

A Review of Failure Analyses in Engineering: Causes, Effects and Possible Solutions

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Abstract— Failure analysis is centred on finding the reasons why machine parts lose functioning in an unintended way. In order to identify the damage's primary cause and ensure that it doesn't happen again, failure analysis investigation is necessary in determining the maximum amount of a specific type of load that may be applied to a structure without producing failure. It is frequently of interest throughout the design phase for engineering constructions. This provides the factor of safety against machine failure. This study is aimed at a review of failure analysis in recent times and as such 51 articles were reviewed, most of which were published no later than 2017. In this study, we critically examined and endorsed the idea of using failure as a methodological concept to foster creativity. Engineering-related operational methods, such as causes of failure, types of failure, possibility thinking, and reflexivity following failure, aided in reinforcing this educational study. We also made assumptions about potential design components for a technologically sophisticated failure assessment.

Keywords— Failure Analysis, Causes of failure, types of failure, Engineer, Reflexibility.

I. INTRODUCTION

Engineering failure investigation methods are numerous and are constantly evolving as they get more complex. Invented and made accessible tools, hardware, and computing software are employed, for instance, in the assessment of sub-microscopic stages or substrates of materials, the quantification of minuscule quantities of elements, and the three-dimensional modeling of stresses and deformations of delicate objects are all examples of this type of work. This entire process has allowed the failure investigator (FI) to more precisely quickly identify the urgent causes and consequences of a failure [1]. Because of consistent advancements in other disciplines, the FI can now produce reports more quickly. For example, with recent advances in printing, digital photography and computer hardware and software, and internet technology, the FI can conduct site evaluations, process relevant images, search up some virtual literary works, compose a brief draft report, make a hard copy ready by the next day, or send an electronic copy across the globe in even less time [2]. Such speed and effectiveness were unthinkable twenty years ago. [1-2]. However, despite all of the aforementioned developments, a meticulously designed investigative technique, supervised by human talents and carried out by human investigators, must first be carried out before any results or reports may be

produced. Hock-Chye et al, [1] suggest that any or all of the following steps ought to be incorporated into such a process: Getting background knowledge, chemical analysis and physical examination/testing, computer modelling and stress analysis, writing a report. Failure analysis (FA) necessitates that the FI exceeds the traditional scope of layout procedure in order to identify the exact causes of the failure and, on occasion, double-check the design. The demands expertise with primary strains and stresses, as well as failure mechanisms, fields that are usually only learnable through some kind of highly academic syllabus, experience in the field, and additional research [3].

REVIEW OF ENGINEERING FAILURES

A. Causes of Failure

If an engineer has a concept of why something happened, they are likely to be more successful at diagnosing, learning from, and working through analyzing failure. Hence the want to learn more about the underlying reasons behind failed designs [2].

1) *Insufficient understanding*: Engineers could start taking on duties that are outside of their expertise. This could be due to a drive for achievement, company pressure, or a number of other reasons. Regardless of the situation, poor design is the final outcome. Worse, ignorance may result in dangerous designs. This should never be done. In Ontario, Canada, where I work, the engineering act states that technicians may only work in fields for which they are qualified. Above all, we owe it to the general populace to ensure their safety. I believe similar laws exist in the vast majority of nations [3-4].

2) *Lack of coordination between the Fabricator and the Erector*: It all boils down to communication in the fabricator-engineer interaction. When possible, both parties must listen carefully and be willing to adjust. Failure to communicate just leads to frustration and absurd meme material [5-7].

3) *Failure to Comprehend*:

Engineers must be reminded on a regular basis that their work is not for their own gain. Their work is completed for a client, who could be an integrated marketing division, as in the automotive sector, or an outside party. This means that once

you begin working, you must ascertain what the client truly desires [3-4].

4) *Communication Bridge During Production:* Ineffective communication among the many design specialists engaged, such as between engineers working on conceptual design and those in charge of overseeing construction progress [8].

5) *Poor Craftmanship:* Workmanship is the calibre and expertise a contractor applies to finishing a project. When a contractor disregard building documentation, manufacturer installation instructions, or industry quality standard standards, poor workmanship will usually result. When correct procedure is not followed, it may lead to incomplete or flawed work, both of which are indications of subpar workmanship [9].

Other causes of failure in engineering as proposed by Mishra, [10] are; lack of understanding of science and/or technology, lack of understanding of the materials, limitations of the materials that were used, professional ethical compromises and a failure to recognize the profession's obligation to the community at large could both lead to disastrous failures, lack of expert design and construction experience, particularly when unique buildings are required, code and specification complexity that makes them difficult to understand and use correctly, inadequate field inspector training and shortened construction and/or design times.

B. Types of Failure

There are numerous types of faults linked to mechanical parts/items. A number of these failure mechanisms are discussed in more detail below.

1) *Fatigue Failure:* The word "fatigue failure" refers to the crack of a material that occurs because of the accelerated cracking of its flaky surface under alternating or cyclic pressures. Fatigue failure can eventually result in safety problems and the destruction of vital infrastructure.

In many engineering and construction applications, fatigue failure is a common type of failure. The intensity and/or frequency of the imposed stress determine the extent of the fatigue's effects. For instance, if a short metal rod is continuously bent back and forth in alternating directions, it may break. The rod will eventually shatter after repeated cycles of applying tension. The fatigue failure that caused this break [11-12].

There are numerous distinct types of fatigue, however. Engineers can identify whether fatigue dangers may influence a particular material or product by using failure modal and effects analysis and an understanding of each type's individual features. The following are the most typical forms of fatigue failure:

- **Mechanical fatigue:** This kind of failure is typically caused by a mechanical strength issue and is frequently linked to poor raw material selection, production errors, flimsy welds, or bad design [13].

- **Creep fatigue:** happens when a build-up of thermal or cyclic loads causes the material to deform over an extended period of time, eventually causing creep failure and the item to stop functioning properly [13].
- **Corrosion fatigue:** A given material reacts with an outside element, typically water or other environmental elements, to cause corrosion. The original material becomes more brittle and more vulnerable to cracking brought on by cyclic loads as oxidation changes its physical characteristics [13-14].
- **Thermo-mechanical fatigue:** The combined effects of mechanical, creep, and corrosion fatigue result in this situation of collapse. Because temperature extremes cause creep and external conditions cause corrosion, metals are more highly susceptible to degradation and rupture when repeatedly exposed to the effects of cyclic loading.

Microbiologically influenced corrosion (MIC), viable cultures can produce the most insightful data, corrosion products may need to be sampled and tested [15]. Failure due to corrosion occurs when a substance is exposed to corrosion. This state needs to be preserved and protected right now. When corrosion fails due to microbiologically influenced corrosion (MIC), viable cultures can produce the most insightful data, corrosion products may need to be sampled and tested [16-17].

- 2) *Creep failure:* Creep is the prolonged deformation that worsens over time under a constant strain or tension. It occurs as a result of repeated exposure to elevated external forces applied, and it has a greater impact on materials exposed to heat. This is a failure situation that some businesses, including aerospace, must think about while creating products such as jet engines [18-21].

C. Types of failure in another perspective

Johnson et al, [19], opined that the many failure types have an impact on the various emotions and conversation events that surround them. They classified failure into three distinct axes, such as; stakes, intent and referent.

- 1) *Stakes:* The stakes for performance might vary depending on the audience and significance of the failure. Low stakes failures take place out of the public eye and there is still time for improvement before a formal evaluation. Public failures or failures with high stakes happen when active testing serves as the final assessment of a design [20].
- 2) *Intent:* The intent is a crucial factor in categorizing failure. It is intended failure when a design is tested until it fails or if it fails in a specific (planned) way. It is undesired, nonetheless, if the design is unable to meet the necessary standards or adhere to the established restrictions [21].
- 3) *Referent:* Failure may depend on how it is seen. Failure of a design in relation to the specified criteria is an objective failure. However, there are times when a design may be

perceived as a failure in comparison to other designs or as "not good enough." The failures are arbitrary in certain situations [22].

D. Effect of Failure

The term "failure effect" describes the immediate impacts of a defect on capabilities, operation, or status as perceived or encountered by the user. Some of the effects include user harm, product or process malfunction, decrease in product quality, deviation from requirements, discharge of odors and noise, and so on. Furthermore, the influence of these failings on other systems in direct contact with the flawed system must be considered. When an element fractures, the subsystem with which it comes into contact may vibrate as a result. FMEA is a method for examining potential failures and how they could affect the system [23].

Experiences of engineering failure, cause and effects.

1) *Hyatt Regency Walkway Fall: The Hyatt Regency Resort in Kansas City, Missouri, launched in 1978.* This hotel's meeting facilities and 40-story hotel tower were joined by an atrium with an open design. There were three pathways inside the atrium that led from the hotel to the second, third, and fourth floor meeting centres. 50 feet high, 117 feet wide, and 145 feet long made up the atrium.

Main reasons for collapse - A number of factors contributed to the Hyatt Regency walkway's demise. The layout of the walkways was the primary contributing factor. The walkways' suggested layout was as follows;

Proposed design.

- Large flange beams ended up hanging from a box beam utilized on either corner of the walkway.
- The flange frames were merged to the exterior of the box beam by a buckled clip angle.
- The other end of the walkway was backed by a sliding direct effect, while the other end was fastened to a plate.
- Each box beam of the walkway's supporting washer and nut were weaved onto the supporting rod.

The design was altered from a single to a double hanger rod as a result of disagreements between G.C.E. and Havens, purely because Havens did not want to thread the entire rod in order to insert the washer and nut as reported by Hyatt Regency Walkway collapse, [24].

Actual design.

The actual design was as follows:

- Each support rod's tip was fastened to a cross beam of the atrium's roof.
- The second rod was attached to the box beam four inches away and gone through all the bottom end of the box beam, where a washer and nut were attached.
- In a similar fashion, to support the second level, extra shafts were raised below [24].

4) Tacoma Narrows Bridge.

The Tacoma Narrows Bridge opened to traffic on July 1, 1940. Soon afterward, on November 7, 1940, its main span

collapsed into the Tacoma Narrows due to aeroelastic flutter, a natural occurrence caused by a 42-mph wind. The bridge collapse had long-term consequences for engineering and science. Despite the fact that aeroelastic flutter was found to be the cause of the bridge's failure, the occasion is illustrated in many undergraduate physics reading materials as an instance of elementary compelled resonance, with the air supplying an outer recurring incidence that suited the natural structural frequency. Its failure also speeded up research into bridge aerodynamic efficiency and aeroelasticity, which influenced the designs of all major long-span bridges built around the world [25].

Nobody was killed as a result of the bridge's collapse. However, Leonard Coatsworth and another man left a small dog in a car on the bridge, but then when they proceeded to rescue it, the terrified dog bit both of them. The dog eventually drowned. The bridge collapse was captured on 16mm film by Barney Elliott, the owner of a nearby photography shop, and the picture shows Leonard Coatsworth departing his car and having crossed the bridge. The library of congress selected the Tacoma Narrows Bridge collapse for integration in the United States National Film Registry in 1998 as "culturally, historically, or aesthetically significant." The recording continues to be displayed to engineering, physics, and architecture pupils as a lesson in caution [26].

The towers and side spans, that had survived the collapse of the main span but had been damaged beyond repair, were dismantled beginning shortly after the incident occurred and lasting until May 1943. Because of the United States' participation in the Second World War, as well as engineering and finance concerns, efforts to change the bridge were delayed [27].

II. FAILURE ANALYSIS

A. Methods of Analysing Failure

As more sophisticated tools, equipment, and computing software are created and utilized, the strategies used in the evaluation of engineering failures become more diverse and diverse. These are used to analyze sub-microscopic phases or coatings of materials, to measure negligible amounts of elements, and to model stresses as well as deformations of intricate objects in three dimensions [28]. All of them have enabled the Failure Investigator (FI) to nail down the two main causes of a failure with greater accuracy than ever before [29].

Methods used to carry out failure analysis include;

1) *Fishbone/Ishikawa diagram:* Ishikawa diagram, sometimes known as a fishbone diagram (Figure 1), is a visual representation of the failure analysis technique. The bones are probable reasons, and the head is the issue we are studying.

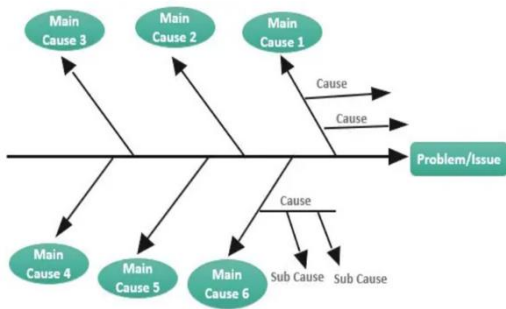


Figure 1- A fishbone diagram [30].

The failure/event/effect we are researching can be caused by a variety of reasons, which is the underlying premise of the entire diagram. It is commonly utilized in the IT, aerospace, and medical fields to optimize processes [31].

How to create a fishbone/Ishikawa diagram by Srivastav, [31].

- Draw a fish's head in the upper right corner. We draw consciousness to the problem at hand here. On the left, make a backbone.
- Add branches to the backbones that would list the main reasons. List the most important 4 to 8 reasons.
- Below these primary causes are the causes and sub-reasons. These can be discovered through a brainstorming or by closely managing the entire procedure and acknowledging any factors that may jeopardize quality.

Advantages of Ishikawa diagram.

- This method is frequently applied to product design, quality enhancement, and defect reduction.
- Rather than concentrating on one explanation, this process gives us with a scope of all possible explanations, allowing us to not only identify the root reason for the present problem but also prevent future mishaps [32].

Limitations of Ishikawa diagram.

- It is not recommended to apply this method just once. Instead, this action should be carried out consistently to be proactive in finding any potential gaps.
- In conclusion, an illustration of cause-and-effect relationships is a fishbone diagram.
- Even though the device is simple to employ, it is extremely effective at improving a procedure and the performance of a product or service. By continuously implementing it, an organization can be early on recognizing any process weaknesses and fixing problems with speed and accuracy [3].

2) Failure Modes and Effects Analysis (FMEA).

Failure analysis is based on figuring out what causes a machine part to stop working as it should. Finding the damage's primary cause and ensuring that it doesn't happen again call for failure analysis investigations [5]

Failure-mode analysis is the next step required after identifying a potential issue with the machine train or one of its linked systems in order to accurately correctly identify the

failure mechanism and identify which machine train component is declining. Failure mode assessment tracks the amount of machine-train challenges and their symptoms, yet it fails to always identify the true source of problems [9].

Nonetheless, the protection of equipment has been the primary concern of the social sciences as they have evolved. As a consequence, today's designers should approach their task from the jointly unique perspectives of superior efficiency, cost effectiveness, and dependability. Nishida et al [6] classified design bases into the following categories.

- Design that allows for failures while maintaining safety (damage-tolerant or fail-safe design).
- A design that eliminates failures (safe-life design).

Almost all steel constructions using Case 1 above. Case 2 is limited to planes with strict weight limits and components with limited service life throughout terms of service features, such as bushings and wire ropes. Numerous reports describe structures that failed despite being developed to be failure-free and having generously high estimated safety factor values. It is widely accepted that fatigue is partially responsible for much more than 80 to 90 percent of steel structure failures [6].

Breakdown can show us vital insights regarding how we can avoid it. Failure examples are typically real-world data that cannot be obtained through laboratory-scale small-scale experiments. In general, past questions about disappointment stories are more important than examples of overcoming adversity. It is critical to identify the causes of various failures and implement preventative measures to prevent them from occurring again. This is also critical because the results can be used to develop good design rules [6].

History of FMEA.

The aerospace industry conducted the first official FMEAs, that were especially concerned with safety issues, in the middle of the 1960s. FMEAs quickly gained traction as an important tool for improving safety, especially in the chemical processing industries. According to Mikulak et al, [8], the primary goal of safety FMEAs was and continues to be going to prevent safety accidents and incidents.

Engineers have long sought out potential flaws in items and procedures, but the FMEA method formalizes the process and creates words that can be used both within and across businesses. It is accessible to staff members of all ages, both technical and non-technical. The FMEA technique was revised for use as a quality improvement tool in the automotive industry [33].

3) Fault Tree Analysis (FTA).

Boolean logic linkages are used in fault tree analysis to pinpoint the failure's primary cause (Figure 2). It makes an attempt to simulate how a system breakdown spreads. This aids in the development of well-defined systems with appropriate redundancies by reliability engineers, ensuring that component failures do not always lead to system-wide failures [34].

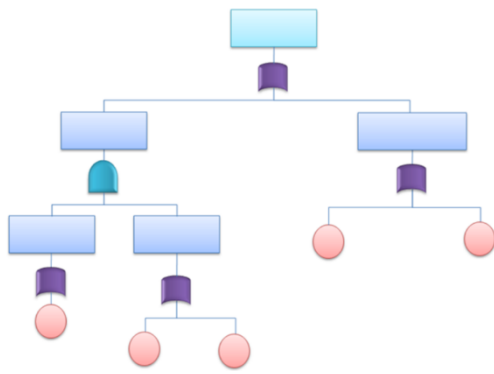


Figure 2– FTA Diagram [34].

B. Failure Analysis Tools

Fractography is the method of failure analysis which involves the study of the fracture surface. This involves the microscopic examination of the fracture surface. The key observations required are locating the rupture origin, determining the direction of crack propagation, and establishing the fracture mechanism. Certain tools, such as the scanning electron microscope (SEM), are used:

Scanning Electron Microscope (SEM)

SEM creates a picture by sweeping or scanning a fine electron beam across the surface of a bulk material. The intensity of the measured signal when the relevant spot on the sample is irradiated by the beam is represented by brightness at any location. Figure 3 shows a picture of a typical SEM and the low out of parts that make up the microscope. The scanning electron microscope (SEM) is commonly used for surface imaging. It is frequently used because of its speed, versatility, simplicity, and low sample preparation requirements [35].

TABLE .1.0
ADVANTAGES AND DISADVANTAGES OF SEM.

Advantages	Disadvantages
Resolution as low as 15 nanometres	Cannot image wet samples
Traceable standard for magnification	limited when used to image non-conductive samples
Chemical analysis	Is bulky and expensive

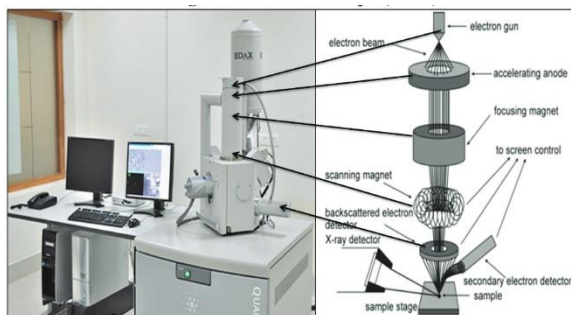


Figure 3– Parts of a Scanning Electron Microscope (SEM). [36].

1) Transmission Electron Microscopes (TEM).

Transmission electron microscopes (TEM) are microscopes that view specimens and create a greatly magnified picture using an electron particle beam. In order to make a picture, TEMs need a high voltage electron beam. An electron gun just at top of a TEM fires electrons through the microscope's vacuum tube [37-38]. Rather than using a glass lens to concentrate light (as in optical microscope), the TEM uses an electro - magnetic lens to focus electrons into a very small beam. The electrons either disperse or strike a surface at the bottom of the microscope as the beam passes across the extremely thin material. A picture of the specimen with its many components colored differently according to its density is shown on the screen where it may be analysed or photographed [39].

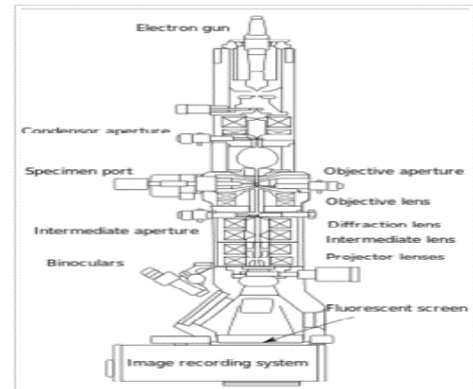


Figure 4: Parts of a Transmission Electron Microscope (TEM) [39]. Figures 4 and 5 shows typical TEM and its schematic diagram.



Figure 5 –Transmission Electron Microscope (TEM) [39].

2) Energy-dispersive X-ray spectroscopy (EDS, EDX, EDXS, or XEDS).

Energy-dispersive X-ray spectroscopy (EDS, EDX, EDXS, or XEDS), also known as energy dispersive X-ray analysis (EDXA or EDAX) or energy dispersive X-ray microanalysis (EDXMA), is a chemical and elemental analysis method. It is based on the interaction of an X-ray excitation source and a sample. A sample EDS machine is shown in Figure 6. Its characterisation capabilities are largely attributable to the fundamental premise that each element has a distinct atomic

structure, resulting in a distinct collection of peaks on its electromagnetic emission spectrum [40]

Figure 6– Energy-dispersive X-ray spectroscopy (SIC | Energy Dispersive X-Ray Spectroscopy (EDS/EDX) [40].



III. CHALLENGES AND POSSIBLE SOLUTIONS

The ‘summary of findings’ (Table 2.0) includes data related to failure analysis performed on different engineering components and systems. This data has been derived from both quantitative and qualitative data analysis of systematic reviews from various researchers.

This table includes information on the three modes in which failure analysis can be carried out on a system or on a machine component, also includes the type of test being performed or the problem being analysed, the cause of the problem, effects and possible solutions to which these various problems can be solved, with the aim of taking corrective measures to fix the problem and prevent against further failures.

TABLE. 2.0
SUMMARY OF FINDINGS

S/ N	Author (s)	Mode type	Test problem	Cause(s)	Effect(s)	Solution(s)
1.	Hlevnjak et al, [12]	Ishikawa diagram	The distribution of an oil slick on the water's surface	Accidents on shore platforms, drilling equipment and wells, oil transfusion from storage tanks to tanks at fuel stations. Winds, ocean currents, and other factors influence spread.	Hypothermia, poisoning, drowning, disturbed breeding grounds, deformities, etc.	Using an oil boom or containment boom.
2.	Uti, [41].	Ishikawa diagram	To identify the causes of bearing deficiencies in automobile wheels.	Man, Bearing Manufacturing Car exploitation, replacement of service bearings.	Failing wheel bearing.	install new wheel bearings in place of the damaged ones. Replace the bearing and axle seals.
3.	Maisuradze and, Antakov, [16].	FMEA	Mechanical components made of alloyed steels fail due to fatigue.	Friction of conjugated parts, surface deterioration damage, metallurgical flaws, and geometrical asymmetry are all examples of flaws. Flaws in thermal, thermochemical, and mechanical treatment.	Premature fatigue failures of mechanical component.	All moving parts should be well greased to ensure that they move when they should, relieving pressure on solid components.
4.	Cody, [18].	FTA	To reduce failures in software	CDN not delivering assets Fronted server errors, backend server errors	Severe financial loss, time or resources.	Extra planning, early software testing, Automation.
5.	Yaeger, [17].	FMEA	Failure analysis of SRM charge structure	Aging, cracking, long-term self-weight load, dehumidification and interface deboning, etc.	Creep effects, deformation, change in charge type.	Maintenance – since the main cause of failure is aging.

1. The problem, cause, effects, and solutions were all shown on the Ishikawa diagram, with the aim to analyse the problem of oil spillage at large water bodies. The solution to oil spillage shown in the diagram was the use of a containment boom. According to [41] the purpose of a containment boom is to stop the oil spill from spreading and/or to direct the oil toward a collection site. Multiple containment booms may be joined end to end and hauled by one or more vessels to completely enclose a bigger oil spill. [41]. The problem, cause, effects and solutions were all shown on the Ishikawa diagram.

2. In addition to leaving, a faulty roller bearing can impact on improving and cause significant wear on other suspension components, such as the hub and cv joints, if you don't have a tire on your car. Furthermore, it causes the transmission and tires to wear out more rapidly or unevenly.

The purpose of the Ishikawa was to highlight the problem and the solutions [42].

3. The conclusion of this analysis is as follows:

- In order to protect the structure, fatigue stresses— which are material- and time-dependent stresses— need to be taken into account.
- The fatigue life will be considerably impacted by the structure's shape.
- The life is reduced the wider the applied stress range.
- Design that keeps stress levels below the point of weariness [43].

4. While failure in software might not be avoidable, all that can be done is to be prepared for what lies ahead [44]

5. The charge structure propellant aging, cracking, dehumidification and interface deboning, solid engine seals permanent deformation and rebound capacity, and other failure conditions are caused by SRM throughout its entire life cycle.

However, whether or not the charge structure fails are what ultimately determines whether SRM will fail [45].

6. The primary and secondary causes in this study's Ishikawa diagram, which is based on the literature, contain the six information systems components and are classified into 4M categories. For each secondary reason that contributes to the issue to a degree that falls within the client-specified range, potential remedies have been created in this study. Component difficulties are described as a percentage using sectoral statistics. Since the data on component problems from sectoral statistics is only available for the machine category, this study does not show the percentage of problems with the entire information system [46].

7. In extension to the solution of delivery performance by using simulation FTA, the company should also implement the other remaining mitigation strategies to guard against the following risks: vehicles waiting for orders in Delivery Units for an extended period of time; vehicles returning to registration offices and waiting for new Delivery Memos; vehicles needing to be unloaded and cancelled; and lengthy stuffing lines and waiting times [47-48].

IV. CONCLUSION

Failure Analysis is a principal aspect of engineering which aids in the understanding of causes and thus procurement of solutions and preventions to such failures. The method involves the use of analytical tools and software including the fish-bone diagram, the fault tree analysis and the scanning electron microscope to mention a few.

This research paper yielded the following conclusions:

- Failure analysis requires a Failure Investigator (FI) to accurately pinpoint the exact cause of the failure
- That the most common causes of failure are poor craftsmanship and a lack of understanding. In summary, human error.
- That the FMEA and Ishikawa diagram are popular and effective failure analysis methods.
- That microscopic analysis of failure, known as fractography, is a widely accepted means of sample failure analysis
- And that, Failure Analysis is an invaluable branch of engineering which prevents many disasters.

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