A Study on the Prevention of Secondary Accidents Based on the Analysis of High-Speed Train Accidents

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Abstract

**Purpose:** Railroads are public transportation used by a large number of unspecified passengers, and the vehicle itself is large and very fast, so there is a lower probability of general accidents than road traffic, but once it occurs, it leads to a major accident, causing great human and property damage. In particular, high-speed railways running at 300km/h are obliged to realize the value of absolute safety, but in 2021, the number of high-speed railway accidents increased from 1 to 4 compared to the previous year, causing the reliability of railways to drop sharply. In order to prevent high-speed railway accidents through this, two aspects, primary accident prevention and secondary accident minimization, should be considered at the same time.

**Method:** The study applied Heinrich’s Law (Heinrich’s Law), the principle of industrial safety, called the law of 1:29:300, in which dozens of minor accidents and hundreds of signs must appear before a major accident. In particular, it analyzed cases of high-speed railway accidents, which are major accidents among domestic railway accidents, and large-scale derailment accidents by overseas high-speed railway operators. One major accident is caused by hundreds of signs and repetitive and unconscious behaviors that cause the accident. Preemptive preventive measures are needed to prevent further major accidents from occurring on high-speed railways.

**Results:** The causes of derailment accidents among high-speed train accidents in Korea were railroad workers’ insensitivity to railway safety, lack of business cooperation between workers in different occupations, and lack of KORAIL safety management system. Overseas high-speed train accidents were derailment accidents in Germany, China, and France, which were also caused by railroad workers’ ignorance and lack of safety management systems. In order for railway safety to become an absolute value, the need for train wireless protection was emphasized not only to preemptively prevent primary accidents but also to minimize secondary accidents.

**Conclusion:** In this paper, train wireless protection devices were considered to prevent secondary accidents among railway safety fields. The train wireless protection devices warns other train engineers nearby to take emergency measures within a 2-4km radius when the engineer of the train presses the switch of the train protection device in the event of an emergency such as an accident during train operation. Railway accidents must continue to innovate the safety system for interfaces between sub-systems, so if train wireless protection devices are technically upgraded and systematic response algorithms are developed and applied to railway sites, it will be possible to block the "1" major accidents referred to in Heinrich’s Law. In the future, empirical research on the contents of the study more requires experimental application considering the railway operation organization and operating environment.

**Keywords:** Railroad, High-Speed Train, Railroad Accident, Accident Case, Secondary Accident

1. Introduction

In railroad transportation, several systems are intricately connected to each other. Risk factors always exist among such connections, and the railroad operators, etc., are making great
efforts to reduce the risk factors. However, there are only a few perfect measures to reduce the risk factors. This is because, even if perfect countermeasures are developed, new risk factors are created between the countermeasures, thereby resulting in another risk. As such, it is impossible to eliminate all risk factors, and hence, if risk factors are not managed, very serious damages to life and property occurs, requiring the safety management of risk factors.[1]

Heinrich’s law, also called the 1:29:300 rule, is a statistical law which means that dozens of minor accidents and hundreds of signs related to a major accident must appear before any major accident occurs.[2] When this rule is applied to the railroad, a secondary accident is the one which leads to a collision or a collision with a high-speed train passing after one large railroad accident, that is, the primary high-speed train accident. In this case, it means that dozens of minor accidents, that is, primary high-speed train accidents and hundreds of signs, must appear for some reason before secondary accidents occur. In this case, the hundreds of signs refer to the signs that are routinely taken care of through education, training, and maintenance in the organization, or the signs that have been overlooked without finding a specific cause.[3]

The railroad operator offers the trust of absolute safety to the destination in order to provide the railroad passengers with the value of speed, accuracy, and punctuality of travel, and this is the point of contact where 100% of mutual value is exchanged between the high-speed train service provider and the customer, which means zero railroad accidents, and such becomes the core value of safe operation.[4][5].

According to Heinrich’s Law, a single secondary accident should never occur, yet since an accident always occurs at an unexpected moment, it led to a secondary accident in the 2013 Daegu KTX collision derailment. In order to prevent accidents, it was reminded that even if all the efforts are made to prevent secondary accidents by mobilizing the knowledge and skills possessed by experts, unexpected variables are always latent. The importance of the railroad safety cannot be overemphasized. Hence, if a railroad accident occurs despite active response, it is also very important that the railroad workers have a well-equipped emergency preparedness training system and solidify a safety culture through continuous learning and training so as not to lead to secondary accidents[6][7]. In this paper, based on the causes of high-speed train derailments in Gwangmyeong Station, Daegu Station, and Gangneung Line and in countries operating high-speed railroads abroad, it is intended to propose a plan for preventing major accidents corresponding to “1” of Heinrich’s Law 1:29:300.

2. Analysis of Domestic and Foreign High-Speed Train Accidents

2.1. Domestic high-speed train accidents

Since the high-speed train was launched in 2004, there have been 36 major and small primary accidents such as the KTX train stopping due to a breakdown in the Gimcheon Tunnel in July 2011, and 36 KTX accidents occurred in 2011, 4 accidents in July 2011 alone. During a special audit of KORAIL in 2011, when breakdowns and accidents occurred frequently on railroads including KTX, the Board of Audit and Inspection established a railroad safety committee consisted of about 20 outsiders to conduct inspections and evaluations of safety measures and safety systems[8][9]. As a result, the number of accidents and breakdowns has decreased somewhat, yet the customers still remember the past accidents, and the anxiety about railroad accidents is not completely resolved while they are using high-speed trains[10].

<Figure 1> illustrates the status of train accidents for the past 10 years(2012-2021) compiled in the railroad safety information comprehensive management system of the Korea Transportation Safety Authority in order to identify dozens of minor accidents according to Heinrich’s Law(https://www.railsafety.or.kr).
Train accidents are largely classified into crossing accidents, derailment accidents, and collision accidents, and over the past 10 years, there have been 13 collisions, 53 derailments, and 100 crossing accidents, for a total of 166. Among which, the number of crossing accidents accounted for the most, and while the number of crossings decreased year by year, the number of crossing accidents did not decrease but increased and decreased, and it is determined that effective safety measures are inadequate[7].

**Figure 1.** Status of train accidents over the last 10 years(2012-2021).

As a result of analyzing the railroad traffic accidents and railroad safety accidents for the last 5 years of high-speed trains by collecting high-speed train-related accident statistics from the train accident status for 10 years in <Figure 1> through the same management system, it was analyzed as in <Table 1>. It turned out that, among the railroad traffic accidents, there were 1 derailment, 28 general railroad traffic accidents, and 8 railroad safety accidents[11].

**Table 1.** High-speed rail accident related statistics.

<table>
<thead>
<tr>
<th>Content and year category</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum</td>
<td>10</td>
<td>16</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td>Railroad traffic accident (derailment)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Railroad traffic accident</td>
<td>7</td>
<td>11</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Railroad safety accident</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

Among the data in <Table 1> above, and among the major high-speed train accidents, and among the major high-speed train accidents, the 4 accidents among high-speed train derailment accidents with a possibility of secondary accidents or secondary accidents are summarized, and the Gwangmyeong Station high-speed train accident would be noted the first. The accident occurred due to the negligence of the worker at the construction company, which resulted in the
failure of the contact lock nut, inadequate supervision of cable replacement work, non-compliance with the safety regulations of the signal facility maintainer, and unauthorized direct connection to the route indication circuit, and the change of the signal facility was not accurately notified to the controller, and it was investigated that the controller was also inadequate in responding to the obstacles of the line changer due to inaccurate information [12]. Furthermore, the accident was caused by the railroad workers’ insensitivity to railroad safety, their lack of cooperation between workers in different occupations, and inadequate safety management system of KORAIL (Air Rail Accident Investigation Committee 2011).

Second, the Daegu KTX train collision derailment accident in 2013 may be noted [13]. The accident occurred at the moment when the KTX train from Busan to Seoul passed through Daegu Station, the Mugunghwa train bound for Seoul, which had to wait for the KTX train on another track to completely pass through the track, misunderstood the signal and departed, and it ultimately turned out to be an accident which occurred while colliding with a part, and 9 KTX trains and 1 Mugunghwa train derailed thereby [12][13][14].

The problem was that, within a minute of the relevant collision, it was recorded that, the KTX heading for Busan entered from the opposite track, and it was a major accident that derailed and collided with the side of the tilted KTX, thereby leading to a secondary accident that paralyzes both the upper and lower lines of the Gyeongbu Line (Air Railroad Accident Investigation Committee 2013).

The third is the 2018 Gangneung Line KTX derailment accident, and this accident caused the derailment to occur by constructing the track changer cable that changed the direction of the train in the opposite direction, and in the inspection process, it was not confirmed that the display was reversed, and it was investigated that the changes were not accurately reflected in the supervision process. As a result, the track switching device was displayed as normal on the signal control panel, and the KTX passing through this point derailed, injuring 58 passengers and causing property damages of KRW 22.7 billion (Air Railroad Accident Investigation Committee 2018).

The fourth is the SRT derailment accident that occurred in the Honam Maintenance Group in 2020, whose cause was that the SRT captain sped from the speed limit of 60 km/h to 91/km/h during the test drive, hit the car screen sign and deviated from the track. As a result, 3 employees were injured and property damages worth 3.2 billion won were caused (Air Railroad Accident Investigation Committee 2020).

<Table 2> briefly illustrates the details above.

<table>
<thead>
<tr>
<th>Year</th>
<th>Accident details</th>
<th>1st</th>
<th>2nd</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Gwangmyeong station KTX-sancheon train derailment accident: the cause of the accident was directly connected to the track indicator circuit of the track changer with a jumper wire.</td>
<td>○</td>
<td></td>
<td>0 death</td>
</tr>
<tr>
<td>2013</td>
<td>1st: collision(mugunghwa, KTX), derailment 2nd: side contact of KTX passenger car signal misinterpretation.</td>
<td>○</td>
<td>○</td>
<td>0 death</td>
</tr>
<tr>
<td>2018</td>
<td>Gangneung line KTX: accidents caused by various human errors, such as derailment of the junction, misconnection, etc.</td>
<td>○</td>
<td></td>
<td>0 death</td>
</tr>
</tbody>
</table>

*Table 2. Summary of high-speed train accidents that occurred in domestic high-speed trains.*
2.2. Overseas high-speed train accidents

The first was an accident in November 2015 when a TGV 744 high-speed train which was carrying out a test run in the second stage of the LGV Eastern Europe Line near Eckwersheim in northeastern France derailed, killing 11 people and injuring 42 people [15]. This accident was caused by the ignorance of the engineer, and it was the starting point of the accident when the speed limit was exceeded by nearly 100 km during the test drive, where the failure to slow down was the largest cause of accident [15][35].


The second accident is these in which 101 passengers were killed in a derailment accident of high-speed train ICE 884 in Edesse, Hanover, Germany in June 1998. Surprisingly, the cause of this accident was 'poor maintenance' in which one wheel of the railroad vehicle was not properly maintained, and the time, experts said the main reason was the absence of a diagnostic system. The accident left Germany, a technological powerhouse, a most humiliating case, which was considered to have arisen from the ignorance and arrogance of technical knowledge of the German railroad related workers [36].

(https://en.wikipedia.org/wiki/Eschede_derailment)

Third, in July 2011, some devices of the high-speed train on the Hangpu Line high-speed railroad in Wenzhou, Jiangsu Province, southeastern China, broke down, and the high-speed train in operation was discontinued, where the subsequent train collided, derailed, crashed, which turned into a major accident that led to a secondary accident. The accident began when the preceding train was struck by lightning and lost power while it was running, and the subsequent train following it collided with the stopped preceding train every 10 minutes, and both trains derailed 4 passenger cars, two of which were a bridge fell off the bridge. Usually, the train control system would be activated and the following trains could be stopped, but the signal system in the relevant section was also broken due to lightning strikes, and the following trains did not receive a stop signal, the Chinese explained. Such unexpected natural disasters could also lead to secondary accidents, suggesting that large-scale accidents can only be prevented by having a systematic maintenance manual [16][37].

(https://en.wikipedia.org/wiki/Wenzhou_train_collision)

Table 3 summarizes and illustrates the cases of high-speed train derailment which arose overseas.

<table>
<thead>
<tr>
<th>Year</th>
<th>Accident details</th>
<th>1st</th>
<th>2nd</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Exceeding the speed limit (operation with safety switch off)</td>
<td>o</td>
<td></td>
<td>11 deaths</td>
</tr>
<tr>
<td>1998</td>
<td>Poor maintenance of high-speed rail vehicle wheels</td>
<td>o</td>
<td></td>
<td>101 deaths</td>
</tr>
</tbody>
</table>
2.3. A comprehensive analysis of domestic and foreign high-speed train accidents

The causes of accidents due to the above domestic and foreign high-speed train accidents are summarized as railroad workers’ insensitivity to railroad safety, lack of business cooperation among workers by occupation, and lack of safety management system of railroad operating institutions. In particular, various factors such as lack of system and mechanical defects are pointed out, but above all, human mistakes stemming from the problems of people who operate them are analyzed as the most important reason[17][18].

In domestic accidents, driving security devices installed to prevent accidents caused by human mistakes did not operate normally, and accidents worsened due to careful driving by high-speed railway drivers, negligence of forward monitoring, and late operation of emergency braking systems. In particular, the Daegu accident led to a secondary accident as the controller not only neglected measures such as displaying a stop signal on the descending signal or not notifying the approaching train to protect the Daegu area immediately after the first collision, but also did not properly take measures such as suspension of operation and non-traditional beams at the central control center[19].

In addition, railroad operation companies have a systematically insufficient system for mobilization of manpower in case of an emergency, and due to the absence of driving-related organizations, the implementation of driving plans, driving systems, education and training plans, and education and training of locomotive crew and train crew members are insufficient, so it is necessary to improve the control system and improve the safety management system.

Because human factors are complex and diverse, it is not easy to assess and control the risks to human factors. Various measures may be prepared to reduce human errors of drivers only when the experience of near accidents and environmental physical improvements of drivers are made together. After an accident, education and training should be systematically carried out, such as active management, mental management, rational improvement of shift work, prevention of stress-causing factors and near accidents, and improvement of healthy sleep quality[20].

Among the cases of overseas high-speed rail accidents, the collision of a follow-up train due to a breakdown of the signal system caused by lightning in China could lead to secondary accidents in natural disasters, suggesting that a more systematic maintenance manual is needed to prepare for natural disasters.

2.4. Analysis of the policies to strengthen the railroad traffic safety in the national railroad network construction plan

Based on the overseas high-speed train accident cases described in 2.2 above, the study on the measures to reduce railroad accidents applicable in Korea was also conducted[21]. An important opportunity for the paradigm of railway safety to change becomes possible in the event of a series of incidents that become a big social issue. For railroad safety, among the contents of the 4th national railroad network construction plan(2021-2030) in Korea, 7 directions were announced to lead the balanced national development and green mobility[MOLIT 4th National Railway Network Construction Plan].

Included in these directions were the transition towards the performance-oriented management system based on durability and usability and strengthen railroad safety by preferentially investing in railroad facilities with high breakdown frequency and high damage in the event of an accident or failure through precise analysis of the frequency of railroad accidents and failures.
caused by facility causes. <Table 4> is an analysis of the contents of the reinforcement of railroad safety continuously pursued in the national railroad network construction plan from 2006 through 2030.

Table 4. Contents of the plan for strengthening the railroad safety[38].

<table>
<thead>
<tr>
<th>Division</th>
<th>Railroad safety reinforcement plan</th>
</tr>
</thead>
</table>
| 1st national railway network construction plan | -Reinforcement of railroad crossing safety management  
-Screen door installation to prevent accidents near the platform  
-Maintenance of detailed standards for railway vehicle safety standards |
| 2nd national railway network construction plan | Railroad safety reinforcement plan: included in the following tasks  
-Connecting major bases nationwide with high-speed KTX network  
-Establishment of express railroad network, green railroad logistics system |
| 3rd national railway network construction plan | Creating safe and convenient facilities  
-Improvement of old facilities and reinforcement of railroad safety  
-Signal system compatibility, train operation safety reinforcement |
| 4th national railway network construction plan | Creating a safe and convenient user environment  
-Reinforcement of performance-oriented railroad safety  
-Transition to safety-oriented management system  
-Detailed analysis of railway accidents and failure frequency  
-Priority investment in railway facilities with high breakdown frequency |

In addition, the Railroad Safety Act, a general legal system for railroad safety, has been enacted and has been in effect since 2005. Pursuant to Article 5 of this Act, the State shall formulate and implement a comprehensive railroad safety plan every five years, and the State, a local government, a railroad operator, etc. shall formulate and implement an annual implementation plan each year pursuant to Article 6. However, despite various railway safety-related systems and stricter regulations, railway accidents and operation failures continue to occur due to poor implementation at railway sites[23]. Therefore, it is necessary to spread the safety culture for safety management centered on accident prevention and establish a system to implement it.

3. Train Wireless Protection Device to Prevent the Secondary Accidents

The railroad operators are trying to provide the best value of safe mobility culture the moment customers purchase a ticket, but the secondary accident in Daegu and the secondary accident of high-speed train in China in 2013 caused a lot of casualties and material damages. In order to prevent further secondary accidents from against occurrence, it was reviewed whether the secondary accident could be prevented with the train radio protection device, which is already being used as an efficient method for the safety system on railroad[24][25].

That is, when an emergency situation such as an accident occurs while the train is running, the train operator warns other train engineers within a radius of 2 to 4 km to take emergency measures when the train operator presses the switch of the train protection device, and this is a system which prevents secondary accidents by automatically stopping the operation of other trains within the vicinity[26]. However, if an accident such as a train derailment, collision, or collision occurs during train operation, the engineer or crew member, who must inform other trains in the vicinity of the situation, may face physical or psychological abnormalities, and hence, there may be situations in which it is difficult to operate the switch of the train protection device by the crew. Furthermore, there may be a problem that the train protection device does not operate due to physical damages to the communication cable, etc. In particular, in the case of the non-operation of the train protection device, since the risk of secondary accidents such as collision by trains running adjacent is very high, it is necessary to secure a safety system for the operation of the train protection device[27].
In the case of the control room, if the high-speed train running in the direction of disembarkation disappears from the status board, or if the condition that the train is running is displayed, that is, the high-speed train which moves with the control room operating software operation algorithm and train number is used, it is considered that 2 types of situations can be detected[28]. By designating a follow-up train and a merchant train based on the 2 points of occurrence of the disembarkation high-speed train, the control room can take actions to slow it down at a speed which can be stopped immediately and, if necessary, take actions to halt it. Furthermore, if action is not taken within the time limit, the control system needs to send the relevant information to the engineer of the train approaching the accident point through a radio or smartphone, etc. If the vehicle does not slow down, it is necessary to have an emergency braking function. If such a measure is possible, it is determined that it will play a sufficient role in preventing secondary accidents by further enhancing the utility value of the train wireless protection device installed on all trains[27][28].

During the 2017 KORAIL national audit, the need for the train wireless protection system was emphasized with the content such that it is necessary to ensure the safety of the people by operating the train wireless protection system properly, and in December 2020, the KSC regulations were amended and are currently used after the railroad technical review committee’s deliberation for the train wireless protection device[27]. <Table 5> is an analysis of the possibility of a major accident depending on the operator’s consciousness and the presence or absence of a train wireless protection device installed on the locomotive[28][29].

<table>
<thead>
<tr>
<th>Device installment</th>
<th>Engineer’s consciousness</th>
<th>Possibility of developing into a major secondary accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Existence</td>
<td>Manual Auto None Existent</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>It can happen if you do not take immediate action by a witness or the control room.</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>It can be prevented by taking action by a trained engineer.</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>It can happen if you do not take immediate action by a witness or the control room.</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>It can be prevented by taking action by a trained engineer.</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>It can automatically stop the entry of up and down trains.</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>An action by a trained engineer or it can be prevented automatically.</td>
</tr>
</tbody>
</table>

4. Conclusion

In the railroad transportation, when an accident occurs, a very large loss occurs and the ripple effect is large, and hence, it is necessary to continuously innovate the safety system for the interface between subsystems[30]. If the train radio protection system is technically upgraded, the organization’s systematic response algorithm can be developed and applied for the railroad field, and it is determined that it will be possible to block the "1" large-scale accident referred to in Heinrich’s law.

In this paper, it is intended to achieve zero railroad accidents that which the railroad operators deliver to the customers at the point of contact with them, and it also examined thermal radiation protection devices to prevent secondary accidents in the field of railroad safety[31][32]. In the future, as an empirical study on the research content, it will be necessary
to apply experimentally considering the railroad operating organization and operating environment[31][32].

In order to secure railway safety, I am confident that railway safety will be secured when the government, local governments, railway facility managers, railway operators, and professional institutions fulfill their roles and responsibilities, and each member of each institution is faithful to his or her work with a heavy responsibility.

In the end, it is important to ensure that the CEO and all employees working in the field are not negligent in the given tasks with a united mind.

The occurrence of railroad accidents creates a significant anxiety in the society as a whole. Railroad is an essential means of transportation which promotes public convenience and leads social development[33][34]. For the genuine establishment of railroad safety, sincere efforts of the people concerned for railroad improvement and development, public interest and support, and active participation are required. It is expected that people will be able to enjoy safety, which is a basic human right, by performing the common task of railroad safety towards the secondary accident prevention.

5. References

5.1. Journal articles


5.2. Books


5.3. Additional references


6. Appendix

6.1. Author’s contribution

<table>
<thead>
<tr>
<th>Initial name</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author EP</td>
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</tr>
<tr>
<td></td>
<td>- Set of concepts ☑</td>
</tr>
<tr>
<td></td>
<td>- Design ☑</td>
</tr>
<tr>
<td></td>
<td>- Getting results ☑</td>
</tr>
<tr>
<td></td>
<td>- Analysis ☑</td>
</tr>
<tr>
<td></td>
<td>- Make a significant contribution to collection ☑</td>
</tr>
<tr>
<td></td>
<td>- Final approval of the paper ☑</td>
</tr>
<tr>
<td></td>
<td>- Corresponding ☑</td>
</tr>
<tr>
<td></td>
<td>- Play a decisive role in modification ☑</td>
</tr>
<tr>
<td></td>
<td>- Significant contributions to concepts, designs, practices, analysis and interpretation of data ☑</td>
</tr>
<tr>
<td></td>
<td>- Participants in Drafting and Revising Papers ☑</td>
</tr>
<tr>
<td></td>
<td>- Someone who can explain all aspects of the paper ☑</td>
</tr>
</tbody>
</table>

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