



Practical Application of Reliability Engineering

An Online Continuing Education Course for Engineers

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Practical Application of Reliability Engineering

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Course Introduction

Reliability Engineering (RE) is an engineering field that applies techniques to prevent or reduce the likelihood of failures. This is primarily concerned with how to estimate reliability and employ a risk management approach for failures if their root causes have not been corrected. Reliability Engineering applies both quantitative and non-quantitative skills in order to achieve the results of maximizing reliability and minimizing costs due to failure.

This course will provide a foundation for applying reliability engineering to influence design. Examples and concepts within the course apply to electrical, mechanical, civil, industrial, and chemical engineering. It covers common principles of reliability in a simple and practical way, as well as how to incorporate Reliability Engineering concepts. The course makes the complex subject of Reliability Engineering into a more practical and lucid application on how to improve the reliability of a system or facility. Upon completing this course, participants will be able to

- 1) Estimate reliability by performing straightforward reliability calculations
- 2) Apply best practices and methods of Reliability Engineering in industrial, commercial, and institutional environments, such as failure mode and effect analysis (FMEA), risk assessment, cost versus benefit analysis, physics of failure, and root cause analysis
- 3) Understand the fundamentals of Reliability Engineering enough to be able to work with a reliability consultant and/or learn how to apply reliability software

The focus will primarily be on mechanical, structural, and electrical systems, with some attention paid to solid state or electronic systems. The student is encouraged to apply the learned concepts and processes and tailor them to their scope of job duties and requirements. Tailoring includes applying a scalable approach and remembering Reliability Engineering encompasses probability and is not an exact science.

This course is not specifically presented as a safety course. The course will focus primarily on failure due to aging instead of failure due to random reasons such as human error (i.e., operator mistakes). There are complex engineering topics such as

Physics of Failure, which are explained with as much detail as possible within the limited amount of page space. Hence, some of the topics, like reliability math, may require the student to further learn more on their own by looking back to the math references.

Key and Fundamental Concepts

Reliability

Reliability is central to Reliability Engineering and is generally accepted as the probability that an item (i.e., system, asset, component, etc.) will perform a required function without failure under stated conditions for a stated period. It is based on the number of failures per specified period. The specified period could be the number of cycles or operating hours. Stated conditions include situations such as operating within its intended environmental conditions as well as other design factors like proper lubrication, required supply voltage, etc.

Availability

Availability is a measure of reliability and maintainability. Availability is the percentage of time the system is ready to perform functions and is dependent on reliability and maintainability. The mean time to replace or repair is measured by maintainability. Ease with repairing or replacing a failed unit means the units is very maintainable. This course focuses on forecasting and improving reliability and will not focus on maintainability.

$$\text{Availability} = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}}$$

Availability can apply to repair or replacement scenarios. Mean time to failure applies to a replaceable unit.

$$\text{Availability} = \frac{\text{MTTF}}{\text{MTTF} + \text{Mean Time to Replace}}$$

Mean time between failures (MTBF) applies to a repairable unit.

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{Mean Time to Repair}}$$

Risk

Uncertainty of failure is central to reliability; therefore, Reliability Engineering applies risk management concepts. Risk is determined by the uncertainty and the consequence of a failure.

$$\text{Risk of Failure} = \text{Uncertainty Score} \times \text{Consequence Score}$$

Not all failures may result in a safety risk. For example, a medical system may consist of two respiratory air pumps, a primary pump, and an identical backup or redundant pump. An operator may allow for the primary pump to run to failure without causing the system to lose any of its functions by running the backup pump.

Failure and Physics of Failure

Failure is the inability of an item to perform its intended function. Based on Physics of Failure (PoF), the failure due to wear out is inevitable. An item can be designed, maintained, and operated to extend its life however, eventually, it will wear out.

PoF is the knowledge and understanding of the processes and mechanisms that induce failure to predict and grow or improve reliability. Based on historical research documented in “Friction and Wear of Materials” by Professor Ernest Rabinowicz of the Massachusetts Institute of Technology’s Department of Mechanical Engineering, the below pie chart (Figure 1) represents the breakdown of failure causes for “moving equipment” failure. Movement can be rotational or linear motion; it includes such equipment as turbines, internal combustion engines, pumps, electric motors, compressors, drive belt systems, and actuators. Improper operation and maintenance (O&M) are related to human error or safety, and obsolescence means that an aging, but still-reliable equipment may become less ‘useful’ because it does not perform as well as newer and more technologically advanced equipment. Hence, this obsolete equipment would be replaced as part of a technology refreshment.

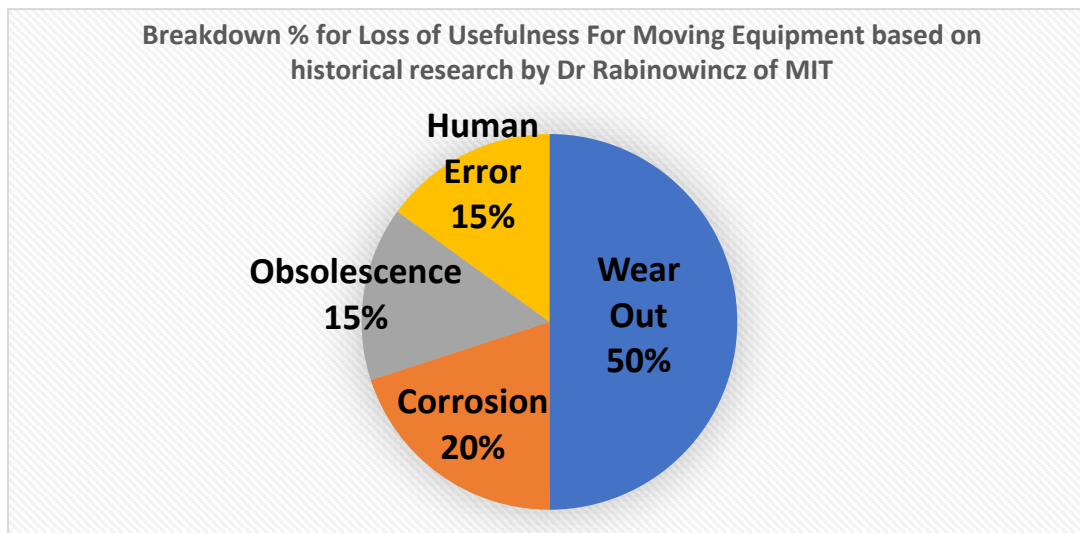


Figure 1: Pie Chart of Reasons for Equipment Loss based on “Friction and Wear of Materials”

This course highlights failure due to wear out and corrosion since they account for 70% of failures. Any equipment that moves is at risk for wear out. Metallic equipment is at risk for corrosion. Wear-out and corrosion are considered age-related failures, whereas failures due to human error, natural disasters, and accidents are random failures.

Wear out failures occur as a result of deterioration processes. Ultimately the unit or item weakens over the operating time or number of cycles it performs. Types of deterioration can include the following three processes. They represent common modes or ways materials can fail based on the configuration of the item.

1) Fatigue: weakening of a material caused by repeated loading and unloaded that results in progressive and localized damage such as loss of strength and material, and possibly the growth of cracks. For example, this is seen with each surface of a tire that undergoes cyclical friction contact with the ground.

2) Creep: is the likelihood of a solid material to move slowly or deform permanently under the influence of sustained stresses based on the material's properties, exposure time, exposure temperature, and the applied load. An example is a turbine blade that unpredictably creeps to the point of rubbing against the turbine housing, and then failing. The same risk is associated with temperature changes from equipment power cycling that cause creep to solder joints on surface-mounted electronic components.

3) Delamination: is a mode of failure where a material fractures into layers; it is commonly referred to as layer separation, such as with composite material. This could relate to other modes such as corrosion, which causes layers of reinforcement steel (i.e., rebar) to corrode and expand at the concrete's surface. The expansion puts greater stress on the concrete at the surface to crack and separate from the underlying concrete.

Corrosion is also a deterioration process but will be discussed separately. It is a chemical reaction where a metal like iron becomes more stable (i.e., more “noble”) by losing electrons. A unit’s strength and ability to perform its function will gradually decrease with age as corrosion progresses.

There are specialized material engineering and mechanical engineering courses that study wear out and corrosion. They cover in detail the mechanics and behavior behind wear out and corrosion processes. Also, they examine methods to mitigate the risks associated with wear out and corrosion. Due to the limited amount of course time, this course will only summarize some of the concepts from these specialized courses. Reliability Engineering methods such as hardening or ruggedizing a design and Factor of Safety (FoS) will be addressed to address specific examples of wear out and corrosion.

Risk management actions include such as providing proper lubrication and analyzing the lubrication oil for any evidence of metal shavings, which would be symptoms of wear out for metallic equipment. An engineer may consult the maintenance team on the results of the lubrication oil analysis. With profound knowledge of the equipment’s design, the engineer may estimate how worn out the equipment is based on trends from the periodic analysis of the lubricating oil. This allows the forecasting of the remaining life of the equipment. Assuming the lubrication is in accordance with the original design, it may allow the engineer to redesign the system to improve lubrication and therefore reduce wear out.

Fault and Fault Tolerance

A fault could be noncompliance with the requirements of a design. A fault is a defect that may lead to a failure based on the item’s tolerance of faults. The greater the fault tolerance, the greater the ability of the item to tolerate faults and still not fail and function as intended.

A fault may worsen to the point that it creates a failure based on the item’s tolerance to the fault. It could be hidden or non-hidden defects such as a software bug or noncompliant coating resulting in hidden corrosion within a hardware component. Eventually, the corrosion worsens to the point that the structure fails.

Quality and Reliability

Even if quality assurance ensures the item has no hidden or visible defects like software bugs or under-rated fasteners, the item may still undergo failure due to wear out, such as friction. With quality assurance, the item is produced, operated, and maintained as it is designed and planned. For example, designing a motor in accordance with the National Electrical Manufacturers Association (NEMA) standards will ensure the equipment will operate as expected. This leads to significantly reducing, if not virtually eliminating, non-age (or random) failures. It ensures the predictability of the motor’s

reliability behavior. The motor will behave as predicted from Reliability Engineering math and analysis, such as wearing out. Also, rigorous quality assurance allows the engineer to separate failures due to wear out and random failures like incorrect operation and maintenance.

Mechanical Integrity

Reliability encompasses the quality-related field of Mechanical Integrity (MI). The Occupational Safety and Health Administration (OSHA) defines MI as the “management of critical process equipment to ensure it is designed and installed correctly, and that it operates and is maintained properly.” MI is analogous to quality assurance; they ensure the item is properly designed, operated, and maintained, so the only likelihood of failure is due to wear-out and not random reasons, like improper maintenance. OSHA applies MI by regulating and auditing the operation and maintenance of process equipment such as those used in chemical manufacturing systems like oil refineries and natural gas processing facilities.

Reliability Engineering Standards and Reliability Analysis Center

A library of standards serves as the primary tool kit to implement a RE program for your system or facility. These are standards besides the industry design standards, such as the NEMA standards mentioned in the previous paragraph. Also, in addition to the RE standards, there are reliability software tools like Reliasoft and hardware tools like built-in testing capabilities that will assist with implementing the RE program.

The U.S. airline industry was the first to implement RE in the 1950s. The U.S. military was the first to form the Reliability Analysis Center (FAC) at Rome Laboratory. Eventually, the RA standards were taken down in the 1980s-1990s. The RE standards eventually were adopted by the RMQSI Knowledge Base.

The System Reliability Engineering (SRE) standards were purchased, which will essentially provide the same information as the SRE program. However, the Reliability Engineering (RE) standards are a non-copyrighted program. However, the Reliability Engineering (RE) standards are a non-copyrighted program. There are other industry associations and organizations that provide RE-related standards. However,

Reliability Engineering Standards and Organizations

As mentioned previously, industry associations and organizations provide RE-related standards.

