective variables representing high and low heavy truck volume. Second, the larger highway width across a grade crossing possibly causes higher incident frequency at an HRGX than that of a narrower highway width because the former might lead to higher speeds of highway vehicles than the later does. Thereby, larger highway width is marked as a corresponding proxy Width(H) against the other proxy Width(L) of the narrower highway width. Next, the heavy vehicle would take longer time for passing an HRGX with double-track than that of an HRGX with single-track, meaning that heavy vehicles possibly have higher risk for passing through an HRGX of double-track than an HRGX located at single-track. Finally, an HRGX near a highway intersection might have higher risk of traffic collisions and/or gate breaking incidents because heavy vehicles are also easy to be stuck on an HRGX if a highway intersection is nearby and signal preemption is not conducted. Therefore, the proxy Intersection(H) is marked for the HRGXs near a highway intersection against the proxy Intersection(L) which represents an HRGXs without an intersection nearby.

### 3.2 Modeling Procedure

In modeling the risk levels of an HRGX, a three-step hierarchical structure is developed, which is shown in Figure 4. The numbers of BCYs/CCYs could be obtained by using the crash and gate breaking datasets of all the 360 selected HRGXs. At the single-factor level, the BCYs/CCYs would be recalculated according to each of the previously defined binary variable and each factor respectively has their BCY/CCY of high and low level proxy. The level of significance of each of the binary variables is tested by using the independent-*t* test method. By evaluating the significance of the proxy's effects on the recorded BCYs/CCYs, the significant proxy variables or risk factors will be further selected as the candidates for the next double-factor modeling process. In order to develop a more effective layer-based hierarchical procedure, the significant proxy variables with high level proxy item ($F_i$(H)) which possesses the maximum HRGX number will be selected as the base proxy for the next combination process of the double-factor analysis. In the second layer, the base proxy (Fi (H)) paired with the proxies of other factors becomes a series of double-factor items (see Figure 4 for the demonstration). Similarly, the significant proxy variables with high level sub-proxy ($F_i$(H)$F_j$(H)) which has the maximum number of HRGXs in the second layer will be selected for the double binary variables and employed for the final combination process. Consequently, all the combinations of triple-factor are developed by incorporating the high level proxy of the rest of the factors and the sub-proxy ($F_i$(H)$F_j$(H)), which becomes the high level sub-sub proxy of triple-factor, as shown as $F_i$(H)$F_j$(H)$F_1$(H), $F_i$(H)$F_j$(H)$F_2$(H), …$F_i$(H)$F_j$(H)$F_k$(H). The BCY/CCY associated with each of the high level sub-sub proxy ($F_i$(H)$F_j$(H)$F_k$(H)) will be compared with that of the high level sub-proxy ($F_i$(H)Fj(H)) of two-factor if the mutually exclusive categories between $F_i$(H)$F_j$(H) and $F_i$(H)$F_j$(L) shows a level of significance in the independent-*t* test. From the aforementioned procedure for all the high level risk analysis of the relationship between BCY/CCY and combinations of selected risk factors, the most critical combination among the proxies which result in higher BCYs or CCYs at HRGXs would be identified.

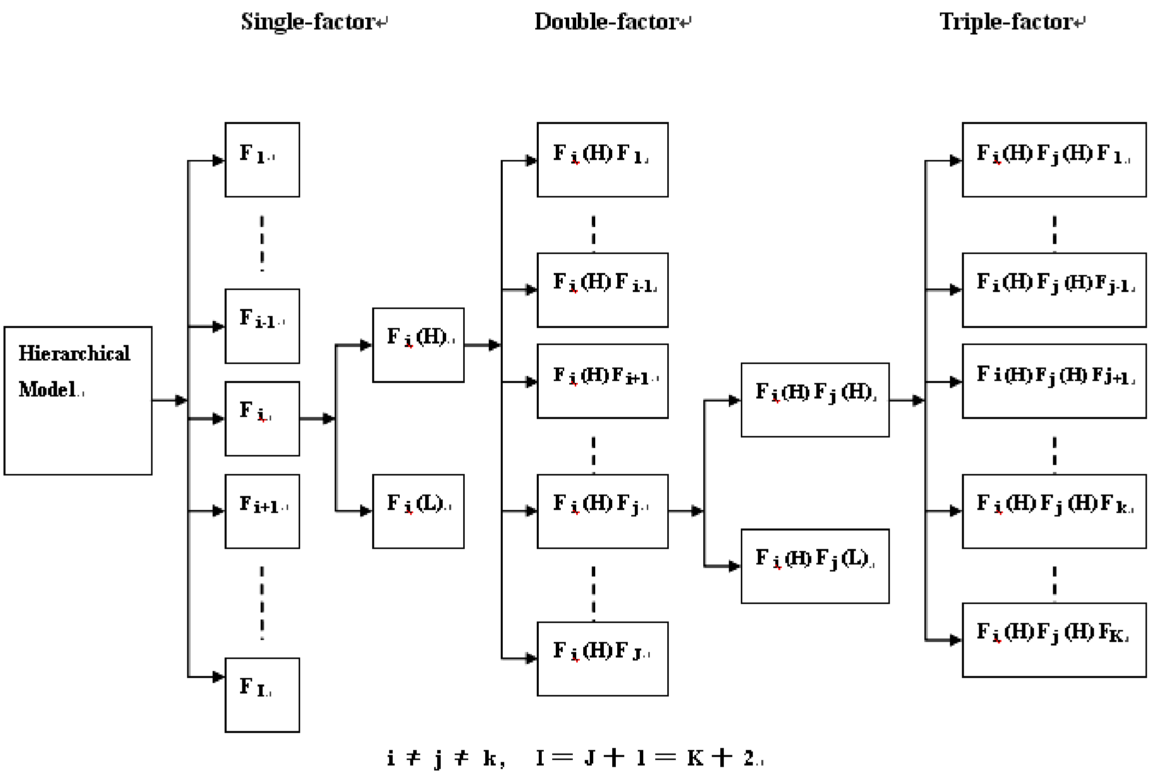


Figure 4. Three-layer hierarchical model for HRGX risk assessment

## 4. RESULTS AND DISCUSSION

### 4.1 Single-Factor Analysis

In the 360 selected HRGXs, two factors including track (single/double) and intersection (yes/no) are essentially binary variables. Other factors such as DTTs, width of highway and truck volume are respectively classified into high and low levels by using the K-means analysis method. The distributions for the samples for all the selected factors are shown in Table 1. The high traffic volumes of both highway (trucks) and railway (DTTs) expectedly show a significantly positive effect on the crash frequency (CCY) and/or gate breaking frequency (BCY). Especially, proxy Truck(H) is identified as the most significant factor that results in higher number of BCYs and CCYs. The larger highway width which induces higher traffic volume and faster traffic flow is corresponding to more traffic collisions and/or gate breakings than that of a narrower HRGX (see Table 1). If an HRGX is closed to a highway intersection(s), both the BCY and CCY are higher than that of the HRGX without any highway intersection nearby. It is also found that the heavy vehicle is easy to be stuck on the HRGX with a highway intersection nearby. On the other hand, the BCY of an HRGX located at the double-track rail infrastructure is significantly higher than that of an HRGX with single-track. However, the CCY model does not reveal the same result.

### 4.2 Double-Factor Analysis

The DTTs and number of track(s) are the two major factors which have two respective maximum numbers of HRGXs with high levels of risk, and they are commonly employed to the double-factor analysis. Each of the two high risk factors is combined with other factors to obtain a series of combined double-factor scenarios. The results are shown in Table 2. As shown in Table 2, the highest BCYs and CCYs are caused at the sub-proxy DTT(H)Truck(H), followed by the sub-proxy Track(H)Truck(H). In other words, the combination of both high traffic volume of highway and railway is the most critical double-factor to affect crash and gate breaking frequency at the investigated HRGXs. On the contrary, the double-factor scenarios involved factor of intersection paired with proxy DTT(H) and Track(H) do not exhibit a significant effect on the BCY or CCY except the sub-proxy Track(H)Intersection(H) on the CCY. All the double-factor scenarios of high DTT or double-track combined with factor of highway width show significantly positive effects on the BCYs and CCYs (see Table 2).

### 4.3 Triple Factor Analysis

In the triple factor analysis, the most significant double-factor combinations found in the previous step are the sub-proxy DTT(H)Width(H) and Track(H)Width(H). They are selected for the triple-factor analysis. Factors of intersection and truck are input to the last combined scenarios for the triple-factor analysis. Consequently, in the triple-factor layer, the most significantly positive effect on both the BCYs and CCYs are sub-sub proxy DTT(H)Width(H)Truck(H) and Track(H)Width(H)Truck(H). As to the factor intersection involved in the triple-factor scenario, it shows a significantly positive effect on the BCY but not for the CCY.

For the empirical study results revealed above, the most effective factor on the BCYs/CCYs of heavy vehicle at HRGXs is the “Truck Volume”. Those scenarios which involved Truck Volume either in the single-factor or combined-factor analysis reveal more crash and/or gate breaking frequency than others. Although the single factor "Intersection" shows a significant effect on both the CCYs and BCYs, it is the least effective factor combined with the high traffic volume involved the DTTs and/or the Truck Volume. Especially, the scenarios of the Intersection paired with both two high traffic volumes have no any impact on the CCYs. The TRA or a rail operation might prepare respective safety improvement means in light of these findings in the empirical study results under a cost-effective manner.

Table 1. First-layer analysis of the hierarchical model for heavy vehicle's BCYs/CCYs

| No. | Scenario assigned | Samples | Range | BCY | *p*-value | CCY | *p*-value |
|---|---|---|---|---|---|---|---|
| 0 | General | 360 | | 60.46 | | 1.39 | |
| 1 | DTT(H) | 214 | 120~313 | 80.13 | $p < 0.001$ | 1.74 | $p < 0.05$ |
| 2 | DTT(L) | 146 | 12~116 | 31.63 | | 0.87 | |
| 3 | Track(H) | 236 | 2 | 75.81 | $p < 0.05$ | 1.60 | |
| 4 | Track(L) | 124 | 1 | 31.95 | | 1.01 | |
| 5 | Width(H) | 79 | 12.5~50 | 133.40 | $p < 0.001$ | 2.68 | $p < 0.01$ |
| 6 | Width(L) | 281 | 3~12 | 39.61 | | 1.02 | |
| 7 | Intersection(H) | 289 | yes | 66.66 | $p < 0.05$ | 1.57 | $p < 0.05$ |
| 8 | Intersection(L) | 71 | no | 35.24 | | 0.66 | |
| 9 | Truck volume(H) | 28 | 957~9652 | 228.88 | $p < 0.01$ | 3.81 | $p < 0.1$ |
| 10 | Truck volume(L) | 282 | 3~924 | 46.24 | | 1.18 | |

Table 2. Second-layer analysis of the hierarchical model for heavy vehicle's BCYs/CCYs

| No. | Scenario assigned | Samples | BCY | *p*-value | CCY | *p*-value |
|---|---|---|---|---|---|---|
| 1 | DTT(H)Intersection(H) | 179 | 85.35 | | 1.90 | |
| 2 | DTT(H)Intersection(L) | 35 | 53.42 | | 0.95 | |
| 3 | DTT(H)Width(H) | 59 | 145.18 | $p < 0.01$ | 3.50 | $p < 0.01$ |
| 4 | DTT(H)Width(L) | 155 | 55.37 | | 1.08 | |
| 5 | DTT(H)Truck volume(H) | 19 | 262.93 | $p < 0.05$ | 5.26 | $p < 0.05$ |
| 6 | DTT(H)Truck volume(L) | 195 | 62.32 | | 1.40 | |
| 7 | Track(H)Intersection(H) | 196 | 78.84 | | 1.80 | $p < 0.1$ |
| 8 | Track(H)Intersection(L) | 40 | 50.93 | | 0.83 | |
| 9 | Track(H)Width(H) | 60 | 143.47 | $p < 0.01$ | 3.33 | $p < 0.01$ |
| 10 | Track(H)Width(L) | 176 | 51.89 | | 1.05 | |
| 11 | Track(H)Truck volume(H) | 20 | 252.97 | $p < 0.05$ | 5.00 | $p < 0.05$ |
| 12 | Track(H)Truck volume(L) | 216 | 57.55 | | 1.33 | |

Table 3. Third-layer analysis of the hierarchical model for heavy vehicle's BCYs/CCYs

| No. | Scenario assigned | Samples | BCY | *p*-value | CCY | *p*-value |
|---|---|---|---|---|---|---|
| 1 | DTT(H)Width(H)Intersection(H) | 53 | 156.79 | $p < 0.05$ | 3.52 | |
| 2 | DTT(H)Width(H)Intersection(L) | 6 | 42.55 | | 3.33 | |
| 3 | DTT(H)Width(H)Truck(H) | 13 | 342.2 | $p < 0.05$ | 6.67 | $p < 0.05$ |
| 4 | DTT(H)Width(H)Truck(L) | 46 | 89.39 | | 2.61 | |
| 1 | Track(H)Width(H)Intersection(H) | 54 | 154.68 | $p < 0.05$ | 3.33 | |
| 2 | Track(H)Width(H)Intersection(L) | 6 | 42.55 | | 3.33 | |
| 3 | Track(H)Width(H)Truck(H) | 13 | 342.58 | $p < 0.05$ | 6.67 | $p < 0.05$ |
| 4 | Track(H)Width(H)Truck(L) | 47 | 88.39 | | 2.41 | |

## 5. CONCLUDING REMARKS

In this research, a three-layer hierarchical risk analysis approach was developed and demonstrated its capability to identify the risk factors and their combinations for the assessment of their effects on crash and/or gate breaking frequency at HRGXs. A railway authority could improve the priority HRGXs with high BCYs/CCYs by using the proposed hierarchical risk analysis model. In addition, the railway authority might alternatively focus on some high-risk HRGXs revealed in the multiple combinations of the influence factors instead of the HRGXs with significantly effective single-factor, if the safety improvement budget is a constraint. In addition, although most past researches investigated the effects of some risk factors on crash and/or gate breaking frequency mostly by regression based models, some specific factors could be identified about their effects by using the combined-factor steps of the proposed hierarchical clustering analysis. Moreover, the most effective binary variables could be found in each layer of the hierarchical based model. Finally, by comparing the numerical analysis results between the single-factor and double-factor or between the double-factor and triple-factor scenarios, the most risk factors could be effectively identified and their marginal effects on the reduction of crash and/or gate breaking frequency can be further evaluated.

## ACKNOWLEDGEMENTS

The authors would like to thank TRA, which provided the historical crash and gate breaking data, and grade-crossing inventory data set in the empirical study. This research was partially supported by a grant (NSC 99-2221-E-006-116) from the National Science Council, Taiwan.

## REFERENCES

Anandarao, S. and C. D. Martland (1998) Level crossing safety on East Japan Railway Company: Application of probabilistic risk assessment techniques. *Transportation*, 25 265-286.

Cho, H., and L. R. Rilett (2007) Improved transition preemption strategy for signalized intersections near at-grade railway grade crossing. *Journal of Transportation Engineering,* ASCE, 133(8), 443-454.

Davey, J., A. Wallace, N. S., Freeman, J. (2008) The experiences and perception of heavy vehicle drivers and train drivers of dangers at railway level crossings. *Accident Analysis and Prevention*, 40, 1217-1222.

Davey, J., D. Wishart, J. F., Watson, B. (2007) An application of the driver behaviour questionnaire in an Australian organizational fleet setting, *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(1), 11-21.

Federal Highway Administration (2000) *Manual on Uniform Traffic Control Devices. Millennium edition*, U.S. Department of Transportation, Washington, D. C., U.S.A.

Federal Railroad Administration (2002) *North Carolina "Sealed Corridor" Phase I, Executive Summary and Treatment Techniques*. Report to Congress, U.S. Department of Transportation, Washington, D. C., U.S.A.

Hu, S. R, Li, C. S., Lee, C. K. (2010) Investigation of key factors for accident severity at railroad grade crossings by using a logit model. *Safety Science*, 48, 186-194.

Hu, S. R., Lin, J. P. (2012) Effect of train arrival time on crash frequency at highway-railroad grade crossings: General classification regression model. *Transportation Research Record: Journal of the Transportation Research Board*, 2298, 61-69.

Khattak, A. J. (2009) Comparison of driver behavior at highway-railroad grade crossings in two cities. *Transportation Research Record: Journal of the Transportation Research Board*, 2122, 72-77.

Khattak, A. J., McKnight, G. A. (2008) Gate rushing at highway-railroad grade crossings. *Transportation Research Record: Journal of the Transportation Research Board*, 2056, 104-108.

Millegan, H., Yan, X., Richards, S., Han, L. (2009) Evaluation of effectiveness of stop sign treatments at highway-railway grade crossings. *Transportation Research Record: Journal of the Transportation Research Board*, 2122, 78-85.

Park, P. Y. J. (2007) Estimating effectiveness of countermeasures based on multiple sources: Application to highway-railway grade crossings, *Dissertation, Doctor of Philosophy,* University of Waterloo, Canada.

Saccomanno, F. F., Fu, L., Miranda-Moreno, L. F. (2004) Risk-based model for identifying high-rail grade crossing blackspots. *Transportation Research Record: Journal of the Transportation Research Board*, 1862, 127-135.

Saccomanno, F. F., Grossi, R., Greco, D., Mehmood, A. (2001) Identifying black spots along highway SS107 in southern Italy using two models. *Journal of Transportation Engineering*, ASCE, 127(6), 515-522.

Savage, I. (2006) Does public education improve rail-highway crossing safety? *Accident Analysis and Prevention*, 38(1), 234-247.

Taiwan Railways Administration (2011) *Annual railroad safety report in Taiwan area*. TRA, MOTC, Taiwan.

Yan, X., Richards, S., Su, X. (2010) Using hierarchical tree-based regression model to analyze and predict crash risk at passive rail-highway grade crossings. *Accident Analysis and Prevention*, 42(1), 64-74.