Proceedings of the Sixth International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 7, Paper 11.7
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.7.11.7

Application of Systemic Thinking to Learn Safety Culture and Human Reliability Perspectives in Freight Train Derailments

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Abstract

This paper presents a systemic theory analysis approach, based on the comparison between the Risk Management Framework (RMF) and System Engineering theory (SE). To demonstrate the timeline of the accident and the safety barrier classifications that prevent accidents and protect the railway system from damage, three aspects should be reviewed and understood: Technical Reasons, Human Factors, and Organizational Influences.

During 2018-2022, there were ten freight train derailment investigations or safety digests undertaken by RAIB. To learn the safety culture issue regarding the freight train derailments three cases have been considered, such as Llangennech (R012022), the failure of track fastening system design (R022021) at Eastleigh, and the derailment due to longitudinal train dynamics at London Gateway (R142023).

The Llangennech derailment was precisely analysed in this work, the work investigated the organizational influence and human reliability factors, then discussed the reliability test during the maintenance procedure, and the utilization of a machine learning algorithm to deploy fault diagnostic action.

A revised Human Error Assessment and Reduction Technique (revised HEART) and utilization of Error Producing Conditions (EPCs) will also be further discussed. In addition, the Human Factors Analysis and Classification System (HFACS) was advised, as the integration process of human factors, the precondition for unsafe acts and organizational influence.

Furthermore, the paper suggests a Bayesian Networks (BNs) method to illustrate the reliability assessment model in maintenance systems and to improve Prognostic and Health Management (PHM). The quality analysis of key component reliability was discussed in this work on the technical side.

Keywords: human reliability analysis, accident investigation model, systemic theory, human factors analysis and classification system, risk management framework, freight derailments mechanism.

1 Introduction

Train derailments are one of the highest consequence risks to the operation of railways; whilst train derailments are rare, they do still occur. This paper focuses on an analysis of the risks and control associated with freight train derailments, using derailment records and derailment investigation reports from Great Britain (GB).

1.1 Background

Whilst freight train derailments present a different risk profile to passenger derailments, they are still important to control and could result in safety risks to staff and the public; they also can cause significant disruption to railway operations and damage to rolling stock and infrastructure. There are a range of barriers that control the risk of freight train derailments, including track and track design standards, maintenance rules, and operational rules; these barriers are reviewed further in the results presented in Section 4.

A preliminary analysis is not efficient in answering the long-term problems of freight train derailments, regarding the Social-Technic system perspective, including Technical Reasons, Human Factors, and Organizational Environmental Influence.

Muhamedsalih (2016) reviewed records of freight train derailments between 1973 and 2013; focusing on derailments associated with two types of track defect: track twists and cyclic top [10]. Track twist is a short wavelength difference in height between the left and right rail, whilst cyclic top is cyclic vertical irregularity. Figures 1 and 2 show a summary of Muhamedsalih's findings.

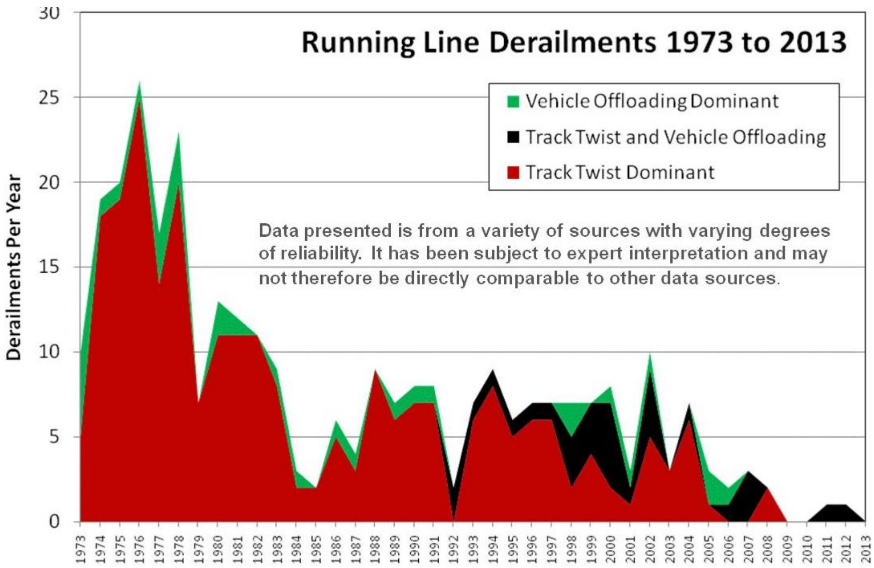

Figure 1 GB Derailments in track twist 1973 – 2013 (Muhamedsalih, 2016)

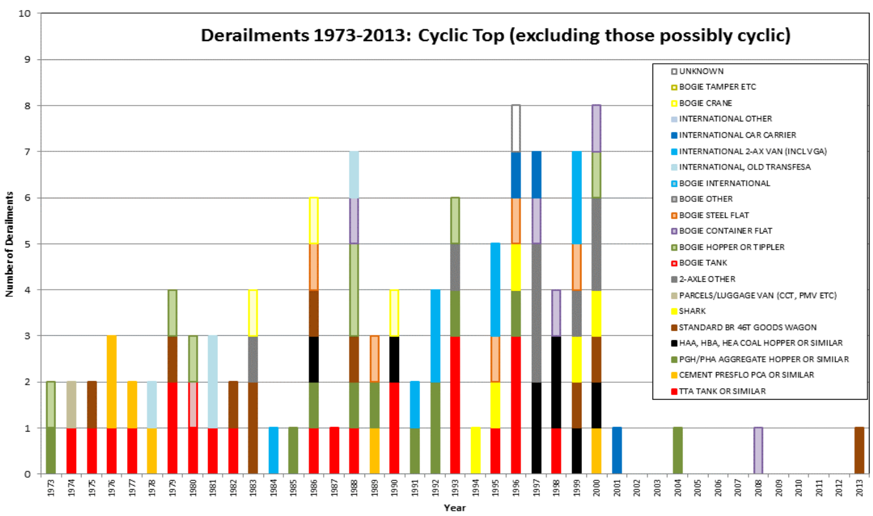

Figure 2 GB Derailments cyclic top 1973 – 2013 (Muhamedsalih, 2016)

As shown in the figures the numbers of derailments of both types were significantly lower in 2003 – 2013, compared to the previous 30 years; however, they are still non-zero. This suggests safety barriers have significantly improved, but further work is still required.

Peng (2022) carried out a more detailed review of 197 freight derailments of all causes between 2003 and 2013; the main causal factors were: Track defects (80), Irregular working (43), and Rolling stock issues (29). Then the Track twist (21), Gauge spread (20), Point mechanism (12), Defective switch and crossing (10), track corrugation or "cyclic top" (8), suspension/ bogie (6), Brake part (3) and axle failure (8) are categories in the derailment history list, respectively.

The analysis presented in this paper focuses on three scenarios reviewed in this work, based on the accident investigation reports from derailment Llangennech (R012022), the failure of track fastening system design (R022021) at Eastleigh, the gauge spread defect in Sheffield (R072021), the wheel flats defect at Pencoed (R032023) and Petteril Bridge (R102023), and the derailment due to longitudinal train dynamics at London Gateway (R142023). In terms of the systemic evaluation and audit, the Llangennech accident was first analysed.

Furthermore, in terms of the various fundamental solutions of the railway subsystems that were suggested, from the engineer's point of view, there are study tasks toward the Railway System Engineering Vee-Process, such as the work denoted by the system decomposition and system integration: the Mission analysis (Continuous quality improvement plan), the System requirement, the Functional decomposition (Verify subsystem), the Physical decomposition (Test component), and the Build component, as the integrated Reliability process.

The work established the validation, verification and test plan, to illustrate system decomposition and integration. The Practical vee process can be used as the reliability process, to improve the quality design of systemic components. However, the work was trying to help better understand the risk management framework and safety management within the accident analysis. Moving from hindsight (accident investigation) to foresight (safety evaluation) was mentioned in the literature review [12, 13].

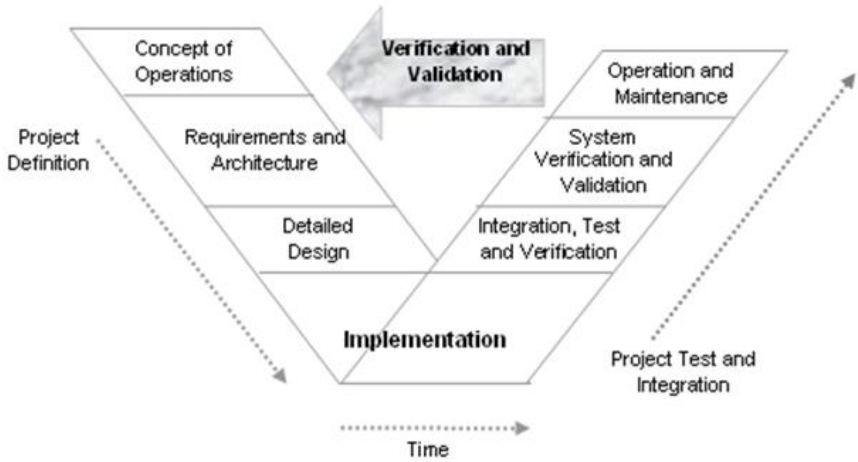

Figure 3 Example of safety management model (Le Coze, 2013)

It is worthwhile to mention that the accidents investigation model was discussed throughout 2019's thesis, there were four main scenarios reviewed: Porthkerry derailment (R102015), Heworth derailment (R162015), Camden derailment (R212014) and Moor station derailment (R072009). The analysis work first surveyed the derailment mechanism, such as track Vertical Longitudinal Split defect (VLS), track Geometry Deterioration, and Freight Vehicle Uneven Loading issues.

Then the track geometry deterioration process learned the Markov Chain transition process, and the initial result of the Bayesian Belief Network (BBN) was reviewed. However, the work required further investigation, due to a lack of practical data resources, there should be an experimental design for the reliability analysis of NDT methods, and the functional analysis Wheelchex system as the 'DDD' functions, namely, detection, diagnose, and deploy functions.

Nevertheless, the statistic model can be studied in the R studio or Minitab project, the review of the fundamental knowledge of the railway track subsystem was necessary. Probability and statistics with reliability, queuing and computer science application as the background knowledge of quality analysis, written by Kishor Trivedi (2015). The wheelset degradation analysis tasks, and track degradation model were denoted (Lin, 2008; Andrade, 2017).

1.2 Human Factor & Safety Culture

The Human Factors Analysis and Classification System (HFACS) application in the literature review and the accident investigation reports were advised [18]. The need for Human Reliability Analysis (HRA) states that a social-technical system requires a functional understanding of human-machine interaction, such as the human factor and human cognitive process.

The human cognitive process concluded that the Technique for human-error prediction (THERP), Generic error modelling system (GEMS), and Performance shaping mechanism (PSM or factors), the work illustrated the generations of human factor analysis approach, to learn the analysis procedure.

The Safety Culture aspects can be presented as the Communication and Trust issue (Sharon. Clarke's opinion), a good safety climate can be characterized by a positive attitude to safety, a similar cognitive process, or training towards the understanding of skill-rule-knowledge behaviour. The human data processing mechanism, or the "ladder of abstraction or levels of behaviour" can be learned.

It is worthwhile to mention that Rasmussen's opinion about major accidents is an organizational migration to cross the boundary of acceptable performance. The freight train derailment can cause serious consequences to the trackside, for instance, the Llangennech derailment caused three wagons to catch fire. Around 446,000 litres of petroleum products were spilled. The accident happened in August 2020, and the extensive damage to the track and the underlying formation, and the need to remove contaminated soil, meant that the route was not fully reopened until 5 March 2021

The other case (Gloucester, R202014) was in 2013, the train derailed on track with regularly spaced dips in both rails, a phenomenon known as cyclic top, and there was damage to four miles of track, signalling cables, four level crossings and two bridges.

Then the Functional and Social Configuration (Golightly, 2013) was read to establish work tasks, in terms of the Signaler, Electrical control room operator (ECRO), Person in Charge of the Possession (PICOP), and Engineering supervisor (ES). The analyzing part describes the function description, relevant element of work context, mechanism to manage situation awareness (technical and procedural), and factor shaping situation awareness.

Furthermore, Le Coze (Sensitizing model for industrial safety assessment) mentioned from hindsight to foresight, the reflection of the safety culture should demonstrate the implicit system engineering designing. The author then applied the systemic theory and safety models to understand the accidents. There is the Barrier definition and classification introduced from the literature. For example, the improvement of the Safety Barrier performance shaping factor, due to the audit work and training, with knowledge transferring from hindsight to foresight would be established in the report.

2 Previous Works

According to the National Freight Safety Group (2020, issue 5), at the moment, the freight-integrated plan for safety indicated that the wagon condition on the network was the main risk for freight train accidents in the decade.

The first approach examines a set of representative scenarios, based on real incidents, constructed from a human reliability analysis perspective. 'By looking in detail at these incidents it has been possible to identify and refine several characteristics that describe the underlying nature of human error-producing conditions in this context. These may include the physical, temporal social configuration of the work, or the protection involved.'

An important consideration in applying human reliability understanding in areas, such as vehicle checks and brake tests (VIBT), or rail track-work is to define how it maps to other characterisations of safety and safety-related functions. The barrier functions exist within any domain for prevention or protection from accidents. Specifically, the barrier systems may involve physical or human components and processes and may be active or passive designed, or associated with Skill-Rule-Knowledge (SRK) behaviour [12].

The second approach was to quantify the failure probability of individual barriers and understand each barrier’s system reliability through generic task unreliability and Error Producing Condition (EPC). Then the author describes the role and functions in PHM, and how they can work together to achieve safety requirements. The current HEART mode illustrated that accident investigation, expert judgment, and quantification model builds up, however, the revised methodology worked with psychological theories and classification, to support the structural understanding of the error-producing conditions, and to provide the cognitive bridge between human erroneous action and perception deviation.

To analyze the accidents, the author will focus on not only the technical factors, but also the human reasons, and organizational influence. The Risk Management Framework (RMF) is then mentioned to understand the dynamic society problem. This method integrated from the view of Macro, meso to Micro, from an environmental perspective to the organizational performance boundary to the individual cognition technology. The method can be analysed in the accidents from several defences against accident, and each part/level of the functional abstraction introduced the limitation in the system. To improve risk management as a control issue, there are a few disciplines that should be considered: the identification of controllers, such as tasks, acts and errors; work objectives; information on actual state of affairs; capability and competence; and responsibility or commitment.

Machine vision techniques have been developed using AI systems, and can replace human visual inspection, to deliver dimensional measurements, defect inspection, image recognition, etc. These innovative technologies are used to improve system reliability. Additionally, accident investigation reports were collected, computing support technique was investigated to support the construction work; the preliminary computerized operators' reliability and error database (CORE-Data) with human error probabilistic models are discussed within the scenarios analysis.

To understand the failure mechanism, the barrier functional analysis based on the preliminary research work, there are the definition and classification of barrier system. Then in the analysis task, there is the Detect-Diagnose-Deploy to illustrate the central heart of the barrier functions. The ideology of the barrier function reviewed the Plain Line Pattern Recognition (PLPR) technologies, Ultrasonic Test Train (UTU), and Wheelchex system in the British railway industry. In the preliminary laboratory work, the track failure mechanism was studied, such as the vertical longitudinal split defect classified in the work undertaken by Kumar (2006) [16].

Furthermore, the new reliable technology of Trouble Moving EMU Detection System (TEDS), Trackside Acoustic Detection System (TADS), or Train Coach Running Diagnosis System (TPDS) will be learned and examined in the work (Zhu, 2022) [3]. The dynamic response analysis (T1267) revealed the TADS system for the axle-bearing failure prognosis, and vice versa. The report analyzed and comprised the cost-benefit of the on-track and on-vehicle devices, respectively.

3 Methods

The thesis focused on 'A comprehensive study with scenario, barrier description and practical experimental into track geometry deterioration model to analysis freight train derailments', the work mainly focused on the technical aspects, the understanding of the track and vehicle failure mechanisms. Additionally, the application of a Markov Chain transition matrix was utilized to predict the track geometry degradation process and was validated through track geometry recording data and the calculation of Standard Deviation.

Hence, it is necessary to think the safety culture and organizational influence could have more effect on the learning tasks from accidents. To evaluate the safety barrier reliability, Duijm (2006) mentioned that the audit map toward risk management [6]:

- Deficiencies in the safety management delivery system
- Increased likelihood of deficiencies in the output of the management delivery system
- Increased likelihood of deficiencies in conditions for safe operation (lack of competence, lack of maintenance)
- In addition, deficiencies in safety culture
- Finally, increased probability of failure on demand of the barrier

SCQPI diagram can be traced back from the literature review in the management Audit procedure part. The role of this work can only be applicable in the regulation or the association factors, due to the long-term problem within the system, at the economic, technical, management, and human factors.

Therefore, the important steps are to explore the regulatory standards, regulatory oversight, government policy or legislation, supply chain, owning companies, and interfaces between organizations and industry associations, to review the redundancies and deficiencies in the privatization system, such as the RAIB recommendation that short-term commercial contacts may encounter with the long-term investment decisions (R012022).

Additionally, the analysis approach was discussed in the Australian research group investigation of railway accidents using the HFACS model. The results showed unsafe supervision, unsafe acts, preconditions for unsafe acts, and organizational influence factors that affect the incidents. For example, in the Llangennech accident investigation, the unsafe supervision denoted inadequate supervision, and planned inadequate operation; the precondition included the technological environment factors and crew resource management.

This paper aims to provide a Systemic theory to understand how accidents happen, Peter Underwood and Patrick Waterson (2014) support the accident investigations through the comparison between the Swiss Cheese Model, the Australian Transports Safety Bureau (ATSB), the AcciMap and the Systems Theoretic Accident Modeling and Processes Model (STAMP). This STAMP theory was designed based on control theory through the understanding of hierarchy operational structure and enforces constraints on hazards thereby preventing accidents [1]. In addition, the method was invented to audit the interpretative management structure, with the concepts of control, restriction, and feedback loops.

Initially, the AcciMap developed by Rasmussen (1997), is also known as the Risk Management Framework (RMF) [5]. Accidents are considered to result from the loss of control over potentially harmful physical processes. 'According to his theory, each organizational level in the system affects the control of the hazards and a vertically integrated view of system behaviour is required', and 'the AcciMap has developed as a means of analysis the series of interacting events and decision-making processes which occurred throughout a socio-technical system and resulted in a loss of control (Branford, 2009).'

Instead of understanding human performance conditions, the STAMP analysis procedure focuses on the key shaping factors, such as the management delivery system and human operator aspects, there are Safety-related responsibilities (i.e. Performing supervisor's inspection, identifying work to be planned and carried out), unsafe decisions and control actions (i.e. Forgot to carry out the supervisor visual inspection of the track section, the capability of identifying fatigue failure through current inspection methods), reasons for unsafe decisions and control actions (i.e. NR did not have any comprehensive data about the condition of points elements across its network at the time of the accident which contributed to an incomplete understanding of the performance of its switches and crossings assets at the component level, risk perception), and then context, respectively.

Based on the survey of quantifying barrier systems in SCQPI, Rasmussen's theory of Risk management framework and the SCQPI technique above, the author extracted the Freight train maintenance procedures from accident investigation reports, shown in the functional barrier below. To illustrate the impact of human reliability and performance-shaping mechanisms regarding the barrier system, then the Bayesian Network can be utilized to evaluate system reliability. In the Quantitative analysis, the posterior probability can be inferred by the prior information and failure probabilities in HRA. The Human Action (HA) and Human Effect (HE) are defined in the HRABN model, to predict the systemic failure probability was firstly approached.

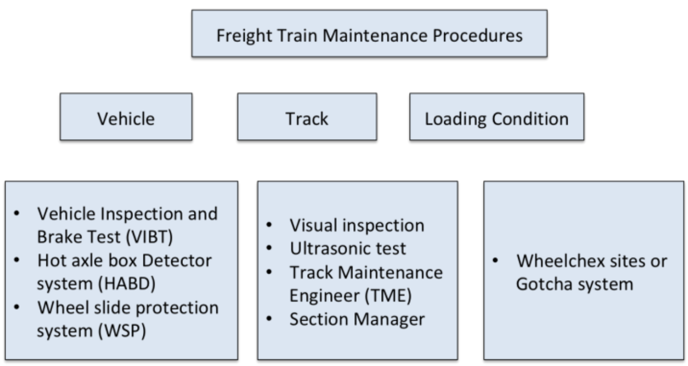

Figure 4: Interpretative Structure of the Maintenance Procedure

Consequently, the Fault Diagnostic Technology based on Vibration, Image detection technology, and Machine Vision techniques is examined to support reliability-centred maintenance. Precisely, the **Plain line Pattern Recognition** techniques were reviewed and installed on the UK railway networks before 2013, in addition to this image detection technology, applications were developed rapidly in the area of fault detection on the track, the vehicle, or the pantograph systems. Stemming from machine vision, artificial intelligence, deep learning, and machine learning techniques, traditional NDT methods might be replaced. In China, take the Trouble of Moving EMU Detection System (TEDS) as one example, the trackside equipment, detection stations, and monitoring stations installed visual capture cameras to record, control, and warn of defects [3].

3.1 Technical Support

This part contributed to the understanding of the Llangennech freight derailment (R012022) failure mechanism, and there are two issues to discuss, such as the reliability analysis of key components on the air braking system of freight vehicle, and classification of the failure type of braking system with the machine learning algorithm as the data process.

Reliability is quality over the long run, simply stated as the ability of the product to perform the intended function over some time. The numerical value is the probability that the product will function satisfactorily during a particular time, such as, the value of 0.93 means the probability that 93 of 100 products would be functional well after the prescribed time, and 7 products would not function. However, the probability distribution can be used to learn the failure rate of units of products (Besterfield, 1998).

The method of arranging the components affects the reliability of the entire system, and different components can be arranged in series, parallel, or combination. Nevertheless, the complex products are a combination of series and parallel arrangement of components, here is an example of system reliability evaluation. Normal types of the continuous probability distributions used in reliability studies are exponential, normal and Weibull.

Therefore, the R software was utilized for the reliability data analysis, and there can be censored or uncensored data. Take the ‘Survival’ package as one example, the work is capable of performing hazard and survival analysis.

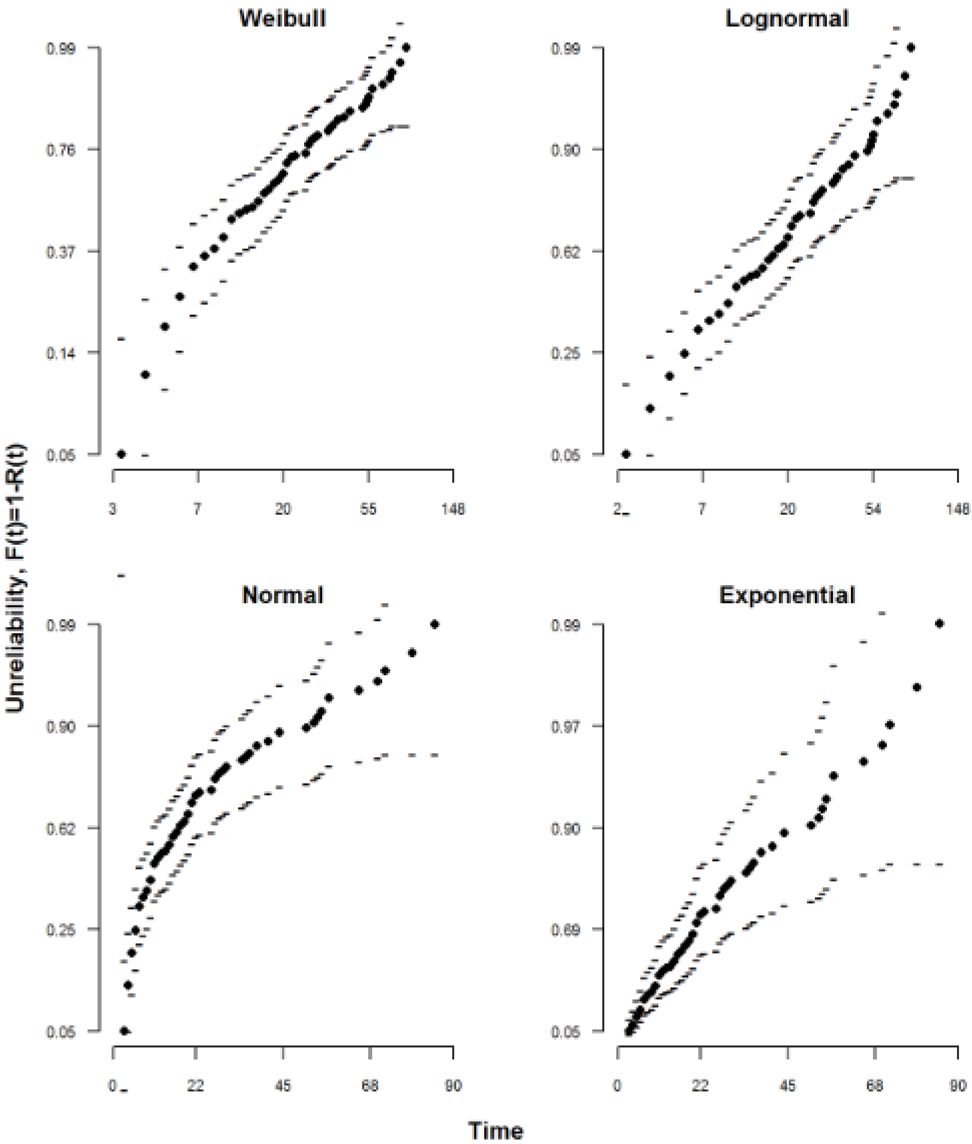

Figure 5: The continuous probability estimation of a key component

The short maintenance cycle and low-key component reliability were the main problems in the Llngennech freight train derailment. Normally, the maintenance cycle for the control valve of the truck braking system, the empty and loaded vehicle adjustment valve, and the brake adjuster, which is used to adjust the braking system and ensure proper braking performance, is eight years. It is necessary to improve the reliability of braking system components (Lu, 2012).

For example, the control valve is the main part of the braking system for freight vehicles, and the anti-corrosion for the key component can prevent or delay corrosion, to extend service life and maintain functionality. There should be a physical test for the control valve, and the maintenance cycle no more than 2 years. The other method is an investigation of the vibrational reliability of the control valve, according to the experiment, the acceleration test can examine the different types of valves with higher or lower reliability in various situations.

In respect to the accident original report, the brake system fault can be divided into two types, brake cylinder air pressure abnormity, and air brake cylinder mechanical fault. Following RAIB report, the paragraph 68, "the air pressure was sufficient to produce a partial brake application at some point on the journey to all the wheels on the third wagon." Likewise, Pei (2018) established that the application of a **Support Vector Machine (SVM)** to classify the main fault reasons based on the Matlab code, there are four types: for example, Brake Sensitivity Failure (type 1), Brake Stability failure (type 2), Improper Release Failure (type 3), or Natural Release Failure (type 4) [11]. The work utilized the classification result as the input of the diagnostic Bayesian Network to reason the failure mechanism of the brake system. The air brake system is a complex Pneumatic transmission system, it is mainly comprised of an automatic brake valve, independent brake valve, relay valve, distribution valve, inverter valve and operating valve. Then diagnostic **Bayesian networks (BNs)** are generated for different fault events through the causal reasoning process. As a result, the inspection sequence of Brake Sensitivity Failure (type 1) should be, according to the severity of the consequence: ① the fit between the main valve spool and spool seat (check if it is tight enough); ② the diaphragm plate of the main piston in the main valve is aged or cracked; ③ the brake cylinder rubber cup is aged and damaged; ④ the brake cylinder lacks oil; ⑤ if there is leakage at the threaded pipe and flange connection of the brake cylinder; ⑥ the piping system from the auxiliary air reservoir to the brake cylinder is leaking; ⑦ the cylinder body of the brake cylinder is scratched or damaged; ⑧ the sealing ring ('O' ring) of the main valve may not function properly; ⑨ the piping system connecting the intermediate body and the auxiliary air reservoir is blocked; ⑩ the size of the charging hole in the main valve is too large, based on the learning task of BN diagnostic map and SVM classification algorithm.

4 Accident Analysis Results

There are three typical scenarios reviewed in this work, based on the accident investigation reports from the Llangennech (R012022), the failure of track fastening system design (R022021) at Eastleigh, the gauge spread defect in Sheffield (R072021), the wheel flats defect at Pencoed (R032023) and Petteril Bridge (R102023), and the derailment due to longitudinal train dynamics at London Gateway (R142023).

Accident Scenarios Review and Barrier Description:
On the technical side, the previous AIM investigated the Basic Visual Inspection, the different Ultrasonic tests (U5 and U8), the Wheelchex system, Plain Line Pattern Recognition (PLPR), and various PHM approaches in the UK were investigated.

4.1 Scenario Analysis

Llangennech (R012022) derailment investigated the Braking system failure due to the inadequate requirements from the Entity in Charge of Maintenance (ECM).

- The ECM may perform the maintenance function and the vehicle management delivery, for example, identify maintenance activities affecting safety critical components, design and install appropriate maintenance facilities;
- Although the RAIB reports point out that the supervision and audit of subcontracted activities were not effective.
- The organizations involved in the investigation are DB Cargo Maintenance (DBCM) which undertook the PPM (every four-monthly) and VIBT (yearly), the Arlington fleet service devised the General repair (seven-yearly) procedures, etc. There were at least eleven vehicle maintenance activities carried out before the derailment.

The application of RMF analysis and system engineering (SE) analysis procedure listed the following matters, which lead to providing the main answers:

1. The integration between system theory and system engineering approach. The ECM certification process describes the system design analysis and requirements; in Appendix F, the ECM certificate was required for the rail vehicle, and the ECM (TOUAX, the wagon owner) should be in charge of the management, maintenance development, fleet maintenance management, and maintenance delivery. The functional management decomposition included the maintenance, and operational companies. There should be a summary of the failure of the supervisor team and operator failure frequency. For example, unsafe supervision denoted inadequate supervision (failure to provide proper training, failure to provide adequate technical data/procedure), planned inadequate operation (poor crew pairing), failure to correct the problem (identify risk), and supervisory violation.
2. Rasmussen's ideal is about functional abstraction rather than structural decomposition. Meanwhile, the train passed the Hot axle box detector system (HABD) at the Pembrey site, this equipment indicated that the wheelset was rotating properly at the time, without the intervention and warning system. (paragraph 139)
3. Functional Maintenance and physical configuration indicated the role of each operational function of companies. To carrier out the work according to the instructions and regular specific procedure. The accident report mentioned the inadequate inspection of the wagon maintenance procedure, the reliability control of the brake system component should be suggested in further research. According to the original report (paragraphs 82-83), the loose fastening of valves on the pipe bracket was due to the inadequacy of the ECM maintenance requirement and Touas management delivery group. Meanwhile, the AFSL and DBCM carried out the vehicle inspection and preventive maintenance, respectively. There was no precise instruction for the brake test, the required torque setting for nuts securing the relay valve, and the replacement of elements, such as the studs, nuts, and washers (paragraphs 87-89). These operational faults can be classified and defined

as the error-producing condition, as the approaching the acceptance performance's boundary in safety culture, namely, the unlearned skill, and misperception of risk and severity of consequence. In the HFACS analysis model, the precondition included the technological environment factors (equipment/control design), and crew resource management (failure to conduct an adequate brief, poor communication/coordination, or inadequate training).

4. The reliability analysis of the braking component on wagon 89005. The brake system concluded that the control reservoir, distributor, auxiliary reservoir, relay valve, variable load sensing device, brake cylinders, and brake blocks. In addition, the component test should consider the reliability of each element, such as the washer, the nuts, the pipe bracket, mounting studs, and the 'O' ring (seal the air passages between the relay valve and pipe bracket). Research undertaken by Hu (2010) demonstrated the possibility of the application of Bayesian belief networks (BNs) to analyze brake cylinder pressure work normally [8]. In terms of the Fault detection and diagnosis (FDD) methods, Hou (2023) investigated different literature learned the air braking system [9].

About the freight train maintenance delivery project, the author reviewed the causal factors and attribution factors, then listed the following problems that should be of concern.

- Touax carried out the function of management of the ECM, the reason for inadequate requirement and supervision of VIBT, GR and PPM, as the barrier functions in this scenario, is due to the inadequate monitoring, review and audit, the Functional decomposition, the Verification test and Component test in the subsystem, according to the system engineering requirements.
- There were yearly or four-monthly vehicle inspections and repair actions according to the original investigation report, such as the DBCM staff not identifying that the washers were missing on the relay valve, or "might have identified that no washers were fitted to the relay valve, that contractors were frequently reusing old nuts and washers, and that the nuts were not be adequately tightened".
- Lack of risk perception and SE component tests might be one reason, in terms of the mechanical understanding (structural test) of the air brake system failure, and the Reliability test is to construct the quantitative model, based on the accident scenario, expert judgement and severity analysis.
- Regarding the role of functional design and the responsibility of each level in the risk management group, Webtec Faively should report the maintenance procedure to Arlington Fleet Services (in charge of GR) and DB cargo Maintenance (in charge of PPM and VIBT), then the two companies take the responsibility to give the feedback for Touax or the safety risk assessment, as the wagon owner and ECM. The estimated failure of the component and visual inspection/supervision inspection, the author has discussed in the PhD thesis (2022) [13,14].
- Meanwhile, the Error producing condition in the revised HEART method, mentioned the human reliability analysis, for instance, the conflict between

immediate and long-term goals (EPC 18), the remedial measure should be "goals should be tested by management for mutual compatibility, and where potential conflicts are identified these should either harmonious or made prominent so that a comprehensive management control program can be created to reconcile such conflicts as they arise rationally. Furthermore, the EPC 17-19 can be learned in the analysis part. [2]"

4.2 Other Two Accidents

In addition, the other two accidents are: the Eastleigh derailment (R022021) was due to many track fastenings that had degraded. Regarding the safety concern of the track fastening system design, the standard EN13481 requires the application of 3 million loading cycles, varying load between 510 kg and 10.2 Tons, it states a significantly higher number of loading cycles than test requirements during the operational lifetime. More precisely, the lateral force at the switches and crossing was leading to the fast-brittle failure, after an independent metallurgical inspection post derailment. Furthermore, the Eastleigh maintenance delivery unit (MDU) was incapable of detecting that the fastening system was prone to fatigue failure with the lateral force. Following the derailment, NR commissioned the building research establishment (BRE), to determine the failure mechanism of the fastening system due to the lateral force, and the longitudinal crack exhibited at the surface of the concrete might not reveal the fatigue of the fastening components. These investigations suggested the difficulty of Visual inspections, hand-propelled track recording devices, or manual track gauges to detect track faults.

The London Gateway derailment (R142023) case study showed the risk of longitudinal train dynamic effects and longitudinal compression force. The work reviewed the design approval and maintenance of the Ecofret 2. VTG Rail also recognized that the new Ecofret 2 wagons constituted a significant change under the Common Safety Method on Risk Evaluation and Assessment 17 (CSM REA). Wabtec used an industry-standard railway vehicle dynamics computer simulation package to help assess compliance with requirements for dynamic behaviour and safety against derailment on twisted tracks. The supporting analysis work identified a running behaviour issue that led Wabtec to conclude that special devices were needed to control primary lateral suspension movement. Otherwise, the VTG Rail's inspection and maintenance regime comprised a weekly in-service visual inspection of the vehicle and detailed annual VIBT for the Ecofret 2 wagons. Therefore, the derailment risk due to Longitudinal Compressive Force (LCF) should be considered in the traction and brake effect, the buffer interaction, and the coupling tightness as the key indicators. Furthermore, several of these related to uncertainties associated with effects that could result in greatly increasing the magnitude of the predicted maximum longitudinal compressive force, such as, the coupling tightening and slack, the coupler friction loss, the air brake system equipment, the speed-dependent braking effect and the train resistance.

4.3 Reliability Centered Maintenance (RCM)

The Analysis of the case study and barrier description listed each barrier and the error-producing condition. There are traditional inspection units: PLPR, VIBT, TME or Section Manager (track), Visual inspection, Wheelchex or Gotcha site, etc.

James Reason (1997) developed the Swiss Cheese Model (SCM), which included four layers of barriers leading to the accident, instance, the organisational influences, unsafe supervision, preconditions for unsafe acts and the actual unsafe acts. Later Wiegmann and Shappell (2000) qualitatively investigated each barrier and classified the human error, integrated with the understanding of the safety culture environment. Various applications utilized these methods, the disadvantage of this method was the lack of quantitative estimation of the human error probability, the author introduced the revised HEART model, to establish the quantitative understanding of the human reliability analysis, namely, HFACS and HEART application. In this work, the author only discussed the human reliability perspective following the accident investigation.

HFACS defined HEART			
Unsafe acts & Active failure	error	decision error	EPC 4: a means of supressing or overriding information which is too easily accessible
			EPC 12: a mismatch between perceived and real risk
			EPC 32: inconsistency of meaning of displays and procedures
		skill-based error	EPC 6: a mismatch between an operator's model of the world and that imagined by designer
			EPC 9: a need to unlearn a technique and apply one which requires the application of an opposing philosophy
			EPC 16: an impoverished quality of information conveyed by procedures and person-person interaction
			EPC 23: unreliable instrumentation
		perceptual error	EPC 22: little opportunity to exercise mind and body outside the immediate confines of the work
			EPC 24: a need for absolute judgements which are beyond the capability or experience of an operator
	violation	routine violations	EPC 13: poor, ambiguous or ill-matched system feedback
			EPC 17: little or no independent checking or testing of output
			EPC 21: an incentive to sue other more dangerous proceudres
			EPC 28: little or no intrinsic meaning in a task
			EPC 33: a poor or hostile environment
		exceptional violations	EPC 3: a low signal-to-noise ratio
			EPC 8: a channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information
			EPC 11: ambiguity in the required performance standards

Table 1: Analysis of barrier description

Reliability Centered Maintenance (RCM) was designed to undertake a functional analysis and fault diagnostic through the understanding of the whole system, the brevity of investigating failure mode and effects, and is based on the exemplification of the system component reliability. There are three steps to assure safety and integrity: Failure data statistics or incident reports, Expert evaluation, and Quantification model build-up. This work contributed to the Audit work of a freight train derailment accident, to evaluate the supervision and subcontract activities, in terms of the human error probability, and safety culture issues within the social-technical environment.

Llangennech	Audit map of supervision and subcontracted activities						
Unsafe Acts	Generic Task Unreliability	Error Producing Conditions	Remedial Measure	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Reliability Assessment
ECM: Touax	C: Complex task requiring high level of comprehension and skill	a shortage of time available for error detection and correction;					
		a means of suppressing or overiding information or features which is too easily accessible;					
		no means of conveying spatial and functional information to operators in a form which they can readily assimilate.					
AFS: General Repair	F: Restore or shift a system to original or new state following	no clear direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted;					
		a conflict between immediate and long-term objectives;					
		unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel.					
DB: PPM and VIBT	G: Completely familiar, well-designed, highly practised, routine task occurring several times per hour, performed to highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids.	no obvious means of reversing an unintended action;					
		little or no independent checking or testing of output;					
		a mismatch between the educational achievement level of an individual and the requirements of the task;					
		no obvious way to keep track of progress during an activity;					
		poor ambiguous or ill-matched system feedback.	technological environment				

Table 2: Parameters of exemplification

Practically, the human reliability analysis (HRA) strategy might be evaluated by the revised HEART method and the Accident Investigation Reports (RAIB) dataset, to estimate the mean value of Human Error Factors. Then there is the Relative Strength of Error-Producing Conditions (EPCs), which are used to assess the Task parameters in the Case studies.

To validate the EPCs' relative contribution, there are typical factors, such as the Technique unlearning, the Misperception of risk, the Conflict of objectives, the Inexperience, and Low morale [2]. In addition, the Propensity Score Matching (PSM) calculated the effective measurements regarding the accident’s consequence, with the covariance listed and discussed in the other paper.

5 Conclusions

In this work, the systemic theories and models contributed to learning the accident consequences, and the derailment failure mechanism is discussed. The author reviewed the 2020-2023 freight derailment accident reports based on the RAIB investigation and mentioned the organizational influence through interpretative structural understanding.

The key results should be concentrated on the Audit of the maintenance delivery system, to introduce reliability estimation of the technological and the human performance aspects, through quantifying and classifying unsafe acts description in the freight train management system.

Furthermore, the benefit of the mathematical model would learn the effects of each barrier function, and it can map in the BN with the conditional probability distribution table to evaluate system reliability and, therefore, to improve the system safety inference with limited resources.

Acknowledgements

I gratefully acknowledge the valuable cooperation of Professor Simon Iwnicki, Dr Rawia Rashidy, Dr Philip Shackleton (from the Institute of Railway Research, the School of Computing and Engineering, University of Huddersfield), and Dr Charles Watson (from the University of Birmingham) in preparing the application notes.

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