Case study of Cox regression:

Regression approach to tire reliability analysis

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Regression approach to tire reliability analysis

V.V. Krivtsov*, D.E. Tananko, T.P. Davis

Ford Motor Company, MD 412/PDC, 20901 Oakwood Blvd, Dearborn, MI 48121-2053, USA

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This paper focuses on a particular failure mode known as tread and belt separation (TBS). In the event of TBS, the whole (or a part of the) tread and the second (upper) steel belt leave the tire carcass and the first (lower) steel belt (see Fig. 1).

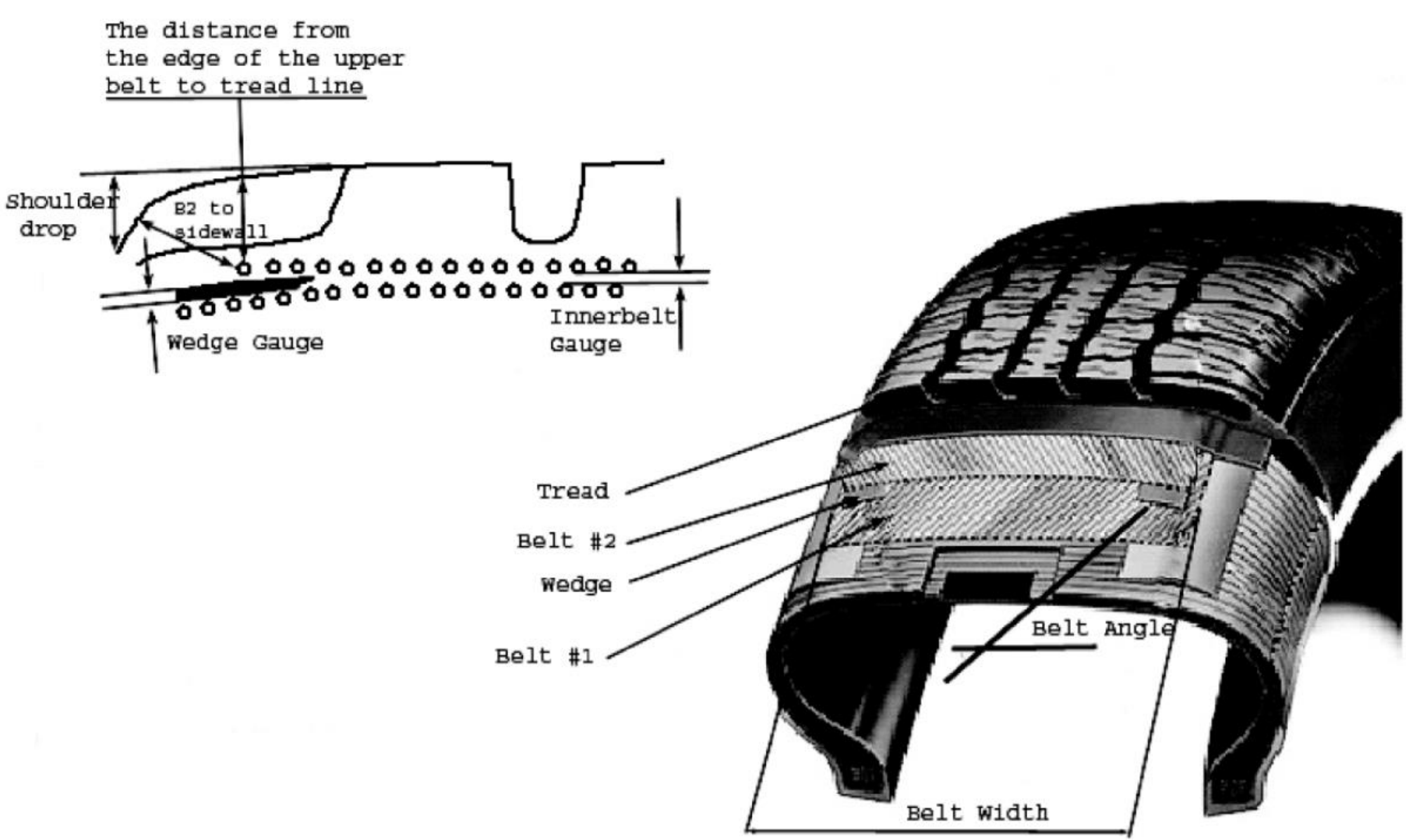

Fig. 1. Elements of radial tire.

Covariates:

- tire age
- wedge gauge
- interbelt gauge
- end of belt #2 to buttress
- peel force (adhesion force of rubber between steel belts, characterized as the force required to separate belts in the specimen of a given dimension)
- percent of carbon black (a chemical ingredient of the rubber affecting its mechanical characteristics, such as *tear resistance*).

Test procedure:

- warm up over 2 h at 50 mph
- cool down over 2 h at full stop
- in the 1300 lb regime: speed steps starting at 75 mph and increasing by 5 mph every half-hour till 90 mph and then every hour till failure
- in the 1500 lb regime: all the above speed steps are of half-hour duration

Table 1
Test data set used in proportional hazard analysis

Tire age	Wedge gauge	Interbelt gauge	EB2B	Peel force	Carbon black (%)	Wedge gauge × peel force	Survival	Censoring (1-compl, 0-cens)
1.22	0.81	0.88	1.07	0.63	1.02	0.46	1.02	0
1.19	0.69	0.77	0.92	0.68	1.02	0.43	1.05	1
0.93	0.77	1.01	1.11	0.72	0.99	0.49	1.22	0
0.85	0.80	0.57	0.98	0.75	1.00	0.42	1.17	1
0.85	0.85	1.26	1.03	0.70	1.02	0.64	1.09	0
0.91	0.89	0.94	1.00	0.77	1.03	0.59	1.09	1
0.93	0.98	0.84	0.92	0.72	1.00	0.55	1.17	1
1.10	0.76	0.94	1.01	0.84	0.98	0.55	1.10	0
0.95	0.53	0.96	0.91	0.58	1.00	0.27	1.00	1
0.94	0.87	1.11	0.88	0.72	0.99	0.65	1.15	1
1.08	1.13	1.12	0.93	0.75	0.96	0.79	0.98	1
0.89	1.03	1.28	0.97	0.68	1.02	0.53	1.24	0
1.41	0.79	0.83	0.91	1.00	1.00	1.00	0.98	1
1.50	0.72	0.76	0.97	0.76	0.96	0.35	1.15	1
1.21	0.54	0.70	0.95	0.59	1.00	0.30	0.65	1
2.01	0.76	0.94	1.01	0.53	1.00	0.35	0.97	1
1.49	0.64	0.70	1.02	0.71	0.97	0.41	0.85	0
1.55	0.63	0.71	1.13	0.66	1.00	0.40	0.98	0
1.23	0.84	1.09	1.04	0.76	0.98	0.57	1.02	0
2.60	1.05	1.21	1.07	1.06	0.99	1.05	1.14	0
2.26	0.98	1.34	1.02	0.87	1.00	0.89	1.18	0

Table 2
Estimates of proportional hazard model with covariates identified in Section 2

Explanatory variable	Beta	Standard error	*t*-value	*p*-value
Tire age	2.109	1.393	1.514	0.130
Wedge gauge	−9.686	4.638	−2.088	0.037
Interbelt gauge	−10.677	4.617	−2.313	0.021
Belt 2 to sidewall	−13.675	8.112	−1.686	0.092
Peel force	−34.293	13.651	−2.512	0.012
Carbon black (%)	−48.349	33.448	−1.445	0.148
Wedge × peel force	20.839	8.860	2.352	0.019

Table 3
Estimates of proportional hazard model with statistically significant covariates

Explanatory variable	Beta	Standard error	*t*-value	*p*-value
Wedge gauge	−9.313	4.069	−2.289	0.022
Interbelt gauge	−7.069	2.867	−2.466	0.014
Peel force	−27.411	10.578	−2.591	0.010
Wedge A × peel force	18.105	7.057	2.566	0.010

Table 3 shows the estimation results of the model that includes only statistically significant covariates. The log-likelihood of the final solution is −19.968, while the log-likelihood of the null model is −28.886. The likelihood ratio chi-square statistic is 17.837 with 4 degrees of freedom and the associated *p*-value is 0.001.

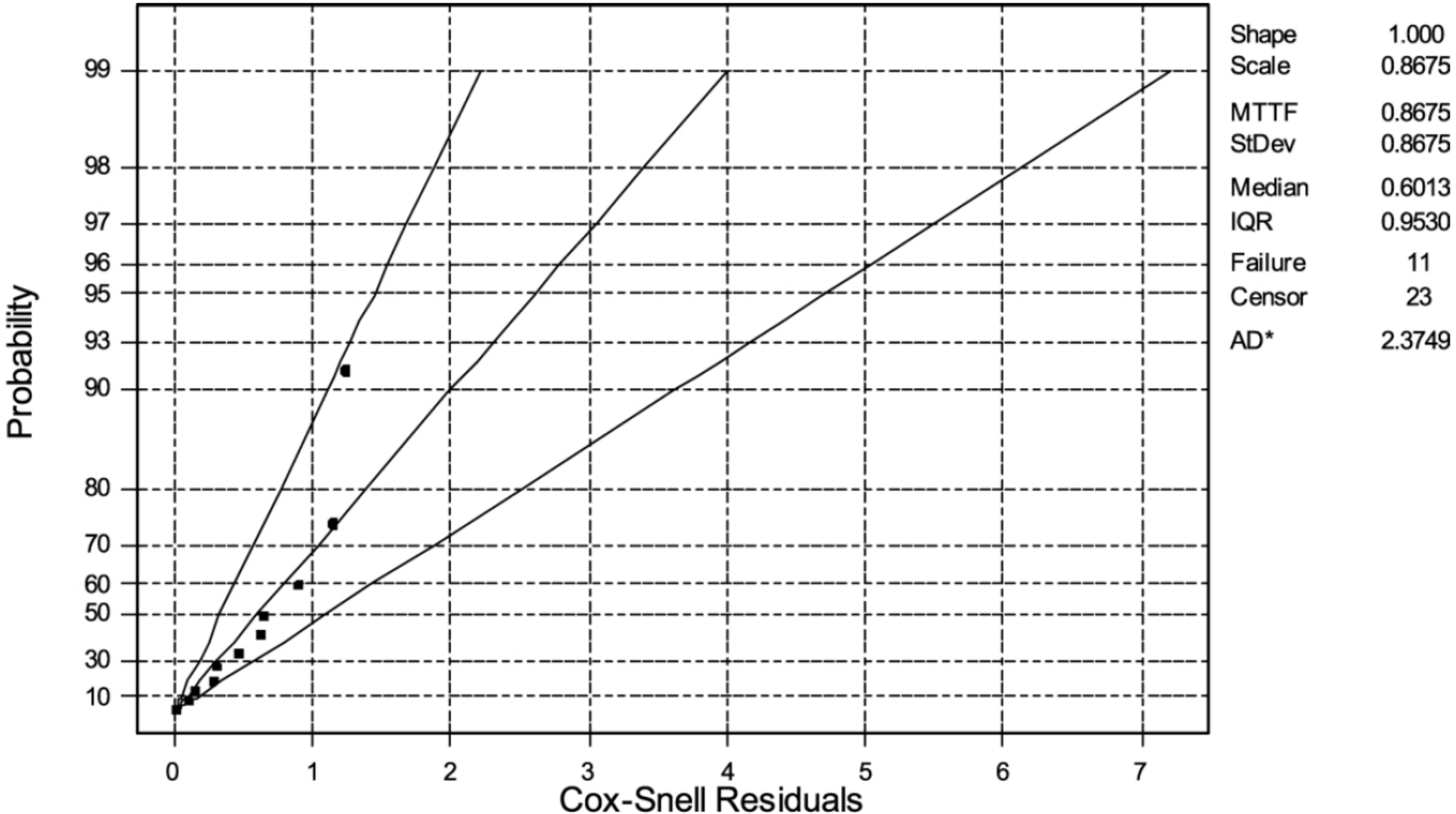

Fig. 4. Exponential probability plot of Cox–Snell residuals.