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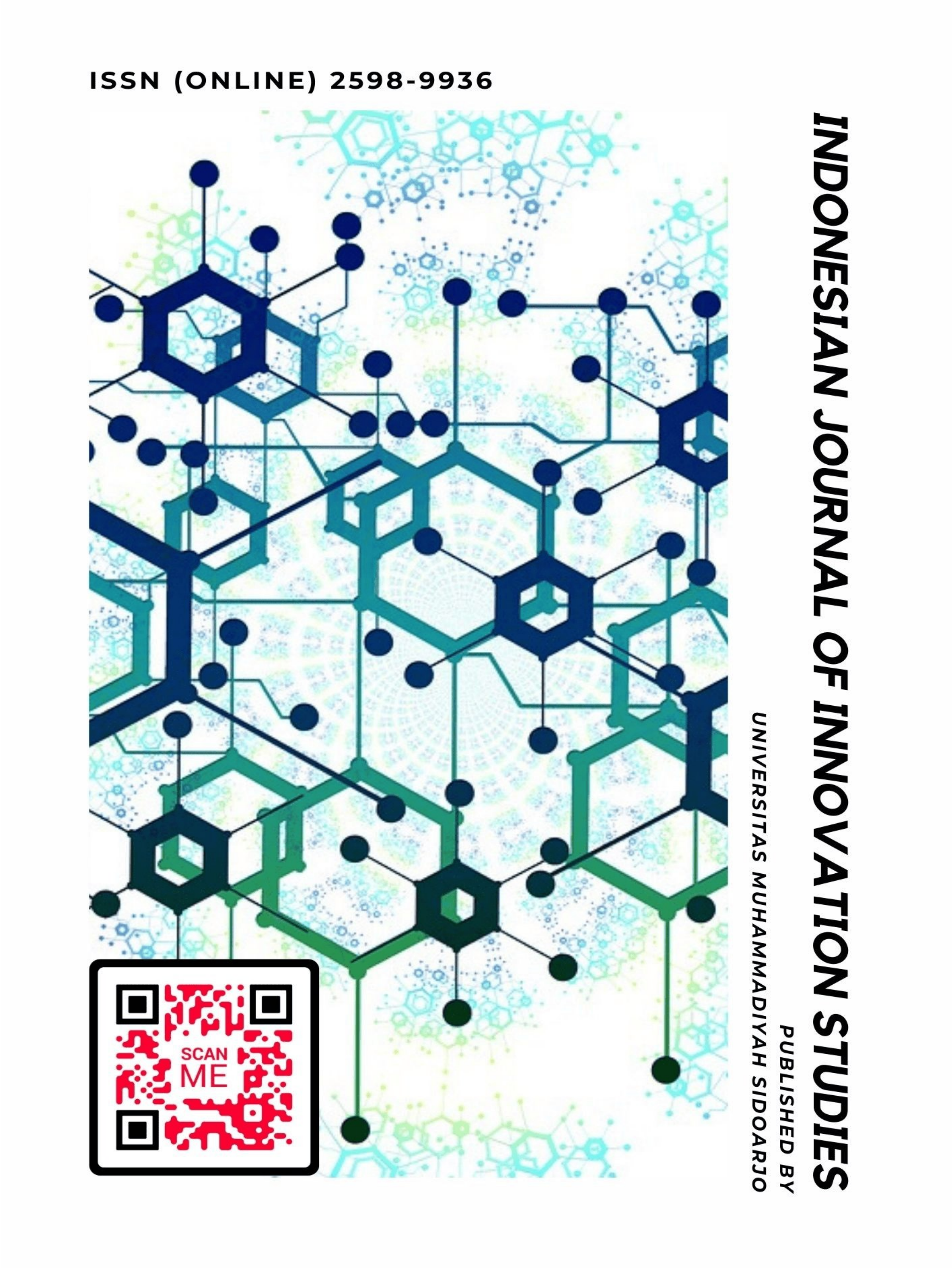

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Workload and Decision Errors in Copper Cathode Harvesting

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Abstract

General Background: Workload management is essential in high-risk manufacturing operations because excessive physical and cognitive demands can reduce concentration, productivity, and workplace safety. **Specific Background:** Copper cathode harvesting requires operators to work in demanding refinery conditions involving physical endurance, sustained attention, and accurate task execution. **Knowledge Gap:** Existing workload assessments often examine physical workload or human error separately, while integrated evidence combining cardiovascular load and cognitive reliability analysis in copper cathode harvesting remains limited. **Aims:** This study aimed to analyze operators' physical and mental workload and identify potential human errors in copper cathode harvesting operations. **Results:** Using Cardiovascular Load and Cognitive Reliability and Error Analysis Method, data from 20 operators showed an average %CVL of 40.11%, classified as moderate physical workload, although one operator reached the heavy category and two operators reached the moderately heavy category. CREAM analysis placed the work in tactical control mode, with error probability ranging from 0.001 to 0.1. The highest Human Error Probability value was 0.1, found in evaluate, identify, and record cognitive activities. **Novelty:** This study integrates CVL and CREAM to connect physical workload, cognitive control mode, and human error probability in copper cathode harvesting. **Implications:** The findings support workload balancing, fatiguecontrol, decision support, procedural reinforcement, and targeted safety improvements in refinery operations.

Highlights:

- Average %CVL reached 40.11%, indicating a moderate burden category.
- Tactical control mode produced an error range of 0.001 to 0.1.
- Evaluate, identify, and record activities showed the highest HEP value.

Keywords: CREAM, CVL, Human Error, Refinery Plant, Workload.

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Introduction

The industrial manufacturing sector in Indonesia plays a strategic role in supporting national economic growth [1]. With digitalization and globalization, companies are required to manage human resources optimally, specifically in balancing workers' capabilities with work demands. One important aspect of this management is workload. Workload is the effort that must be expended to fulfill work demands and is an important factor influencing performance and productivity [2]. An inappropriate workload can impact workers' well-being. A high workload can reduce worker productivity. Workload is influenced by work environment conditions and cognitive demands [3]. An imbalanced workload can lead to overstress or understress, which can impact performance and increase workplace safety risks [4].

PT XYZ is a company that process copper concentrate through pyrometallurgical processes and is the first copper smelting and refining company in Indonesia. The work environment at this company is extremely high-temperature and noisy, requiring operators to possess optimal physical and mental endurance. Although supported by technology, the role of operators remains crucial in maintaining production quality, especially at the refinery plant, which serves to refine copper cathodes until ready for market.

The demanding and high-risk working conditions at refinery plants require operators to remain focused and aware, and to have physical endurance and mental stability in order to stay focused and avoid workplace injuries and accidents. These conditions have the potential to cause work-related fatigue, characterized by a decrease in concentration and awareness [5]. This is evidenced by the large amount of data on workplace accidents in 2024–2025 found at refinery plants, which indicates that the majority were caused by human error, such as operational mistakes resulting from a loss of concentration that can be caused by fatigue due to high workloads [6]. Therefore, a comprehensive analysis is needed to identify the levels of physical and mental workload experienced by operators, along with the factors influencing the workload. Objective workload measurement is essential to identify the sources of fatigue and the potential for human error. In addition, calculating the Human Error Probability (HEP) is also necessary to measure the probability of human error occurring during work processes.

This research was conducted to analyze the physical and mental workload of operators and to identify potential human errors in the operational activities of copper cathode in the refinery plant of PT XYZ. This research used the Cardiovascular Load (CVL) method to measure physical workload and the Cognitive Reliability and Error Analysis Method (CREAM) to analyze mental workload and the probability of human error. The results of this research are expected to provide a comprehensive overview of operators' workload conditions, identify the factors causing human error, and serve as a base for improvements in increasing work safety and productivity.

Methods

This research uses a quantitative approach to analyze the physical and mental workload of operators at the PT XYZ refinery plant. This approach aims to obtain objective and measurable results regarding the operators' working conditions and the potential for human error. The data used in this study consists of primary and secondary data. Primary data was obtained through direct measurement of operators' heart rates using a oximeter, distribution of questionnaires based on the Common Performance Conditions (CPC) framework to 20 operators as respondents, and interviews with experts possessing experience in the operational process of copper cathode production. Meanwhile, secondary data consist of data on production processes, production volumes and targets, in addition to data on workplace accidents that have occurred at the company. Physical workload measurement was conducted using the Cardiovascular Load (CVL) method by calculating the percentage of cardiovascular load (%CVL), which is based on the ratio of the work heart rate to the worker's maximum heart rate. The calculated %CVL results were then compared with the classification of workload levels as established [7]. The use of heart rate as an indicator is based on its sensitivity to changes in workload, where increased physical activity is accompanied by an increase in heart rate, so it can be used to assess the severity of the workload experienced by operators.

Furthermore, mental workload was analyzed using Cognitive Reliability and Error Analysis (CREAM), which is part of Human Reliability Analysis (HRA). This method is used to evaluate operators' cognitive abilities and identify potential human errors in task execution [8]. Analysis using the CREAM method is conducted in two stages. Analysis using the CREAM method is conducted in two stages[9][10][11]: the basic method and the extended method. In the basic method stage, the research begins with the task analysis to identify the sequence of work activities in the copper cathode refining process. Following this, an assessment is conducted on the Common Performance Conditions (CPC) that influence operator performance. The CPC assessment is performed by the operators as empirical data and validated by expert judgment to ensure consistency with actual conditions.

The results of the CPC assessment can be used to determine the control mode based on the combination of existing working conditions, and to identify the generic error probability associated with the task. The next step is the extended method, which focuses on a more in-depth analysis of cognitive aspects[12] [13]. At this stage, a cognitive demand profile is developed by classifying work activities into cognitive functions, such as observation, interpretation, planning, and execution. Then, potential cognitive failures are identified for each work activity. Based on these identification results, cognitive failure probability (CFP) values are calculated, which are used to determine the human error

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probability (HEP) for each activity. Through these analytical steps, this research aims to obtain a comprehensive overview of the operators' physical and mental workload levels and to identify potential human errors in operational activities[14][15]. The results obtained are expected to serve as a basis for formulating improvement recommendations to enhance workplace safety and productivity at PT XYZ's refinery plant.

Result and Discussion

A. Physical Workload Measurement

Determining physical workload by measuring heart rate to determine energy levels, workload, CVL percentage, and energy consumption for individual operators. The CVL percentage for copper cathode harvesting operators is shown in Table 1.

Table 1. % CVL copper cathode harvesting operator

No	Code	Age	DNK	DNI	DNK Max	%CVL	Category	Notes
1	O1	28	110	60	192	37,88	Moderate	Repairs are needed but not urgent
2	O2	30	116	70	190	38,33	Moderate	Repairs are needed but not urgent
3	O3	24	136	80	196	48,28	Moderate	Repairs are needed but not urgent
4	O4	40	114	79	180	34,65	Moderate	Repairs are needed but not urgent
5	O5	21	105	88	199	15,32	Low	No fatigue
6	O6	38	112	73	182	35,78	Moderate	Repairs are needed but not urgent
7	O7	24	140	80	196	51,72	Moderate	Repairs are needed but not urgent
8	O8	28	115	84	192	28,70	Low	No fatigue
9	O9	35	142	76	185	60,55	Moderately Heavy	It is acceptable to work in a short period of time, but repair is needed
10	O10	24	109	76	196	27,50	Low	No fatigue
11	O11	45	126	73	175	51,96	Moderate	Repairs are needed but not urgent
12	O12	36	161	65	184	80,67	Heavy	Repair work must be completed as soon as possible
13	O13	45	102	74	175	27,72	Low	No fatigue
14	O14	45	146	64	175	73,87	Moderately Heavy	It is acceptable to work in a short period of time, but repair is needed
15	O15	52	104	84	168	23,81	Low	No fatigue
16	O16	32	96	73	188	20,00	Low	No fatigue
17	O17	55	99	78	165	24,14	Low	No fatigue
18	O18	30	114	64	190	39,68	Moderate	Repairs are needed but not urgent
19	O19	46	120	68	174	49,06	Moderate	Repairs are needed but not urgent
20	O20	21	108	64	199	32,59	Moderate	Repairs are needed but not urgent
Average			118,75	73,65	185,05	40,11		

Using:
DNK : Working pulse rate
DNI : Resting pulse rate
DNK Max : Maximum pulse rate

Table 1. indicates that there is one operator in the heavy workload category with a CVL value of 80.67% and two operators in the moderately heavy workload category, with values of 60.55% and 73.87%. This situation indicates the need for corrective actions to prevent excessive fatigue and the risk of health issues. In addition, there are ten operators in the moderate workload category (30%–60%) and seven operators in the low workload category (<30%). The average CVL value for all operators is 40.11%, which falls within the moderate category. A recapitulation of energy consumption by operators of copper cathode harvesting is shown in Table 2.

Table 2. Operator Energy Consumption

No	Code	Age	DNK/Xt	DNI/Xi	Et (kcal/min)	Ei (kcal/min)	K (kcal/min)
1	O1	28	110	60	4.99	2.13	2.86
2	O2	30	116	70	5.49	2.51	2.98
3	O3	24	136	80	7.41	2.99	4.42
4	O4	40	114	79	5.32	2.94	2.38
5	O5	21	105	88	4.60	3.44	1.16

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No	Code	Age	DNK/Xt	DNI/Xi	Et (kcal/min)	Ei (kcal/min)	K (kcal/min)
6	O6	38	112	73	5.16	2.65	2.51
7	O7	24	140	80	7.84	2.99	4.85
8	O8	28	115	84	5.41	3.21	2.20
9	O9	35	142	76	8.06	2.79	5.28
10	O10	24	109	76	4.91	2.79	2.12
11	O11	45	126	73	6.41	2.65	3.76
12	O12	36	161	65	10.34	2.31	8.04
13	O13	45	102	74	4.38	2.69	1.68
14	O14	45	146	64	8.52	2.27	6.25
15	O15	52	104	84	4.52	3.21	1.32
16	O16	32	96	73	3.95	2.65	1.31
17	O17	55	99	78	4.16	2.89	1.27
18	O18	30	114	64	5.32	2.27	3.05
19	O19	46	120	68	5.85	2.43	3.42
20	O20	21	108	64	4.83	2.27	2.56
Average					5.87	2.70	3.17

Based on Table 2, the results of the energy consumption calculations show that there are three operators with energy consumption values above 5 kcal/minute, which are 5.28 kcal/minute, 8.04 kcal/minute, and 6.25 kcal/minute. Furthermore, the average energy consumption for all operators is 3.17 kcal/min, which is below the specified limit.

B. Mental Workload Measurement

1. Basic Method

The first stage in determining the Human Error Probability (HEP) using the CREAM method is to formulate a task analysis. The hierarchical task analysis (HTA) is formulated to describe the work process in detail, so that each stage of the copper cathode harvesting activity can be clearly identified. The HTA formulated in this research serves as a reference for expert judgment in understanding the entire workflow, in order to facilitate the assessment of general work conditions, specifically in determining ratings for the Common Performance Conditions (CPC) factors. The task analysis in the Copper Cathode Harvesting Process is shown in Table 3.

Table 3. Tasks Analysis in the Copper Cathode Harvesting Process

No	Work Stages	Steps in Each Work Stage	
1	Preparation for Copper Cathode Harvesting	1.1	Briefing on work safety.
		1.2	Wearing full PPE.
		1.3	Restricting access to the work area.
		1.4	Checking the operational condition of cranes/hoists and lifting equipment before use.
		1.5	Inspecting the condition of the electrolysis cells before harvesting.
2	Stop the Electrolysis Process	2.1	Turning off the power to the electrolysis cells.
		2.2	Ensure there is no electrical current (zero energy check) in the system.
		2.3	Verify that the electrolyte is in a safe condition for harvesting.
3	Remove the Electrodes from the Electrolysis Cell	3.1	Open the cell plug to drain the electrolyte from the electrolysis cell.
		3.2	Place the crane/hoist above the electrolysis cell.
		3.3	Hook the electrode and scrap anode to the lifting equipment according to procedure.
		3.4	Hoist the cell in a safe and controlled movement.
		3.5	Move the electrode to the prepared waiting area for the stripping process.
4	Clean the Electrolysis Cell	4.1	Clean any residual anode slime or dirty residue from the electrolysis cell.
		4.2	Place the anode slime into the provided storage container.
		4.3	Inspect the condition of the electrolysis cell to ensure no anode slime or scrap anodes are left behind.
5	Washing and Stripping the Copper Cathodes	5.1	Move the electrodes from the waiting area to the Cathode Washing and Stripping Machine (CWSM) input area.
		5.2	Wash the electrodes to remove any remaining electrolyte residue.
		5.3	Strip the electrodes to separate the copper cathodes and SS blanks.
		5.4	Inspect the copper cathodes to determine if they are good or defective.
6	Inspect the Condition of the Copper Cathodes	6.1	Double-check the physical condition of the copper cathodes based on the established standard.
		6.2	Classify copper cathodes that do not comply with the quality standard.

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No	Work Stages	Steps in Each Work Stage	
		6.3	Rework copper cathodes with defects that can be repaired.
		6.4	Deliver rejected copper cathodes to the smelter.
		6.5	Bundle the copper cathodes that comply with the standard.
		6.6	Document the results or the quantity of copper cathode bundles.
		6.7	Place the copper cathode bundles in the storage warehouse.
7	Clean the Work Area and End the Work Activity	7.1	Clean the work area of materials and equipment.
		7.2	Return work equipment to their initial storage locations.
		7.3	Remove PPE in accordance with applicable procedures.
8	Report the results of the copper cathode harvesting activity to the supervisor.		

Then, an assessment of Common Performance Conditions (CPC) was conducted. The CPC assessment in this research included nine aspects evaluated by expert judgment. The results of this assessment were used to describe the company's general conditions in performing specific tasks, and to identify factors that could affect performance and the potential for human error. The CPC assessment is shown in Table 4.

Table 4. CPC assessment

CPC Name	Category	Expected Impact
Adequacy of organization	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Reduced
	Deficient	Reduced
Working conditions	Advantageous	Improved
	Compatible	Not significant
	Incompatible	Reduced
Adequacy of MMI and operational support	Supportive	Improved
	Adequate	Not significant
	Tolerable	Not significant
	Inappropriate	Reduced
Availability of procedures/plans	Appropriate	Improved
	Acceptable	Not significant
	Inappropriate	Reduced
Number of simultaneous goals	Fewer then capacity	Improved
	Matching current capacity	Not significant
	More than capacity	Reduced
Available time	Adequate	Improved
	Temporarily inadequate	Not significant
	Continuously inadequate	Reduced
Time of day	Day time	Not significant
	Night time	Reduced
Adequacy of training and experience	Adequate, high experience	Improved
	Adequate, limited experience	Not significant
	Inadequate	Reduced
Crew collaboration quality	Very efficient	Improved
	Efficient	Not significant
	Inefficient	Not significant
	Deficient	Reduced
Σ Improved = 4		
Σ Reduced = 1		

The next step is to determine the control mode based on the results of the Common Performance Conditions (CPC) assessment by expert judgment. In the copper cathode harvesting process, the CPC assessment results were 4 in improved category and 1 in reduced category. These results were then plotted on a control mode graph to determine the appropriate control mode, as shown in Figure 1.

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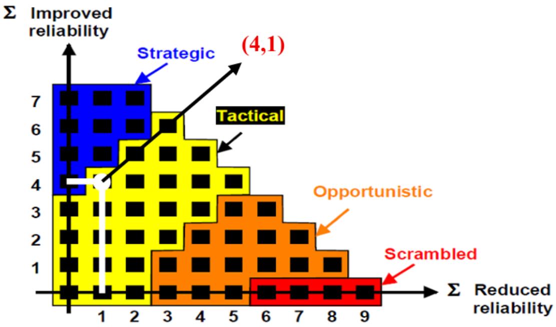

Figure 1. CPC relationship graph to control mode

Based on the relation between the Common Performance Conditions (CPC) assessment results and the control mode, the probability interval of errors caused by operators at the PT XYZ refinery plant can be determined. In the copper cathode harvesting activity, the analysis results indicate that the work is in the tactical control mode with an error probability interval of $0.001 < p < 0.1$. This condition indicates that operator performance generally complies with the planned procedures, but there is still a possibility of deviations or errors in task performance.

2. Extended Method

The secondary stage of the CREAM method is the extended method, which determines the probability of error for each task in the copper cathode harvesting process based on the results of the Hierarchical Task Analysis (HTA) and Cognitive Failure Probability (CFP). In this stage, the first step is to identify the cognitive aspects of each task, which include processes such as observation, interpretation, planning, and execution. Next, potential cognitive failures that may occur in each activity are identified. Then, the final stage involves calculating the Cognitive Failure Probability (CFP) value. The CFP value is calculated by multiplying the number of Common Performance Conditions (CPC) effects for each task by the corresponding nominal CFP value. These calculation results are then used to determine the Human Error Probability for each task in the copper cathode harvesting process. The assessment of cognitive failures in the copper cathode harvesting process is summarized in Table 5. A recapitulation of the Cognitive Failure Probability calculations is shown in Table 6.

Table 5. Assessment of cognitive failure in the copper cathode harvesting process

CPC Name	Category	Cognitive Function			
		OBS	INT	PLA	EKS
Adequacy of organization	Very efficient	1,0	1,0	0,8	0,8
Working conditions	Compatible	1,0	1,0	1,0	1,0
Adequacy of MMI and operational support	Adequate	1,0	1,0	1,0	1,0
Availability of procedures/plans	Appropriate	0,8	1,0	0,5	0,8
Number of simultaneous goals	More than capacity	2,0	2,0	5,0	2,0
Available time	Adequate	0,5	0,5	0,5	0,5
Time of day	Day time	1,0	1,0	1,0	1,0
Adequacy of training and experience	Adequate, limited experience	1,0	1,0	1,0	1,0
Crew collaboration quality	Very efficient	0,5	0,5	0,5	0,5
Weighting Factor		0,4	0,5	0,5	0,32

Table 6. Cognitive Failure Probability in the copper cathode harvesting process

Task Code	Work Activities	Cognitive Activity	Error Mode	Nominal Error Mode	Weight. Factor	CFP
1.1	Briefing on work safety.	*Communicate*	E5	0,03	0.32	0,0096
1.2	Wearing full PPE.	*Execute*	E2	0,003	0.32	0,00096
1.3	Restricting access to the work area.	*Regulate*	O2	0,007	0.4	0,0028
			E5	0,03	0.32	0,0096
1.4	Checking the operational condition of cranes/hoists and lifting equipment before use.	*Verify*	O2	0,007	0.4	0,0028
1.5	Inspecting the condition of the	*Evaluate*	I1	0,2	0.5	0,1
			P1	0,01	0.5	0,005

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Task Code	Work Activities	Cognitive Activity	Error Mode	Nominal Error Mode	Weight. Factor	CFP
	electrolysis cells before harvesting.					
2.1	Turning off the power to the electrolysis cells.	*Execute*	E3	0,0005	0.32	0,00016
2.2	Ensure there is no electrical current (zero energy check) in the system.	*Verify*	O2	0,007	0.4	0,0028
2.3	Verify that the electrolyte is in a safe condition for harvesting.	*Verify*	O3	0,003	0.4	0,0012
3.1	Open the cell plug to drain the electrolyte from the electrolysis cell.	*Execute*	E3	0,0005	0.32	0,00016
3.2	Place the crane/hoist above the electrolysis cell.	*Regulate*	O1	0,001	0.4	0,0004
			E2	0,003	0.32	0,00096
3.3	Hook the electrode and scrap anode to the lifting equipment according to procedure.	*Execute*	E2	0,003	0.32	0,00096
3.4	Hoist the cell in a safe and controlled movement.	*Regulate*	O1	0,001	0,4	0,0004
			E1	0,003	0,32	0,00096
3.5	Move the electrode to the prepared waiting area for the stripping process.	*Execute*	E1	0,003	0,32	0,00096
4.1	Clean any residual anode slime or dirty residue from the electrolysis cell.	*Execute*	E2	0.003	0.32	0.00096
4.2	Place the anode slime into the provided storage container.	*Execute*	E3	0.0005	0.32	0.00016
4.3	Inspect the condition of the electrolysis cell to ensure no anode slime or scrap anodes are left behind.	*Verify*	O3	0.003	0.4	0.0012
5.1	Move the electrodes from the waiting area to the Cathode Washing and Stripping Machine (CWSM) input area.	*Execute*	E3	0.0005	0.32	0.00016
5.2	Wash the electrodes to remove any remaining electrolyte residue.	*Execute*	E2	0.003	0.32	0.00096
5.3	Strip the electrodes to separate the copper cathodes and SS blanks.	*Execute*	E2	0.003	0.32	0.00096
5.4	Inspect the copper cathodes to determine if they are good or defective.	*Evaluate*	I1	0.2	0.5	0.1
			P1	0.01	0.5	0.005
6.1	Double-check the physical condition of	*Verify*	O3	0.003	0.4	0.0012

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Task Code	Work Activities	Cognitive Activity	Error Mode	Nominal Error Mode	Weight. Factor	CFP
	the copper cathodes based on the established standard.					
6.2	Classify copper cathodes that do not comply with the quality standard.	*Identify*	I1	0.2	0.5	0.1
6.3	Rework copper cathodes with defects that can be repaired.	*Execute*	E2	0.003	0.32	0.00096
6.4	Deliver rejected copper cathodes to the smelter.	*Execute*	E5	0.03	0.32	0.0096
6.5	Bundle the copper cathodes that comply with the standard.	*Execute*	-	-	-	-
6.6	Document the results or the quantity of copper cathode bundles.	*Record*	I1	0.2	0.5	0.1
			E2	0.003	0.32	0.00096
6.7	Place the copper cathode bundles in the storage warehouse.	*Execute*	E2	0.003	0.32	0.00096
7.1	Clean the work area of materials and equipment.	*Execute*	E2	0.003	0.32	0.00096
7.2	Return work equipment to their initial storage locations.	*Execute*	E3	0.0005	0.32	0.00016
7.3	Remove PPE in accordance with applicable procedures.	*Execute*	E4	0.003	0.32	0.00096
8	Report the results of the copper cathode harvesting activity	*Communicate*	-	-	-	-

Analysis results showed that the highest Cognitive Failure Probability (CFP) or Human Error Probability (HEP) values in the copper cathode harvesting process were found in the cognitive aspect of interpretation, with the error mode being errors in making decisions. These highest values were found in tasks with codes 1.5, 5.4, 6.2, and 6.6, each with a value of 0.1. Based on the CFP assessment table for copper cathode harvesting operations, the tasks with the highest CFP values are related to cognitive activities such as evaluate, identify, and record. This indicates that stages involving assessment, condition recognition, and information recording have a higher error probability than other activities. These findings indicate that copper cathode harvesting operators still have difficulties in adjusting tasks or decisions to achieve work objectives accurately, which has the potential to increase the risk of human error.

C. Disscussion

The results of the research indicate that the physical workload of operators during the copper cathode harvesting process at the PT XYZ refinery plant is moderate, with an average %CVL of 40,11%; however, there is significant variation among operators, including those in the heavy and moderately heavy categories. This condition indicates an imbalance in workload distribution that has the potential to cause physical fatigue. Physiologically, an increase in %CVL is related to increased cardiovascular activity due to high work demands, which in the long term can reduce performance and increase the risk of workplace accidents.

From a mental perspective, the CREAM analysis results indicate that the work is in tactical control mode with an error probability of $0,001 < p < 0,1$, which indicates that operators are working according to procedures but still have the potential for deviations. This is influenced by CPC factors, specifically the number of tasks exceeding capacity, which directly increases the operators' cognitive load.

In addition, the highest CFP or HEP value of 0,1 was identified in tasks related to cognitive activities such as evaluate, identify, and record. These results indicate that errors mostly occur during the interpretation and decision-making stages. The results show that higher-level cognitive activities are more sensitive to errors because they require complex

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information processing, particularly in extreme work environments. Accordingly, human error in these processes is influenced by a combination of physical workload, cognitive strain, and working conditions.

Conclusion

Based on the research objectives, it can be concluded that operators involved in the copper cathode harvesting process at the PT XYZ refinery plant generally experience a moderate level of physical workload, though variations indicate that some operators experience a higher workload that could lead to fatigue. In addition, the mental workload indicates that operators work under tactical control conditions, meaning that work activities follow established procedures, but there remains a risk of errors, specifically in activities involving high-level cognitive processes such as evaluation, identification, and documentation. The primary findings of this research indicate that the critical human error point is in the decision-making stage, not in routine physical or operational activities. Scientifically, there is a correlation between physical and mental workload, where an increase in physical workload can trigger fatigue that impacts cognitive function, therefore increasing the probability of errors. So, human error in this work is not only influenced by individual factors but also by the interaction between physical demands, cognitive load, and working conditions. The implication is that a systemic improvement approach is needed, which includes balancing the distribution of workloads, improving the quality of work procedures, and strengthening training and supervision for cognitive tasks. For future research, it is recommended to integrate other methods or conduct a more in-depth ergonomics-based analysis to evaluate workplace environmental factors and work system design more comprehensively. The implementation of these efforts is expected to improve work efficiency, safety, and productivity in a sustainable way.

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