Reliability Engineering

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Contact Hours: Monday*, 04:30 PM to 05:30 PM at E-106*

Gyan Ranjan Biswal received his B.E. in Electronics Engineering from the Pt. Ravishankar Shukla University, India in 1999 and M. Tech. (Honors) in Instrumentation & Control Engineering from the Chhattisgarh Swami Vivekananda Technical University, India in 2009 followed by Ph.D. in Electrical Engineering, specialized in the area of Power System Instrumentation (Power Generation Automation) from the Indian Institute of Technology Roorkee, India in 2013.

He is expertise in Design and Development of cooling systems for large size electrical generators, and the C&I of process industries. He has been in academia for about twelve years. Presently, he is with VSS University of Technology, Burla, India at the capacity of Associate Professor, EEE from Dec. 2016, and HOD, EEE from Jan. 2020 to Feb. 2023, and conferred with the Best faculty Award for the AY 2021-22 under Professor/ Associate Professor category . He has more than 75 publications in various Journals and Conferences of Internationally repute to his credit. He also holds a patent as well, and filed one more. He also adapted one international edition book published by Pearson India. He received research grants of US $80,000 (INR 64 lakhs). He has been supervised 02 Ph.D. theses and 09 Masters' theses, and ongoing 03 PhD theses. He has also been recognized with many national and international awards by elite bodies. He has been awarded with CICS award under the head of Indian National Science Academy for travel support to USA, MHRD Fellowship by Govt. of India, and Gopabandhu Das Scholarship in his career. His major areas of interests are Power System Instrumentation, Industrial Automation, Robust and Intelligent Control, the Smart Sensors, IoT enabled Smart Sensors, the Smart Grid, Hydrogen Cooling System, Hydrogen Storage and Its Processing, Fuel Cell lead Sustainable Sources of Energy, and System Reliability.

Dr. Biswal is a Fellow IE (India), Senior Member of IEEE, USA, and Life Member of ISTE, India. He is actively involved in review panels of different societies of international repute viz. IEEE, IFAC, and the ISA. Currently, he is also actively involved as a Member of IEEE–SA (Standards Association) working groups; IEEE P1876 WG, IEEE P21451-001 WG, and IEEE P1415. He has also been invited for delivering guest lectures at World Congress on Sustainable Technologies (WCST) Conf. 2012, London, UK, INDICON 2015, New Delhi, India, National Power Training Institute (NPTI), Nangal, India, and G.B. Pant Engineering College, Pauri, Gharwal, India, Surendra Sai University of Technology, Burla, as a guest expert in 2016 IEEE PES General Meeting Boston, MA, USA, 1st Annual Webinar of Complex Engineering System, Politecnico di Milano, Italy in 2022, and Keynote lecture in 12th EAI International Conference on Sensor Systems and Software, Portugal in 2021.

Syllabus

Reliability Engineering

MODULE-I (6 HOURS)

Types of System, Qualitative and Quantitative assessment, Use of quantitative assessment, Reliability Definition and Concepts, Reliability Indices and Criteria, Reliability and Availability, Absolute and Relative Reliability, Reliability Evaluation Technique, Reliability Improvement, Reliability Activities in System Design & its Economics, Basic Probability Theory, Binomial Distribution and its engineering applications.

MODULE-II (10 HOURS)

Network modeling concepts, Series & Parallel Systems, Series-Parallel System, Partially Redundant & Standby redundant System. Modeling and Evaluation Concept, Conditional Probability Approach, Cut Set Method, Application and Comparison of Previous Technique, Tie Set Method, Connection Matrix Technique, Event Trees, Fault Tree, Multi-Failure Mode.

MODULE-III (8 HOURS)

Distribution Concept & terminologies, General Reliability Function& their evaluation techniques, Shape of Reliability Function. The Poison Distribution & the Normal Concept, Exponential, Weibull, Gamma, Rayleigh, Lognormal and rectangular distributions, Data Analysis, System Reliability Evaluation of different kinds of Using Probability Distributions, Mean Time to Failure, Wear out And Component Reliability, Maintenance And Component Reliability.

MODULE-IV (8 HOURS)

Discrete Markov Chains: General Modeling Concept, Stochastic Transitional Probability Matrix, Time Dependent Probability Evaluation, Limiting State Probability Evaluation, Absorbing States, Application of Discrete Markov Technique.

Continuous Markov Process: General Modeling Concept, State Space Diagrams, Stochastic Transitional Probability Matrix, Evaluating Limiting State Probabilities, Evaluating Time Dependent State Probabilities, Reliability Evaluation in Repairable System, Mean Time to Failure, Application of Technique To Complex System.

MODULE-V (7 HOURS)

Frequency andDuration Technique: Application to Multistate Problems, Frequency Balance Approach, Two Stage Repair and Installation Process. Approximate System Reliability Evaluation. System with Non-Exponential Distribution. Monte Carlo Simulation.

Text and Reference Books

Recommended Text Books:

1. Roy Billinton, Ronald N. Allan. “Reliability Evaluation of Engineering Systems”Second Edition.

Reference Books:

* Gupta A.K., Reliability, Maintenance and Safety Engineering. University Science Press.

Other Important References

Reference Sites:	
1.	NPTEL, The National Programme on Technology Enhanced Learning (NPTEL): https://nptel.ac.in/
2.	MIT OpenCourseWare : https://ocw.mit.edu/index.htm
3.	https://www.youtube.com/channel/UC0ISZ4dMZcIBeIzjZVRZhJw/videos [Gyan Ranjan Biswal @gyanranjanbiswal5649]

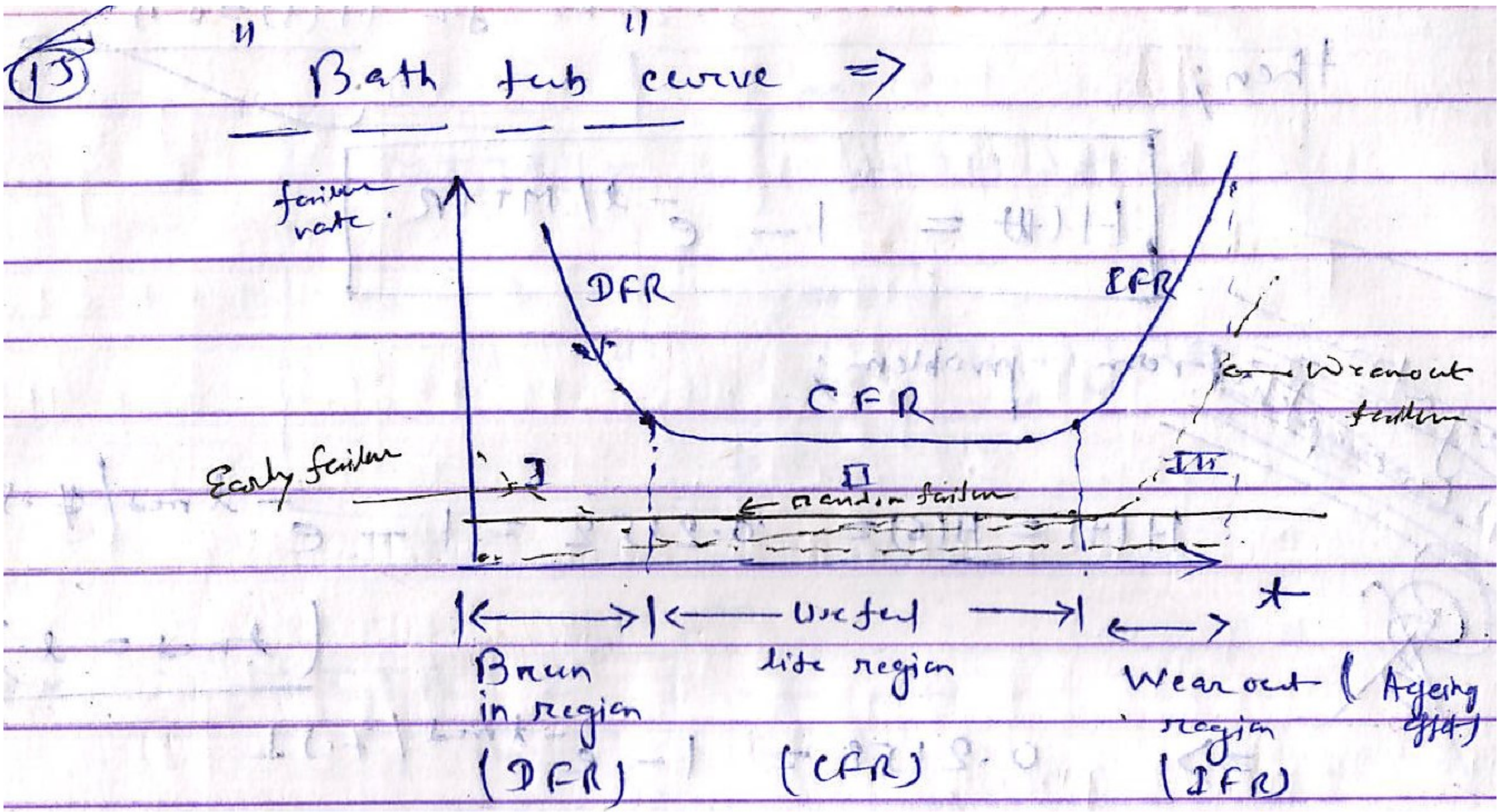
Course Outcomes

Upon successful completion of this course, you (students) will be able to

CO1	Define the basic terms in reliability engineering concepts.
CO2	Construct and implement the network modelling of simple and complex systems.
CO3	Evaluate probability distribution for reliability of a system.
CO4	Incorporate discrete and continuous Markov processes for reliability evaluation.
CO5	Express competence on approximate reliability evaluation techniques.

Introduction

Reliability Engineering ???



* **Ex :-** Child Born & growth start of life

1. Brun in region (DFR) = At start risk is very high. i.e probability of failure is ↓es with time. ∴ so getting DFR. curve,

Ex :- new born baby & child of 5 - years

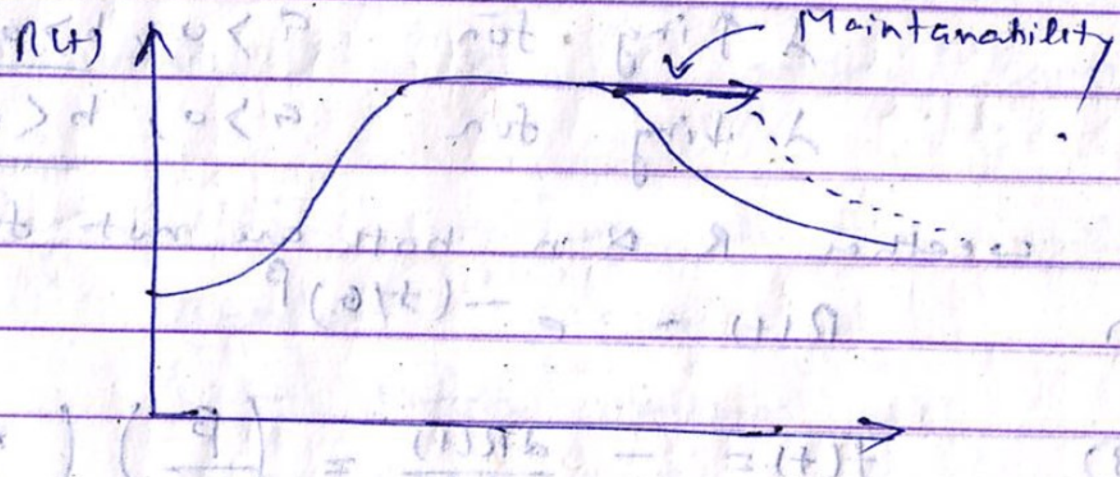
2. CFR (Useful Region) ⇒ In this curve; failure / hazard rate is constant; so is called CFR region. Practically we prefer this region to implement all design, implementation & useful appl^n. As rate of failure is known / constant.

Ex:– 10-year child to 50 year person

* As far as distribution is concerned; we are using Exponential distributi (CFR) to defines that curve.

3. Wear out region ⇒ After CFR region; this region; ageing effect will come under consideration, i.e it is consider as a IFR region; hence in progress with time; failure rate ↑es with progress in time.

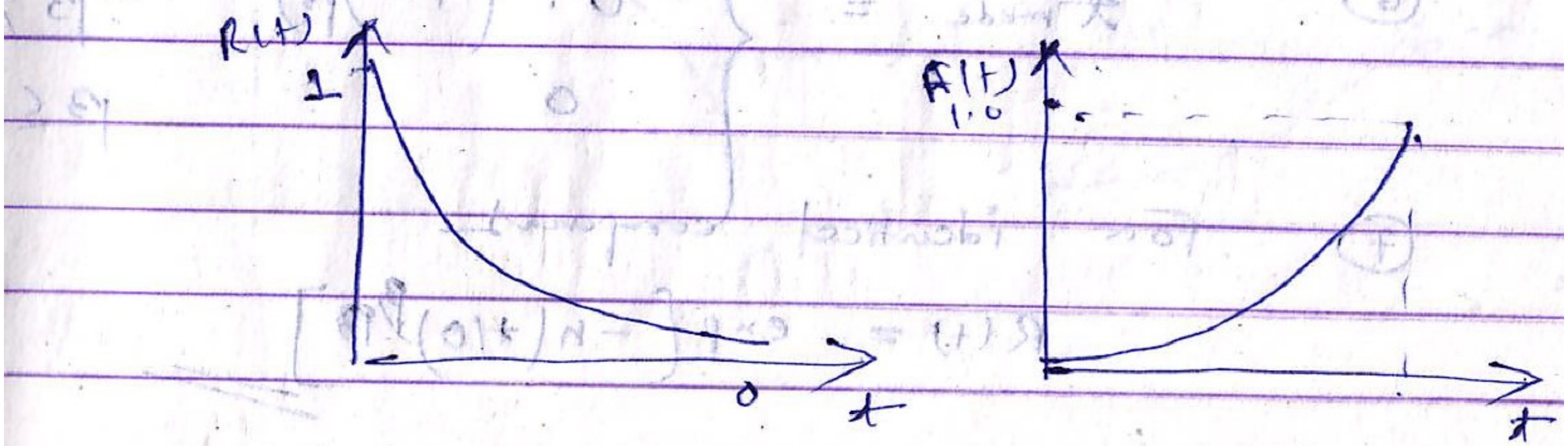
* Reliability & failure are complement of each other.

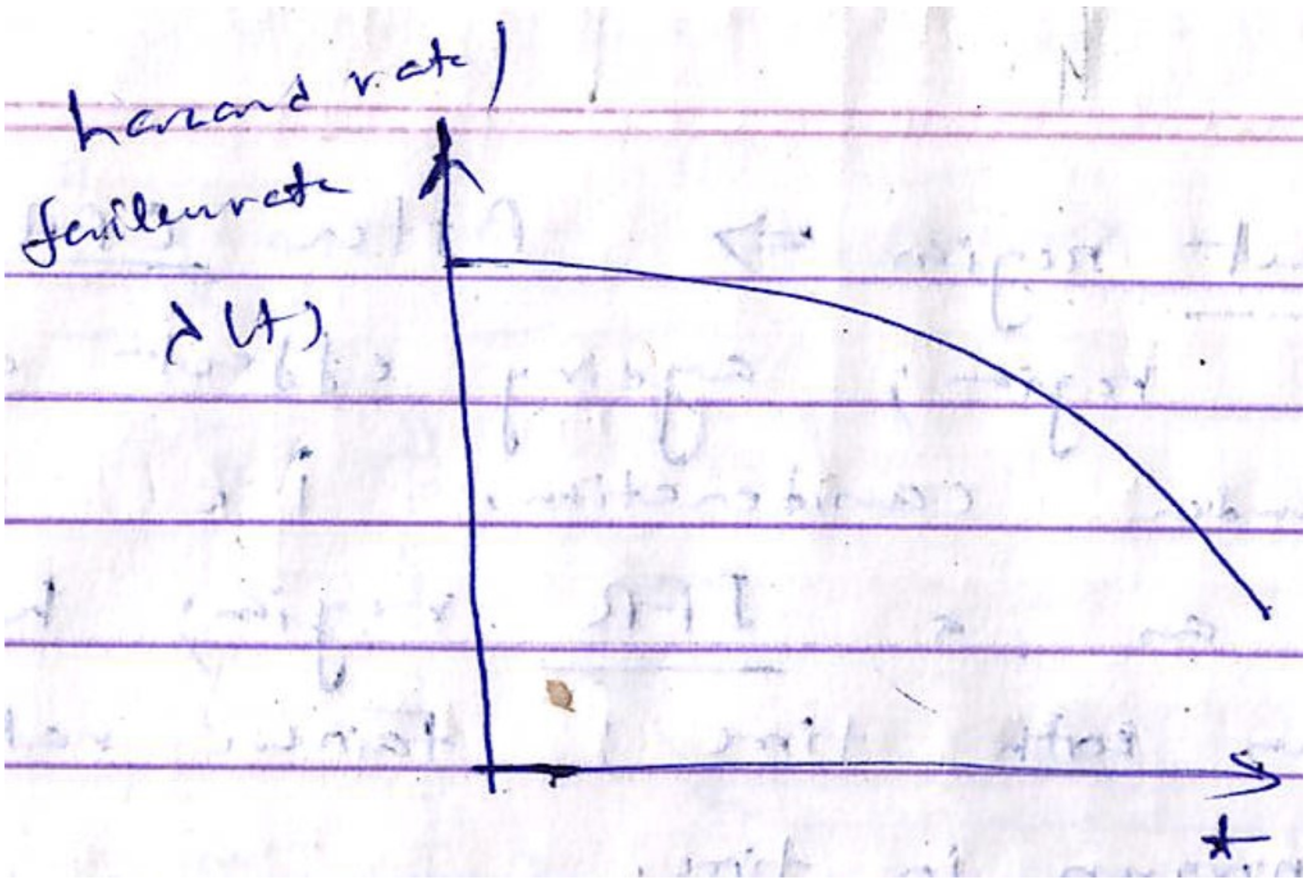


By maintaining a system; we can further ↑es the reliability of the system i.e as CFR region ↑es, IFR will ↓es

* To define IFR & DFR regim; by default we use <u>Weibull Distribution</u>. Other options are log normal & normal Distribution.

★ **In Burn-in Region ⇒**





hazard rate /
failure rate
λ(t)
t

* Weibull Distribution (IFR / DFR region) ⇒ ↑ing / ↓ing failure rate.

① $\lambda(t) = a t^{b}$

λ ↑ing for $a > 0$, $b > 0$.
λ ↓ing for $a > 0$, $b < 0$

weather R & in both are not fixed.

② $R(t) = e^{-(t/\theta)^{\beta}}$

③ $f(t) = -\dfrac{dR(t)}{dt} = \left(\dfrac{\beta}{\theta}\right)\left(t/\theta\right)^{\beta-1} \cdot e^{-(t/\theta)^{\beta}}$

β – shape parameter
θ – scale "

(4) (i) $MTTF = \theta\, \Gamma\left(1+\frac{1}{\beta}\right)$

(ii) variance $\sigma^2 = \theta^2 \left\{ \Gamma\left(1+\frac{2}{\beta}\right) - \left[\Gamma\left(1+\frac{1}{\beta}\right)\right]^2 \right\}$

(iii) std. deviation $= \sqrt{\sigma^2} = \sigma$

(5) $$t_{med} = \theta\left(-\ln(R)\right)^{1/\beta}$$

(6) $$t_{mode} = \begin{cases} \theta \cdot \left(1-\frac{1}{\beta}\right)^{1/\beta} & \beta > 1 \\ 0 & \beta \le 1 \end{cases}$$

(7) For identical component

$$R(t) = \exp\left[-n\left(t/\theta\right)^{\beta}\right]$$

(16) Exponential Distribution ⇒ (Independent time failure model)

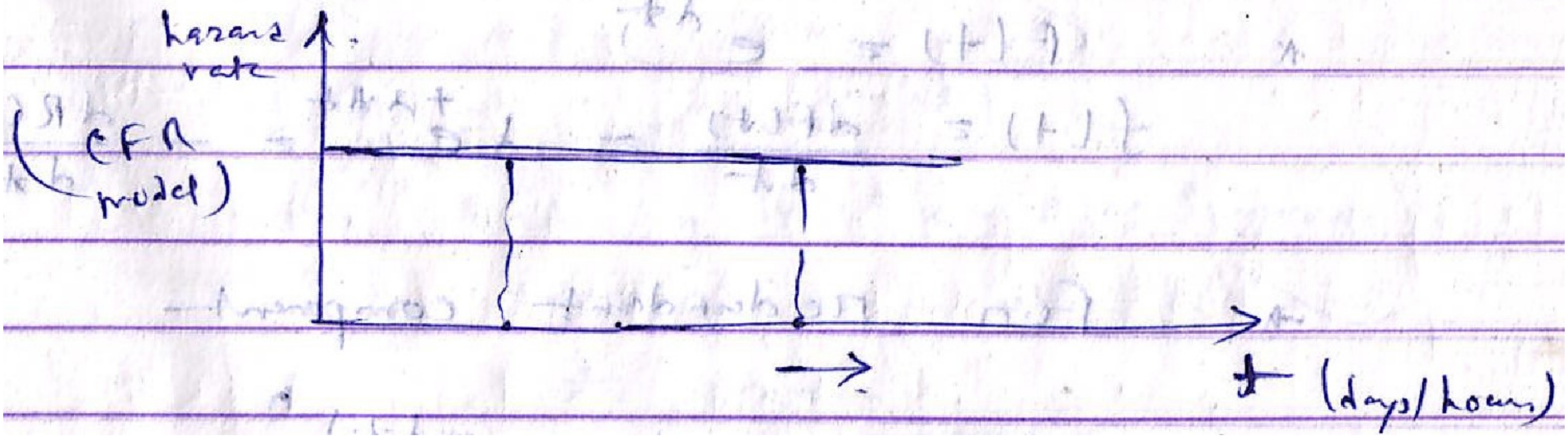
A failure distribution that has a constant failure rate is called an "exponential probability distribution" & it is one of most reliability distribution.

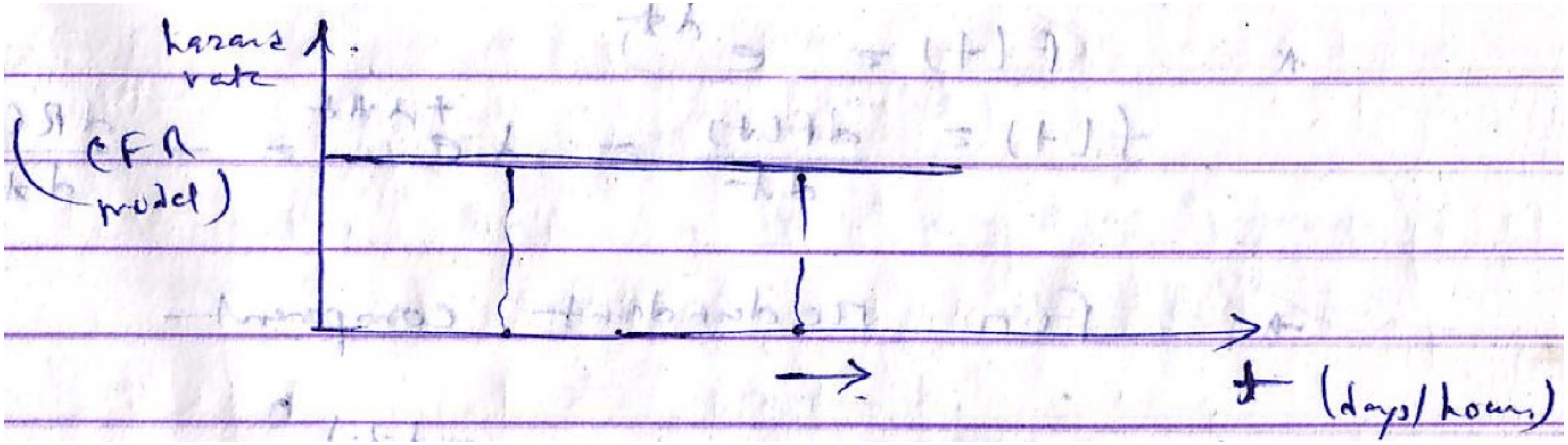
Due to constant failure rate it is called CFR model. Failure due to completely random / chance events will follow this distribution. It should dominate during the useful life of a system / components.

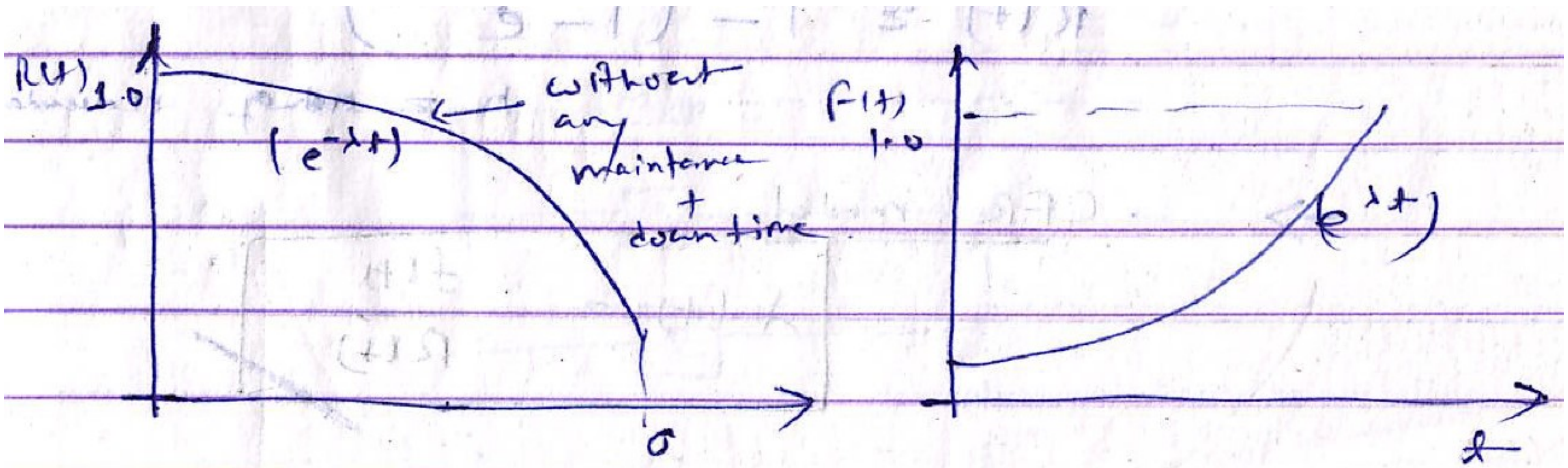
* Region for failure in this region are –

(1) random causes.

(2) [illegible]




hazard rate
(CFR model)
t (days/hours)


R(t)
1.0
$(e^{-\lambda t})$
without any maintenance + down time
0
F(t)
1.0
$(e^{\lambda t})$
t

i.e CFR model is being maintained with exponential decay in terms of $R(t)$. / Exp. ↑es in $F(t)$;

if $\lambda(t)$ is hazard rate function then

* $R(t) = e^{-\lambda t}$ —— (1)

* $MTTF = \int_0^\infty R(t)\, dt = \int_0^\infty t\, f(t)\, dt$

$f(t)$ = p.d.f. of func

* $\lambda = \dfrac{1}{MTTR}$

$\therefore$ Std. deviation $= \sqrt{\sigma^2} = \sqrt{\dfrac{1}{\lambda^2}} = \dfrac{1}{\lambda}$

* Now $F(t) = 1 - R(t) = 1 - e^{-\lambda t}$

* $F(t) = e^{\lambda t}$

$f(t) = \dfrac{dF(t)}{dt} = \lambda e^{+\lambda t} = -\dfrac{dR(t)}{dt}$

* For redundant component

$$R(t) = 1 - (1 - e^{-\lambda t})^n$$

n = no. of redundancy.

$\Rightarrow$ CFR model

$$\boxed{\lambda(t) = \frac{f(t)}{R(t)}}$$

(+) Memorylessness = in CFR region, system can be any time, it will be failed as rates is constant. So it need not to be memory, irrespective of time in this duration (non predictable)

Ex:- $R(t|T_0) = \dfrac{R(t+T_0)}{R(T_0)} = \dfrac{e^{-\lambda(t+T_0)}}{e^{-\lambda T_0}} = \dfrac{e^{-\lambda t} \cdot \cancel{e^{-\lambda T_0}}}{\cancel{e^{-\lambda T_0}}}$

$= e^{-\lambda t} = R(t)$

Appl^n ⇒ CFR implies completely random & independent failures over time and hence results in lack of memory. So it has basic three char. ⇒

1. Randomness
2. Const failure rates (CFR)
3. Memorylessness

$$R(t) = \exp\left\{ -\int_0^t \lambda(t')\, dt' \right\}$$

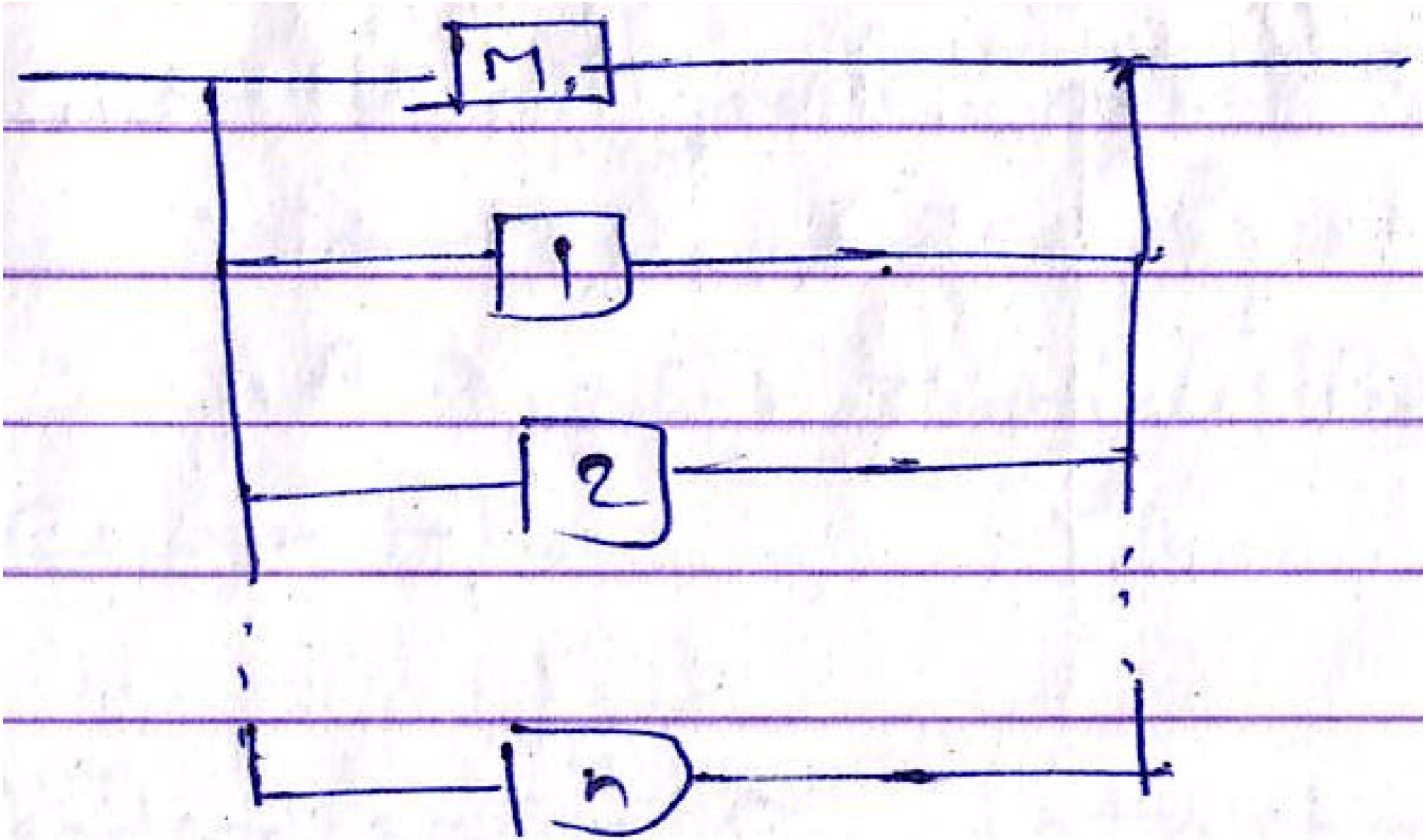
Redundancy of CFR :—

$$R(t) = 1 - (1 - e^{-\lambda t})^n$$

as order of n ↑ ⟷ R(t) improves

i.e MTTF will be better & hence

to improve.


M,
1
2
n

10.2 Ebling

(17) Different type of ~~Distribution~~ Design methods ⇒ (to Inc maintability)

In order to increase maintainability (availibility) in some manner the repair time must be reduced. There are several key concepts that should be followed as part of any design activity that supports this reduction :—

(1) Fault Isolation {Self Diagnostics} ⇒ Diagnosis of a failure with the identification of the fault is a major task in the repair process. It can take several forms:

(a) Manual ⇒ It is a trial & error procedure, with the aid of meters, oscillos-copes, gauges, tech. drawing etc.

(b) Automatic ⟹ the failed unit is generally removed from the rest of the system & connected to a computerized test station.

(c) Self diagnostic ⟹ on failure of model switches to a diagnostic model & internally isolated & identified failed part. is referred as BIT (Built-In-Test) / BITE (Built-in-Test-Equipment).

② Part Standardization & Interchangeability ⇒

It affect reliability design.

Standardization results in reducing to a minimum the range of parts that must be maintained & stocked. So the amount of training & skill required to perform maintenance may be reduced.

③ Modularization & Accessibility ⇒

Modularization means the packaging of components in self-contained functional units / model / facility maintanance.

Ex :- Black Box of a Air craft.

with the help of Modu. we can further

★ cut down the cost also.

$$\text{Mean no. of module to Repair} = \lambda M T$$

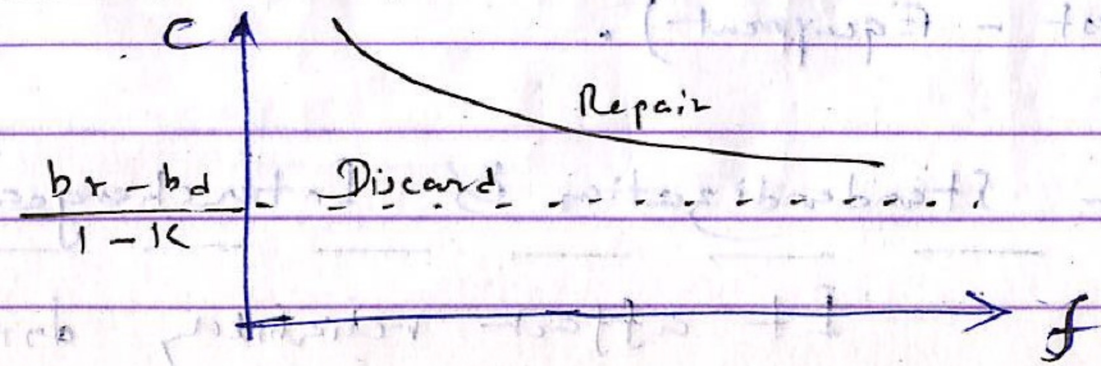
λ → failure rate

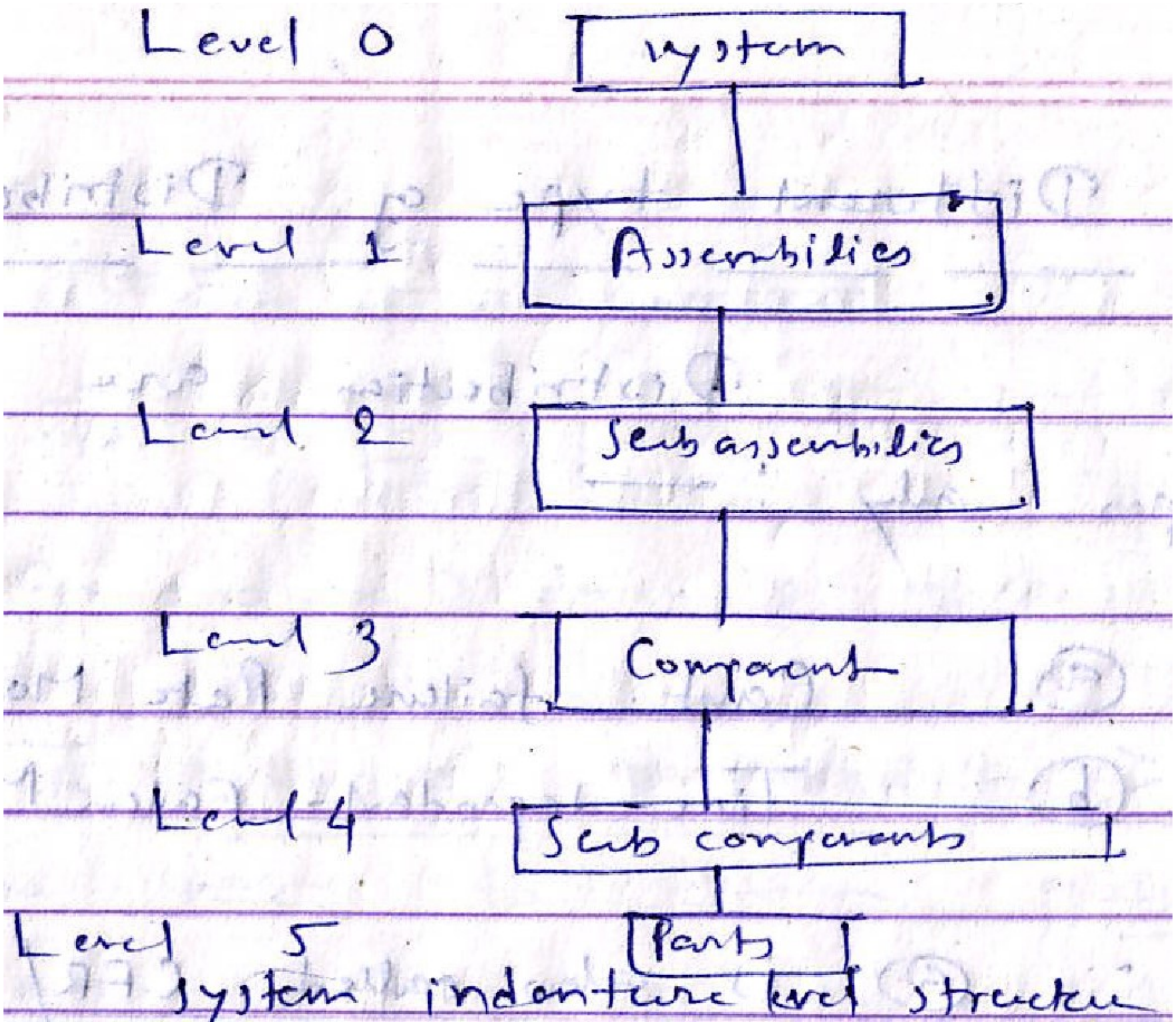
M – no. of modules

T → total repair time / resupply time

(4) Repair Vs. Replacement ⇒

For several system if; if Repairing is not in under control in terms of cost; then Replacement is good idea. & it can be judge by indenture levels of a system.




Level 0
system
Level 1
Assemblies
Level 2
Sub assemblies
Level 3
Component
Level 4
Sub components
Level 5
Parts
system indenture level structure

(5) Proactive Maintance ⇒
defined as ~~either~~
either – preventive maintenance
or – predictive maintenance.

(a) preventive main. ⇒ it has economic consideration. & it should be done aggressively.

$$E[N(t)] = \int_0^T \rho(t)\,dt$$

$\rho(t)$ = intensity functn of a nonhomogeneous poisson process.

(b) predictive maintenance ⟹ As part (a) preventive counts to reduces the freq. of failures. While in predictive maintance equipment / components are monitered on evaluated in order to predict when the failure is going to occur.

(18) Different type of Distribution ⇒

Distribution are basically two types only :—

(a) Const. failure Rate Model (time independent)

(b) Time dependant failure Model

∴ (a) is also called CFR / Time independent

& (b) is either IFR / DFR consist of

uses to design memory devices

→ The Weibull Distribution

→ " Normal Distribution

→ " Lognormal —"—

* (a) (i) as per described in ans. no. (16) is also known as Exponential Distribution.

(b) (1) Weibull Distribution ⇒ is the best option available to us for time - dependent failure model as this

(f) technique empowered to work out both IFR & DFR region equally.

if $\lambda(t)$ is hazard rate function

$$\lambda(t) = a\,t^{b} \quad \text{(1)}$$

$\lambda(t)$ is ↑ing for $a > 0$, $b > 0$

& ↓ing " $a > 0$, $b < 0$

hence

(p.d.f.) $f(t) = -\frac{dR(t)}{dt} = \frac{dF(t)}{dt}$

$$f(t) = \left(\frac{-\beta}{\theta}\right)\left(t/\theta\right)^{\beta-1} \cdot e^{-(t/\theta)^{\beta}}$$

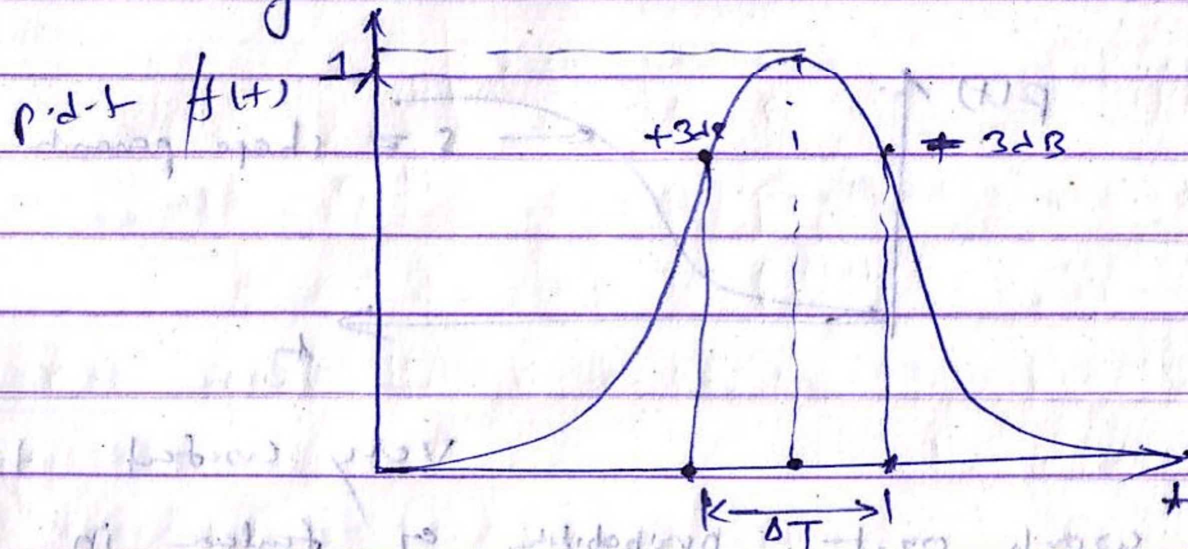
(2)

Appl^n ⇒ For analysis & designing pt. of view is Imp.

② The Normal Distribution ⇒ Works.

ⓐ where need to consider gaussian response.

ⓑ wants to convert stocastic / random / non periodic signal into limited period range.



$$\Delta f = \frac{1}{\Delta T}$$

$$f(t) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left\{ -(t-\mu)^2 / 2\sigma^2 \right\}$$

$$-\infty < t < \infty$$

Appl^n ⇒ ① most widely utilized to design caused system / to convert non-causal into causal response.

② all communication equipment / system are designed, tested & implemented based on this distribution technique.

③ Implementation is done most widely by Normal Distribution.

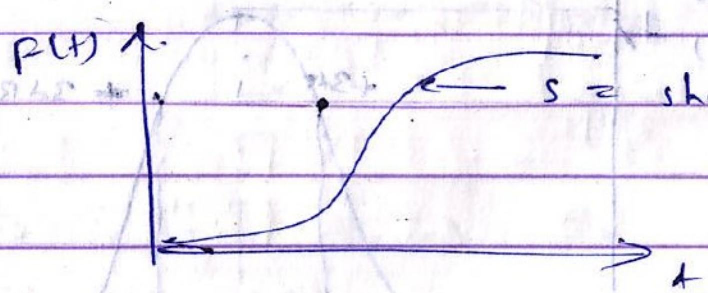
* CLT (Central Limit Theorem) is used to define it.

③ The Lognormal Distribution ⇒

p.d.f is given by

$$f(t) = \frac{1}{\sqrt{2\pi}\, s t} \exp\left\{ -\frac{1}{2s^2}\left(\ln \frac{t}{t_{med}}\right)^2 \right\}$$

$\because t \geq 0$



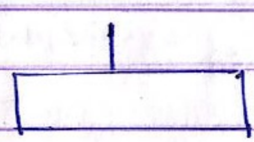
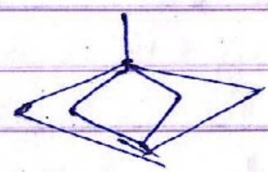
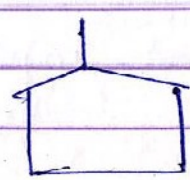
very useful to work out probability of failure in IFR region & is easy to apply where Logarithm approach is difficult.

(19) Fault Tree Analysis ⇒

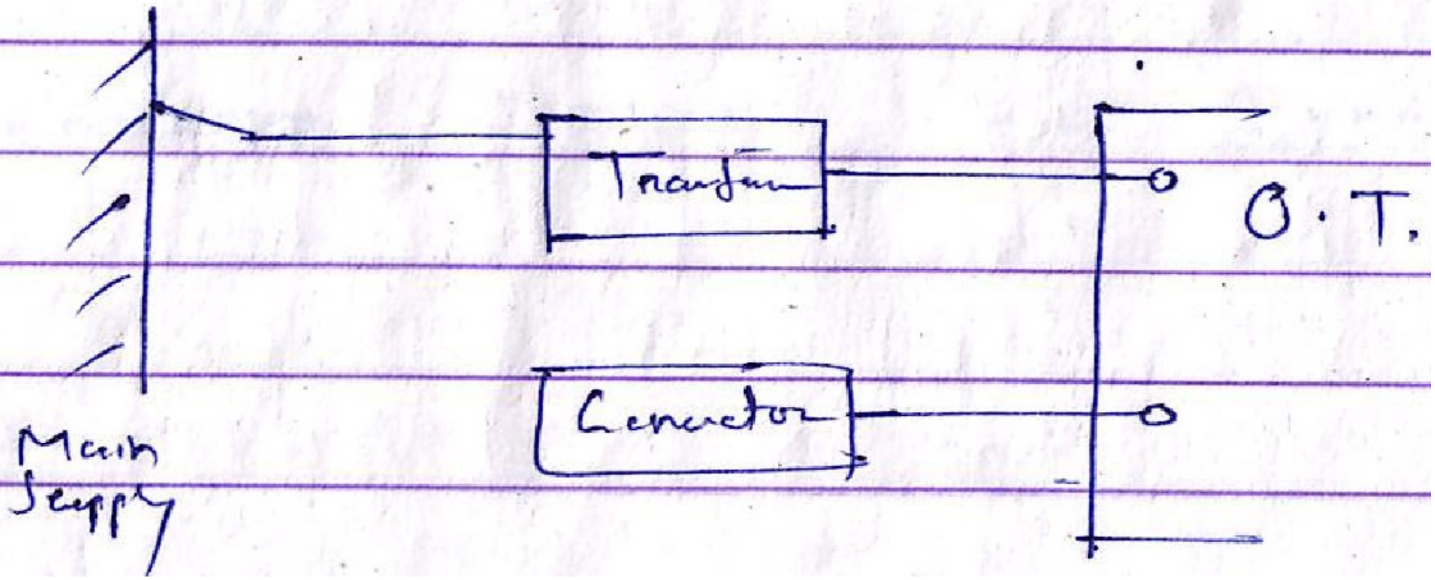
There are different way of looking at the problem, namely to see / identify how the system may fail to function. & this analysis is called "Fault tree analysis".

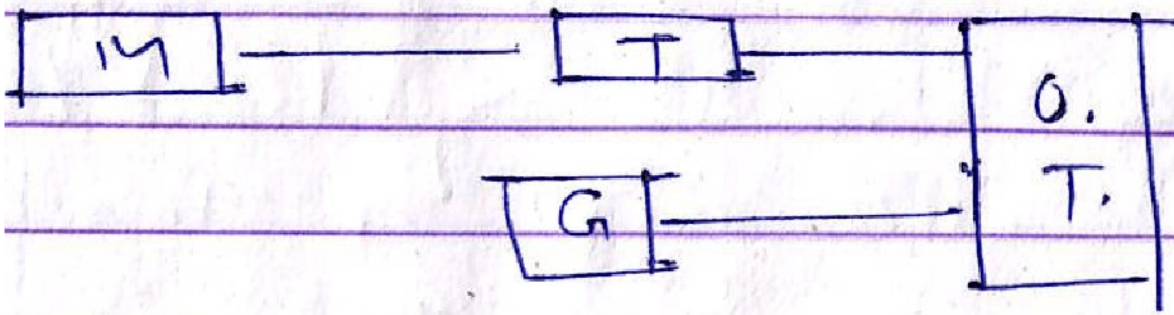
Normal approach is to design fault tree diagram is moving from L → R & Top → Down.

Fault tree - construction ⇒

	Symbols	Name of symbol	Meaning
①		Circle	– Basic failure (events where F(t) can be cal. from provided data)
②		– Diamond	– Basic fault ~~events~~ (this fault can be subdevided into Basic failure)
③		– Rectangle	– Resultant event (intermediate events via a logic gates)
④		– Double Diamond	– Represent an event (where causes will be specified later)
⑤		– House	– Represent an basic event (while system is operating)

Ex:- Example 8.3 (L.S. Srinath)



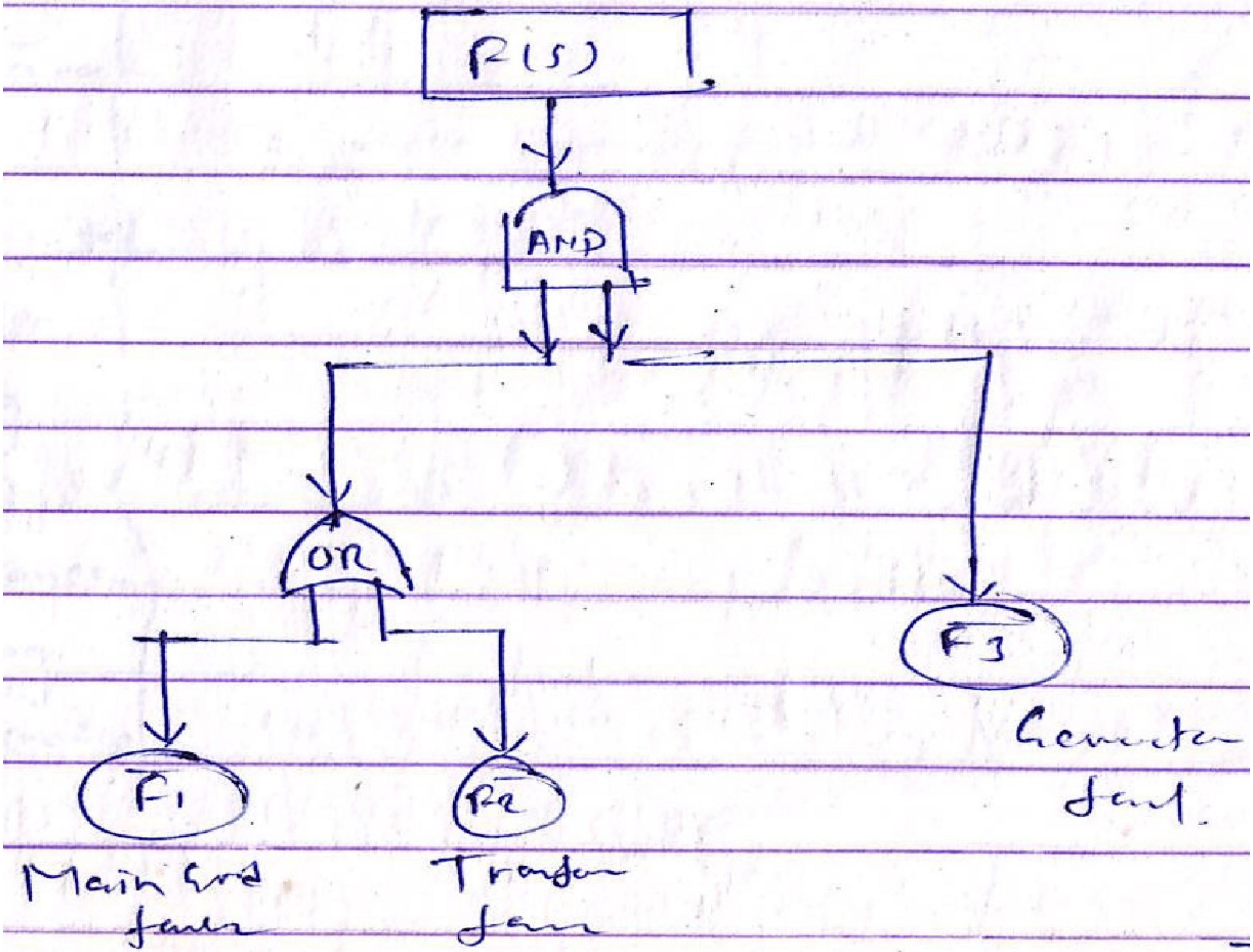


$$R(s) = (M \text{ AND } T) \text{ OR } G$$

$$F(s) = 1 - R(s)$$

$$F(s) = (\bar{M} \text{ OR } \bar{T}) \text{ AND } \bar{G}$$

$$\because \left\{ \begin{aligned} \bar{M} &= 1 - R_M \\ \bar{T} &= 1 - R_T \\ \bar{G} &= 1 - R_G \end{aligned} \right.$$


F(S)
AND
OR
F1
F2
F3
Main Grid failure
Transfer failure
Generator fault.

chap. 7
Fabling

(20) Diff^n bet^n Static & Dynamic Reliability ⇒

Pt. to made difference	Static	Dynamic
(1) Situation		
(2) Stress Duration		
(3) Reliability		
(4) Load applied		
(5) Type of Loads		
(6) P.d.f.		
(7) Types		
(8) Bath Tub curve position		
(9) MTTF		
(10) Function		
(11) Causes of failure		

(12) Models

(13) Operating conditions

(14) Future Tendency

(15) Appl^n

(16) Environmental condition

(17) Testing

(18) Types of maintanance

(19) Derating

(20) Failure modes

chap 7
12b1-9

(21) Covariate Model $\Rightarrow$ Helps to develope failure distribution involving one / more covariate / explanatory variables (i.e. one / more of the distribution parameters)

$$\therefore \quad \alpha(x) = f(x_1, x_2, \ldots, x_k) \quad \text{--- (1)}$$

where

$$x = (x_1, \ldots x_k) \;\&$$

$$x_i = \text{the } i\text{th covariate.}$$

A covariate may be V / I / T / humidity or other measure of stress / environment. It is two types :—

① Proportional Hazard Model —

here individual hazard rate functions are proportional to each other.

ⓐ Exponential case : For CFR model

$$\lambda(x) = \sum_{i=0}^{k} a_i x_i \quad \text{---} (2)$$

∴ a_i = unknown para

x_i = transformed variables

ⓑ Weibull case :—

char. life time (θ) depends on covariate

∵ shape para (β) not "

$$\lambda(t/x) = \lambda_0(t)\, g(x)$$

$$\therefore g(x) = \exp\left(\sum_{i=1}^{k} a_i x_i\right) \quad \text{---} (3)$$

(2) Location-scale Model :—

$$\mu(x) = \sum_{i=0}^{k} a_i x_i$$

& $y = \mu(x) + \sigma z \quad \because \sigma > 0$

(a) Normal case :— —— (4)

$\therefore y = \mu(x) + \sigma z$

similarly z is normally distributed with $\left.\begin{array}{l}\mu(x) = 0 \; \& \\ \sigma^2 = 1\end{array}\right\}$

(b) Lognormal case :—

Setting $T = e^{y}$ —— (5)

$(\because y = \mu(x) + \sigma z)$

$$R(t) = 1 - \phi\left(\frac{\ln t - \mu(x)}{s}\right) \text{ —— (6)}$$

(22) Physics of failure Models ⇒

depends upon (1) Material prosperation

(II) Operating profile

(3) Envionnmental Conditions

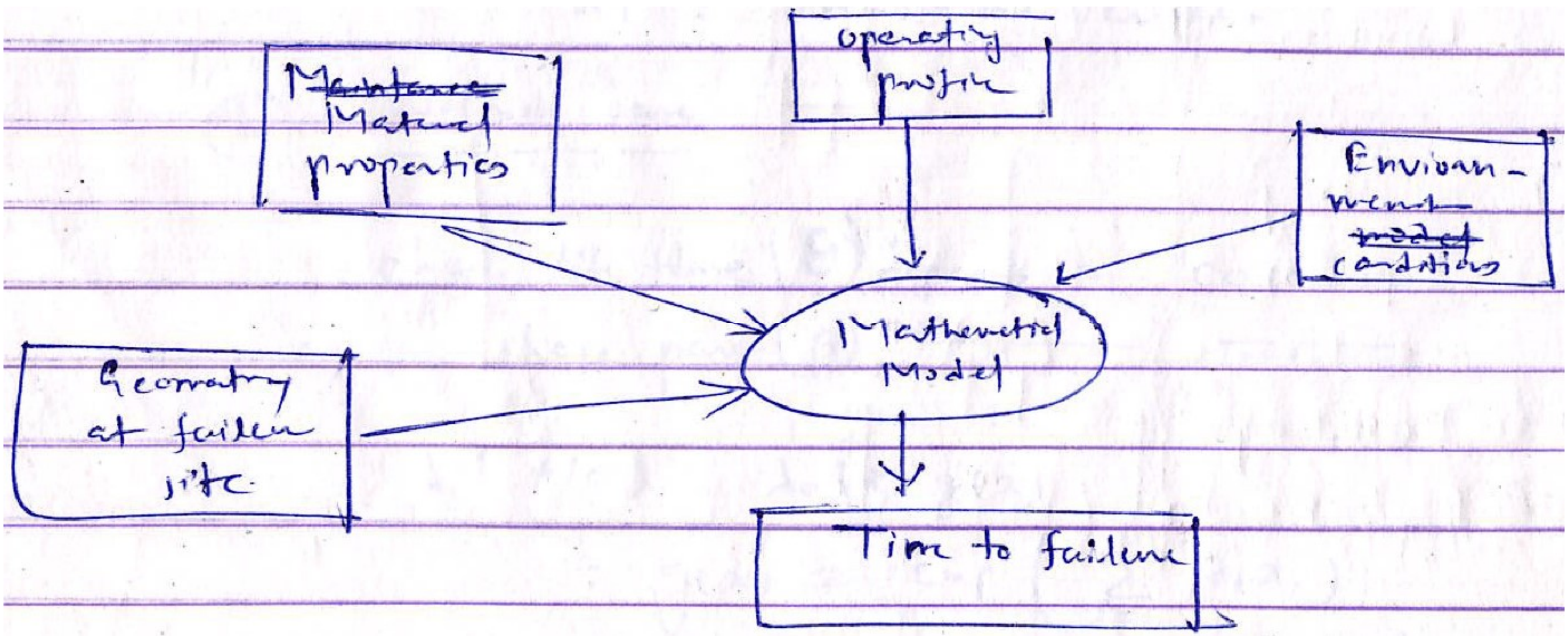
(4) Geometry at failure side

(5) Mathematical Model

(6) Time of failure

Although there is no well defined approach for developing physical failure models, several ~~steps~~ general steps can be identified :–

(a) Identify failure sites & mechanisms
(b) Construct mathematical model
(c) Estimate reliability
(d) Det. dominant service life
(e) Redesign to increase service (design) life.


~~Maintenance~~ Material properties
Operating profile
Environment ~~model~~ conditions
Geometry at failure site
Mathematical Model
Time to failure

Exercise
11.3

(23) A replaceable & repairable engine, having MTBF = 10 hr.

and back up unit having MTBF = 5 hr.
Also given repair avg = MTTR = 2 hr.

Steady state availability = (A) = ?

Ans

let

$$\lambda_1 = 1/10 = 0.1$$

& $$\lambda_2 = 1/5 = 0.2$$

r = repair ay = ~~2 hrs~~ $\frac{1}{MTTR}$

$$\therefore r = \frac{1}{MTTR} = \frac{1}{2} = 0.5$$

$$\lambda_3 = 0 \quad (\text{assuming})$$

Now in steady state availability

$$A = P_1 + P_2 \quad \text{—— (1)}$$

$$\therefore P_1 = \left(1 + \frac{\lambda_1}{\lambda_2} + \frac{\lambda_1 + \lambda_3}{\gamma}\right)^{-1}$$

$$P_2 = \frac{\lambda_1}{\lambda_2} P_1$$

$$P_3 = \frac{\lambda_1 + \lambda_3}{\gamma} \cdot P_1$$

$$\boxed{A = P_1 + P_2}$$

$$\therefore P_1 = \left(1 + \frac{0.1}{0.2} + \frac{0.1 + 0}{0.5}\right)^{-1} = \cancel{1.7}\ 0.588$$

$$P_2 = \frac{\lambda_1}{\lambda_2} \cdot P_1 = \frac{0.1}{0.2}(\cancel{0.77}\ 0.588) = \cancel{0.85}\ 0.294$$

$$P_3 = \left(\frac{0.1 + 0}{0.5}\right) 0.588 = 0.\cancel{2 \times 17}\ 0.24 = 0.\cancel{34}\ 0.1176$$

Steady state Availability $= A = P_1 + P_2 = \cancel{1.7 + 0.85}\ 0.588 + 0.294$

$$= 0.882 \quad \cancel{2.55}$$

Thank you