FAILURE MODE AND EFFECT ANALYSIS FOR MECHANICAL COMPONENT OF DIY 3D PRINTER

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ABSTRACT

Failure Mode and Effects Analysis (FMEA) is a widely used tool for identifying potential failure modes in a system, evaluating their effects, and implementing measures to mitigate or eliminate them. In the case of a DIY 3D printer, FMEA can be used to identify potential failure modes that could lead to sub-optimal performance or even complete system failure. The FMEA process involves identifying potential failure modes, determining their severity, likelihood of occurrence, and detectability, and then prioritizing them based on their risk priority number (RPN). This process can be used to identify potential failure modes in various aspects of the 3D printer system, including mechanical components. In the maritime sector, the use of 3D printers in replacing several main machinery parts is now seeking demand. There is no denying that using this technology in the industry has both benefits and drawbacks. Yet as time passes, this technology's deficiencies continue to be corrected and it keeps growing. Understanding modern technologies like 3D printing is therefore highly beneficial. Knowing how well the printer is in excellent condition and locating the printer issue that will result in the machine being underpowered are some aims of the risk assessment. A risk analysis of printer failure is essential to prevent failure while running the printer. The printer's durability will occasionally decrease, and it is simple to destroy the internal components by pushing them to perform harder than they can. Understanding the state of this printer is the primary goal of risk assessment or risk failure analysis. Hence, in this project, the mechanical components of DIY 3D printer failure risk assessment are conducted using FMEA.

Keywords: Failure Mode and Effect Analysis (FMEA), RPN number, DIY 3D printer, Maritime sector

1.   INTRODUCTION

Do It Yourself (DIY) can be defined as the completion of home remodelling and maintenance tasks by homeowners without the aid of professionals [1]. Material extrusion (FDM)-type Cartesian additive manufacturing is the most common machine that people always build on their own. Even in real-life situations, some people are excited to have built their 3D printer as a hobby or for business purposes. Purchasing different specifications of components related to the printer and assembling it according to their desired wishes. Building own DIY 3D printer may be a cost-effective way to get started with the technology and a learning experience for someone to become more familiar with the inner workings of a 3D printer. When something fails, learn how the 3D printer functions and how to fix them. More work goes into building a 3D printer than it does into purchasing a fully completed printer that is ready to print. Moreover, DIY 3D printer patterns offer an excellent choice for newcomers who want to understand the mechanics since they make it simpler to get started. The kits often provide all the materials needed, including the necessary tools, components, and instructions, removing some of the guesswork involved in creating the printer[2].

FMEA is one of the methods used for ongoing quality improvement. An organized analytical technique called an FMEA is used to pinpoint failure modes and their consequences. Focusing on failure mechanisms and their effect assists in identifying the steps required to enhance the product and processes [3]. The main advantages of using the FMEA method are cost savings, which have a significant impact on warranty returns, a shorter time between the project phase and market entry, and an increase in operational safety. These advantages result from the technique's widespread use in various industries. The development of customer satisfaction is the ultimate objective for realizing these advantages since it ensures the expansion of the organization's competitiveness and the enhancement of its

reputation in the marketplace [4]. While for this project is more focused on detecting the highest probability of failure regarding DIY 3D printers.

A single location in space can be found and described using a Cartesian coordinate system by utilizing three coordinates that are, respectively, positioned along the X-, Y-, and Z-axes, each of which is perpendicular to the other two. While one axis may properly represent a location along a line, three axes allow us to locate any point in three dimensions [5].

The x, y, and z axes of a Cartesian printer are used to move the extruder or print head in all three directions. The three axes define the movement in three-dimensional space. Z is forward or backwards, Y is up or down, and X is left or right [5]. Cartesian printers may produce things with intricate geometries by using printheads with two or more axes of motion that can move independently or in concert. Such printers have a print bed that oscillates up and down along the Y-axis and back and forth along the X-axis. The Z-axis is used to move the print head. The Z-axis is used to move the print head.

Stepper motors employ a pulse technique as well as a built-in microprocessor. The controller has no way of knowing if the issued orders are carried out. In the event of a malfunction, it loses its position and must be reset to zero. Stepper motors have more torque at low speeds than servo motors, but they are not as exact because of the shortcomings noted. However, they are less costly. As a result, they are appropriate for the most typical 3D printing applications [6]. A specific kind of electric motor called an extruder motor is used in 3D printers to regulate the flow of filament, which is a substance like metal or plastic that builds up the printed item layer by layer. For example, in this research, a metal V6 hotend extruder was used. Its perfect specification makes it suitable to be used as the heating element. Nozzle diameter of 0.4mm and require 40W of electricity to function well. It comes in the complete set of cooling fan, nozzle, heat sink and heater block with thermistor.

Next, the usage of the Arduino Mega 2560 motherboard in this research enables it to be the main controller of this DIY 3D printer. The movement of all components was processed and controlled by this controller. Therefore, serious actions need to be taken to maintain the accuracy of this controller [7].

There are three types of software are required for 3D models; the use of software to prototype actual items is known as computer-aided design (CAD). Second, there's the computer-aided manufacturing (CAM) program, sometimes known as a slider, which translates the design into mechanical instructions for the printer robot. Third, the printer control software transmits instructions to the printer at the appropriate moment, allowing users to interact with the printer's functionalities and settings in real-time [8].

The necessity to enhance the performance and dependability of these printers to guarantee safe and efficient operation is the issue that a project on the FMEA of a DIY 3D printer attempts to solve. Because of their affordability and accessibility, DIY 3D printers are becoming increasingly popular among organizations such as marine companies. Unfortunately, these printers frequently use commercially available parts and may not go through thorough quality control testing, which increases the possibility of error or breakdown.

However, these failures can have a variety of effects, from small setbacks to significant safety risks like fire or harm. Furthermore, failure modes may not be immediately obvious without such a structured approach and may be challenging to detect and resolve[9]. FMEA is a known technique for identifying and minimizing probable failure modes in complex systems, and it may be used to increase the dependability and accessibility of DIY 3D printers. To guarantee the proper and secure functioning of these printers, the problem statement for the FMEA of a DIY 3D printer project is to identify probable failure modes, evaluate their influence on the printer's performance, and design ways to reduce these risks.

Finally, the study aims to contribute valuable insights into understanding and managing the deficiencies in DIY 3D printers. The study addresses the emerging role of 3D printing in ensuring the integrity and functionality of critical components. The research aims to develop a risk priority number (RPN) that can guide efforts in mitigating or eliminating identified risks.

2. RESEARCH METHODOLOGY

The techniques applied throughout the project are described. This will cover areas including the way to figure out which challenges are preventing the project from working properly, how to figure out the mechanical, electrical, electronic and software component problems of the DIY 3D printer, and how to gather data after the project is functioning properly. The focus will be on the approaches used in determining and resolving the difficulties the printer encountered. Factors influencing its use, such as efficacy, cost, and time required, must be examined to determine how practical a method is[10].

First, a fault tree diagram was used to analyse the data that had been gathered. A tree diagram is an easy method to show how events unfold. Tree diagrams are very helpful in probability because they capture all potential outcomes. By referencing manual books and industrial workers, all relevant factors were examined to get data on printer component failure.

After creating the failure tree diagram, the failure mode and effect analysis risk assessment table will be developed. Engineering frequently uses failure mode and effect analysis to depict the risk value [11]. FMEA may be used to pinpoint and rank possible issues with a DIY 3D printer's component when it is under refurbishment. Using this knowledge, preventive measures may then be created and put into place to lessen the probability of failure.

The main advantages of using the FMEA method are cost savings, which have a significant impact on warranty returns, a shorter time between the project phase and market entry, and an increase in operational safety. The development of customer satisfaction is the ultimate objective for realizing these advantages since it ensures the expansion of the organization's competitiveness and the enhancement of its reputation in the marketplace [4]. While for this project is more focused on detecting the highest probability of failure regarding DIY 3D printers. The aerospace, military, automotive, electrical, mechanical, and semiconductor sectors are just a few of the industries that have implemented FMEA [12].
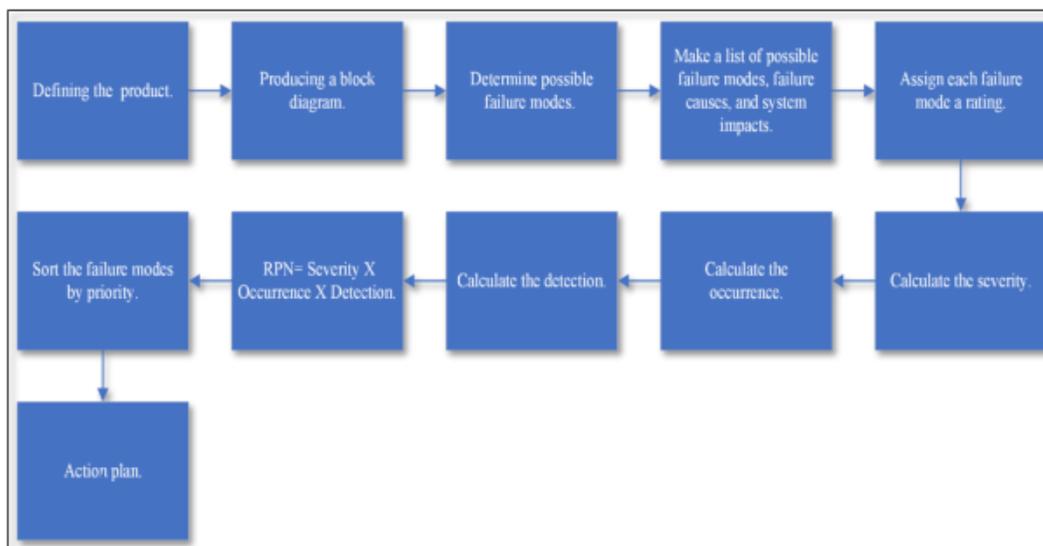

Figure 1: FMEA process block diagram.

Figure 1 above shows the process of conducting FMEA. The first step involves defining the system, method, or product under analysis. This lays the groundwork for a comprehensive examination. Following this, a block diagram is produced to visually represent the final product or process, showcasing the interconnections among its main components or procedures. Subsequently, potential failure modes are identified, either through the application of a categorization system or collaborative brainstorming with field experts.

Once the failure modes are determined, a list is compiled detailing potential causes of failure and the corresponding impacts on the system. Each failure mode is then assessed based on severity, occurrence, and detection, with ratings assigned to quantify these aspects. The severity of each failure mode is evaluated by considering its implications on efficiency, security, and cost.

Furthermore, the likelihood of each failure scenario occurring is calculated by examining design elements, materials used, and the manufacturing process. The Risk Priority Number (RPN) is then determined using the formula RPN = Severity × Occurrence × Detection. This numerical value provides a quantitative representation of the risks associated with each failure mode. To prioritize corrective actions, the failure modes are sorted based on their RPNs, with those possessing the highest values receiving immediate attention. An action plan is subsequently created, outlining specific tasks and designating responsibilities. This plan guides the implementation of corrective measures. Finally, adherence to the recommendations put forth by the FMEA team is crucial for ensuring the effectiveness of the analysis and maintaining the integrity of the system or product under scrutiny.

The severity rating is a measure of the consequence of a failure of the system. The occurrence rating is a measure of the likelihood of a failure occurring. While the detection rating is a measure of the chance of a failure being detected. Table 1 below shows the parameters for severity, occurrence, and detection matrix.

Table 1: Severity, Occurrence and Detection Matrix

Severity Rating	Occurrence Rating	Detection Rating
1 - 2	Extremely unlikely	Very easy to detect
3 - 4	Unlikely	Easy to detect
5 - 6	Possible	Difficult to detect
7 - 8	Likely	Very difficult to detect
9 - 10	Almost certain	Impossible to detect

The actions that must be made to address the issue are included in the treatment category. These actions include avoiding, transferring, reducing, and accepting risks that might result in an engine failure. The risk treatment category table is displayed in Table 2 below.

Table 2: Risk treatment category.

Risk Treatment		
Treatment Category	Description	Action
Accept	i. When dangers are recognised and cannot be prevented or eliminated, or when there is no feasible course of therapy. ii. The organisation will take on the risk if it is determined that it fits within its risk appetite.	No need action plan
Reduce	i. Training, testing, control, and management system improvement can all help with this. ii. When the degree of risk exposure (Probability) is high, yet there might be a loss (impact) connected to it is little, the company will want to take action to lower the risk.	Action required
Avoid	i. One way to achieve this is to stop engaging in or carrying out activities. ii. An organisation will want to reduce or eliminate a risk if it has a high likelihood and significant effects.	Eliminate the process flow
Transfer	i. Through contracts, insurance, or memorandums of understanding, another party may participate entirely or in part. ii. The organisation will want to transfer a risk when there is little chance of it happening but a high chance of its effects.	Pass over the risk to 3rd party

3.   RESULTS

This section will discuss the results of the analysis conducted. The DIY 3D printer is divided into 4 different categories which are mechanical, electrical, electronic and software. All the data recorded are based on the FMEA table that can be found in the appendix of the full report.

3.1   Mechanical components

Table 3: Mechanical components results

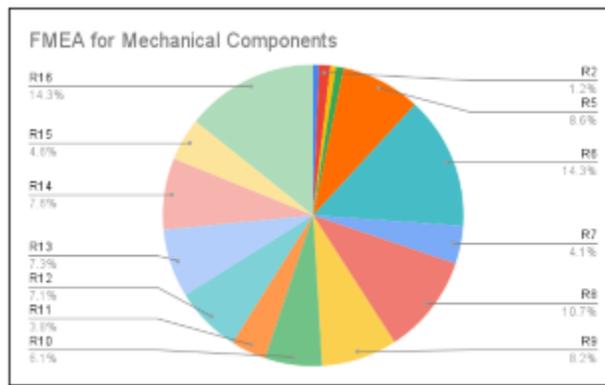| Potential risk	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
RPN	12	24	12	16	168	280	80	210	160	120	75	140	144	150	90	280

Figure 2: Pie chart for mechanical components

Table 3 and Figure 2 correlate with each other. Both R1 and R3 have recorded the lowest RPN number for this mechanical component category with 12 scores. It is equivalent to 0.61%. While R6 and R16 both have recorded the highest RPN score with 280. Representing 14.3% of the risk in this category.

3.2   Electrical components

Table 4: Electrical components result.

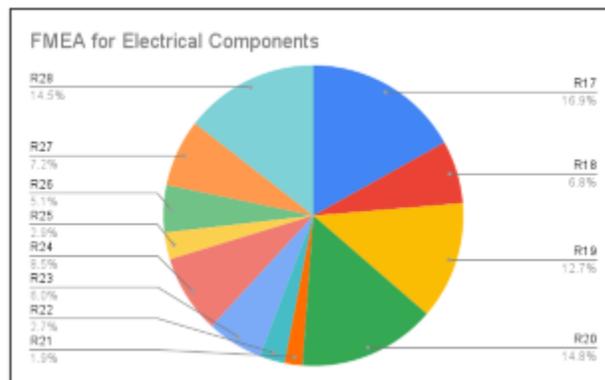| Potential risk	R17	R18	R19	R20	R21	R22	R23	R24	R25	R26	R27	R28
RPN	280	112	210	245	32	45	100	140	48	84	120	240

Figure 3: Pie chart for electrical components

Table 4 and Figure 3 exhibit a strong correlation. In the electrical component category, R21 has documented the minimum RPN score, achieving a score of 32, which corresponds to 1.9%. On the other hand, R17 have jointly attained the highest RPN score, totalling 280 and representing 14.5% of the risk within this specific category.

3.3   Electronic components

Table 5: Electronic components result.

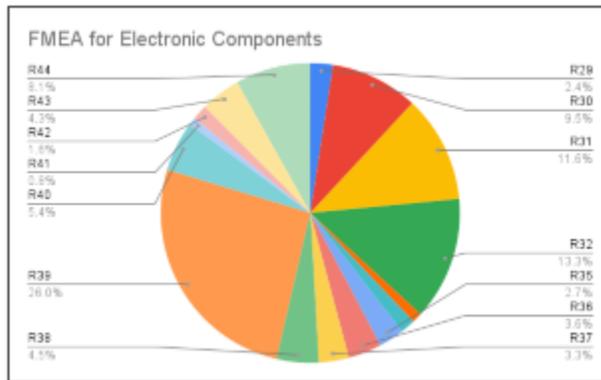| Potential risk	R29	R30	R31	R32	R33	R34	R35	R36	R37	R38	R39	R40	R41	R42	R43	R44
RPN	54	210	256	294	24	36	60	80	72	100	576	120	18	36	96	180

Figure 4: Pie chart for electronic components

Table 5 and Figure 4 exhibit a correlation. In the electronic components category, R41 have documented the minimum RPN value, scoring 18, which constitutes 0.81%. Conversely, R39 have registered the maximum RPN score at 576, reflecting 26.03% of the risk within this category.

3.4   Software/ Firmware

Table 6: Software/ firmware results.

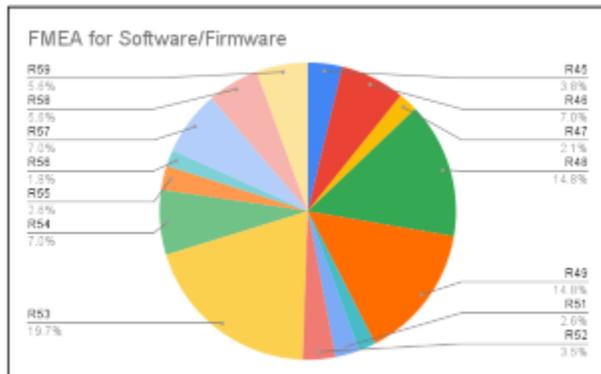| Potential risk	R45	R46	R47	R48	R49	R50	R51	R52	R53	R54	R55	R56	R57	R58	R59
RPN	64	120	36	252	252	32	45	60	336	120	45	30	120	96	96

Figure 5: Bar chart for software/firmware

The correlation between Table 6 and Figure 5 is evident. Within the software/ firmware category, R56 has the lowest RPN, scoring 30, equivalent to 1.8%. On the other hand, R53 stand out with the highest RPN score of 336, constituting 19.7% of the risk within this category.
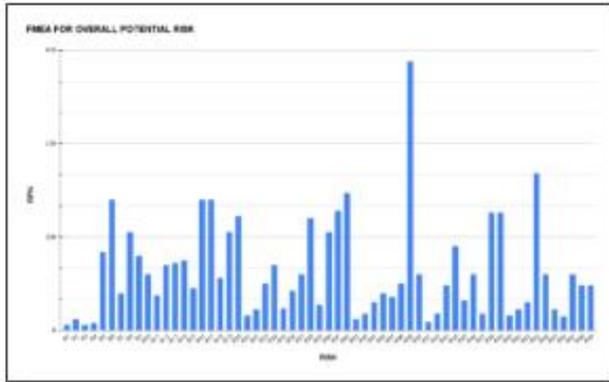
3.5   Overall potential risk

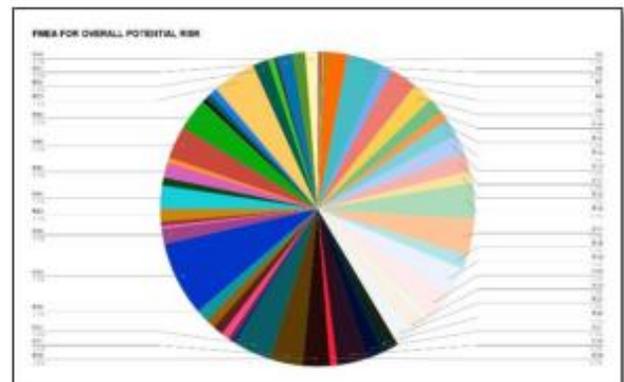*Figure 6: Bar chart for overall risk*

Figure 7: Pie chart for overall risk

Based on the overall results obtained in this chapter, by referring to Figure 6 and Figure 7, R39 shows the highest possible risk that could happen while running the DIY 3D printer. This risk was included in the end stop failure. The fact that the end stop switches are continually actuated while the printer is in use is one typical source of mechanical wear and tear over time. Inaccurate readings can also be caused by miscalibration, or misalignment of the end stop switches. Failures of the end stop can also be caused by electrical problems, such as faulty or weak wire connections. The main consequence is a reduction in positional precision during 3D printing. The extruder or print bed of the printer may go beyond what is planned if the end stop is unable to trigger precisely. This misalignment may cause print flaws, layer misalignments, or even attempts by the printer to print beyond its actual working limits. This indicates that it will have the highest priority need to be concerned.

While R1 and R3 both show the lowest RPN score, thus showing the lowest priority to be concerned. R1 was included in the bed levelling failure. Bed levelling failure in 3D printers can result in a serious problem that cause the print inaccuracies and general printer inefficiency. Mechanical misalignment or wear in the printer's levelling system, which comprises the bed itself, its mounting components, and the levelling sensors or probes, is one of the main reasons for bed levelling failure. These mechanical parts may stop giving the printer's control system precise data when they are worn out or misaligned. Due to the printer's inability to account for differences in the build surface, prints may not adhere correctly or display uneven layer heights as a result.

Meanwhile for R3 was related to the filament feeding failure. Frequently, filament-related factors, extruder-related problems, or software settings are the main causes of filament feeding failure. Failure of the filament feeding procedure can negatively impact the 3D printing procedure. The quality of the 3D-printed item shows the impact of filament feeding failure. Irregular extrusion can result in gaps, layer misalignment, and generally subpar print quality. Additionally, it could result in print failures when the print warps or separates from the print bed. This indicates that it will have the lowest priority need to be concerned.

4.　　CONCLUSION

In conclusion, Failure Mode and Effects Analysis (FMEA) is a crucial tool in identifying and mitigating potential failure modes in a DIY 3D printer system. By evaluating risks' severity, chance of occurrence, and detectability, the FMEA process offers an organized method for ranking and addressing them according to their risk priority number (RPN). Maintaining peak performance and averting system failures necessitates the application of FMEA to several 3D printer system components, including software, electrical, mechanical, and electronic parts.

FMEA could be the most effective method for improving the performance and extending the lifespan of DIY 3D printers. From the analysis conducted, the possible failure of the system can be identified, and the issue can be solved. It will reduce the time consumed to mitigate the problems due to its directional approach. The central focus on understanding and assessing the state of the DIY 3D printer through risk assessment aligns with the broader aim of ensuring the printer's durability and preventing underperformance or potential damage to internal components. The recognition of the need for risk analysis in preventing printer failure, especially in scenarios where the printer may be pushed beyond its limits, underscores the importance of proactive measures to maintain the printer's optimal condition.

In this project, faulty firmware has been recorded as the highest possible risk that could threaten the entire system of the DIY 3D printer. It shows around 576 scores on its RPN number. As a result, proper actions need to be taken to put the firmware in its perfect condition. One example that can be used is ensuring the firmware is free from any virus. Regularly scan for the firmware to avoid any faulty coding and files. Finally, this risk assessment table could be the guide for the users that using this DIY 3D printer. It provides a manual book by gives the proper mitigation recommendations to solve the issue.

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