WARSAW UNIVERSITY OF TECHNOLOGY

The Faculty of Power and Aeronautical Engineering

ANK 315 AIRCRAFT MAINTENANCE LECRURE 5

KAMILA KUSTROŃ, Ph. D Eng

AIRCRAFT DESIGN DEPARTMENT

1 INTRODUCTION TO AIRCRAFT MAINTENANCE
2 STUDENTS' PRESENTATIONS (INTRODUCING YOURSELF IN A PRESENTATION MAINTENANCE POLICIES
3 AVIATION ORGANIZATIONS, AUTHORITY REGULATIONS;
4 STUDENTS' PRESENTATIONS
5 DEPENDABILITY, RELIABILITY, AVAILABILITY, SAFETY, INTEGRITY, MAINTABILITY, RELIABILITY OF SYSTEMS, FMEA/FMECA, FTA, HOMEWORK 1
6 DEGRADATION PROCESSES, DAMAGES, RCM, MSG3 , HOMEWORK 2
7 INTRODUCTION TO DIAGNOSTICS, NDT, SHM, EHM, HUMS
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10 HUMAN FACTOR AND FLIGHT SAFETY
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Kamila Kustron, Ph. D.

ANK 315 AIRCRAFT MAINTENANCE

RELIABILITY

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Reliability

Reliability can be defined as the ability of a system or component to perform its required functions under ***stated conditions*** for a specified period of time

In the aviation industry and even in general, operators want infinite performance, at ***zero life-cycle costs***, with 100% availability from the day they take delivery to the day they dispose of it

One step to reach a high level of availability is to increase the reliability of the products, although this on its own can't fulfill all those demands, but it is a link in the chain consisting of ***reliability, maintenance and logistics support***, where **maintenance comes as a natural part of reliability**

Five functional characteristics in reliability calculations
for T – random variable of airworthiness time

1. $Q(t) = P(T \le t)$

2. $R(t) = 1 - Q(t) = P(T > t)$

3. $f(t) = -\frac{dR(t)}{dt} = \frac{dQ(t)}{dt}$

4. $\lambda(t) = -\frac{1}{R(t)}\frac{dR(t)}{dt}$

5. $\Lambda(t) = \int_0^t \lambda(\tau)d\tau$

$$Q(t) = P(T \leq t)$$

Unreliability Function , Q(*t*), *F*(*t*), is the probability that a failure will occur before time *t* and is called the Cumulative Distribution Function [CDF]

Q(*t*) = 1-***R*(*t*)**

Q(*t*) is also referred to as the unreliability function and can be thought of representing the probability of failure prior to some time, *t*

The **Unreliability Function** is usually used when probabilities of failure are being calculated

Five functional characteristics in reliability calculations
for T – random variable of airworthiness time

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5. $\Lambda(t) = \int_0^t \lambda(\tau) d\tau$

$$R(t) = 1 - Q(t) = P(T > t)$$

Reliability Function, *R*(*t*),
represents the probability of failure prior to some point in time, represented by *t*

The Reliability Function is usually used when reliabilities are being calculated

Five functional characteristics in reliability calculations for T – random variable of airworthiness time

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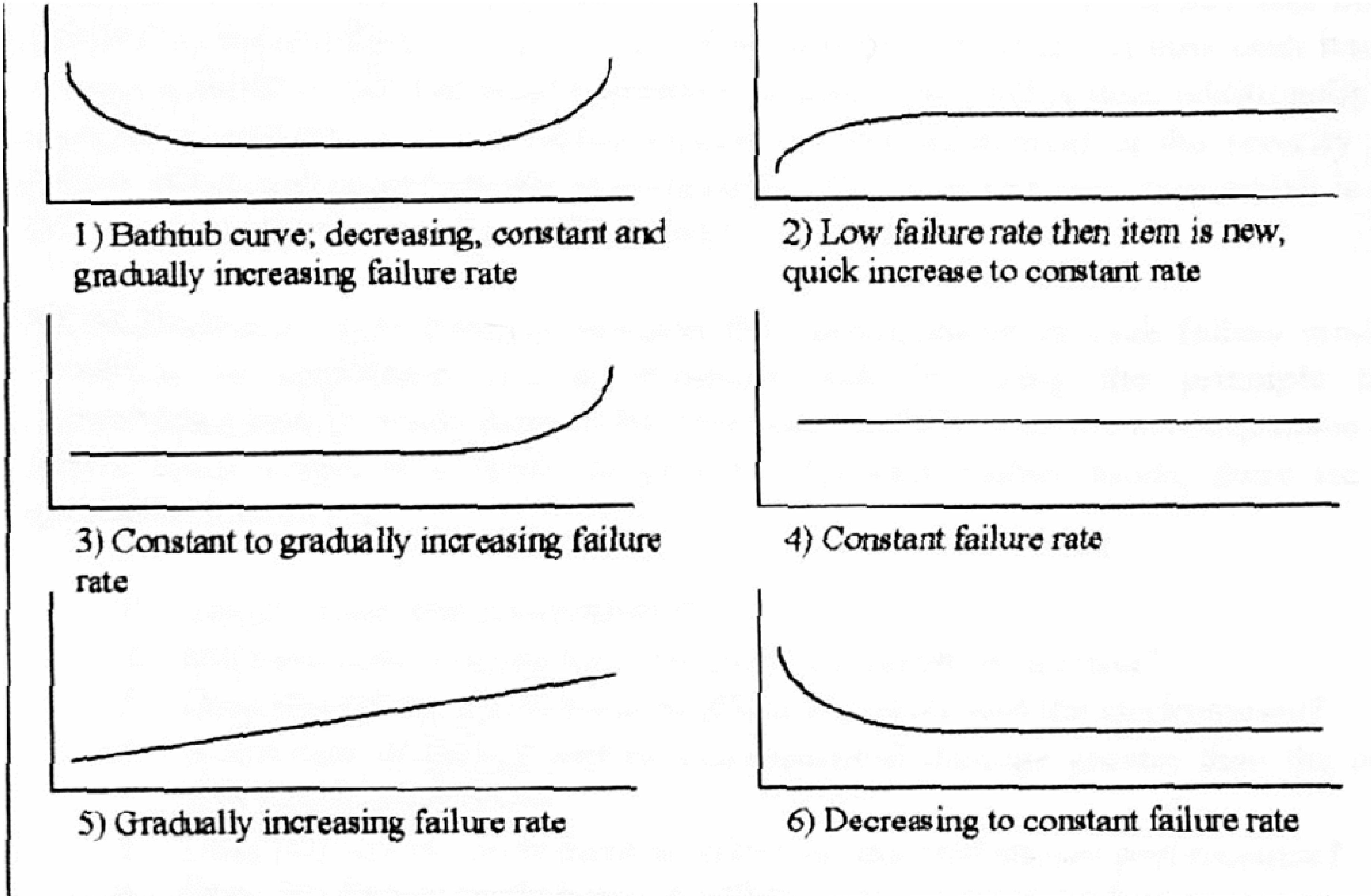
Failure_rate(t)= $f(t)/R(t)$

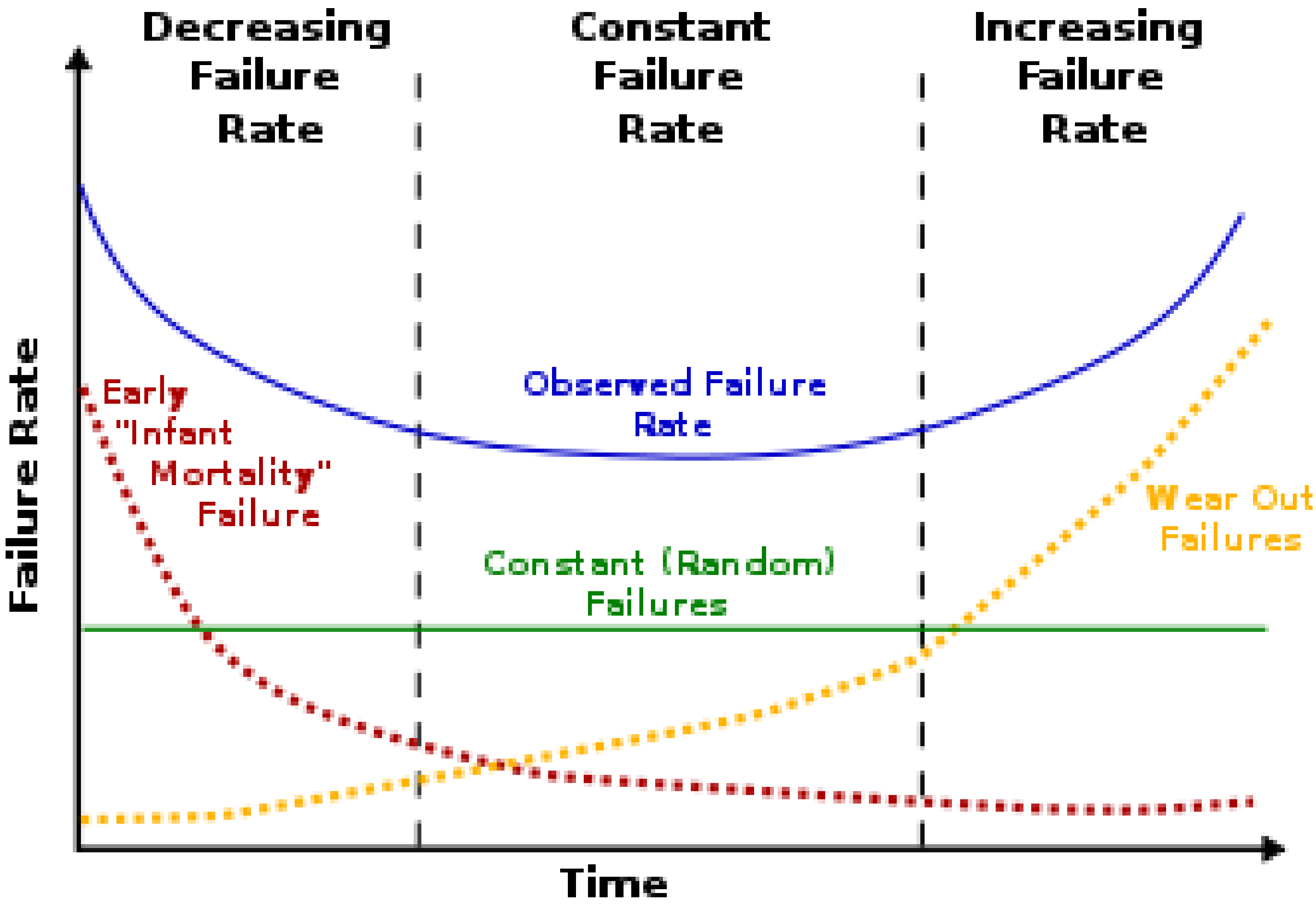
$$\lambda = \frac{R(t_1) - R(t_2)}{(t_2 - t_1) \cdot R(t_1)} = \frac{R(t) - R(t + \triangle t)}{\triangle t \cdot R(t)}$$

over a time interval ($t_2 - t_1$) from t_1 (or t) to t_2 and Δt is defined as ($t_2 - t_1$)

Note that this is a conditional probability, hence the $R(t)$ in the denominator

Different Pattern of Failure Rate



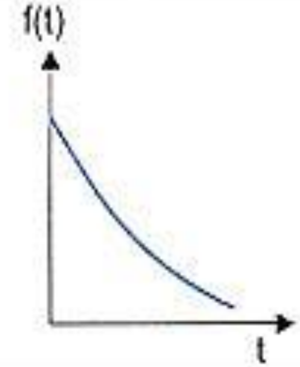
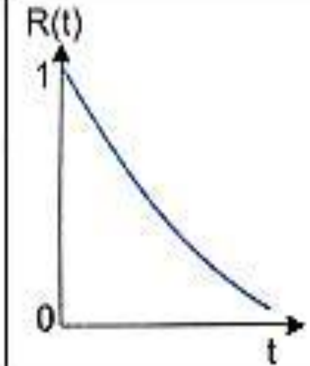
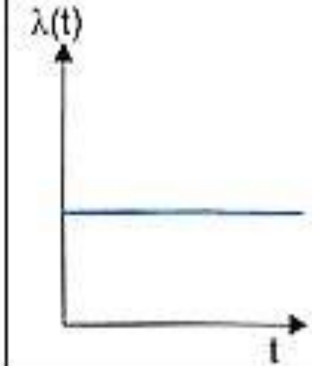
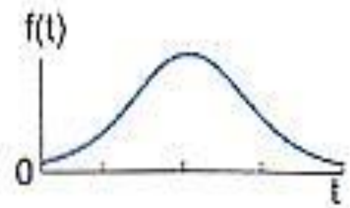
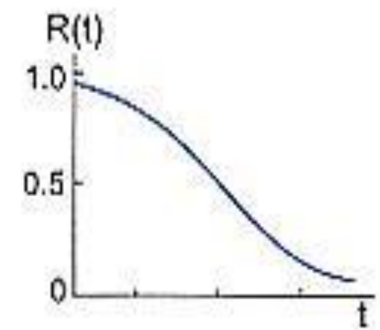
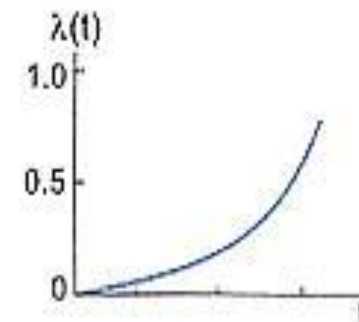
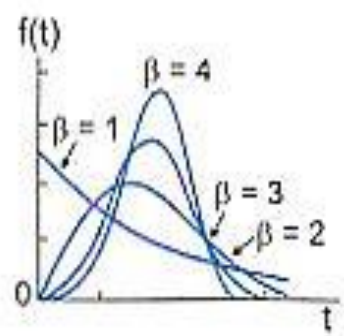
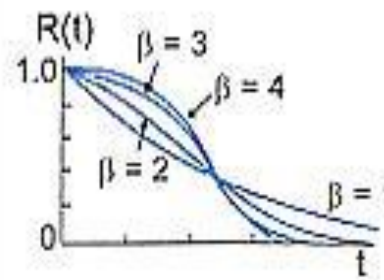
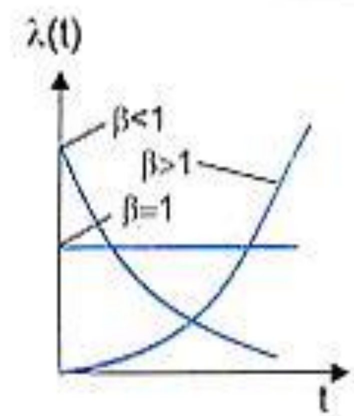


three phases:

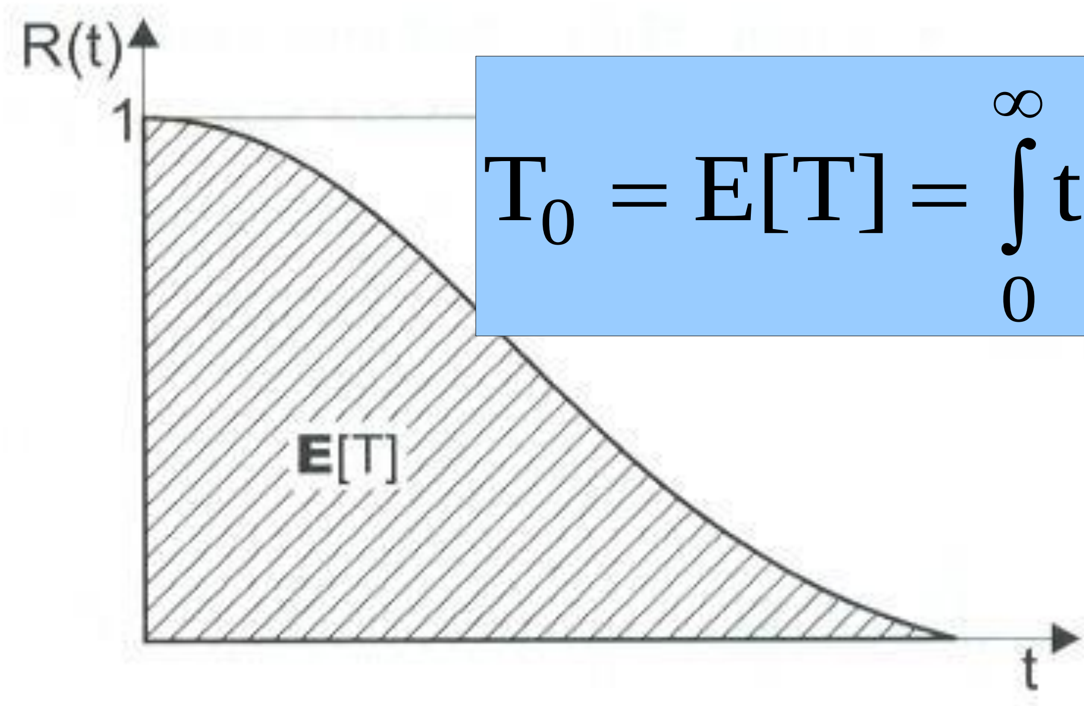
- The phase is a decreasing failure rate , known as early failure
- The second phase is a constant failure rate, known as randomfailures
- The third phase is an increasing failure rate, known as wear-out failures

$R(t)=$		$1-Q(t)$	$\int_t^{\infty} f(x)dx$	$\exp[-\int_0^t \lambda(x)dx]$	$\exp[-\Lambda(t)]$
$Q(t)=$	$1-R(t)$		$\int_0^t f(x)dx$	$1-\exp[-\int_0^t \lambda(x)dx]$	$1-\exp[-\Lambda(t)]$
$f(t)=$	$-\frac{d}{dt}R(t)$	$\frac{d}{dt}Q(t)$		$\lambda(t)\exp[-\int_0^t \lambda(x)dx]$	$\frac{d}{dt}\{\exp[-\Lambda(t)]\}$
$\lambda(t)=$	$-\frac{d}{dt}[\ln R(t)]$	$-\frac{d}{dt}\{\ln[1-Q(t)]\}$	$\frac{f(t)}{\int_t^{\infty} f(x)dx}$		$\frac{d}{dt}\Lambda(t)$
$\Lambda(t)=$	$\ln\frac{R(0)}{R(t)}$	$\ln\frac{1-Q(0)}{1-Q(t)}$	$\int_0^t \frac{f(t)dt}{\int_0^t f(x)dx}$	$\int_0^t \lambda(x)dx$	

TYPE OF RANDOM VARIABLE DISTRIBUTION

TYPE OF RANDOM VARIABLE DISTRIBUTION		PROBABILITY DENSITY FUNCTION PDF	RELIABILITY	FAILURE RATE
EXPOTENTIAL	$f(t) = \lambda \exp(-\lambda t)$ $R(t) = \exp(-\lambda t)$ $\lambda(t) = \text{const}$ $\Theta = \frac{1}{\lambda} \quad (\Theta = T_0)$			
NORMAL (GAUSS)	$f(t)\frac{1}{\sqrt{2\pi}}\sigma \exp\left[-\frac{(t-m)^2}{2\sigma^2}\right]$ $R(t) = 1 - \int_0^t f(\tau)d\tau$ $\lambda = \frac{f(t)}{R(t)}$			
WEIBULL	$f(t) = \frac{\beta}{\Theta}\left(\frac{t}{\Theta}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\Theta}\right)^{\beta}\right]$ $R(t) = \exp\left[-\left(\frac{t}{\Theta}\right)^{\beta}\right]$ $\lambda = \frac{\beta}{\Theta}\left(\frac{t}{\Theta}\right)^{\beta-1}$			

1.Expected variable, Mean Time E[T] as time to first failure



$$T_0 = E[T] = \int_0^\infty t \cdot f(t)dt = \int_0^\infty R(t)dt$$

2. Variance

$$Var[T] = D^2[T] = \sigma^2$$

Reliability Predictions (MTBF)

- Form the basis of Reliability Analyses
  - Compute predicted system failure rate or Mean Time Between Failures
    - Failure Rate is usually expressed in Failures per 10^6 or 10^9 hours
    - MTBF is usually expressed in terms of hours
      - Example: for a system with a predicted MTBF of 1000 hours, on average the system experiences one failure in 1000 hours of operation or a Failure Rate of 1000 per 10^6 hours
  - Methodology
    - Use accepted standards
      - Model failure rates of components
      - Analyze system
      - Calculate the system predicted failure rate or MTBF
    - Evaluate prediction vs target or required MTBF
      - Evaluate stress or temperature reduction design changes
      - Evaluate practicality of design change especially when MTBF is self imposed

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ANK 315 AIRCRAFT MAINTENANCE

RELIABILITY OF SYSTEMS

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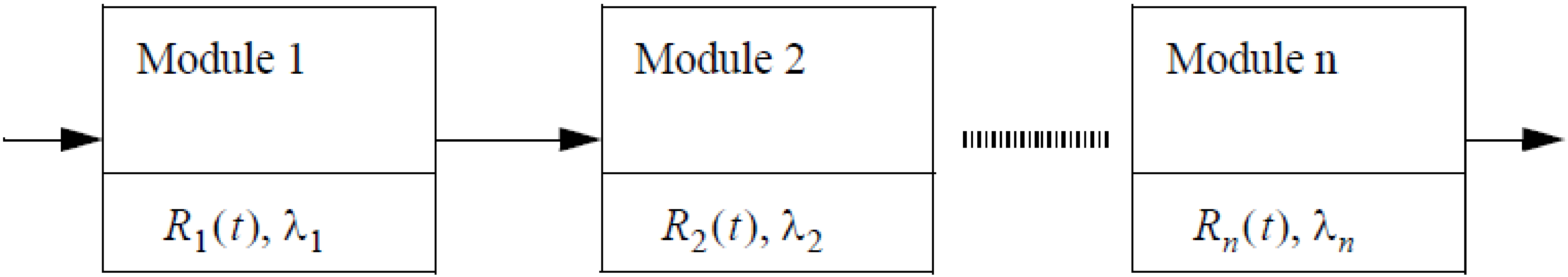
- SERIAL SYSTEM RELIABILITY



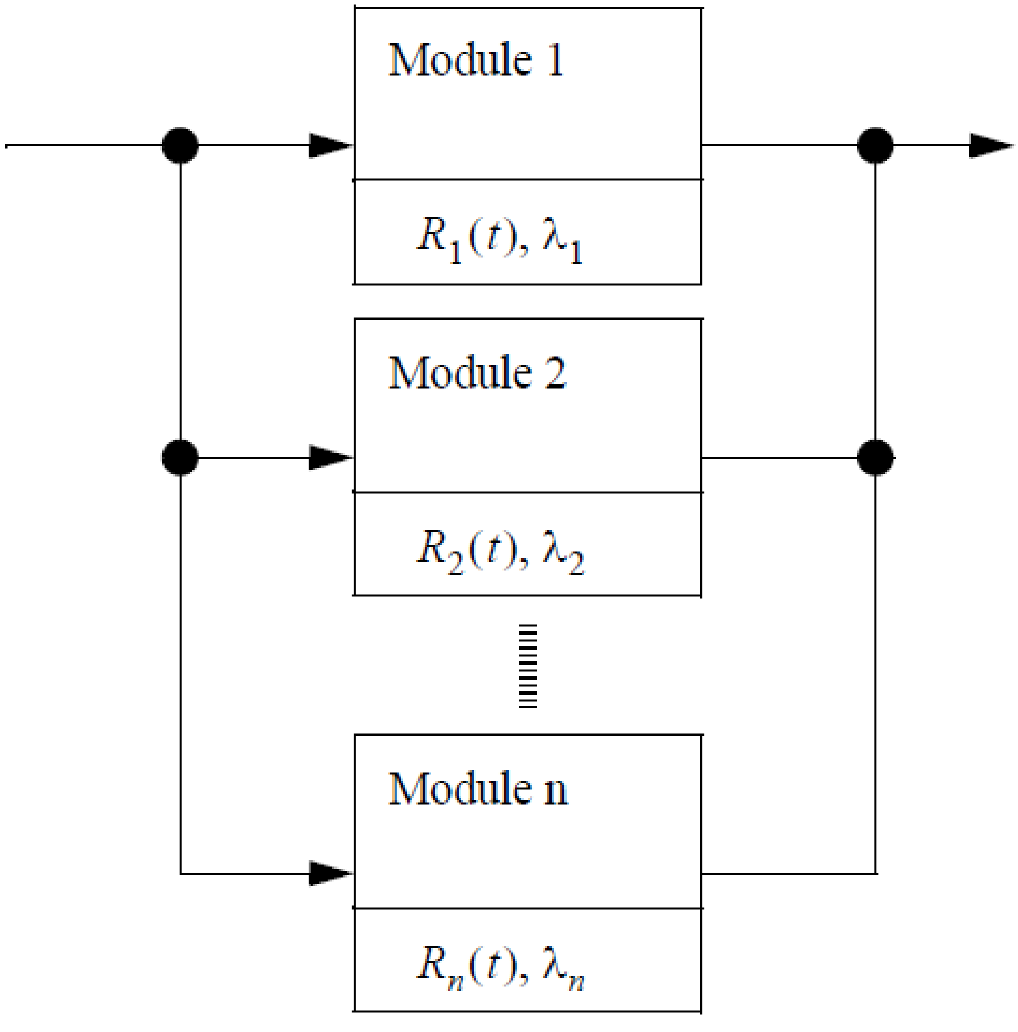
$$R_s(t) = (R_1(t))(R_2(t))\dots(R_n(t)) = \prod_{i=1}^{n} R_i(t)$$

where,

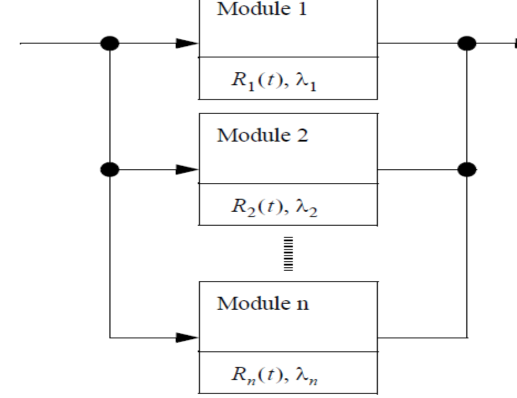
$R_s(t)$ = the reliability of a series system at time t

$R_i(t)$ = the reliability of a unit at time t

- PARALLEL SYSTEM RELIABILITY



- PARALLEL SYSTEM RELIABILITY



$$Q_p(t) = (Q_1(t))(Q_2(t))\ldots(Q_n(t)) = \prod_{i=1}^{n} Q_i(t)$$

$$R_p(t) = 1 - Q_p(t) = 1 - \prod_{i=1}^{n} (1 - R_i(t))$$

where,

$Q_s(t)$ = the unreliability of a parallel system at time t

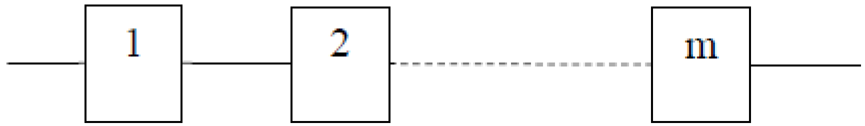
$Q_i(t)$ = the unreliability of a module at time t

$R_p(t)$ = the reliability of a parallel system at time t

$R_i(t)$ = the reliability of a module at time t

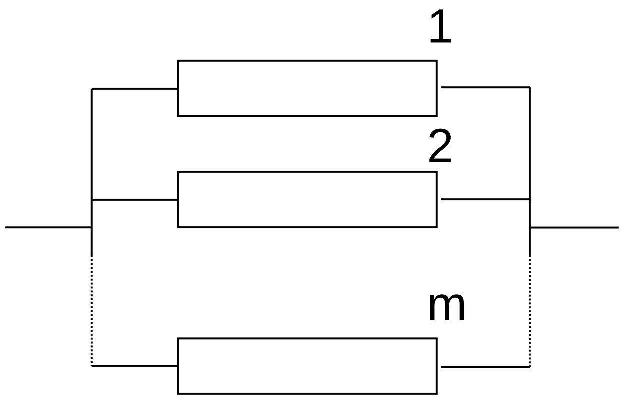
Note: The parallel form will not result in a simple closed form as it did with the series case.

RELIABILITY OF THE SYSYTEM



$$R(t) = \prod_{i=1}^{m} R_i(t)$$

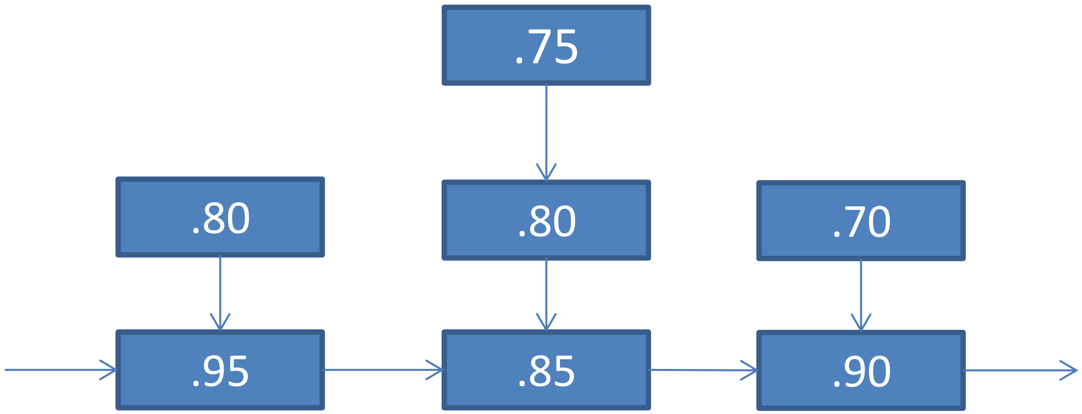
SERIES SYSTEM RELIABILITY

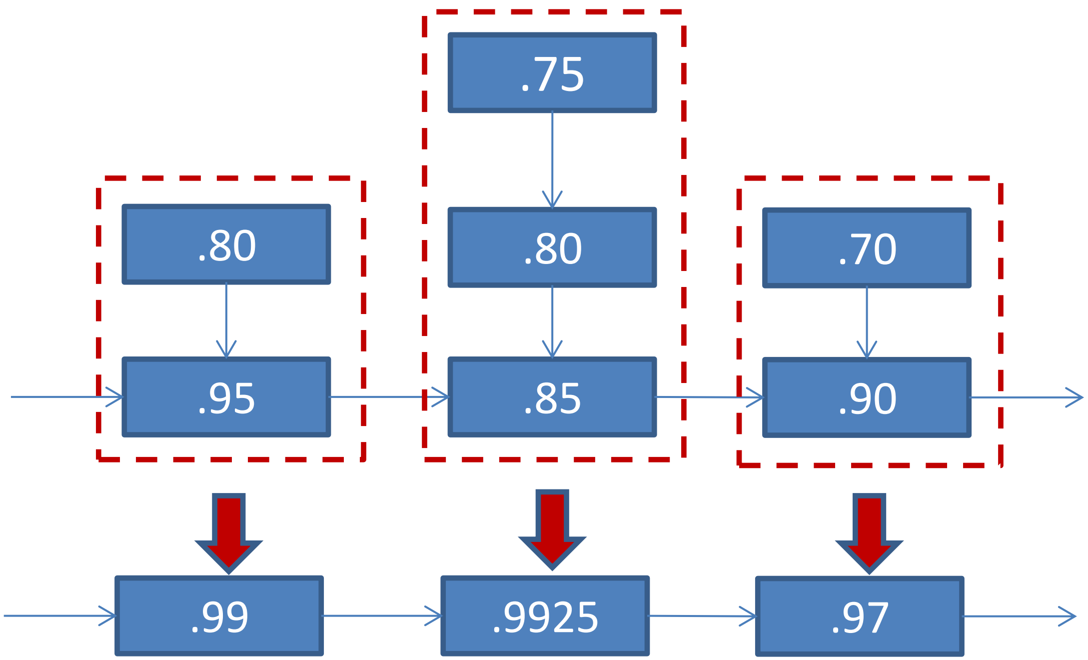


$$R(t) = 1 - \prod_{i=1}^{m} \left[1 - R_i(t)\right]$$

PARALLEL SYSTEM RELIABILITY

What is the reliability of this system?





ANK 315 AIRCRAFT MAINTENANCE

RCM, FMEA/FMECA, FTA

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RELIABILITY CENTERED MAINTENANCE

RELIABILITY ASSESSMENT

COMPARISON WHAT WE HAVE AND WHAT WE SHOULD HAVE

IF RELIABILITY CHARACTERISTICS ARE LOWER THAN WE NEED, WE MUST PREPARE IMPROVEMENT STRATEGY

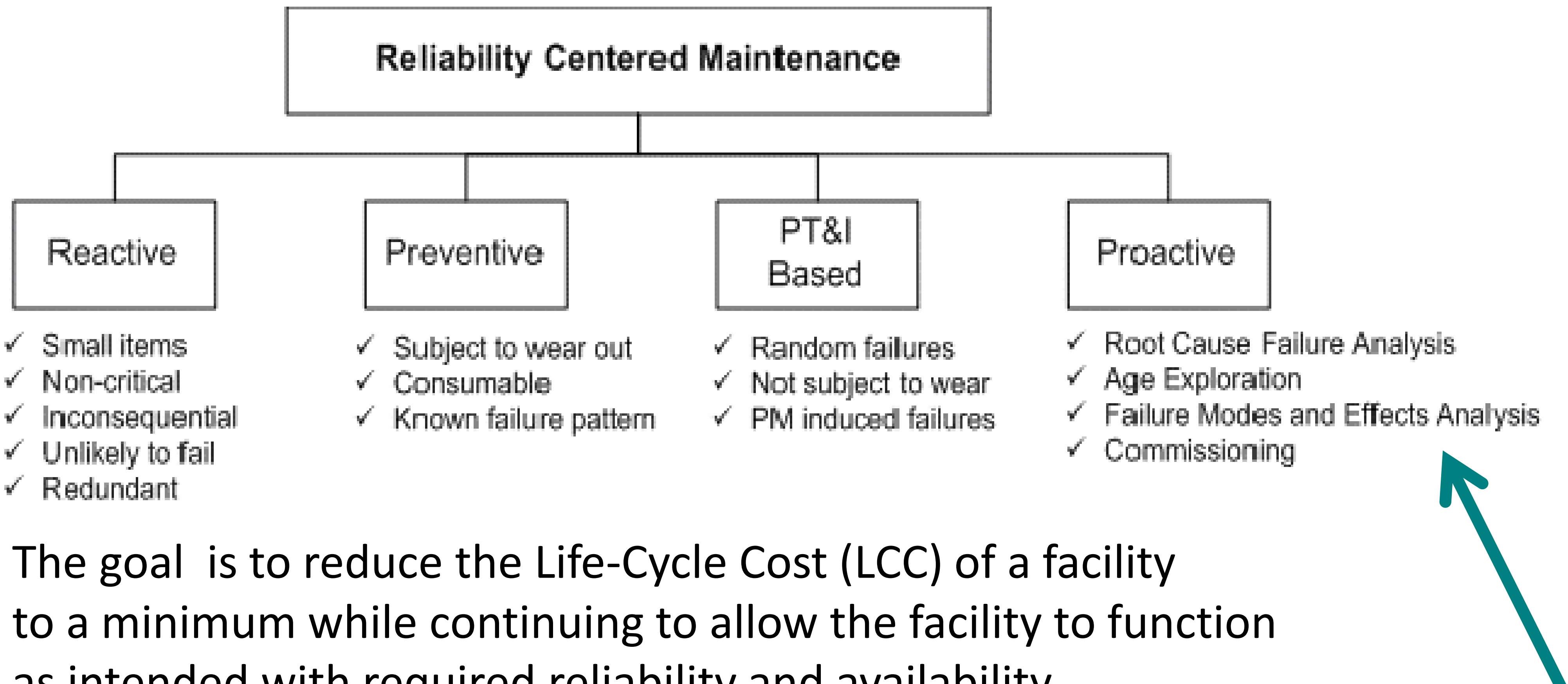
HOW?

WE MUST FIND THE ELEMENTS IN RELIABILITY STRUCTURE WHICH DECREASE RELIABILITY OF THE SYSTEM

NEXT APPLY SOLUTION TO IMPROVE RELIABILITY OF THESE ELEMENTS

EASY? … THAT....

Reliability-Centered Maintenance (RCM) integrates:
Preventive Maintenance (PM)
Predictive Testing and Inspection (PT&I)
Repair (reactive maintenance), and
Proactive Maintenance to increase the probability that a machine or component will function in the required manner over its design life-cycle with a minimum amount of maintenance and downtime



The goal is to reduce the Life-Cycle Cost (LCC) of a facility to a minimum while continuing to allow the facility to function as intended with required reliability and availability

FAILURE MODE & EFFECT ANALYSIS

MIL-STD-1629 A
BS 5760 Part 5
SAE ARP5580
QS-9000
SAE J1739

.Recommended Failure Modes and Effects Analysis (FMEA) Practices for Non-Automobile Applications , Product Code: ARP5580 Date Published: 2001-07-01, Issuing Committee:G-11r, Reliability Committee

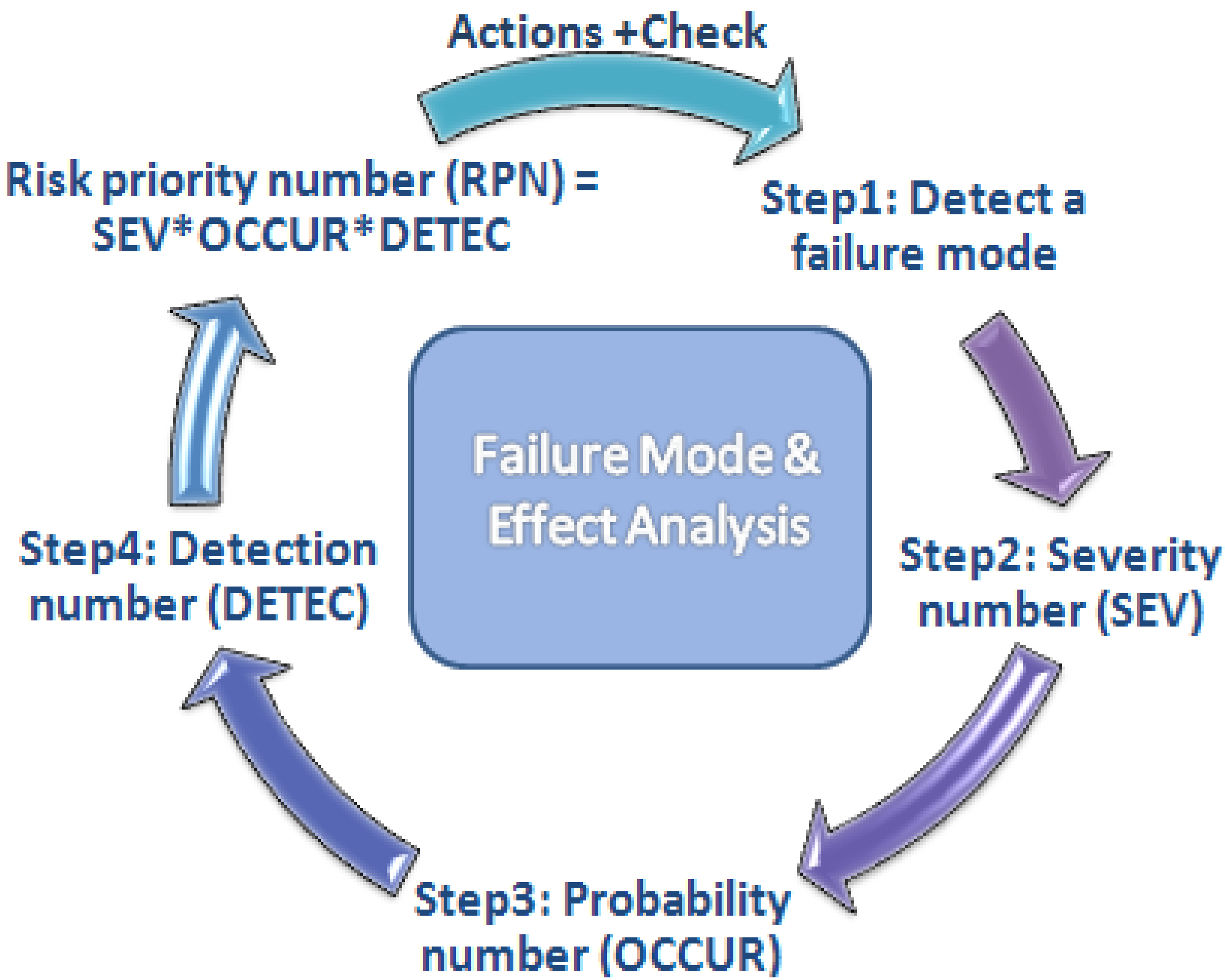
Scope

Recommended Failure Modes and Effects Analysis (FMEA) Practices for Non-Automobile Applications describes the basic procedures for performing a Failure Modes and Effects Analysis (FMEA). It encompasses functional, interfaEA) Practices for Non-Automobile Applications describes tce, and detailed FMEA, as well as certain pre-analysis activities (FMEA planning and functional requirements analysis), post-analysis activities (failure latency analysis, FMEA verification, and documentation), and applications to hardware, software, and process design. It is intended for use by organizations whose product development processes use FMEA as a tool for assessing the safety and reliability of system elements, or as part of their product improvement processes. A separate, Surface Vehicle Recommended Practice, J1739, is intended for use in automobile applications.

Purpose: In developing this procedure the subcommittee has endeavored to develop a procedure that reflects the best current commercial practices. This procedure was developed in recognition of today's intense and competitive market demands for high reliability, affordability, and speed to market. The subcommittee had several objectives in defining the FMEA process: 1. Define a basic methodology to include functional, interface, and detailed FMEA. This will facilitate performing the analysis throughout the design process, from early in the conceptual stage to implementation and production. 2. Extend the methodology to include both product and process FMEAs. The methodology can be applied to the many technologies (e.g., mechanical, electrical, software, etc.) used in the development of a product. This helps to facilitate communications between all the parties involved in the development of a system and is useful in a concurrent engineering environment. 1. Provide simple techniques for ranking failure modes for corrective actions and for identifying fault equivalencies. 2. Define the types of information needed for the FMEA in electronic databases, thus facilitating semi-automation of the analysis. 3. Provide procedures for managing the FMEA and for getting the most benefit from the analysis.

Formal Analysis Techniques

Failure Modes and Effects Analysis (FMEA)



Fault Tree Analysis

Fault Tree Analysis (FTA) is a popular and productive hazard identification tool. It provides a standardized discipline to evaluate and control hazards. The FTA process is used to solve a wide variety of problems ranging from safety to management issues.
This tool is used by the professional safety and reliability community to both prevent and resolve hazards and failures. Both qualitative and quantitative methods are used to identify areas in a system that are most critical to safe operation. Either approach is effective. The output is a graphical presentation providing technical and administrative personnel with a map of "failure or hazard" paths. FTA symbols may be found in Figure 8- 5. The reviewer and the analyst must develop an insight into system behavior, particularly those aspects that might lead to the hazard under investigation.
Qualitative FTAs are cost effective and invaluable safety engineering tools. The generation of a qualitative fault tree is always the first step. Quantitative approaches multiply the usefulness of the FTA but are more expensive and often very difficult to perform.

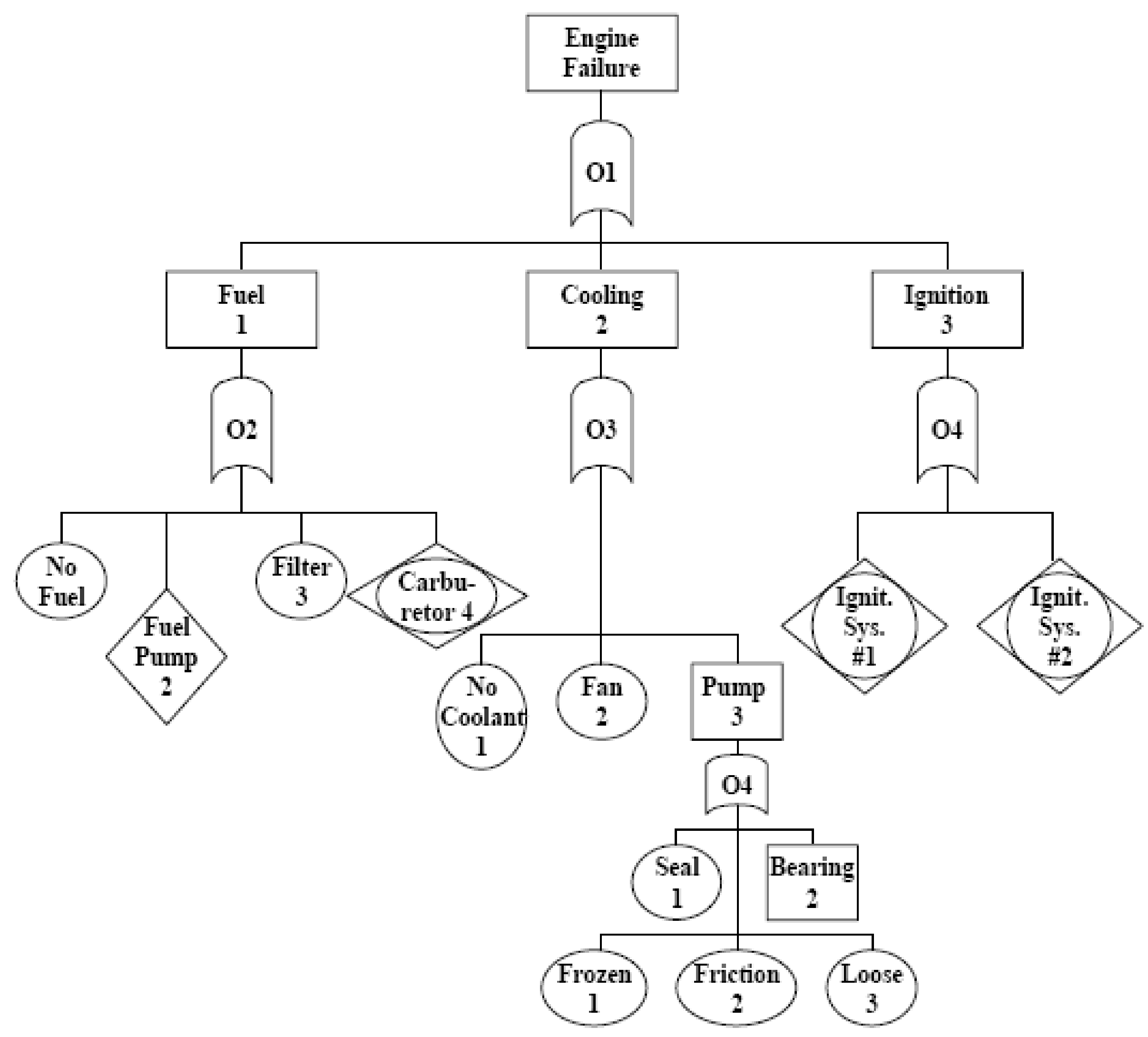
Fault Tree Analysis

An FTA (similar to a logic diagram) is a "deductive" analytical tool used to study a specific undesired event such as "engine failure." The "deductive" approach begins with a defined undesired event, usually a postulated accident condition, and systematically considers all known events, faults, and occurrences that could cause or contribute to the occurrence of the undesired event. Top level events may be identified through any safety analysis approach, through operational experience, or through a "Could it happen?" hypotheses. The procedural steps of performing a FTA are:

- Assume a system state and identify and clearly document state the top level undesired event(s). This is often accomplished by using the PHL or PHA. Alternatively, design documentation such as schematics, flow diagrams, level B & C documentation may reviewed
- Develop the upper levels of the trees via a top down process. That is determine the intermediate failures and combinations of failures or events that are the minimum to cause the next higher level event to occur. The logical relationships are graphically generated as described below using standardized FTA logic symbols
- Continue the top down process until the root causes for each branch is identified and/or until further decomposition is not considered necessary
- Assign probabilities of failure to the lowest level event in each branch of the tree. This may be through predictions, allocations, or historical data
- Establish a Boolean equation for the tree using Boolean logic and evaluate the probability of the undesired top level event
- Compare to the system level requirement. If it the requirement is not met, implement corrective action. Corrective actions vary from redesign to analysis refinement

Fault Tree Analysis

The FTA is a graphical logic representation of fault events that may occur to a functional system. This logical analysis must be a functional representation of the system and must include all combinations of system fault events that can cause or contribute to the undesired event. Each contributing fault event should be further analyzed to determine the logical relationships of underlying fault events that may cause them. This tree of fault events is expanded until all "input" fault events are defined in terms of basic, identifiable faults that may then be quantified for computation of probabilities, if desired. When the tree has been completed, it becomes a logic gate network of fault paths, both singular and multiple, containing combinations of events and conditions that include primary, secondary, and upstream inputs that may influence or command the hazardous mode.



Evaluating a Fault Tree Analysis

FTA is a technique that can be used for any formal system safety program analysis (PHA, SSHA, O&SHA)

The FTA is one of several deductive logic model techniques, and is by far the most common.

The FTA begins with a stated top-level hazardous/undesired event and uses logic diagrams to identify single events and combinations of events that could cause the top event
The logic diagram can then be analyzed to identify single and multiple events that can cause the top event. Probability of occurrence values are assigned to the lowest events in the tree

FTA utilizes Boolean Algebra to determine the probability of occurrence of the top (and intermediate) events. When properly done, the FTA shows all the problem areas and makes the critical areas stand out. The FTA has two drawbacks:

- Depending on the complexity of the system being analyzed, it can be time consuming, and therefore very expensive
- It does not identify all system hazards, it only identifies failures associated with the predetermined top event being analyzed. For example, an FTA will not identify "ruptured tank" as a hazard in a home water heater. It will show all failures that lead to that event. In other words, the analyst needs to identify all hazards that cannot be identified by use of a fault tree

Fault Tree Analysis

The first area for evaluation (and probably the most difficult) is the top event. This top event should be very carefully defined and stated. If it is too broad (e.g., aircraft crashes), the resulting FTA will be overly large. On the other hand, if the top event is too narrow (e.g., aircraft crashes due to pitch-down caused by broken bellcrank pin), then the time and expense for the FTA may not yield significant results. The top event should specify the exact hazard and define the limits of the FTA. In this example, a good top event would be "uncommanded aircraft pitch-down," which would center the fault tree around the aircraft flight control system, but would draw in other factors, such as pilot inputs and engine failures. In some cases, a broad top event may be useful to organize and tie together several fault trees.

Some fault trees do not lend themselves to quantification because the factors that tie the occurrence of a second level event to the top event are normally outside the control/influence of the operator (e.g., an aircraft that experiences loss of engine power may or may not crash depending on altitude at which the loss occurs).

Fault Tree Analysis

A quick evaluation of a fault tree may be possible by looking at the logic gates. Most fault trees will have a substantial majority of OR gates. If fault trees have too many OR gates, every fault of event may lead to the top event. This may not be the case, but a large majority of OR gates will certainly indicate this. An evaluator needs to be sure that logic symbols are well defined and understood. If nonstandard symbols are used, they must not get mixed with other symbols.

Check for proper control of transfers. Transfers are reference numbers permitting linking between pages of FTA graphics. Fault trees can be extremely large, requiring the uses of many pages and clear interpage references. Occasionally, a transfer number may be changed during fault tree construction. If the corresponding sub-tree does not have the same transfer number, then improper logic will result. Cut sets (minimum combinations of events that lead to the top event) need to be evaluated for completeness and accuracy. Establishing the correct number of cuts and their depth is a matter of engineering judgment.

Fault Tree Analysis

Each fault tree should include a list of minimum cut sets. Without this list, it is difficult to identify critical faults or combinations of events. For large or complicated fault trees, a computer is necessary to catch all of the cut sets; it is nearly impossible for a single individual to find all of the cut sets. For a large fault tree, it may be difficult to determine whether or not the failure paths were completely developed. If the evaluator is not totally familiar with the system, the evaluator may need to rely upon other means. A good indication is the shape of the symbols at the branch bottom. If the symbols are primarily circles (primary failures), the tree is likely to be complete. On the other hand, if many symbols are diamonds (secondary failures or areas needing development), then it is likely the fault tree needs expansion.

Faulty logic is probably the most difficult area to evaluate, unless the faults lie within the gates, which are relatively easy to spot. A gate-to-gate connection shows that the analyst might not completely understand the workings of the system being evaluated. Each gate must lead to a clearly defined specific event, i.e., what is the event and when does it occur? If the event consists of any component failures that can directly cause that event, an OR gate is needed to define the event. If the event does not consist of any component failures, look for an AND gate.

Fault Tree Analysis

When reviewing an FTA with quantitative hazard probabilities of occurrence, identify the events with relatively large probability of occurrence. They should be discussed in the analysis summaries, probably as primary cause factors.

A large fault tree performed manually is susceptible to errors and omissions.

There are many advantages of computer modeling relative to manual analysis (of complex systems):

- Logic errors and event (or branch) duplications can be quickly spotted.
- Cut sets (showing minimum combinations leading to the top event) can be listed.
- Numerical calculations (e.g., event probabilities) can be quickly done.
- A neat, readable, fault tree can be drawn.

Fault Tree Analysis