Introduction to Reliability Engineering

Rick Liddy
LTU MCS Instructor

April 4, 2009

Rick Liddy

28 Years of Experience at Ford Motor company

Reliability Engineer highlights:

- Led the team that invented the Life Test Development process

- Developed a method that improves Failure Modes and Effects Analysis (FMEA) for Worldwide Ford Motor Co application. (Received recognition with a patent). Subject Matter expert in developing the following FMEA classes: In-class, On-line, in-class supplemental, Management in-class and Management on-line

- Implemented Cox's non-parameter analysis to Field (Warranty) data.

- Developed an improved Warranty forecasting method. Trained North American Operation Engineers.

- Engine support of the Flexible Fuel Vehicle Program (FFV) meaningful tests

Definition of Reliability

Reliability is the probability of a component/system functioning to its design intent over a specified time period.

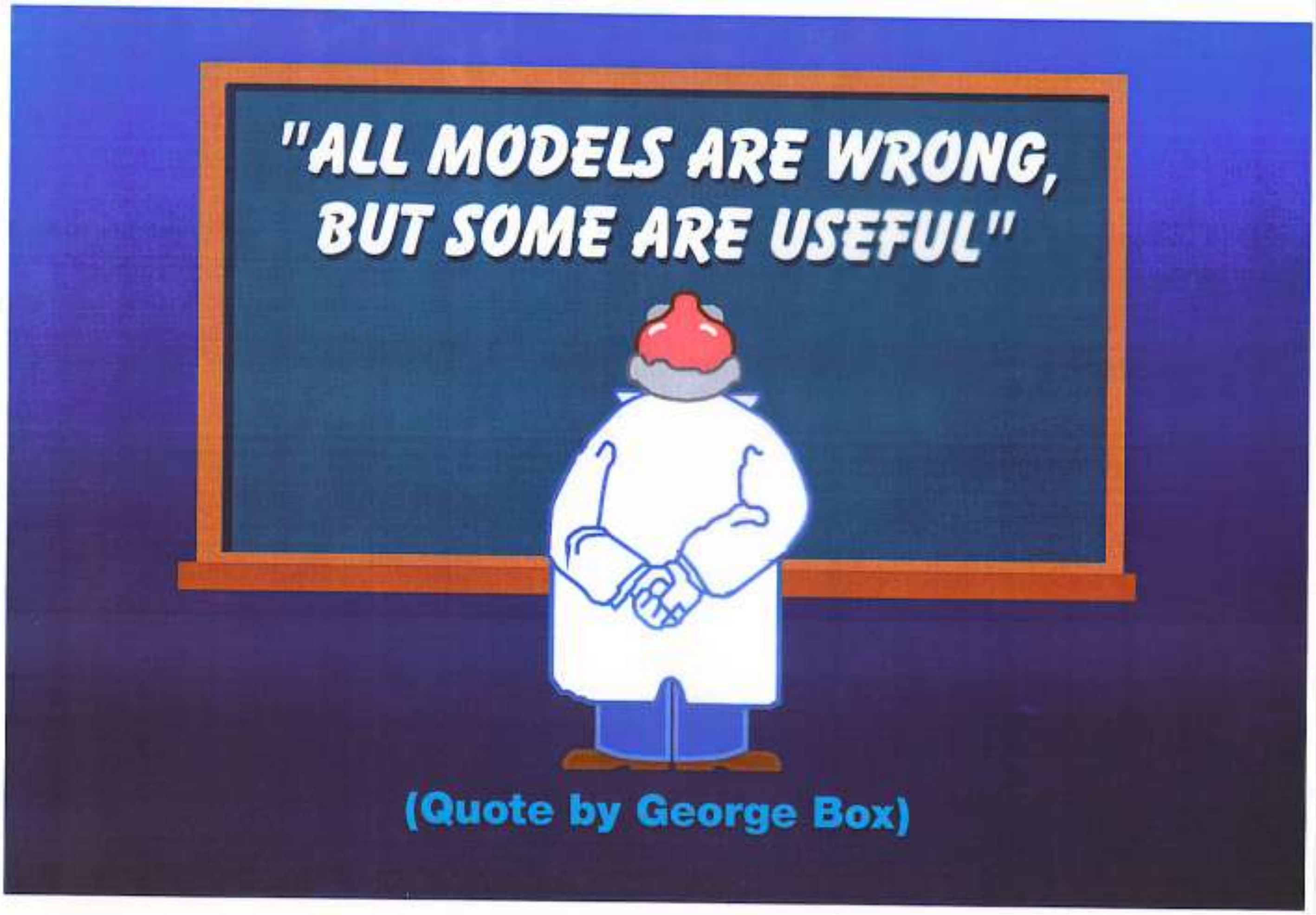
Reliability Activity Types

Preventative:

Reliability is integrated into the design process to meet design reliability objectives

Reaction:

Monitors field data to provide information for future or existing designs.


"ALL MODELS ARE WRONG,
BUT SOME ARE USEFUL"
(Quote by George Box)

Some Reliability Engineering Tasks

- Predict and identify failures modes
- Optimize designs
- Develop meaningful tests
- Predict reliability
- Identify potential concerns

One key tool is the Hazard function!

The Hazard Curve

The Hazard Curve is the instantaneous failure rate at a specified age t.

$$h(t) = \frac{f(t)}{R(t)}$$

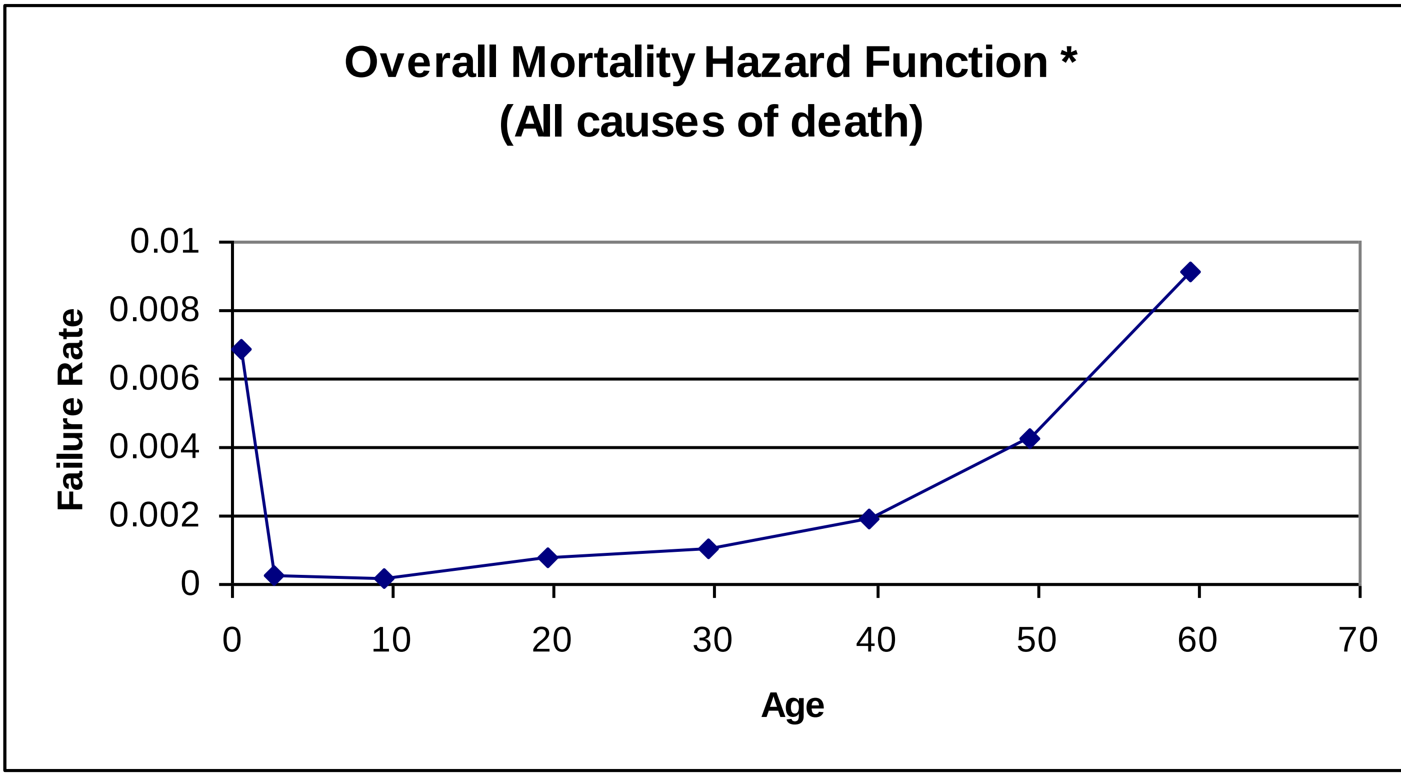
Where:

f(t): density function
R(t): Reliability function
h(t): hazard function

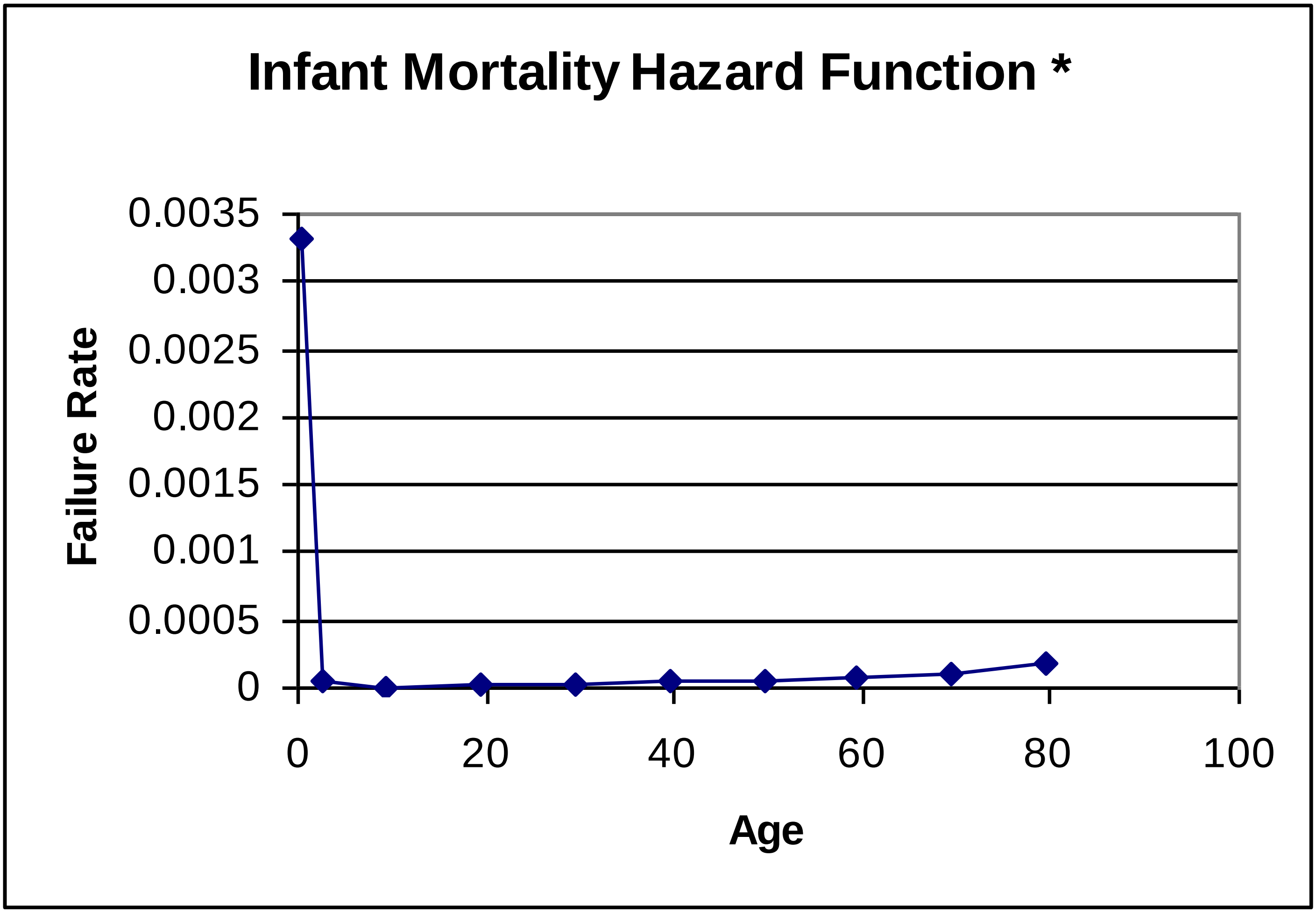
An example of this curve is the human life cycle.

Hazard function example: Mortality rates

Data source: National Center for Health Statistics (NCHS)

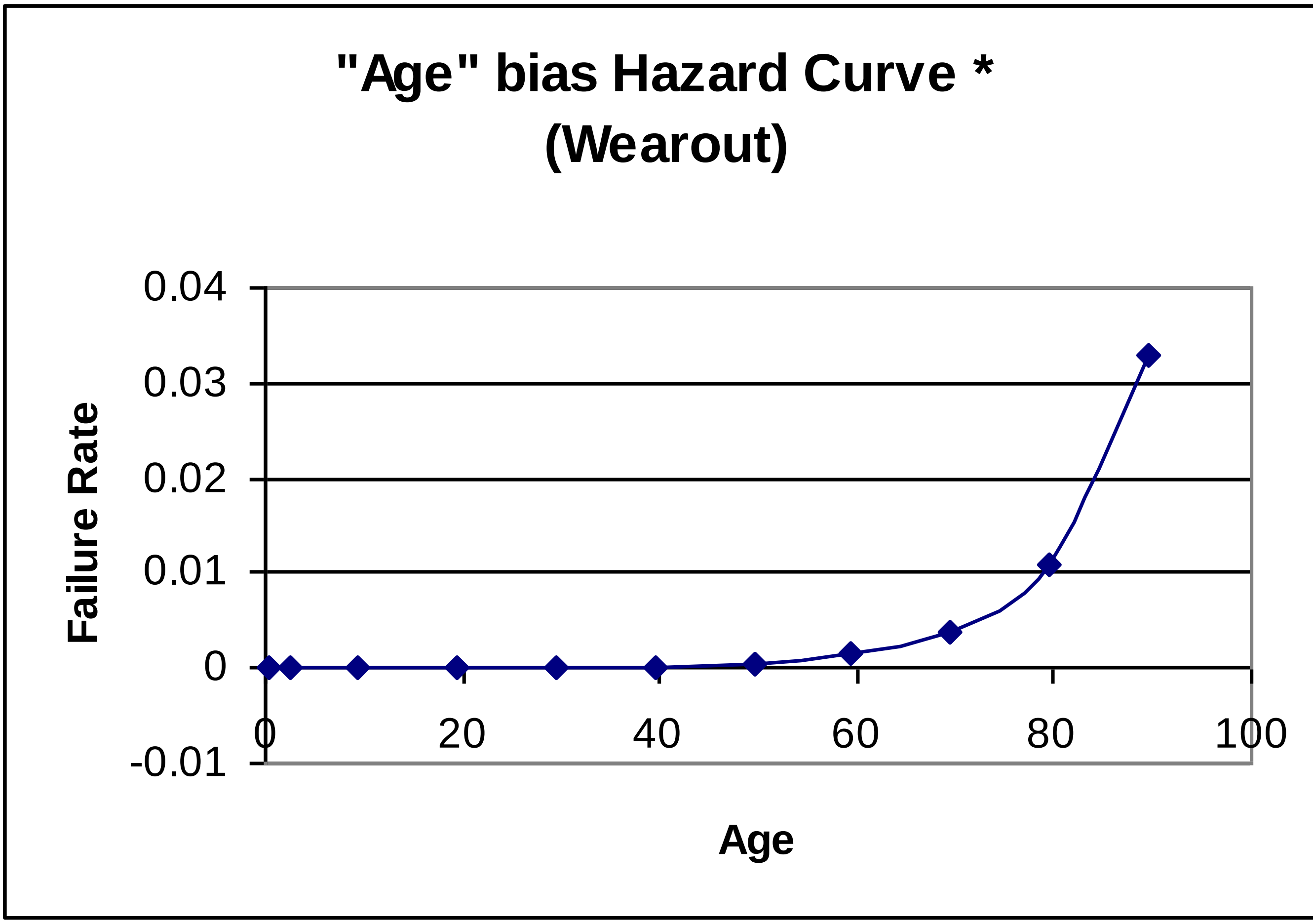


* Data from 2004 National Center for Health Statistics (NCHS)



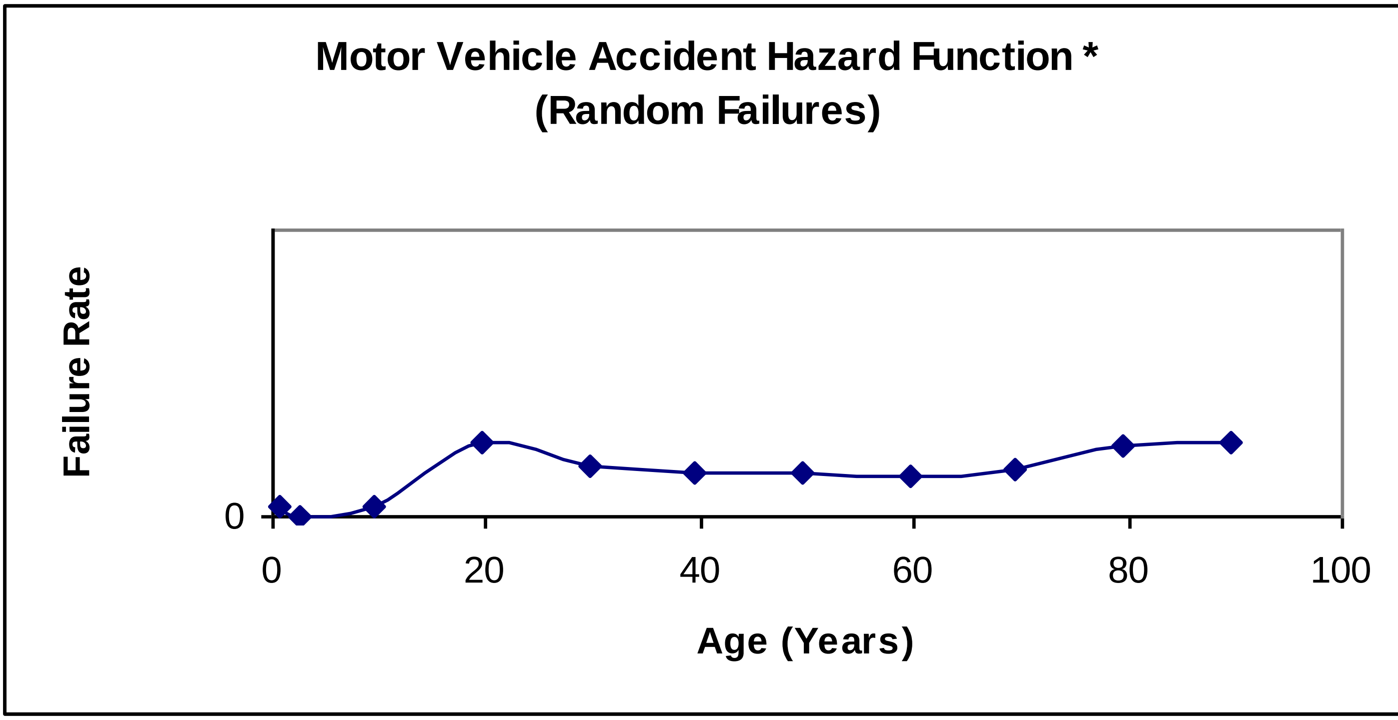
* NCHS illness categories:

- Congenital malformations (Q00-Q99)
- Disorders related to short gestation (P07)
- Unknown causes (R95-R00)



* NCHS illness category:

- Ischemic heart diseases (I20-I25)



* NCHS illness category:

- Motor vehicle accidents (see NCHS for codes)

Infant Mortality Example

Exploring a “Widget” using Warranty Data

2001 Model year:
30 Repairs and 400 vehicles sold or 7.5%

2000 Model Year comparison:
40 repairs and 1500 vehicles sold or 2.7%

Step 1: Identify a concern

Contingency table

	Case 1	Case 2	Total
Population 1	O_{11}	O_{12}	n_1
Population 2	O_{21}	O_{22}	n_2
Total	C_1	C_2	N

$H_o: \ p_2 \leq p_1$

$H_A: \ p_2 > p_1$

$$T_{statistic} = \frac{\sqrt{N}[(O_{11})(O_{22}) - (O_{12})(O_{21})]}{\sqrt{(n_1)(n_2)(C_1)(C_2)}}$$

Reject H_o if $T_{statistic} < \chi^2_{1,.05}$

(95% Confidence level)

Reliability Infant Mortality Example

Step 1: Identify a concern

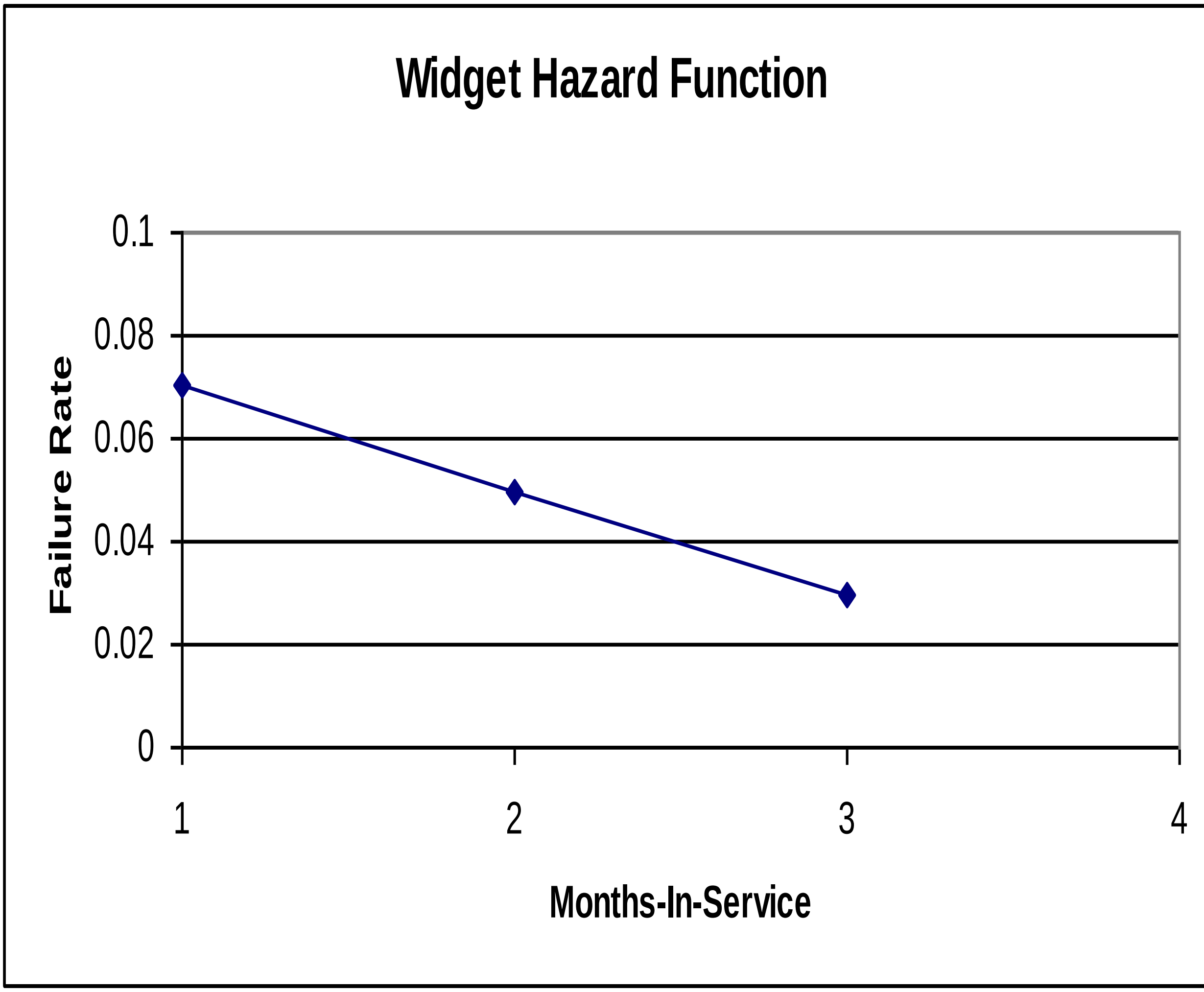
Widget Contingency table

Model year	Repairs	Non-repairs	Total
2000	40	1460	1500
2001	30	370	400
Total	70	1830	1900

$$T = \frac{\sqrt{1600}[(40)(370) - (1460)(30)]}{\sqrt{(70)(1830)(1500)(400)}} = -4.1842$$

Suspect the year 2001 is significantly higher then 2000 if T< -3.841 (95% Confidence level)

Step 2: Investigate



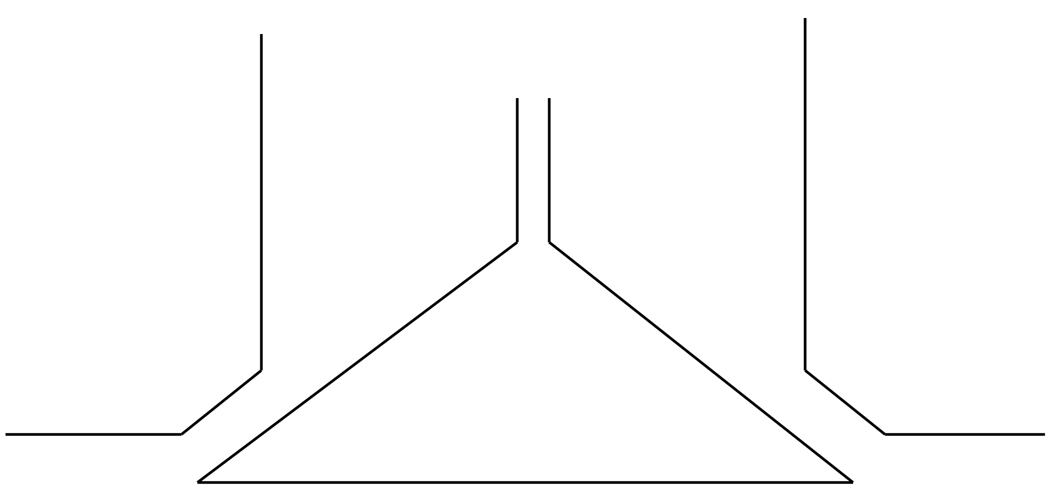
Widget Conclusions

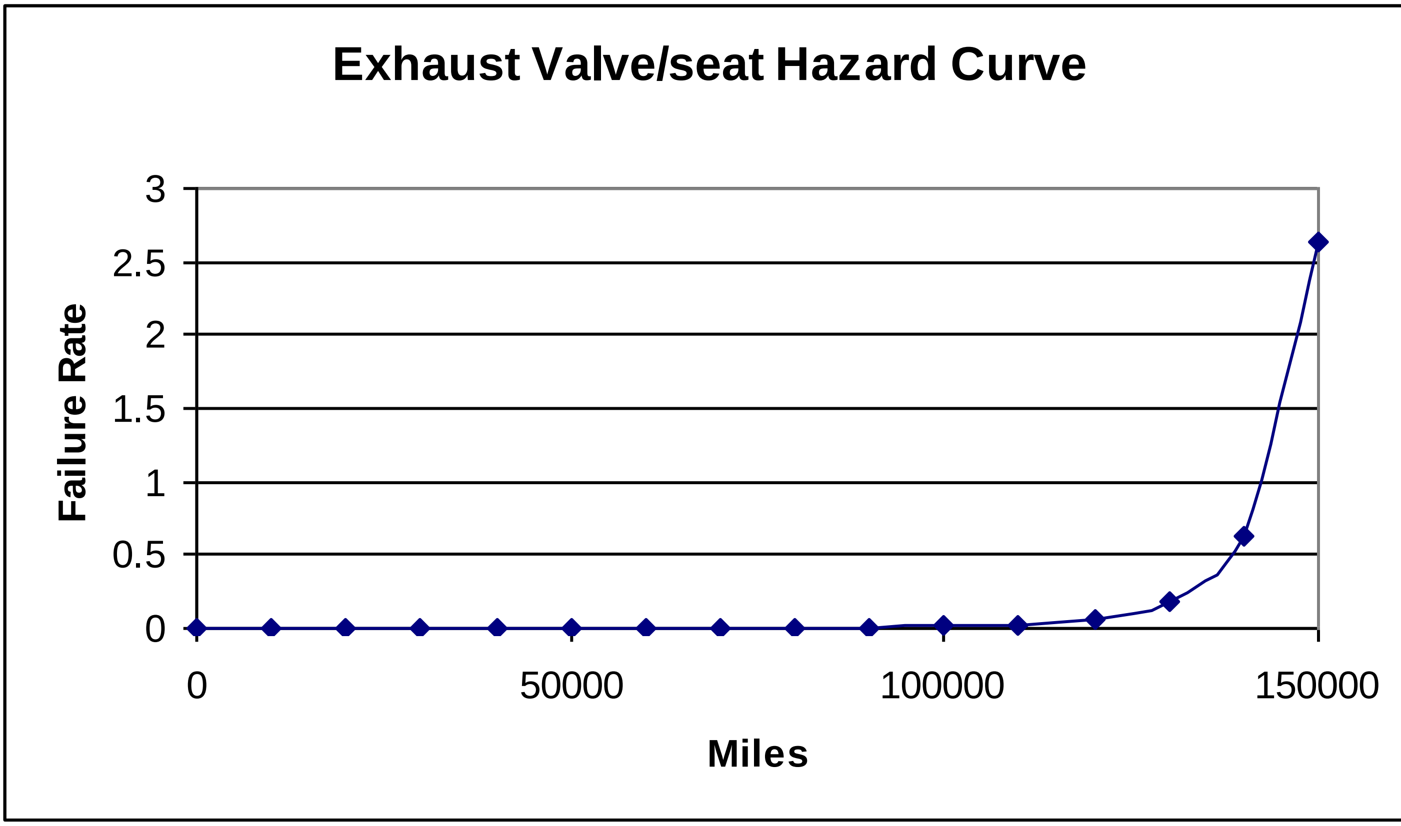
- The 2001 repair rate was significantly higher than 2000. Definitely needs to be investigated.

- The type of Failure was infant mortality, probable cause was in manufacturing or assembly

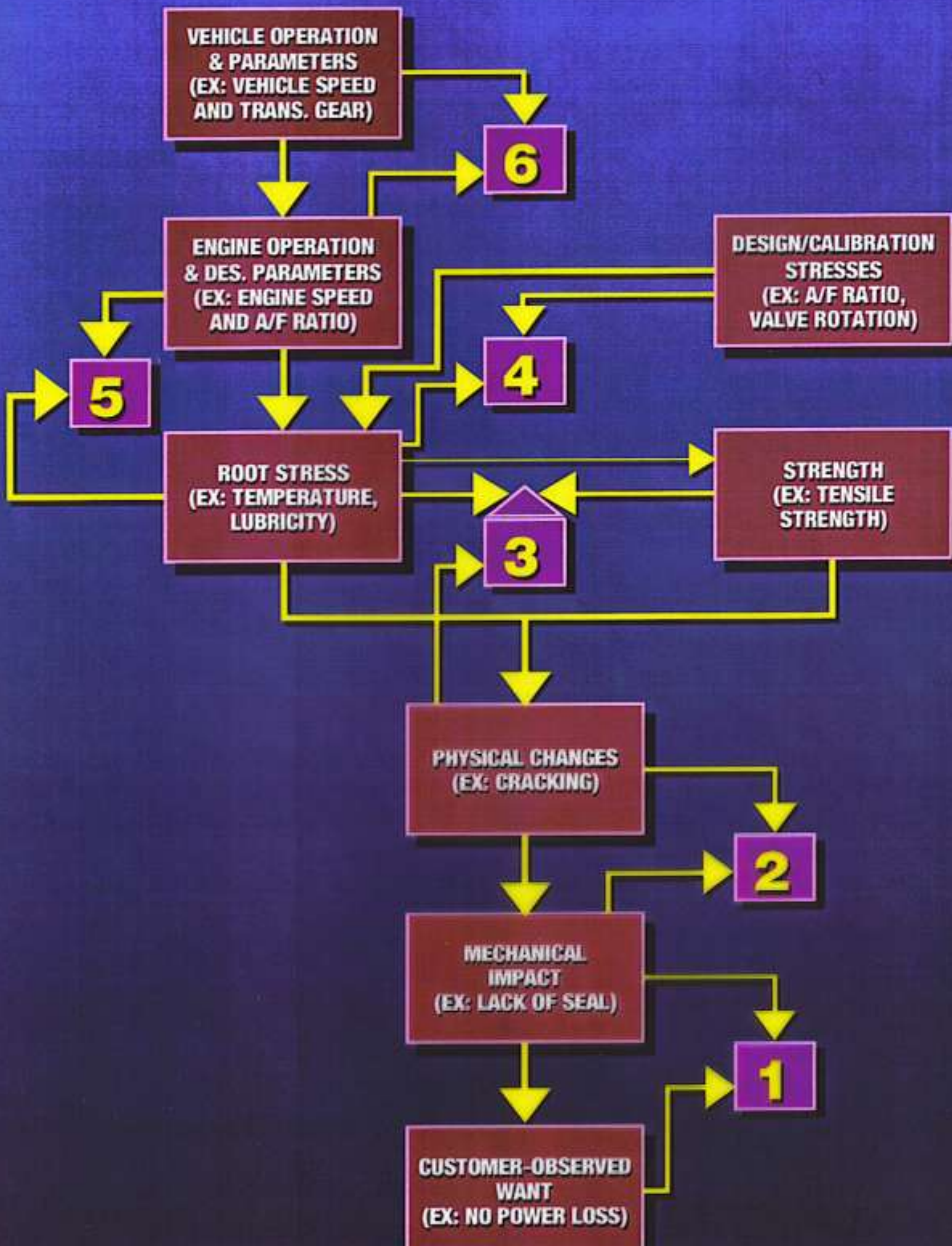
Wearout Example
Exhaust Valve/Seat Wear

Exhaust Valve/Seat Wear System




Exhaust Valve/seat Hazard Curve
Failure Rate
3
2.5
2
1.5
1
0.5
0
0
50000
100000
150000
Miles

EXHAUST VALVE/ SEAT STRESS-STRENGTH FLOW



Exhaust/valve Study
#6 Vehicle and Engine Relationships

Engine Parameters	Vehicle Characteristics					Environmental Parameters		
	Vehicle speed (MPH)	Axle Ratio	Transmission gear	Payload	Fuel Type	Altitude	Temperature	Humidity
Engine Speed (RPM)	●	○	●	○	○			
Engine Load	○	Δ	○	○		○		
Air/Fuel Ratio	Δ				○		Δ	○

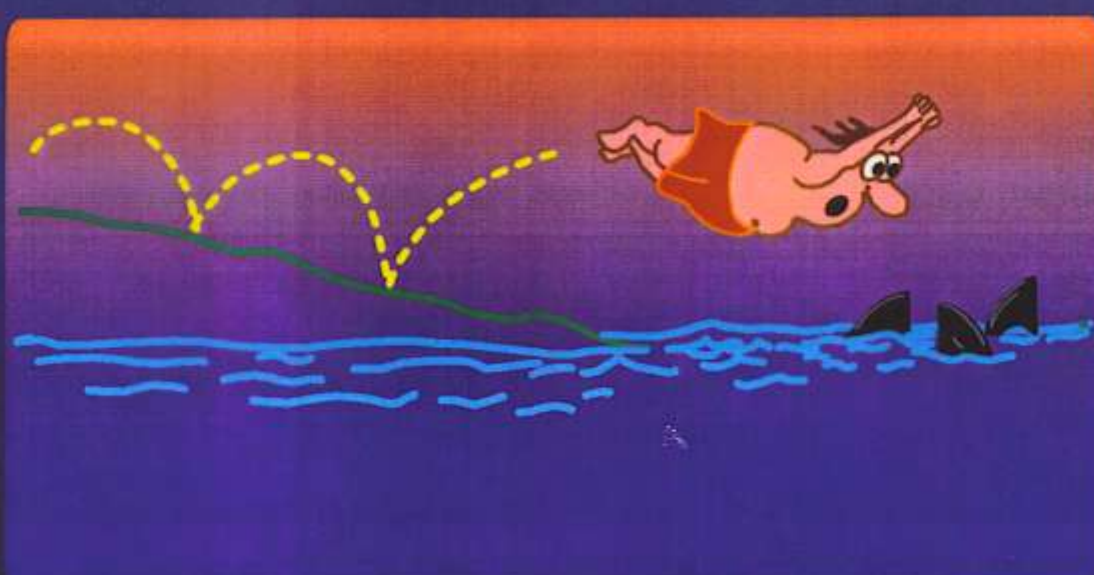
● Strong correlation
○ Medium Correlation
Δ Weak Correlation

WHAT ARE THE EFFECTS OF EXCESSIVE RECESSION, AS SEEN BY THE CUSTOMER?

- LOSS OF POWER
- EXCESSIVE NOISE
- FUEL ECONOMY LOSS
- EXCESSIVE OIL CONSUMPTION
- HIGH EMISSIONS

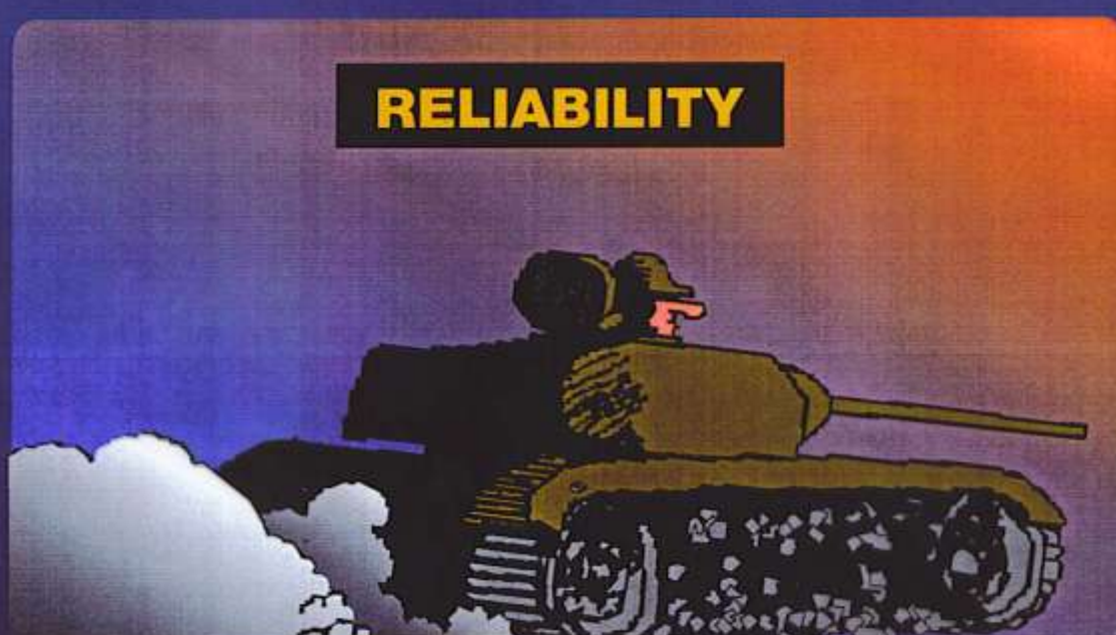
WHAT ARE THE MAIN STRESS FACTORS THAT CAUSE RECESSION?

- CYCLES
- TEMPERATURE
- LUBRICITY
- FORCE
- ROTATION



WHAT ARE THE STRENGTH FACTORS?

- HARDNESS
- SEAT ANGLE
- MATERIAL LUBRICITY PROPERTIES

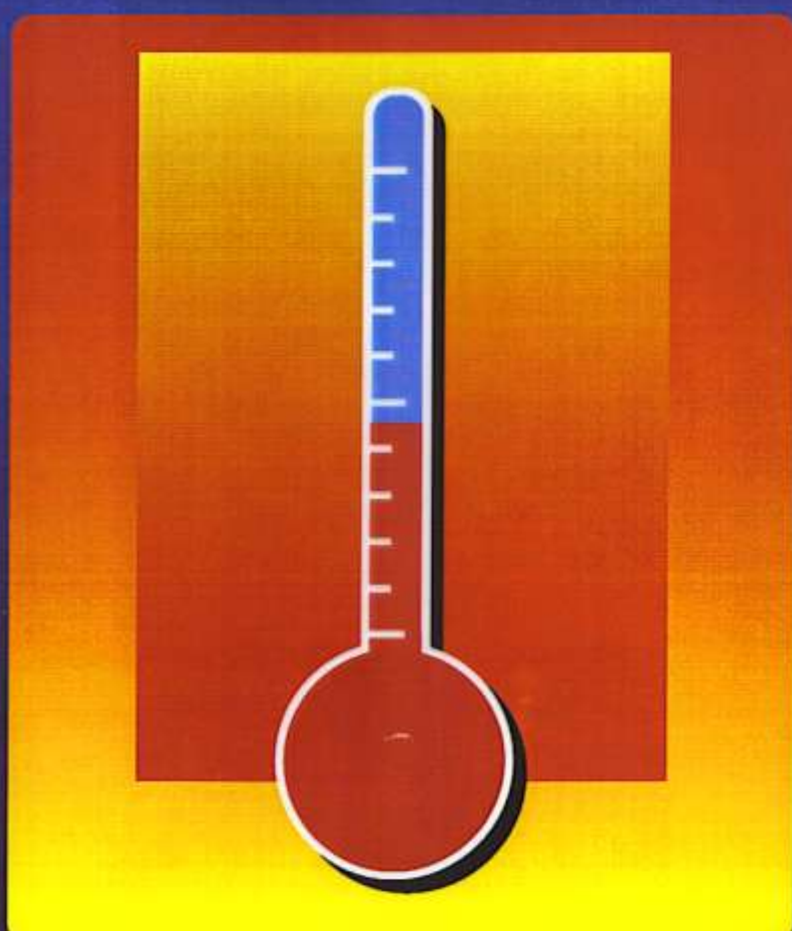


TEMPERATURE EFFECT:

RECESSION RATE = (CONSTANT) * (RPM^3)

OR CAN BE REWRITTEN AS:

RECESSION RATE = (CONSTANT) * $(RPM/1000)^3$



Test results:
.014 inches of recession in 1000 hours of testing at a constant engine speed of 3000 RPM

How much recession would you expect at a constant engine speed of 2000 RPM for 2500 hours?

$$.014 \text{ in}/1000 \text{ hr} = k^* (3000/1000)^3$$

$$K = .00052$$

RECESSION RATE

$$@\ 2000 \text{ RPM} = (.00052) * (2000/1000)^3 \text{ in}/1000 \text{ hr}$$

$$= .00416 \text{ in}/1000 \text{ hr}$$

RECESSION FOR
2500 HOURS = .0104 in.

ENGINE SPEED DISTRIBUTION

DRIVER:	AVG.	STD. DEV.
EASY	1500	400
AVERAGE	2000	500
SEVERE	3000	600

FINAL MODEL:

RECESSION =

$$(\text{constant}) * \sum_{i=1}^{N} \text{Time}_i * [\text{RPM}_i / 1000]^3$$

Or if you have N equal time intervals:

RECESSION =

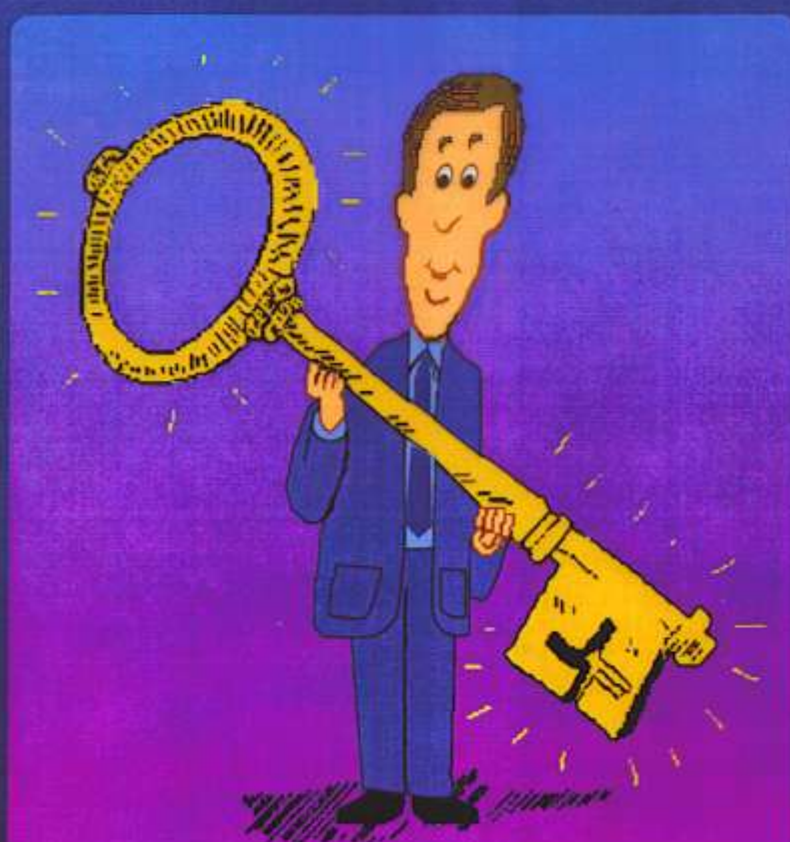
$$\text{TIME} * (\text{constant}) * \frac{\sum_{i=1}^{N} [\text{RPM}_i / 1000]^3}{N}$$

WHERE:

- i:	Index for a specific driving mode
- Recession:	Is total recession (inches)
- Time:	The amount of time at each driving mode (hours)
- TIME:	The total amount of operational time (hours)
- Constant:	The constant for a specific design
- RPM_i:	The engine speed for a specific driving mode
- N:	The total number of driving mode in a specific customer profile

BENEFITS:

- PREDICTIONS FOR LOW FAILURE PROBABILITIES
- REDUCED LIFE TESTING
- RELEASE DESIGNS WITH FEWER SURPRISES



WHAT YOU NEED TO DO?

- UNDERSTAND THE FAILURE MECHANISM
- IDENTIFY SIGNIFICANT FACTORS RELATIVE TO THE FAILURE
- MODEL THE FAILURE
- DETERMINE MODEL RELATIONSHIPS EITHER THEORETICALLY OR EMPIRICALLY

Weibull Distribution

$$R(t) = e^{[-(t/\theta)^{\beta}]}$$

R(t): Reliability at time t

t : Time (Minutes, Hours Cycles)

β = Weibull slope

Θ : Characteristic Life

Reliability distribution function

$$R(t) = e^{[-(t/\theta)^{\beta}]}$$

$$\ln [R(t)] = \ln [e^{[-(t/\theta)^{\beta}]}]$$

$$\ln [R(t)] = [-(t/\theta)^{\beta}] \ln [e]$$

$$\ln [R(t)] = [-(t/\theta)^{\beta}]$$

$$- \ln [R(t)] = [(t/\theta)^{\beta}]$$

$$\ln \{ - \ln [R(t)] \} = \ln [(t/\theta)^{\beta}]$$

$$\ln \{ - \ln [R(t)] \} = \beta \ln (t) - \beta \ln (\theta)$$

$$\ln \{ -\ln [R(t)] \} = \beta \ln (t) - \beta \ln (\theta)$$

Let $y = \ln \{ -\ln [R(t)] \}$

$m = \beta$

$x = \ln (t)$

$b = -\beta \ln (\theta)$

$$y = m x + b$$

Weibull Distribution Summary

Density function

$$f(t) = (\beta/\theta^{\beta})(t^{\beta - 1})\, e^{[-(t/\theta)^{\beta}]}$$

Reliability distribution function

$$R(t) = e^{[-(t/\theta)^{\beta}]}$$

Cumulative distribution function

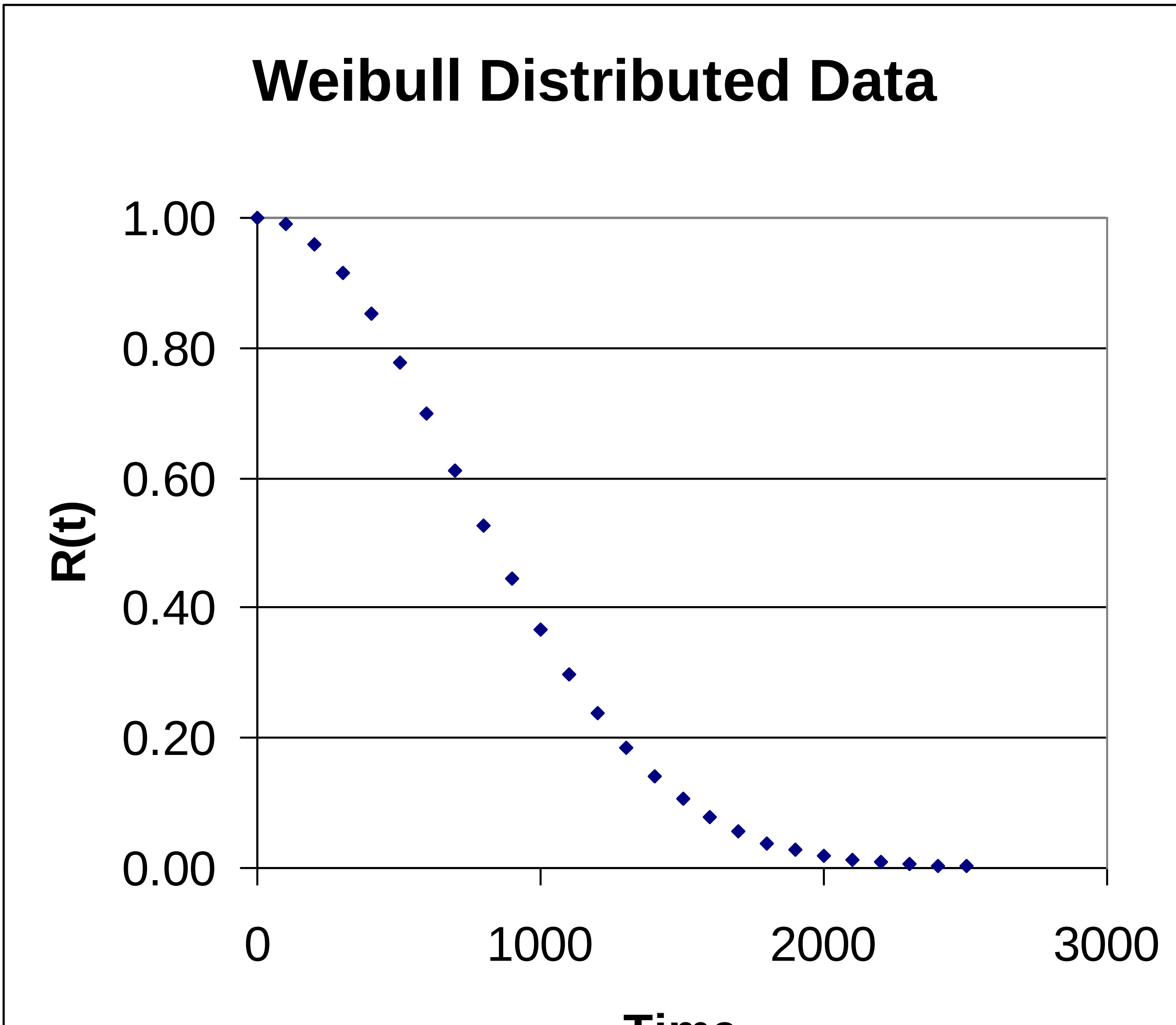
$$F(t) = 1 - e^{[-(t/\theta)^{\beta}]}$$

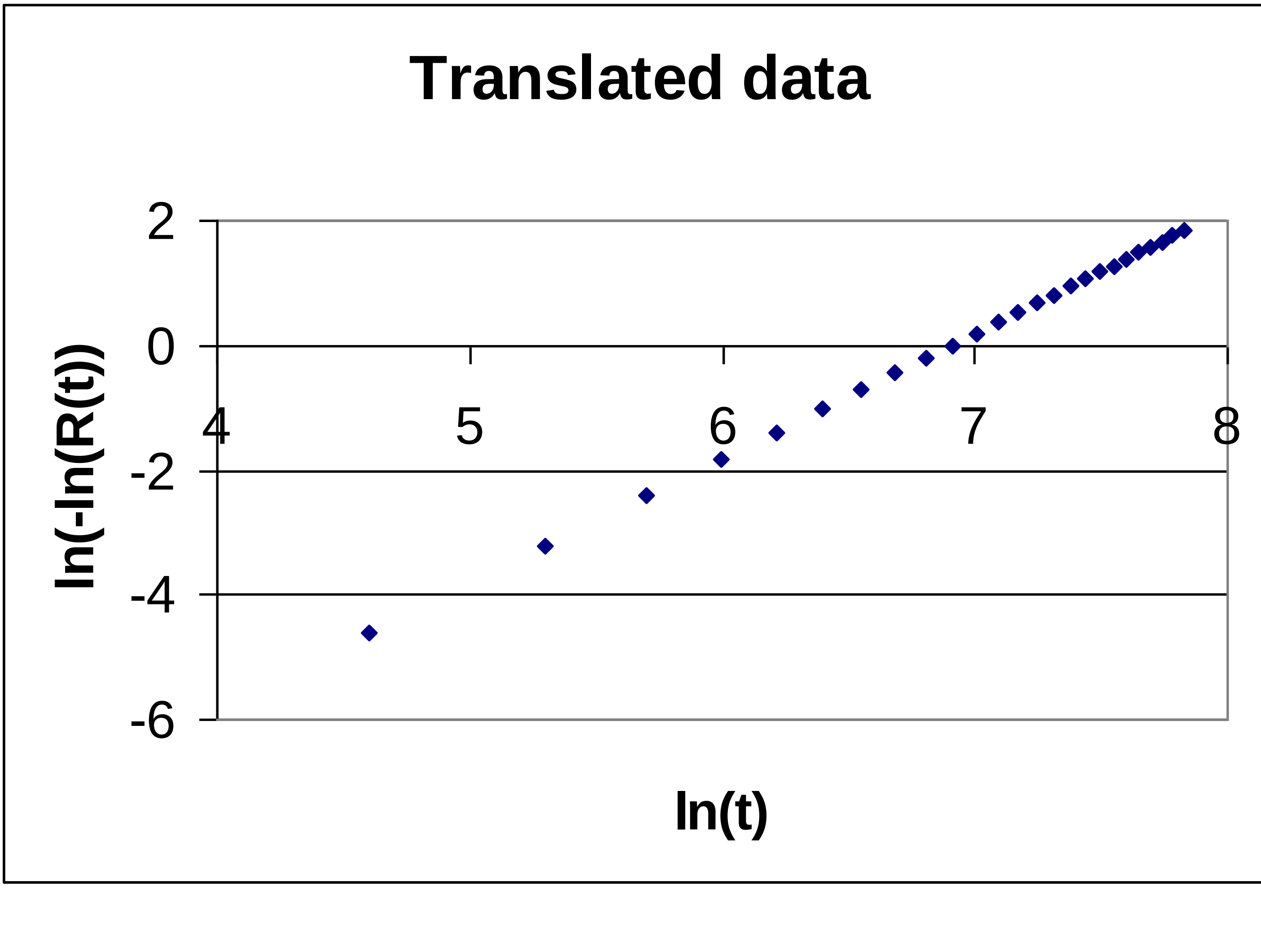
Hazard function

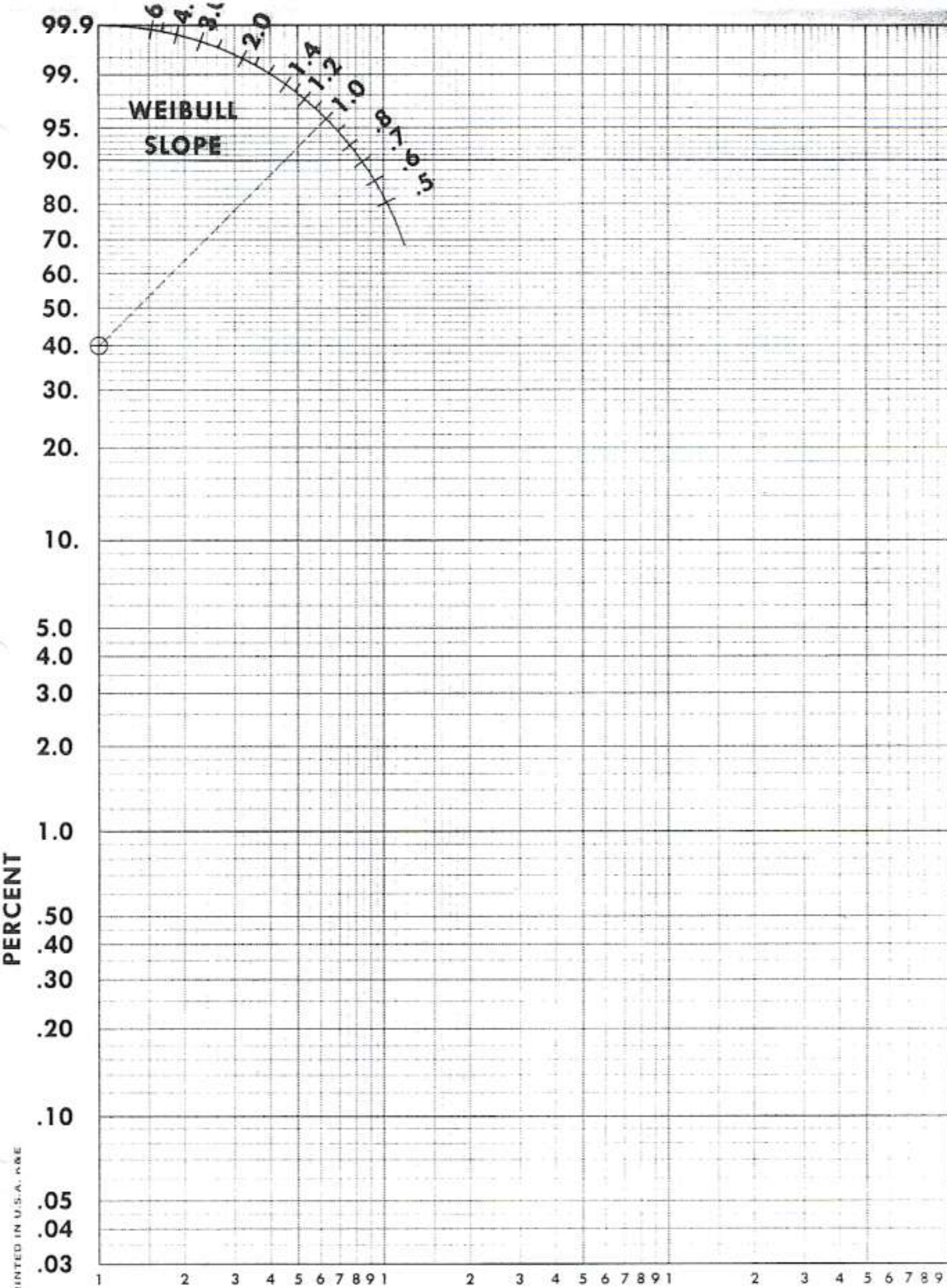
$$h(t) = f(t)/R(t)$$

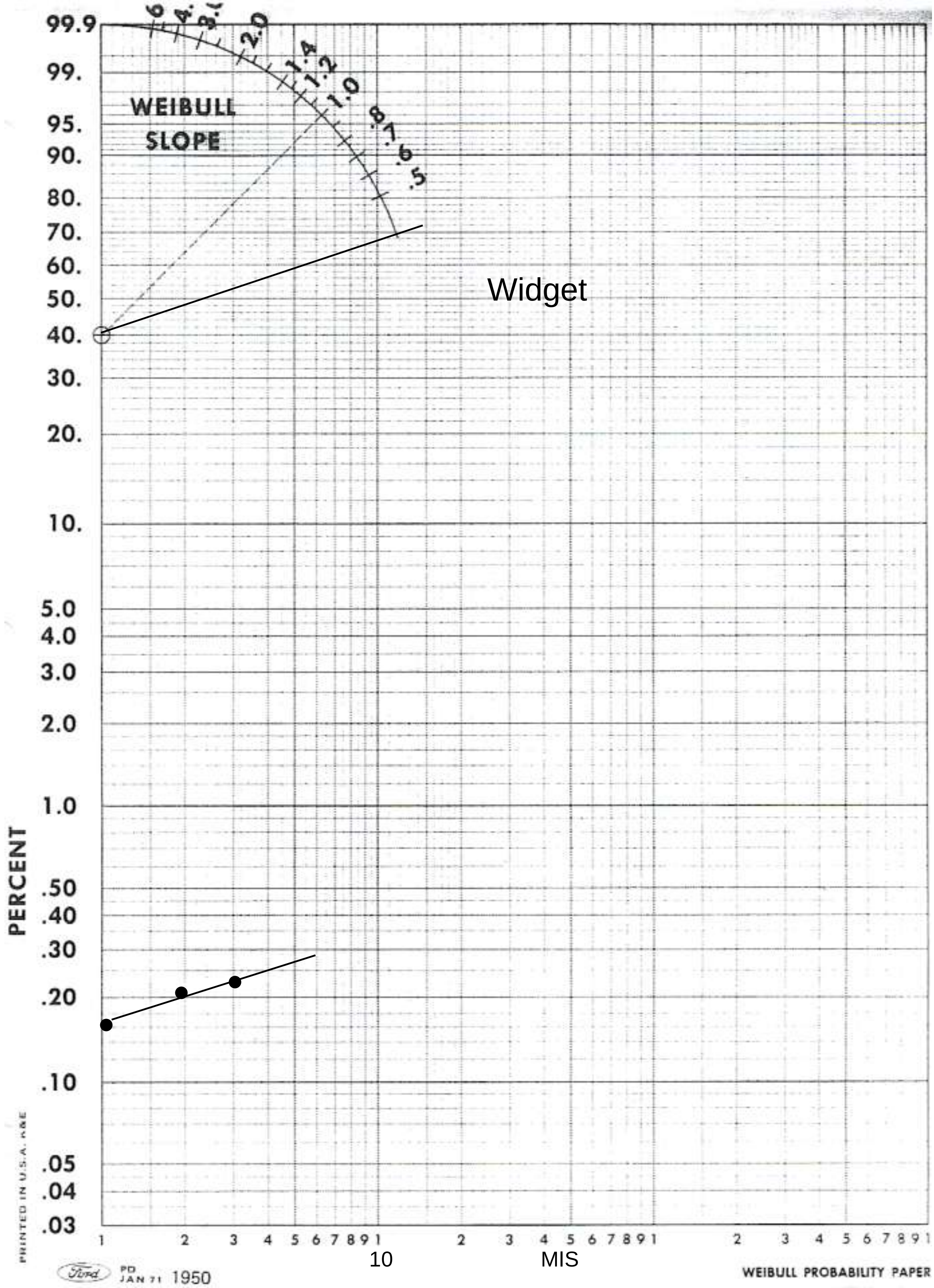
$$= (\beta/\theta^{\beta})(t^{\beta - 1})$$

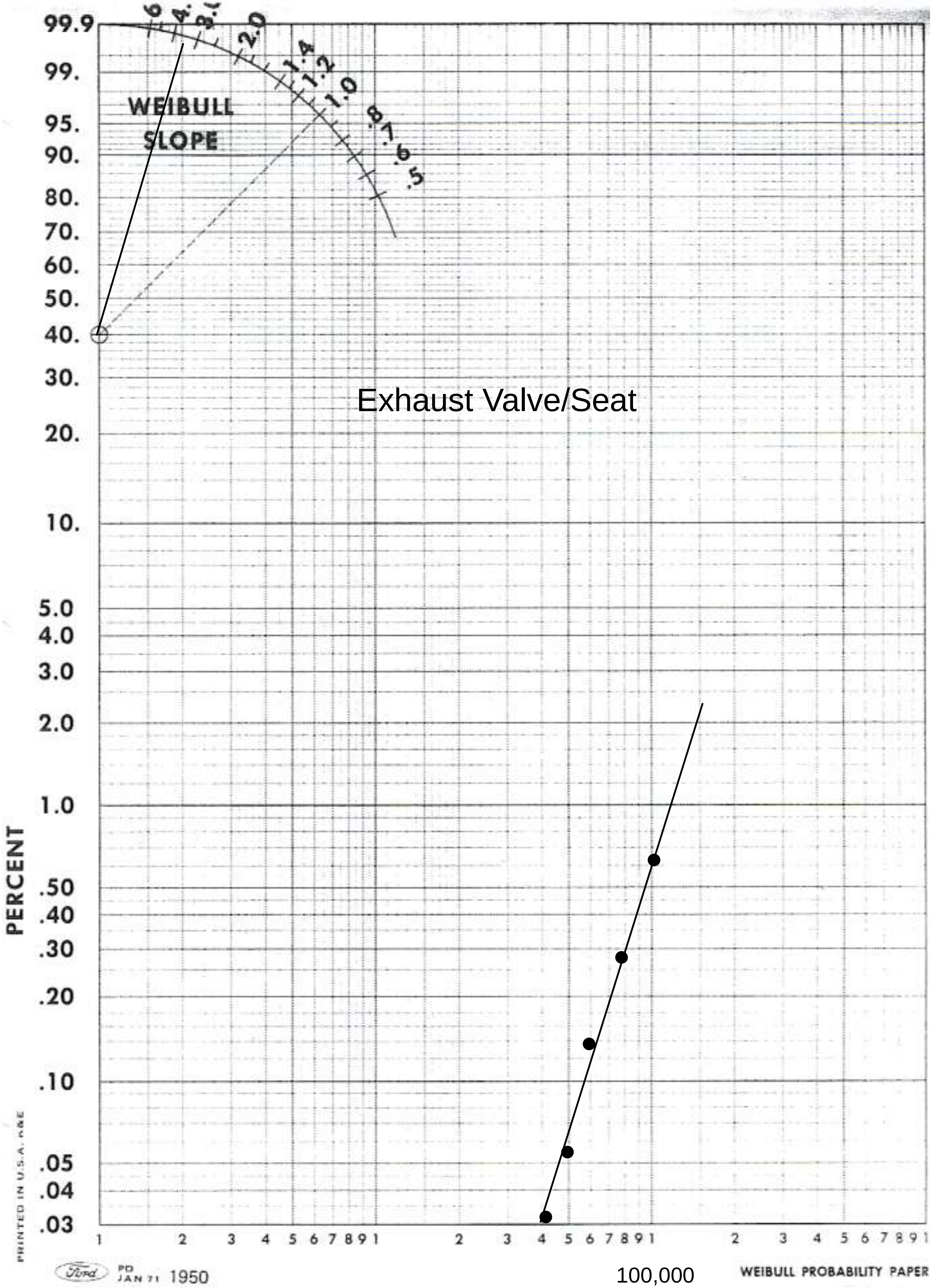
				Transformed Data	
Theta	Beta	t	R(t)	t'	R'(t)
1000	2	0	1.0000		
1000	2	100	0.9900	4.6052	-4.6052
1000	2	200	0.9608	5.2983	-3.2189
1000	2	300	0.9139	5.7038	-2.4079
1000	2	400	0.8521	5.9915	-1.8326
1000	2	500	0.7788	6.2146	-1.3863
1000	2	600	0.6977	6.3969	-1.0217
1000	2	700	0.6126	6.5511	-0.7133
1000	2	800	0.5273	6.6846	-0.4463
1000	2	900	0.4449	6.8024	-0.2107
1000	2	1000	0.3679	6.9078	0.0000
1000	2	1100	0.2982	7.0031	0.1906
1000	2	1200	0.2369	7.0901	0.3646
1000	2	1300	0.1845	7.1701	0.5247
1000	2	1400	0.1409	7.2442	0.6729
1000	2	1500	0.1054	7.3132	0.8109
1000	2	1600	0.0773	7.3778	0.9400
1000	2	1700	0.0556	7.4384	1.0613
1000	2	1800	0.0392	7.4955	1.1756
1000	2	1900	0.0271	7.5496	1.2837
1000	2	2000	0.0183	7.6009	1.3863
1000	2	2100	0.0122	7.6497	1.4839
1000	2	2200	0.0079	7.6962	1.5769
1000	2	2300	0.0050	7.7407	1.6658
1000	2	2400	0.0032	7.7832	1.7509
1000	2	2500	0.0019	7.8240	1.8326


Weibull Distributed Data
1.00
0.80
0.60
0.40
0.20
0.00
R(t)
0
1000
2000
3000
Time


Translated data
2
0
-2
-4
-6
4
5
6
7
8
ln(-ln(R(t)))
ln(t)


WEIBULL
SLOPE
6
4.
2.0
1.4
1.2
1.0
.8
.7
.6
.5
99.9
99.
95.
90.
80.
70.
60.
50.
40.
30.
20.
10.
5.0
4.0
3.0
2.0
1.0
.50
.40
.30
.20
.10
.05
.04
.03
PERCENT
1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1
PRINTED IN U.S.A. K&E


WEIBULL
SLOPE
Widget
PERCENT
99.9
99.
95.
90.
80.
70.
60.
50.
40.
30.
20.
10.
5.0
4.0
3.0
2.0
1.0
.50
.40
.30
.20
.10
.05
.04
.03
10
MIS
PRINTED IN U.S.A.
PD JAN 71 1950
WEIBULL PROBABILITY PAPER



WEIBULL SLOPE
Exhaust Valve/Seat
PERCENT
99.9
99.
95.
90.
80.
70.
60.
50.
40.
30.
20.
10.
5.0
4.0
3.0
2.0
1.0
.50
.40
.30
.20
.10
.05
.04
.03
1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1
100,000
WEIBULL PROBABILITY PAPER
PRINTED IN U.S.A. K&E
Ford PD JAN 71 1950

Reliability tools and related topics

- Statistical Analysis
- Regression Analysis
- Reliability Methods (e.g. Reliability distributions)
- Weibull Analysis
- Accelerated Life Tests
- Cox’s Nonparametric Hazard Method
- Failure Modes and Effects Analysis (FMEA)
- Design of Experiments (DOE)
- Tolerance Design (Tolerance Optimization and trade-offs)
- Parameter Design (Optimal design methods)
- System Engineering (Topics in product development)
- Axiomatic Design (analysis of function and design controls)
- TRIZ (invention theory)
- Fault Tree Analysis (FTA)
- Statistical Process Control (SPC)

Who has the task of Reliability?

Is it the Design Engineer or Reliability Engineer?

Any Questions?

Email: liddy@ltu.edu

Reliability Survey

http.//www.surveymonkey.com/LTU_Reliability_Survey