Evaluation of IEC 61508 Defenses for Common Cause Failures in Railway Industry*

Sirisha Bai Govardhan Rao[1,2], Julieth Patricia Castellanos-Ardila[2], and Sasikumar Punnekkat[2]

[1] *Alstom*, Västerås, Sweden
[2] *Mälardalen University*, Västerås, Sweden
{sirisha.bai.govardhan.rao,julieth.castellanos,sasikumar.punnekkat}@mdu.se

Abstract. The assessment of Common Cause Failures (CCF), i.e., failures of multiple components due to a shared root cause, is essential during probabilistic risk assessment in safety-critical industries. However, not all contributing causes to CCF are directly observable at the component level as they typically stem from systematic factors, i.e., design, operations, or environmental conditions. Thus, industries need to implement methodologies such as the β-factor model to account for these causes. The β-factor estimation suggested by the functional safety standard IEC 61508 is based on the assessment of a defined set of defense measures. However, the extent to which these defense measures address the industry-specific CCF remains unclear due to limited contextual validation. In this paper, we evaluate the defense measures proposed by IEC 61508 with a specific focus on their applicability to the railway industry. To support this evaluation, we define a four-step process inspired by post-mortem analysis, a method traditionally used to learn from past projects. This process is applied to a set of historical railway safety events, allowing us to identify significant CCF events and their underlying root causes. We then make a categorization based on the root causes of CCF in relation to the defense measures outlined in IEC 61508 and estimate the corresponding β-factor for each category. Finally, we assess the coverage and adequacy of the standard's defenses in addressing the identified CCF. The insights gained from this study aim to support the development of more robust, context-aware CCF assessment methods for the railway sector.

Keywords: Common Cause Failure · IEC 61508 · β-factor · Railway.

1 Introduction

According to the International Electro-technical Commission (IEC) definition, reliability[3] is the ability of a product, system, or service to perform its intended

* This Research has been supported by the Knowledge Foundation (KKS) in collaboration with Alstom and Mälardalen University.

[3] https://shorturl.at/vSkHT

function under specified conditions of use for a designated period of time. To achieve high reliability, it is common practice to introduce redundancy in critical elements, ensuring the system can continue operating despite individual component failures. However, Common Cause Failures (CCF) [18] pose a significant challenge, as they can cause multiple units or components to fail simultaneously due to a single underlying root cause. Thus, CCF quantification plays a major role in the failure probability analysis performed in the safety-critical industries.

Different methods to estimate CCF have been adopted. As reported in [15], there are two main kinds of methods. The *explicit methods* model each CCF as a basic event shared by the affected components, commonly using Fault Tree Analysis. The *implicit methods* account for CCF through joint probabilities or correlations. The latter is considered valuable when CCF are not directly observable in the component, such as those stemming from systematic factors related to design, operations, or environmental conditions [10], also called residual causes. Examples of implicit models are the *α-factor model* [13], and the *Binomial Failure Rate model* [17]. However, the most common and widely used model among the industries is the *β-factor model* [8]. The β-factor model estimates the contribution of CCF by multiplying the total failure rate by a β value. In the absence of empirical data, this β value is typically derived using a checklist-based approach that assesses the effectiveness of implemented defense measures, i.e., control mechanism that reduces the likelihood of failures. Various industries rely on this method since it was recommended in the standard IEC 61508-6:2010 [2]. The railway industry is not an exception [19], [12]. The effectiveness of the defense measures outlined in IEC 61508, particularly for railways, remains uncertain due to limited contextual validation.

This paper aims to close the above mentioned gap by providing an evaluation with a particular focus on the Railway industry. For this, we propose a structured four-step process inspired by the principles of post-mortem analysis [14], a method traditionally employed to extract lessons learned from past projects. Our aim is to systematically uncover meaningful patterns associated with CCF and to understand the extent to which these failures are addressed by the defenses outlined in IEC 61508. First, we review historical safety events from a specific railway context to identify CCF occurrences and their root causes. Second, we make a categorization based on the root causes of CCF in relation to the defense measures outlined in IEC 61508. Third, we estimate the β-factor for each category, reflecting the influence of applicable defense mechanisms. Finally, we assess the coverage of the IEC 61508 defense measures in addressing the identified CCF. The insight gathered in this research can guide the development of more robust defense mechanisms that can lead to more context-aware CCF assessments in the railway industry.

The rest of the paper is structured as follows. In Section 2, we provide essential background information. In Section 3, we present the methodology created for our evaluation. In Section 4, we apply the methodology and present the obtained results. In Section 5, we present a general discussion related to our findings, threats to validity and the correspondence to our work with the SPI manifesto. Finally, in Section 6, we present conclusions and future work.

2 Background & Related work

In this section, the basic background concepts of this research are introduced.

2.1 β-factor model

The β-factor model was initially proposed [8] and developed with focus on the nuclear industry. In this model, β-factor is the percentage of failure attributed to the CCF in the overall failure rate. The parameters that are considered mainly in this model are 'β' and 'λ', where, β-factor is the fraction of unit failures that are common mode and 'λ' is the probability of system failure rate, given by the number of failures over a period of time.

$$\lambda = \frac{\text{number of failures}}{\text{part-hours of operation}} \tag{1}$$

The 'λ' can be considered to be the sum of two mutually exclusive components 'λ_1' and 'λ_2'

$$\lambda = \lambda_1 + \lambda_2 \tag{2}$$

where, 'λ_1' is the independent failure rate i.e., failures that do not affect other components in the system (see equation 3), and 'λ_2', is the common cause failure rate (see equation 4).

$$\lambda_1 = (1 - \beta)\lambda \tag{3}$$

$$\lambda_2 = \beta\lambda \tag{4}$$

The β-factor in this model can be estimated in both quantitative (i.e., estimated based on the past historical data) and qualitative (i.e., estimated based on the assessment applied CCF defense measures) ways [16]. The standards such as IEC 61508 also recommended this methodology in which β-factor is estimated in a qualitative way based on the assessment of applied defense measures.

2.2 Defense strategy to mitigate Common Cause Failures

The CCF must be carefully considered and mitigated in safety-critical industries such as nuclear. In this context, the nuclear industries collect and maintain the CCF data and try to identify the root causes of CCF [7]. Furthermore, they developed defense measures to mitigate the CCF. Based on this knowledge, different β-factor models such as Humphreys model [11] were evolved in which the defenses are considered in the form of sub-factors. The defenses were developed focusing mainly on the design, operational and environmental root causes of common cause failures. They are described as follows:

– **Design Causes:** These include functional deficiencies, design realization and also the issues which arise during manufacture, installation and commissioning of systems.
– **Operational causes:** These include the procedural errors occurring during testing, operations and maintenance phases. It also related to the activities associated with the interface between system and staff.
– **Environmental causes:** These include the extremes of environment and discrete energetic events either within or outside of system boundaries.

2.3 IEC 61508 standard

The IEC 61508 standard [2] developed defense strategies for the root causes (see Section 2.2) based on the Humphreys model [11] and Unified Partial Method (UPM) [5]. The IEC 61508 further created checklist questions for each defense measure. For example the defense measure *competence/training/safety culture* has two checklist questions as shown in Table 1. The standard provides two value sets, X and Y, for each checklist question depending on whether diagnostic testing is applied, and taking into account the logic subsystem (LS) and sensors & final elements (SF). Similarly, each of the eight defense measures in the standard includes checklist questions with predefined values.

Table 1: Checklist questions of a defense measure

Competence/training/safety culture	X_{LS}	Y_{LS}	X_{SF}	Y_{SF}
Have designers been trained (with training documentation) to understand the causes and consequences of common cause failures?	2,0	3,0	2,0	3,0
Have maintainers been trained (with training documentation) to understand the causes and consequences of common cause failures?	0,5	4,5	0,5	4,5

2.4 Related work

The check-list based β-factor estimation methodology suggested by IEC 61508 standard is the commonly used methodology in the railway industry for the CCF evaluation. For example, in the paper [12], the β-factor methodology suggested by IEC 61508 standard is adopted for the β-factor estimation of fire safety system in railway industry. In the paper [19], the β-factor estimation of train operation control systems in railways utilized the same β-factor methodology for CCF evaluation. In addition, in the research [6], several architectures are chosen for study based on the β-factor methodology recommended by IEC 61508. Furthermore, the PDS method (palitelighet for datamaskinbaserte sikkerhetssystemer), which is similar to β-factor estimation methodology of IEC 61508 was also developed focusing railway applications [9]. However, IEC 61508 standard is an umbrella standard which is applicable to variety of industries such as manufacturing, oil/gas industry, energy sector and many more including railways. Hence, the effectiveness of defense measures considered in the β-factor estimation of IEC 61508 standard for the railway-specific root causes is uncertain. Therefore, in this research we assess the effectiveness of IEC 61508 defense measures against the identified root causes of CCF events in railways.

3 Methodology

The railway industry usually estimates CCF by using the β-factor model (recalled in Section 2.1) suggested by the IEC 61508 standard. In the absence of sufficient empirical data, the β value is typically derived using a checklist-based approach that evaluates the effectiveness of implemented defense measures (recalled in Section 2.2). However, the adequacy of these defense measures remains uncertain due to limited validation in specific contexts. In this paper, we aim to close this gap by answering the following questions.

RQ1. How can CCF be identified from historical events recorded in the railway domain?
Commonly, CCF remain hidden within the general incident records that companies collect during operations. This lack of clarity makes it difficult to distinguish CCF events from isolated failures, complicating efforts to understand occurrence patterns fully, which in turn can undermine the efforts to develop adequate mitigation strategies. Therefore, developing a clear understanding of how to identify CCF from historical events is a critical step toward improving the accuracy of CCF estimation.

RQ2. To what extent are the defense measures proposed in IEC 61508 applicable to the railway domain?
IEC 61508 was designed to be broadly applicable across various industries, providing a general range of defense measures for addressing a generalized set of CCF. However, the specificity of the railway domain, e.g., operational conditions, differs from other sectors, such as process industries or nuclear. Moreover, inadequate adaptation of defense measures to railway-specific risks can compromise mitigation strategies and distort CCF estimations. Therefore, it is crucial to evaluate whether these generic defense measures are adequate for mitigating CCF in this context.

To answer the previously stated questions, we apply the methodological process illustrated in Fig. 1. This process is inspired by Post-Mortem Analysis (PMA) [14], a research method used to systematically investigate past events that led to a problem, such as a system failure, safety incident, or project delay. Our approach adopts key elements of PMA, including data collection from historical records, data analysis to identify underlying causes, data categorization based on relevant defense measures, and expert review to validate the findings. Our process is composed of four main steps.

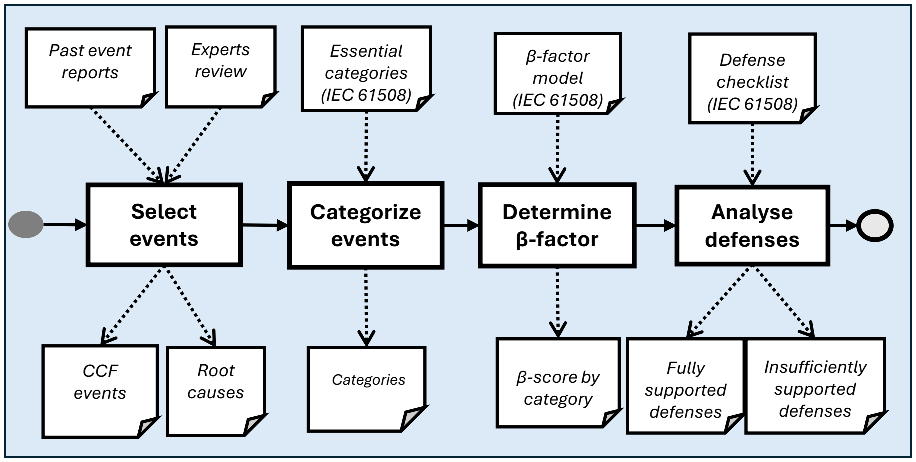

Fig. 1: Steps in our evaluation process

1. **Select Events**: In this step, failure data is extracted from historical event reports provided by Alstom[4], which maintains records of accidents identified during validation, installation, testing, or operational phases. To identify CCF events within this dataset, we applied two selection criteria [1]: (i) events in which two or more components failed due to the same root cause, and (ii) sets of events that, although occurring separately, share a common root cause. This step results in a curated list of CCF events[5] along with their corresponding root causes. Expert reviews are also incorporated to validate and finalize the event selection.
2. **Categorize Events:** In this step, we classify the selected events based on the essential categories provided by IEC 61508. For this, we used the basic sources of the β-factor. In particular, this model was developed by building on two earlier models: the Humphreys model [11] and the Unified Partial Method (UPM) method [5], both of which emphasize defenses against three primary root causes of CCF: design, operation, and environment. We classify each event according to these root cause categories (see Table 2).
3. **Determine β-factor:** In this step, we estimate the β-factor of the model provided in IEC 61508 by analyzing the scoring distribution of defense categories based on their applicability to different root causes (see Section 2.2). The standard includes certain checklist questions for each defense and assigns scores to them. For example, the checklist questions under the defense measure competence/training/safety culture of operational root cause are shown in Table 1. The β-factor is estimated based on the overall score gained from the assessment of applied defenses to the system. There are different num-

[4] https://www.alstom.com/
[5] https://rb.gy/lukc3r

Table 2: Root Causes Categories and Defense Measures

Category	Defense Measures
Design	Separation/segregation Diversity/redundancy Complexity/design/application/maturity/experience Assessment/analysis and feedback of data
Operation	Procedures/human interface Competence/training/safety culture.
Environmental	Environmental control Environmental testing.

ber of checklist questions under each defense. These defenses measures are related to the root cause categories presented in Table 2.

4. **Analyze Defenses Support:** In the final step, we evaluate the distribution of defense scores across the different root cause categories defined in IEC 61508 (see Table 2). The aim is to assess the level of support for the identified CCF events and their associated root causes within the railway domain. Examining the distribution of defenses among design, operational, and environmental factors allows us to better understand the strengths and potential gaps in the existing defense strategies proposed by IEC 61508, particularly in relation to the specific challenges faced in railway systems.

4 Results

In this section, we present the results obtained by applying the methodology outlined in Section 3, following each step of the process.

4.1 Selecting the events

Our review of historical data focused on safety event reports collected over a five-year period, specifically from 2020 to 2024. Only the reports belonging to this timeframe were considered relevant for this study. The identification of CCF events within this large dataset was performed by applying the selection criteria defined for this step, ensuring a systematic and objective filtering process.

Once the relevant CCF events were identified, the data were systematically organized into Excel sheets to enable a structured and traceable analysis. Two separate sheets were created to distinguish between events selected according to the two different types of selection criteria. This organization allowed for more precise tracking, easier cross-referencing, and clearer documentation of the analysis process, which was essential given the complexity and volume of the reviewed data. In total, 30 CCF events were identified, with 18 events selected through Criterion 1 and 12 events through Criterion 2. The corresponding root causes for these events are detailed in the “Source” column of Table 3.

Following the identification of CCF events, a detailed validation process was conducted in collaboration with railway industry safety experts. Two main meeting sessions were organized, each dedicated to reviewing events identified through one of the selection criteria, and several follow-up communications via email were carried out to clarify specific cases and refine the event list further. During the first meeting, the events selected based on the first criterion were presented and discussed, focusing on the mechanisms leading to multiple component failures from a single cause. The second meeting addressed the events identified using the second criterion, which grouped separate events sharing the same root cause. This review was essential for validating the technical relevance of the selected events and ensuring practical alignment with the operational contexts.

Table 3: Identified root causes of CCF in railways

Root Cause Category	Source
Design	Engineering - Others Material - Others Material - Supplier Process Management (2) Material - Design Issue Procurement - Supplier material issue Procurement - Supplier - Others Procurement - Supplier - Design non conformity Material - Not Conform to specifications Industrialization/manufacturing issue
Operation	Operations - Manufacturing Manpower issue Manpower - Self-inspection inefficient (2) Operations - Others Train Operation - Training and Competencies Documentation - not detailed enough (5) Manpower - Training Manpower - Error / Identification (2) Maintenance - Documentation Method - Other (2) Maintenance - Others Documentation - mistake Method - Process Management
Environmental	Environment - Others

4.2 Categorizing the events

In this step, we categorized the identified CCF events based on the essential root cause categories outlined in Table 2. Among the 30 events selected in the previous step, 5 were attributed to the root cause *documentation - not detailed enough*, 2 to *material - supplier process management*, 2 to *manpower - self-inspection inefficient*, 2 to *manpower - error/identification*, and 2 to *method - other*. The remaining events were associated with a variety of other specific root causes, as detailed in Table 3. Overall, the distribution of root causes shows that 10 events were linked to design-related issues, 19 events to operational issues, and 1 event to an environmental factor. This distribution is visually summarized in Fig. 2. The analysis clearly indicates that operational root causes are the dominant contributors to CCF events in the railway domain.

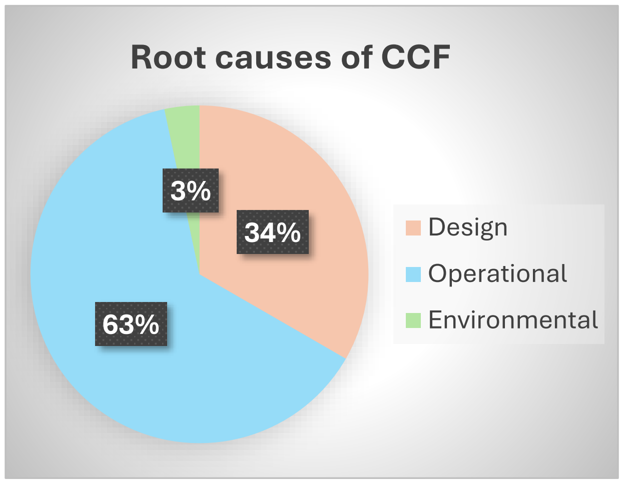

Fig. 2: The percentage distribution of the root causes of CCF

4.3 Determine the β-factor estimation

As recalled in Section 2.1, the IEC 61508 standard adopts the β-factor model to estimate the probability of CCF. In this model, the β-factor is calculated separately for the logic subsystem, sensors, and final elements. To mitigate the probability of CCF, the standard introduces a set of defense measures (see Table 2), each intended to reduce the likelihood of common cause events. Each defense measure is linked to a series of checklist questions and assigned values based on engineering judgment (see Table 1). The contribution of each measure is divided into two value sets, labeled X and Y, depending on whether diagnostic testing is considered (recalled in Section 2.3). The cumulative effect of these type of defense measures contributes to the reduction of the overall CCF probability. Finally, the overall score (S) obtained from the checklist evaluation is used to estimate the β-factor according to the following formula:

$$S = X + Y (\beta \text{ for the undetected failures}) \tag{5}$$

Table 4: Calculation of β in IEC 61508 standard

Score S	**β % for logic subsystem**	**β % for sensors and final elements**
120 or above	0.5%	1%
70 to 120	1%	2%
45 to 70	2%	5%
Less than 45	5%	10%

The β% for undetected failures is estimated based on the score (S) as presented in Table 4. The distribution of defense measures, derived from the analysis of the obtained scores (S), is summarized in Table 5. This distribution shows that the highest percentage of scores is attributed to defenses addressing design-related root causes. Defenses targeting environmental root causes contribute to a lesser extent, while defenses related to operational root causes have the smallest contribution. The influence of these defense scores on the overall β value is illustrated in Fig. 3. This analysis concludes that, within the IEC 61508 standard, the overall β-factor is primarily shaped by design-related defenses, with environmental and operational defenses playing progressively smaller roles based on the weighting criteria used in the β-factor estimation process.

Table 5: Defense Measures and overall scores

Defense measure	**Scores (S) of the logic subsystem (LS)**	**Scores (S) of sensors and final elements (SF)**
Separation/segregation	10	10
Diversity/redundancy	29.5	21.5
Complexity/design/application/maturity/experience	10	10
Assessment/analysis and feedback of data	10	10
Procedures/human interface	13	10
Competence/training/safety culture	10	10
Environmental control	10	10
Environmental testing	20	20

4.4 Analyze the defenses

For the assessment of IEC 61508 defense measures and their support in mitigating the railway CCF, we underwent three main steps which are discussed in Section 4.1, Section 4.2 and Section 4.3. From the first step, we identified the CCF events and their root causes. In the second step, we categorize the events based on their root causes and which shows that the railways are highly affected

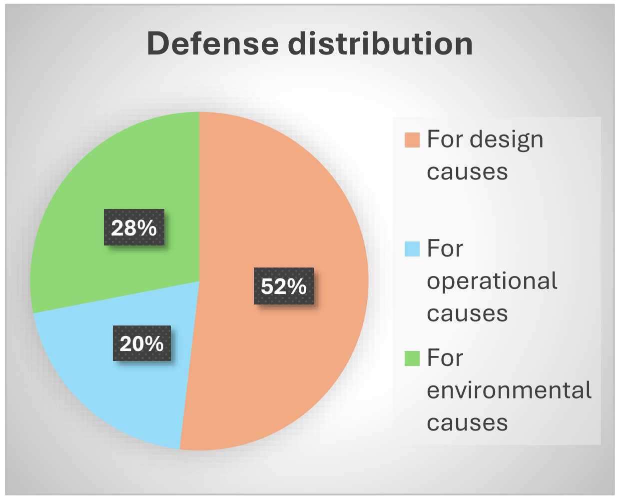

Fig. 3: Defense percentage that attributes to overall β

by CCF through operational root causes (see Fig.2). In the third step, we analyzed the defense support for each type of root cause that contribute to overall β-factor value in IEC 61508. As a result, we identified that the overall β-factor value in IEC 61508 is highly dominated by the defenses related to design (see Table 5). Even in the absence of operational defenses the system still achieve a β value of 1% in logic subsystem and 2% in sensors and final elements. Hence from analyzing all these steps, we identified a gap between the IEC 61508 defense support and observed CCF events in railways. We conclude that the IEC 61508 defenses strategies are lacking the adequate defense support in mitigating railway CCF concerning the operational root causes.

5 Discussion

In this section, we present our findings, we discussed threats to validity and we explained the correspondence to SPI Manifesto.

5.1 Findings

The research findings demonstrate the answers to the research questions raised in this paper. First, to achieve the answer to RQ1, we adopted a methodology (see Section 3) and identified a set of CCF events. Subsequently, we categorized the CCF events (see Section 4.2) based on their root cause (see Table 3). From this categorization, we found that the major root causes impacting CCF events in railways are operational root causes (see Fig.2), following the design and environmental root causes.

We furthermore achieved the answer to our next research question RQ2. For this purpose, we underwent two main steps, as recalled in Section 4.3 and 4.4. As a first step we analyzed the β-factor estimation in IEC 61508 and found that the β value is highly dominated by the defense score concerning design (see Fig. 3) rather than operational and environmental defenses. Even in the absence of operational defenses, the logic subsystem achieves a β-value of 1%, while sensors and final elements reach 2%. However, the identified CCF events in the railway domain are largely attributed to operational root causes (see Fig. 2). This information may serve as evidence of a mismatch between the types of defense mechanisms emphasized in the IEC 61508 standard and the actual characteristics of CCF events observed in railway systems.

5.2 Threats to Validity

The validity of the results are discussed in this section by analyzing three main threats [4]. They are construct validity, internal validity and external validity.

1. **Construct validity:** To collect data about CCF events from the historical railway safety events, two criteria were adopted and tested primarily on a small amount of data. The nuclear industry have adopted the similar type of criteria in the past to identify the CCF events from their data sources. Hence, it is already proven criteria to identify the CCF events. Thus, it is ensured that the criteria is appropriate and there is no threat for validity.
2. **Internal validity:** The study design in this research is made by an author which is assessed by two other authors. The results identified in this research study were demonstrated to three railway industry experts. One among those experts reviewed the research results. Thus the threat is mitigated.
3. **External validity:** The findings of this study are based on an analysis of data collected over a five-year period (2020–2024) from the railway industry. A total of 30 CCF events were identified, of which only one was attributed to environmental root causes. However, it is important to note that the statistical data in this research is sparse, limiting the extent to which the results can be generalized. Nonetheless, the study provides valuable insights into the types of root causes that most commonly impact CCF in the railway sector and highlights the need for a greater number of appropriate defense mechanisms. This research contributes to the railway industry's understanding of CCF and supports future investigations in this area.

5.3 Correspondence to SPI Manifesto

In this research, the industry-specific issues are identified by focusing on the railway industry and their CCF events. This addresses the principle 1 of SPI Manifesto i.e., *know the culture and focus on needs*. The experiences from the past data are utilized to identify the CCF events to mitigate the CCF in railways. This addresses the principle 3 of SPI Manifesto [3] i.e., *base improvement on* *experience and measurements.* In this research a set of CCF events are identified and knowledge has been shared to the practitioners about the types of root causes that are impacting CCF. This addresses the principle 4 of SPI Manifesto [3] i.e., *Create a learning organization.*

6 Conclusion & Future work

In this paper, we discovered a total of 30 CCF events from a historical source related to railway incidents. Later, we segregated them based on their root causes. A total of 19 events were attributed to operational root causes, while 10 were linked to design-related causes and one to an environmental root cause. We also analyzed the β-factor estimation using the model recommended in IEC 61508. We found that the resulting values are heavily influenced by defenses targeting design-related root causes, while contributions from operational and environmental root causes are comparatively underrepresented. The absence of defenses addressing operational root causes still results in a β-value of 1% for the logic subsystem and 2% for sensors and final elements. This leads to a discrepancy between the applied defense measures and the actual root causes observed in railway systems, resulting in a innapropriate β-factor value. Hence, from this research we conclude that the defense measures concerning operational root causes must be prioritized in railways unlike in IEC 61508 standard to achieve more appropriate railway-specific β value.

In the future, we plan to develop more robust and context-aware defense strategies to support CCF quantification in the railways based on the insights from this research. These strategies will be designed to reflect the specific operational and technological characteristics of railway systems improving the relevance of CCF mitigation efforts. We also envision integrating these strategies into domain-specific taxonomies or ontologies to enable the systematic structuring of CCF-related knowledge. Such representations can enhance the consistency of assessment processes and facilitate the reasoning required for CCF quantification. Finally, we aim to explore more efficient methods for reporting and contextualizing failure rate data, allowing for more accurate and operationally grounded quantification of CCF. This approach could strengthen the analytical and practical applicability of CCF assessments in the railway industry.

References

1. Common-cause failure database and analysis system: Event data collection, classification, and coding (NUREG/CR-6268, INEL/EXT-07-12969, Revision 1), prepared by T.E. Wierman, D.M. Rasmuson, and A. Mosleh (university of maryland). `https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6268/index.html`, [Accessed: 2025-04-12]
2. IEC 61508-6: Functional safety of electrical/electronic/programmable electronic safety-related systems – part 6: Guidelines on the application of parts 2 and 3. `https://webstore.iec.ch/publication/5520`, [Accessed: 2025-03-21]

3. The SPI Manifesto. `https://conference.eurospi.net/images/eurospi/spi_manifesto.pdf`, [Accessed: 2024-03-11]
4. Ahonen, J.J., Savolainen, P.: Software engineering projects may fail before they are started: Post-mortem analysis of five cancelled projects. Journal of Systems and Software 83(11), 2175–2187 (2010)
5. Brand, V.: UPM 3.1: A pragmatic approach to dependent failures assessment for standard systems. AEA Technology (1996)
6. Du, S., Ma, L., Cao, Y.: Comprehensive analysis on safety and reliability of safety-related systems considering common cause failure. In: 2018 International Conference on Control, Automation and Information Sciences (ICCAIS). pp. 531–535. IEEE (2018)
7. Edwards, G.a., et al.: Defences against common-mode failures in redundancy systems. SRD R196 January (1981)
8. Fleming, K.N.: Reliability model for common mode failures in redundant safety systems. Tech. rep., General Atomics, San Diego, CA (United States) (1974)
9. Hokstad, P., Håbrekke, S., Lundteigen, M.A., Onshus, T.: Use of the PDS method for railway applications. Norway: SINTEF Technology and Society 15, 5–23 (2009)
10. Hokstad, P., Rausand, M.: Common cause failure modeling: status and trends. Handbook of performability engineering pp. 621–640 (2008)
11. Humphreys, R.: Assigning a numerical value to the beta factor common cause evaluation. Reliability'87 (1987)
12. Kaymakci, O.T., Ustoglu, I., Divriklioglu, E.: Reliability assessment of fire safety systems in railway industry: a case study. Journal of the Chinese Institute of Engineers 38(3), 286–296 (2015)
13. Mosleh, A.: A multi-parameter, eventbased common-cause failure model. SMiRT9 Paper No. M7/3 (1987)
14. Myllyaho, M., Salo, O., Kääriäinen, J., Hyysalo, J., Koskela, J.: A review of small and large post-mortem analysis methods. Proceedings of the ICSSEA, Paris pp. 1–8 (2004)
15. Qiu, S., Ming, X.: Explicit and implicit bayesian network-based methods for the risk assessment of systems subject to probabilistic common-cause failures. Computers in Industry 123, 103319 (2020)
16. Rao, S.B.G., Castellanos-Ardila, J.P., Punnekkat, S.: A systematic review of β-factor models in the quantification of common cause failures. In: 2023 49th Euromicro Conference on Software Engineering and Advanced Applications (SEAA). pp. 262–269. IEEE (2023)
17. Vesely, W.: Estimating common cause failure probabilities in reliability and risk analysis: Marshall-olkin specializations. Nuclear systems reliability engineering and risk assessment 2(314-341) (1977)
18. Xie, L., Lundteigen, M.A., Liu, Y.: Safety barriers against common cause failure and cascading failure: literature reviews and modeling strategies. In: 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). pp. 122–127. IEEE (2018)
19. Xue, W., Zhao, Y., Xiao, J., Zhang, M.: The research and application of fail-safe technologies in rail transit train operation control system. In: 2014 10th International Conference on Reliability, Maintainability and Safety (ICRMS). pp. 1100–1104. IEEE (2014)