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Analysis Of the Influence of The Work Environment on Employee Health in The Production Process Uses FMEA And SEM Methods

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ABSTRACT

Industrial transformation at the moment this is very impactful for development technology periodically large and complex. Development this industrial technology usually called industry 4.0. Industrial revolution 4.0. influence the world of business even. The industrial revolution had an impact on aspects life humans, including in the field occupational safety and health (K3). PT. XYZ is company fiberglass manufacturing operating in Batam still difficulty in face challenge related K3 problems. Although has There is K3 regulations and standards that have been determined in the fiberglass manufacturing industry. Bad his knowledge about K3 owned by the operator so can cause Health problems for employees. Based on from results of data analysis that has been carried out can be known that mark connection environment Work to disturbance health is obtained value 85.8% with that can be concluded that environment work is very influential to health problems. Can be known. The resulting RPN value is 80 points the is in the factors reason disturbance health Work that is man. With That need do purposeful improvement. For minimize happen disturbance health.

Keywords: *Health Disorders, K3, Industrial Revolution*

Introduction

Globalization is often linked with progress technology and information are limitless, however Actually globalization relate with various field life. Consequence from current globalization This partitions a country with another country becomes fade Because convenience obtained in interact in various ways field. [1].

Batam is one of them cities in Indonesia that have role important in industry manufacture. which is located in the Riau Islands, Batam has location strategic for establish company manufacture. Potential for manufacturing industry in the city very Batam strategic Because Batam is on track trading international. Presence industry manufacturing in Batam has given contribution big to growth economy in the city Batam[2].

Industrial transformation at the moment this is very impactful for development technology periodically large and complex. Development this industrial technology usually called industry 4.0. *Industrial revolution* 4.0. influence the world of business even the industrial revolution had an impact on aspects life humans, including in the fields occupational safety and health (K3). With exists development industrial revolution 4.0. Of course, demand A company do changes to the implementation of K3. Of course, K3 in the current era must can be adjusted with technology information and communication, knowledge as well as use digital application[3]

With exists automation opportunity for implementation of K3 will far more *advance.* Automation as track industry 4.0 controls that have influence is very important for K3. Besides that, with exists automation adjustments to stations Work will Far more ergonomic because of its implementation own additions to tools for overcome A problems that exist in the company [4]. Health and Safety Work (K3) is efforts made for create environment healthy and safe work, so can reduce probability accident work / illness consequence resulting negligence demotivation and deficiency productivity work. According to

the Republic of Indonesia Basic Health Law No. 9 Years. 1960 Chapter I Article II, Health Work is something Health conditions that aim to ensure that society worker obtain highest degree of health, good physical, spiritual and social, with business prevention and treatment to disease or Health problems caused by work and the environment Work nor disease general. reason safety work frequently found is behavior that is not safe of 88% and conditions an environment that doesn't safe by 10%, or second matter the happen in a way simultaneously [5]

Figure 1. Production Area

Occupational health and safety (OHS) represents a critical organizational imperative directly impacting worker well-being, productivity, and long-term business sustainability [6]. Contemporary OHS theory emphasizes that workplace health outcomes result from complex interactions between physical environmental factors (noise, lighting, temperature, air quality, ergonomics), organizational systems (safety management, supervision, procedures), and human behaviors (compliance, risk perception, safety culture) [7]. The Job Demands-Resources (JD-R) model provides a robust theoretical framework explaining how adverse working conditions create excessive demands that deplete worker physiological and psychological resources, while supportive work environments function as protective factors mitigating health risks [8]

In manufacturing contexts particularly hazardous industries such as fiberglass production—workers face multiple concurrent occupational exposures including airborne particulates (glass fiber dust), chemical irritants (styrene resins, solvents), physical stressors (noise, heat, inadequate lighting), and ergonomic challenges (manual material handling, repetitive motions)[9]. These hazards align with Heinrich's Domino Theory of accident causation, which posits that unsafe conditions interact with unsafe behaviors to produce workplace injuries and illnesses. [10]. Recent evidence demonstrates that cumulative environmental exposures in manufacturing significantly predict both acute occupational injuries and chronic health conditions, with synergistic effects when multiple hazards coexist. [11].

Despite regulatory frameworks such as Indonesia's Law No. 1/1970 on Occupational Safety and Presidential Regulation No. 21/2010 on OHS inspection, implementation challenges persist in Indonesian manufacturing sectors. PT XYZ, a fiber glass boat and automotive parts manufacturer employing 280 workers in Batam Industrial Estate, exemplifies these challenges. Over the past three years (2022-2024), health complaints among production operators have escalated significantly (Figure 2), with documented cases including respiratory irritation (38% of complaints), skin disorders (27%), eye irritation (18%), thermal discomfort (12%), and musculoskeletal symptoms (5%). Preliminary workplace assessments revealed inadequate personal protective equipment (PPE) compliance (estimated 62% adherence during random audits), absent preventive maintenance schedules for production machinery, insufficient local exhaust ventilation at fiber cutting and resin application stations, and inconsistent implementation of 5S workplace organization principles.

This situation reflects broader patterns in Indonesian small-to-medium manufacturing enterprises (SMEs) where limited OHS resources, inadequate safety management systems, and weak enforcement mechanisms result in preventable occupational health problems. [12]. The fiber glass industry presents particularly complex OHS challenges due to simultaneous exposures to multiple hazard classes chemical (resins, catalysts), physical (fiber dust, noise, heat), and ergonomic (manual handling) requiring systematic risk assessment and prioritization methodologies to guide evidence-based interventions.

The problems that occur within PT include a lack of production operator discipline in the use of complete PPE, which often result in health problems among employees and lead to a decline in worker health, disrupting employee health. The decline in PT's health. XYZ employees in 3 (three) year’s final experience increase complaint health. Following graphic amount complaints experienced by employees in 3 (three) year’s finals:

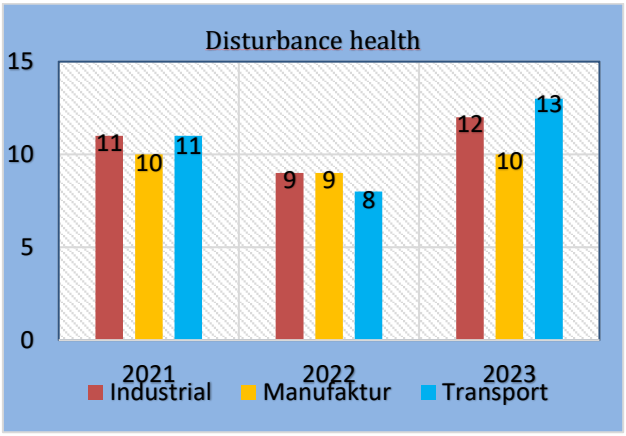

Figure 2. Graph Amount Complaint 3 Years Final

Analysis *Structural Equation Model* (SEM) is technique strong statistics in establish measurement models and structural models. The SEM method has ability more analysis and predictions great *(stronger predicting power*) compared analysis path and regression multiple because SEM is capable analyze down to the deepest level to variable or model under study. Parameter estimation in SEM analysis requires a number of assumption critical like size samples must be at least 10 times larger indicators and data must normally distributed. The SEM-PLS analysis method is SEM based analysis variants that don't need large samples and not must multivariate normal. [13]

FMEA is A method used for inspect reason disabled or failure occurred during the production process, evaluate priority the risk that causes emergence complaint health, and help take action for avoid [14]identified problems as danger reason Decreased employee health. It was also explained that FMEA method combines knowledge and experience man for identify potency failure from something product or process, evaluate failure something product or process and impact help engineer for do action repair or action preventive, remove or reduce possibility happen failure. FMEA method is very helpful and easy used for identify and measure level risk accident Work. [15]

Research Methods

Environment Work has a significant influence on the health of workers or employee condition environment become decider on workers' health or employee. Where environment intended work of course environment clean, neat work comfortable and safe for workers and employees. With That can increase productivity work on employees [2].

***Structural Equation Model* (SEM)**

Equation model structural (*Structural Equation Modeling*) is generation second technique analysis possible multivariate researcher test connection between complex variables both recursive and non-recursive for obtain comprehensive picture about the whole model. SEM can test in a way together:

1. Structural model: connection between construct independent with dependent [16] [17]
2. *measurement* model: relationship (*loading* value) between indicator with construct *(latent).*

Combined structural model testing with measurement possible researcher for:

1. Test error measurement (*measurement error*) as the part that doesn't inseparable from SEM.
2. Do analysis factor simultaneously with testing hypothesis.

This research uses the SmartPLS application.

***Failure Mode and Effect Analysis* (FMEA)**

The Failure Mode and Effect Analysis (FMEA) method is something technique used for identify in prevent failure or disability so that A the product produced can fulfil standards desired by the company.

Following the steps in do analysis method FMEA:

1. Determine the failure mode.
2. Determine mark *occurrence* level frequent failures appear.
3. Determine mark *severity* level severity.
4. Determine mark detection appearance failure.

Here's the core matrix in measurement mark RPN:

Table 1. Score Matrix

RPN Score Value	
Scale	**information**
1	very low
2	low
3	currently
4	tall
5	very high

The research flowchart can be seen below:

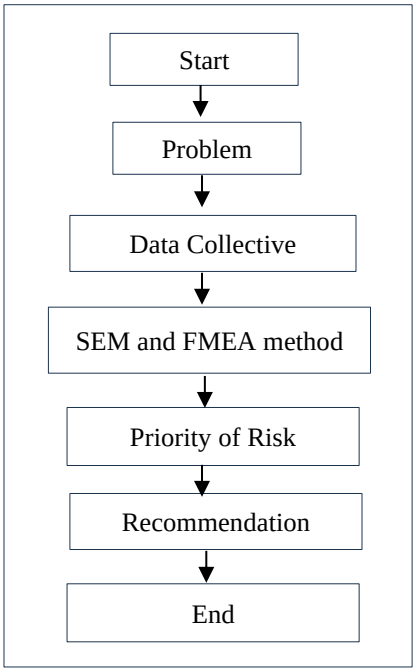

Figure 3. Research Flowchart

Research Novelty: Integrated SEM-FMEA Framework

This study addresses the identified gaps by proposing an integrated SEM-FMEA framework that creates synergistic methodological value for occupational health risk management:

SEM Component: Predictive Causal Analysis

SEM serves as the quantitative foundation by:

- Modeling complex relationships: Simultaneously estimating relationships between multiple work environment dimensions (industrial deficiencies, manufacturing deficiencies, transport deficiencies) and health outcomes, accounting for measurement error and testing theoretical propositions derived from JD-R theory
- Quantifying predictive strength: Providing standardized path coefficients (β) indicating relative causal influence, coefficient of determination (R^2) measuring explained variance, and statistical significance testing (t-values, p-values) validating relationships
- Validating theoretical models: Empirically testing whether hypothesized causal pathways align with observed data through fit indices and construct validity assessments

Practical value: Identifies *which* work environment factors most strongly influence health outcomes, providing evidence-based justification for intervention focus areas and enabling resource allocation based on effect size magnitude.

FMEA Component: Prescriptive Risk Prioritization

FMEA serves as the operational translation tool by:

- Decomposing validated factors: Breaking down SEM-identified significant predictors (e.g., "manufacturing deficiency") into specific failure modes (operator SOP non-compliance, absent preventive maintenance, missing machine guards, inadequate ventilation)

- Quantifying actionable risk: Assessing each failure mode's Severity (health impact magnitude), Occurrence (exposure frequency), and Detection (control adequacy) to calculate Risk Priority Numbers enabling objective prioritization
- Generating intervention hierarchy: Ranking failure modes from highest to lowest RPN, directly indicating which specific conditions require immediate versus deferred action based on risk magnitude

Practical value: Translates statistical evidence into *specific, prioritized action items* (e.g., "implement daily PPE compliance audits" for RPN=80 human factor risk), enabling resource-constrained organizations to focus on highest-impact interventions first.

Integration Synergy: Evidence-Based Prioritization

The combined SEM-FMEA framework creates value exceeding either method alone:

1. Statistical grounding of FMEA focus: SEM results direct FMEA analysis toward statistically validated high-impact factors, ensuring prioritization efforts concentrate on factors demonstrably linked to health outcomes rather than subjectively selected risks
2. Operational translation of SEM findings: FMEA transforms SEM's explanatory power ("work environment explains 85.8% of health variance") into prescriptive guidance ("prioritize these five specific interventions in this sequence based on RPN rankings")
3. Methodological triangulation: Convergence between SEM-identified significant predictors and FMEA-identified high-RPN risks strengthens confidence in findings through mixed-method validation (quantitative statistical modeling + structured expert judgment)
4. Complete decision-support cycle: The framework provides both the "why" (SEM causal evidence justifying intervention necessity) and the "what/when" (FMEA prioritization guiding implementation sequence), addressing the persistent research-practice gap in OHS (Leveson, 2020).

Results and Discussion

Data collection

Based on data collection that has been the data obtained is carried out from three definition ie industrial deficit, deficit manufacturing and transport deficiencies carried out use questionnaire and identification field in a way direct aim for see how much big influence environment Work on employee health.

Data processing

SEM method

This SEM method is used for see connection accident work that occurs in each existing deficiencies at PT. XYZ on Employee Health. For looking for Level of relationship accident work on employee health can be done with use approach *Smart PLS* (*Partial least squares)*. With determine latent variable (*variable construct*) and variables observed (*manifest*).[18]

Table 2. Assumption Latent Variables and Variables Very I

A11 - A21 - A31 environment	B11 = Irritation eye
A12 - A22 - A32 Method	B12 = wound burn
A13 - A23 - A33 Human	B13 = shortness of breath B14 = Irritation skin
A14 – A24 - A34 Material	B15 = Burns B16 = lungs

With **Table 2** above shows a hypothetical model for latent variables and observed variables.

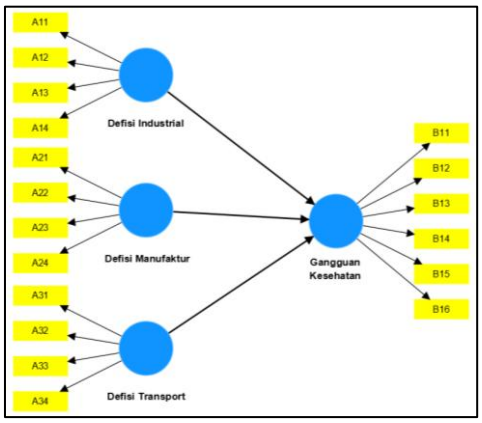

Figure 4. Model Flow Diagram

Evaluation *Outer model*

Evaluation *Outer model* done for do testing to ensure validity, reliability and significance *Outer model*.

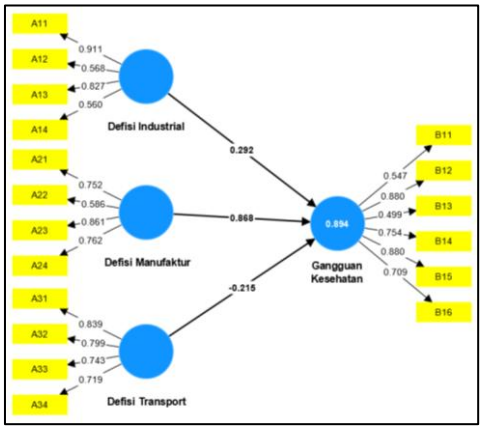

Figure 5. Factor Loading Value

Is known B13 factor loading value has mark factor *loading* below <0.50 p That signify that indicator needs to be taken out from the model and carried out estimate repeat.

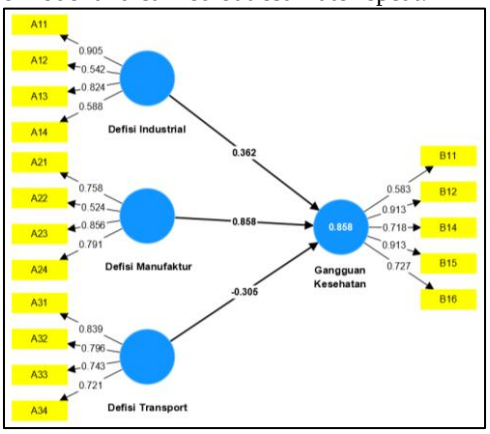

Figure 6. Re- estimated Factor Loading Value

After done estimate reset on value *Loading Factor* so get Loading factor value that meets conditions > 0.50 and each definition donate sufficient value big like industrial deficit contributes value 0.362 definition manufacturing 0.858 and transport 0.305 with matter it was stated that each value the construct is stated validate and every indicator value is capable measuring latent variables [19].

Table 3. Reliability Values Construct Exogenous

construct Exogenous	AVE > 0.5	CR > 0.7	conclusion
A1 Industrial	0.534	0.814	Good Reliability
A2 Manufacture	0.552	0.827	Good Reliability
A3 Transport	0.603	0.828	Good Reliability
B1 Disorder health	0.610	0.884	Good Reliability

AVE and CR values for each indicator stated has fulfil provision because own AVE value > 0.5 and CR value > 0.7. So that all latent variables have good consistency in measure the indicators.

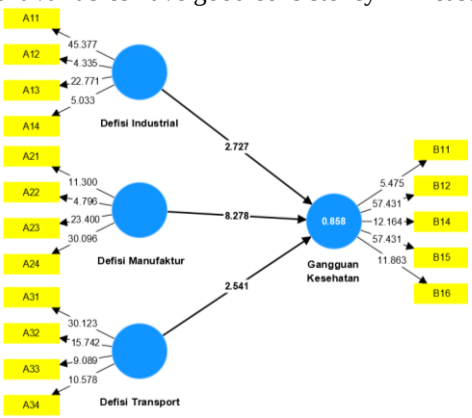

Figure 7. Path Diagram t-value

Based on the *path* diagram above, it is known that Industrial indicators contributed value 2,727, manufacturing amounting to 8,278 and transport 2,541 with That can be concluded that third indicator Already stated significance.

Evaluation of Inner models

Evaluation of structural models done with use R2 value for construct dependent, value path coefficient or t- count every track for testing significance between construct in the structural model.

Table 4. Inner Model Significance

	Mean (M)	STDEV	Tcount	Ket
(A1) > (B1)	0.310	0.113	2,727	Significant
(A2) > (B1)	0.864	0.104	8,278	Significant
(A3) > (B1)	0.256	0.120	2,547	Significant

Based on table above is known that each indicator influential significant to variable exogenous. Variable Environment Work influential direct to disturbance health.

Table 5. Relationships Accident Work with Employee Health

Connection	R value ^{2}
Environment work (A) – Distraction health (B)	0.858

Based on table connection environment Work with employee health can is known that results R value ^{2} is of 0.858. that value identifies that environmental endogenous construct Work For can explain Endogenous construct of employee health.

Dominant Factor Reason Employee health problems

Problems that arise in the work area Of course just caused Because a number of factors that influence it, in matter This determining the factors that occur disturbance health done with method *brainstorm* with parties related. Following these results *brainstorming* that has been done against 5 factors, namely: [20].

Table 6. Brainstorming

No	Factor	Reason
1	Man	Lack of Internal operator discipline use PPE at all times Work not enough understand the SOP inside use tool protector yourself at the moment Work
		Is not carried out in the production area
2	Machine	The machine used No own safety and not done checking on time before use
		are not done repairs to machines that will be used during the production process

3	Material	Materials used made from easy fiberglass destroyed when done cutting
		Use material chemistry
4	Method	Lack of supervision of employees in Use complete PPE at all times Work
		Are not done checking the environment Work
5	Environment	Production area not cleaned so that dusty
		Is not carried out in the production area

After know factors reason emergence disturbance health in the PT area. XYZ, results from brainstorming later served to in *fishbone* diagram form as in the picture under This:

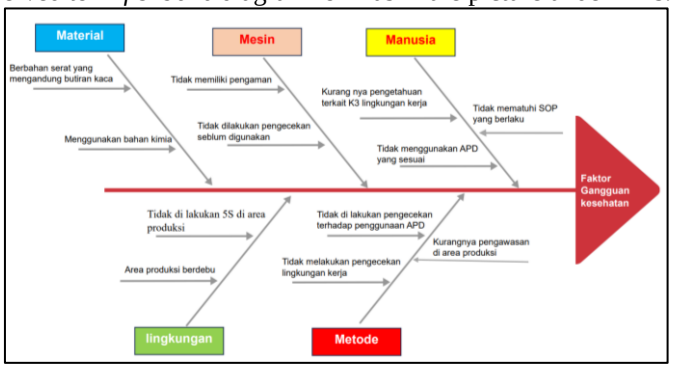

Figure 8. Fishbone Diagram

The following is a more detailed explanation of the five factors that cause employee health problems:

1. Factor: Human

The human factor is a very important and dominant aspect in maintaining occupational safety and health (OHS). This table identifies several key causes [12]:

a. Lack of operator discipline in using Personal Protective Equipment (PPE).

Operators are not disciplined in wearing PPE while working, such as helmets, gloves, masks, safety shoes, etc. This also indicates a lack of understanding of SOPs (Standard Operating Procedures), which should be the primary guideline for work activities. As a result, the risk of accidents and health problems increases due to the lack of adequate personal protection.

b. Failure to implement 5S in the production area.

5S is a Japanese visual management method (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) that aims to create a clean, tidy, and safe work environment. Failure to implement 5S results in a disorganized and dirty work area, potentially leading to workplace accidents. For example, tools are scattered, work paths are obstructed, or chemical spills are not promptly cleaned up.

c. The machines used lack safety features and are not checked before use.

Some machines in the production area are not equipped with standard safety features, such as moving part guards, emergency stop buttons, or automatic sensors. Worse still, there is no routine inspection of the machine's condition before use. This is very risky, as the potential for damage or workplace accidents is very high. Operators can suffer injury due to negligence or technical malfunctions of the machine [21].

2. Machines

No repairs are performed on machines intended for use during the production process [22]:

Machines used are damaged or worn out but are still used without prior maintenance or repair. This is very dangerous because suboptimal machines can cause workplace accidents such as injuries, pinching, or even poisoning if the machine leaks or releases hazardous substances.

3. Materials

The material used is fiberglass, which easily shatters during cutting [23]:

Fiberglass is a material composed of fine glass fibers that can easily be released into the air when cut or sawed. If not handled with proper safety procedures, these particles can be inhaled by workers and cause respiratory problems, skin irritation, or eye irritation.

4. Method

a. Using chemicals [24]**:**

The use of chemicals in the production process (e.g., solvents, resins, or adhesives) is very risky if not handled using safe work methods. Direct contact or vaporization of these materials can cause irritation, burns, respiratory problems, and long-term risks such as chronic poisoning.

b. Lack of supervision of employees in using complete PPE while working:

Even though PPE is available, supervisors do not consistently ensure that all workers use it correctly and completely. As a result, protection against occupational risks is not optimal.

c. Failure to inspect the work environment:

The absence of routine inspections or OHS audits in the work area can result in potential hazards not being immediately identified. For example, the presence of pools of liquid, chemical leaks, damaged ventilation, or poor lighting.

5. Environment

a. The production area is not cleaned and becomes dusty:

A dirty and dusty work area can cause respiratory problems, especially if the dust contains hazardous particles such as glass fibers or chemical residue. Dust can also stick to equipment and increase the risk of accidents due to slippery or unstable surfaces [25].

b. Not implementing 5S in the production area:

As previously explained, 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) is a system that promotes order, cleanliness, and discipline in the workplace. Without the implementation of 5S, the work environment becomes unsafe, inefficient, and has a high potential for accidents [16].

Calculation RPN value is carried out for now level the most dominant risk as well as own highest possibility so that give rise to impact detrimental negative for employees and companies RPN calculation is carried out with method *Severity* x *Occurrence* x *Detection.* RPN value is obtained from results interviews conducted on *safety* management in the company. The following is the data obtained from results interview [23].

Table *7. RPN Calculation*

Product Or Process Step	***Potential Failure Mode***	***Potential Failure Effect***	***Severity***	***Occurrence***	***Detection***	**RPN**
Man	Lack Of Operator Discipline	Cause Employee Easy Exposed Straight to The Cause Disturbance Health	4	3	5	60
	Minimal Knowledge Related to K3 In Environment Work	Risk Happen Disturbance Health Tall	3	3	3	27
	The Operator Does Not Implement The K3 SOP That Has Been Determined	Give Rise to Employee Health Problems	4	4	5	80
Machine	No Own Safety on The Machine	Results Cutting Scattered	3	3	4	36
	Are Not Done Repairs to The Machine	Potency Happen Health Problems in The Production Process Tall	4	4	4	64
	No Do Checking on Time Will Be Used	Cause Problems in The Production Process	4	3	3	36
Method	Lack Of Supervision of Operators at The Time Work	Risk Accident Work Can Taller	2	3	2	12
	Are Not Done Checking Each PPE Division in A Way Periodically	Cause The Operator Does Not Use PPE	2	4	3	36
Material	Raw Materials Used Made from Fiberglass	Easy To Fly If Blown Wind	3	3	4	36
	Using Chemicals	Dangerous If Exposed Keep Going Continuously	3	4	3	36
Environment	Work Area Dusty	Flying Dust	4	3	4	48
	Temperature Room Hot	Make The Operator Not Comfortable	3	3	4	36

	Near With Material Chemistry	Material Chemistry Dangerous	4	3	4	48

After count RPN value for fifth factor so furthermore factor with highest RPN value Then ranking is determined based on RPN value from the largest lowest. Following This is results RPN value for each factor that is:

Table *8*. *Determination Ranking of the Highest RPN Values for Each Factor*

Factor	***Failure Mode***	***Risk Priority Number* (RPN)**	***Ranking***
Man	The operator does not implement the K3 SOP that has been determined	80	1
Machine	Are not done repairs to the machine	64	2
Environment	Near with material chemical and dusty	48	3
Material	Raw materials used made from fiberglass	36	4
Method	Lack of Supervision of operators at the time Work	24	5

After done identification with determine the highest RPN value is factor reason happen disturbance health at PT. XYZ. This aim was carried out for determine prior so a must thing done is do improvement of the causative factors Health problems p This done for reduce happen disturbance health experienced by PT workers. XYZ.

Table 9. Design Repair

Failure Mode	What	Why	Where	Who	When	How	Repair Planning
	What the first goal	Reason	Repair Location	Executor	Completion Target	Control Category	
Operators do not implement the K3 SOP that has been set	Reducing the incidence of employee health problems	Ensure employees are safe, secure and comfortable while working	All Division	HSE Management and company	April 2024	HSE Management	1. Conducting a briefing before work begins. 2. Rearranging the work area and implementing 5S routinely throughout each production process. 3. Repairing machines that will be used during maintenance. 4. Supervising the use of complete PPE during the production process. 5. Routinely checking PPE in each production area. 6. Providing guidance on the use of PPE on each production line.

Conclusion

Based on from results of data analysis that has been carried out can be known that mark connection environment Work to disturbance health is obtained value 85.8% with That can be concluded that environment work is very influential to disturbance health. Reason happen disturbance health work is caused by humans or that operator myself who doesn't implement the SOP that has been determined by the party Company K3 Management. Evaluation resulting risks disturbance health can be known with see the RPN value becomes mark priority. Can be known the resulting RPN value is 80 points the is in the factors reason disturbance health Work that is man. With That need do purposeful improvement for minimize happen disturbance health.

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