ISSN: 0976-3376

Available Online at http://www.journalajst.com

ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 14, Issue, 06, pp. 12561-12567, June, 2023

RESEARCH ARTICLE

EXPLORING RAILWAY FORENSICS: TOP APPROACHES AND FUTURE DIRECTIONS

Gurleen Kaur[1*] and Bhavika Moza[2]

[1*]Assistant Professor, Department of Forensic Science, School of Paramedical Science, RIMT University, Punjab
[2]MSc. Forensic science, University Institute of Applied Health Science, Chandigarh University, Punjab

ARTICLE INFO

Article History:
Received 20th March, 2023
Received in revised form
17th April, 2023
Accepted 25th May, 2023
Published online 20th June, 2023

Keywords:
Rails, Track, Human Factors, Investigation, derailment, Rolling Contact Fatigue, Track buckling, Continously wielded rail, challenges, future directions, etc

ABSTRACT

Railway incidents can have significant safety implications for the railway system, its components, and people involved, leading to train delays and financial losses. Railway forensic investigations play a crucial role in understanding the causes and circumstances of these accidents. This field is continuously evolving and offers scope for improvement. Various organizations are responsible for conducting thorough railway examinations, highlighting the importance of their expertise in investigations. Examining rolling stock is essential for analyzing train condition and performance. Track analysis involves evaluating track conditions, maintenance practices, and potential failure mechanisms. Human factors in railway accidents are addressed, recognizing the need to consider human behavior and decision-making in forensic investigations. An evaluation of fatalities associated with railway incidents in different countries provides valuable insights. The future of railway forensic includes advancements like drone surveillance, artificial intelligence, technological innovations, training, and collaboration among stakeholders to enhance investigation techniques and improve safety measures. This review paper serves as a comprehensive resource for researchers, forensic experts, and organizations involved in railway forensic, offering valuable insights into current practices, challenges, and potential avenues for development in this important field of investigation.

Citation: ***Gurleen Kaur and Bhavika Moza.* 2023.** "Exploring railway forensics: Top approaches and future directions", *Asian Journal of Science and Technology*, 14, (06), 12561-12567.

INTRODUCTION

Trains are generally known being a chain of vehicles that is propelled with help of engine for transport of passengers, live-stock or parcels while travelling through a defined track. Train accident are all events that impact railway, and can be described as an event that brings loss or can bring loss to railway, any rolling stock, railway parts and passengers. Given the importance of railways, ensuring their safety is of utmost importance. The field of railway forensics is a developing area of investigation that aims to identify the root causes of railway accidents and enhance safety protocols to prevent similar incidents in the future. Investigations are carried out by experts who use a combination of scientific and technical methods to analyze accidents. It involves a range of disciplines, including mechanical engineering, human factors, and computer science. Mechanical engineering expertise is required to investigate rolling stock failures and track-related issues. Human factors experts investigate the actions of railway personnel and analyze safety protocols. Computer science experts analyze train control systems and examine safety-critical events (Zhu *et al*., 2019). The key components of railway forensics include track analysis, rolling stock examination, human factors analysis, and data analysis.

Corresponding author: Gurleen Kaur
Assistant Professor, Department of Forensic Science, School of Paramedical Science, RIMT University, Punjab

Track analysis involves examining the rails and sleepers for signs of wear, stress, and deformation. Rails and sleepers are subjected to wear and stress due to continuous use, heavy loads, and extreme weather conditions. Track analysis involves examining the rails and sleepers for signs of wear, such as flattened or worn rail heads, corrugation, and shelling. These defects can cause trains to derail or lead to broken rails, which can cause accidents (Jones & Ashby, 2019a). Rolling stock examination involves studying locomotives, wagons, and other equipment to identify mechanical failures and defects. Constant usage of rolling stock leads to wear, making it crucial to detect any problems proactively to prevent accidents (Kuzishyn & Batig, 2018). Human factors analysis is a critical aspect of railway forensics, it is often responsible for a significant number of accidents. This involves investigating the actions of railway personnel and analyzing safety protocols to identify potential weaknesses (Kyriakidis *et al*., 2015). Data analysis involves examining train control systems, identifying safety-critical events, and analyzing train operations. Utilizing data analysis enables the identification of hidden trends, empowering railway operators to proactively implement measures. Railway forensics also involves the use of various techniques, such as non-destructive testing, computer simulation, and forensic analysis (Bešinović *et al*., 2021). (Krishna *et al*., 2017b). Case studies of railway accidents are essential in understanding the importance of railway forensics. Through thorough examination of accident causes, railway operators can pinpoint potential safety hazards and implement proactive measures. Applying insights gained from railway accidents can effectively prevent the occurrence of similar incidents in the future.

Train accident types: Train accidents can be caused due to collisions, derailment etc. Collisions cause high amount of damage, Collision can be cause by man-made error or equipment failure. Derailments are more frequent than the collisions, but not that impactful unless there is a collision. They are mostly caused due to technical failures like improperly laid tracks, defected communication system, obstacles on the tracks. Natural forces like heavy land or rock slides can also derail the trains.

Derailment are of two types:

1. **Sudden derailment:** can be caused due to excessive velocity at curve. Obstruction on the track, sudden load shift, or badly defected wheels or springs.
2. **Gradual derailment:** Badly worn-out vehicles, tracks, or error in operation of train can cause derailment. (Gaur, 2011)

Organizations responsible for railway forensic investigation: In USA, the Federal Railroad Administration (FRA) was set to examine train accidents and give priority to safety regulations and in 1967 National Transportation Safety Board (NTSB) was also formed for investigation of highly serious accidents consisting highway, waterbodies, railroads to find and establish reasons with giving much focus to the trains carrying passengers. Generally, FRA can conduct over 100 railway accident investigations in their capacity (Bibel, 2012). In India, the Commissioner of Railway Safety (CRS) is responsible for investigating all railway accidents. Accident occurred is reported first to Station Master(SM) and in their absence the railway in charge of area where event occurred. The Guard of a train involved in an accident or incident is expected to take immediate actions to protect adjacent lines and the same line, send information to control/SMs on either side, save lives and render first aid, call for doctors and seek assistance from railway men on the train, preserve and safeguard all clues of the possible cause of the accident. It is mandatory to report the accident to the CRS according to railway act 1989. The CRS is an independent statutory authority appointed by the government. After reporting the event CRS conducts an investigation, which includes examining the scene and relevant documents. Once the investigation is complete, the CRS prepares a report outlining the causes of the accident and any recommendations for improving railway safety. The railway administration may be required to take corrective action based on the report's findings. Other agencies, such as the police, National Disaster Response Force, and Indian Railways' own safety organization, may also be involved in the investigation to ensure a comprehensive examination and identify opportunities to enhance railway safety. (*CRS- Brief History and Functions*, n.d.)

Components of examination for railway forensics

Rolling Stock Examination: Rolling contact fatigue (RCF) is a broad term used to encompass various types of issues that arise from the the build-up of excessive shear stresses in the vicinity of the wheel-rail contact point. These stresses result in deformation that exceeds shear limit or ductility.(Grassie & Kalousek, 1997). Rolling contact fatigue is a common form of wheel-rail damage, accounting for 41% of all tread damage. It leads to destructive phenomena on rail, and is influenced by various factors, including the motion characteristics of the wheel-rail system, friction coefficient, rolling method, and surface roughness, wheel-rail materials, processing defects, structural form of rail vehicles, and environmental factors. (L. Ma *et al*., 2018) One such environmental factor is ambient temperature and humidity. In colder regions or at high latitudes, winter conditions can result in extremely low ambient temperatures, reaching as low as -50°C. These temperature extremes can lead to a reduction in the size and irregular arrangement of pearlite in the rail material. This, in turn, increases the material's tensile and yield strength, making it more brittle and prone to cleavage-dominated (brittle) fracture modes. Ma *et al*. reported that temperatures closer to -15°C approach the ductile to brittle transition temperature resulting in significant rolling contact fatigue damage.(L. Ma *et al*., 2018). In contrast, elevated ambient temperatures have a lesser impact on rolling contact fatigue (RCF) compared to the rapid rise in flash temperature, which can reach several hundred degrees. Gaining insights into how environmental factors affect rolling contact fatigue (RCF). is crucial for developing effective strategies to prevent and mitigate wheel-rail damage in railway forensics. (Zhu *et al*., 2019)

Researchers conducted comprehensive studies on how the railway track interacts with new rolling stock when it's moving fast. The study used both theoretical and experimental approaches. According to the study findings, the average stress values within the rails ranged from 44.37 to 70.00 MPa, in all areas values were lower than the maximum allowable values. With the increase in speed, vertical force decreased by 9.39%, lateral forces decreased by 19.79%. A decrease in stresses at specific locations, including edge of the rail flange, edge of rail head, and the neck of rail by 15.86%, 16.67%, and 8.74% observed respectively. The study provided valuable insights into the operational characteristics of the railway track during accelerated movement. Establishing average stress values and the impact of speed changes on the studied parameters can help investigators determine if the railway track was properly designed and maintained, and if the rolling stock was operated within safe limits.(Hubar *et al*., 2020) Forensic railway-transport expertise's related to freight wagon derailments have been increasing annually. An article identifies the main reasons for freight wagon derailments in Ukrainian railways over the last five years and suggested directions are put forward to enhance the mathematical model of a freight wagon. It encompasses all relevant factors., including hidden ones, that may contribute to derailment, as identified through computer experiments. Through the analysis of recent railway derailments in Ukraine, it has been determined that approximately 20% of cases can be attributed to obvious causes, while around 7% have implicit and less apparent factors contributing to them. In order to examine these cases, the utilization of an advanced mathematical model is essential. In relation to the malfunctions observed in the running gears of the wagons, which resulted in derailments, nonnormative wear of structural elements constituted 39.4% of the cases, while nonnormative gaps in the axle-boxes and side bearers accounted for 29.3%. The research calculations performed with the advanced mathematical model of a freight wagon indicated that neglecting the forces generated by the closure of gaps in the slides, axle-boxes, and the guiding forces on wheel-sets can result in inaccurate outcomes during forensic railway investigations. (Batig *et al*., 2020)

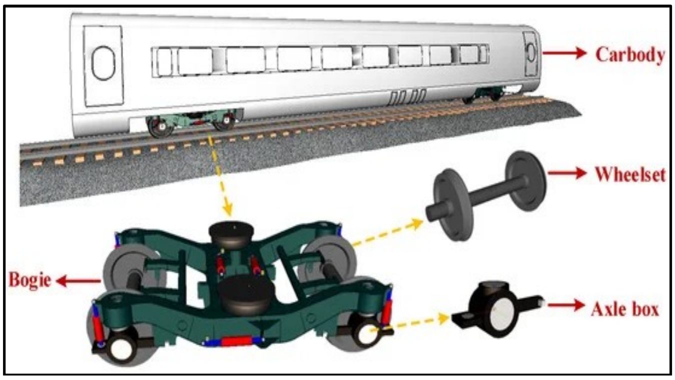

Fig. 1. Axle box and wheel sets (Q. Ma *et al*., 2022)

An investigation was conducted to assess the suitability of a previously developed mathematical calculation for evaluating dynamic characteristics of the mechanical component of the DPKr-2 diesel train. The primary objective of the study was to ascertain the maximum accelerations experienced by the train body in both the vertical and horizontal axis. Additionally, the investigation aimed to determine the coefficients of dynamics in these axes in suspensions. These coefficients were found to be influenced by factors such as the train's speed, length of geometrical irregularities present on the railway track and amplitude. The research aimed to determine the speeds at which resonance phenomena occur, presenting a potential risk to movement of the diesel train. This analysis took into account the parameters of geometrical irregularities on the track. Furthermore, the study established the maximum allowable amplitude of geometrical irregularities for a specific length ensuring that the coefficients of vertical and horizontal dynamics in the primary suspension remained within permissible value.(Kuzyshyn *et al.*, 2019)

Degree of deviation	Smoothness deviations, mm	Allowable speed obtained as a result of calculations, km/h	Deviation on the length of up to 20 m, mm	Allowable speed obtained as a result of calculations, km/h
I	up to 6 including		up to 8 including	
II	over 6 up to 12 including	180	over 8 up to 12 including	180
III	over 12 up to 20 including		over 12 up to 16 including	
IV	over 20 up to 25 including	120	over 16 up to 20 including	150
	over 25 up to 30 including	110	over 20 up to 30 including	105
V	over 30 up to 35 including	75	over 30 up to 40 including	55
	over 35 up to 50 including	15	over 40 up to 50 including	movement stops
	over 50	movement stops	over 50	movement stops

Fig. 2. It depicts the maximum speed limit permitted for DPKr-2 diesel train on the basis of deviations(Kuzyshyn *et al.*, 2019)

When it comes to forensic investigations of railway accidents that involve the failure of rolling stock structural elements, it is not possible to physically recreate the conditions. An article presents a methodology for identifying the wear and tear mechanisms affecting various components. and components due to friction during operation of rail transport, using methods from mechanics, mathematical modeling, and computer simulation. (Кузин *et al.*, 2016)

Track Examination

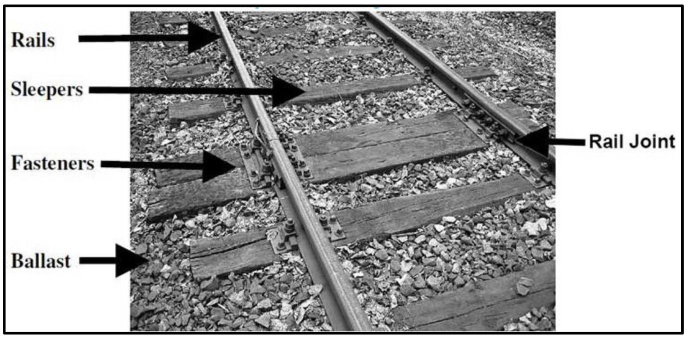

Fig. 3. Traditional railway track with joints
http://www.railjoint.com/news/rail-track-components.html

Fig. 4.Continuous welded rail (Jones & Ashby, 2019b)

The Continuous Welded Rail (CWR) technique is employed to connect rail segments seamlessly to create a continuous track without any gaps or joints. With CWR, the individual rail sections are welded together, forming a single, uninterrupted rail that can extend for several miles. This is in contrast to traditional railroad track construction, where rail segments are connected using fishplates or joint bars. These jointed tracks allow for some flexibility and movement to accommodate temperature-related expansion and contraction.(Jones & Ashby, 2019a)

The increase in global temperatures directly affects steel rails, as they naturally expand when exposed to higher temperatures. This expansion can lead to the build-up of axial compression forces in Continuously Welded Rail (CWR) due to heat waves. While CWR can offer a smoother train ride, it also has drawbacks, such as an increased risk of track buckling when the axial forces in the rail reach their limit, which depends on track conditions. Track buckling has been identified as a significant factor in train derailments, resulting in tragic loss of lives and valuable assets, as evidenced by numerous incidents. Track buckling primarily occurs in the lateral plane, making the lack of track lateral resistance a major contributing factor to this phenomenon. (Ngamkhanong *et al.*, 2022). Track buckling is typically triggered by slight lateral misalignments that generate lateral forces, often referred to as follower forces. Numerous studies and reports have indicated a proportional relationship between the number of hot days (temperatures over 20°C) and the occurrence of track buckles. It is worth noting that despite having fewer very hot days in 2016-17 compared to previous years, track buckling increased during that period, likely due to the occurrence of the hottest day recorded in those years. (Ngamkhanong *et al.*, 2022)

The conventional rail-tie-ballast track structure, typically utilized for conventional trains, encounters difficulties in maintaining long-term stability and the necessary track precision when operating at higher speeds. The authors have developed a technique to represent the complex distributed-parameter system of the track structure to simplified system. The paper investigates the utilization of this model to generate responses from both on-car and trackside. To assess the model's accuracy and identify necessary adjustments, field measurements were collected from various North American railroads and used for evaluation. The computer model's accurate predictions, enhanced response and longer stability have been instrumental in the initial design of new track structures, presently undergoing evaluation. (Ahlbeck *et al.*, 1978). Static buckling refers to the buckling of long continuously welded rail (CWR) tracks solely due to thermal load, without any involvement from vehicles. Dynamic buckling, which holds greater relevance to the industry, refers to the instability of CWR tracks caused by moving vehicles in the presence of thermal loads. A thorough comparison between static and dynamic track buckling is conducted. For each scenario, a sensitivity analysis of pertinent parameters is performed. The study's results reveal that train loads exert a notable influence on both the buckling and safe temperature of track. Under a severe braking scenario involving a wagon equipped with out-of-round wheel defects of order 3, the buckling temperature exhibits a decrease of approximately 5.5 °C compared to the static case. To summarize, the study emphasizes the impact of train loads on buckling characteristics of the track. and emphasizes the importance of considering dynamic factors in addition to static thermal effects when assessing track buckling risks(Kish & Samavedam, 1991). A new and versatile buckling model was developed, specifically designed to be executed on a personal computer (PC). This innovative model addresses the limitations present in other models by incorporating vehicle load effects, improving the representation of nonlinear lateral resistance, and introducing rational safety criteria. One crucial aspect considered by this model is the reduction in lateral resistance caused by a track uplift bending wave under vehicle loads. Additionally, it recognizes the softening behaviour of lateral resistance at larger displacements, a phenomenon that previous research failed to acknowledge. By calculating the energy required for buckling to occur, this model assesses the level of safety of CWR tracks at a given rail temperature (Kish & Samavedam, 1991). (Lazorenko *et al.*, 2019) discusses contemporary techniques and structures aimed at strengthening the roadbed to improve the effectiveness of heavy transportation. Through thorough investigation and resolution of these concerns, it becomes feasible to enhance the stability and durability of the roadbed, leading to improved performance of the railway track when subjected to heavy load conditions.

Various techniques are utilized for identifying damages and conducting condition monitoring of railway tracks.

Non-destructive testing technologies: These methodologies encompass various techniques, including acoustic emission test, radiograph test ,magnetic testing, , eddy current test, and the application of dye penetrate fiber optic sensors. These technologies enable the detection of defects and anomalies in the track structure without causing any damage.(Krishna *et al*., 2017a) Visual inspection is a commonly utilized approach for detecting defects in railway tracks. It involves visual inspections and assessments carried out by specialized personnel. While it is the primary method for defect identification, it can be time-consuming and expensive to implement. (Krishna *et al*., 2017a).

HUMAN FACTORS

Historical railway accidents have frequently been linked to human errors, persisting despite the implementation of new equipments aimed at reducing railway incidents.(Kyriakidis *et al*., 2015). The paper presents a case study that examines human errors in railway accidents and incidents, providing a comprehensive analysis, based on an investigation of more than 1,000 cases that occurred in 2004. A detailed analysis was performed on 90 selected cases that were clearly caused by human error, using a classification structure for human error analysis. The analysis results include the causes of the events, types and modes of errors, the workers involved, and the type of tasks performed. (Ko *et al*., 2007) A study focuses on UK railways and examines human error-related railway accidents that occurred between 1945 and 2012. The objective of the study is to assess whether there have been any changes in the quantity and categories of railway performance shaping factors (R-PSFs) that influence human performance and contribute to human error. Furthermore, the study evaluated the data quality in investigation reports and investigated whether there have been advancements in data collection practices over the years. The findings suggest that while there has been a notable improvement in the quality of data examination and collection, the average quantity and categories of factors influencing human errors have remained consistent, despite a decline in the rate of accidents. (Kyriakidis *et al*., 2015). The errors were categorized using the Human Factors Analysis and Classification System (HFACS), a widely adopted framework. 40 reports were reviewed, the identification of human error was done using a tool or error taxonomy for human error identification (HEI). Taxonomies play a valuable role in providing a holistic understanding of the causes behind numerous incidents, facilitating the identification of recurring factors contributing to failures and contributory factors (Thomas & Rhind, 2003Kanse *et al*., 2005).

This study represents the initial endeavour to utilize an error taxonomy in analyzing incident specific to the Australian rail industry. According to the study findings, approximately 50% of the incidents were attributed to equipment failures caused by inadequate maintenance. Lapses in attention linked to reduced alertness and physical fatigue were the most prevalent unsafe behaviours contributing to accidents and incidents. The study revealed that organizational factors, such as insufficiently designed driver safety systems, were commonly identified as contributing to the incidents. The analysis of the incidents showed that nearly all of them were connected to one or other organizational factor, emphasizing the importance of enhancing resources maintenance and organizational processes to effectively mitigate incidents in Australia. The study proposes the adaptation of HFACS to develop a specialized framework for the rail industry, enabling more accurate identification of errors. (Baysari *et al*., 2008) (Shappell & Wiegmann, 1997). A total of 407 railway accident/incident reports in China from 2003 to 2014 were gathered and analyzed using the HFACS framework. The findings showed that the railway system had four errors that occurred most frequently: 'organizational system,' 'inadequate supervision,' 'personal alertness,' and ‘competence errors’. Furthermore, they investigated the relationships and patterns of "paths between categories" across the four levels in the HFACS framework. This analysis aimed to identify strategies for preventing or reducing the occurrence of human errors. (Zhou & Lei, 2018)

In this study, 19 rail safety investigation reports were examined to analyze train driver errors related to rail accidents and incidents in Australia. Two error identification tools, namely the HFACS and the Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr-rail version), were utilized to identify and categorize these errors. Both versions identified reduced alertness and incorrect driver assumptions as factors that have the most impact on driver errors. However, both tools failed to consider certain distinct factors associated with the occurrence of errors. As a result, it is advisable to modify the existing tools or develop a new tool that ensures comprehensive and consistent classification of errors.(Baysari *et al*., 2009). A computer-aided system known as CAS-HEAR, which stands for Computer-Aided System for Human Error Analysis and Reduction, can aid analysts in identifying various levels of error causes and their interconnected relationships. Nine field investigators from six railway organizations in Korea evaluated a prototype of CAS-HEAR, confirming its usefulness. However, for practical implementation some modifications to the contextual and causal factors are necessary. (San Kim *et al*., 2010)

The Success Likelihood Index Method (SLIM) is widely utilized to assess the probability of human error (HEP) in critical railway operations. However, accurately determining the weights of performance shaping factors (PSFs) becomes challenging due to the interdependencies among them. To address this limitation, a hybrid SLIM approach that incorporates empirical study and Complex Network is proposed to assess HEP while accounting for the dependencies among PSFs. To validate the effectiveness of this approach, Monte Carlo simulation is employed to derive the reliability state. The consistency between the obtained results and the simulation outcomes, along with their alignment with existing knowledge and experience in the railway operations field, confirms the efficacy of this approach.(Zhou & Lei, 2020)

Challenges in railway forensic investigation: Securing a crime scene and gathering evidence can be a challenging endeavour, particularly in railway accidents where the nature of the incident can vary from localized to wide spread. Additionally, there is a pressing need to maintain the flow of railway traffic. The task of the investigating officer and forensic field unit workers is crucial and requires meticulous attention, particularly when it comes to collecting body parts and searching for and gathering evidence. (Khan, n.d.) The digitalization process has impacted the railway industry as much as any other domain. Although new technologies such as digital interlock systems, automated operation bring numerous advantages, they also introduce potential vulnerabilities that can be exploited. Furthermore, the utilization of readily available commercial of the shelf hardware and software (CotS) is also a factor to consider, along with the traditionally closed systems becoming more open, poses another issue. The author puts forth a framework aimed at ensuring the integrity and accountability of evidence in the railway domain through the establishment of a chain of custody (Cosic *et al*., 2021). When examining asite with scattered wreckage and perishable evidence, it is important to thoroughly document all findings. Perishable evidence should be carefully collected and photographed. Recordings of environmental conditions, equipment, temperature of brakes, tracks, wheels, bearings, and the position of other trains and vehicles in proximity are to be documented. Additionally, the positions of injured or deceased persons have to be documented before their removal. It is essential to secure and protect the crime scene to prevent any damage or destruction of the evidence. The names, contact details, and addresses of witnesses are to be recorded. If injured individuals are able to provide information, their injuries should be noted to help investigators estimate the speed of a train prior to impact. For deceased individuals, a post mortem examination must be conducted, and a full record should be maintained.(Sharma *et al*., 2022)

Railway accident epidemiology: The department of forensic medicine in Bydgoszcz conducted research that was focused on autopsies performed on train accident victims during year1992-2002. In 1992 most number of railway accidents were observed. The research suggest most serious injuries were formed in people while laying on their chest. (Bloch-Bogusławska *et al*., 2006) 18 death reports in urban rail traffic fatalities were collected that occurred between year 2005-2008 Shanghai. From 18 cases 14 were of suicide and 4 were accident. The 14 cases of suicide died due to head injury and remaining 4 died of traumatic shock.(Hu *et al*., 2009) (Tyagi *et al*., 2015) Noted manner and cause of railway fatalities in Mumbai city railways. Common causes for death found was due to head injury (24 cases) and then other causes were shock and injury to organs. The least prevalent cause were septicemia. These all occurred due to blunt force injury. Most deaths occurred in younger age groups. Found highest railway death among the Mumbai railway stations is at Parel to Curry-road station, they opined this is caused by less area in foot bridge at Parel station, overpopulation, rush during office hours and absence of any fencing. Preventive measures were suggested to curb the railway accidents for example: formation of boundary walls, fences alongside of tracks. For crossing the tracks sufficient and durable foot bridges and subways should be built. (Sudhakar Suresh *et al*., 2016) stated large number of people dying every year due to railway accident, out of 9483 autopsies 480 cases were of railway fatalities. In the 1st year of study 4.79% of total cases reported followed by 5.31% of total cases in 2nd year, therefore an increase of 0.52% was seen.

In conclusion, the findings from the various studies and reports on railway accidents reveal important insights into the causes and patterns of death in such incidents. The analysis highlights the significance of severe injuries in railroad accidents, with a higher prevalence among males. Suicides and accidents were identified as the primary modes of death, often resulting from head injuries and traumatic shock. The studies underscore the need for effective crime scene management and evidence collection, especially considering the challenges of securing the scene while maintaining railway traffic. The findings highlight the significance of forensic experts and underscore the necessity of identifying and comprehending the precise mechanisms of death in railway accidents. This knowledge can contribute to the improvement of safety measures and enhance the effectiveness of forensic investigations in these cases.

Future Directions: Unmanned Aerial Vehicles (UAVs), also known as drones, are gaining momentum in their utilization for surveillance purposes across different contexts. Nevertheless, despite the considerable potential they hold, there exist several obstacles that must be overcome to ensure the suitability of unmanned aerial vehicles (UAVs) for real-world applications that require optimal performance, reliability, and protection of privacy.

Table 1. Presenting epidemiology and pathology of railway accidents & deaths

Author/ Date	Topic/ Question	Statistics	Findings: Cause and Mode of death	State / Part of world
1. (Bloch-Bogusławska *et al*., 2006)	Study conducted to analyze fatalities resulting from rail-vehicle incidents spanning the period from 1992 to 2002.	65 – train accidents 86% males 14% female Highest no. of cases 1992 Severe injuries in railroad accident	Multi organ injury	Bydgoszcz
2. .(Hu *et al*., 2009)	An investigation carried out on fatalities occurring in urban rail traffic accidents specifically in Shanghai.	18 death reports 14: suicide 4: accident	Most had head injury and remaining 4 died of traumatic shock	Shanghai
3. (Tyagi *et al*., 2015)	Study of pathology of death from Mumbai train accidents	24 death cases	Head injury (24 cases) and then other causes were shock and injury to organs.	Mumbai
4. (Sudhakar Suresh *et al*., 2016)	Forensic expert duties in railway forensics	9483 cases 480 cases due to railway fatalities	Homicide or suicide which can also be disguised as accident	Mortuary of Gandhi hospital Secunderabad
5. (Moses &Ammani, 2019)	An analysis conducted on fatalities resulting from railway accidents over the course of January to December.	Total 5240 autopsies were conducted in out of which 474 railway accidents.	Multiple injuries, head injury Death happened while crossing track or in case of suicide the person jumped or lied on the track.	Osmania General Hospital Mortuary
6. (Driever *et al*., 2002)	This study focuses on the morphological findings observed in fatal railway collisions.	38 cases of railway fatalities 10 in upright position 11 in laying outside track 13 laying inside 21 people: died from suicide 10 people: died due fromaccident	Survey confirmed over rolled in laying position therefore it can be suicide If Upright position it can be accident Over rolled injuries cause loss of parts of body, multiple organ injuries, body cavities opened.	Bonn Institute Of Legal Medicine in Bonn, Germany
7.(Patil *et al*., 2012)	Railway death were studied for observing pattern of injuries	97 railway death studied 90: males 7: females Majority age group 21-30 years 67 people: died due to accident 30 people: died due to suicide	9 showed highBlood Alcohol Concentration levels Main mechanism of death is decapitation and dividing of thorax area Head injury is most common in suicidal deaths	India

One critical area where drones could be of great assistance is in the monitoring of transit infrastructures, such as railways, where they could help reduce costs and improve surveillance capabilities. Drones also offer the opportunity to introduce smart sensing features that can enhance railway monitoring, automate operations, increase safety, provide prognostic information, and even support forensic investigations. The study also discusses ongoing experimentation with intelligent video technology using drones and shares preliminary findings and future possibilities.(Flammini *et al*., 2016). The paper presents a novel approach for the development of a robust railway crack detection scheme (RRCDS) using an IR sensor assembly as part of a railway track geometry surveying system. In the proposed system, Bluetooth technology is utilized to mitigate the risk of train accidents. Two IR sensors positioned at the front end of an inspection robot, which continuously monitor the railway track and provide feedback to an Arduino controller. Whenever a crack is detected, the system promptly sends the crack's location to a mobile phone via Bluetooth communication. The proposed system offers numerous advantages over traditional detection techniques. These advantages encompass cost-effectiveness, low power consumption, reduced analysis time, improved safety standards for rail tracks, and the provision of an efficient testing infrastructure.(Krishna *et al*., 2017b)
A novel approach has been developed for conducting in-situ forensic analysis of rail corrosion damage, utilizing advanced 3D imaging techniques. The method incorporates handheld laser scanners to capture high-resolution 3D image data of the rail surface directly at the site of investigation. Moreover, the acquired 3D image data is utilized for conducting finite element analysis, which allows for the simulation of cyclic loading. This analysis helps identify vulnerable regions where cracks may initiate due to the presence of corrosion. To validate the proposed approach, a case project was conducted, affirming the feasibility and practicality of the forensic methodology.(Safa *et al*., 2015) Artificial Intelligence (AI) is gaining significant traction in numerous engineering sectors, including railway transportation. To support researchers and practitioners in comprehending AI methodologies, research domains, disciplines, and their diverse applications, a well-structured taxonomy has been introduced. This taxonomy serves as a valuable resource, providing insights into AI techniques' general applicability as well as their specific implementation in railway contexts. Additionally, the paper covers important considerations such as ethics of AI in railways.(Bešinović *et al*., 2021). Implementing preventive measures, including regulatory frameworks, intelligent signaling systems, and comprehensive personnel training, can effectively mitigate the risks associated with technical, human, and intentional failures in railway operations. These measures encompass the installation of robust alarm and security, as well as the consistent monitoring of rail installations (Prasad & Prasad, 2018)

CONCLUSION

In summary, this review paper offers a comprehensive analysis of the field of railway forensic, encompassing a wide range of topics related to the examination and investigation of railway incidents. The discussion encompasses the roles and responsibilities of organizations involved in railway examinations, including the examination of rolling stock and track analysis. Track buckling has been identified as a significant factor in train derailments, resulting in tragic loss of lives and valuable assets, as evidenced by numerous incidents. The study delves into the examination of human factors in railway accidents, emphasizing the significance of comprehending human behavior and its influence on safety. Additionally, the paper highlights the challenges faced in railway forensic investigations, such as securing the crime scene, collecting evidence, and ensuring minimal disruption to railway operations. Lastly, the review identifies future directions for the field such as drones explored for surveillance, forensic analysis of rail corrosion damage based on 3D imaging, use of Artificial Intelligence (AI) emphasizing the need for advancements in technology, training, and collaboration between different stakeholders. Overall, this review paper serves as an essential resource for researchers, forensic experts & organizations involved in investigation of railway incidents, providing insights into current practices, challenges, and potential areas for improvement in railway forensic.

REFERENCES

Ahlbeck, D. R., Meacham, H. C., & Prause, R. H. (1978). THE DEVELOPMENT OF ANALYTICAL MODELS FOR RAILROAD TRACK DYNAMICS. In A. D. KERR (Ed.), *Railroad Track Mechanics and Technology* (pp. 239–263). Pergamon. https://doi.org/https://doi.org/10.1016/B978-0-08-021923-3.50017-6

Batig, A., Kuzyshyn, A., Sobolevska, J., Milyanych, A., &Hrytsyshyn, P. (2020). Ways to improve the mathematical model of a freight car for the execution of forensic railway-transport expertises. IOP Conference Series: Materials Science and Engineering, 985(1), 012008. https://doi.org/10.1088/1757-899X/985/1/012008

Baysari, M. T., Caponecchia, C., McIntosh, A. S., & Wilson, J. R. (2009). Classification of errors contributing to rail incidents and accidents: A comparison of two human error identification techniques. Safety Science, 47(7), 948–957.

Baysari, M. T., McIntosh, A. S., & Wilson, J. R. (2008). Understanding the human factors contribution to railway accidents and incidents in Australia. Accident Analysis & Prevention, 40(5), 1750–1757.

Bešinović, N., De Donato, L., Flammini, F., Goverde, R. M. P., Lin, Z., Liu, R., Marrone, S., Nardone, R., Tang, T., &Vittorini, V. (2021). Artificial Intelligence in Railway Transport: Taxonomy, Regulations, and Applications. IEEE Transactions on Intelligent Transportation Systems, 23(9), 14011–14024.

Bibel, G. (2012). Train wreck: the forensics of rail disasters. JHU Press.

Bloch-Bogusławska, E., Engelgardt, P., Wolska, E., & Paradowska, A. (2006). Analysis of deaths caused by rail-vehicles in the materials collected by the Department of Forensic Medicine in Bydgoszcz in the years 1992-2002. Archiwum Medycyny Sadoweji Kryminologii, 56(3), 181–186.

Cosic, J., Schlehuber, C., &Morog, D. (2021). Digital forensic investigation process in railway environment. 2021 11th IFIP International Conference on New Technologies, Mobility and Security (NTMS), 1–6.

CRS- Brief history and functions. (n.d.). Retrieved May 16, 2023, from https://safety.indianrail.gov.in/sims/links/CRS/PDF_Files/1.1_CRS-HistoryFunction.pdf

Driever, F., Schmidt, P., & Madea, B. (2002). About morphological findings in fatal railway collisions. Forensic Science International, 126(2), 123–128.

Flammini, F., Naddei, R., Pragliola, C., &Smarra, G. (2016). Towards automated drone surveillance in railways: State-of-the-art and future directions. Advanced Concepts for Intelligent Vision Systems: 17th International Conference, ACIVS 2016, Lecce, Italy, October 24-27, 2016, Proceedings 17, 336–348.

Gaur, J. R. (2011). Investigation of railway accidents. Forensic Audit, 79.

Grassie, S. L., & Kalousek, J. (1997). Rolling contact fatigue of rails: characteristics, causes and treatments. Proceedings of 6th International Heavy Haul Conference, The International Heavy Haul Association, Cape Town, South Africa, 381–404.

Hu, Y.-P., Cao, Y., & Ma, K.-J. (2009). Analysis of the death cases in the urban rail traffic accident in Shanghai. Fa Yi Xue Za Zhi, 25(3), 198–199.

Hubar, O., Markul, R., Tiutkin, O., Andrieiev, V., Arbuzov, M., & Kovalchuk, O. (2020). Study of the interaction of the railway track and the rolling stock under conditions of accelerated movement. IOP Conference Series: Materials Science and Engineering, 985(1), 012007. https://doi.org/10.1088/1757-899X/985/1/012007

Introduction to Indian Railway. (n.d.). Retrieved May 16, 2023, from https://rdso.indianrailways.gov.in/works/uploads/File/FC-01-Introduction%20to%20Railway.pdf

Jones, D. R. H., & Ashby, M. F. (2019a). Chapter 31 - Thermal Expansion. In D. R. H. Jones & M. F. Ashby (Eds.), Engineering Materials 1 (Fifth Edition) (pp. 501–513). Butterworth-Heinemann. https://doi.org/https://doi.org/10.1016/B978-0-08-102051-7.00031-2

Jones, D. R. H., & Ashby, M. F. (2019b). Chapter 31 - Thermal Expansion. In D. R. H. Jones & M. F. Ashby (Eds.), Engineering Materials 1 (Fifth Edition) (pp. 501–513). Butterworth-Heinemann. https://doi.org/https://doi.org/10.1016/B978-0-08-102051-7.00031-2

Kanse, L., van der Schaaf, T. W., Vrijland, N. D., & van Mierlo, H. (2005). Comparing two approaches to failure recovery: medication preparation versus chemical plants. Proceedings of the 2005 Annual Conference on European Association of Cognitive Ergonomics, 183–189.

Khan, M. K. (n.d.). Deaths in railways and role of forensic medicine.

Kish, A., &Samavedam, G. (1991). DYNAMIC BUCKLING OF CONTINUOUS WELDED RAIL TRACK: THEORY, TESTS, AND SAFETY CONCEPTS. Transportation Research Record.

Ko, J.-H., Jung, W.-D., & Kim, J.-W. (2007). An Analysis of Human Error Mode and Type in the Railway Accidents and Incidents. Journal of the Korean Society of Safety, 22(4), 66–71.

Krishna, B. R., Seshendra, D., Raja, G., Sudharshan, T., & Srikanth, K. (2017a). Railway track fault detection system by using ir sensors and bluetooth technology. *Asian Journal of Applied Science and Technology* (AJAST), 1(6), 82–84.

Krishna, B. R., Seshendra, D., Raja, G., Sudharshan, T., & Srikanth, K. (2017b). Railway track fault detection system by using ir sensors and bluetooth technology. *Asian Journal of Applied Science and Technology* (AJAST), 1(6), 82–84.

Kuzishyn, A., &Batig, V. M. (2018). USE OF ADDITIONAL ASSESSMENT CRITERION FOR TRAFFIC SAFETY AGAINST RAILWAY WHEEL DERAILMENT FOR FORENSIC RAILWAY TRANSPORT EXAMINATION. Theory and Practice of Forensic Science and Criminalistics, 18, 454–461. https://doi.org/10.32353/khrife.2018.51

Kuzyshyn, A., Kostritsa, S., Ursulyak, L., Batig, A., Sobolevska, J., &Voznyak, O. (2019). Research of the impact of geometric unevenness of the railway track on the dynamic parameters of the railway rolling stock with two-stage spring suspension. IOP Conference Series: Materials Science and Engineering, 664(1), 012024. https://doi.org/10.1088/1757-899X/664/1/012024

Kyriakidis, M., Pak, K. T., & Majumdar, A. (2015). Railway accidents caused by human error: historic analysis of UK railways, 1945 to 2012. Transportation Research Record, 2476(1), 126–136.

Lazorenko, G., Kasprzhitskii, A., Khakiev, Z., &Yavna, V. (2019). Dynamic behavior and stability of soil foundation in heavy haul railway tracks: A review. Construction and Building Materials, 205, 111–136. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.01.184

Ma, L., Shi, L. B., Guo, J., Liu, Q. Y., & Wang, W. J. (2018). On the wear and damage characteristics of rail material under low temperature environment condition. Wear, 394–395, 149–158. https://doi.org/https://doi.org/10.1016/j.wear.2017.10.011

Ma, Q., Liu, Y., Yang, S., Liao, Y., & Wang, B. (2022). A Coupling Model of High-Speed Train-Axle Box Bearing and the Vibration Characteristics of Bearing with Defects under Wheel Rail Excitation. Machines, 10(11), 1024.

Moses, T. & Ammani, J. (2019). A Comprehensive Study of Deaths due to Railway Accidents Reported at a Tertiary Care Hospital Mortuary during the Period of January to December 2015. International Journal of Contemporary Medical Research [IJCMR], 6. https://doi.org/10.21276/ijcmr.2019.6.8.56

Ngamkhanong, C., Goto, K. & Kaewunruen, S. (2022). 6 - Rail infrastructure systems and hazards. In R. Calçada& S. Kaewunruen (Eds.), Rail Infrastructure Resilience (pp. 97–109). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-12-821042-0.00010-1

Patil, B., Raghavendra, K. M., Uzair, S., & Patil, D. B. (2012). A study on pattern of injuries in railway deaths. Indian Journal of Forensic Medicine and Toxicology, 6, 71–73.

Prasad, A., & Prasad, I. (2018). Advanced Techniques in Railroad Engineering: Railroad Accident Causes and Innovative Prevention Techniques. In Forensic Engineering 2018: Forging Forensic Frontiers (pp. 259–269). *American Society of Civil Engineers Reston,* VA.

Safa, M., Sabet, A., Ghahremani, K., Haas, C., & Walbridge, S. (2015). Rail corrosion forensics using 3D imaging and finite element analysis. *International Journal of Rail Transportation*, 3(3), 164–178.

San Kim, D., Baek, D. H., & Yoon, W. C. (2010). Development and evaluation of a computer-aided system for analyzing human error in railway operations. *Reliability Engineering & System Safety,* 95(2), 87–98.

Shappell, S. A., &Wiegmann, D. A. (1997). A human error approach to accident investigation: The taxonomy of unsafe operations. The *International Journal of Aviation Psychology*, 7(4), 269–291.

Sharma, B., Bhat, A., Singh, A., Kumar, P., Khanna, S., Vita, D., Kaur, E., & Singh, J. (2022). Railway Disaster: A Track Of Forensic Investigation.

Short Note on Complete and Updated List of Railway Zones in India. (n.d.).

Sudhakar Suresh, K., Kumar, R., Hari, N., & Narayan Reddy, K. S. (2016). The Job of a Forensic Expert in Railway Fatalities-Redefined! *Indian Journal of Forensic Medicine & Toxicology*, 10(1).

Thomas, L. J., & Rhind, D. J. A. (2003). Human factors tools, methodologies and practices in accident investigation: implications and recommendations for a database for the rail industry. Cranfield University.

Tyagi, S., Sukhadeve, R. B., Parchake, M. B., & Pathak, H. M. (2015). Mumbai local: Life line or life stealing. Journal of Indian Academy of Forensic Medicine, 37(3), 246–249.

Zhou, J.-L., & Lei, Y. (2018). Paths between latent and active errors: Analysis of 407 railway accidents/incidents’ causes in China. Safety Science, 110, 47–58.

Zhou, J.-L., & Lei, Y. (2020). A slim integrated with empirical study and network analysis for human error assessment in the railway driving process. *Reliability Engineering & System Safety*, 204, 107148.

Zhu, Y., Wang, W., Lewis, R., Yan, W., Lewis, S. R., & Ding, H. (2019). A review on wear between railway wheels and rails under environmental conditions. *Journal of Tribology*, 141(12).

Кузин, Н., Meshcheryakova, T., Kuzin, O., Kurileva, E., & Gordinskaya, N. (2016). The use of mathematical and computer modelling in solving the problems or rail transport expert examination. *Journal of Applied Mathematics and Computational Mechanics,* 15, 93–98. https://doi.org/10.17512/jamcm.2016.4.10

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