# Introducing a “Semester long” course

# *Introduction to Reliability Engineering*

Instructor: Jim Breneman

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# Course outline

| Month | Day | Time | Title |
|---|---|---|---|
| February | 9 | Noon-2PM | Class Introduction-Overview&Start with Probability |
| February | 23 | Noon-2PM | Probability (Hint: Reliability is Applied Probability)-Part 1 |
| March | 8 | Noon-2PM | Probability (Hint: Reliability is Applied Probability)-Part 2 |
| March | 22 | Noon-2PM | Discrete and Continuous distributions-Part 1 |
| April | 12 | Noon-2PM | Discrete and Continuous distributions-Part 2 |
| April | 26 | Noon-2PM | Weibull Distribution -Part 1 |
| May | 10 | Noon-2PM | Weibull Distribution -Part 2 |
| May | 24 | | |
| June | 14 | Noon-2PM | Reliability Modeling -- parallel, series, redundant, standby systems |
| June | 28 | Noon-2PM | FMEA-Part 1 |
| July | 12 | Noon-2PM | FMEA Part 2 |
| July | 26 | Noon-2PM | Reliability Testing -Part 1 |
| August | 9 | Noon-2PM | Reliability Testing -Part 2 |
| August | 23 | Noon-2PM | Reliability Testing -Part 3 |
| September | 13 | Noon-2PM | Reliability Allocations and Predictions, Reliability Growth-Part 1 |
| September | 27 | Noon-2PM | Reliability Allocations and Predictions, Reliability Growth-Part 2 |
| October | 11 | Noon-2PM | System Safety Analysis and link to Reliability-Part 1 |
| October | 25 | Noon-2PM | System Safety Analysis and link to Reliability-Part 2 |
| November | 8 | Noon-2PM | Maintainability & Human Reliability-Part 1 |
| November | 22 | Noon-2PM | Maintainability & Human Reliability-Part 2 |
| December | 13 | Noon-2PM | Other Topics (TBD) |

Caution: There may be changes in the subject matter, dates, depending on presentation time, etc.



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# What to expect

1. Classes will be on every 2nd and 4th Friday of the month Noon-2PM, starting FEB 9.
2. Each class will last ~2 hours, with a ~10 minute break after the 1st hour.
3. Exercises/problems will be "suggested" during the presentation of each session. Work through each problem. The solutions will be discussed at the next session.
4. As you go over the session charts at home and have questions, write them down and we'll go over the questions at the next session. If you have to miss the next session email me your question and I'll get back to you with an answer.
5. I will be using EXCEL and MINITAB in this course.



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# Background...

- Everyone has a personal concept of "reliability."
- We think of our automobile & home appliances as being dependable, trustworthy, consistent, ... and we mentally assign some degree of *reliance* to them.
- More formally, reliability engineering is the assurance science that provides engineering proof of ability for continued performance of the engineered product.
  - This includes in conceptual design, full-scale design, manufacturing, test, production, and field support.



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# Reliability Approach



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# This Is Where We Want To Go

- Reliability is an integral part of how your company develops products and production systems
  - ***Plan for it - Design for it - Do it (and verify) - Learn from it (and get even better)***
- Customer focus
  - ***External customers*** **stay and new customers come to your company based on reliability**
  - ***Internal customers*** **get better designs and more effective production systems to succeed with**
- Business performance improves
  - **Better and Possibly Faster Product and Production System Launch**
  - **Increased Customer Satisfaction**
  - **Increased Overall Equipment Effectiveness**


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# Scope of Efforts

- Some companies choose to scope their efforts...
  - **Complex Products -** Products that have several layers of complexity and active electrical and mechanical elements
  - **Critical Applications -** Products that are used in critical applications with stringent government or industry requirements
  - **Production Systems -** Production Systems that are critical to internal performance even if the product made is not a risk

What is YOUR company's focus?


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# Reliability Definition vs. the "Real World"

- Reliability is the probability that an item can perform its intended function for a specified interval under stated conditions following prescribed procedures.

- *There are "Real World" conflicts with this textbook definition that we need to keep in mind…*
  - **Probability** – Customers expect a **probability of 1**, "It Works"
  - **Intended Function** – The product may be used in unintended ways and still be expected to work
  - **Under Stated Conditions** – The product may be operated outside of the stated conditions and still be expected to work
  - **Prescribed Procedures** – Customers may not have the required tools or skill level and may not follow procedures and still expect the product to work

➔ *Customers are looking for Quality over Time*



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# Probabilistic Definition of Reliability

- *Reliability* is defined as the probability that a system survives for some specified period of time. It may be expressed in terms of the random variable **t,** the time-to-system-failure. The PDF, $f(t)$, has the physical meaning,
- for vanishingly small $\Delta t$:

$$f(t)\,\Delta t = P\{\,t < \mathbf{t} + \Delta t \le \mathbf{t} + \Delta t\,\} = \left\{\begin{array}{l}\text{probability that failure}\\ \text{takes place at a time}\\ \text{between } t \text{ and } t+\Delta t\end{array}\right\}.$$

- the CDF now has the meaning:

$$F(t) = P\{\mathbf{t} \le t\} = \left\{\begin{array}{l}\text{probability that failure}\\ \text{takes place at a time less}\\ \text{than or equal to } t\end{array}\right\}.$$

- We define the reliability as:

$$R(t) = P\{\mathbf{t} > t\} = \left\{\begin{array}{l}\text{probability that a system}\\ \text{operates without failure}\\ \text{for a length of time } t\end{array}\right\}.$$

Lot's more to come about this!!



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# How Can Reliability Help?

- Reliability Tools
  - Focused Efforts on Critical Areas
  - Efficient and Effective implementation
  - Supports Product Development (e.g.. Stage Gate)
- Life Cycle Perspective
  - Customer expectation of reliability does not stop when the product ships or the warranty period is over
  - We must know how the product performs over the intended life and feed that knowledge back for Continuous Improvement
  - Total Cost of Ownership versus Lowest Sticker Price
  - Higher Overall Equipment Effectiveness leads to Lowest Production Cost
- Quality System
  - Reliability efforts support ISO 9001 (a globally recognized standard for quality management.)
    - Clause 7 Product Realization
    - Clause 8 Measurement Analysis and Improvement


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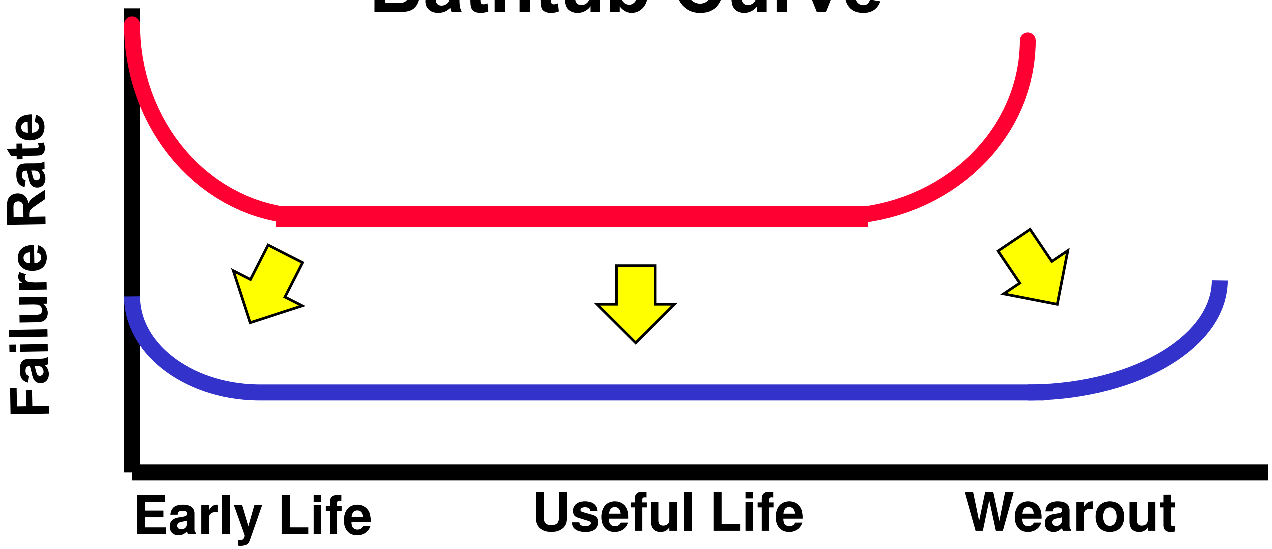
# Managing Reliability

- Reliability Engineering

  A systems approach to planning for, designing in, verifying, and tracking the reliability of products throughout their life to achieve reliability goals.

**"Bathtub Curve"**





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# Reasons for Reliability Engineering

- Competition… customer demand, driven by customer perception, NOT company marketing.
- Need to reduce cost(particularly warranty cost), reduce manpower
- Complexity of most products:

| Number of critical components | Individual component reliability | | | |
|---|---|---|---|---|
| | 99.00% | 99.90% | 99.99% | 99.999% |
| | System Reliability | | | |
| 10 | 90.44% | 99.00% | 99.90% | 99.99% |
| 100 | 36.60% | 90.48% | 99.00% | 99.90% |
| 250 | 8.11% | 77.87% | 97.53% | 99.75% |
| 500 | 0.66% | 60.64% | 95.12% | 99.50% |
| 1,000 | 0.00% | 36.77% | 90.48% | 99.00% |
| 10,000 | 0.00% | 0.00% | 36.79% | 90.48% |
| 100,000 | 0.00% | 0.00% | 0.00% | 36.79% |


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## Products increase in complexity with time

- The farm tractor - an actual example of increase in product complexity with time.

| Farm Tractor model year | Number of critical components | Tractor reliability per year* | # of tractors failing per year per 1000 tractors |
|---|---|---|---|
| 1935 | 1,200 | 88.70% | 113 |
| 1960 | 2,250 | 79.90% | 201 |
| 1970 | 2,400 | 78.70% | 213 |
| 1980 | 2,600 | 77.10% | 229 |
| 1990 | 2,900 | 74.80% | 252 |

* assuming critical components are in series, and an average component reliability is 99.9%

- To prevent this degradation in system performance component reliability **<u>must</u>** be increased!!



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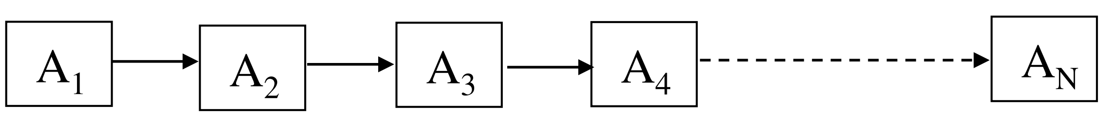
# Where Reliability Engineering came from...

- During the expansion of the aircraft industry after WW I the fact that an aircraft engine might fail was partly instrumental in the development of the multi-engined aircraft.
- In the 1930’s reliability (or unreliability) was expressed in terms of an average number of failures per unit time or as a mean failure rate for an aircraft.
- Mathematical reliability modeling began in the 1940’s in Germany during the development of the V-1 rocket.. Since the the first rockets were 100% UNRELIABLE  the German mathematician Robert Lüsser developed the concept that a series system reliability was equal to the product of its component reliabilities. Hence the reliability of the individual components must be much higher than the system reliability.




where $\text{Reliability}_{sys} = A_1 x A_2 x A_3 x A_4 x \dots x A_N$



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# Where Reliability Engineering came from, continued

- In the US during the 1940's improving reliability became an extension of quality. Better design, stronger materials, harder and smoother wear surfaces, advanced inspection instruments were used to extend the useful life of the part or assembly. Other advances included the beginning of "Design for maintenance accessibility", and most notably management interest and enthusiasm in developing sampling plans for inspection, control charts for high production machine tools, supplier quality levels… as well as supplier incentives for the delivery of higher quality complex products.
- 60% of the airborne equipment shipped to Far East in WWII arrived damaged; 50% of the spares and equipment in storage became unserviceable before usage.
- 60-75% of radio vacuum tubes in communications equipment at this time were failing… sparking the development of solid-state electronics.

And so it progressed ….



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# Where Reliability Engineering came from, continued

- In the 1950's:
  - increased importance of safety… especially in aerospace & nuclear fields.

    (in 1950 DOD established an Ad Hoc Group on Reliability; later made permanent as the Advisory Group on the Reliability of Electronic Equipment (AGREE))
  - began to use failure rate, life expectancy, design adequacy, success prediction
  - during Korean War DOD found that it cost $2 per year to maintain every $1 in electronics… hence wiser to design for reliability than to repair equipment after failure.
  - began to study human error reliability
  - RAND Corporation produces study that summarizes statistical theories and techniques applicable to reliability and leads RCA to establish an organized program for the reliability discipline.
  - (Nov 1954) 1st National Symposium on Reliability and Quality Control was held and published proceedings. Now called the Reliability Availability Maintainability Symposium (RAMS).



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# Introduction to Reliability Engineering

- In the 70s through early 90s, the Department of Defense (DOD) saw significant improvement in weapon system Reliability and Availability.
- However, this focus was lost during the 90s and institutional knowledge/expertise were further lost in acquisition reform resulting in a decrease in system Reliability, Maintainability, and Availability.
- The figure on the next slide traces the relative health of the Navy reliability program beginning in 1963 and projecting into the future.
- The Table following provides a detailed description of the events that led to these fluctuations.



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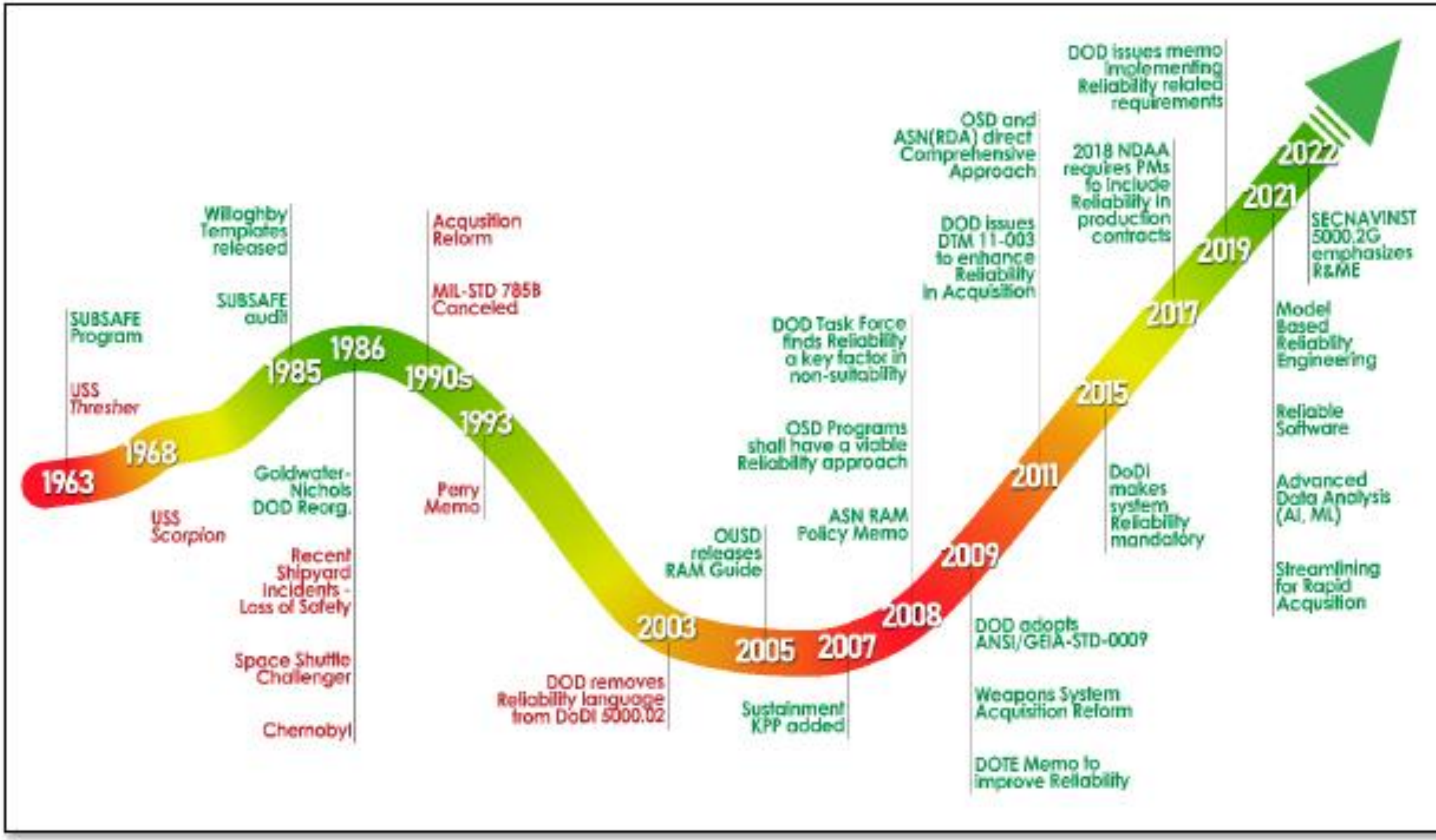
DOD Reliability Health 1963-2022



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## Where Reliability Engineering came from, continued

- Currently:
  - Reliability modeling is done throughout industry, utilizing Monte Carlo simulation to adjust for variation in failure modes.
  - Software reliability, while a major focus, varies in emphasis by product and company.
  - Reliability and Six Sigma initiatives are integrated.
  - Computing capability- better, faster, cheaper!!
  - Field data is still a mess but getting better.


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# Reliability Education… a few of the schools in US

- USAF Institute of Technology- initiated Master's degree in System Reliability Engineering 1962.
- US Naval post-graduate school- began teaching product assurance courses in 1960
- University of Arizona- initiated reliability courses in 1963, Master's program in 1969, PhD in ME with Reliability Engineering option.
- University of Maryland- began offering MS and PhD in Reliability Engineering in 1989.
- University of Tennessee-Knoxville offers an MS in Reliability – 2007.
- Rutgers- has a Quality & Reliability Engineering option in Industrial & Systems Engineering Dept.
- New Jersey Institute of Technology offers a MS in Assurance Sciences in the IE dept.
- George Washington University- Institute for Reliability & Risk Analysis in the School of Engineering
- University of Michigan –Industrial & Operations Engineering , Quality Control & Reliability Engineering MS



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# Differences between Reliability & Quality Control

| | Reliability | Quality Control |
|---|---|---|
| 1 | deals with behavior of failure rate over a period of time | deals with % out of spec, % defective at ONE point in time |
| 2 | deals with all periods of a part or component's existence | deals primarily with the manufacturing stage of a product |
| 3 | deals with design concepts and methodologies | deals with conversion of design drawings and specs into parts, components, etc. |
| 4 | Assures design of high optimum reliability and monitors all aspects of product life cycle | assures that reliability is not degraded during manufacture & assembly |
| 5 | | assures that manufacturing processes result in a uniform product |



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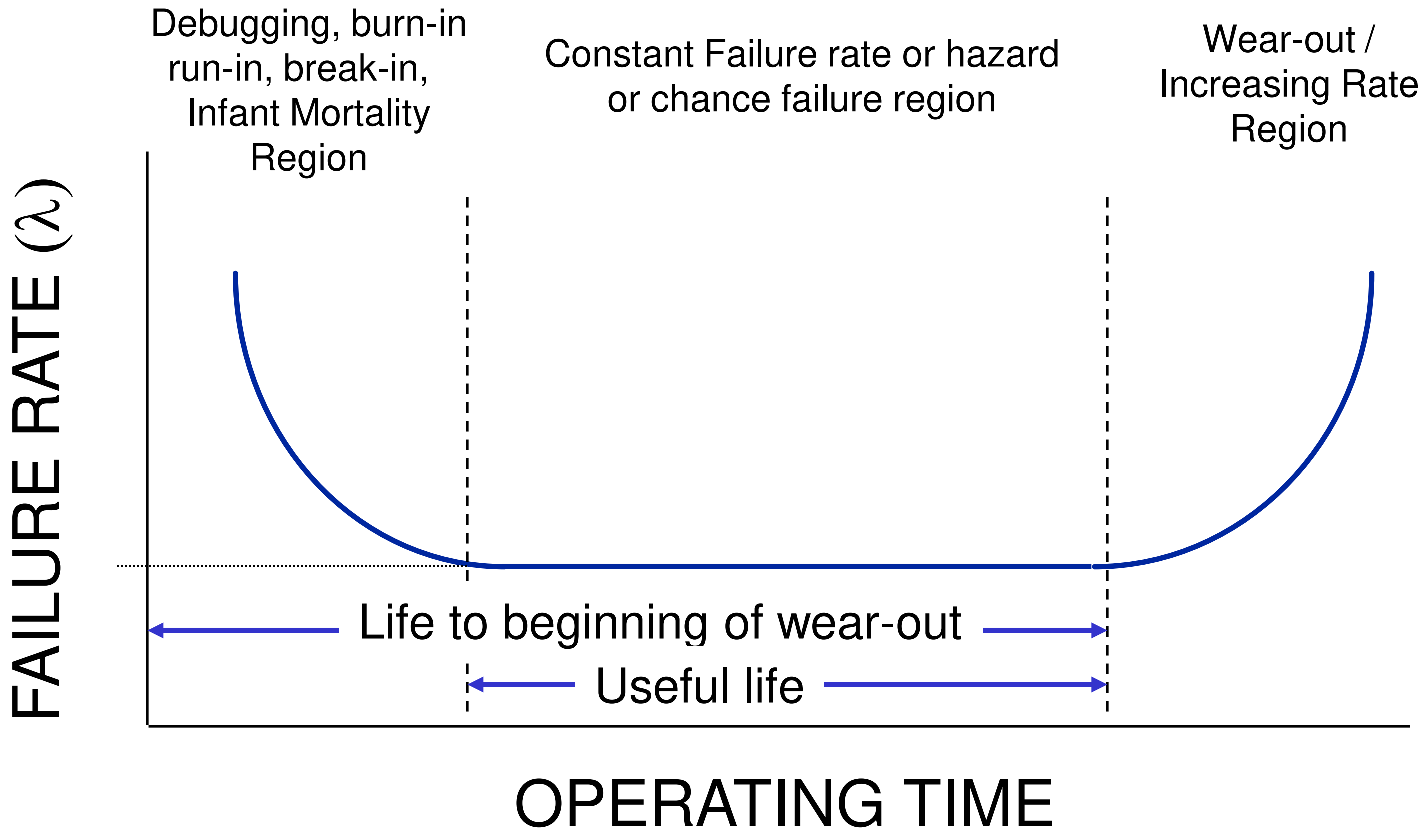
# Introduction to Reliability Engineering

The fundamental… Reliability Bathtub curve



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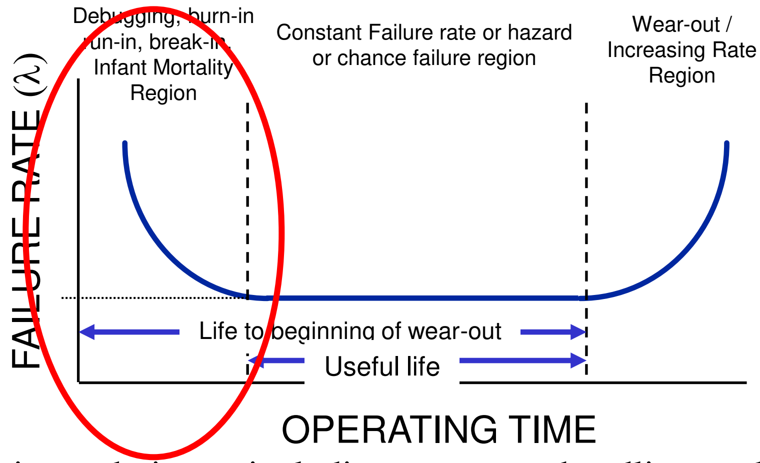
# Introduction to Reliability Engineering

## Early failure causes… decreasing failure rate




- Poor manufacturing techniques, including processes, handling, and assembly practices
- Poor quality control
- Poor workmanship
- Insufficient burn-in/break-in
- Insufficient debugging
- Substandard materials
- Substandard parts
- Replacing failed components with nonscreened ones.
- Parts that failed in storage (improper storage,packaging or transportation)
- Parts failing when energized for the 1st time
- Contamination
- Human error
- Improper installation
- Improper start-up



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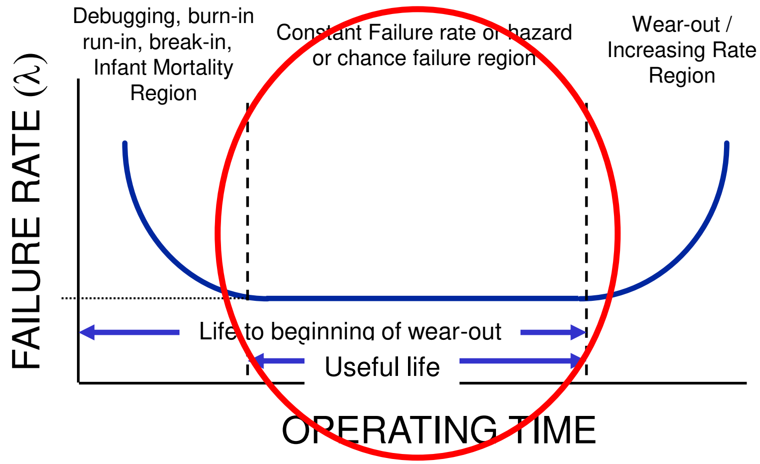
## Chance failure causes… constant failure rate




- Insufficient safety factors
- Occurrence of higher than expected random loads
- Occurrence of lower than expected random strength.
- Defects that escape best inspection techniques
- Human errors in usage
- Misapplication
- Abuse
- Unexplainable causes
- Act of God failures due to storms, lightning, earthquakes, floods, etc.



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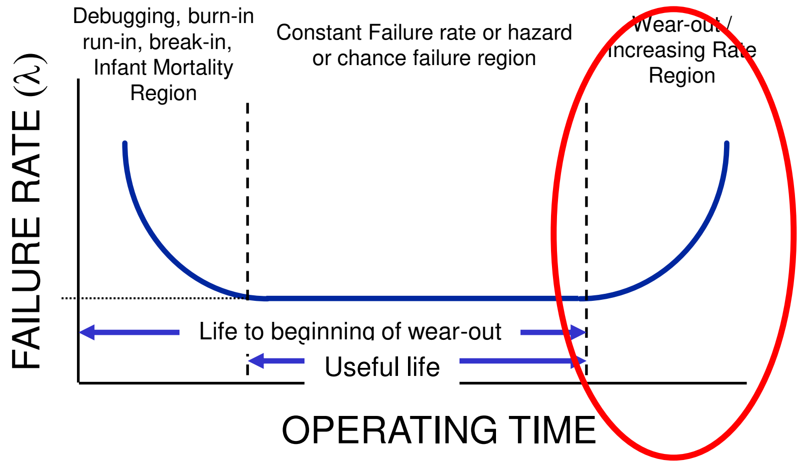
# Introduction to Reliability Engineering

## Wear-out failure causes… increasing failure rate




- Aging
- Wear (Stress rupture, creep rupture)
- Degradation in strength
- Fatigue (LCF, HCF, TMF)
- Creep
- Corrosion
- Mechanical, Electrical, Chemical or hydraulic deterioration
- Replacement of failed parts by partially aged ones
- Short design life



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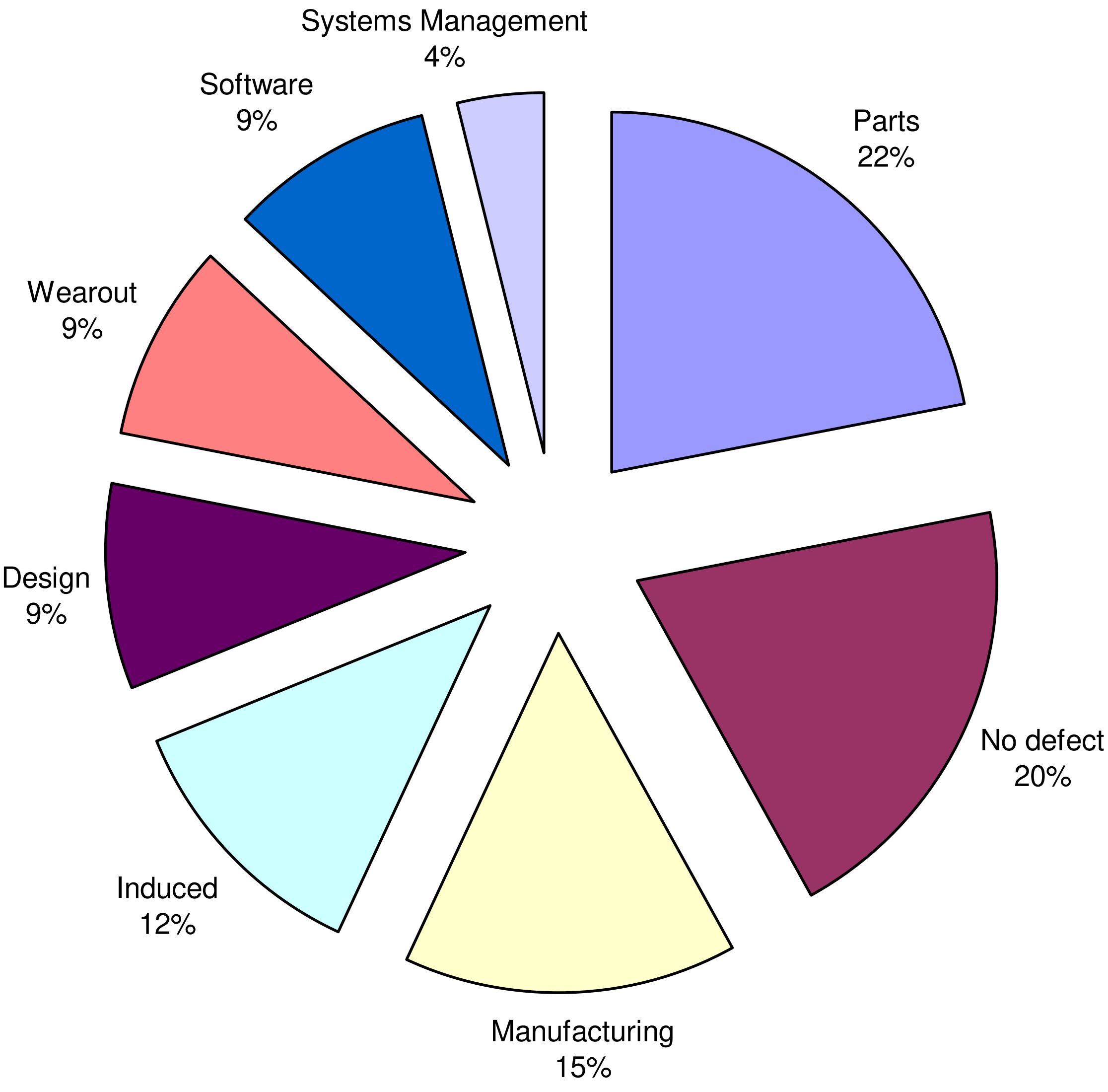
# Introduction to Reliability Engineering

## Failure cause distribution for Electronic Systems



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# Introduction to Reliability Engineering

Some more Reliability definitions:

1. *Reliability is a measure of the continuous delivery of correct service.*

*by Laprie*

2. *The quality of being trustworthy or of performing consistently well.*

3. *The extent to which an experiment, test, or measuring procedure yields the same results on repeated trials.*



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## Course outline

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| February | 23 | Noon-2PM | Probability (Hint: Reliability is Applied Probability)-Part 1 |
| March | 8 | Noon-2PM | Probability (Hint: Reliability is Applied Probability)-Part 2 |
| March | 22 | Noon-2PM | Discrete and Continuous distributions-Part 1 |
| April | 12 | Noon-2PM | Discrete and Continuous distributions-Part 2 |
| April | 26 | Noon-2PM | Weibull Distribution -Part 1 |
| May | 10 | Noon-2PM | Weibull Distribution -Part 2 |
| May | 24 | | |
| June | 14 | Noon-2PM | Reliability Modeling -- parallel, series, redundant, standby systems |
| June | 28 | Noon-2PM | FMEA-Part 1 |
| July | 12 | Noon-2PM | FMEA Part 2 |
| July | 26 | Noon-2PM | Reliability Testing -Part 1 |
| August | 9 | Noon-2PM | Reliability Testing -Part 2 |
| August | 23 | Noon-2PM | Reliability Testing -Part 3 |
| September | 13 | Noon-2PM | Reliability Allocations and Predictions, Reliability Growth-Part 1 |
| September | 27 | Noon-2PM | Reliability Allocations and Predictions, Reliability Growth-Part 2 |
| October | 11 | Noon-2PM | System Safety Analysis and link to Reliability-Part 1 |
| October | 25 | Noon-2PM | System Safety Analysis and link to Reliability-Part 2 |
| November | 8 | Noon-2PM | Maintainability & Human Reliability-Part 1 |
| November | 22 | Noon-2PM | Maintainability & Human Reliability-Part 2 |
| December | 13 | Noon-2PM | Other Topics (TBD) |

Caution: There may be changes in the subject matter, dates, depending on presentation time, etc.



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