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Failure Tree Analysis of CNC Plasma Cutting Machine for Occupational Safety on Shipyard

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Abstract*— The advancement of ship production technology in Indonesia involves the implementation of modern techniques integrating computer-based design and production facilities, such as Computer-Aided Manufacturing (CAM) for operating production machines utilizing Computer Numerical Control (CNC). One specific type of CNC machine utilized in ship production is the plasma cutting CNC machine. Despite being crucial to production, these machines frequently encounter failures that impede the production process. Through prior failure analyses conducted by the company, it has been identified that the dust collector air hose component exhibits the highest failure rate with six distinct failure modes. This article conducts qualitative and quantitative analyses of the causes of failure in the air hose dust collector of CNC plasma cutting machines using the Fault Tree Analysis (FTA) method. FTA is employed as a method to ascertain the fundamental causes of the event. The analysis results are utilized to provide recommendations for controlling objectives related to occupational safety. Six failure trees are generated, comprising a total of 28 basic causes. The most frequently occurring types of basic causes are associated with workers, methods, and materials. The probability of occurrence for the minimal cut set of each failure tree has been successfully computed. These calculations reveal that all top events possess probability values exceeding 76%. Specifically, the event of the dust collector air gap breaking has the highest probability value, reaching 99.8783%, which is a composite of 15 basic causes. Control recommendations are provided in the form of substitution, engineering solutions, and administrative controls.

Keywords— CNC Machine, Failure Cause, Fault Tree Analysis, Safety, Shipbuilding.

I. INTRODUCTION

Indonesia is home to approximately 250 shipyard industry companies with respective production capacities for new building and ship repair reaching 1 million dead weight tonnage (DWT) and up to 12 million DWT per year [1]. The majority of these shipyards are small-scale and dispersed across Indonesia. Among them, only 25 companies possess capacities ranging from 5,001 to 50,000 DWT, four of which are State-Owned Enterprises (SOEs), namely: PT Dok and Perkapalan Kodja Bahari (DKB), PT PAL Indonesia, PT Industri Kapal Indonesia, and PT Dok and Perkapalan Surabaya (DPS). The limited capacity and facilities, coupled with predominantly outdated and conventional production equipment, constitute the underlying reasons for the low level of productivity in the national shipyard industry [2].

Investments, such as acquiring additional equipment or machinery, are necessary to bolster the operations of shipyards characterized by substantial capital and a sizable workforce. Moreover, this must be complemented by a concurrent expansion of skilled Human Resources (HR) within the maritime sector [3]. Some improvements in ship production technology in Indonesia are carried out by applying modern technology that integrates computer-based design and production facilities, such as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). CAD functions for the design process, while CAM plays a role in the ship manufacturing process to plan, organise and control the operation of Computer Numerical Control (CNC) based production machines [4]. One type of CNC machine involved in the ship production process is CNC Plasma Cutting [5].

The CNC Plasma Cutting machine employs plasma gas, sprayed through a nozzle at high pressure and a temperature of 25,000°C. Capable of cutting steel plates and workpieces up to 147 mm thick, this machine generates vibrations and dust during the cutting process, which may lead to pollution and subsequently affect the performance of the CNC plasma cutting machine. A decrease in machine performance can be in the form of a reduced level of accuracy [6]. Based on observations at a shipyard company in Surabaya, although classified as vital production equipment, this machine often fails, hampering the production process. This will hamper the production process as a result of the machine repair process. In another shipyard company, the CNC Plasma Cutting machine is the machine that has the highest downtime [7]. Based on one of the accident investigation results from EDT Forensic Engineering & Consulting, there was an explosion of the CNC Plasma Cutting machine when it was turned on [8].

Considering these issues and occurrences, it becomes imperative to analyze the causes of CNC Plasma Cutting machine failures to devise appropriate countermeasures [9]. Several methods exist for analyzing failure causes, including Failure Mode and Effect Analysis (FMEA), Root Cause Analysis (RCA), Reliability Block Diagram (RBD), and Fault Tree Analysis (FTA) [10]. FTA is often preferred due to its simplicity in determining the causal relationships of failure modes. FTA can provide a simple representation

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of the relationship between failure modes and their causes [11]. The approach taken in this method is top-down. Failure from a top event is then detailed causes, up to a basic cause of failure (basic event) [12]. This method can illustrate the state of the basic event and the relationship between the basic event and the top event [13].

FTA was employed as one of the methods in the proposed enhancement of production quality using CNC Milling machines at PT PINDAD Bandung [14]. Furthermore, FTA for CNC Milling machines has been utilized in analyzing the design of the base crankshaft pulley puller machining jig [15]. The FTA method has also been applied to assess the effectiveness of CNC machines in one of the Engineering Procurement Construction (EPC) companies [16]. However, from several uses of FTA for CNC machines, there is no application of FTA to analyse the failure of CNC Plasma Cutting machines. Therefore, this article will present the results of the FTA analysis to analyse the causes of failure on the CNC plasma cutting machine of a shipyard industry in Surabaya. The FTA results are then given recommendations for control, with the hope that workers can work safely and the production process is not hampered.

II. METHOD

The CNC plasma cutting machine that will be discussed in this article, has received a risk analysis by the company. Based on the results of the risk analysis, it is known that one of the critical components of the CNC plasma cutting machine is the dust collector air hose component which has six failure modes. Each failure mode of the component is then analysed for its causes using the FTA method. In the failure tree analysis, the logical connection between the fault or failure and its causes is represented in the form of an image, as shown in Figure 1. The failure tree is a non-cyclic but directed graph, which consists of two types of nodes, namely events and gates. An event is an occurrence in the system, usually the failure of a subsystem down to its individual components. Events can be divided into basic events that occur spontaneously and intermediate events that are caused by one or more other events [17].

The FTA method has symbols and gates to make it easier to identify an event. Determination of causal factors with FTA by determining the minimum cut set which is a collection of basic causes that cause intermediate events and top events. Cut set analysis will be a reference for corrective action to prevent top events based on existing priorities [18].

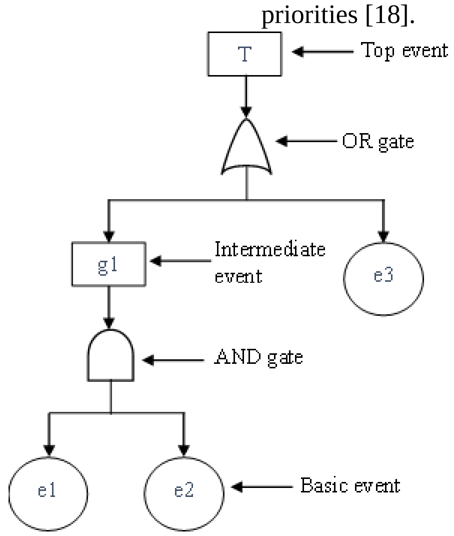

Figure 1. Failure Tree Structure [17]

The development of FTA for each failure mode engaged experts proficient in the domain of CNC plasma cutting. These experts comprised machine operators, the company's Occupational Safety and Health (OHS) team, and the maintenance team, with one representative from each group. After the creation of the failure tree, the model analysis was carried out in two stages, namely the qualitative stage and the quantitative stage. Qualitative analysis is performed by reducing the fault tree to a minimal cut set (MCS), which is the number of independent products consisting of the smallest combination of basic events necessary and sufficient to cause a top event. The bottom up method is used in the determination of MCS. In quantitative analysis, the probability of a top event occurrence is calculated mathematically, taking into account the failure rate or probability of each basic cause. The probability value is calculated using equation 3, based on the failure rate information (equation 1) and the reliability value (equation 2). This value is then used as the basis for calculating the probability of occurrence of top events based on MCS information using the rules in equation 4. The results of the quantitative analysis provide information on which failure modes are prioritised for control in order to ensure occupational safety and health. The provision of control recommendations uses the principles of the hazard control hierarchy based on ISO 45001: 2018 [19].

$$Failure\ rate, \mu = \frac{n}{t} \quad (1)$$

$$Reliability, R = e^{-\mu t} \quad (2)$$

$$Probability, P = 1 - R \quad (3)$$

N where n is the number of events in time t.

$$If\ AND\ gate\ then\ F = f_1 \cdot f_2 \cdot f_3 \cdots f_k$$

$$If\ OR\ gate\ then\ F = 1 - (1 - f_1) \cdot (1 - f_2) \cdot (1 - f_3) \cdots (1 - f_k)$$

Where F is the probability of the top event occurring and f_k is the probability of the kth basic cause occurring.

III. Results and Discussion

The CNC plasma cutting machine component analysed is the dust collector air hose or wind hose. This component has six failure modes, namely leaking air hose, loose air hose, malfunctioning air regulator, broken air hose, broken air hose and brittle air hose.

3.1 FTA of Leak Air Hose

The occurrence of leaking air hoses from dust collectors has 12 basic causes, as presented in Figure 2. The probability values of the twelve basic causes of leaking air hoses are presented in Table 1. Based on the calculation results, it is found that the hose is bent too often (basic cause K) is the highest basic cause of leaking air hose. The MCS determination of the top event of the leaking air hose was carried out with the following calculation:

$$M3 = A + B$$

$$M2 = C + D + M3 + E + F = C + D + A + B + E + F$$

$$M5 = G + H + I$$

$$M4 = M5 + J + K + L = G + H + I + J + K + L$$

$$M1 = M2 \cdot M4$$

$$= (C + D + A + B + E + F) \cdot (G + H + I + J \quad K + L)$$

$$= CG + CH + CI + CJ + CK + CL + DG + DH + DI + DJ + DK + DL + AG + AH + AI + AJ + AK + AL + BG + BH + BI + BJ + BK + BL + EG + EH + EI + EJ + EK + EL + FG + FH + FI + FJ + FK + FL$$

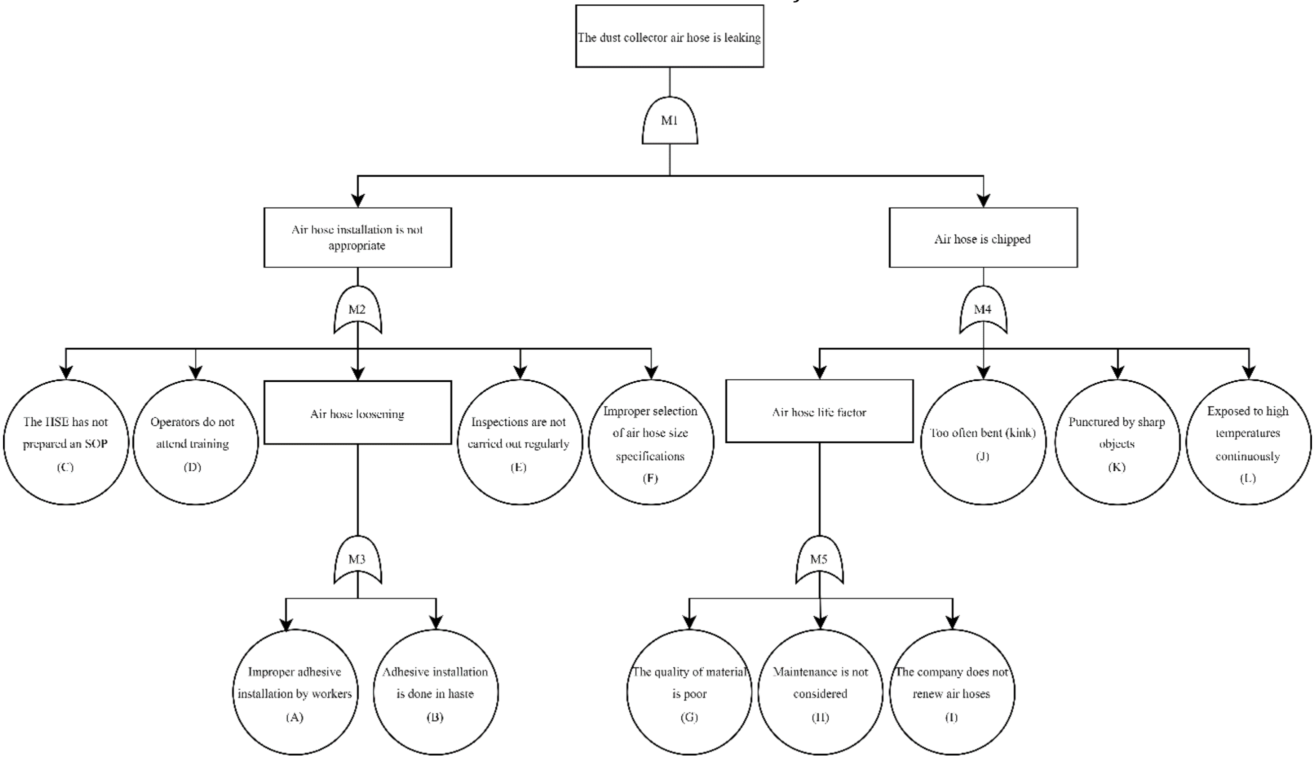

Figure 2. FTA of Leak Air Hose

Based on Figure 2, it is known that there are several causes of leakage in the dust collector hose, namely improper and hasty adhesive installation, absence of SOPs, operators do not participate in training, inspections are not carried out regularly and the selection of improper hose size specifications, basic hose quality is poor, maintenance is not considered, the company does not renew the air hose, the hose is bent too often, punctured by sharp objects and exposed to high temperatures continuously.

TABLE 1.
PROBABILITY VALUE OF *BASIC CAUSE* LEAKING AIR HOSE

Code	*Basic Cause*	Failure rate, μ	Reliability, R	Probability, P
A	Improper application of adhesive by workers	0,666666	0,513452	0,486548
B	Adhesive installation is done in a hurry	0,666666	0,513452	0,486548
C	HSE has not prepared an SOP	0,333333	0,716556	0,283444
D	Operators do not attend training	0,333333	0,716556	0,283444
E	Inspections or checks are not carried out regularly	0,333333	0,716556	0,283444

Code	*Basic Cause*	Failure rate, μ	Reliability, R	Probability, P
F	Selection of air hose size specifications is not correct	0,333333	0,716556	0,283444
G	Poor quality of constituent materials	0,333333	0,716556	0,283444
H	Care or maintenance is not considered	0,333333	0,716556	0,283444
I	The company did not renew the air hose	0,333333	0,716556	0,283444
J	Too much flexing	2	0,135363	0,864637
K	Pierced by sharp objects	0,666666	0,513452	0,486548
L	Continuous exposure to high temperatures	1	0,367917	0,632083

Based on Table 1, the probability value of the twelve basic causes of leaking air hoses shows that the highest basic cause is the hose is bent too often with a probability value of 0.864637.

3.2 FTA of Loose Air Hose

The event of the air hose from the dust collector coming loose has 7 basic causes, as presented in Figure 3. The probability values of the seven basic causes of the air hose coming loose are presented in Table 2. The MCS determination of the top event of the air hose coming loose is done with the following calculation:

$M3 = A + B$

$M2 = C + D + M3 + E + F = C + D + A + B + E + F$

$M1 = M2 + M = C + D + A + B + E + F + M$

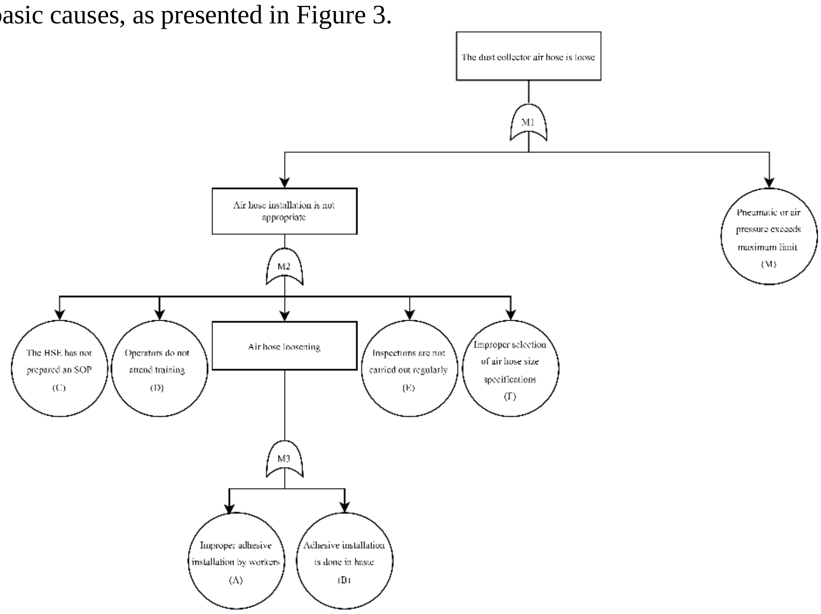

Figure 3. FTA of Loose Air Hose

According to Figure 3, the occurrence of loose air hoses in the *dust collector* stems from various factors. These include the HSE's failure to establish standard operating procedures (SOP), operators neglecting training sessions, imprecise and rushed adhesive installations, irregular inspections, incorrect selection of air hose size specifications, and pneumatic air pressure surpassing the maximum limit.

TABLE 2.
PROBABILITY VALUE OF BASIC CAUSE AIR HOSE LOOSE

Code	*Basic Cause*	Failure rate, μ	Reliability, R	Probability, P
A	Improper application of adhesive by workers	0,666666	0,513452	0,486548
B	Adhesive installation is done in a hurry	0,666666	0,513452	0,486548
C	HSE has not prepared an SOP	0,333333	0,716556	0,283444
D	Operators do not attend training	0,333333	0,716556	0,283444
E	Inspections or checks are not carried out regularly	0,333333	0,716556	0,283444
F	Selection of air hose size specifications is not correct	0,333333	0,716556	0,283444
M	Pneumatic or air pressure exceeds maximum limit	1,666666	0,1889083	0,8110962

Referring to Table 3, the probability values of the basic causes contributing to the loosening of the air hose indicate that the highest probability value is associated with the basic cause of pneumatic pressure exceeding its maximum limit, with a probability value of 0.8110962.

3.3 FTA of Air Regulator Not Functioning

The malfunctioning air regulator event has 9 basic causes, as presented in Figure 4. The probability values of the nine basic causes of malfunctioning air regulators are presented in Table 3. Determination of the MCS of the top event of the air regulator not working is done with the following calculation:

$$M3 = A + B$$
$$M2 = N + M3 = N + O + P + Q$$
$$M4 = R + S$$
$$M5 = T + U + V$$
$$M1 = M2 + M4 + M5$$
$$= N + O + P + Q + R + S + T + U + V$$

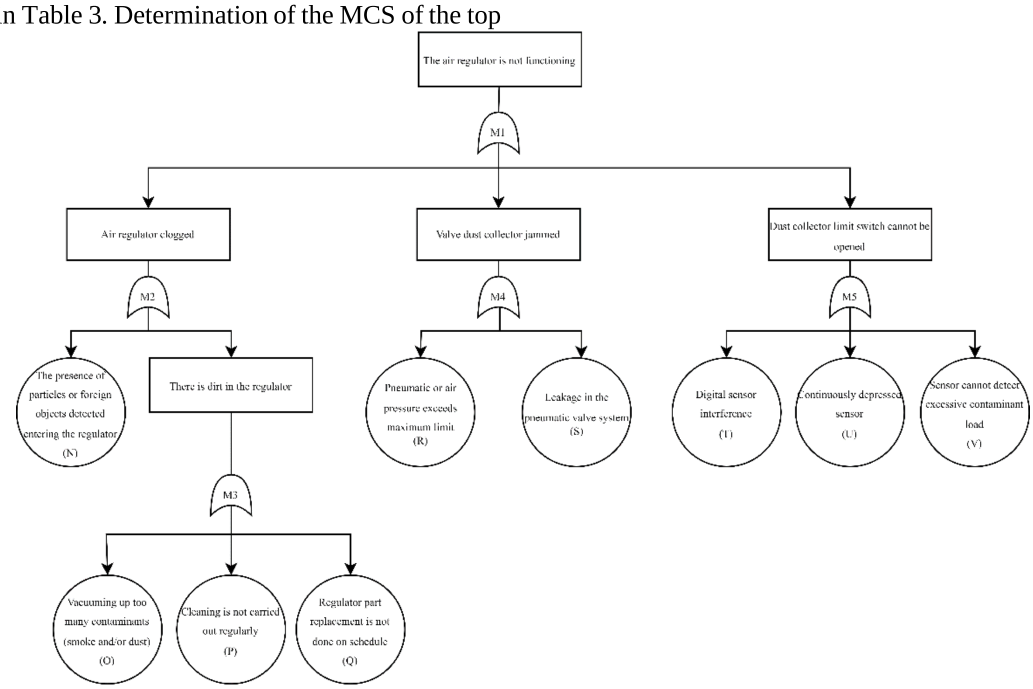

Figure 4. FTA Air Regulator Not Functioning

Based on Figure 4, the malfunction of the air regulator stems from several underlying causes, including the ingress of particles into the regulator, excessive intake of contaminants such as smoke or dust, irregular cleaning of the regulator, failure to replace regulator parts according to schedule, exceeding the maximum limit of pneumatic pressure, leakage in the pneumatic valve system, interference with digital sensors, continuous depression of the sensor, and inability of the sensor to detect excessive contaminant loads.

TABLE 3.
PROBABILITY VALUE OF BASIC CAUSE MALFUNCTIONING AIR REGULATOR

Code	*Basic Cause*	Failure rate, μ	Reliability, R	Probability, P
N	The presence of particles or foreign objects detected entering the regulator	2	0,135363	0,864637
O	Vacuuming up too many contaminants (smoke and dust)	0,333333	0,716556	0,283444
P	Cleaning is not done regularly	0,333333	0,716556	0,283444
Q	Regulator part replacement not on schedule	0,333333	0,716556	0,283444

Code	*Basic Cause*	Failure rate, μ	Reliability, R	Probability, P
R	Pneumatic or air pressure exceeds maximum limit	1,666666	0,1889083	0,8110962
S	Leakage in the pneumatic valve system	0,333333	0,716556	0,283444
T	Digital sensor interference	0,333333	0,716556	0,283444
U	Continuously depressed sensor	0,333333	0,716556	0,283444
V	Sensor cannot detect excessive contaminant load	0,333333	0,716556	0,283444

Based on Table 3. the probability value of the basic cause of the air regulator not functioning from 9 basic causes, there is the highest probability value, namely the presence of particles or foreign objects detected entering the regulator with a value of 0.864637.

3.4 FTA of Rupture Air Hose

The ruptured air hose event has 15 *basic causes*, as presented in Figure 5. The probability values of the fifteen *basic causes of the* ruptured air hose are presented in Table 4. Determination of the MCS of the *top event of ruptured* air hose is done by the following calculation:

$$M3 = X + Y$$
$$M2 = W + M3 + Z = W + X + Y + Z$$
$$M5 = O + P + Q$$
$$M4 = N + M5 = N + O + P + Q$$
$$M7 = A + B$$
$$M6 = C + D + M7 + E + F = C + D + A + B + E + F$$
$$M1 = M + M2 + M4 + M6$$
$$= M + W + X + Y + Z + N + O + P + Q + C + D + A + B + E + F$$

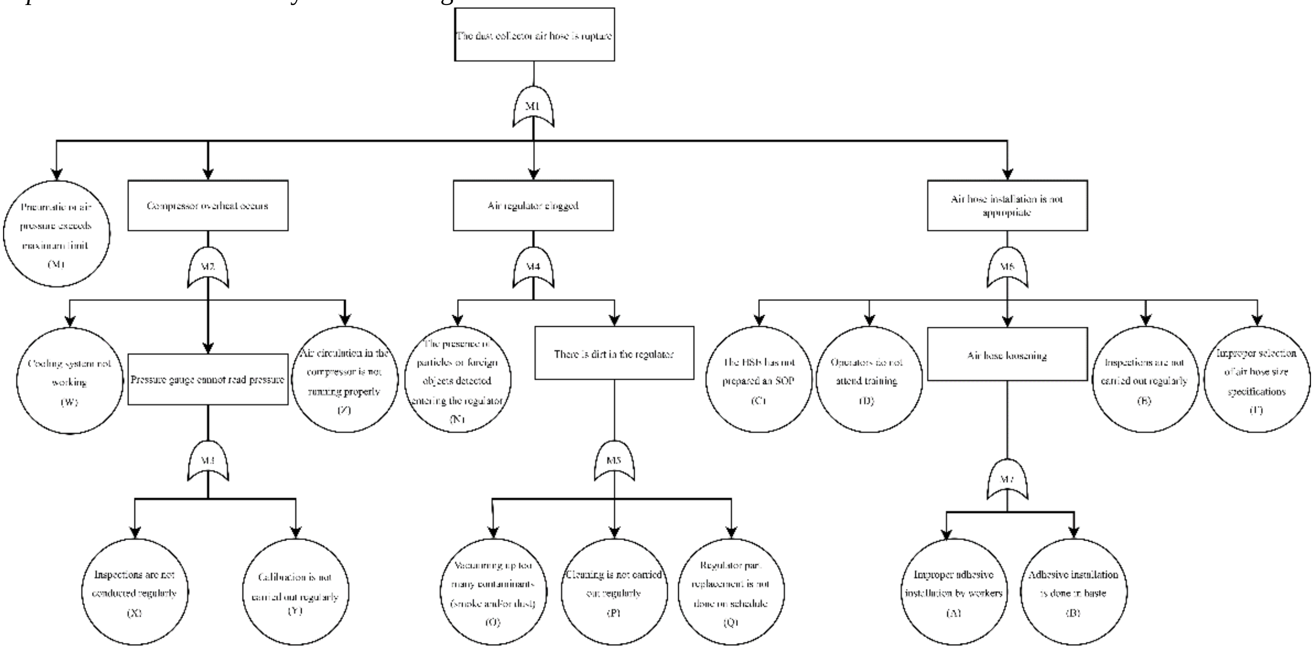

Figure 5. FTA of Reputure Air Hose

According to Figure 5, there are 15 basic causes attributed to air hose rupture. These include pneumatic pressure exceeding the maximum limit, malfunctioning cooling pipes, inactive air circulation in the compressor, lack of routine inspection and calibration of pressure gauges, infiltration of particles into the regulator, excessive intake of contaminants such as smoke or dust, irregular cleaning of the regulator, failure to replace regulator parts according to schedule, absence of prepared SOPs by HSE, operators' lack of participation in training, incorrect and hurried installation of adhesive on the hose, irregular hose inspection, and incorrect selection of air hose size specifications.

TABLE 4.
PROBABILITY VALUE OF BASIC CAUSE AIR HOSE RUPTURE

Code	*Basic Cause*	Failure rate, μ	Reliability, R	Probability, P
M	Pneumatic or air pressure exceeds maximum limit	1,666666	0,1889083	0,8110962
W	Cooling pipe/Cooling System not working	0,333333	0,7165e56	0,283444
X	Inspections or checks are not carried out regularly	0,333333	0,716556	0,283444
Y	Calibration is not done regularly	0,333333	0,716556	0,283444
Z	Air circulation in the compressor is not running properly	1	0,367917	0,632083

Code	*Basic Cause*	Failure rate, µ	Reliability, R	Probability, P
N	The presence of particles or foreign objects detected entering the regulator	2	0,135363	0,864637
O	Vacuuming up too many contaminants (smoke and dust)	0,333333	0,716556	0,283444
P	Cleaning is not done regularly	0,333333	0,716556	0,283444
Q	Regulator part replacement not on schedule	0,333333	0,716556	0,283444
C	HSE has not prepared an SOP	0,333333	0,716556	0,283444
D	Operators do not attend training	0,333333	0,716556	0,283444
A	Improper application of adhesive by workers	0,666666	0,513452	0,486548
B	Adhesive installation is done in a hurry	0,666666	0,513452	0,486548
E	Inspections or checks are not carried out regularly	2	0,135363	0,864637
F	Selection of air hose size specifications is not correct	1	0,367917	0,632083

According to Table 4, among the 15 basic causes contributing to air hose rupture, the highest probability value is associated with irregular inspection or lack of inspection, along with the detection of particles or foreign objects entering the regulator, with a value of 0.864637.

3.5 FTA of Disconnected Air Hose

The air hose disconnected event has 7 basic causes, as presented in Figure 6. The probability values of the seven basic causes of the air hose disconnected are presented in Table 5. The determination of the MCS of the top event of the broken air hose is done by the following calculation:

$M2 = \mathrm{G} + \mathrm{H} + \mathrm{I}$

$M1 = M2 + J + L + AA + BB = G + H + I + J + L + AA + BB$

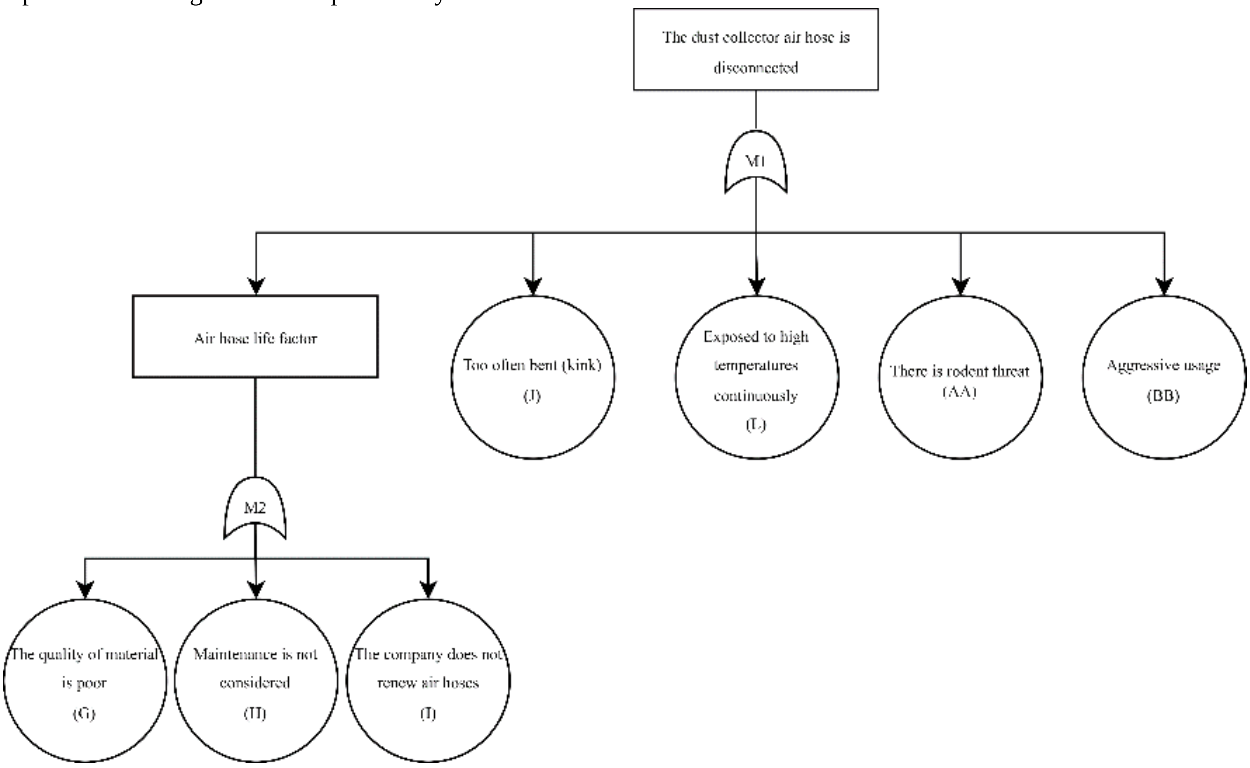

Figure 6. FTA of Disconnected Air Hose

According to Figure 6, there are seven basic causes attributed to broken air hoses. These include poor quality of the constituent materials in the hose, lack of maintenance consideration, failure by the company to renew the air hose, frequent bending of the air hose, continuous exposure to high temperatures, and the threat posed by rodents and aggressive handling.

TABLE 5.
PROBABILITY VALUE OF *BASIC CAUSE* AIR HOSE BREAKS

Code	*Basic Cause*	Failure rate, μ	Reliability, R	Probability, P
G	Poor quality of constituent materials	0,333333	0,716556	0,283444
H	Care or maintenance is not considered	0,333333	0,716556	0,283444
I	The company did not renew the air hose	0,333333	0,716556	0,283444
J	Too often flexed (Kink)	2	0,135363	0,864637
L	Continuous exposure to high temperatures	1	0,367917	0,632083
AA	There is a rodent threat	1,333333	0,263633	0,736367
BB	Aggressive use	1,666666	0,1889083	0,8110962

According to Table 5, among the seven basic causes contributing to the breaking of the air hose, the highest probability value is associated with the hose being bent too often (kinked), with a value of 0.864637.

3.6 FTA of Fragile Air Hose

The fragile air hose event has 4 basic causes, as presented in Figure 7. The probability values of the four basic causes of the fragile air hose are presented in Table 6. The determination of the MCS of the fragile air hose top event is done by the following calculation:

$M2 = G + H + I$

$M1 = M2 + BB = G + H + I + BB$

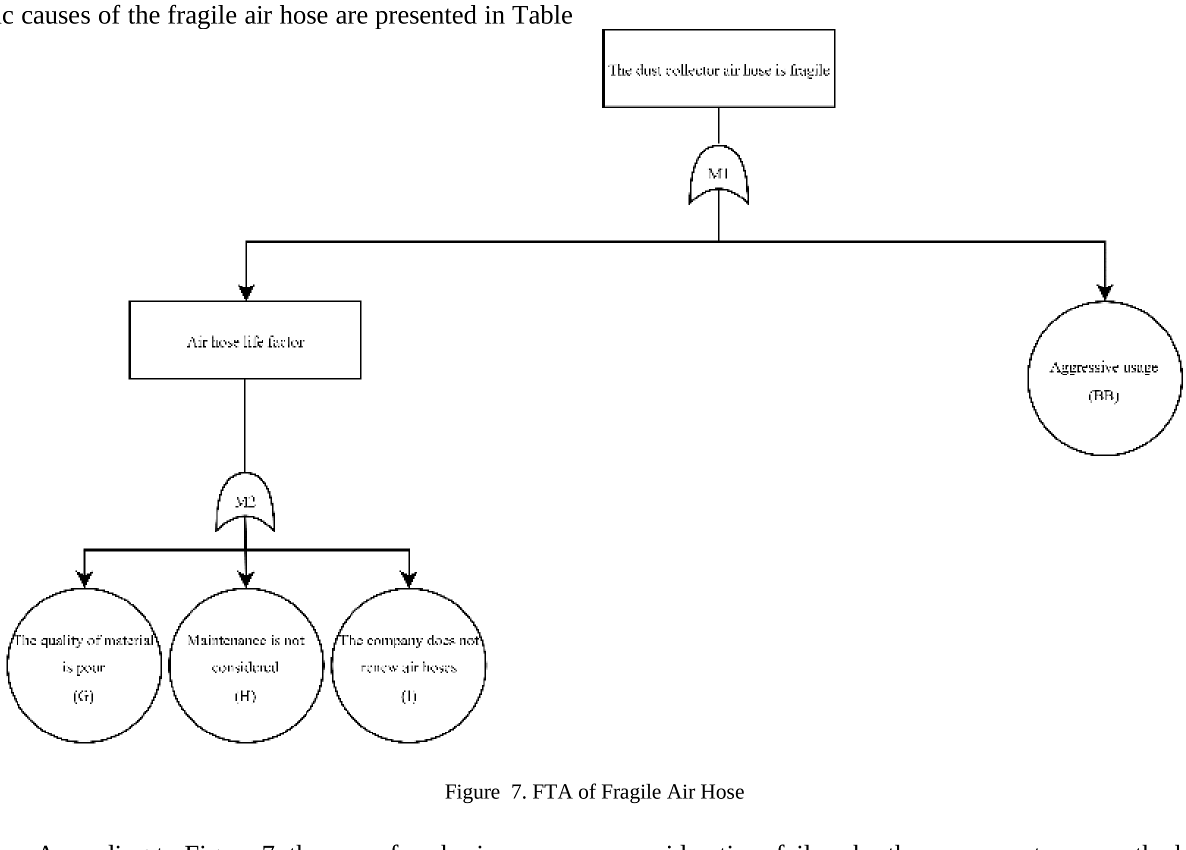

Figure 7. FTA of Fragile Air Hose

According to Figure 7, there are four basic causes of brittle air hoses, namely poor quality of the material composing the air hose, lack of maintenance consideration, failure by the company to renew the hose, and the utilization of aggressive hoses.

TABLE 6.
PROBABILITY VALUE OF BASIC CAUSE FRAGILE AIR HOSE

Code	*Basic Cause*	Failure rate, µ	Reliability, R	Probability, P
G	Poor quality of constituent materials	0,333333	0,716556	0,283444
H	Care or maintenance is not considered	0,333333	0,716556	0,283444
I	The company did not renew the air hose	0,333333	0,716556	0,283444
BB	Aggressive use	1,666666	0,1889083	0,8110962

Based on Table 6. the basic cause probability value of the fragile air hose of there are 4 basic causes with the highest probability value is due to the use of aggressive air hoses with a value of 0.8110962.

3.7 Minimum Cut Set Probability

The results of the calculation of the MCS probability of each are given in Table 7. Based on Table 7, the highest probability value is owned by the top event of the dust collector air hose rupture, which is 99.88%. This shows that the possibility of the dust collector air hose rupturing is very high, so it needs to be prioritised for control (Kang et al., 2019). Control recommendations for each basic cause that makes up the MCS that causes the dust collector air hose to rupture are presented in Table 8. The types of control provided are substitution, engineering and administrative control.

TABLE 7.
PROBABILITY VALUE MCS OF EACH TOP EVENT COMPONENT AIR HOSE CNC PLASMA CUTTING MACHINE

No.	*Top Event*	*% Probability* MCS
1	*Dust collector* air hose leaking	77,98
2	*Dust collector* air hose loose	96,22
3	Air regulator not working	76,60
4	*Dust collector* air hose broken	99,88
5	*Dust collector* air hose broken	99,76
6	Fragile *dust collector* air hose	81,61

Based on Table 7. the MCS probability value of each *top event of the* air hose component of the CNC *plasma cutting* machine is the highest, namely the *dust collector* air hose rupture with a probability value of 99.88%

TABLE 8.
MCS PROBABILITY VALUE OF EACH *TOP EVENT OF* AIR HOSE COMPONENT OF CNC *PLASMA CUTTING* MACHINE

Code	Type of *Basic Cause*	Type of Control	Control Recommendations
A	Improper application of adhesive by workers	Substitution	Replace the hose fastening material with a strong or sturdy material
B	Adhesive installation is done in a hurry	Administrative control	Conduct *Safety* briefing/toolbox *meeting* before work starts, *safety patrol, safety inspection,* and supervision efforts from the *safety* department.
C	HSE has not prepared an SOP	Administrative control	Establish a special SOP for air hose operation
D	Operators do not attend training	Administrative control	Organise training for CNC *Plasma Cutting* operators so that operators get an expert certificate licence in the form of a training certificate and for maintenance workers to have a mechanical maintenance technician expert certificate.
E	Inspections or checks are not carried out regularly	Administrative control	- Conduct inspections as scheduled - Check all components before use or operation and also after each use.
F	Selection of air hose size specifications is not correct	Administrative control	- Conduct an air hose feasibility test - Holding quality control (QC) by the QC before the air hose is installed and checking the certificate of eligibility of the air hose to be used.
M	Pneumatic or air pressure exceeds maximum limit	Engineering	*Emergency Shutdown* then check the *pressure gauge*

Code	Type of *Basic Cause*	Type of Control	Control Recommendations
N	The presence of particles or foreign objects detected entering the regulator	Substitution	Replace the regulator with a new *part*
O	Vacuuming up too many contaminants (smoke and dust)	Substitution	Replace air regulators that are no longer fit for use with new air regulators
P	Cleaning is not done regularly	Administrative control	Organised a bulletin on safety climate which aims to make workers work according to procedures and prioritise the 5Rs (Ringkas, Rapi, Resik, Rawat, Rajin).
Q	Regulator part replacement not on schedule	Administrative control	Make a regulator *part* replacement schedule, Conduct *safety inspections*
W	*Cooling system* not working	Engineering	Make system improvements by competent parties
X	Inspections or checks are not carried out regularly	Administrative control	Scheduling inspections to be conducted on a regular basis
Y	Calibration is not done regularly	Administrative control	Always calibrate the *pressure gauge* by competent and authorised officers or parties from inside and/or outside the company at least once a year, depending on the frequency of use.
Z	Air circulation in the compressor is not running properly	Engineering	Always switch on the blower during the cutting process, so that contaminants such as smoke and dust that are scattered are sucked up and out into the free air.

According to Table 8, the control measures implemented for damage to the air hose of the CNC plasma cutting machine based on each basic cause reveal the utilization of a hierarchy of control. Control is executed through a combination of substitution, administrative control, and engineering controls on average.

3.8 Discussion

Based on the causal delineation of all failure modes of each top event of the air hose component of the CNC plasma cutting machine, the causes of failure that often appear are codes A to I. Basic causes A, B, and D are associated with worker-related factors. Causes C, E, H, and I are linked to work methods, while causes F and G are attributed to component materials. These outcomes are directly comparable to research concerning CNC machine failure analysis [20], which indicates that worker, method, and material factors play a role in CNC machine failure. Calculation of the MCS probability of each top event of the air hose component of the CNC plasma cutting machine gives the result that three top events have a probability value of more than 90% and the rest are not less than 76%. This value suggests that all top events are nearing potential failure. These outcomes align with research on CNC machine damage analysis, which emphasizes that one of the priority control measures should address the malfunction of the dust collector [21]. Of all the root causes, the most common type of recommendation is administrative control, followed by substitution and engineering.

IV. Conclusion

There are six FTAs that were successfully compiled for the air hose or wind hose component of the CNC Plasma Cutting machine. The analysis results show that the dust collector air hose rupture has the highest probability value of 99.8783% of the 15 basic causes. Control recommendations are given in the form of substitution, engineering and administrative control. Hopefully, these recommendations can be implemented to ensure occupational safety and health.

This article is limited to failure analysis on one of the CNC plasma cutting machine components. Further research can be conducted on other components by combining other failure analysis methods, so as to provide a more comprehensive failure analysis of CNC plasma cutting.

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