Operational Risk Identification and Mitigation of the Chemical Production Process of PT. X Using Failure-Mode and Effect Aalysis (FMEA) and Chemical Health Risk Assessment (CHRA) Methods

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***Abstract*—PT. X is a German-based multinational chemical company that produces surfactant as one of its products. As a chemical processing company, the operational activities of the production process in PT. X poses risks that could happen at any time. This research is conducted to identify, analyze, and propose mitigation plan for the risks in one of the plants operated by PT. X. Interviews are conducted to identify the risks using Fishbone diagram as the framework and the Ishikawa method to categorize the causes. There are 86 risks that are identified consisting of 51 operational risks and 35 risks of chemical exposure. To be more thorough, the identified operational risks are assessed using the Failure-Mode and Effect Analysis (FMEA) and the chemical exposure risks are assessed using the Chemical Health Risk Assessment (CHRA). From the 206 risk causes, 31% are caused by Man, 28% are caused by Machine, 22% are caused by Material, 15% are caused by Method, and 5% are caused by the Environment. The FMEA produces Risk Priority Number (RPN) which led to risk prioritizing using the Pareto diagram and risk mapping, resulting in 24 risks being prioritized that consists of 15 medium-level risks and 9 low-level risks with no high-level risk present. The CHRA produces Risk Rating (RR) and Level of Risk that resulted in 77 low-level and 19 moderate-level risks for risk for inhalation exposure, and 9 moderate-level risks and 86 high-level risks for the exposure through dermal contact. It produces the decision of 17 inadequate control measures for chemical exposures. These assessments are further processed to devise the appropriate contingency plan, mitigation plan, and action plan.**

***Keywords*—Risk Management, Failure-Mode and Effect Analysis, Chemical Health Risk Assessment, Risk Response Plan.**

I. INTRODUCTION

SURFACTANT is not a commonly known word, yet the world depends on it. According to Y. Nakama on Cosmetic Science and Technology, surfactants are substances that create self-assembled molecular clusters called micelles in a solution (water or oil phase) and adsorb to the interface between a solution and a different phase (gases/solids). In simpler terms, surfactant reduces surface tension between liquid and liquid, solid, or gas. It may act as a wetting agent, emulsifier, foaming agent, and dispersant in products like inks, emulsions, paints, sanitizers, shampoos, toothpaste, detergents, inks, firefighting foams, insecticide, and others.

The market for surfactants was valued at over USD 36 billion in 2020, and it is anticipated to grow at a Compound Annual Growth Rate (CAGR) of over 4% in terms of revenue over the following five years (2022-2027). COVID-19 had a negative effect on the market in 2021. Due to the pandemic scenario, several nations were put under lockdown, which caused people to drive less frequently. This had a negative effect on the demand for lubricants and fuel, which in turn reduced the demand for fuel additives and surfactants. However, the current situation has seen an increase in the awareness of personal hygiene and clean environments, which has sparked the need for personal and household cleaning products and boosted the market growth of surfactants.

The importance of surfactant is seen on its derivative products such as toiletries and household cleaning items. With a compound annual growth rate (CAGR) of 15.1%, the worldwide toiletries market is anticipated to increase from $190.14 billion in 2020 to $218.8 billion in 2021. In 2021, the actual market for household cleaning goods was worth USD 235.76 billion. The market is anticipated to increase at a CAGR of 4.4% between 2022 and 2029, rising from USD 247.94 billion in 2022 to USD 334.16 billion in 2029. The impact of COVID-19 on the world has been unprecedented and staggering, and the pandemic has resulted in a rise in demand for household cleaning products in every region.

Some of the major players of surfactant industry are Nouryon, Evonik Industries AG, Kao Corporation, Stepan Company, and PT. X. PT. X is a German-based multinational chemical company that produces surfactant as one of its products. PT. X produces several types of surfactants and several types of other chemicals as well. PT. X acts as a supplier for companies such as Unilever that produces household items. To keep up with the demand, and as its core business process, PT. X operates in several chemical plants that produces a very huge amount of chemicals daily. This condition made PT. X vulnerable to accidents and hazards.

These accidents and hazards, should they happen, will incur loss to the afflicted person as well as the company. The afflicted person will at least have an injury, and the company have to take care of the person while suffering from economical and production loss. Even though it may not happen, the potential of the event happening is a risk that cannot be ignored. Other risks are also threatening the production process of PT. X. Equipment failure, operator error, and other things may happen at any given time. For

Table 1.
Risk Identification

No.	Risk Code	Potential Failure Mode
1	R33	The product gets lumped inside the hopper
2	R6	Sulphur pump failure
3	R9	Cooling blower for SO3 failure
4	R16	Ph fluctuation
5	R23	The electrodes snapped off
6	R1	The discharge from the compressor is over pressured
7	R2	Air temperature discharged is too high
8	R20	The product forms bubbles
9	R26	The concentration of active meter and water in the VHAN fluctuate
10	R30	The temperature is not hot enough to dry the ammonia gas
11	R32	The chain of the scrapper snapped off or malfunctioned
12	R35	The moisture is not completely absorbed
13	R36	The vacuum for the intensive filter broke down
14	R7	Pipe heater to burner failure
15	R8	Cooling blower for SO2 failure
16	R10	Inner tube of the shell and tube heat exchanger leakage
17	R11	Disturbed fatty alcohol flow
18	R14	Cooling water for SO3 reactor failure
19	R15	The temperature in the neutralizer is too high
20	R21	The pipe is leaking
21	R24	The temperature in the VHAN is too high
22	R34	The extruder stopped in the middle of production
23	R37	The mechanical seal on the agitator wears down
24	R38	The agitator stopped working
25	R17	The concentration of active meter and water fluctuate
26	R19	The operator connected the wrong line
27	R25	Ph fluctuation in the VHAN
28	R28	The hot water for plate heat exchanger is blocked
29	R31	Condenser vacuum failure
30	R39	The mixer stopped working
31	R40	The operator does not use the right method to lift the sacks
32	R8	Cooling blower for SO2 failure
33	R27	Overdosed peroxide in the VHAN
34	R5	Transfer failure
35	R12	Disturbed fatty alcohol distribution in the tubes
36	R18	Overdosed peroxide
37	R29	The paste is not drained perfectly before continuing the process
38	R22	The palettes get knocked down
39	R3	Forklift is unavailable
40	R4	Material spillage

example, one of the processes in PT. X is prone to blocking because both the material and the process is sensitive. It has been a continuous failure since it was implemented and even though improvements have been made it still is a repeated event. Once the process is blocked, it takes 2-4 days to clean the equipment before it can restart the production which is a big loss to the company. Another example was that there was an accident where an employee got splashed by hazardous chemical that burns the skin. Therefore, this research is expected to support PT. X in identifying the risks on the production process.

Limited to the operational risks, this research will divide the risks into the operational risks that may happen on the production floor, and the risks posed to the employees because of the exposure from the chemicals. The methods used in this research are Failure Mode and Effect Analysis (FMEA) for the operational risks and Chemical Health Risk Analysis (CHRA) for the chemical exposure risks. Based on several studies, both FMEA and CHRA methods give significant result for the organization. For example, in the journal article "Risk Assessment Using the FMEA Method in the Organization of Running Events" by Peter Kardos, et al. in 2021, the application of the FMEA method's modified technique led to a precise evaluation of the organization's risks. The FMEA has an impact on the broader organization, internal policies, and processes in addition to helping identify and evaluate risks. While in the journal article "Chemical Health Risk Assessment at the Chemical and Biochemical Engineering Laboratory" by Siti Nurul Hunadia Husin, et al. in 2011, the results of the evaluations using CHRA shows the significance of the danger of exposure to hazardous substance and the adequacy of current control methods in order to create a secure working environment. After the risks have been identified, a contingency plan and an action plan will be designed for PT. X as a recommendation on how to face the risks.

II. LITERATURE REVIEW

A. Risk

The Oxford English Dictionary defines risk as a chance or possibility of danger, loss, or injury or other adverse consequences. Risk is the effect of uncertainty on objectives. What it means by effect is deviation from the intended objective that can be either good or bad. Working towards an objective in the future pose an uncertainty of events that could affect the outcome of the intended objective. So, a risk is something that has not happened yet, it is a potential event that could deviate the intended outcome.

B. Accident

Accidents are unintended, unplanned events that cause damage or loss to people, things, productivity, or almost anything else that has intrinsic value. Through higher

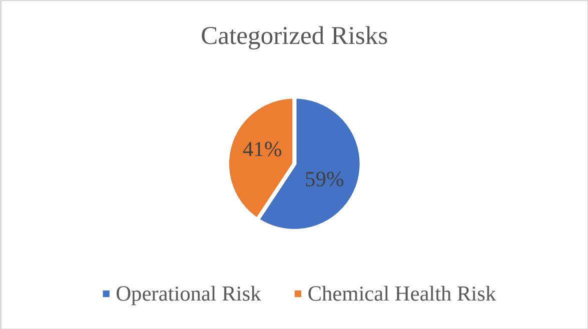

Figure 1. Identified Risk Categorization.

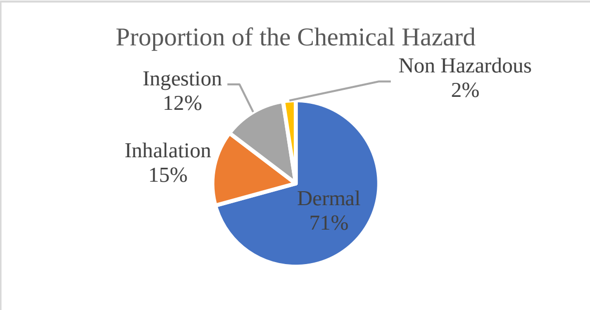

Figure 2. Proportion of Chemical Hazard.

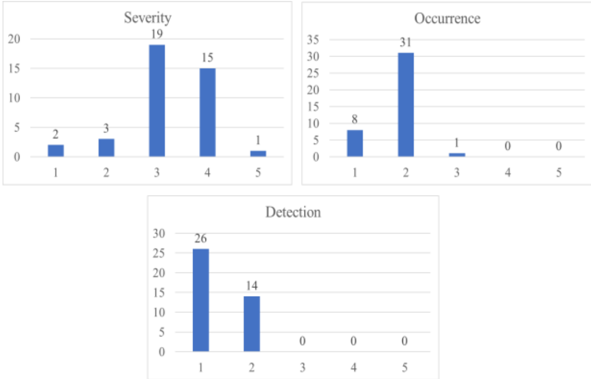

Figure 3. Risk Criterion distributions.

manufacturing costs, poorer productivity, and long-term repercussions on staff morale and public perception, these losses raise an organization's operational costs [1]. All accidents have causes, and it requires a further act of faith to believe that the vast majority of accidents can be avoided. However, accidents rarely occur as a result of a single cause. Typically, there are several contributing factors. One is typically referred to as the direct reason when it predominates, but others may be contributory causes [2].

C. Hazard

A hazard is a situation that may cause injury, death, property loss, equipment damage, or environmental destruction. Hazard itself can be defined as the source of energy as well as the physiological and behavioral elements that, when out of control, result in hazardous events, according to Merna in 2007 [1]. A failure of a system or component may result in a hazard, although this is not necessarily the case; a hazard may still exist.

There is a difference between a hazard and a hazard event. Hazards "may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation," but a hazardous event is the "manifestation of a hazard in a particular area during a particular period of time". According to the United Nation Office for Disaster Risk Reduction (UNDRR) in 2020, hazards are clustered into meteorological and hydrological hazards, extraterrestrial hazards, geohazards, environmental hazards, chemical hazards, biological hazards, technological hazards, and societal hazards.

D. Process Safety Management (PSM)

In procedures involving highly hazardous chemicals, unanticipated discharges of toxic, reactive, or flammable liquids and gases have been documented for a long time. Various industries that use highly hazardous chemicals that can be toxic, reactive, combustible, explosive, or exhibit a mix of these traits continue to experience incidents. Any time these extremely dangerous compounds are not properly regulated, there is a risk of an unintentional release regardless of the industry that utilizes them that could cause a disaster. To help ensure safe and healthy workplaces, Occupational Safety and Health Association (OSHA) released a proposed standard called "Process Safety Management of Highly Hazardous Chemicals" that contains standards for the management of hazards connected with processes involving highly hazardous chemicals [3].

E. Risk Management

ISO define risk management as coordinated activities to direct and control an organization with regard to risk. External and internal causes and influences affect organizations of all types and sizes, making it questionable if they will achieve their goals. Risk management is an iterative process that aids businesses in developing strategies, attaining goals, and making well-informed decisions. It's a part of governance and leadership, and it's crucial to how the company is run at all levels. It aids in the development of management systems. Risk management encompasses all aspects of an organization's operations, including interactions with stakeholders. Considering the organization's external and internal contexts, as well as human behavior and cultural elements.

F. Failure-Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is a methodical approach for identifying and preventing issues with products and processes before they arise. The goals of FMEA were to reduce defects, improve safety, and boost customer happiness. Finding every potential failure mode for a process or product is the goal of an FMEA. When a product performs improperly or malfunctions in some other way, it is considered to have failed. Failures are not just restricted to defects in the product. Because user error can sometimes result in failures, the FMEA should also account for these kinds of failures. Anything that can be done to guarantee that the product functions properly regardless of how the consumer uses it will bring it that much closer to having completely satisfied customers [4].

G. Chemical Health Risk Assessment (CHRA)

One of a company's main responsibilities is to safeguard workers against the harmful effects of chemicals. It is necessary to assess every chemical used at work in order to determine, evaluate, and manage any health risks connected to work activities involving the usage of the chemicals. As a

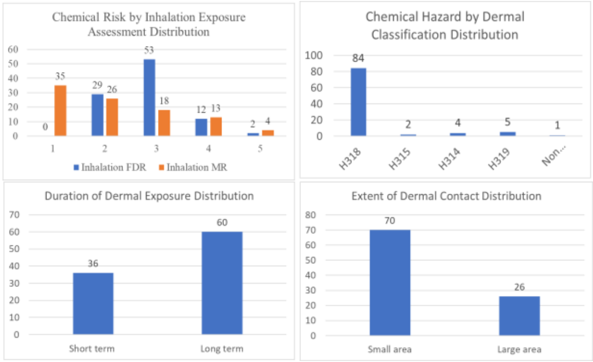

Figure 4. Chemical Health Risk Assessment.

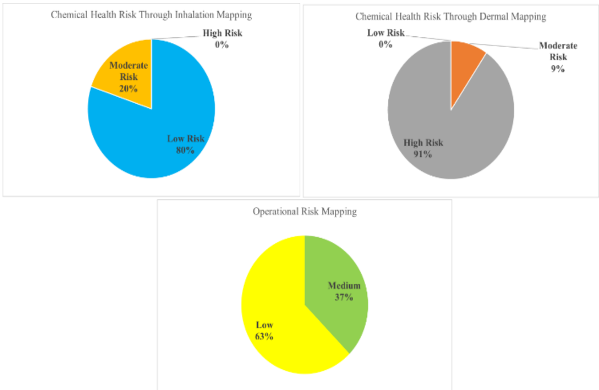

Figure 5. Risk Mapping Categories.

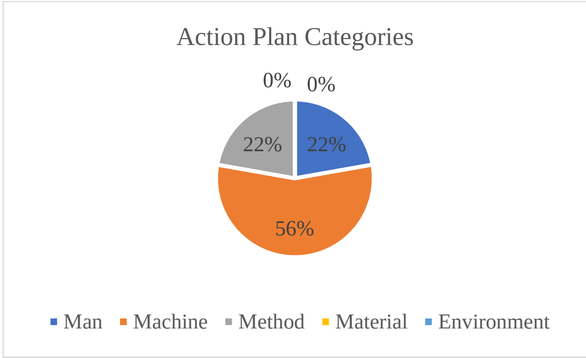

Figure 6. Risk Response Categories.

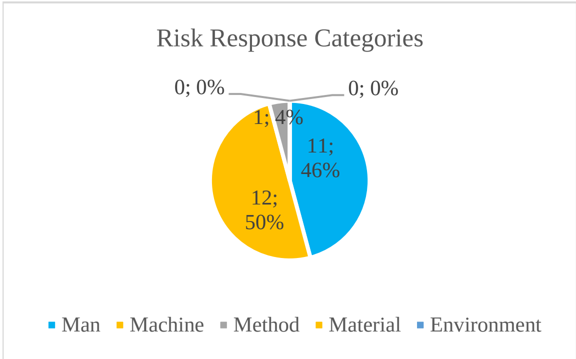

Figure 7. Action Plan Categories.

result, it is the company's responsibility to evaluate any potential health concerns associated with the use of chemicals harmful to humans or CHTH in the workplace. The evaluation of how CHTH are used at work and the associated health hazards constitutes an assessment of risk to health. The decision of the appropriate course of action to limit worker exposure will rely on the level of health risk associated with the usage of CHTH in a certain job activity. One of the ways to carry out an assessment regarding how CHTH affect the employees is by conducting a Chemical Health Risk Analysis (CHRA). It is done to ensure that any decisions regarding the appropriate control measures, worker induction and training, exposure monitoring program, and medical surveillance program of CHTH in the workplace can be done as effective and efficient as possible [5].

H. Contingency Plan

A contingency is something that could potentially occur in the future and frequently results in issues or necessitates further preparations. A contingency plan is a strategy created to assist an organization in effectively responding to a large potential future event or circumstance. Because it might be used as an alternative course of action in the event that projected results are not realized, a contingency plan is frequently referred to as "Plan B". Contingency plans are backup plans that companies only use when a catastrophe or unforeseen circumstance affects business operations or poses a risk to their employees. It is a plan for a scenario and a result when the original plan fails or cannot be carried out. A contingency plan can also be seen as a tool for controlling the risk that the scenarios pose.

I. Action Plan

An action plan is a summary or list of every job that must be carried out in order to accomplish a goal. Action plans can be utilized to achieve both big and little goals. It can be modified for both group and individual purposes. The best technique to construct an action plan varies. It can be set up in any way that makes it easier for the user to keep track of all they need to do to reach their goal. Action plans are frequently laid out as tables or spreadsheets, with the first column listing each job, task, or stage and the following columns listing other crucial information.

J. Fishbone Diagram

A cause-and-effect diagram, sometimes known as a "fishbone" diagram, can be helpful for categorizing concepts and brainstorming potential causes of a problem. A fishbone diagram provides a visual representation of cause and effect. The issue or result is seen at the fish's mouth or head. On the smaller "bones," numerous cause categories are indicated along with potential contributory causes. By instructing the team to look at the categories and examine alternate causes, a fishbone diagram can be useful in identifying potential explanations for an issue that might not otherwise be considered.

III. METHODOLOGY

A. Problem Identification

This phase contains the initial stages of conducting this research by formulating the background problems that formulate the objectives, then conducting literature studies and field studies to prepare the author for the project methodologically and analytically. The first step is to determine the problem statement of the project. Given to understand from the background, there are many risks involving the operational process of a large chemical company like PT. X which pose several threats either directly or indirectly to the company’s well-being. Then the problem triggers the objective of this project. Author needs to provide a risk management analysis for PT. X to give an assistance to avoid those risks.

The next step is to provide the necessary knowledge for the author. That is the use of literature studies and field studies. It aims to provide a deeper understanding of the concept of the research to be carried out. Field study was conducted with the aim of providing a detailed description of the business processes of PT. X, so that the risk aspects that can arise and the triggers for the risk can then be identified. Literature studies are more directed at providing study materials for research objects through literature in the form of books, journals, or previous research which consists of subjects regarding risks, risk management, FMEA, and CHRA.

B. Data Collection

This stage consists of collecting the data necessary to be the input in the next stages. The necessary data consists of the production process, the activities in each process, the chemicals and their hazardous characteristics, the risks of each activity, the causes of each risk, the impact of each risk, and their control measures. Following the data collection, recording, and processing stages, lastly is to analyze and interpret the result. There are two methods used in this research, namely FMEA and CHRA. The CHRA acted as a compliment for the FMEA because the latter could not assess the risk of chemical exposure effectively. The FMEA could not factor the risk of the chemicals and the extent of each exposure, conversely the CHRA could only assess the risk of chemical exposure. Which made both methods are indispensable to go hand-in-hand to assess the risk in a chemical production process.

C. Risk Assessment using FMEA

In the risk assessment stage, there are three tasks that must be carried out, namely risk identification, risk analysis, and risk evaluation. Therefore, at this stage it is also necessary to first collect data that will be used to identify risk events and risk agents. A risk event is a risk that could arise in a business process, and a risk agent is a risk trigger that can result in one or more risk events. Literature studies, past research on procurement risks, current firm risk data, and observations in field studies all contribute to the identification of risk agents and risk occurrences. The identified risks are then confirmed through interviews with experts from multiple areas from each associated business process unit for then to be analyzed and evaluated.

D. Risk Assessment using CHRA

In using CHRA, each chemical is paired with its respective tasks. Before doing so, it is necessary to identify the hazard classification of each chemical and information on the manual task regarding its duration, frequency, and intensity. The assessment itself is divided into risk through inhalation and risk through dermal, according to the route of entry. The risks are analyzed with the help of several matrixes provided by the Department of Occupational Safety and Health (DOSH) of Malaysia to find out the extent of the exposures.

E. Risk Response Planning

After the risk priority has been designed, an appropriate response has to be assigned to each of the selected risks. The general way to respond to the risks is either to mitigate, transfer, avoid, or accept each risk. After the decision has been made, a contingency plan is made regarding on how to treat the risks. The plan is made with the objective of completely eliminating the risks or to at least reduce the impact of the risks. After assessing the chemical hazard, chemical exposure, and the current control measure, the appropriate action needs to be taken. The decisions are based on the state of the assessment, whether it have a high, moderate, or low risk, and whether they have an adequate or inadequate control.

IV. RESULT AND DISCUSSION

A. Company Profile

PT. X is established in Mannheim, Germany, on April 6, 1865. The newly formed business will manufacture both the essential inorganic chemicals and dyes. PT. X has always been export-focused and markets its goods internationally. With an emphasis on chemicals, materials, industrial solutions, surface technologies, nutrition and care, and agricultural solutions, PT. X currently has six Verbund locations and 232 additional production sites spread throughout 90 countries. There are three industrial facilities in Indonesia, one of which produces chemicals for personal care products in Cimanggis, Depok.

B. Process Activities

The Cimanggis site of PT. X mainly produces surfactants as its product. There are three continuous processes and four batch processes that produces numerous types of surfactants. Its largest productions are carried out in the continuous processes which are sulfation, turbo-tube dryer (TTD), and grinder. It is found that there are 51 activities and 125 sub-activities, with 35 of which are done manually and came directly in contact with 17 chemicals.

All three processes are interconnected in that the core material came from the previous process. The first process is sulfation which turns sulfur into surfactant in the form of a paste. Some of the half-finished paste gets transferred to the TTD to be dried into solid product in the form of a needle. Then, the needle from the TTD is processed again in the grinder to make it into fine powder. Although the processes are connected to each other, the preceding process do not directly affect the succeeding process immediately. Each of them is a continuous process, but discrete towards the others. Each process finishes their own process before transferring the result to the next process and the output is also divided for distribution and work-in-process purposes. That means all of the processes is carried out simultaneously according to their own schedules, not dependent on others. Unless a significant situation arises where the work-in-process raw material from the preceding process are unable to be produced for a certain amount of time.

C. Risk Identification

After identifying work activities, risk identification is carried out for each of the sub-activity that has been identified. The risks identified are risks that have the potential to cause failure in work activities so as to impede or reduce the output quality of the observed operational activities. Table 1 is the result of the risk identification.

The risk identification process is done by interviewing the experts on the field, namely several operators, production department assistant manager, maintenance supervisor, and environment, health, and safety department, using the Fishbone diagram as the framework. It is done by analyzing the failure in each of the sub-activity that has happened before or could happen in the future and categorizing their causes using the Ishikawa method of man, machine, material, method, and environment. From all of the 125 sub-activities, 58 of which have no apparent risks according to the result of the interviews. Leaving 67 activities to be further analyzed. Later, it was found out that from those 67 activities, a number of 86 risks arose. The risks are then categorized into operational risks and chemical health risks after seeing that, as a chemical processing company, the risk of chemical exposure is quite significant for PT. X, thus it needs to be analyzed by itself. Figure 1 is the graphic of the risk categorization.

For the chemical health risks, the risk identification process is slightly different. It is done by using the GHS hazard classification system to identify the risks of the chemicals that came in contact with an employee in the manual activity. Each chemical may cause multiple hazards, and of all 17 chemicals a total of 41 hazards are possible. Figure 2 is a diagram of the proportion of the apparent chemical hazards according to their route of entry.

It has been mentioned before that the causes of the risks are being identified simultaneously using the Ishikawa framework. The result is from 86 risks, there are a total of 206 causes. Most of the cause came from the manpower, machinery, and material. It needs to be further analyzed as to why those three have the highest risk cause number. The risks caused by manpower mainly came from the manual activity which an operator came in contact with the chemical. There are some instances where the operator does not fully equip the regulated PPE. For this, PT. X requires all of the employees to undertake a job-specific training upon entering and also routine refresh training to remind all employees regarding the job regulation. PT. X also requires and/or provides the employees for necessary certification. For the machinery, the processes in PT. X mainly consists of automated process with adequate control measures. But it can be seen that there are still room for improvement. As for the material, it comes down to the nature of the chemicals used in the process which are very sensitive, sticky, and high in viscosity.

D. Risk Assessment

After the risks are done being identified, it is then assessed using the appropriate method. In this case, the methods are FMEA for the operational risks and CHRA for the chemical health risk. In FMEA, the risks are assessed using three criterion which are severity, occurrence, and detection. Severity indicates how significant the impact will be if the risk occurs, occurrence indicates the likelihood of the failure modes to happen, and detection indicates the level of effectiveness for the system to notice the failure modes before or when it happens. A questionnaire is distributed to some of the employees of PT. X to get the assessment value of the risk. To get the central tendency of the result, a median is calculated on the questionnaire responses. Figure 3 is the distribution for the severity, occurrence, and detection.

From the graphs above, it can be seen that only one risk possesses the severity scale of five. It means that the risk may cause safety-related catastrophic failure should it occur. The risk mentioned is failing pipe heater when transferring sulfur to the burner. Aside from the increasing viscosity of the sulfur, the malfunctioning steam heater may cause physical damage to an employee. For the occurrence and detection, it can be seen that almost all risk possesses the scale of one and two. It can be implied that the control measures and procedures are adequate enough to keep the failure modes down from happening.

In CHRA, the assessment process is quite similar. For each route of entry that is analyzed, the severity and occurrence of the risk is valued. But there are no detection criteria because it is happening daily, so the control measures are not just identified but also assessed. In CHRA, the severity is assessed using magnitude rating by finding out the degree of chemical release and degree of the chemicals absorbed for risk from inhalation exposure and comparing the hazardous qualities of the chemicals with the extent of contact for risk from dermal. For the occurrence, the frequency of the task and its duration is assessed for risk from inhalation exposure and duration of exposure is assessed for risk from dermal contact. Figure 4 is the distribution for the chemical health risk assessment.

For the inhalation exposure risk, two of the risks possesses the FDR scale of five and four of the risks possesses the MR scale of five. It means that there are instances where the operator came in contact with the chemicals for more than one time per day or per shift with seven or more hours per shift, and there are instances where the operator has to do heavy work in a heavily airborne chemical situation. For the dermal contact risk, it can be seen that most of the chemical possesses H318 classification that could cause serious eye damage or eye irritation in a long term and small area of contact.

E. Risk Evaluation

Risk evaluation consists of calculating the risk value (RPN, RR, and Level of Risk), mapping of the risks, and prioritizing the risks. RPN is the risk value of the operational risk that is obtained by multiplying the severity, occurrence, and detection values from the FMEA assessment. RR or risk rating is the risk decision for the chemical health risk through inhalation that is obtained by calculating exposure rating (ER. Level of risk is the risk decision for the chemical health risk through dermal contact obtained by comparing the hazardous qualities of the chemical, its duration of exposure, and the extent of the contact. Both factors are calculated using the CHRA matrixes provided by the DOSH of Malaysia. The operational risk with the highest RPN is R33 when the product gets lumped inside the hopper in the TTD process with the value of 24. The chemical health risk through inhalation with the highest RR is when the operator is filling, dry cleaning equipment, and wet cleaning equipment related to powder product in the grinder process with the value of twelve. For chemical health risk through dermal contact, the highest Level of Risk is H2 which are apparent in 53 activities.

These calculations are important for the next step of the process which is mapping and prioritizing. The RPN value is mapped according to the risk mapping matrix and prioritized using the Pareto diagram. For RR and Level of risk, they are mapped and prioritized using the result of the calculation paired with the adequacy of the existing control measures. The risk mapping categories can be seen in Figure 5. It can be seen from the Figure 5 that most of the operational risk and chemical health risk through inhalation consists of low-level risk while the chemical health risk through dermal consists of mostly high-level risk. For the operational risk, there is no high-level risk and only one that have the severity level of five that is already included in the Pareto diagram. So, it is decided that the risks outside the Pareto Diagram will not be included for further process. For the chemical health risk, after considering the RR and Level of Risk with the control measures, it is found that fourteen technical control measures are deemed inadequate which all belongs to engineering control and three organizational control measure in terms of personal hygiene and personal exposure monitoring.

F. Risk Response

The risk response planning consists of three types of planning. Contingency plan for the operational risk action plan in case the risk happens, mitigation plan to reduce the chances or impact of the risk before it happens, and action plan for the chemical health risk that is happening and have to be tackled immediately. The response plan is only devised for the prioritized risk, which means there are 24 operational risks and 9 chemical health risks. In devising the contingency plan, the aspects taken as consideration is the failure mode, the main cause, the trigger or indicator, and the response. For example, the air compressor may be over pressured because one of its discharge valves is closed, indicated by the slowing air flow intake in the drying bed that would cause production delay by inefficient reactions in the burner. Therefore, the maintenance team must standby to resolve the problem before it gets too much and the production is stopped.

In devising the mitigation plan, four general strategies are considered which are avoid, mitigate, transfer, and accept. Risk avoidance means to eliminate the risk, mitigation means to reduce the likelihood or the impact of the risk, transfer means to shifting the responsibility of the risk to another party, and acceptance means accepting the possibility of the risk happening. It was found that the actions are divided into avoidance and mitigation. There is no risk appropriate to be transferred or accepted, according to the experts in PT. X. There are 58% of the risks to be avoided, and 42% of the risks to be mitigated.

The response plan is also devised to resolve the causes that are categorized using the Ishikawa framework. This is done in hope that it helps PT. X when considering which part in their production process needs to be improved more urgently. The proportion of the actions categories can be seen in Figure 6. Inferred from the Figure 6, there are no recommended actions regarding material and environment. This is because with current technology, at least in PT. X, the chemicals used cannot be substituted or changed proportionally to avoid the risk in the chemical's nature and PT. X already design for the work environment to be as safe as possible. That being said, half of the actions are designed for the machinery, with manpower related actions are numbering in eleven or 46%, and method related actions are only one or 4%.

This number correlates with PT. X whose nature is capitally intensive, focusing on the process efficiency making almost all of the activity to be automated rather than increasing the number of manual activity or manpower. The number is still quite consistent with the action plan. After the chemical health risk assessment, it is found that most of the lacking control came from the machinery, then is the manpower and method. Figure 7 is the distribution of the action plan categories.

V. CONCLUSIONS AND SUGGESTIONS

A. Conclusions

The conclusions that can be drawn from this research. There are three main processes in PT. X that are divided into several activities and sub-activities. Each sub-activities are then analyzed to find out the risks that each sub-activity poses. The risk identification process is done by interviewing the experts using the Fishbone diagram and the Ishikawa method as a framework for the risk and its causes. From 125 sub-activities, 58 of which does not have an apparent risk so only 67 of them are processed further. There are 86 total risks that are present in the operational activities of the production process in PT. X and 51 of it is categorized as operational risks that is grouped as forty risks. After the operational risks have been identified, it is then assessed by the experts in PT. X which are the assistant manager of the production department, the maintenance planner supervisor, the EHS support, and an engineering consultant through questionnaire regarding the severity, occurrence, and detection of the risks. Because there are multiple respondents to the questionnaire, the median value of the answers is calculated to find the central tendency. The result is used for calculating the RPN of each risk to help the risk mapping and prioritizing process. The highest number of RPN in this research is 24 for R33 which is the product gets lumped inside the hopper. While the lowest number of RPN is one for R3 and R4 which are unavailable forklift and material spillage when in transfer using a forklift. Then the risks are prioritized using the Pareto diagram, resulting in 24 risks that are responsible for 80% of the system failure. The risks are also mapped into high, medium, and low but seeing that there is no high-level risk present it is decided that the risks included in the Pareto diagram is enough. Considering the risks with the severity scale value of five is already included. The final decision is there are 24 risks out of forty risks to be prioritized.

There are 86 identified risks in the operational activities of the production process in PT. X and 35 of which is the risk of chemical exposure in the manual activities. As a chemical processing company, especially in the SO3 plant, the operators in PT. X came in contact with nineteen chemicals in their manual tasks. There are 38 manual tasks that may be carried out multiple times for multiple chemicals. Each chemicals possess multiple hazardous qualities, and the chemicals possess 41 hazardous characteristics in total. With six is harmful if inhaled, 29 is harmful to human skin, five is harmful if swallowed, and only one chemical is considered as non-hazardous by the GHS classification. Therefore, the manual tasks that came in contact with the hazardous chemicals have to be analyzed. First is by identifying the frequency, duration, degree of release, degree of inhaled while working, the chemical's hazardous properties, its duration of contact with skin, and the extent of the skin contacted by interviewing the operators and reviewing the company procedures. That information is used to find out the exposure level of the chemicals to the operators through a series of matrixes. The exposure level is defined by risk rating (RR) for the exposure through inhalation, and Level of Risk for the exposure through dermal contact. There are 96 iterations of chemicals and tasks and the assessment resulted for 77 low-level risks, nineteen moderate-level risks, and zero high-level risk for inhalation exposure, and one riskless, zero low-level risk, nine moderate-level risks, and 86 high-level risks for dermal exposure. The highest RR value is twelve while the lowest RR value is two, and the highest Level of risk is H2 while the lowest Level of Risk is M1. The assessment result is used as a basis for determining the adequacy of technical and organizational control measures. The control measure analysis is done by interviewing the production department and engineering department. Technical control measure is divided into isolation control, engineering control, and PPE while organizational control is divided into organization's regulations on adoption of safe work system, information appropriation, personal hygiene, emergency response preparedness, personal exposure and general air level monitoring, medical surveillance, and specific actions to be taken regarding carcinogenic, mutagenic, and reprotoxic (CMR) chemicals. The result is there are fourteen inadequate engineering control, one inadequate personal hygiene control, and two inadequate personal exposure monitoring control. In the end, this method is treated as a complementary method for the risks that are part of the identified risks but are hard to accurately assessed using just the other method.

The risk response plan is divided into contingency plan, mitigation plan, and action plan. There are 24 actions for contingency plan and mitigation plan, from 24 prioritized operational risks, and nine action plans from the assessment results. It is divided because, according to the expert in PT. X, not all of the proposed actions in the mitigation plan that includes improvements and changes would be accepted. It will take quite a time to implement even if it was, so it was needed to propose another plan that could immediately be taken in case a risk occurs. Also, the chemical health risk needs to be handled immediately because prolonged exposure will cause more damage to the employee's health. For the mitigation plan, there is ten risks to be mitigated while fourteen are to be avoided with no risk to be transferred or accepted. The proposed response plan composed of twelve actions caused by the machinery that counted for 50%, eleven actions caused by the manpower that counted for 46%, one action caused by the method that counted for 4%, and no actions regarding material or environment. This result is consistent with the nature of PT. X to be capitally intensive rather that labor intensive.

B. Suggestions

The suggestions that could be given for future research. It may be necessary to analyze further regarding the interdependency of the risks by using a different method such as House of Risk (HOR), Analytical Network Process (ANP), or Bayesian Network.

To learn more extensively on the production process before continuing further research especially in designing the response plan.

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