Reliability Education Opportunity: "Reliability Analysis of Field Data"

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@ University of Maryland

Discussion Outline

- Introduction
- Practical Importance of Reliability Analysis of Field Data
- Modelling Peculiarities in Reliability Analysis of Field Data
  - Staggered Production/Sales
  - Bivariate Models (Time & Usage)
  - Seasonality
  - Data Maturation Issues
- Illustrative Case Studies
- Proposed Course Structure
- Conclusions

Practical Importance of Reliability Analysis of Field Data

- **Root cause analysis** and **future failure avoidance** through statistical engineering inferences on the failure rate trends and factors (covariates) affecting them
- **Lab test calibration** by equating percentiles of the failure time distributions in the field and in the lab
- **Cost avoidance** through early detection of field reliability problems
- **Cash flow optimization** through the prediction of the required warranty reserve and/or the expected maintenance costs

Staggered Production/Sales

Nonparametric Estimation

Formalized Data Structure:

Number of vehicles	Time in service intervals $i = 1, \ldots, k$	Failure time intervals $j = 1, \ldots, k$									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	***k***
v_1	**1**	r_{11}									
v_2	**2**	r_{21}	r_{22}								
v_3	**3**	r_{31}	r_{32}	r_{33}							
v_4	**4**	r_{41}	r_{42}	r_{43}	r_{44}						
v_5	**5**	r_{51}	r_{52}	r_{53}	r_{54}	r_{55}					
v_6	**6**	r_{61}	r_{62}	r_{63}	r_{64}	r_{65}	r_{66}				
v_7	**7**	r_{71}	r_{72}	r_{73}	r_{74}	r_{75}	r_{76}	r_{77}			
v_8	**8**	r_{81}	r_{82}	r_{83}	r_{84}	r_{85}	r_{86}	r_{87}	r_{88}		
v_9	**9**	r_{91}	r_{92}	r_{93}	r_{94}	r_{95}	r_{96}	r_{97}	r_{98}	r_{99}	
v_k	***k***	r_{k1}	r_{k2}	r_{k3}	r_{k4}	r_{k5}	r_{k6}	r_{k7}	r_{k8}	r_{k9}	r_{kk}

Hazard function at the *j*-th failure time *unit* interval:

$$\hat{h}_j = \frac{d_j}{n_j}$$

Number of failures at time unit interval *j*, with $r_0 = 0$:

$$d_j = \sum_{p=j}^{k} r_{pj}$$

Risk set exposed at time unit interval *j* :

$$n_j = \sum_{p=j}^{k} \left(v_p - \sum_{q=1}^{j-1} r_{pq} \right)$$

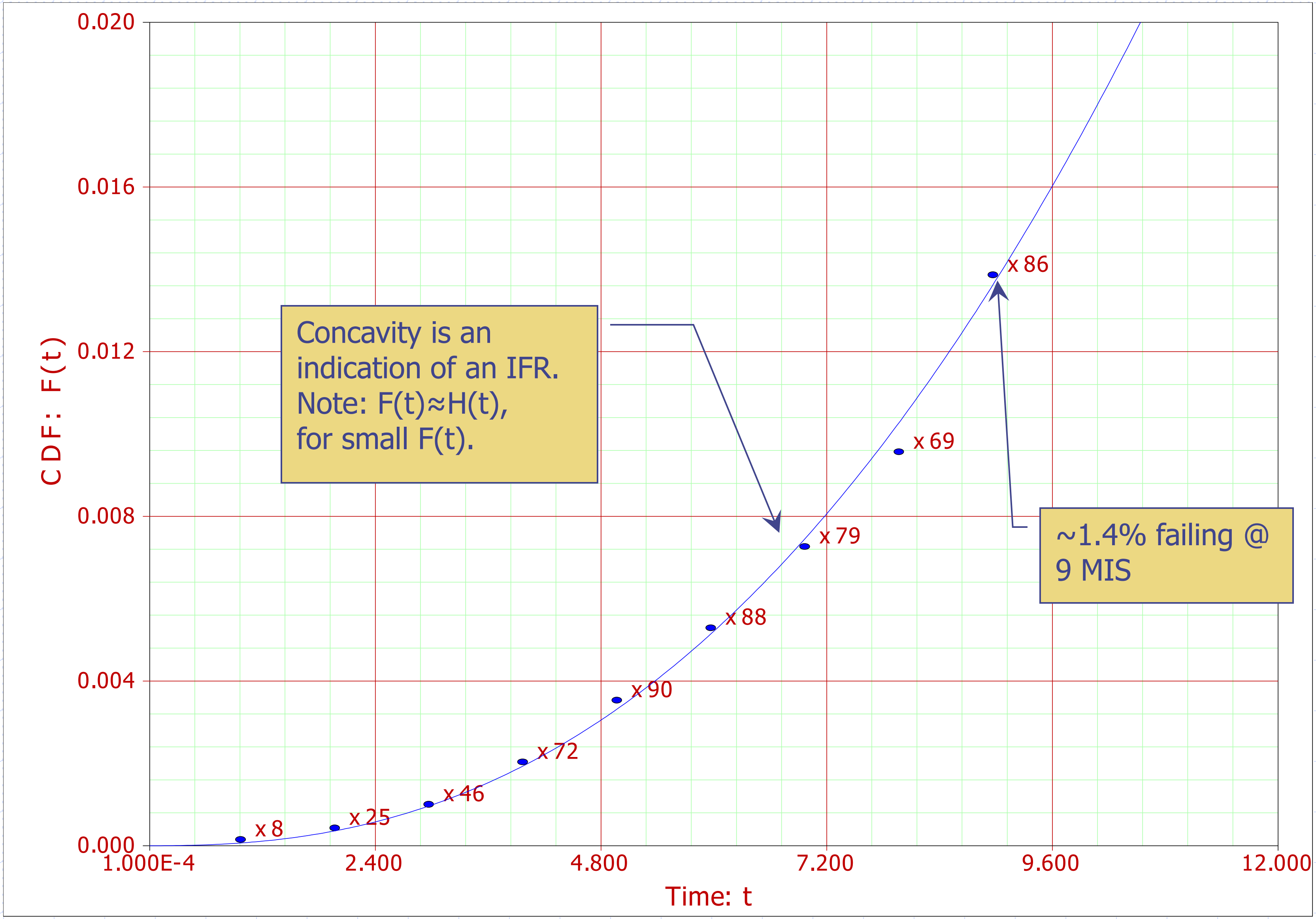
Numerical Example

Sales Month	Volume	Jan'02	Feb'02	Mar'02	Apr'02	May'02	Jun'02	Jul'02	Aug'02	Sep'02	Oct'02	Nov '02
		Repair Month										
Jan'02	10,000		1	3	6	9	15	17	20	22	41	64
Feb'02	10,000			0	2	5	10	12	18	19	24	45
Mar'02	10,000				1	4	5	10	14	18	20	23
Apr'02	10,000					1	2	7	11	16	17	20
May'02	10,000						0	1	6	12	17	18
Jun'02	10,000							1	3	4	9	16
Jul'02	10,000								2	3	7	11
Aug'02	10,000									1	4	6
Sep'02	10,000										1	3
Oct'02	10,000											0
Nov '02	10,000											

Mechanical Transfuser Example:
24MIS/Unlm usage warranty plan

Month in Service: Time t	Risk Set n(t)	Risk Set (corr) n'(t)	Repairs d(t)	Hazard h(t)=d(t)/n'(t)	Cum Hazard H(t)=Σh(t)	Reliability R(t)=e{-H(t)}	CDF F(t)=1-R(t)
0	110,000	110000	0	0	0	1	0
1	100,000	100000	8	0.00008	0.00008	0.99992	0.00008
2	90,000	89992	25	0.00028	0.00036	0.99964	0.00036
3	80,000	79967	46	0.00058	0.00093	0.99907	0.00093
4	70,000	69921	72	0.00103	0.00196	0.99804	0.00196
5	60,000	59849	90	0.00150	0.00347	0.99654	0.00346
6	50,000	49759	88	0.00177	0.00524	0.99478	0.00522
7	40,000	39671	79	0.00199	0.00723	0.99280	0.00720
8	30,000	29592	69	0.00233	0.00956	0.99049	0.00951
9	20,000	19523	86	0.00441	0.01396	0.98613	0.01387
10	10,000	9437	64	0.00678	0.02075	0.97947	0.02053

Mechanical Transfuser: Nonparametric Inferences



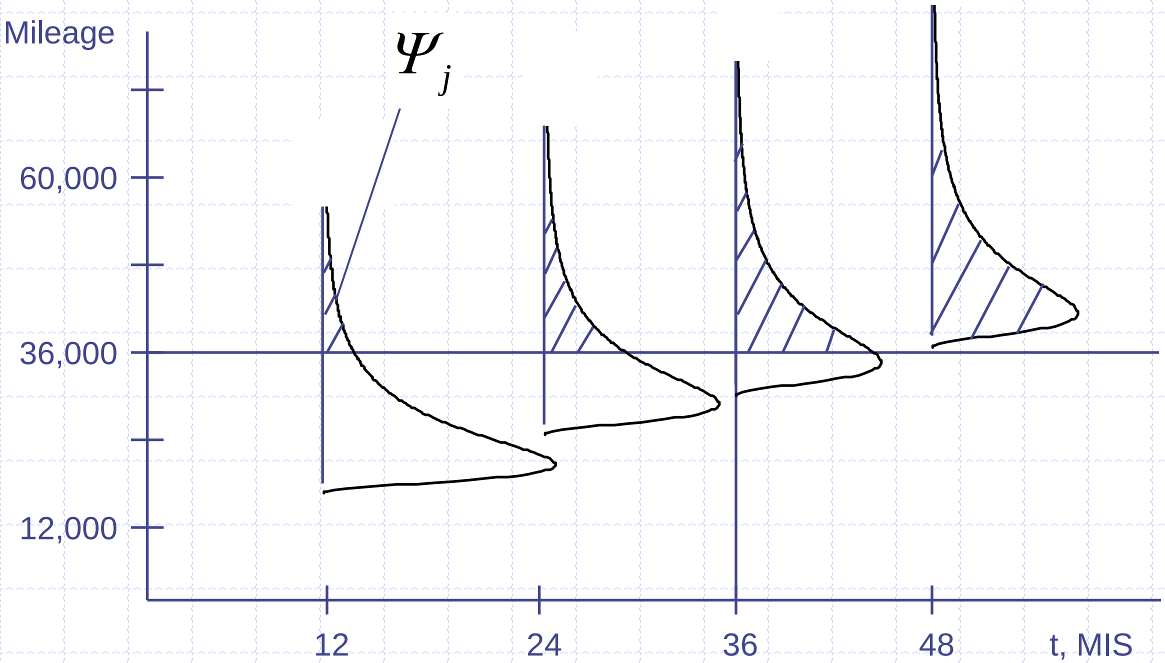
Nonparametric Estimation under a Bivariate Warranty Plan

Risk set exposed at time unit interval j:

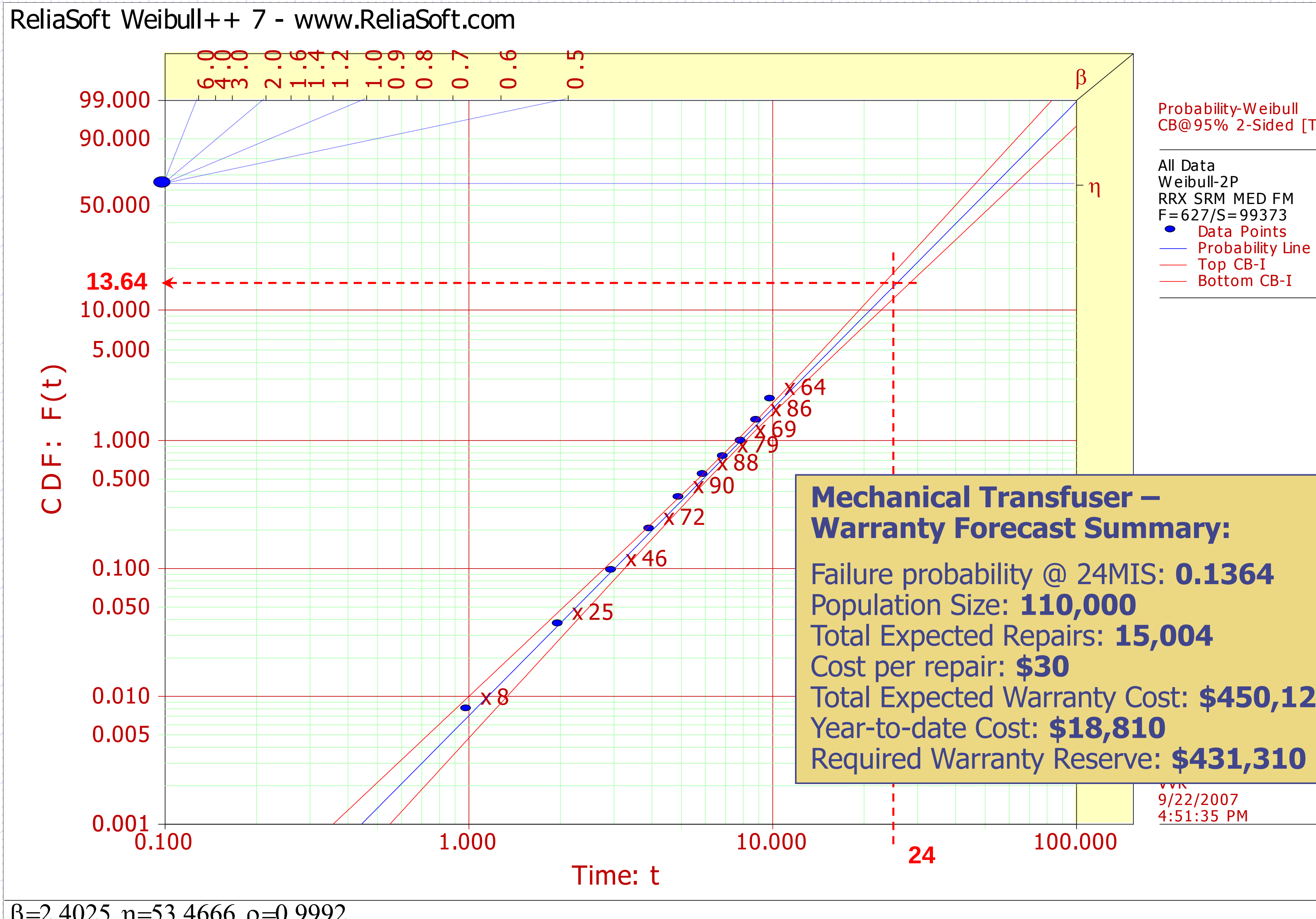
$$n_j = \left(\sum_{p=j}^{k}\left(v_p - \sum_{q=1}^{j-1} r_{pq}\right)\right)\Psi_j$$

Probability of mileage not exceeding the warranty mileage limit at failure time unit interval j:

$$\Psi_j$$



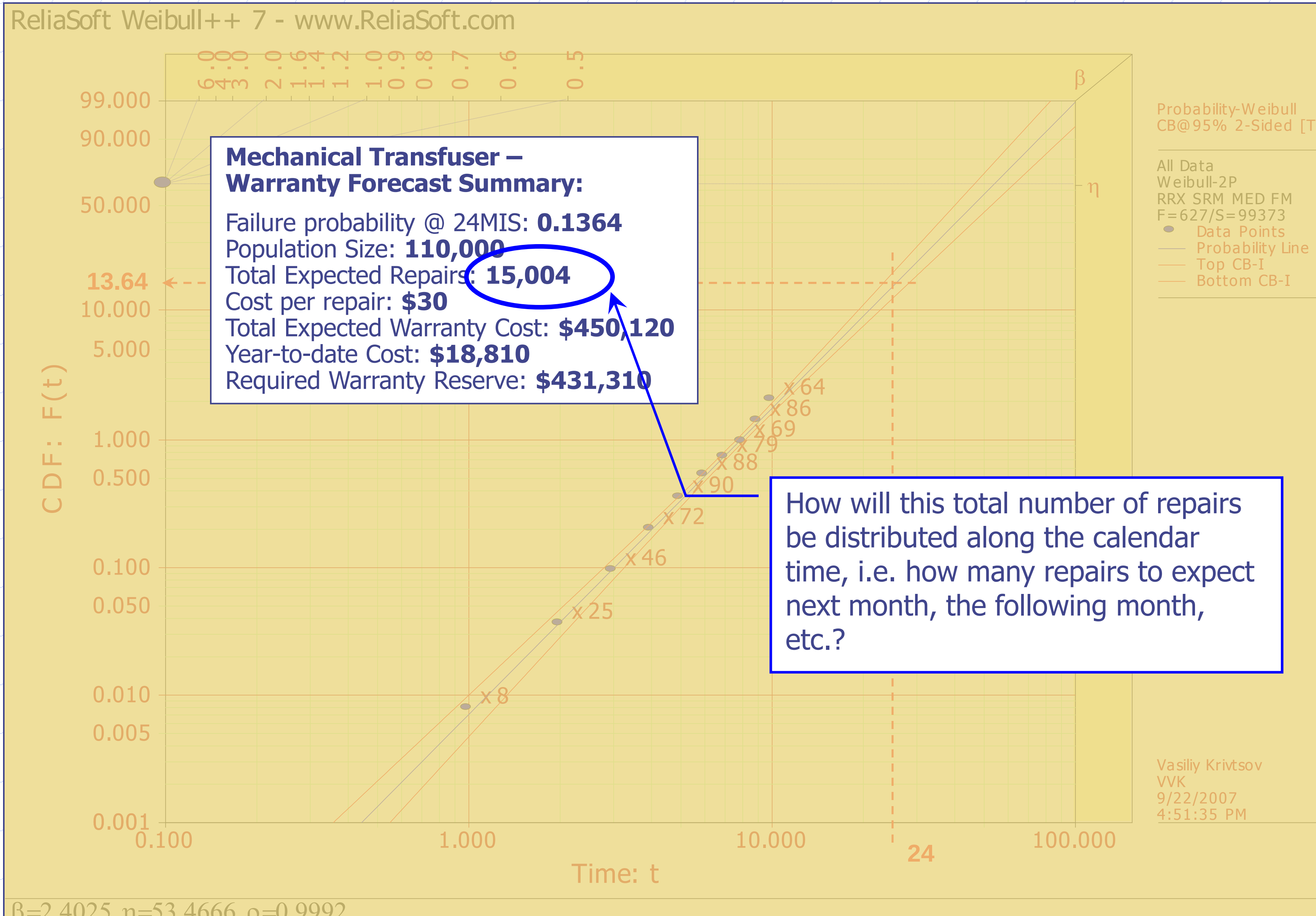
Weibull Probability Plot: Mechanical Transfuser Data



Mechanical Transfuser – Warranty Forecast Summary:

Failure probability @ 24MIS: **0.1364**
Population Size: **110,000**
Total Expected Repairs: **15,004**
Cost per repair: **$30**
Total Expected Warranty Cost: **$450,120**
Year-to-date Cost: **$18,810**
Required Warranty Reserve: **$431,310**

Calendarized Forecasting



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How will this total number of repairs be distributed along the calendar time, i.e. how many repairs to expect next month, the following month, etc.?

Calendarized Forecast (generic example)

Calendar Time

Time in Service

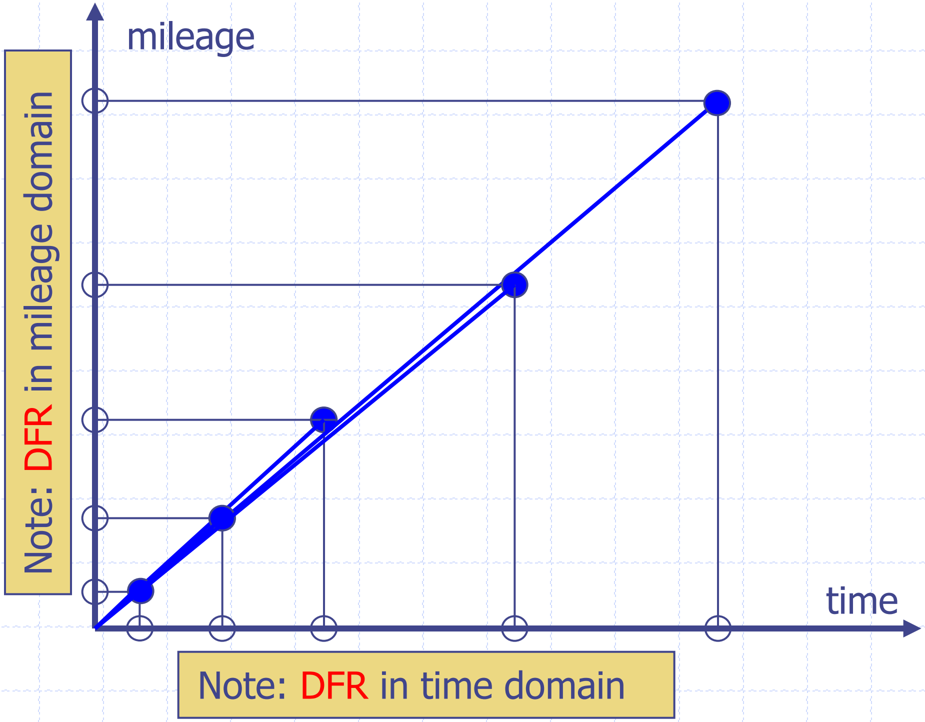
		Population Exposed						Predicted Number of Repairs					
Time	Parametric PDF	thru Oct'02	in Nov'02	in Dec'02	…	in Sep'04	in Oct'04	thru Oct'02	in Nov'02	in Dec'02	…	in Sep'04	in Oct'04
0	0	110000	0	0		0	0	0					
1	0.0001	100000	10000	0		0	0	6	1	0		0	0
2	0.0003	89992	10008	10000		0	0	27	3	3		0	0
3	0.0006	79967	10025	10008		0	0	49	6	6		0	0
4	0.0010	69921	10046	10025		0	0	69	10	10		0	0
5	0.0014	59849	10072	10046		0	0	84	14	14		0	0
6	0.0019	49759	10090	10072		0	0	92	19	19		0	0
7	0.0023	39671	10088	10090		0	0	93	24	24		0	0
8	0.0029	29592	10079	10088		0	0	84	29	29		0	0
9	0.0034	19523	10069	10079		0	0	66	34	34		0	0
10	0.0039	9437	10086	10069		0	0	37	40	40		0	0
11	0.0045	0	9437	10086		0	0	0	43	46		0	0
12	0.0051	0	0	9437		0	0	0	0	48		0	0
13	0.0057	0	0	0		0	0	0	0	0		0	0
14	0.0063	0	0	0		0	0	0	0	0		0	0
15	0.0069	0	0									0	0
16	0.0076	0	0									0	0
17	0.0082	0	0									0	0
18	0.0088	0	0									0	0
19	0.0094	0	0									0	0
20	0.0100	0	0									0	0
21	0.0106	0	0	0		0	0	0	0	0		0	0
22	0.0112	0	0	0		0	0	0	0	0		0	0
23	0.0118	0	0	0		10000	0	0	0	0		118	0
24	0.0124	0	0	0		10008	10000	0	0	0		124	124
							total ->	**609**	**222**	**272**	**…**	**242**	**124**

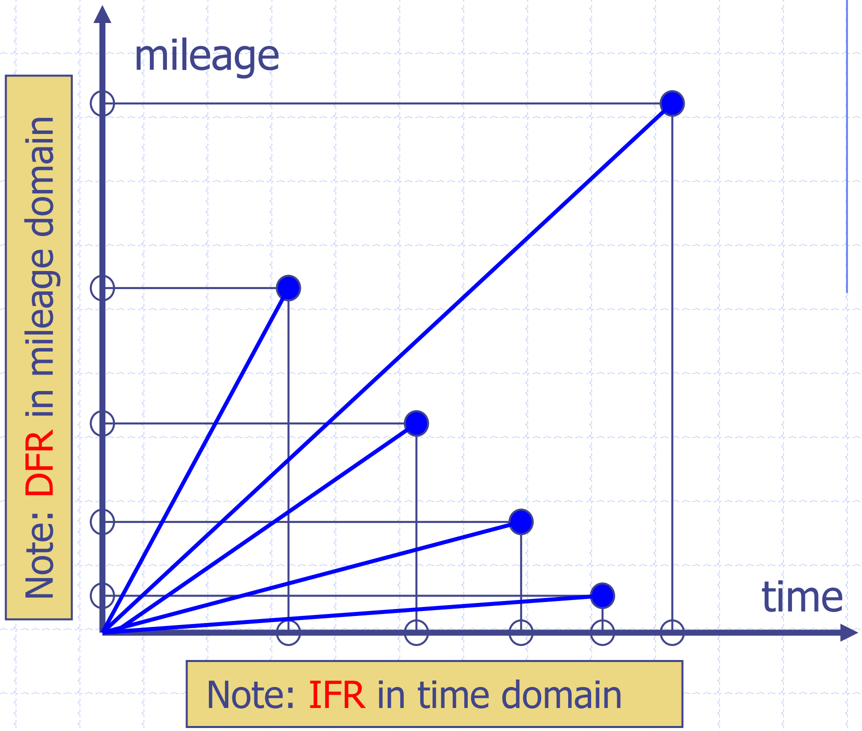
15,004

$$d_j = \sum_{i=j}^{k} f(t_i)\, n_{ij}(t_{i+1} - t_i)$$

Time vs. Usage

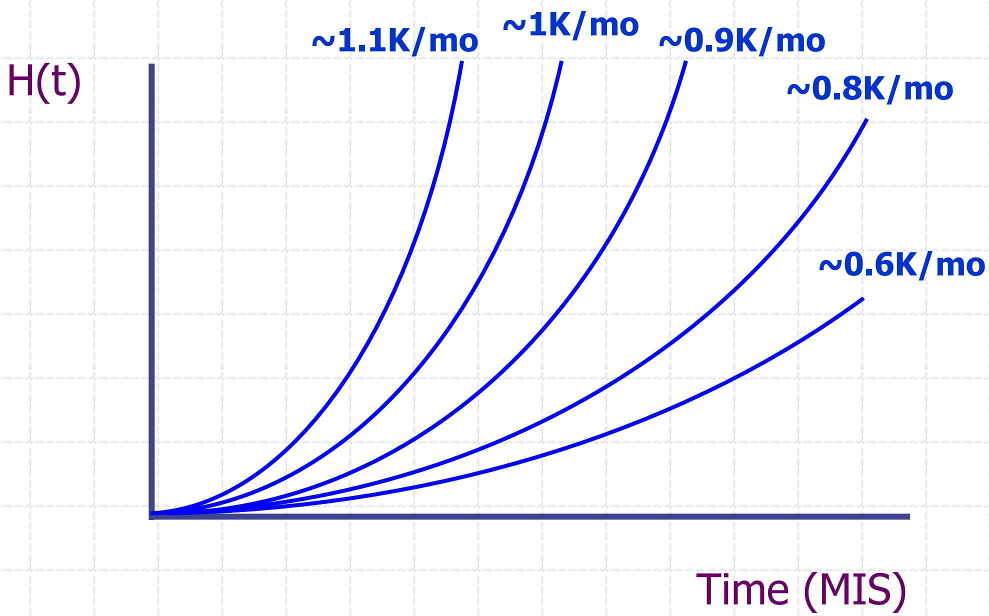
Time or usage?

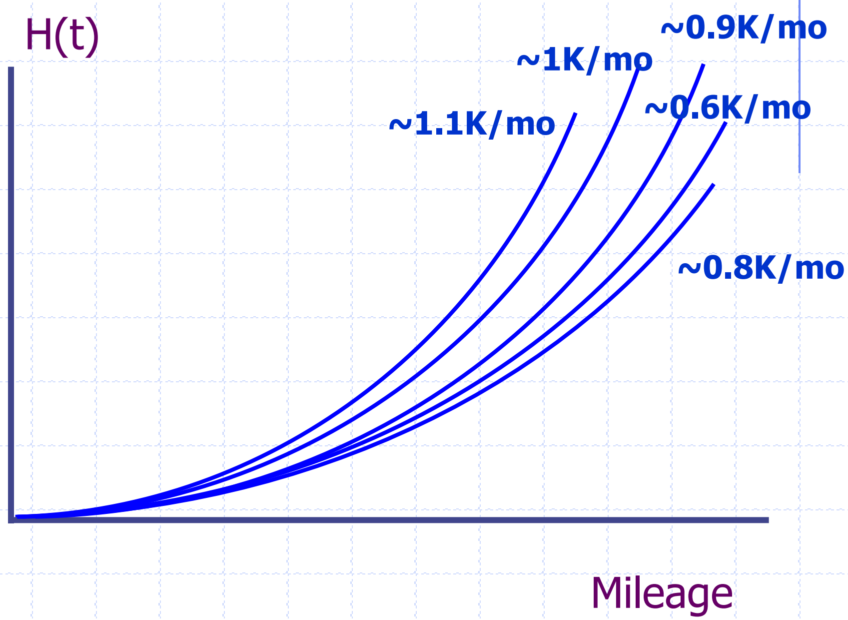




Depending on variability in mileage accumulation rates of individual vehicles, the same data may result in a contradicting inference in time and mileage domains.

Time or usage?
(Hu, Lawless & Suzuki, 1998)

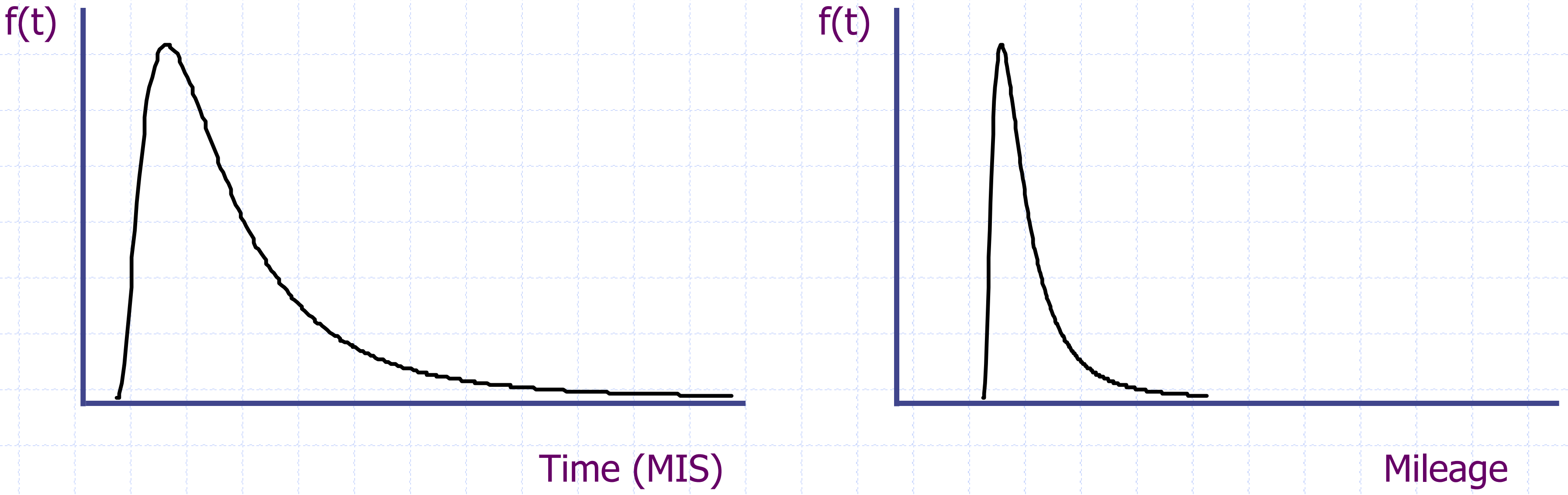




Note: cum haz functions in time domain appear to be dependant on mileage accumulation, which suggests that time may be NOT the appropriate domain for this failure mode.

Note: cum haz functions in mileage domain appear to be independent of mileage accumulation, which suggests that mileage may be the appropriate domain for this failure mode.

Time or usage?
(Kordonsky & Gertsbakh, 1997)



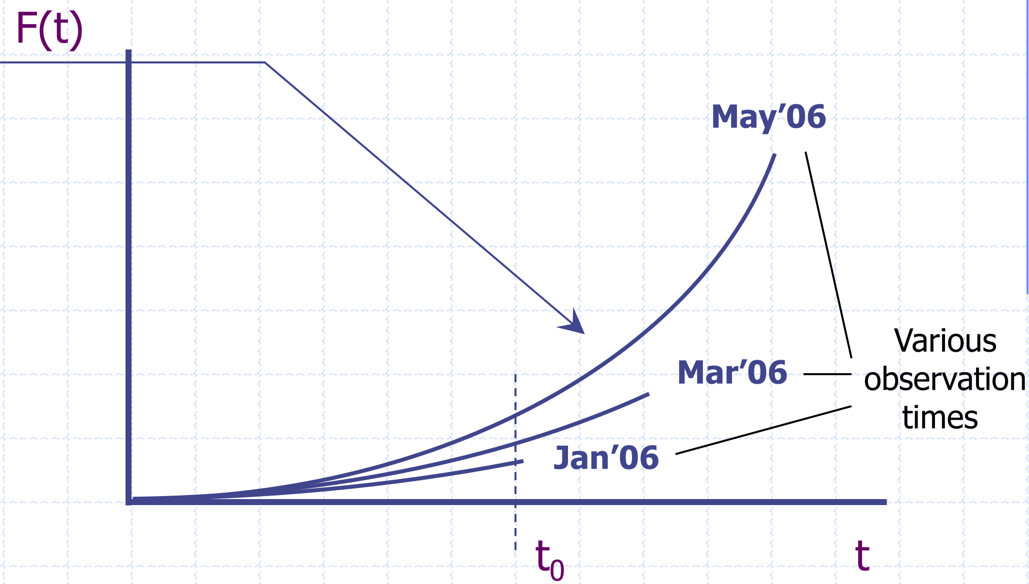
Choose the scale that provides a lower coefficient of variation of the respective failure distribution.

Data Maturity

Data Maturity: Lot Rot

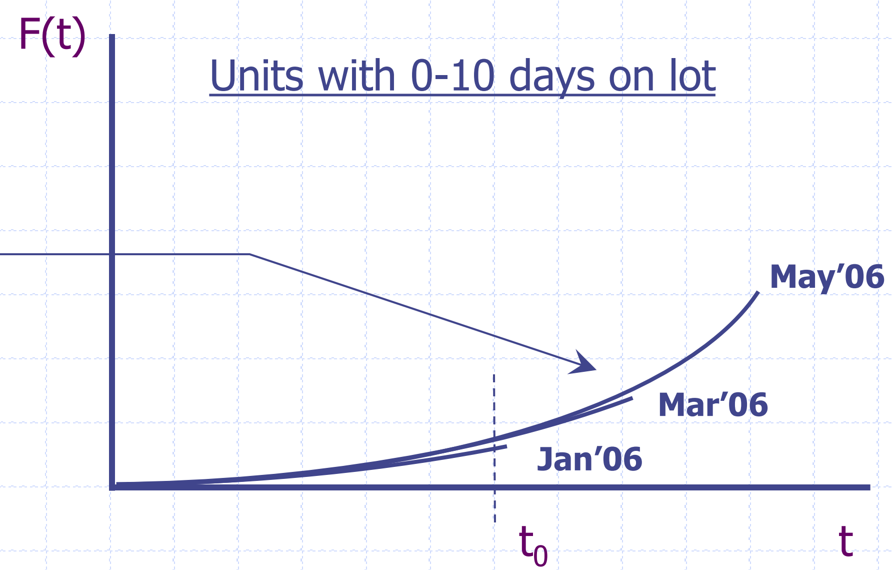
Data Maturity Problem:

CDF estimates for a nominally homogeneous population at a fixed failure time change as a function of the observation time.



Possible cause:

"Lot Rot", i.e., vehicle reliability degrades from sitting on the lot prior to be sold.



Solution:

Stratify vehicle population by the time spent on lot (the difference between sale date and production date).

Data Maturity: Reporting Delays

Data Maturity Problem:

CDF estimates for a nominally homogeneous population at a fixed failure time change as a function of the observation time.

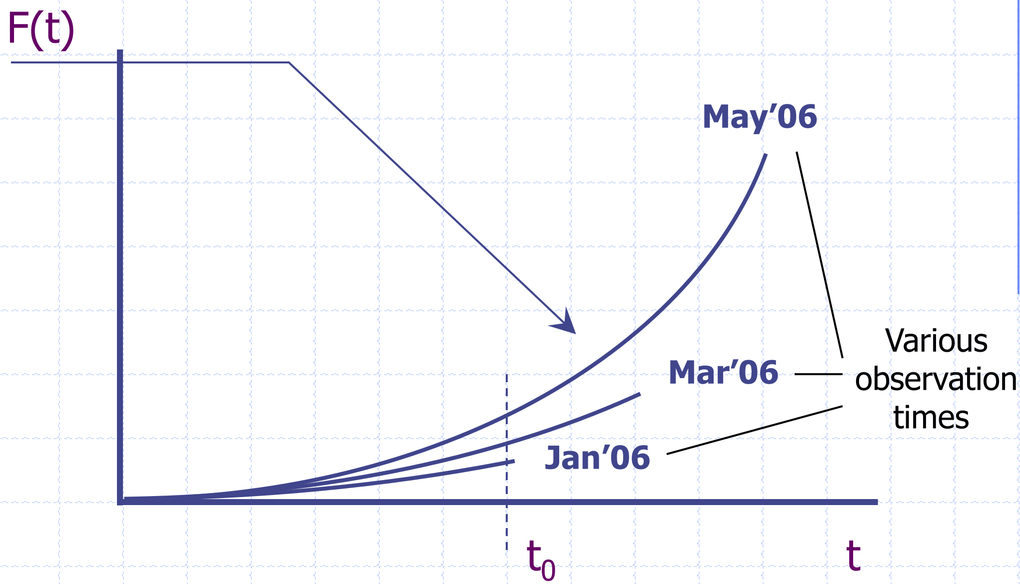
Possible cause:

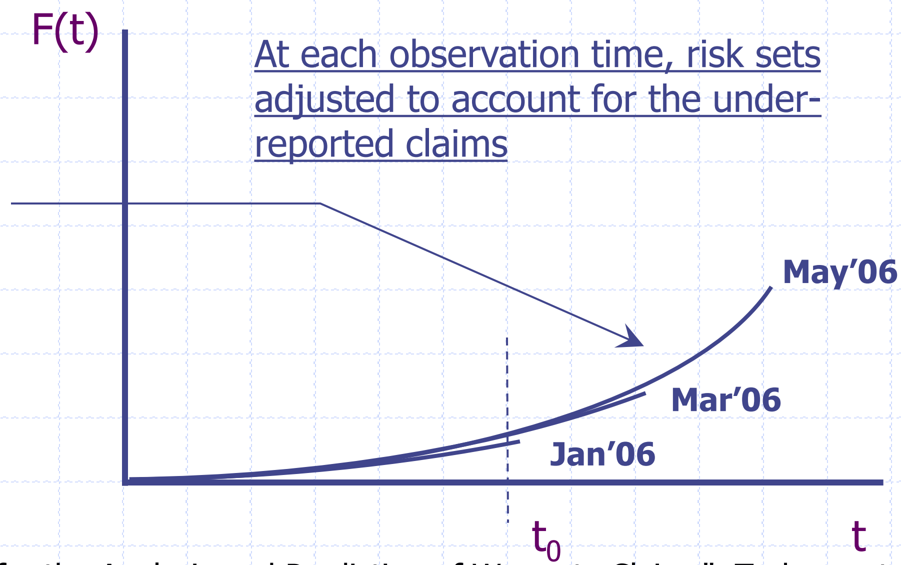
The number of claims processed at each observation time is under-reported due to the lag between repair date and warranty system entry date.

Solution:

Adjust* the risk set by the probability of the lag time, Ω_j:

$$n_j = \left(\sum_{p=j}^{k}\left(v_p - \sum_{q=1}^{j-1} r_{pq}\right)\right)\Omega_j$$





* J. Kalbfleisch, J. Lawless and J. Robinson, "Method for the Analysis and Prediction of Warranty Claims", Technometrics, Vol. 33, # 1, 1991, pp. 273-285.

Data Maturity: Warranty Expiration Rush

Data Maturity Problem:

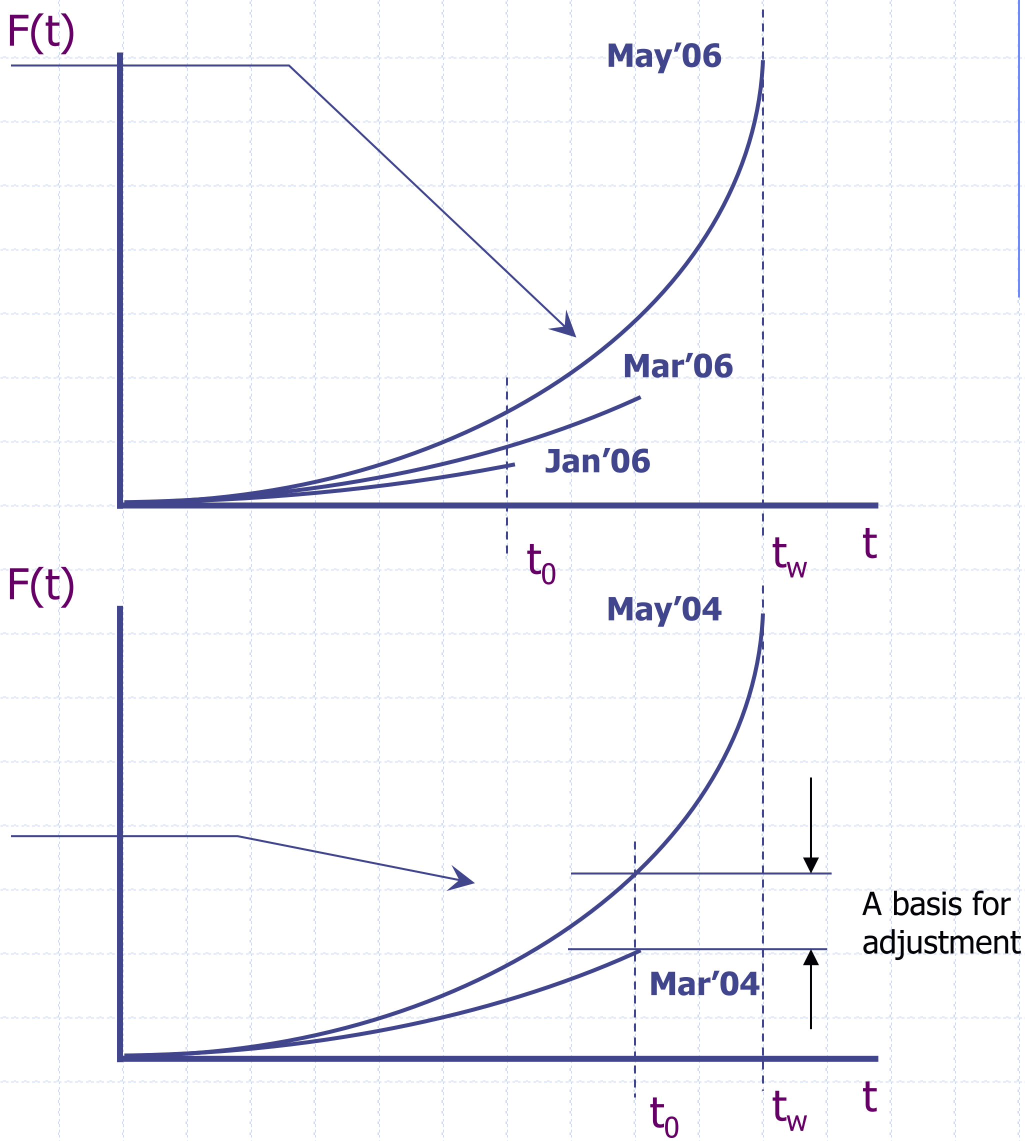
CDF estimates for a nominally homogeneous population disproportionably increases as a function of the observation time and proximity to the warranty expiration time.

Possible cause:

"Soft" (non-critical) failures tend to not get reported until the customer realizes the proximity of warranty expiration date.

Solution:

Use historical data on similar components to empirically* adjust for the warranty-expiration rush phenomenon.



*B. Rai, N. Singh "Modeling and analysis of automobile warranty data in presence of bias due to customer-rush near warranty expiration limit", Reliability Engineering & System Safety, Vol. 86, Issue 1, pp. 83-94.