Exploration and Analysis of Resilience Engineering Factors in Electricity Distribution Organization

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Abstract. The electricity distribution sector is known for its high risk and complex sociotechnical system. PT PLN (Persero), electricity company in Indonesia, reported that 75% of work-related accidents happened in its distribution sector. It can be reasonably assumed that the safety-I approach is incapable of reducing the number of accidents. Resilience engineering (RE) then emerged as a part of a modern approach called safety-II in occupational health and safety management. This study aims to explore RE dimensions that affect resilience potential in the distribution sector of PT PLN (Persero) and determine critical area that need improvement for achieving zero accident. Questionnaire of 100 technical service officers in Unit Induk Distribusi Jakarta Raya were collected and analyzed using principal component analysis (PCA) and importance-performance analysis (IPA). This study makes scientific contribution by generating seven novel dimensions of RE specifically tailored to the electricity distribution organization. These dimensions (% variance) are risk management (30,51%), collaborative culture (12,42%), safety commitment (6,28%), adaptive decision-making (5,71%), incident readiness (4,49%), continuous learning (4,00%), and personnel competency (3,89%) with total of 67,29% variance explained. After being classified in the IPA matrix, it was identified that priorities on personnel competency, collaborative culture, and continuous learning should be placed to enhance resilience potential.

Keywords: *resilience engineering, safety-II, zero accident*

1 Introduction

Electricity distribution sector is a complex sociotechnical system that is associated with a high level of risk. As Saurin and Junior observed in [1], there is a risk of electrocution and falling from a height. Furthermore, work is carried out in a variety of geographical, time, and weather conditions, which increases the likelihood of work-related accidents. PT PLN (Persero) (hereinafter referred to as PLN), the electricity company in Indonesia, reported that 75% of work accidents that occurred from March 2022 to June 2024 came from the electricity distribution sector. Based on this number, 42% victims were dead while the remaining suffered serious (32%) and minor injuries (26%). This indicates that zero accident program initiated in February 2022 and implementation of the Occupational Health and Safety Management System (OHSMS) have not proven

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effective in preventing work-related accidents. Consequently, it is necessary for management to extend its attention to this problem.

The concept of safety becomes important, as it provides an understanding of OHSMS's focus in the organization to reduce the frequency of work-related accidents. In the field of safety, two distinct approaches have emerged: safety-I and safety-II. According to Hollnagel in [2], safety-I focuses on anomalies that occur at certain times, such as accidents, so it is called "managing by snapshot". In comparison, safety-II approach not only identifies anomalies but also recognizes successful operational routines, which is why it is referred to as "managing by everyday work.". Based on observation, PLN still emphasizes the implementation of safety-I. This is evident from the fact that accident investigation reports currently serve as the primary source of organizational learning with the objective of preventing a further recurrence of the same incident.

Safety-I approach, itself, is insufficient for preventing work-related accidents in the future. Safety-I and safety-II are considered as two complementary approaches which means that they do not replace each other as stated by Albery, *et al*. in [3]. Subsequently, resilience engineering (RE) emerged as a concept that integrate these two safety approaches in OHSMS within organization as explained by Patriarca, *et al.* in [4]. According to Chen, *et al.* in [5], RE has ability to enhance safety performance. RE can align safety and performance by promoting a culture of proactive risk management, continuous learning, and adaptability as explained by Azadeh, *et al.* in [6].

According to Costella, *et al.* in [7], RE can be implemented to high-risk systems with complex interrelationship between components in system and high degree of uncertainty. As Saurin and Junior explained in [1], electricity distribution sector is one of that complex, dynamic, and unstable systems. Furthermore, RE is also applied to other sectors, including mining by Pillay, *et al.* in [8], hospital by Azadian in [9], petrochemical by Shirali, *et al.* in [10], gas refinery by Zarei, *et al.* in [11], solid waste management by Rubio-Romero, *et al.* in [12], construction site by Chen, *et al.* [5], and nuclear power plant by Kim, *et al.* [13]. These studies also use RE dimensions to assess resilience potential, as stated by Woods and Wreathall in [14]. According to Ranasinghe, *et al.* in [15], use of RE dimensions vary depending on the context of organization. Based on literature review in the last 15 years, there are 52 RE dimensions with different names. Therefore, this study gives scientific contribution in identifying novel RE dimensions that enhance resilience potential in the context of electricity distribution in PLN using an exploratory approach. Furthermore, RE dimensions are classified using Importance-Performance Analysis (IPA) as the basis for developing strategy to achieve zero accident.

2 Literature Review

2.1 Safety-I and Safety-II

According to Hollnagel in [2], safety-I is the traditional approach to safety management, which focuses on preventing things from going wrong. It defines safety as the absence of accidents or incidents. Safety is seen as a condition which as few things as possible go wrong, and performance variability (especially human errors) is viewed negatively. On the other hand, safety-II is a modern, proactive approach to safety management that focuses on ensuring things go right. It defines safety as the ability to succeed under varying conditions and emphasizes learning from everyday performance to enhance resilience. The differences between the two approaches are summarized in the following Table 1.

Table 1 Characteristics of safety-I and safety-II from De Leo, *et al*. in [16]

Concepts	Safety-I	Safety-II
Safety definition	"Minimize the things that can go wrong"; safety is seen as inversely related to the number of negative events	"Maximize the things that go right"; safety is seen as proportional to the number of positive outcomes
Focus	Examine adverse outcomes and their causes	Examine all outcomes, both positive and negative, along with their causes
Safety management principle	Reactive; responds to accidents or risks	Proactive; aims to anticipate potential events
System behavior	Bimodal (either good or bad outcomes)	Considers performance variability that may lead to both positive and negative outcomes
Mechanism of bad outcomes	Based on causality (identifying one or more causes for failures, potentially connected through complex models)	Based on emergence (viewing failure and success as results of various interacting factors, not easily explained)
Human factor	Viewed as a possible liability	Viewed as a source of flexibility and adaptability

2.2 Sociotechnical System

The concept of sociotechnical systems addresses the interdependence and interaction between social (human, organizational) and technical (machines, technology) components within a system. The system's overall performance depends on how these components interact with each other, rather than their individual attributes, as stated by Saurin & Patriarca in [17]. Safety-II emphasizes the importance of learning from successful operations, understanding how things go right, and enhancing system resilience. Resilience is a key in managing safety in sociotechnical system. Resilience engineering (RE) builds on Safety-II, focusing on enhancing the system's ability to adapt and recover from disturbances, as stated by Hirose & Sawaragi in [18].

2.3 Resilience Engineering

There are four pillars to build resilience potential as proposed by Hollnagel, *et al.* [19]: respond (know what to do), monitor (know what to look for), anticipate (know what to expect), and learn (know what has happened). Responding requires preparedness, which is based on anticipation, including ability to distinguish between what is urgent and what is important as explained by Patriarca, *et al*. in [20] and Pęciłło in [21]. Podgórski in [22] mentioned that monitoring involves continuous observation of the system's operations and potential threats. Patriarca, *et al*. in [20] and Pęciłło in [21] explained that anticipating refers to the ability of a system to predict and prepare for future challenges, threats, and opportunities. Learning is understood as learning from both failures and successes, as stated by Pęciłło in [21].

2.4 Principal Component Analysis

Hair, *et al.* in [23] explained that factor analysis is a statistical tool for analysing the structure of correlations among a large number of variables, such as survey responses, by defining sets of strongly related variables known as factors. Also in [23], factor analysis can be used to achieve the desired objectives from both exploratory and confirmatory methods. Exploratory factor analysis (EFA) is a helpful for identifying structure among a set of variables or as a data reduction method. There are two methods for factor extraction: principal component analysis (PCA) and common factor analysis (CFA). PCA is used to reduce dimensions to a manageable number after correlation between items and also remove items with inadequate factor loadings or cross-loadings, as explained by Field in [24]. Application of PCA before importance-performance analysis is shown in other studies by Aghajanzadeh, *et al.* in [25].

2.5 Importance-Performance Analysis

According to Martilla & James in [26], IPA provides a matrix with four quadrants, shown in Figure 1. Perceived importance ratings are on horizontal axis while actual performance ratings are on vertical axis. Explanation of each quadrant based on focus of this study as follows:

- Quadrant 1: Keep up the good work (high importance and performance)
  RE factors that are both highly valued and effectively implemented within the organization. Continued focus on these strengths will solidify the company’s resilience and commitment to safety.
- Quadrant 2: Possible overkill (low importance, high performance)

RE factors that well-executed, but may not significantly impact the overall effectiveness of the OHSMS. This would suggest reallocating resources to more critical areas, thereby improving overall system flexibility and adaptability without compromising safety.

- Quadrant 3: Low priority (low importance and performance)
  RE factors that have minimal impact on resilience or safety performance within OHSMS. This indicate no need for further improvement efforts or additional resources.
- Quadrant 4: Concentrate here (high importance, low performance)
  RE factors that are crucial and require immediate attention, as they play a key role in preparing the organization to handle disruptions and maintain safety under diverse conditions.

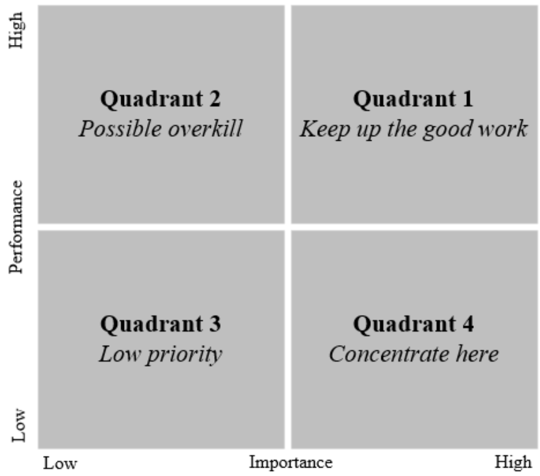

Figure 1 Importance-performance matrix adopted from Martilla & James in [26]

3 Methodology

3.1 Systematic Literature Review

This study conducted a systematic literature review (SLR) to explore the dimensions of RE that contribute to safety in high-risk industries adopted from Ranasinghe, *et al.* [15]. Structured search was conducted across two databases, Scopus and Science Direct, starting 2010 to August 2024. The criteria used for the selection of relevant studies included: research that analysed RE dimensions, topics related to safety in the context of high-risk industries, and publication types in the form of conferences and journals in English. The keywords used in the search from databases were "resilience", "resilience engineering", and "safety". Figure 2 illustrates the research selection process, which was conducted using the

SLR method. The database search yielded 759 articles which 476 were excluded from title analysis because they were not related to safety. A further, 168 articles were excluded from abstract analysis because they focused on other aspects of resilience. Finally, 89 articles were excluded from full-text analysis because they did not consider the RE dimension in their study. Following these three screening stages, 26 articles were selected for further review.

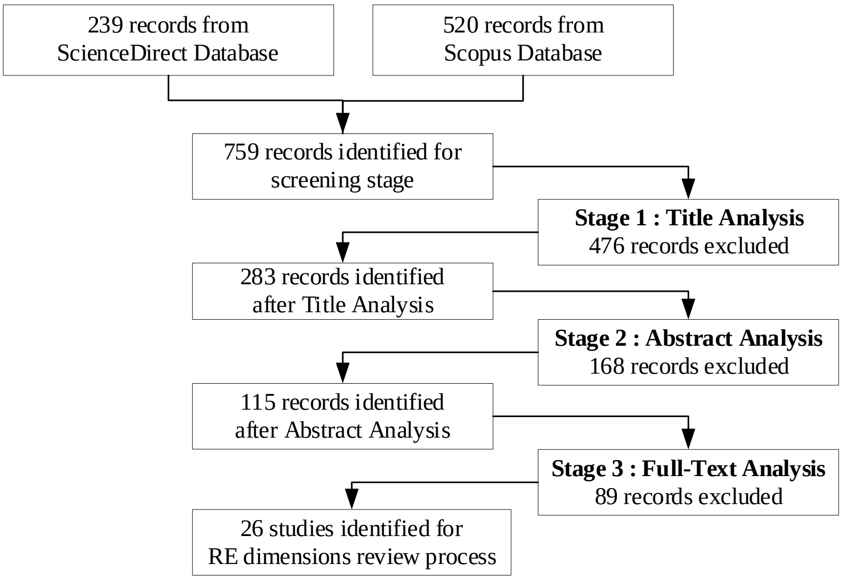

Figure 2 Systematic literature review adopted from Ranasinghe, *et al.* in [15]

3.2 Questionnaire Design

Total of 26 studies were identified based on the SLR results, which were used to identify the RE dimensions employed in the research. From the identification results, 52 RE dimensions were obtained. Subsequently, a validation process was conducted, involving one expert in the safety field and five practitioners whose experience is directly relevant to electricity distribution sector. The objective of this validation process was to identify the RE dimensions (along with the corresponding statement items) that are important for measuring resilience potential and relevant in the context of the PLN. Table 2 shows the experience of the experts and practitioners involved in the validation process. From the validation results, 27 statement items were obtained.

This study used a questionnaire, wherein respondents were requested to respond to items measuring current condition (Performance) and level of importance (Importance). The questionnaire consisted of 27 statement items, which were measured using a Likert scale from 1 to 6, as detailed in Table 3.

Table 2 List of experts and practitioners in the safety field

No	Expert/ Practitioner	Experience	Recent Position
1	Expert 1	> 15 years in safety field	Manpower Minister of Indonesia
2	Practitioner 1	> 10 years in distribution sector	HSSE Manager in Unit Induk Distribusi Jakarta Raya
3	Practitioner 2	> 10 years in distribution sector	HSSE Planning and Budget Monitoring Manager in HSSE Division, Head Office
4	Practitioner 3	> 10 years in distribution sector	HSSE Planning, Evaluation, and Performance Manager in HSSE Division, Head Office
5	Practitioner 4	> 8 years in distribution sector	Technical Supervisor in Unit Induk Distribusi Jawa Barat
6	Practitioner 5	> 8 years in distribution sector	HSSE Supervisor in Unit Induk Distribusi Jawa Barat

Table 3 Response classification using six Likert scale

Likert Scale	Performance	Importance
1	Strongly disagree	Strongly unimportant
2	Disagree	Unimportant
3	Somewhat disagree	Somewhat unimportant
4	Somewhat agree	Somewhat important
5	Agree	Important
6	Strongly agree	Strongly important

Subsequently, the data obtained from the questionnaire underwent a validity and reliability test using SPSSv27. Budiastuti and Bandur in [27] explain that the validity test is carried out by comparing the correlation between items with the average value of all items, which is known as the item-to-total Pearson correlation. A correlation greater than 0.30 indicates good validity, as stated by Tabachnick & Fidel in [28]. The results of the validity test at the 95% confidence level indicate that one item (X17) has a correlation of 0.142, suggesting that the item is invalid. The reliability of the data was then assessed using the Cronbach Alpha test. According to Manning & Munro in [29], alpha coefficient value of more than 0.80 indicates good reliability. The results of the reliability test show an alpha coefficient value is 0.832 for 27 items, indicating that they are internally consistent. Based on the results of the reliability test, invalid item X17 is still included in the questionnaire as a whole.

3.3 Data Collection and Analysis

The questionnaire was distributed to respondents via an online platform, specifically Google Forms. Target respondents were determined using purposive sampling with number of 100 technical service officers in the Unit Pelaksana Pelayanan Pelanggan. The reason was because they directly exposed to electric current, which was a consequence of their work of inspection and maintenance of distribution networks. The data obtained from the questionnaire will later be processed using factor analysis and PCA methods to derive new RE factors. Subsequently, these new RE factors will be analysed and visualized using IPA matrix. IPA matrix can illustrate the difference between expected performance of OHSMS by technical service officers and the actual performance in the field. Additionally, visualization with IPA matrix can provide insights to management for planning improvement strategies in achieving zero accident.

4 Results and Discussions

4.1 Demographic Characteristics

A total of 100 technical service officers participated in the survey from six Unit Pelaksana Pelayanan Pelanggan in the Unit Induk Distribusi Jakarta Raya. Table 4 presents the demographic characteristics of the respondents. The respondents were distributed as follows: 97 males and 3 females. The largest age group was 36-45 years, representing 40% of the total. Majority of respondents (82%) had completed high school, while only 6% had obtained a diploma. At the time of this study, 49% of respondents had been working in the distribution sector for 1-10 years, while only 1% had been employed for over 30 years.

Table 4 Demographic Characteristics

Characteristic	Category	Number of respondents	Percentage (%)
Gender	Male	97	97%
	Female	3	3%
Age	18-25 years	5	5%
	26-35 years	29	29%
	36-45 years	40	40%
	>45 years	26	26%
Education	High school	82	82%
	Diploma	6	6%
	Bachelor's degree	12	12%
Working period in distribution sector	1-10 years	49	49%
	11-20 years	44	44%
	21-30 years	6	6%
	>30 years	1	1%

4.2 Results of Factor Analysis

An exploratory factor analysis was conducted on a data set comprising 100 observations using PCA and varimax rotation using SPSSv27. The objective was to reduce the number of items to a smaller number of factors. First, a significance test using Bartlett's test of sphericity and a sampling adequacy test using the

Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA) test were conducted. Figure 3 depicts the test results. The KMO-MSA test yielded a value of 0.806, indicating that the overall data set is adequate. The Bartlett's test yielded a P-value of less than 0.05, suggesting that there is sufficient correlation between items. Based on these initial test results, factor analysis can be conducted.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.806
Bartlett's Test of Sphericity	Approx. Chi-Square	1312.727
	df	351
	Sig.	<,001

Figure 3 KMO and Barttlet Test

Moreover, factor extraction process is undertaken using principal component analysis (PCA) method. The results of factor extraction process indicate that variable X13 has a communality of 0.0479, which is less than 0.50. Consequently, variable X13 is excluded from factor analysis, as the total variance explained does not reach 50%. KMO-MSA test and Bartlett's test were conducted once more, yielding a value of 0.811 and P-value of less than 0.001. These results indicate that factor analysis could be carried out. Following the deletion of variable X13, the communality of all remaining variables exceeded 0.50. Based on the eigenvalue criteria, the number of factors extracted is seven with a total variance of 67.29%. According to Hair et al. in [23], total variance of at least 60% is sufficient for social science research.

The subsequent process is component rotation, which is designed to determine the tendency of a variable to a specific factor. According to Hair, *et al.* in [23], factor loading between 0.30 and 0.40 are considered minimally acceptable, while loadings above 0.50 are considered significant. The rotation method used is orthogonal (VARIMAX), as this allows factor loading to be maximized to one factor, making it easier to interpret. Table 5 shows the results of the VARIMAX rotation, along with the names of the factors.

Table 5 Factor analysis result with factor loading >0.40

Factor	Items		Factor loading	Cronbach Alpha
F1. Risk Management	X2	I identify potential hazards at work as early as possible.	0,790	0,865
	X3	I adapt to changes in the work environment.	0,603	
	X5	I am aware of safety risks in my work.	0,658	
	X9	I respond quickly when an unexpected incident occurs.	0,570	
	X10	I observe the implementation of safety culture at work continuously.	0,618	

Factor	Items		Factor loading	Cronbach Alpha
	X19	I identify and evaluate risks in my work.	0,718	
	X21	I know what to do to reduce the severity of an accident.	0,752	
F2. Collaborative Culture	X16	PLN implements an OHS management system that can be well understood by all employees and partners.	0,450	0,803
	X25	My supervisor promotes a safety culture in daily work.	0,867	
	X26	My coworkers promote a safety culture in daily work.	0,620	
	X27	PLN strives to prevent human error by understanding employee/partner behavior and work environment.	0,777	
F3. Safety Commitment	X6	Top management of PLN makes safety as a top priority in the organization's goals.	0,813	0,676
	X7	Everyone is responsible for their own work.	0,663	
	X20	I always try to prevent the possibility of accidents.	0,499	
F4. Adaptive Decision-Making	X11	I have alternative ways of carrying out work outside the standard procedure.	0,770	0,680
	X14	I am allowed to make decisions autonomously under certain conditions without having to seek approval from my supervisor.	0,640	0,674
	X17	My work is aligning with the company's goal to achieve zero accidents.	0,405	0,511
	X24	I give tolerance to safety violations at work.	0,833	0,718
F5. Incident Readiness	X4	I maintain standards at work, even in unsafe conditions.	0,707	0,766
	X8	I report any incidents that occur without fear of punishment.	0,524	0,605
	X12	To do my work, I do not find any obstacles related to resources, both in terms of quantity and quality.	0,724	0,699
	X15	After an incident, I can recover work conditions to normal in a short time.	0,594	0,546
F6. Continuous Learning	X1	I learn not only from success in day-to-day performance, but also from near misses and work accidents.	0,763	0,616
	X18	PLN can manage any changes that have both positive and negative impact on organization.	0,581	0,542
	X22	PLN conducts comprehensive investigations when accidents occur.	0,520	0,662
F7. Personnel Competency	X23	I have sufficient competence in safety to do every work.	0,727	0,737

The PCA results indicate that the RE factors formed show similarities with the four cornerstones for building potential resilience and RE factors used in previous studies. Risk management (F1) reflects "awareness" by Saurin & Junior, *et al.* in [1] and "monitoring" by Podgórski in [22] which enable continuous measurement of risk and the anticipation of any changes that may affect organization. Collaborative culture (F2) reflects "teamwork" which can reduce human error and increase system reliability, as described by Azadeh, *et al.* in [30]. Safety commitment (F3) reflects "top management commitment" by Saurin & Junior, et al. in [1] which indicate that health and safety become organizational values rather than a transient priority. Adaptive decision-making (F4) reflects "flexibility" by Saurin & Junior, *et al.* (1) and "responding" by Patriarca, *et al.* in [20] and Pęciłło in [21] — that is individuals must adapt to changing working conditions. Incident readiness (F5) reflects "responding" by Patriarca, *et al.* in [20] and Pęciłło in [21] which requires preparedness to provide effective and on-time response. Continuous learning (F6) reflects the ability to learn from both incidents and everyday work, as described by Pęciłło in [21]. Personnel competency (F7) reflects the ability of individuals to perform their work in an acceptable manner which is useful to improve resilient safety culture, as proposed by Shirali, *et al.* in [10].

4.3 Results of IPA

The IPA results indicate that the average importance and performance are 5.22 and 5.11, respectively. Using the formula proposed by Aghajanzadeh, *et al.* in [25], gap of -0.11 was obtained from the difference between performance and importance, as illustrated in Figure 4. This gap suggests that there is a need for improvement in the implementation of OHSMS in the organization, due to the importance of ensuring safety to achieve zero accidents.

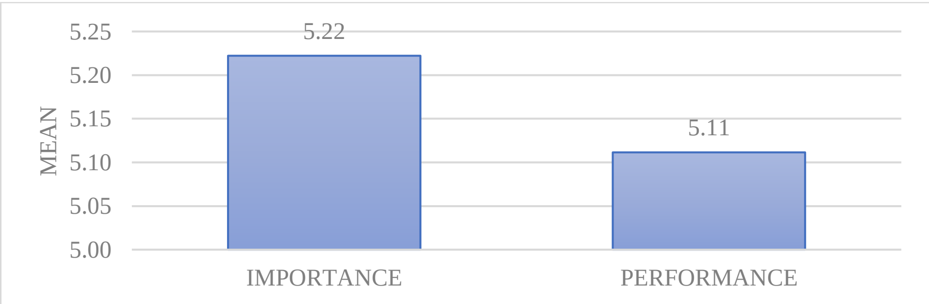

Figure 4 Overall importance-performance gap

Subsequently, seven novels RE factors were visualized onto the IPA matrix. Figure 5 illustrates the position of each RE factor within the quadrant. As can be seen in the figure, risk management, collaborative culture, safety commitment, continuous learning, and personnel competency are in quadrant 1, while adaptive decision-making and incident readiness are situated in quadrant 3. As illustrated by the IPA matrix, it is recommended that the five RE factors in quadrant 1 must be strengthened. Aghajanzadeh, *et al.* in [25] suggest that prioritization can be achieved by examining the largest gap between perceived importance and actual performance. As illustrated in Table 6, the priority order is to build personnel competency (gap -0.12), foster a collaborative culture (gap -0.11), and enhance continuous learning capability (gap -0.10). In contrast, the two RE factors in quadrant 3 do not require further attention from management.

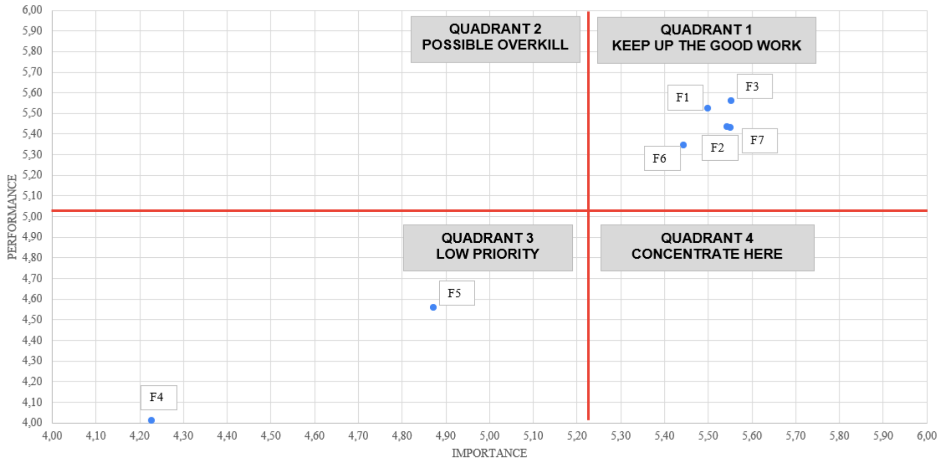

Figure 5 IPA matrix of RE factors

Table 6 Gap importance-performance for seven RE factors

RE factors	Mean importance (I)	Mean performance (P)	Gap = P-I
F1. Risk management	5,50	5,52	0,02
F2. Collaborative culture	5,54	5,43	-0,11
F3. Safety commitment	5,55	5,56	0,01
F4. Adaptive decision-making	4,23	4,01	-0,22
F5. Incident readiness	4,87	4,56	-0,32
F6. Continuous learning	5,44	5,34	-0,10
F7. Personnel competency	5,55	5,43	-0,12

The priority of three factors of RE are aligned with the sources of resilience in electricity distribution organizations identified by Saurin & Junior, *et al.* in [1]. Enhancing personnel competence can be achieved through training courses for electricians. Collaborative culture is manifested by sharing information between team members regarding hazards. Information shared includes successful experiences in dealing with certain hazards, which represents an implementation of continuous learning principle in the context of resilience.

5 Conclusion

PLN needs to foster resilience within its OHSMS to achieve zero accidents goal. This study introduces seven novel factors of RE that have been derived from a comprehensive literature review of past fifteen years' studies, thus providing a more nuanced understanding of RE. Moreover, this study provides insights for management regarding three priorities for strengthening resilience potential: building personnel competencies, fostering a collaborative culture, and enhancing continuous learning capability. However, it should be noted that this study also has limitations due to respondent sample. It would be advisable for future research to expand the respondents to other Indonesia regions as well and compare with other factor extraction methods, such as principal axis factoring or maximum likelihood.

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