Highway-rail grade crossing (HRGC) accidents

Subjects: Social Issues | Transportation Science & Technology | Transportation
Contributor: Maxim Dulebenets, Krzysztof Goniewicz

Highway-rail grade crossing (HRGC) accidents pose a serious risk of safety to highway users, including pedestrians trying to cross HRGCs. A significant increase in the number of HRGC accidents globally calls for greater research efforts, which are not limited to the analysis of accidents at HRGCs but also understanding user perception, driver behavior, potential conflicting areas at crossings, effectiveness of countermeasures and user perception towards them. HRGC safety is one of the priority areas in the State of Florida, since the state HRGCs experienced a total of 429 injuries and 146 fatalities between 2010 and 2019 with a significant increase in HRGC accidents over the last years.

Keywords: highway-rail grade crossings ; user safety

1. Highway-Rail Grade Crossing Safety in the European Union

Collisions between vehicles and trains at highway-rail grade crossings (HRGCs), also known as “level crossings”, are a challenge faced globally. **Figure 1** illustrates the number of fatal and serious injuries from 2006 to 2016 at the HRGCs in 28 countries of the European Union (E.U.) based on the data provided by the United Nations Economic Commission for Europe (UNECE) [1]. The data show that except for a sudden increase in the number of accidents in the year of 2012 (575 accidents), the number of accidents reduced by approximately 33.59% between 2009 (640 accidents) and 2016 (425 accidents). A similar trend can be seen for the HRGC fatalities and serious injuries. In particular, fatalities at HRGCs reduced by 37.47% (from 411 to 257 fatalities) between 2009 and 2016, whereas serious injuries reduced by 31.63% (from 332 to 227 serious injuries) [1]. Despite the decreasing trend in the HRGC accidents in the E.U., the actual numbers along with the economic impact still remain fairly high. The UNECE outlined four major issues with the HRGC safety, such as [1]: (1) presence of many passive and poorly protected active HRGCs, where it is too expensive to suggest any technical solution; (2) lack of evidence concerning the problem, causes and associated costs at HRGCs due to the absence of proper collision investigation and availability of statistical data; (3) lack of effective evaluation of risk and management due to the absence of knowhow, capacity and appropriate methods; and (4) poor safety environment due to the absence of understanding regarding the main collision causes, road user responsibility and inadequate collision investigation.

Figure 1. Number of fatal and serious injuries at HRGCs in the E.U. for 2006–2016.

2. Highway-Rail Grade Crossing Safety in the United States

As for the United States (U.S.), the number of fatal and non-fatal injuries at HRGCs fluctuated over the last years. **Figure 2** presents the number of fatal and non-fatal injuries at HRGCs from 2007 and 2019 [2]. The data exhibit that the number of non-fatal injuries at HRGCs reduced by approximately 23.04% between 2007 (1059 non-fatal injuries) and 2019 (815 non-fatal injuries). However, sudden rises in non-fatal injuries were recorded for 2011 (1048 non-fatal injuries) and 2015 (1048 non-fatal injuries). Furthermore, the number of fatal injuries at HRGCs in the U.S. showed an increasing trend

between 2012 and 2019. In particular, the number of fatal injuries increased by approximately 28.57% from 2012 (231 fatal injuries) to 2019 (297 fatal injuries). The HRGC safety issues are viewed as a major concern not only in the E.U. and in the U.S. but in other countries as well [3][4][5][6].

Figure 2. Number of fatal and non-fatal injuries at HRGCs in the U.S. for 2007–2019.

Both E.U and U.S. have specific initiatives in place dedicated to HRGC safety improvements. In particular, the European directive 2014/88/EU is dedicated to common safety indicators of railway infrastructure [7]. This directive puts a specific emphasis on HRGC accidents, provides relevant definitions and presents an outline of the methods that can be used to quantify the economic impact of accidents at HRGCs. On the other hand, the U.S. has a national program, called “Railway-Highway Crossings (Section 130) Program” [8]. As a part of the Section 130 Program, each state receives a certain amount of funding for HRGC safety improvement projects every year. Each state is mandated to prioritize its HRGC locations for safety improvement projects. The program was originally introduced in 1987 and was found to be effective in safety improvements. In particular, the number of fatalities at the U.S. HRGCs decreased by more than 50% since the inception of the Section 130 Program.

3. Risk Contributing Factors at HRGCs

Hao [9] developed three driver injury severity models: (1) overall model; (2) driver injury severity model capturing warning devices; and (3) driver injury severity model capturing age and gender. The results, which were obtained for the U.S. HRGCs, indicated that female drivers and older drivers were likely to experience increased injury severity at HRGCs. Haleem and Gan [10] studied crash contributing factors and injury severity at public HRGCs in the U.S. using the FRA accident database for a total of 5528 public HRGCs and the 2009–2013 time period. The study outcomes demonstrated that various characteristics, such as high speed of trains, age of drivers, road surface, presence of warning bells, could substantially influence the injury levels. Haleem [11] investigated the accidents at private HRGCs using the U.S. data from 2009 to 2014. It was found that more accidents occurred at the private HRGCs that did not have any warning devices. Fewer fatalities were recorded for males and young adults compared to their older counterparts.

Hao et al. [12] studied injury severity at HRGCs by time of day. The FRA data for 25,945 accidents at HRGCs in the U.S. were analyzed for the time period between 2002 and 2011. The results of the study showed that the injury severity at HRGCs for the accidents during AM peak, PM peak and PM off-peak was significantly higher compared to other time periods throughout a day. Zhao and Khattak [13] studied the self-reported inattentive driving at HRGCs. The data were collected by means of a questionnaire distributed among randomly selected households with licensed motor vehicle drivers in Nebraska (U.S.). The results showed that female drivers, younger drivers, drivers from the households with higher income and more frequent use of HRGCs were some of the factors directly associated with inattentive driving at HRGCs. Keramati et al. [14] proposed a competing risk method to evaluate the accident frequency and severity at HRGCs for a period of 30 years in North Dakota (U.S.). The study demonstrated that the train detection system, train services, type of roadway surface, railroad and highway traffic, truck percentage and number of highway lanes could influence the accident occurrence likelihood at HRGCs.

4. Human Factors at HRGCs

U.S. DOT [15] identified human factors as one of the major causes of accidents at HRGCs. The need for effective action plans was highlighted to address safety issues at HRGCs. A series of initiatives in the areas related to education, engineering and enforcement could help in prevention of accidents at HRGCs. Tey et al. [16] analyzed the behavior of drivers at HRGCs with different types of warning devices. The research outcomes indicated poor driver responses at the HRGCs with passive warning devices compared to the HRGCs with active warning devices. Silla and Luoma [17] studied the recurrence of fatalities, accident timing and attributes of people died in pedestrian-train accidents during the 2005–2009 time period on the Finnish railways. It was found that a total of 311 pedestrians were killed as a result of pedestrian-

train accidents. Moreover, a total of 264 accidents were suicides. Naweed [18] investigated psychological factors that could cause driver distraction and inattention for the Australian and New Zealand rail industry. Growing anxiety, disengagement and multi-tasking were found to be some of the significant factors that could intensify the experience of distraction and increase the driver risk.

Read et al. [19] analyzed the HRGC literature to find out the degree to which the systems approach was used to evaluate safety issues at HRGCs. The results of the study illustrated that none of the previously conducted studies relied on the systems approach for understanding driver behavior at HRGCs. It was highlighted that the systems approach could assist with the selection of efficient design enhancements at HRGCs. Salmon et al. [20] studied human factors leading to unintentional non-compliance at HRGCs. A case study of the HRGC accident in Northern Victoria (Australia) was considered, when a truck collided with a passenger train killing 11 train passengers. The primary cause of the accident was identified to be the looked-but-failed-to-see error leading the truck driver to assume that there was no train in the HRGC vicinity. Kyriakidis et al. [21] proposed a framework to recognize the most important human performance attributes, which could substantially influence railroad operations and cause safety issues. The framework was developed based on the 479 railroad operational incidents occurred worldwide over the last 15 years and could be used to identify the appropriate solutions for enhancing the safety level.

Liu et al. [22] evaluated pre-crash driver behaviors at HRGCs with different types of warning devices. A total of 15,639 accidents occurred at the U.S. HRGCs between 2004 and 2013 were analyzed. The analysis outcomes showed that drivers were likely to stop at HRCGs with gates. Flashing lights and audible warning devices at gated HRGCs were found to be effective means of improving safety. Stefanova et al. [23] studied pedestrian behavior at HRGCs and outlined significant gaps in the existing knowledge. A new framework was proposed to arrange the contributing factors of crossing behavior in a hierarchical manner. The conducted case study demonstrated that many different factors affect pedestrian crossing behavior (e.g., station design, location of the overpass, presence of a convenient path). Madigan et al. [24] conducted the human factor analysis for the rail safety incidents in the United Kingdom. A total of 78 reports were reviewed as a part of that study. The reports were mostly concentrated on active failures associated with work-related distraction and environmental factors. Memory failures and attention failures were underlined as well. Larue et al. [25] evaluated risks and errors for highway users at fully protected HRGCs. A significant number of violations of vehicle drivers and pedestrians were noticed for the considered HRGC. It was indicated that the design issues may increase the number of violations at fully active HRGCs. Additional countermeasures could be helpful in reducing the risk level at HRGCs.

5. Geometric Design of HRGCs and Its Impacts on Safety

Lin et al. [26] highlighted that the existing guiding signs, traffic control devices and pavement markings may confuse highway users and result in incorrect turns at HRGCs (i.e., a driver is turning onto the railroad tracks instead of at the nearby intersection). The study suggested a set of countermeasures that can be used to address the issue of incorrect turns at HRGCs. In particular, striping and advanced directional signage was proposed for the upstream side of HRGCs. Supplementary treatments were discussed as well (e.g., side, and median barriers, striping/dynamic envelop pavement markings, illumination). Keramati et al. [27] indicated that limited research efforts focused on the effects of HRGC geometric parameters on their safety performance. A total of 3194 public HRGCs in North Dakota were investigated. The following geometric attributes of HRGCs were considered: (a) acute crossing angle; (b) HRGC width (proportional to the number of tracks); (c) distance between the HRGC and the nearest intersection; and (d) number of highway lanes. The outcomes from the conducted research showed that all the considered geometric attributes could substantially influence the accident severity level. Furthermore, all the considered geometric attributes, except the distance between the HRGC and the nearest intersection, could substantially influence the accident occurrence.

6. General Issues Related to HRGC Safety

Silla and Kallberg [28] studied railway safety in Finland between the years of 1959 and 2008. The results showed a significant enhancement in safety during that period. A significant decrease in the number of fatalities at HRGCs has been attributed to the application of barriers, construction of underpasses/overpasses at HRGCs in high traffic volume areas, elimination of crossings and enhancement in visibility at crossings. Chadwick et al. [29] presented the operational challenges at the U.S. HRGCs with shared operations, where both passenger and heavy freight rail services are available. It was concluded that the introduction of high-speed passenger rail services on the existing freight railroads could increase safety concerns. Phillips and Sagberg [30] conducted the analysis of hazardous events on the approaches to rail signals. The study evaluated responses from 115 train drivers. It was found that inattention, inappropriate schema and lack of signal salience were the main reasons behind missing signals by train drivers. Inattention could be caused by routine exposure to invariant signals.

Khattak and Tung [31] studied pedestrian accidents at HRGCs. Three levels of accident severity were considered, including “no injury”, “injury” and “fatality”. The analysis results showed that fatalities were generally observed at HRGCs with higher train speeds and among female pedestrians. Metaxatos and Sriraj [32] studied the effectiveness of various engineering solutions and educational programs for reducing pedestrian and bicycle fatalities at HRGCs. The research objective was accomplished by means of literature review and consultation with professionals. Major areas requiring attention were highlighted. Abioye et al. [33] studied the prevailing accident and hazard prediction formulae that were used by various state Departments of Transportation in the U.S. A number of challenges in implementation of the models in different states were identified. Kavoosi et al. [34] developed two optimization models to minimize the overall hazard and the overall hazard severity focusing on public HRGCs in the State of Florida. Several customized heuristic algorithms were developed to solve the models.

Khattak et al. [35] aimed to update the existing accident prediction model used in the State of Nebraska (U.S.) and propose a set of guidelines for enhancing safety at HRGCs with gates in urban areas. After evaluation of various candidate models, a Poisson regression model with scaled parameters was recommended for implementation at HRGCs. Pasha et al. [36] analyzed the accidents and hazard prediction models for 589 HRGCs in the State of Florida using different performance measures. The study outcomes demonstrated the superiority of the Florida Priority Index Formula in terms of ranking HRGCs based on their potential hazard. Das et al. [37] conducted a taxicab correspondence analysis for fatal accidents at the U.S. HRGCs between 2010 and 2018 using the fatality analysis reporting system. It was found that fatal accidents occurring during daytime are likely to result in more than one fatality. Moreover, the vehicle type and speed substantially affected the occurrence of fatal accidents at HRGCs.

7. Literature Summary and Contributions of This Work

A detailed review of the HRGC literature identified a significant number of efforts conducted to understand and analyze various causes of accidents at HRGCs. However, many of the reviewed studies put a specific emphasis on a particular group of factors when analyzing HRGC accidents [12][16][18][20][23]. For example, Hao et al. [12] primarily focused on the effects of time of day on the injury severity at HRGCs. Several studies mostly concentrate on human factors that may cause HRGC accidents [16][18][20][23]. Lin et al. [26] and Keramati et al. [27] investigated the effects of HRGC geometric characteristics on their vulnerability to accidents. A recent study conducted by Das et al. [37] analyzed quite a wide array of factors when investigating HRGC accidents but focused only on fatal accidents without considering injury and property damage only accidents. Due to an increase in HRGC accidents in Florida, this study aims to conduct a comprehensive analysis of HRGCs that experienced accidents over the last years. In contrast with many of the previous research efforts, the present study evaluates a wide range of various factors, which include physical and operational characteristics of crossings, vehicle and train characteristics, spatial characteristics, temporal and environmental characteristics, driver actions and related characteristics, and other relevant information. The outcomes of this research are expected to assist the appropriate stakeholders (e.g., state Departments of Transportation) with implementation of safety improvement projects across the state.

References

1. UNECE. Statistical Data on Level Crossings and on Their Safety in EU Countries. 2018. Available online: https://unece.org/DAM/trans/doc/2018/wp6/4d_EUAR_LC_safety_stats_June_2018.pdf (accessed on 10 May 2021).
2. NSC. Railroad Deaths and Injuries. 2021. Available online: https://injuryfacts.nsc.org/home-and-community/safety-topics/railroad-deaths-and-injuries/ (accessed on 10 May 2021).
3. Beanland, V.; Salmon, P.M.; Filtness, A.J.; Lenné, M.G.; Stanton, N.A. To stop or not to stop: Contrasting compliant and non-compliant driver behavior at rural rail level crossings. Accid. Anal. Prev. 2017, 108, 209–219.
4. Saccomanno, F.F.; Park, P.Y.-J.; Fu, L. Estimating countermeasure effects for reducing collisions at highway–railway grade crossings. Accid. Anal. Prev. 2007, 39, 406–416.
5. Evans, A.W. Fatal accidents at railway level crossings in Great Britain 1946–2009. Accid. Anal. Prev. 2011, 43, 1837–1845.
6. Laapotti, S. Comparison of fatal motor vehicle accidents at passive and active railway level crossings in Finland. IATSS Res. 2016, 40, 1–6.
7. EUR-Lex. Commission Directive 2014/88/EU. 2021. Available online: https://eur-lex.europa.eu/legal-content/ (accessed on 16 July 2021).

8. Dulebenets, M.A.; Moses, R.; Sobanjo, J.; Ozguven, E.E.; Abioye, O.F.; Kavoosi, M.; Pasha, J. Development of the Optimization Model for Improving Safety at Rail Crossings in Florida; A Technical Report; Florida Department of Transportation: Tallahassee, FL, USA, 2020.
9. Hao, W. Driver Injury Severity at U.S. Highway-Rail Crossings. Ph.D. Thesis, Department of Civil and Environmental Engineering, NJIT, Newark, NJ, USA, 2013.
10. Haleem, K.; Gan, A. Contributing factors of crash injury severity at public highway-railroad grade crossings in the U.S. J. Saf. Res. 2015, 53, 23–29.
11. Haleem, K. Investigating risk factors of traffic casualties at private highway-railroad grade crossings in the United States. Accid. Anal. Prev. 2016, 95, 274–283.
12. Hao, W.; Kamga, C.; Wan, D. The effect of time of day on driver's injury severity at highway-rail grade crossings in the United States. J. Traffic Transp. Eng. English Ed. 2016, 3, 37–50.
13. Zhao, S.; Khattak, A.J. Factors associated with self-reported inattentive driving at highway-rail grade crossings. Accid. Anal. Prev. 2017, 109, 113–122.
14. Keramati, A.; Lu, P.; Zhou, X.; Tolliver, D. A Simultaneous safety analysis of crash frequency and severity for highway-rail grade crossings: The competing risks method. J. Adv. Transp. 2020, 2020, 1–13.
15. U.S. DOT. Role of Human Factors in Rail Accidents. 2007. Available online: https://www.transportation.gov/testimony/role-human-factors-rail-accidents (accessed on 5 May 2021).
16. Tey, L.-S.; Ferreira, L.; Wallace, A. Measuring driver responses at railway level crossings. Accid. Anal. Prev. 2011, 43, 2134–2141.
17. Silla, A.; Luoma, J. Main characteristics of train–pedestrian fatalities on finnish railroads. Accid. Anal. Prev. 2012, 45, 61–66.
18. Naweed, A. Psychological factors for driver distraction and inattention in the Australian and New Zealand rail industry. Accid. Anal. Prev. 2013, 60, 193–204.
19. Read, G.J.; Salmon, P.M.; Lenné, M.G. Sounding the warning bells: The need for a systems approach to understanding behavior at rail level crossings. Appl. Ergon. 2013, 44, 764–774.
20. Salmon, P.M.; Read, G.; Stanton, N.; Lenné, M.G. The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. Accid. Anal. Prev. 2013, 50, 1278–1288.
21. Kyriakidis, M.; Majumdar, A.; Ochieng, W.Y. Data based framework to identify the most significant performance shaping factors in railway operations. Saf. Sci. 2015, 78, 60–76.
22. Liu, J.; Khattak, A.J.; Richards, S.H.; Nambisan, S. What are the differences in driver injury outcomes at highway-rail grade crossings? Untangling the role of pre-crash behaviors. Accid. Anal. Prev. 2015, 85, 157–169.
23. Stefanova, T.; Burkhardt, J.M.; Filtness, A.; Wullems, C.; Rakotonirainy, A.; Delhomme, P. Systems-based approach to investigate unsafe pedestrian behavior at level crossings. Accid. Anal. Prev. 2015, 81, 167–186.
24. Madigan, R.; Golightly, D.; Madders, R. Application of human factors analysis and classification system (HFACS) to UK rail safety of the line incidents. Accid. Anal. Prev. 2016, 97, 122–131.
25. Larue, G.S.; Naweed, A.; Rodwell, D. The road user, the pedestrian, and me: Investigating the interactions, errors and escalating risks of users of fully protected level crossings. Saf. Sci. 2018, 110, 80–88.
26. Lin, P.-S.; Fabregas, A.; Kourtellis, A.; Bryant, E.; Lall, S. Planning and design for prevention of incorrect turns onto highway-rail grade crossings. Chall. Adv. Sustain. Transp. Syst. 2014, 358–365.
27. Keramati, A.; Lu, P.; Tolliver, D.; Wang, X. Geometric effect analysis of highway-rail grade crossing safety performance. Accid. Anal. Prev. 2020, 138, 105470.
28. Silla, A.; Kallberg, V.-P. The development of railway safety in Finland. Accid. Anal. Prev. 2012, 45, 737–744.
29. Chadwick, S.G.; Zhou, N.; Saat, M.R. Highway-rail grade crossing safety challenges for shared operations of high-speed passenger and heavy freight rail in the U.S. Saf. Sci. 2014, 68, 128–137.
30. Phillips, R.O.; Sagberg, F. What did you expect? CREAM analysis of hazardous incidents occurring on approach to rail signals. Saf. Sci. 2014, 66, 92–100.
31. Khattak, A.; Tung, L.-W. Severity of Pedestrian Crashes at Highway-Rail Grade Crossings. J. Transp. Res. Forum 2015, 54, 91–100.
32. Metaxatos, P.; Sriraj, P.S. Pedestrian safety at rail grade crossings: Focus areas for research and intervention. Urban Rail Transit 2015, 1, 238–248.

33. Abioye, O.F.; Dulebenets, M.A.; Pasha, J.; Kavoosi, M.; Moses, R.; Sobanjo, J.; Ozguven, E.E. Accident and hazard prediction models for highway–rail grade crossings: A state-of-the-practice review for the USA. Railw. Eng. Sci. 2020, 28, 251–274.
34. Kavoosi, M.; Dulebenets, M.A.; Pasha, J.; Abioye, O.F.; Moses, R.; Sobanjo, J.; Ozguven, E.E. Development of algorithms for effective resource allocation among highway–rail grade crossings: A case study for the state of Florida. Energies 2020, 13, 1419.
35. Khattak, A.; Kang, Y.; Liu, H. Nebraska Rail Crossing Safety Research. 2020. Available online: https://dot.nebraska.gov/media/114447/nebraska-rail-crossing-safety-research.pdf (accessed on 10 May 2021).
36. Pasha, J.; Dulebenets, M.A.; Abioye, O.F.; Kavoosi, M.; Moses, R.; Sobanjo, J.; Ozguven, E.E. A comprehensive assessment of the existing accident and hazard prediction models for the highway-rail grade crossings in the state of Florida. Sustainability 2020, 12, 4291.
37. Das, S.; Kong, X.; Lavrenz, S.M.; Wu, L.; Jalayer, M. Fatal crashes at highway rail grade crossings: A U.S. based study. Int. J. Transp. Sci. Technol. 2021.