Proceedings of the Sixth International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 7, Paper 19.3
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.7.19.3

A Comprehensive Study with Scenario, Barrier Description and Human Reliability Assessment to Evaluate Freight Train Derailments

H. Peng

Centre for Fundamental Computing Courses, Sichuan University
China

Abstract

The background part of this work was firstly to learn the history of incident data at the SMIS and AEAT Rail derailment database, attributed to the causal factors analysis and the preliminary statistics process.

The review of the vehicle acceptance test included the Y/Q derailment criterion and the bogie rotation inspection demonstrated the major technical reason. The track geometry deterioration model was calculated in the Markov Chain transition probabilistic model.

The work explained the case analysis in the Porthkerry derailment: the track Vertical Longitudinal Split (VLS) failure mechanism study; the Heworth derailment: the track geometry degradation and Human Reliability Analysis (HRA); the Camden derailment: the freight train unevenly loading derailment compliant to the standard intervention.

The preliminary analysis is not efficient to answer the Long-term questions in the Freight Train Derailments, regarding to this Social-Technic system perspective, including technical reason, human and organizational environment as well as the railway subsystems.

The final objective of this work is to assess barrier failure probabilities from a human reliability perspective, employing methods such as the Human Error Assessment and Reduction Techniques (HEART) and Error Producing Condition (EPCs) approaches.

Keywords: system theory, track geometry deterioration, barrier model, performance shaping factor, human error assessment and reduction techniques, Markov chain transition.

1 Introduction

According to the freight derailment history (2000-2013 AEA & SMIS) and rail accident investigation report (2006-2021), there are at least 197 freight train derailments were recorded:

There was the uneven loading that led to the freight train derailments, whether the vehicle design contribute to the reason? (such as the vehicle design specification, the suspension characteristic, and the vehicle acceptance test in Gloucester/Camden derailment) Is the asymmetric load failure consistent with the current standard limitation?

In the RAIB reports, there were at least 10 incidents due to the defective switch and crossing; and 12 derailment incidents at the S&C due to the vehicle exposed to the poor track geometry, if the RAMS standards and practical data analysis be the consequence? (according to the RAIB original investigation).

From 1992 to 2001, the RSSB T357 (2006) reported that in the derailment risk analysis in statistics, poor loading was the most common principal factor, but the rapid deterioration of track quality was a causal feature. If the author could learn from the incident, for:

1) Perform the operational integration and human response audit.
2) Large-scale experimental focus on the track geometry deterioration model.

2 Aim and Key objectives

The research aim of the work was: to analyse the causes of freight train derailments using the scenario method, barrier description and performance shaping factors evaluation.

1. To review and learn the main safety theories and models used in railway engineering and how these are currently applied to the railway system.

2. Identifying and classifying the different causes of derailment in the railway system can be divided into track failures, vehicle component failures, and uneven loading compliant with the standard; and try to define failures within the Cognitive Reliability and Error Analysis Method (CREAM), such as the performance shaping factor, Skill-Rule-Knowledge based failure.
3. To quantify the failure probability of individual barriers and understand each barriers' system reliability through the generic task unreliability and error-producing condition (EPC).

4. To use a traditional probabilistic model (Markov Chain) to predict the railway geometry system deterioration and the impact on safety.

3 Key literatures

Rasmussen's model (1997) of the dynamic system, distinguished the advantage of systemic thinking rather than the structural procedure [1]. Waterson and Underwood (2014) practically illustrated that the Grayrigg derailment happened due to the switch and crossing failure, their work attribute the risk analysis and accident investigation.

Johnson (1980), Hollnagel (2004), and Sklet (2006) stated the definition of safety barriers, for example, the measurement of the safety performance and attitude verified in the barrier functions: the control, the mitigation and the prevention [2][3]. The author developed the improvement of safety barrier performance through the audit work in the HEART model and SRK-framework definition as the evaluation.

Duijm (2006; 2009) describes a safety management quality scheme to learn the system deficiencies, the likelihood and uncertainty, and the condition of the deficiency in regard to the measurement at the Audit, then establish the safety integrity level (SIL) and the PFD of the safety barrier.

Hollnagel (1998) wrote about the Cognitive Reliability and Error Analysis method, the classification of the safety performance shaping factor (PSF) and the attitude toward the human factor as the main contribution of an incident

Australian research (Baysari, et. al., 2008) discovered 300 human factor failures from 40 RAIB reports through the Human Factor Analysis and Classification System as an accident investigation method [6]. Kim (2013) discovered the causal chain model from 80 RAIB reports through the computer-aid technique.

4 Methodology

A. Data:

This work considered more than 20 accident investigation reports (RAIB, 2006-2021), divided into barrier model (with more than 200 of the Error producing factors) and the scenario analysis, such as, "the calibration and traceability of the wheelchex system" revealed in the Ely derailment analysis; "The vehicle acceptance procedure" illustrated the scrutiny process and self-assurance process ineffectively in the Gloucester derailment study. The external performance shaping factor (PSF) and internal SRK framework influenced the quality of the barrier model established in the scenario analysis.

B. Preliminary analysis:

- Step1: The timeline description of the Case study.

- Step2: the Barrier model based on the original accident investigation report. The improvement of the Safety Barrier performance shaping factor, due to the audit work and training, with knowledge transferring from hindsight to foresight.
- Step 3: the measurement of the barrier and scenario model based on the Human Error Analysis and Reduction Technique (HEART) and Error Producing Condition (EPC), to establish a solution of system deficiencies.
- Step 4: the sequence led to the cognitive task (SRK-based failure) and cognitive profiling of external stressor, and internal performance shaping factors (PSF) explained in the scenario analysis.

C. System Integration:

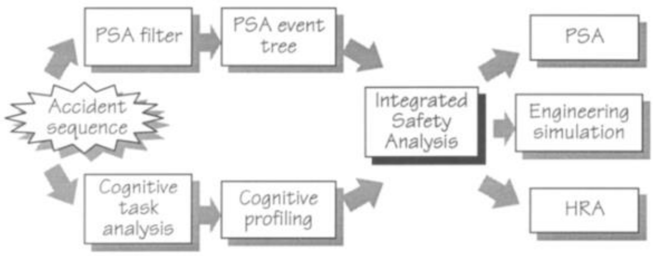

Figure 1: Integrated Safety Analysis

To discuss the understanding of the Integrated safety analysis (ISA) should be combined the probabilistic safety analysis (PSA) and the human reliability analysis (HRA).

Firstly, the accident sequence led to the PSA filter (HEART model and Barrier failure ratio), and PSA event tree based on the CCPs.

Secondly, to learn the cognitive reliability and error analysis method, and performance shaping factors to develop a human reliability analysis evaluation procedure.

Eclectic research for the present questions: the definition of the Performance Shaping factor (PSF) and the distinction to the situation factors (THERP, Technique for Human Error Rate Prediction). Then the human factor analysis and classification system (HFACS) was suggested in the railway safety case study analysis. The analysis results are based on the previous work undertaken by the Australian research group (Baysari, 2008); the precondition of unsafe acts and organizational influence occupied a higher percentage of the railway accident investigation reports.
This part further stated the system engineering thinking in the Human Error Action Taxonomy (HEAT): such as, the phenomenological appearance (Task characteristic), cognitive function (detection, verification, action), and the cognition control mechanism (SRK-based behaviour function).

Thirdly, the dynamic model proposed by Rasmussen (1997) established the structural analysis procedure, there is the Accident map (Risk Management Framework) diagram for a specific accident scenario. It is then possible to calculate the nominal likelihood of failure in each barrier, such as, regarding the hierarchy organizational structure of government policy, regulatory bodies and associations, local area management, technical and operational management, physical process and operator activities, equipment surroundings. The assumed relation between safety management quality, safety culture (SCQPI) and probability of failure on demand of safety barrier is used to evaluate system deficiencies.

5 Case study

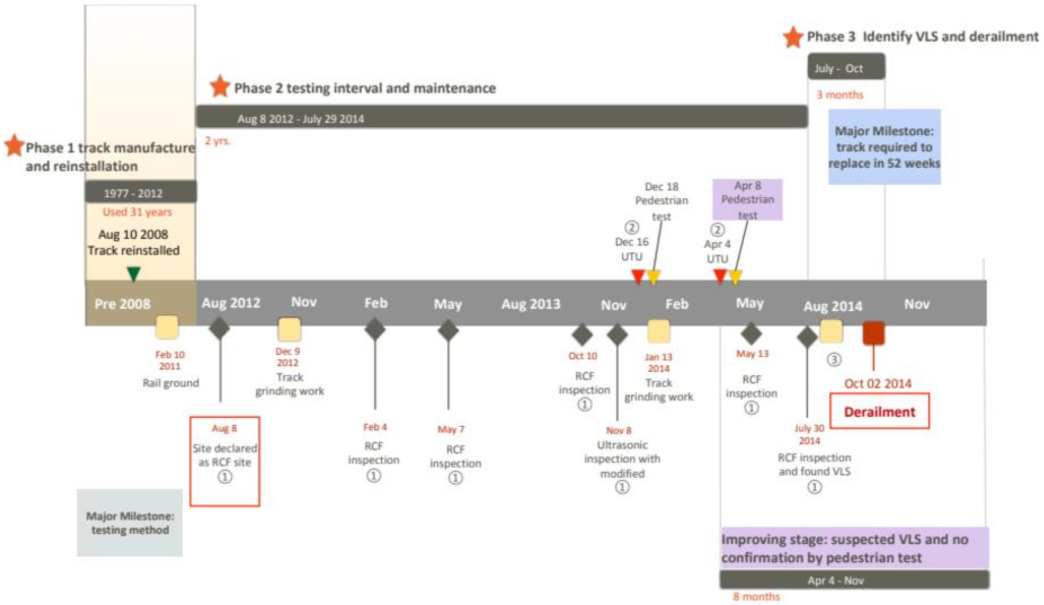

Figure 2: Porthkerry Derailment Timeline

1) Porthkerry derailment

A loaded coal train derailed at Porthkerry on 2 October 2014, in South Wales on the Vale of Glamorgan line. Train loaded with coal at Avonmouth Docks, and then the train passed over a wheel load monitoring installation at Marshfield; data showed the wagon has unevenly loaded. However, the front train passed the site at 16.5 mph, the first 19 wagons passed over the defective rail; therefore, the 20th wagon ran onto the defective left rail when the field side of the rail head broke.

- The cause of the derailment was the failure of a section of the left-hand side rail due to a metallurgical defect within that rail. The defect arose due to impurities within the steel which had been present since manufacture;
- The track repair actions could improve the track quality;
- The RCF site investigation play key role in the Porthkerry derailment;

- The UTU and verification as the latent failure in the functional barrier system.

The precursor indicator model broken track subsection demonstrated that the annual FWI due to the broken fishplates, broken rails, buckled rails, gauge faults, switches and crossing faults, and track twist & geometry faults. The broken rails (in the Porthkerry derailment), the S&C faults and track twists are the most severe factors from April 2010 to April 2016 listed below (RSSB).

To learn the failure mechanism: the critical defects could lead to the rail being broken: Banverket (1998) established that the transverse fracture occupied 44.1%, vertical split 19.4%, welded joint 19.4% and horizontal defect 17.2% (Kumar, 2006).

2) Heworth Derailment

23 October 2014, the accident happened when a train travelling at 51 mph passed through Heworth station. The derailment was caused by wagon worn suspension component, the track geometry deterioration and human unreliability to prevent the incident consequence. There are barrier model and timeline descriptions including the Plain time Pattern Recognition (PLPR), the basic visual inspection, track geometry recording train, track maintenance engineering (TME), Vehicle inspection and Brake Test (VIBT), speed restriction, and track drainage improvement.

In the study of the track degradation analysis, following 50-55 mph of train speed, the measurements of the SD value and track geometry quality are:

i. Top = 3.5 (mm) good
ii. 3.5 to 5.0 satisfactory
iii. 5.0 to 5.9 poor
iv. 5.9 to 6.3 very poor
v. 6.3 maximum = super-red level TSM inspection in 14 days, immediate 30 mph emergency speed restriction and correct within 36 hours.

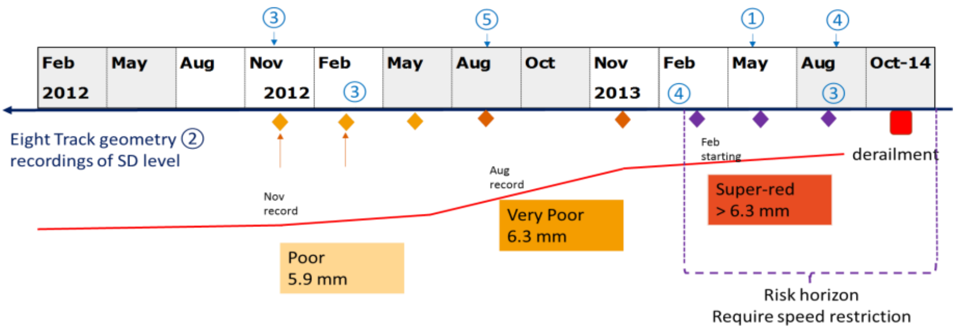

Figure 3: Track geometry deterioration in the Heworth derailment

The standard deviation stated in the GC/RT 5021: The Standard Deviation (SD) is the universally used scientific measurement of the variation of random processing. The vertical and horizontal track profile data have been found similar to the statistical calculation of the magnitude of track irregularities by obtaining the SD measurement level.

$$Standard\ Deviation\ \sigma = \sqrt{1/n \sum_{j-1}^{n} x_{ij}^2 - \bar{x}_i^2}$$

$$TQI = \sum_{i=1}^{7} \sigma_i$$

The track quality index (TQI) combined seven the deviation levels for the track alignment (1), the twist measurement (2), the gauge (3), the left/right longitudinal (4-5), the left/right alignment (6-7), and the cross-level.

According to the accident report 16/2015, the track geometry recording train on the Down Sunderland line recorded the standard deviation (SD) for the vertical value in each eight-mile section. In the historical record, from the 99 miles 220 yards to 99 miles 440 yards, the track had fallen into 'very poor' from August 2013. In 2014 Feb, the record shown the track geometry was 'super-red' level (Figure 3).

From the year of 2011/12 to the 2014/15 financial year, the track geometry recording train identified track geometry faults on the LNE route, the number of defects requiring correction: Newcastle route (about 500 defects), Doncaster route (about 300) and Sheffield route area (about 200) respectively. Three percentages of eighths in the one-mile section of track fall in the 'super-red' level in the Newcastle area.

3) Camden Derailment

The derailment accident happened on 15 October 2013; the train 4L77 was travelling from Birmingham Lawley Street to Felixstowe freight port derailed at Camden road west junction. The accident reasons were the vehicle's lateral and longitudinal imbalance leading to asymmetric loading negotiated with track twist conditions. The combination of the vehicle and track conditions caused reducing the vehicle's resistance to flange climb.

According to the accident report, for the load condition of the derailed wagon, 'the 20ft container was loaded with scrap electrical machines and had a gross weight of 28.83 tonnes; the empty 40ft container on the rear of the wagon weighed 3.88 tonnes.' The information was shown that 'the offset in the centre of gravity of the 20ft container towards the front of the wagon, with the longitudinal eccentricity 3-4\%'. Concerning the analysis report, there was a longitudinal weight ratio of 2.7:1.

		Maximum longitudinal weight ratio	Defination
MIE 0767	10/08/2007	2.37:1	20ft container weighting a maximum of 24 tones
		FEA(B) wagon	40ft container weight a maximum of 35 tones
MIE 0767	15/10/2013	2.7:1	20ft container weighting a maximum of 30 tones
		FEA(B) and FEA_E	40ft container weight between empty weight 3.64 to 9.32
		Maximum Lateral wagon weight ratio	
UIC guideline		1.25:1	
		Maximum Eccentrictiy	Eccentricity refers to position of the gross centre of gravity from the geometric centre of container
ISO 3874:1997		5%	based on the 60% of the total mass of the half of the container length
			[20ft container] offset in the centre of gravity of the load of 303 mm longitudinally or 122 mm laterally

Figure 4: Standard intervention in Camden

6 Key findings

To calculate EPC and failure probabilities in Barrier system for Porthkerry Derailment:

A. the Functional barrier: RCF inspection through the crack propagation

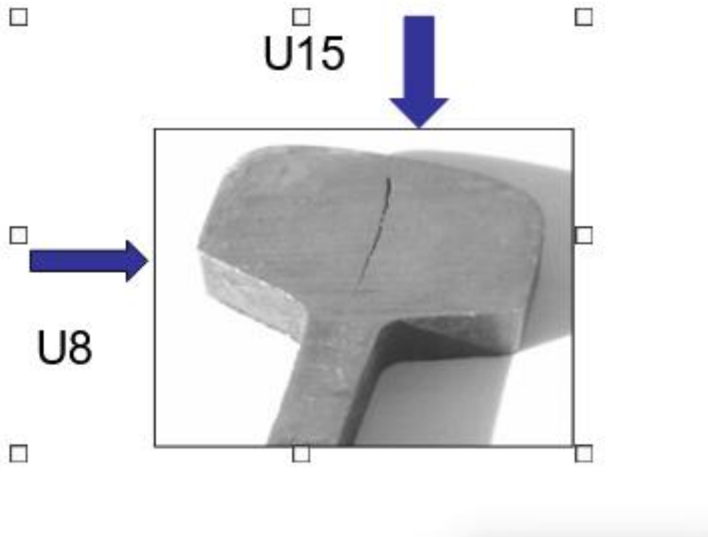

Figure 5: Detect the VLS suspected track fault

- The site has been declared as an RCF site at 8 August 2012, during the track inspection finding out the sign of the low rails RCF in the curve. It might be caused by the heavy trains at lower speeds for the situation in the Porthkerry site;
- At 30 July 2014, the RCF inspection (U8) found the VLS track defect between the 1 mile 321 yard to 340 yard (included the point of derail). The defect was classified as “3L”, and required replacement at 52 weeks;
- Generic Task Unreliability C: Complex task requiring a high level of comprehension and skill;
- Error Producing Condition: Unfamiliarity with a situation which is potentially important but which only occurs infrequently; Shortage of time available for error detection and Correction; A means of suppressing or overriding information or features.

B. the Functional barrier: Ultrasonic test train (UTU) and verifying method

- “Network Rail’s standard NR/SP/TRK/055 ‘Rail Testing: Ultrasonic procedures’ only requires a U8 test to be performed when a U15 test has found a loss of rail bottom signal greater than 50\%, with the signal boosted by a defined amount.”
- Unsafe action: at 16th of December 2013 suspected the track defect, but without the correct verification technique. Then on the day of 18th of December 2013, the pedestrian test carried out to the wrong location but didn’t confirm suspect VLS.
- The next UTU run and verification pedestrian test was on 04/04/2014 and 08/04/2014, while there was intermittent loss of rail bottom signal, without

individual signal loss of more than 50mm, and the U8 test was not undertaken at the action.

- Generic Task Unreliability E: Routine, highly practised, rapid task involving a relatively low level of skill.
- Error Producing Condition: A means of suppressing or overriding information or features; A need to unlearn a technique; No means of conveying spatial and functional information to operators in a form which they can readily assimilate.

C. The functional barrier: Grinding method to prevent rail crack}

- The switches and crossing grinder worked various times (25 passes) on 30 August of 2014 (one month before derailment), was shown that the left-hand rail had a dark band in the centre of the rail after the grinding work on 30th August 2014.
- Generic Task Unreliability F: Restore or shift a system to its original or new state following.
- Error Producing Condition: Low signal-to-noise ratio; Channel capacity overload.

Incident	Functional Barrier	Generic Task Unrelia	Error producing condition	Multiplier	Assessed Proportion c	Assessed Ef	Human Error
Porthkerry derailment	1. RCF inspection through the crack propagation	0.16	Unfamiliarity with a situation which is potentially importan	17	0.1	2.6	7.32E-01
2 October 2014	C: Complex task requiring high level of comprehension and skill	0.12-0.28	Shortage of time available for error detection and Correcti	11	0.01	1.1	
			A means of suppressing or overriding information or featu	9	0.2	1.6	
	2. Ultrasonic test train (UTU) and verifying method	0.045	A means of suppressing or overriding information or featu	9	0.1	1.8	5.32E-01
	E: Routine, highly practised, rapid task involving relatively low le	0.007-0.045	A need to unlearn a technique	6	0.05	1.25	
			No means of conveying spatial and functional information	8	0.75	5.25	
	3. Grinding method	0.0058	Low signal-to-noise ratio	10	0.05	1.45	2.07E-02
	F: Restore or shift a system to original or new state following	0.0008-0.007	A means of suppressing or overriding information or featu	9	0.1	1.8	
			[illegible]	[illegible]	[illegible]	[illegible]	

Figure 6: Porthkerry human failure probabilistic model in HEART Model

7 Discussion

The large scale experimental: example of the SD level calculation based on the track geometry recording data (2013-2014, 70 mileages, at LEC1 2100). The Markov Chain transition matrix could be established the track deterioration probability from the slightly, medium to the severe deterioration state.

In order to understand the track geometry monitoring, the first step is trying to calculate the track standard deviation, and based on the transition matrix to assess the feasibility of the model through the comparison between prediction value and accurate track geometry recording:

$$\begin{bmatrix} S_1 \\ \vdots \\ S_n \end{bmatrix}^k = \begin{bmatrix} P_{11} & \cdots & P_{1N} \\ \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nn} \end{bmatrix} \begin{bmatrix} S_1 \\ \vdots \\ S_n \end{bmatrix}^{k-1}$$

and

$$P_{ij} = P(S^k = i | S^{k-1} = j)$$

$$\sum_{i=1}^{n} P_{ij} = P_{1j} + P_{2j} + \cdots + P_{nj} = 1, (j = 1, 2 \ \ldots n)$$

The track irregularities (track twist) were derived from the characterization, the track recording vehicle, the specification for the measuring device, and the geometric quality assessment (EN 13848-1). The twist measurement was taken simultaneously at the fixed distance; it showed the different gradients between the two points. The algebraic difference between the defined distance of the two cross-levels, which specify equivalent to the wheel-base distance, and the consecutive measurement of the cross-level were calculated. The probabilistic transitions model based on the matrix is illustrated.

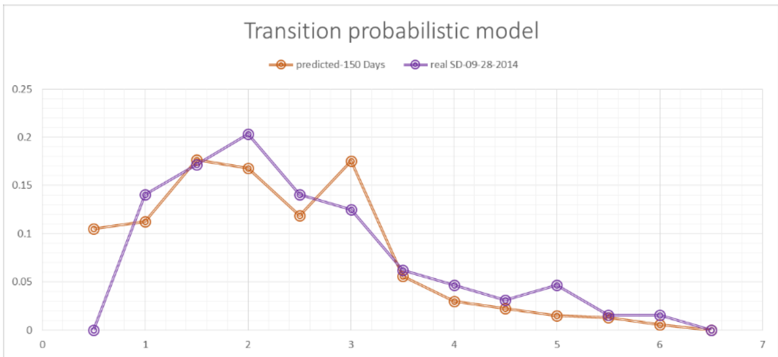

Figure 7: Track geometry deterioration model

The iterations shown above for the transition for the standard deviation depicted the comparison between predicted degradation and real-time recorded Standard Deviate (SD) value.

With respect to the Low Carbon Freight Modelling strategy from 2023 to 2050, the author basically surveys the technical reasons, firstly through the understanding of physical experiments, such as, compilation of the track geometry degradation model, the fatigue reliability prediction methods and the survival analysis. The main failure modes of the system are identified and the system failure probabilities could be calculated.

8 Revised Human Error Assessment and Reduction Technique (HEART) and Error Producing Condition Method (EPC)

This work reviews the 20 freight accident investigation reports. The methods use the Generic Error Modelling System (GEMS), which established the Internal Skill-based behaviour errors, the Knowledge-based behaviour errors and the Rule-based behaviour errors. This analysis plan helps in understanding the relationship between these three types of errors. The analysis results are based on the previous work undertaken by Australian research group (Baysari, 2008) [6]; the precondition of unsafe acts and organizational influence occupied a higher percentage in the railway accident investigation reports. The qualitative matrix between HFACS and EPC relation would be listed in the work.

Incident	Functional Barrier	Generic Task Unrelia	Error producing condition	Multiplier	Assessed Proportion c	Assessed Ef	Human Error
Porthkerry derailment	1. RCF inspection through the crack propagation	0.16	Unfamiliarity with a situation which is potentially importan	17	0.1	2.6	7.32E-01
2 October 2014	C: Complex task requiring high level of comprehension and skill	0.12-0.28	Shortage of time available for error detection and Correcti	11	0.01	1.1	
			A means of suppressing or overriding information or featu	9	0.2	1.6	
	2. Ultrasonic test train (UTU) and verifying method	0.045	A means of suppressing or overriding information or featu	9	0.1	1.8	5.32E-01
	E: Routine, highly practised, rapid task involving relatively low le	0.007-0.045	A need to unlearn a technique	6	0.05	1.25	
			No means of conveying spatial and functional information	8	0.75	5.25	
	3. Grinding method	0.0058	Low signal-to-noise ratio	10	0.05	1.45	2.07E-02
	F: Restore or shift a system to original or new state following	0.0008-0.007	A means of suppressing or overriding information or featu	9	0.1	1.8	
			Channel capacity overload	6	0.2	1.365	
Heworth derailment	1. Plain line pattern recognition (PLPR)	0.00015	Low signal-to-noise ratio	10	0.4	1.3	1.97E-03
23 october 2014	G: Completely familiar, well-designed, highly practised, routine t	0.00008-0.009	Shortage of time available for error detection and Correcti	11	0.2	2.1	
			Poor, ambiguous or ill matched system feedback	4	0.05	1.2	
			A channel capacity overload, particularly one caused by s	6	0.8	4	
	2. Basic visual inspection	0.13	Risk misperception	4	0.01	0.25	1.76E-02
	D: Fairly simple task performed rapidly or given scant attention	0.06-0.13	Conflict of objectives	2.5	0.1	0.45	
			A mismatch between perceived and real risk	4	0.4	1.2	
	3. Track geometry recording train	0.0085	Performance Ambiguity	5	0.05	2.8	2.14E-02
	E: Routine, highly practised, rapid task involving relatively low le	0.007-0.045	Misperception of Risk	4	0.2	1.5	
			Irreversibility	8	0.3	0.6	
	4. Track maintenance engineering (TME)	0.14	Unclear Allocation of Function	1.6	0.01	1.1	3.74E-01
	B: Shift or restore system to a new or original state on a simgle	0.14-0.42	Progress Tracking Lack	1.4	0.02	1.8	
			Shortage of time available for error detection and Correcti	11	0.25	1.35	
	5. Vehicle Inspection and Brake Test (VIBT)	0.006	Misperception of Risk	4	0.3	0.56	2.42E-03
	F: Restore or shift a system to original or new state following	0.0008-0.007	A need to unlearn a technique and apply one which requir	6	0.1	0.8	
			The need to transfer specific knowledge from task to task	5.5	0.2	0.9	
	6. speed restriction	0.002	Irreversibility	8	0.1	1.325	1.80E-03
	F: Restore or shift a system to original or new state following	0.0008-0.007	Channel capacity overload	6	0.05	0.68	
			No clear direct and timely confirmation of an intended acti	3	0.01	0.02	
	7. track drainage improvement	0.12	Poor, ambiguous or ill matched system feedback	4	0.2	1.1	2.59E-02
	C: Complex task requiring high level of comprehension and skill	0.12-0.28	Shortage of time available for error detection and Correcti	11	0.03	0.98	
			Low signal-to-noise ratio	10	0.25	0.25	
			Ambiguity in the required performance standard	5	0.2	0.8	

Figure 8: Independence evaluation of EPC example

To validate the EPCs relative contribution, there are typical factors, such as, the Technique unlearning, the Mis-perception of risk, the Conflict of objectives, the Inexperience and Low moral (Williams, 1988) [10]. Propensity Score Matching (PSM) calculated the effective measurements regarding the accidents consequence, with the covariance listed above.

The revised-HEART model mentions transferring from Common performance conditions to Genotype analysis procedures. the qualitative matrix would be listed in the work. To classify the traditional human factors, information processing psychology and cognitive system engineering, the Human Factor Analysis and Classification System (HFACS) was advised.

Furthermore, the human reliability analysis strategy might be evaluated by 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.
In addition, based on the previous analysis plan (Underwood, 2014) [8], the author introduces the revised-HEART method combined with the Accident map (Risk Management Framework) diagram for a specific accident scenario. It is then possible to calculate the nominal likelihood of failure in each barrier, such as, regarding the hierarchy organizational structure of government policy, regulatory bodies and associations, local area management, technical and operational management, physical process and operator activities, equipment surroundings. The assumed relation

between safety management quality, safety culture (SCQPI) and probability of failure on demand of safety barrier is used to evaluate system deficiencies [5].

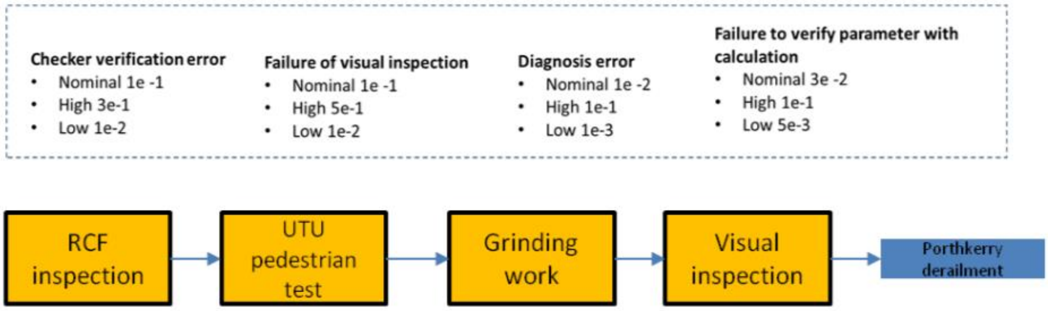

Figure 9: Validation-Boundary of acceptable performance (HPWG, 1996)

Therefore, the Behaviour Shaping Mechanism in terms of boundaries of acceptable performance, and theoretical framework (i.e. HFACS) influence quality control of Safety Barrier systems throughout every step of the retrospective analysis are proposed. The preliminary computerized operator's reliability and error database (CORE-Data) with human error probabilistic models are reviewed based on the scenarios analysis.

- The evaluation analysis plan concluded following steps:
- Barrier model,
- Generic task definition,
- Learned error producing conditions (EPC) and human factor analysis and classification system (HFACS) relative matrix,
- Descriptive analysis through the Accident map diagram assessed by Revised-HEART model,
- Failure Probabilistic Estimation for the system levels,
- System Reliability Evaluation.

9 Conclusion

In this work, the author first discussed and compared the main safety theories and models, such as, the utilization of the Swiss Cheese Model, Human Factor Analysis and Classification System (HFACS), Systems Theoretic Accident Modelling and Processes model (STAMP); and define the capability and advantage of each application in the various accident analysis procedures.
Secondly, the author developed the new methodology in the derailment failure mechanism, cognitive reliability model and asymmetric loading issue; the scenario analysis based on the understanding of the SRK-framework to improve the integrated safety performance.

Thirdly, there are investigations of the derailment mechanism, for instance, the track geometry deterioration, the track twist, the degradation at switches and crossing, the track void, the vehicle frame twist, the suspension characteristics, the friction liner performance and case studies to learn the technical reasons.

Fourthly, the work concluded the quantitative analysis based on the state transition model (track geometry recording data), and the qualitative analysis to demonstrate HEART and cognitive reliability understanding of the performance shaping factors in the normal vehicle/track maintenance regime.

Acknowledgements

I gratefully acknowledge the valuable cooperation of Professor Simon Iwnicki, Dr Rawia El Rashidy, Dr Coen Van Gulijk and Dr Miguel Figueres-Esteban (the Institute of Railway Research, the School of Computing and Engineering, University of Huddersfield) in preparing the application notes.

Bibliography

[1] Le Coze, J. C. (2015). Reflecting on Jens Rasmussen's legacy. A strong program for a hard problem. Safety Science, 71, 123-141. doi:10.1016/j.ssci.2014.03.015

[2] Aven, T., Sklet, S., &Vinnem, J. E. (2006). Barrier and operational risk analysis of hydrocarbon releases (BORA-Release). Part I. Method description. J Hazard Mater, 137(2), 681-691. doi:10.1016/j.jhazmat.2006.03.049

[3] Sklet, S. (2006). Safety barriers: Definition, classification, and performance. Journal of Loss Prevention in the Process Industries, 19(5), 494-506. doi:10.1016/j.jlp.2005.12.004

[4] Duijm, N. J. (2009). Safety-barrier diagrams as a safety management tool. Reliability Engineering & System Safety, 94(2), 332-341. doi:10.1016/j.ress.2008.03.031.

[5] Duijm, N. J., &Goossens, L. (2006). Quantifying the influence of safety management on the reliability of safety barriers. J Hazard Mater, 130(3), 284-292. doi:10.1016/j.jhazmat.2005.07.014.

[6] Baysari, M. T., McIntosh, A. S., & Wilson, J. R. (2008). Understanding the human factors contribution to railway accidents and incidents in Australia. Accid Anal Prev, 40(5), 1750-1757. doi:10.1016/j.aap.2008.06.013.

[7] Kim, D. S., & Yoon, W. C. (2013). An accident causation model for the railway industry: Application of the model to 80 rail accident investigation reports from the UK. Safety Science, 60, 57-68. doi:10.1016/j.ssci.2013.06.010.

[8] Underwood, P., & Waterson, P. (2013). Systemic accident analysis: examining the gap between research and practice. Accid Anal Prev, 55, 154-164. doi:10.1016/j.aap.2013.02.041.

[9] Akyuz, E., Celik, M., Cebi, S., (2016), A phase of comprehensive research to determine marine-specific EPC values in human error assessment and reduction technique, Safety Science, 87, 63–75, dx.doi.org/10.1016/j.ssci.2016.03.013

[10] Williams, J. C.. (1988). A Data-Based Method for Assessing And Reducing Human Error To Improve Operational Performance. Human Factors and Power Plants, 1988. Conference Record for 1988 IEEE Fourth Conference on. IEEE.

[11] Hollnagel, E.. (1998). Cognitive Reliability and Error Analysis Method (CREAM).

[12] HAZARD AND BARRIER ANALYSIS GUIDANCE DOCUMENT (1996), OFFICE OF OPERATING EXPERIENCE ANALYSIS AND FEEDBACK.