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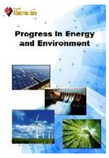

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Original Article

Risk management framework and practices for boiler operations in Malaysia

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Abstract

Boiler operations had a reputation for being one of the most hazardous work environments. Workers in the boiler plant face many safety risks due to the nature of the job. The work environment is often hot and noisy, consisting of several major equipment and operations involved in its process, and there is always a risk for crushing injuries, electrical shocks and burns, boiler fires and explosions, and contact with hazardous chemicals. Numerous activities performed in boiler operations are complex; these operations are hazardous and can cause accidents. This study aims to develop and propose risk management frameworks for working in a hazardous working environment at the boiler plant in Malaysia to prevent and control accidents and implement adequate safety and health management. Next, to analyze the risk factors and hazards for boiler operations based on the nature of work at the boilers in Malaysia using several methods: Bowtie Risk Assessment, Hazard and Operability Study (HAZOP), Failure Mode and Effect Analysis (FMEA). The result showed that the rate based on hazard sources in the boiler division has Extreme Risk levels (8%), High (14%), Medium (35%), and Low (43%). Risk assessment based on the type of hazard in the boiler division has risk levels ranging from high to the lowest score is the danger of Mechanical (25%), Electrical hazard (10%), chemical hazards (6%), and physical hazards (59%). The developed risk management framework with enhanced risk assessment techniques may solve the integration of sustainability aspects in boiler operations safety and risk management.

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1 Introduction

Practically every industry uses steam, and it is well acknowledged that steam generators and heat recovery boilers are essential to power and processing plants [1]. The boiler is crucial plant machinery because it transforms biofuel into electricity. The largest industry in the world is shipping, which is included in this [2]. The boiler is designed to operate in demanding circumstances, including high temperatures, high pressures, and an environment that could be hazardous. On the other hand, continual exposure to those conditions results in the boiler's failure and loss of power. The failures necessitate the shutdown of plants. Therefore, we require a firm safety policy and system to lower the likelihood of failure, especially for more delicate components like the boiler [1,2]. Boiler operation creates hazardous workplaces; thus, businesses must guarantee safe working conditions through systematic, routine hazard identification and risk assessment. Both management and employees must abide by safety standards and procedures. Numerous commercial organizations have demonstrated that effective safety management boosts plant output and efficiency [3].

Boilers are often used in heating applications. The installation of the Fire-tube boiler is straightforward. The fuel is burned within a furnace in a fire tube boiler [4]. The furnace's hot gases then flow via the fire tubes. Inside the boiler's main vessel, the fire tubes are submerged in water [5]. The heat energy of the hot gases is transmitted to the water surrounding them as they are moved through these tubes. As a result, steam is produced in the water and naturally rises to the water's surface, which is kept alongside the fire tube boiler. After that, a sufficient amount of steam is withdrawn from the outlet. The feed water input [7] is used to supply water to the boiler. It is difficult to create very high-pressure steam since the water and steam are held in the same vessel. The main boiler vessel of a fire tube boiler is under pressure; therefore, if it ruptures, there is a chance that an explosion will cause a significant accident [6].

The water-tube boiler has combustion-inscribed tubes as well as tubes that are filled with water. The benefits of a water-tube boiler are described as the steam produced with a lower unit weight per pound, an increase in steam pressure in a shorter amount of time, more flexibility, and an increased capacity for operating at higher steam generation rates. This kind has two primary drums: the upper drum is called the steam drum, and the lower drum is called the mud drum. Both are connected to the riser and down-comer tubes shown in [6].

Recent studies [5-10] suggested that risk management frameworks are necessary for boiler operation operations. In Malaysia, no particular frameworks for risk evaluation of boiler operations have been devised [11]. In contrast to other developed nations and high-risk industries, Malaysia employs a general risk management framework that references the 2008 Hazard Identification, Risk Assessment, and Risk Control (HIRARC) guidelines and standards like the OHSAS 18001-Occupational Health and Safety Management standards, Factory and Machinery Act 1967. Malaysia's Boiler operators have difficulties due to these [12,13]. This research aims to develop and propose an improvement to risk management frameworks for working in a hazardous working environment at the boiler operations in Malaysia. This research also prevents and controls accidents and implements adequate safety and health management. The findings of this research will guide the development of effective and comprehensive risk assessment frameworks for the industry.

2 Literature review

The boiler is among the most important equipment in power plants, converting biofuel into energy. This includes the shipping industry, the most extensive in the world. The boiler is made to work under challenging conditions, such as high temperatures, high pressures, and a potentially dangerous atmosphere. On the other hand, prolonged exposure to those circumstances causes the boiler to fail and lose its strength. Power plants are forced to shut down as a result of the failures. As a result, we need a robust safety policy and system to reduce the chance of failure, particularly for more sensitive components, such as the boiler [1,3].

Boilers are used in industries to generate hot water or steam. There are two main boilers used in power generation: fire-tube boiler and water-tube boiler, according to [2]. Stocker fluid boilers, pulverized boilers, package boilers, thermic fluid (oil) boilers, water tube boilers, and waste heat boilers are various types in industrial, commercial, and institutional facilities. Boiler plant operation is energy-intensive, and hence it is necessary to make the process very efficient at reduced operating cost, as clarified by [4].

The majority of the time, small-scale applications use fire tube boilers. The benefit of these boilers over other varieties is that they are small and take up little room. Fire or hot fuel gases from the burner are channeled via tubes that are part of a fire-tube boiler. In fire-tube boilers, combustion gases can move through tubes that are submerged in water. Additionally, the advantages are easier to fabricate and use. Fire-tube boilers' drawbacks include a lengthy steam generation process and a quick response to load changes. The major components of the boiler's trunk are fluid and pressure vessels. Water is mainly utilized to circulate fluid for heating or creating steam [5].

The water-tube boiler has combustion-inscribed tubes as well as tubes that are filled with water. The benefits of a water-tube boiler are described as the steam produced with a lower unit weight per pound, an increase in steam pressure in a shorter amount of time, more flexibility, and an increased capacity for operating at higher steam generation rates. This kind has two primary drums: the upper drum is called the steam drum, and the lower drum is called the mud drum. Both are related to the pictured riser tubes and descender tubes [6,7].

3 Methodology

3.1 Hazard identification, risk assessment and risk control (HIRARC)

This study review adopts a qualitative methodology to learn more about boiler operation's dangers and worker safety. The amount of risk associated with work safety is then determined using Hazard Identification, Risk Assessment, and Risk Control (HIRARC), which starts with identifying dangers and assessing the risk and ends with risk control. The HIRARC approach will be used for data processing and analysis to assess worker risk safety in the boiler division. Processing and data analysis what to do is to find factors causing accidents most serious in the boiler division. In order to arrive at risk values that can be expressed as scores during the risk level assessment stage, data analysis starts by calculating the risk value derived from consequence rating findings, exposure, and probability. The study's results using the standard are then used to determine whether the value can still be accepted or not and whether the employees' limit for the requirement for additional treatment to lower the risk is reached. The assessment table below was created utilizing the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) approach for data processing in this study.

The method most frequently used to quantify industry risk is semi-quantitative analysis. According to a recent study, two semi-quantitative risk assessment methodologies for occupational risk assessment are recognized in the literature. Based on two-dimensional risk matrices that take accident frequency and the severity of its aftereffects into account [9]. The semi-quantitative risk assessment matrix and the risk calculator are thus the two methods for risk analysis that are most frequently used. The following risk equation is used in the semi-quantitative risk assessment method:

$$\text{Risk (RV)} = \text{Severity(S)} \times \text{Likelihood(L)}$$

Severity is determined based on injury to health, damage to property, and environmental damage. The level and value of severity used in the risk assessment are shown in Table 3.1. At the same time, the likelihood is based on the observation conducted to obtain information on the individual hazard that occurs. Levels and values of the likelihood used in the risk assessment are shown in Table 3.2 [10].

Table 3.1 Level of severity, consequences, and severity value.

Level of Severity	Consequences	Severity Value
Disaster	Many deaths, property damage, and production cannot be recovered	**5**
Fatality	Approximately one death, damage to property if the hazard occurs	**4**
Severe Injuries	Non-fatal injury, permanent disability	**3**
Minor Injuries	Cause disability but not permanent injury	**2**
Negligible injuries	Minimal bruises, wounds, the injury needs first aid treatment	**1**

Table 3.2 Levels of likelihood, frequency, and likelihood value.

Level of Likelihood	Frequency	Likelihood Value
Most likely	Most likely to occur	**5**
Likely	May occur and is not unusual	**4**
Expected	May occur in the future	**3**
Rarely	Unknown to occur after several years	**2**
Unexpected	Practically impossible and never happened	**1**

The Semi-Quantitative Risk Assessment matrix table determines whether the risk value is low, medium, or high. Based on Table 3.3, the green box (RV = 1- 4) shows the low-risk level, while the yellow box (RV = 6-10) shows that medium-risk level, and the red box (RV = 11-25) shows a high degree of the risk level [10]. Table 3.3 shows the Semi-Quantitative Risk Assessment matrix table.

Table 3.3 Likelihood and severity value.

LIKELIHOOD (L)							
SEVERITY(S)			1 Unexpected	2 Rarely	3 Expected	4 Likely	5 Most Likely
	Negligible injuries	1	1	2	3	4	5
	Minor Injuries	2	2	4	6	8	10
	Severe Injuries	3	3	6	9	12	15
	Fatality	4	4	8	12	16	20
	Disaster	5	5	10	15	20	25

3.2 Hazard and operability study (HAZOP)

Hazard and Operability Study (HAZOP) is a method that is used to further identify the highest level of danger by classifying the factors causing accidents in the boiler operation process, such as sources of danger, deviations, and causes of accidents.

Determination of operating process - Record operating processes that identified as an activity that is the scene of an accident incident.

Hazard frequency recording - Recording is carried out against the operation or activities that often have accidents during the specified time.

Recording potential hazards - Recording is carried out based on potentials that may occur in operations indicated to cause accidents.

Risk recording - Recording is carried out based on the risks that may occur in the potential that there is an operation that is indicated to cause an accident.

Guideword determination - Determination of guidewords based on parameters by combining processes or activities against identified sources of danger.

Recording irregularities (Deviation) - The recording of deviations is determined based on activities or activities that are not following operating procedures by looking at potential hazards and risks that occur in operation.

Determination of the cause of the accident (Cause) - Determination of the cause of the accident is carried out by looking at the things that caused the accident based on the activities carried out deviating from the operating procedure.

Determination of action recommendations (Action) - Recommendations for hazard improvement and control measures are carried out using 5 control hierarchies adapted to the operational process, sources of hazards, potential hazards, risks, deviations, and causes of accidents.

Hazard level assessment - Hazard level assessment is carried out after recommendations for improvement and control of the operational process with the highest level of hazard to find out if the recommendations have succeeded in lowering the hazard level of the operation with the highest level of danger.

It was also necessary to set one stage of the operating process for the study application. For analysis and identification of the HAZOP method, spreadsheets with color scales for mapping risk and weighting scales were structured, as shown in Table 3.4.

For the application of HAZOP, two Knots of the flame tube boiler's system were considered. The first was in the boiler's water source, and the second was in the pressure vessel's steam power. Therefore, the HAZOP application was completed in the boiler's water and pressure (steam) movements.

3.3 Failure mode and effect analysis (FMEA)

FMEA is a hazard analysis technique that can pinpoint the potential causes and effects of an item, structure, or system failure. Failure modes, or the reasons why a component might stop working or become damaged, are created by FMEA. As a result of this research, recommendations are made to increase production safety and equipment reliability [16]. Data is gathered from machine history or interviews collected from the engineering department to help FMEA work. The boiler component identification is made now to rank the risk. By multiplying the severity (S), Occurrence (L), and

Detection (D), the RPN value is achieved (D). The FMEA worksheet utilized in this investigation is shown in Table 3.5.

Table 3.4 HAZOP Matrix of risk magnitude.

GRAVITY		PROBABILITY				
CATEGORY		1	2	3	4	5
		Improbable	Remote	Occasional	Probable	Frequent
		Once every 100 years or more	Once every 10 years	Once a year	Until five times a year	More than five times a year
5	Catastrofic (C)	5	10	15	20	25
4	Critical (CR)	4	8	12	16	20
3	Moderate (MO)	3	6	9	12	15
2	Marginal (MA)	2	4	6	8	10
1	Negligible (N)	1	2	3	4	5

RISK MAGNITUDE	
Magnitude	Probability x Gravity
Severe	10 to 25
Significant	4 to 9
Tolerable	1 to 3

Table 3.5 FMEA worksheet.

Item	Function	Failure Mode	Causal Factor	Effect Failure	Severity (S)	Occurrence (O)	Risk (RPN)	Description

3.4 Bowtie risk analysis

Threats (Preventive Measures) and Consequences are the two categories used in the Bowtie Risk Analysis (Mitigation Measures). A risky operation adds to an incident or occurrence. The Top Event is the point at which the hazard is released, and the Consequences are experienced. A list of preventive barriers is kept in case the incident, or Top Event, occurred. In contrast, mitigation barriers prevent, reduce, and mitigate the risk of substantial damages or injuries brought on by the top event. Mitigation Measures are locations where a risk assessment is necessary and where the risk action plan should be given priority. The process involves systematically identifying hazards and effects, assessing the associated risks, and specifying the control and recovery measures that must be in place and maintained in place. Barriers prohibit the escalation of the original threats to one of several outcomes, as shown by the primary threats on the left and illustrated in the shape of a "bow-tie." Barriers show the risk-control strategies that a firm has used. Each identified safety-critical barrier is given to a business group with a specific person in charge after being recognized. Risk in bow-tie methodology is elaborated by the relationship between hazards, top events, threats, and consequences (see Table 3.6).

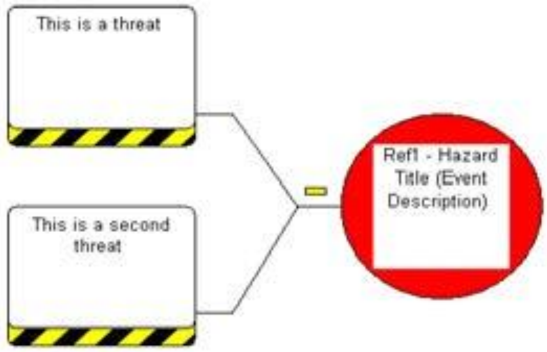
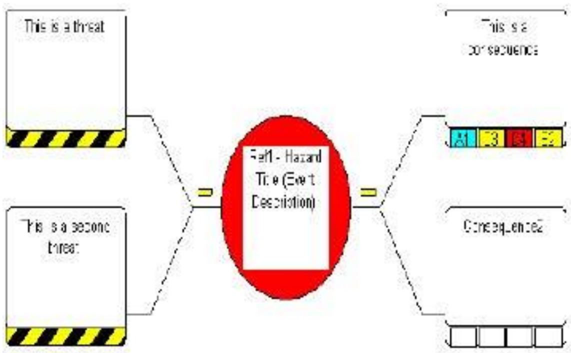
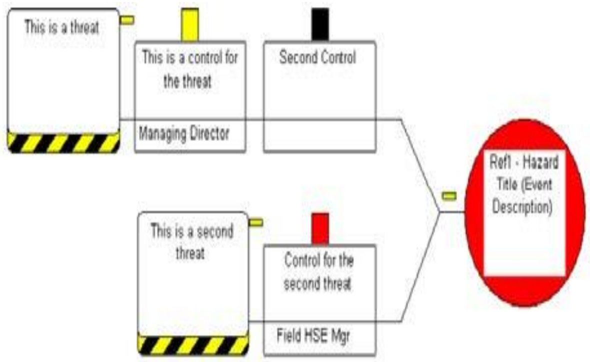
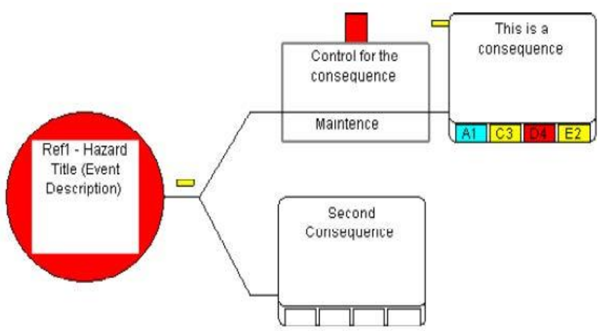
4 Results and discussions

4.1 Hazard identification, risk assessment and risk control (HIRARC)

This section discusses the results obtained from the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) study. The result showed the sources of the dangers are charcoal dust, sparks, heat radiation, falls, pinched, charcoal sprinkle, noise, high electric pressure, explosion, fire, hot material, exposure to chemicals, inhaling chemicals, steam, leaks in drum steam, hot water, excess gas pressure, and embers. The following is a table of observations regarding hazard identification actions in the boiler operation.

In this research in the boiler division, a hazard identification observation sheet aims to obtain accurate data and measure the success rate of research objectives. From the interviews and identification tables in the observation sheet, it was found that workers in the boiler division carried out twenty-one (21) work activities, as shown in Table 4.1. Thus, it can be concluded that workers in the boiler division do not fully understand the dangers in the work environment. They only expressed the dangers that come from hot materials or fuel, noise, and electricity, which can be said to have Highs, but they do not yet fully understand the sources of danger in the working environment of the boiler division. Then the next step is risk assessment and control so that it becomes a HIRARC registration document which will be compared with secondary data, namely the company's HIRARC.

Table 3.6 The bow-tie steps.

Steps	Model
Step 1. Identify the bow-tie hazard	
Step 2. Assess the Threats	
Step 3. Assess the Consequences	
Step 4. Control	
Step 5. Recover	

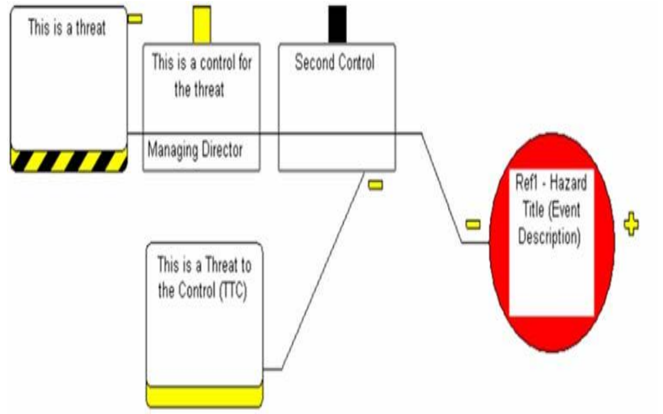
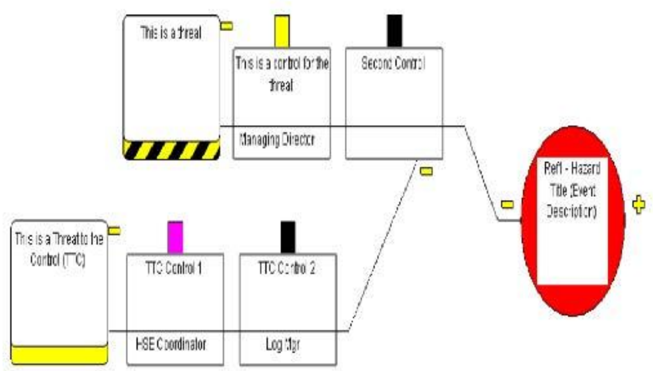
Step 6. Identify threats to the controls	
Step 7. Identify the controls for the threats to the controls	

Table 4.1 Impact matrix for boiler operation.

No	Location	Activities	Potential Hazards	Risk Level
1	Warehouse	Initial unloading of coal transported using container trucks and coal stored for the combustion process	1. Coal Dust	Medium
			2. Sparks	Medium
			3. Heat Radiation	Medium
2	Hopper	The process of protruding coal in the area will have flowed to each conveyor if there is a blockage in the area	1. Heat Radiation	Low
			2. Fall	Low
3	Conveyor	Distributing coal that is ready for use for the following process in the combustion process.	1. Stuck	Low
			2. Heat Radiation	Medium
4	Crusher	Cracking coal according to a predetermined size so that the combustion process can run smoothly if the fuel is following what is needed	1. Coal Dust	Medium
			2. Coal Splash	Low
			3. Noise	Medium
5	Triway	Separating coal that is following its size in boilers 1 and 2 for the combustion process	1. Stuck	Low
			2. High-Pressure Electricity	Medium
6	Bunker	Collects coal to be burned in the furnace after being carried by the conveyor before the coal is fed through the coal feeder	1. Heat Radiation	Medium
			2. Fall	Low
7	Coal Feeder	Receive coal from the coal bunker and control the amount of coal that is put into the pulverizer	1. Coal Dust	Medium
			2. Noise	Medium
8	Furnace	Overall process in the combustion process in boilers that have met the previous requirements and must attach importance to safety for this combustion process	1. Explosion	High
			2. Burn	High
			3. Hot material	Medium
			4. Coal Dust	Medium

			5. Heat Radiation	Medium
			6. Noise	Medium
			7. High-Pressure Electricity	Medium
9	Chemical Maintenance Boiler	Controlling pH and corrosion control in metal boiler water and steam pipes. Since the feed water content of boilers often contains impurities that damage boiler operation and efficiency, it is this substance that will fix the problem	1. Exposed to chemicals	Low
			2. Inhaled	Low
10	Line Steam	Regulate the course of steam in the combustion process so that the steam is stable to the steam drum	1. Noise	Low
			2. Heat Radiation	Low
11	Reheater	Reheat (raise) the vapor temperature on the superheater to get the heat back in this process	1. High-Pressure Electricity	Medium
12	Steam Drum	Collects water from the economizer to be heated by the standard water cycle method, where water with a lower temperature will drop and water whose temperature will enter the drum while releasing the steam to be separated between the steam and the water	1. Hot Steam	High
			2. Heat Radiation	Medium
			3. Leakage in the drum	Low
13	Cyclone	Collecting coal that does not burn in the furnace process to be pushed back using a compressor so that it re-enters the furnace process	1. Coal Dust	Medium
			2. Sparks	Low
14	Super Heater	Further heating *saturated* steam (saturated steam until it produces completely dry steam)	1. Hot Steam	High
			2. Hot Water	Low
15	Economizer	Heating water after passing through the high-pressure heater, the heating is carried out by utilizing the heat from the flue gas, which is the residue of combustion in the furnace	1. Hot Steam	Low
			2. High-Pressure Electricity	Low
			3. Excess Gas Pressure	Low
16	Chimney	Provides ventilation for hot exhaust gases or smoke from the boiler furnace to be discharged into the outside atmosphere	1. Coal Dust	Low
			2. Heat Radiation	Low
17	Downcomer	Flow the hot grains of water to be heated through the pipes arranged in the furnace wall	1. Hot Water	Low
18	Scoot blower	Cleaning deposits, ash, and slags by using steam so that the flow of gas can carry away dust, ash, or soot	1. Coal Dust	Medium
			2. Heat Radiation	Low
19	Safety Valve	Protects against the danger of overpressure in boiler steam, as well as protects piping and other process tools	1. Excess Gas Pressure	Low
			2. Coal Dust	Medium
20	Burner	Burning coal and silica sand and also used High-Speed Diesel to make coal more flammable	1. Burn	Medium
			2. Embers	Medium
21	Id Fan	Vacuum the boiler so that the gas flow rate becomes smooth and sucks the combustion gas starting from the furnace, passing through the air heater to the stack (chimney)	1. Coal Dust	Medium
			2. High-Pressure Electricity	Medium

From the results of the risk assessment analysis in Fig. 4.1, it is known that the risk value and percentage of risk of all potential hazards, namely, Low as many as 21 types of danger (42.8%), Medium (Medium) as many as 17 types of danger (34.7%), Medium (Medium) as many as 7 types of danger (14.3%) and High (High) as many as 4 types of hazards (8.2%). Furthermore, based on the type of danger, namely, mechanical hazards as many as 12 types of hazards (24.5%), electrical hazards as many as 5 types of hazards (10.2%), chemical hazards as many as 3 types of hazards (6.1%) and physical hazards as many as 29 types of hazards (59.2%).

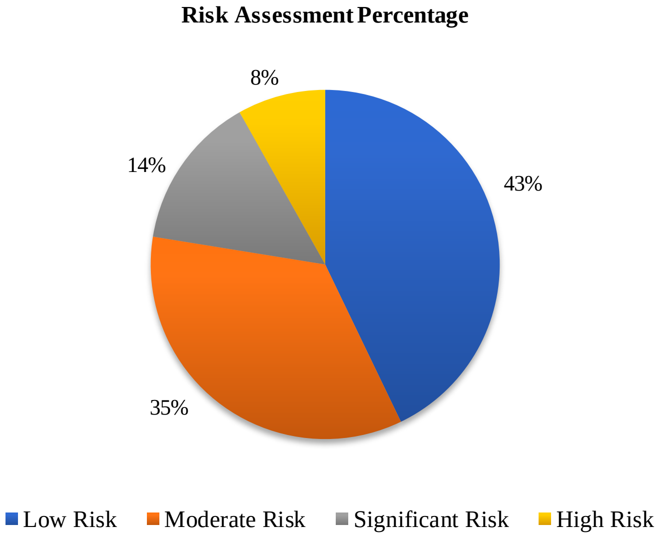


Fig. 4.1 Risk assessment percentage that has been processed from the identification results.

4.2 Hazard and operability study (HAZOP)

HAZOP is a qualitative analysis technique developed to examine the process lines, identify hazards, and prevent problems. In this paper, its analysis was performed through words that guide the reasoning of multidisciplinary study groups for identifying operating discontinuities. Its application was through three basic procedures: (i) identification of the "Connections," which are the probable critical points in the system; (ii) determining the guide words able to cover the possible deviations of the evaluated system; and (iii) assessment of deviations and proposition of mitigation alternatives. In this work, two steps of the boiler operation were analyzed as limiting factors: water flow and pressure. Both processes have a significant impact on boiler operation, in this case. Therefore, the methodology includes both cause and consequence. The application of HAZOP for the first Knot is presented in Fig. 4.2, while Fig. 4.3 shows the application for the second Knot.

The methodology applied produces a classification of the risks in five different categories: Negligible (N); Marginal (MA); Moderate (MO); Critical (CR); Catastrophic (C). If the risk belongs to the "Catastrophic" category, the corrective measures will be set immediately, no matter their cost. On the other hand, if the risk goes to the "Marginal" category, the company will develop a program to establish the planned procedures to remove the described risks or change them into "Moderate" risks.

The HAZOP application pointed to critical points of the system. For the first Knot, the known deviation was apparent concerning the low water flow (guide word: less). Furthermore, for the second Knot, pressure (steam), the deviation is connected to the pressure of low steam (guide word: less) of steam pressure. Therefore, the corrective actions are (i) implementation of an operating manual for the boiler; (ii) piping's preventive maintenance; (iii) operators' training; and (iv) application of an alarm (andon) system for low water level.

4.3 Failure mode and effect analysis (FMEA)

The FMEA revealed that boiler tubes, shells, mud door gaskets, steam feed water pumps, and safety valves are critical components of the boiler system. From the identification of 52 components in the boiler using the FMEA method, it was found that 2 components were included in the high-risk category, and the attemperator and fed water pump components are included in the high-risk category. So that the attemperator and feed water pump components are the top events that will be identified by the Bow tie method.

HAZARDS AND OPERABILITY STUDY (HAZOP) - KNOT 1 - WATER FLOW											
System: Boiler 1					Assessor: Mohd Fahmi Bin Mohd Yusof						LEGEND Tolerable Significant Severe
Project parameter	Guide word	Deviation	Causes	Detections / Safeguards	Consequences	Prob.	Severity		Magnitude		Recommendations and observations
							S	Pr	S	Pr	
Flow	More	High Flow	1. Failure in the pressure switch of the water supply automatic system	Anual calibration and periodic inspection	SECURITY AND HEALTH Explosion of the boiler with consequent injuries to the people PATRIMONY Severe damage in the boiler	2	5	2	10	4	Elaborate and implement a maintenance plan (preventive and e predictive) of the line and a calibration plan
			2. Failure in the boiler's indicator level (float)	Anual calibration and periodic inspection		2	5	2	10	4	
			3. Steam leakage in the water level	Periodic inspection and corrective maintenance		2	5	2	10	4	
			4. Electric failure in the pump since there is failure in the pressure switch and level	Periodic inspection and corrective maintenance		2	5	2	10	4	
Flow	Less	Low Flow	1. Incrustation in the water pipe	Control of water outflow in the system and monitoring and control the demineralization system avoiding saturation	SECURITY AND HEALTH Temperature increase, emission of black smoke and fire in the boiler PATRIMONY Deformation of the internal piping and of the boiler itself	5	1	3	5	15	Implementation of an alarm system (andon) of low water level
			2. Pump failure (mechanical, electrical, cavitation, etc)	Periodic inspection in the pump		3	1	3	3	9	
			3. Semi-open valve	Periodic inspection in the valve		2	1	3	2	6	
			5. Failure in the level	Visual inspection of the level		3	1	3	3	9	
			6. Failure in the pressure switch	Sound signal for low level of water and visual inspection of the level		2	1	3	2	6	

Fig. 4.2 HAZOP Application Knot 1 – Supply of cold water in the boiler.

HAZARDS AND OPERABILITY STUDY (HAZOP) KNOT 2 - STEAM PRESURE											
System: Boiler 1					Assessor: Mohd Fahmi Bin Mohd Yusof						
Project parameter	Guide word	Deviation	Causes	Detections / Safeguards	Consequences	Prob.	Severity		Magnitude		Recommendations and observations
							S	Pr	S	Pr	
Flow	More	High Pressure	1. Excess of fuel in the boiler	Boiler and pressure vessel's manometer	SECURITY AND HEALTH Explosion risk PATRIMONY Disconformity in the productive process	1	5	3	5	3	Elaborate and implement a maintenance plan (preventive and predictive) Substitution of the manual register by an automatic controller Invest in qualification for boilers operators
			2. Pressure register closes during the boilers' operation (Possible operator's failure)	Visual Inspection		2	8	3	16	6	
Flow	Less	Low Pressure	1. Obstruction or leakage in the oil pipe	Boiler and pressure vessel's manometer	SECURITY AND HEALTH Commitment to the productive process PATRIMONY Expenses with corrective maintenance	3	5	4	15	12	Elaborate and implement a operating plan (manual) and preventive maintenance schedule Investiment in the boilers's course of operation for the operators
			2. Operating failure of the operator during the boiler's pressure control (oil and water)	Visual Inspection		3	5	5	15	15	

Fig. 4.3 HAZOP Application Knot 2 – Pressure (Steam).

4.3 Bow tie risk

Table 4.2 shows that of the 52 components identified in the FMEA, the attemperator and feed water pump components are included in the high-risk category. So that the attemperator and feed water pump components are top events that will be identified by the Bow tie method, as seen in Figs. 4.4 and 4.5.

Table 4.2 FMEA worksheet results.

No.	Item	Function	Failure Mode	Causal Factor	Effect Failure	Severity (S)	Occur-rence (O)	Risk (RPN)	Risk Level
1	Attemperator	Vapor components used to degrade the temperature on the boiler for steam supply in jet conditioning engines	Clogged Spray Head, Leakage in attemperator	Lack of maintenance, service life	The resulting steam is too hot, and can damage the quality of tobacco as well as jet conditioning engine components	5	3	15	High
2	Feed water pump	Pumping water feed to boiler	Broken impeller, leaking pipe header	Service life, lack of maintenance	No water Heated In boilers, boilers exploded	5	3	15	High

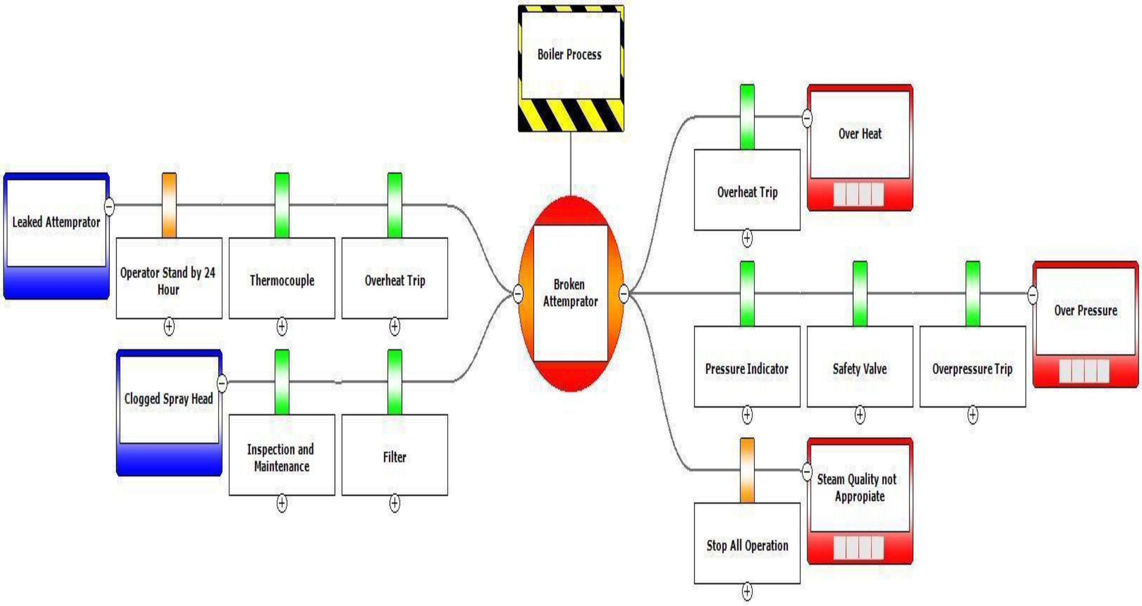


Fig. 4.4 Bow tie diagram results on the attemperator.

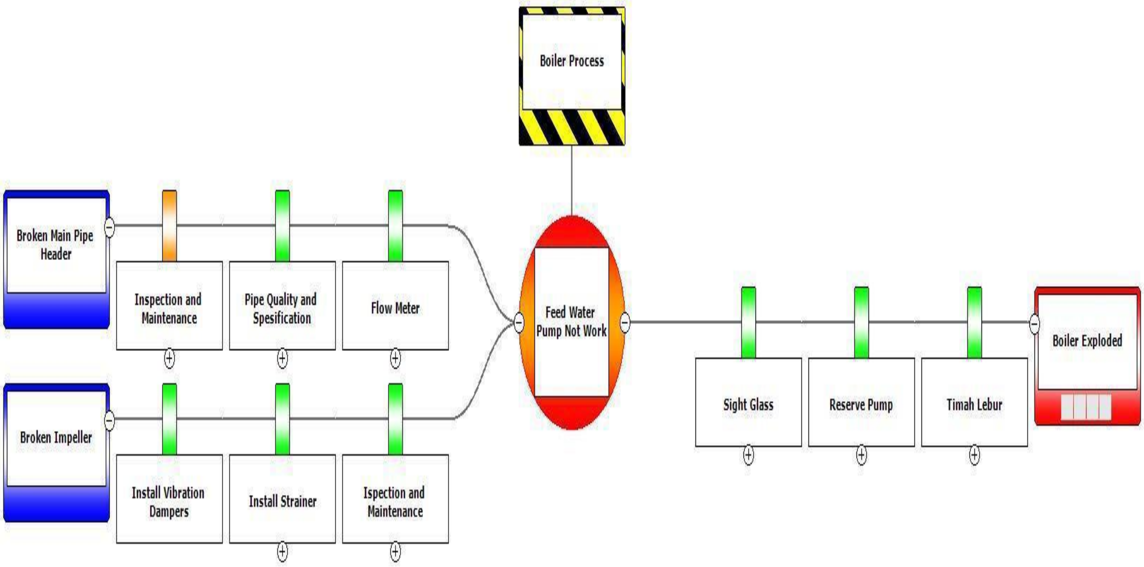


Fig. 4.5 Bow tie diagram results on feed water pump.

Conditions of the high level of risk require a minimum of 1 high effectiveness barrier and 1 medium effectiveness barrier for each threat and one barrier for each consequence. Thus, from the results of identification of the attemperator using the bow tie method, the barriers on each threat are considered insufficient because they only have 1 low effectiveness barrier, each indicated by a red mark. Therefore, it is necessary to add a barrier with a high effectiveness barrier, such as thermocouple installation, overheat trip installation, and filter installation on the attemperator.

The results of the identification of the feed water pump using the bow tie method, the barrier in threat 1 are sufficient, but in the field, there is still often damage to the pipe header, so it is recommended to add a barrier in the form of selecting the correct pipe specifications. The barrier on threat 2 is considered insufficient because it only has 1 low effectiveness barrier indicated by a red mark. Therefore, it is necessary to add barriers with a high effectiveness barrier level, such as the installation of vibration dampers and the installation of strainers.

5 Conclusions

The critical contribution of this research is to create risk management frameworks for boiler operations with improved risk assessment methodologies. The proposed risk management framework includes the inclusion of risk frequency in risk rating calculations, risk criteria parameters for risk likelihood and risk severity, new risk matrix dimensions and instruments to evaluate the existing control measure factors, and new risk categories with five levels that provide more information and a sustainable risk assessment method. This makes it easier to use risk management to address boiler operations' ongoing occupational safety and health issues. The integration of sustainability considerations in boiler operating safety and risk management may be resolved by the created risk management framework and improved risk assessment procedures. Further research could expand the scope of the study to other boiler operations in other countries and cover the whole boiler operations.

Declaration of Conflict of Interest

The authors declared that there is no conflict of interest with any other party on the publication of the current work.

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