Lecture #2:

◎ PSR, PSI Concept

Pavement Serviceability-Performance Concept

Present Serviceability Rating (PSR), 0-5

V. Good - Good - Fair - Poor - Very Poor

(User's Rating - Subjective)

Table 1 - 74 Selected Flexible Pavements

Table 2 - 49 Selected Rigid Pavements

Need to Develop PSI equation:

$$PSI = 5.03 - 1.91\log(1+SV) - 1.38RD^2 - 0.01\sqrt{C+P}$$

$$PSI = 5.41 - 1.80\log(1+SV) - 0.09\sqrt{C+P}$$

PSI = F(SV, RD, C+P) for FLEX

PSI = F(SV, C+P) for Rigid

Handouts:

Carey, W. N., and P. E. Irick, "The Pavement Serviceability-Performance Concept," Highway Research Board, Bulletin No, 250, 1960.

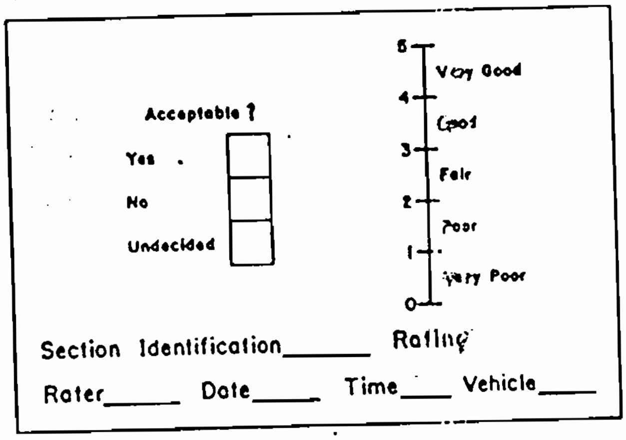


Figure 1. Individual present serviceability rating form.

Measurements for Selected Pavements

Following the acceptability opinion, Tables 1 and 2 give summary values for measurements made on the selected pavements. Measurements are shown in three categories—those that describe longitudinal and transverse roughness, those that summarize surface cracking and, finally, a measurement of the patched area found in the section.

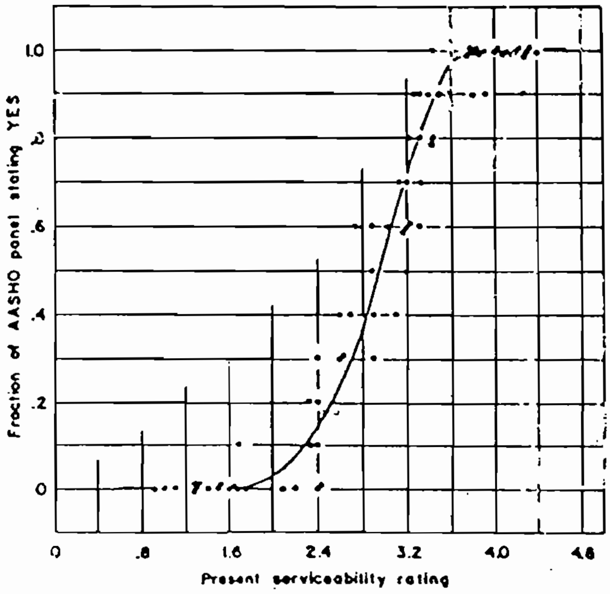


Figure 2. Acceptability vs present serviceability rating; 74 flexible pavements.

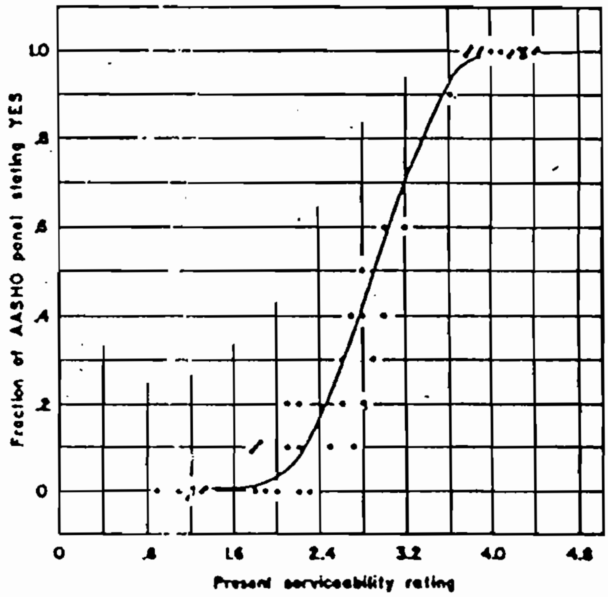


Figure 3. Acceptability vs present serviceability rating; 49 rigid pavements.

TABLE 1

DATA FOR 74 SELECTED FLEXIBLE PAVEMENTS

Pvt. Loc.	Sect. Code	Present Serviceability Ratings: AASHO Panel: 1st PSR	AASHO Panel: Replic. diff. in PSR	AASHO Panel: Std. dev. of PSR among raters	Truck Drvrs PSR	Canad. Raters PSR	Acceptability Opinions, AASHO Panel Fraction: Yes	Fraction: No	SV Mean Slope Var'nce in Wh'pths (x10⁶)	AR Mean AASHO Rdm'tr in Wh'pths in./mi. @10 mph	RD Mean Rut Depth (in.)	RDV Mean Rut Depth Var'nce in² x 100	Major Cracking: Class 2 + 3, ft²/1000 ft²	Major Cracking: Long. & Trans. ft/1000 ft²	Patching P Ft² per 1000 ft²	Transformations: Log (1+SV)	Transformations: RD²	Transformations: Sq. rt. C+P	PSI 121 Pres. Serv. Index	Resid. Diff. Betw'n PSR & PSI
Ill.	F 3	4.3		.1	4.5	4.3	1.0	.0	2.8		.10	.7	0	0	0	.57	.01	.0	3.9	.4
	F 4	2.4		.4		2.0	.0	.6	20.5		.22	9.2	343	0	0	1.33	.05	18.5	2.3	.1
	F 5	3.3		.7	3.5	2.6	.6	.2	9.2		.08	3.6	8	0	0	1.01	.01	2.8	3.1	.2
	F 6	4.4	.1	.2	3.5		1.0	.0	3.5		.08	.7	0	0	0	.65	.01	.0	3.8	.6
	F 7	3.8	.1	.6	2.5	3.6	.9	.0	15.5		.06	.4	0	0	0	1.22	.00	.0	2.7	1.1
	F 8	2.6	.2	.7	2.0	2.7	.3	.6	9.5		.08	5.7	64	0	0	1.02	.01	8.0	3.0	.4
	F 9	3.2	.2	.6	3.0	3.0	.6	.2	14.0		.15	3.4	2	0	3	1.18	.02	2.2	2.7	.5
	F10	2.4	.0	.5	3.0	2.2	.1	.6	16.8		.16	3.4	17	0	14	1.25	.03	5.6	2.6	.2
	F11	1.3	.3	.5	1.5		.0	1.0	42.8		.26	10.3	292	0	11	1.64	.07	17.4	1.6	.3
	F12	1.1	.3	.2	1.0	1.7	.0	1.0	56.0		.19	10.9	21	0	2	1.76	.04	4.8	1.6	.5
Minn.	101	3.8	.3	.4			1.0	.0	1.9		.04	.4	0	29	0	.46	.00	5.4	4.1	.3
	102	3.8		.6			1.0	.0	1.5		.09	.3	0	34	0	.40	.00	5.8	4.2	.4
	103	3.8		.4			1.0	.0	1.7		.05	.2	0	14	0	.43	.00	3.7	4.2	.4
	104	3.8	.0	.4			1.0	.0	2.1		.04	.4	0	9	0	.49	.00	3.0	4.1	.3
	105	3.2		.4			.6	.1	7.0		.14	.5	0	0	10	.90	.02	3.2	3.3	.1
	106	1.3		.4			.0	1.0	58.5		.07	6.6	145	22	35	1.77	.00	14.2	1.5	.2
	107	1.3	.2	.4			.0	1.0	58.4		.08	2.9	75	12	55	1.77	.01	11.9	1.5	.2
	108	2.1		.6			.0	.9	17.6		.13	3.2	15	0	5	1.27	.03	4.5	2.5	.4
	109	1.5	.2	.2			.0	1.0	36.2		.37	5.6	30	2	76	1.57	.13	10.4	1.7	.2
	110	2.4	.0	.9			.0	.8	11.4		.07	3.2	2	0	3	1.09	.00	2.2	2.9	.5
	111	4.2		.2			1.0	.0	1.7		.11	.2	0	0	0	.42	.01	.0	4.2	.0
	112	3.9		.4			1.0	.0	1.4		.09	.2	0	0	0	.38	.01	.0	4.3	.4
	113	3.1	.1	.6			.4	.4	7.8		.08	1.3	1	68	66	.94	.01	11.6	3.1	.0
	114	2.2		.7			.0	.9	27.8		.13	5.2	0	1	4	1.46	.02	2.2	2.2	.0
	115	1.5		.6			.0	1.0	33.4		.08	5.4	0	7	6	1.54	.01	3.6	2.0	.5
	116	2.9	.5	.5			.6	.1	6.0		.02	.7	0	180	0	.85	.00	13.4	3.3	.4
	117	1.6	.0	.6			.0	1.0	39.4		.12	4.6	0	0	0	1.61	.01	.0	1.9	.3
	118	4.0	.2	.3			1.0	.0	1.6		.04	.2	0	0	0	.41	.00	.0	4.2	.2
	119	4.2		.5			1.0	.0	1.3		.03	.2	0	0	0	.36	.00	.0	4.3	.1
	120	2.9	.1	.5			.3	.2	5.8		.01	1.4	0	74	0	.84	.00	8.6	3.3	.4
	301	4.1		.6			1.0	.0	4.6	101	.24	.4	44	43	0	.75	.06	9.3	3.4	.7
	302	4.0		.5			1.0	.0	5.4	123	.34	.5	204	75	0	.81	.12	16.7	3.2	.8
Ind.	303	3.2		.5			.6	.1	20.1	146	.02	.4	12	1	0	1.32	.00	3.6	2.5	.7
	304	2.4	.0	.4			.2	.5	29.2	134	.17	1.8	455	0	17	1.48	.03	21.7	2.0	.4
	305	2.9	.1	.3			.4	.3	9.1	129	.10	1.2	292	0	32	1.00	.01	18.0	2.9	.0
	306	2.4	.2	.5			.3	.5	20.5	161	.12	2.4	816	0	0	1.33	.01	28.6	2.2	.2
	307	1.7	.3	.6			.1	.9	95.9	383	.02	1.9	719	0	111	1.99	.00	28.8	1.0	.7
	308	1.0		.4			.0	1.0	51.8	296	.03	5.1	691	0	161	1.72	.00	29.2	1.5	.5
	309	1.3		.4			.0	1.0	41.2	233	.14	7.0	613	0	159	1.62	.02	27.8	1.6	.3
	310	3.2		.6			.7	.1	11.5	144	.18	2.0	17	0	0	1.10	.03	4.1	2.8	.4
	311	2.7		.4			.4	.4	15.0	162	.14	.8	45	0	0	1.20	.02	6.7	2.6	.1
	312	1.6		.4			.0	1.0	49.8	217	.23	2.3	502	0	31	1.71	.05	23.1	1.5	.1
	313	1.4		.4			.0	1.0	42.0	182	.27	2.9	437	0	72	1.63	.07	22.6	1.7	.3
	314	2.6		.5			.3	.4	19.0	127	.24	1.2	10	64	2	1.30	.06	8.7	2.4	.2
	315	3.4		.7			.9	.0	6.9	107	.22	.2	183	46	0	.90	.05	15.1	3.1	.3
	316	2.9		.5			.5	.4	11.3	140	.09	.8	177	0	4	1.09	.01	13.4	2.8	.1
	317	4.3		.2			1.0	.0	2.9	95	.01	.1	0	0	0	.59	.00	.0	3.9	.4
	318	4.3		.3			1.0	.0	3.3	92	.00	.0	1	0	0	.63	.00	1.0	3.8	.5
	319	4.2	.0	.3			1.0	.0	3.8	92	.12	.2	0	1	0	.68	.01	1.0	3.7	.5
	320	3.9	.3	.4			.9	.0	3.8	105	.16	.4	0	2	0	.68	.03	1.4	3.7	.2
Test Road Sect.	501	3.8		.3			1.0	.0	5.8	132	.08	.3	0	0	0	.83	.01	.0	3.4	.4
	502	3.4		.6			.8	.1	10.3	168	.20	2.2	51	0	0	1.05	.04	7.2	2.9	.5
	503	3.1	.0	.3			.7	.0	7.6	129	.11	.8	17	0	7	.93	.01	4.9	3.2	.1
	504	4.1		.2			1.0	.0	2.6	109	.03	.2	0	0	0	.56	.00	.0	4.0	.1
	505	3.4		.2			1.0	.0	3.8	89	.33	.9	14	0	0	.68	.11	3.7	3.5	.1
	506	3.4		.4			.9	.0	4.8	89	.24	.9	0	0	0	.76	.06	.0	3.5	.1
	507	2.8		.4			.6	.3	7.6	103	.43	1.4	5	0	25	.93	.18	5.4	2.9	.1
	508	3.5		.5			.9	.0	4.0	75	.46	.5	0	0	0	.70	.21	.0	3.4	.1
	509	3.3		.5			.8	.0	2.9	84	.39	.4	9	0	0	.59	.15	3.0	3.7	.4
	510	3.3		.4			.9	.0	5.0	90	.44	1.0	2	0	0	.78	.19	1.3	3.3	.0
	511	3.6		.5			1.0	.0	3.5	90	.47	.6	0	0	0	.65	.22	.0	3.5	.1
	512	3.2		.7			.8	.0	5.1	87	.53	1.3	0	0	0	.79	.28	.0	3.1	.1
	513	3.4		.5			.8	.0	2.6	75	.56	.5	0	0	0	.56	.31	.0	3.5	.1
	514	1.8		.5			.0	.9	11.1	122	.73	5.1	80	0	16	1.08	.53	9.8	2.1	.3
	515	3.3		.7			.9	.0	2.5	79	.38	.5	0	0	0	.54	.14	.0	3.3	.5
	516	2.6		.6			.4	.3	5.4	86	.55	.6	15	0	0	.81	.30	3.9	3.0	.4
	517	3.2		.6			.5	.1	5.4	83	.54	.7	1	0	0	.81	.29	1.2	3.1	.1
	518	1.7		.4			.0	.8	21.0	149	.92	2.8	222	0	0	1.34	.85	14.9	1.2	.5
	519	2.4		.5			.1	.4	6.5	99	.53	1.5	21	0	0	.88	.28	4.6	2.9	.5
	520	3.0	.2	.6			.6	.1	6.8	89	.46	1.0	0	0	0	.89	.21	.0	3.0	.0
Off Site Sect.	521	3.3		.5			.7	.1	4.3	118	.09	.4	0	0	0	.72	.01	.0	3.6	.3
	522	2.7		.4			.6	.1	13.7	185	.11	3.8	300	0	1	1.17	.01	17.4	2.6	.1
	523	2.4		.4			.2	.2	10.8	137	.22	1.3	496	0	52	1.07	.05	23.4	2.7	.3
	524	0.9		.5			.0	1.0	88.1	281	.25	6.2	392	0	60	1.95	.06	21.2	1.0	.1
Sum		215.4	3.9	34.2												75.19	5.59	565.7	215.4*	22.3
Mean		2.91	.16	.46												1.02	.076	7.64	2.91	.30
Sum of Squares		66.85														13.27	1.34	5255	56.42*	10.42*
Sum of Products with PSR																-26.69	-1.51	-369.3		
Sum of Products with $\log(1+\overline{SV})$																	-.166	171.63		
Sum of Products with $\overline{RD}^2$																		-3.90		

*Obtained from Unrounded Calculations

$$PSI\ 121 = 5.03 - 1.91 \log(1+\overline{SV}) - 1.38\overline{RD}^2 - .01\sqrt{C+P}$$

ORIGINAL AASHO FLEXIBLE PSI EQUATION

$$PSI = 5.03 - 1.92\log_{10}(1 + SV) - 1.39RD^2 - 0.01\sqrt{CP}$$

$\log(1 + RDV)$

Note:

PSI = mean panel serviceability rating, (0 - 5);

SV = mean slope variance obtained by CHOLE profilometer in wheel paths (in./in. x 10^6);

RDV = mean rut depth variance (in.^{2} x 100);

RD = mean rut depth (in.);

CP = total cracking plus patching.

Statistics:

$R^2 = 0.84$, SEE = 0.39, N = 74, CV = 13.3%

$$\text{Variance} = \frac{\Sigma(x_i - \bar{x})^2}{n-1} = \frac{\Sigma x_i^2 - \frac{1}{n}(\Sigma x_i)^2}{n-1}$$

$$s.d. = \sqrt{\text{Variance}}$$

$$C.V = \frac{s.d.}{\bar{x}}$$

WEIGHTED FLEXIBLE PAVEMENT EQUATIONS FROM AASHO ROAD TEST:

$$\log_{10} W = \log_{10} \rho + \frac{\log_{10}\left(\frac{4.2 - P}{2.7}\right)}{\beta}$$

$$\beta = 0.4 + \frac{0.081 (L_1 + L_2)^{3.23}}{(D + 1)^{5.19} L_2^{3.23}}$$

$$\rho = \frac{10^{5.93} (D + 1)^{9.36} L_2^{4.33}}{(L_1 + L_2)^{4.79}}$$

$$D = 0.44 D_1 + 0.14 D_2 + 0.11 D_3$$

Where the Statistics for $\log_{10}$W Equation:

$R^2 = 0.70$, SEE = 0.31, N = 1171

Mean Replicate Difference of $\log_{10}$W = 0.17 (n = 126)

(Note: Load Applications Were Adjusted by Seasonal Weighting Function)

Table 2 Designs for Flexible Pavement Experiments

Loop 1

Axle Load: Lane 1 — None; Lane 2 — None

Main Factorial Design — Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
1	0	0	857	858
		8	867	868
		16	833	834
			841	842
	6	0	827	828
		8	847	848
		16	839	840
3	0	0	859	860
			863	864
		8	869	870
			829	830
		16	837	838
	6	0	825	826
			851	852
		8	875	876
			819	820
		16	821	822
5	0	0	823	824
		8	865	866
		16	877	878
	6	0	871	872
		8	849	850
		16	879	880
			873	874

Subsurface Studies — Design 5

Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
3	0	0	861	862
		8	831	832
			853	854
		16	817	818
	6	0	855	856
		8	845	846
		16	843	844
			835	836

Loop 2

Axle Load: Lane 1 — 2,000-S; Lane 2 — 6,000-S

Main Factorial Design — Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
1	0	0	721	722
		4	727	728
	3	0	743	744
		4	717	718
	6	0	755	756
		4	719	720
2	0	0	771	772
		4	729	730
	3	0	759	760
			731	732
		4	741	742
			709	710
	6	0	775	776
			757	758
		4	737	738
			711	712
3	0	0	769	770
		4	739	740
	3	0	773	774
		4	745	746
	6	0	749	750
		4	763	764

Surface Treatment Study — Design 6

Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
Surface Treatment	0	0	733	734
			751	752
		4	753	754
			723	724
	3	0	725	726
			767	768
		4	765	766
			715	716
	6	0	747	748
			735	736
		4	761	762
			713	714

Loop 3

Axle Load: Lane 1 — 12,000-S; Lane 2 — 24,000-T

Main Factorial Design — Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
2	0	0	1	165	166
		4	3	125	126
		8	2	143	144
			2	133	134
	3	0	3	113	114
		4	2	135	136
		8	1	159	160
	6	0	2	127	128
		4	1	157	158
		8	3	111	112
3	0	0	2	137	138
		4	1	163	164
		8	3	109	110
	3	0	1	147	148
		4	3	107	108
			3	115	116
		8	2	129	130
	6	0	3	117	118
		4	2	131	132
		8	1	155	156
4	0	0	3	119	120
		4	2	141	142
		8	1	153	154
	3	0	2	145	146
		4	1	151	152
		8	3	121	122
	6	0	1	161	162
			1	149	150
		4	3	123	124
		8	2	139	140

Shoulder Paving Study — Design 2

Shoulder Paving	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
With	2	3	0	177	178
				179	180
	2	3	8	175	176
				183	184
	4	3	0	173	174
				181	182

Base Type Study. — Design 4

Base Type	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
Crush. Stone	3	2-14	0	169	170
				105	106
Gravel	3	2-14	0	171	172
				103	104

Loop 4

Axle Load: Lane 1 — 18,000-S; Lane 2 — 32,000-T

Main Factorial Design — Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
3	0	4	1	633	634
		8	2	607	608
		12	3	571	572
			3	569	570
	3	4	2	599	600
		8	3	573	574
		12	1	617	618
	6	4	3	585	586
		8	1	623	624
		12	2	601	602
4	0	4	3	583	584
		8	1	619	620
		12	2	603	604
	3	4	1	627	628
		8	2	589	590
			2	597	598
		12	3	575	576
	6	4	2	595	596
		8	3	577	578
		12	1	625	626
5	0	4	2	605	606
		8	3	587	588
		12	1	621	622
	3	4	3	579	580
		8	1	631	632
		12	2	593	594
	6	4	1	629	630
			1	615	616
		8	2	591	592
		12	3	581	582

Shoulder Paving Study — Design 2

Shoulder Paving	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
With	3	0	4	637	638
				609	610
	3	6	4	635	636
				611	612
	5	0	4	639	640
				613	614

Base Type Study — Design 4

Base Type	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
Crush. Stone	3	2-16	4	567	568
				561	562
Gravel	3	2-16	4	565	566

Loop 5

Axle Load: Lane 1 — 22,400-S; Lane 2 — 40,000-T

Main Factorial Design — Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
3	3	4	1	485	486
		8	2	451	452
		12	3	415	416
			3	429	430
	6	4	2	449	450
		8	3	419	420
		12	1	487	488
	9	4	3	413	414
		8	1	471	472
		12	2	441	442
4	3	4	3	411	412
		8	1	481	482
		12	2	443	444
	6	4	1	473	474
		8	2	455	456
			2	453	454
		12	3	425	426
	9	4	2	437	438
		8	3	417	418
		12	1	477	478
5	3	4	2	439	440
		8	3	421	422
		12	1	479	480
	6	4	3	423	424
		8	1	469	470
		12	2	445	446
	9	4	1	475	476
			1	483	484
		8	2	447	448
		12	3	427	428

Shoulder Paving Study — Design 2

Shoulder Paving	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
With	3	3	4	435	436
				407	408
	3	9	4	431	432
				405	406
	5	3	4	433	434
				409	410

Base Type Study — Design 4

Base Type	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
Gravel	3	3-18	4	467	468
				457	458
Bit.	[illegible]	[illegible]	[illegible]	463	464

Loop 6

Axle Load: Lane 1 — 30,000-S; Lane 2 — 48,000-T

Main Factorial Design — Design 1

Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
4	3	8	3	269	270
		12	2	299	300
		16	1	317	318
			1	329	330
	6	8	2	303	304
		12	1	323	324
		16	3	253	254
	9	8	1	321	322
		12	3	267	268
		16	2	309	310
5	3	8	1	319	320
		12	3	261	262
		16	2	315	316
	6	8	3	259	260
		12	2	307	308
			2	305	306
		16	1	327	328
	9	8	2	313	314
		12	1	331	332
		16	3	265	266
6	3	8	2	297	298
		12	1	335	336
		16	3	255	256
	6	8	1	325	326
		12	3	257	258
		16	2	301	302
	9	8	3	263	264
			3	271	272
		12	2	311	312
		16	1	333	334

Shoulder Paving Study — Design 2

Shoulder Paving	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
With	4	3	8	291	292
				275	276
	4	3	16	293	294
				273	274
	6	3	8	295	296
				277	278

Base Type Study — Design 4

Base Type	Surface Thickness	Base Thickness	Subbase Thickness	Test Section No. Lane 1	Test Section No. Lane 2
Crush. Stone	4	3-19	8	287	288
				279	280
Bit.	[illegible]	[illegible]	[illegible]	285	286

Note: Shaded sections are replicates

Ref: Highway Research Board, "The AASHO Road Test," Report 5, Pavement Research, Special Report 61E, Publication No. 954, National Academy of Sciences - National Research Council, Washington, D.C., 1962.

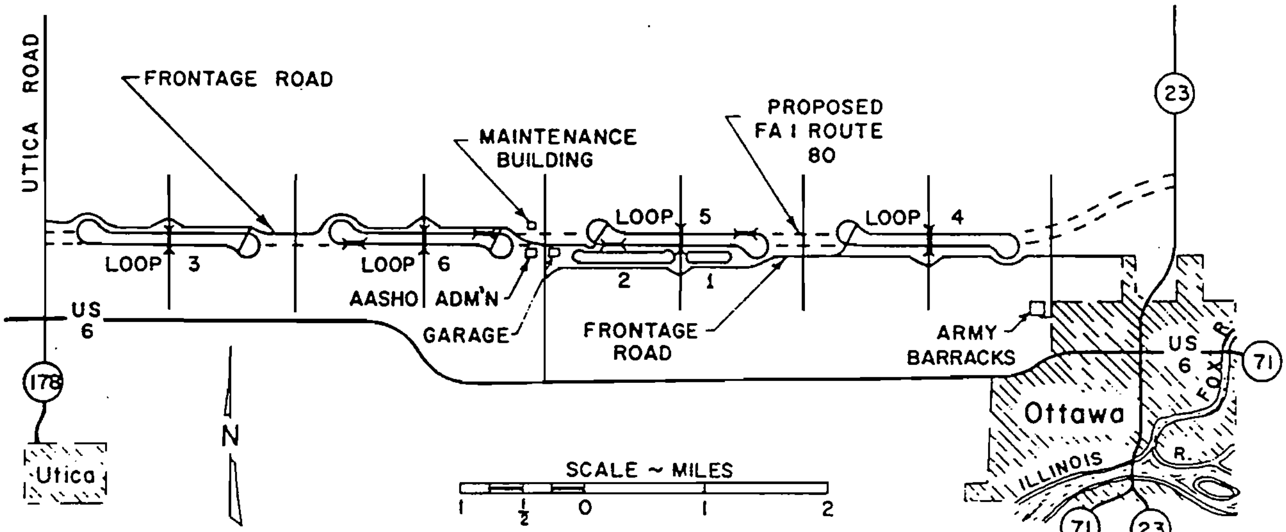


Figure 2. Layout of AASHO Road Test.

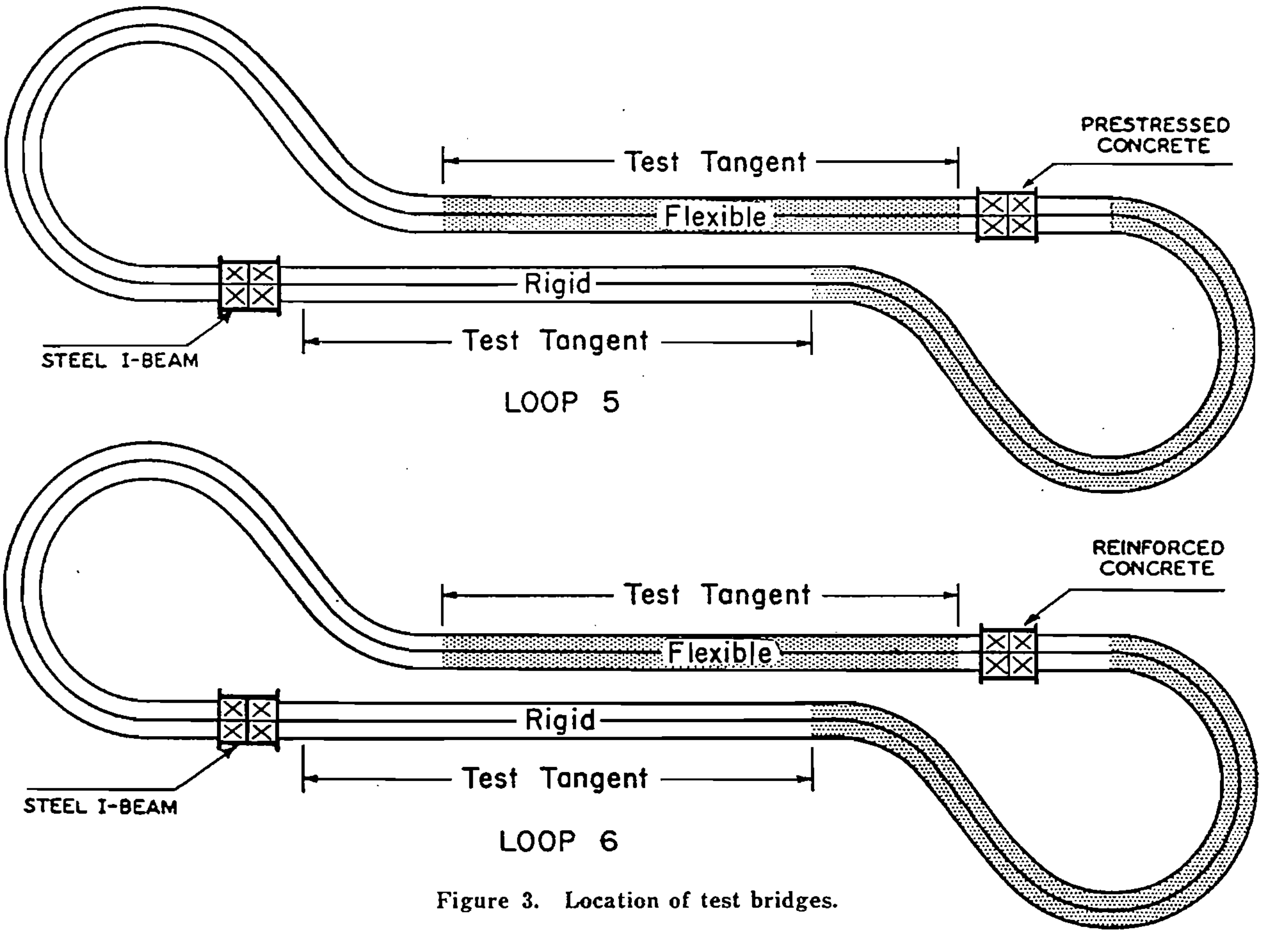
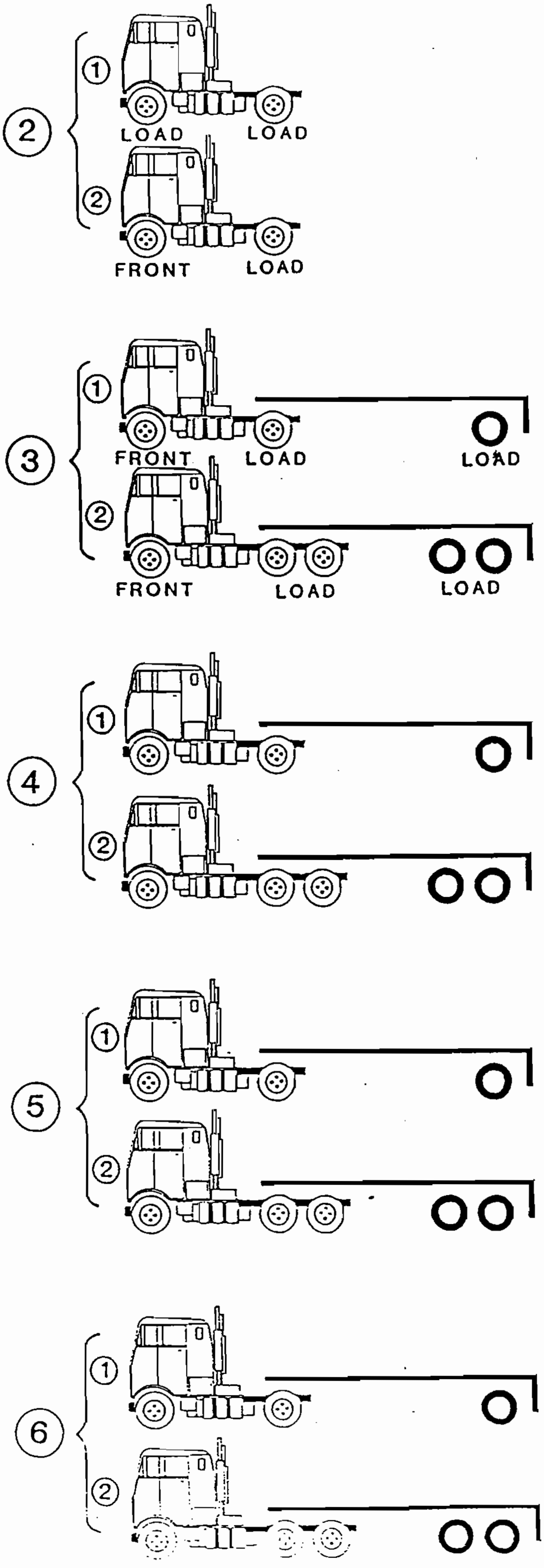


Figure 3. Location of test bridges.

Table 3-2.1 Axle Weights and Distributions Used on Various Loops of the AASHO Road Test (5).



LOOP	LANE	WEIGHT IN KIPS: FRONT AXLE	WEIGHT IN KIPS: LOAD AXLE	WEIGHT IN KIPS: GROSS WEIGHT
2	1	2	2	4
2	2	2	6	8
3	1	4	12	28
3	2	6	24	54
4	1	6	18	42
4	2	9	32	73
5	1	6	22.4	51
5	2	9	40	89
6	1	9	30	69
6	2	12	48	108

Loop 4					
Axle Load					
Lane 1			Lane 2		
18,000-S			32,000-T		
Main Factorial Design Design 1					
Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No. Lane 1	Test Section No. Lane 2
3	0	4	1	633	634
		8	2	607	608
		12	3	571	572
			3	569	570
	3	4	2	599	600
		8	3	573	574
		12	1	617	618
	6	4	3	585	586
		8	1	623	624
		12	2	601	602
4	0	4	3	583	584
		8	1	619	620
		12	2	603	604
	3	4	1	627	628
		8	2	589	590
			2	597	598
		12	3	575	576
	6	4	2	595	596
		8	3	577	578
		12	1	625	626
5	0	4	2	605	606
		8	3	587	588
		12	1	621	622
	3	4	3	579	580
		8	1	631	632
		12	2	593	594
	6	4	1	629	630
			1	615	616
		8	2	591	592
		12	3	581	582

Figure 1-2.1. Pavement Sections Constructed on Loop 4 of the AASHO Road Test.

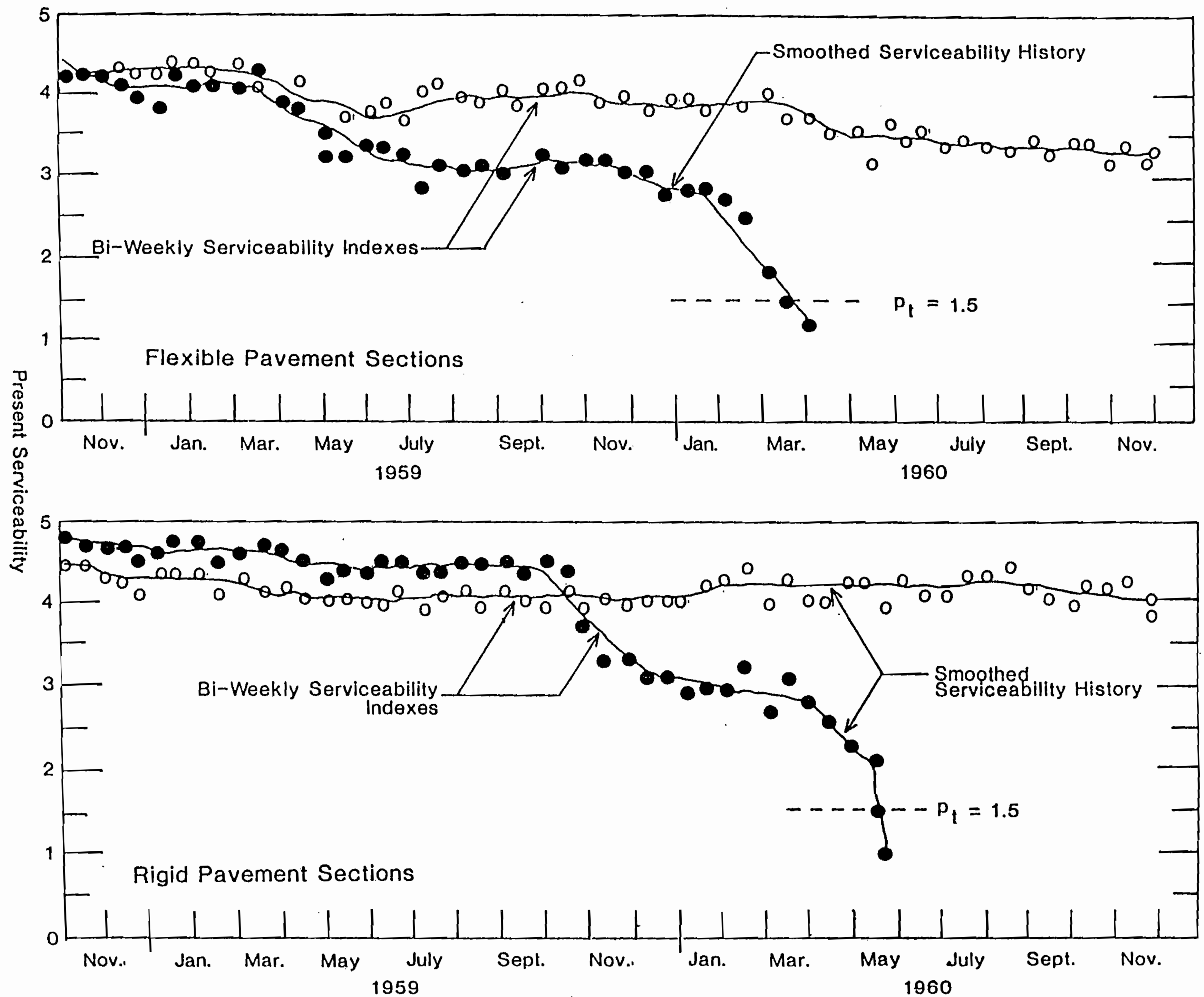


Figure 1-2.2. Typical Serviceability Histories from the AASHO Road Test.

TYPICAL EXAMPLES OF PREDICTION MODELS

1. AASHO ROAD TEST:

$$g = \frac{P_i - P}{P_i - P_t} = \left(\frac{W}{\rho}\right)^{\beta}$$

Where:

g	=	"damage" index;
P_i, P_t, P	=	initial, terminal, and present serviceability indices (0-5), respectively;
W	=	number of standard loads, and;
ρ, β	=	functions of pavement thickness, strength, and axle load configurations.

2. NCHRP 1-19 PROJECT (COPES):

$$DISTRESS = (TRAFFIC\ OR\ AGE)^{a} * (b * DESIGN^{c} + d * SUBGRADE^{e} + f * CLIMATE^{g} + h * MATERIALS^{i})$$

WEIGHTED FLEXIBLE PAVEMENT EQUATIONS FROM THE AASHO ROAD TEST:

$$\log_{10} W = \log_{10} \rho + \frac{\log_{10}\left(\frac{4.2 - P}{2.7}\right)}{\beta}$$

$$\beta = 0.4 + \frac{0.081 (L_1 + L_2)^{3.23}}{(D + 1)^{5.19} L_2^{3.23}}$$

$$\rho = \frac{10^{5.93} (D + 1)^{9.36} L_2^{4.33}}{(L_1 + L_2)^{4.79}}$$

$$D = 0.44 D_1 + 0.14 D_2 + 0.11 D_3$$

Statistics:

For Predicting $\log_{10}$W: $R^2 = 0.70$, SEE = 0.31, N = 1171

(Mean Replicate Difference of $\log_{10}$W = 0.17, n = 126)

For Predicting W: $R^2 = 0.61$, SEE = 155.3, N = 1171

For Predicting PSI: $R^2 = 0.21$, SEE = 0.62, N = 1083

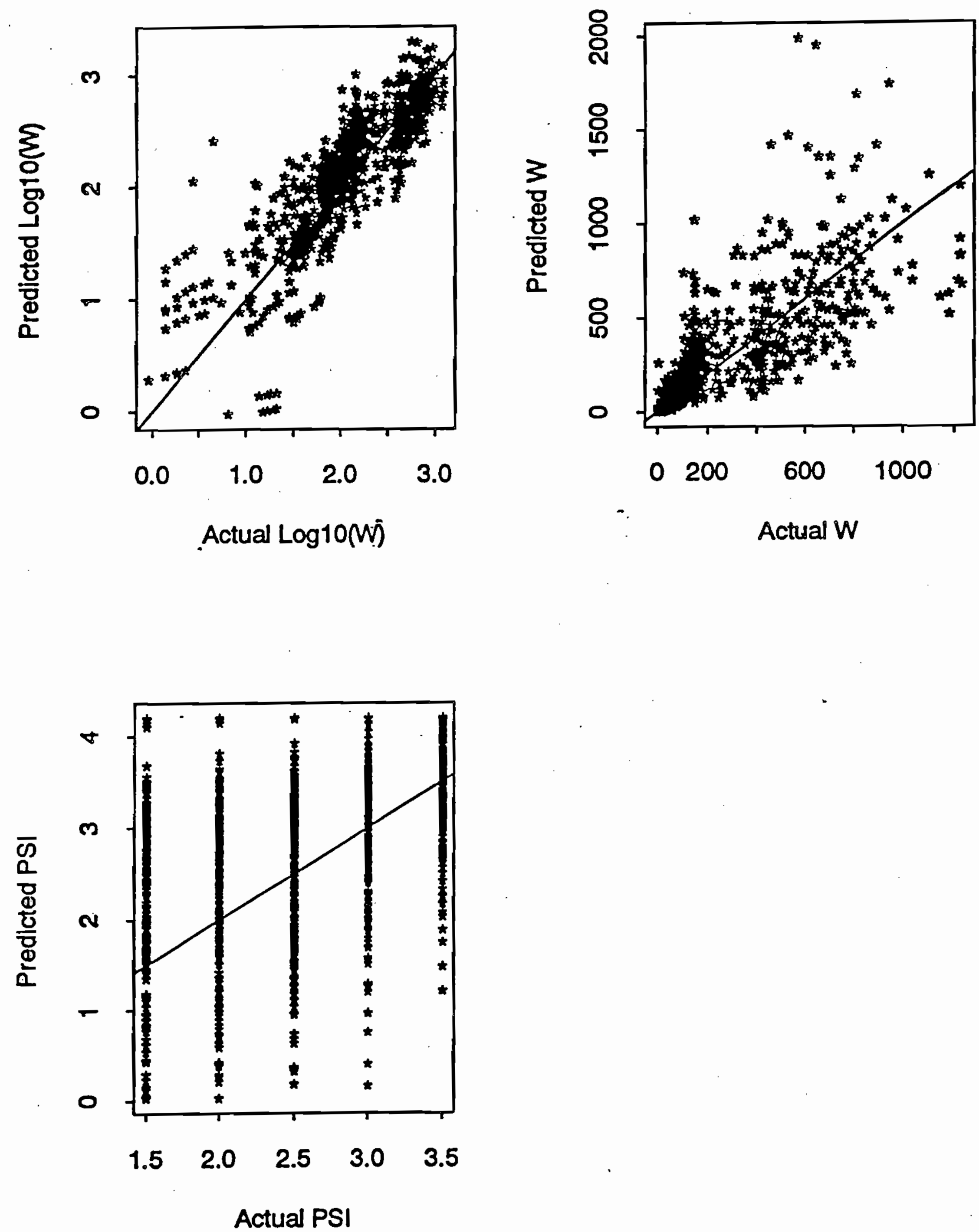


Figure 2.7 - Predicted versus Actual $\log_{10}(W)$, W, and PSI Plots

Table D.4. Axle load equivalency factors for flexible pavements, single axles and p_t 2.5.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.30
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6 98	5.90	5.21	5.39	5.98
30	10.3	9.5	7.9	6.8	7.0	7.8
32	13.9	12.8	10.5	8.8	8.9	10.0
34	18.4	16.9	13.7	11.3	11.2	12.5
36	24.0	22.0	17.7	14.4	13.9	15.5
38	30.9	28.3	22.6	18.1	17.2	19.0
40	39.3	35.9	28.5	22.5	21.1	23.0
42	49.3	45.0	35.6	27.8	26.6	27.7
44	61.3	55.9	44.0	34.0	31.0	33.1
46	75.5	68 8	54.0	41.4	37.2	39.3
48	92.2	83.9	65.7	50.1	44.5	46.5
50	112.	102.	79.	60.	53.	56.

Table D.5. Axle load equivalency factors for flexible pavements, tandem axles and p_t of 2.5.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002
6	.002	.002	.002	.001	.001	.001
8	.004	.006	.005	.004	.003	.003
10	.008	.013	.011	.009	.007	.006
12	.015	.024	.023	.018	.014	.013
14	.026	.041	.042	.033	.027	.024
16	.044	.065	.070	.057	.047	.043
18	.070	.097	.109	.092	.077	.070
20	.107	.141	.162	.141	.121	.110
22	.160	.198	.229	.207	.180	.166
24	.231	.273	.315	.292	.260	.242
26	.327	.370	.420	.401	.364	.342
28	.451	.493	.548	.534	.495	.470
30	.611	.648	.703	.695	.658	.633
32	.813	.843	.889	.887	.857	.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3.00	3.16
46	4.18	3.98	3.58	3.40	3.55	3.79
48	5.08	4.80	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28
52	7.33	6.87	5.93	5.38	5.63	6.17
54	8.72	8.14	6.95	6.22	6.47	7.15
56	10.3	9.6	8.1	7.2	7.4	8.2
58	12.1	11.3	9.4	8.2	8.4	9.4
60	14.2	13.1	10.9	9.4	9.6	10.7
62	16.5	15.3	12.6	10.7	10.8	12.1
64	19.1	17.6	14.5	12.2	12.2	13.7
66	22.1	20.3	16.6	13.8	13.7	15.4
68	25.3	23.3	18.9	15.6	15.4	17.2
70	29.0	26.6	21.5	17.6	17.2	19.2
72	33.0	30.3	24.4	19.8	19.2	21.3
74	37.5	34.4	27.6	22.2	21.3	23.6
76	42.5	38.9	31.1	24.8	23.7	26.1
78	48.0	43.9	35.0	27.8	26.2	28.8
80	54.0	49.4	39.2	30.9	29.0	31.7
82	60.6	55.4	43.9	34.4	32.0	34.8
84	67.8	61.9	49.0	38.2	35.3	38.1
86	75.7	69.1	54.5	42.3	38.8	41.7
88	84.3	76.9	60.6	46.8	42.6	45.6
90	93.7	85.4	67.1	51.7	46.8	49.7

Table D.6. Axle load equivalency factors for flexible pavements, trip axles and p of 2.5.

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0000	.0000	.0000	.0000	.0000	.000
4	.0002	.0002	.0002	.0001	.0001	.000
6	.0006	.0007	.0005	.0004	.0003	.000
8	.001	.002	.001	.001	.001	.001
10	.003	.004	.003	.002	.002	.002
12	.005	.007	.006	.004	.003	.003
14	.008	.012	.010	.008	.006	.006
16	.012	.019	.018	.013	.011	.010
18	.018	.029	.028	.021	.017	.016
20	.027	.042	.042	.032	.027	.024
22	.038	.058	.060	.048	.040	.036
24	.053	.078	.084	.068	.057	.051
26	.072	.103	.114	.095	.080	.072
28	.098	.133	.151	.128	.109	.099
30	.129	.169	.195	.170	.145	.133
32	.169	.213	.247	.220	.191	.175
34	.219	.266	.308	.281	.246	.228
36	.279	.329	.379	.352	.313	.292
38	.352	.403	.461	.436	.393	.368
40	.439	.491	.554	.533	.487	.459
42	.543	.594	.661	.644	.597	.567
44	.666	.714	.781	.769	.723	.692
46	.811	.854	.918	.911	.868	.838
48	.979	1.015	1.072	1.069	1.033	1.005
50	1.17	1.20	1.24	1.25	1.22	1.20
52	1.40	1.41	1.44	1.44	1.43	1.41
54	1.66	1.66	1.66	1.66	1.66	1.66
56	1.95	1.93	1.90	1.90	1.91	1.93
58	2.29	2.25	2.17	2.16	2.20	2.24
60	2.67	2.60	2.48	2.44	2.51	2.58
62	3.09	3.00	2.82	2.76	2.85	2.95
64	3.57	3.44	3.19	3.10	3.22	3.36
66	4.11	3.94	3.61	3.47	3.62	3.81
68	4.71	4.49	4.06	3.88	4.05	4.30
70	5.38	5.11	4.57	4.32	4.52	4.84
72	6.12	5.79	5.13	4.80	5.03	5.41
74	6.93	6.54	5.74	5.32	5.57	6.04
76	7.84	7.37	6.41	5.88	6.15	6.71
78	8.83	8.28	7.14	6.49	6.78	7.43
80	9.92	9.28	7.95	7.15	7.45	8.21
82	11.1	10.4	8.8	7.9	8.2	9.0
84	12.4	11.6	9.8	8 5	8.9	9.9
86	13.8	12 9	10.8	9.5	9.8	10 9
88	15.4	14.3	11.9	10 4	10 6	11.9
90	17.1	15 8	13.2	11 3	11.6	12.3

Figure 6. AASHTO Load Equivalency Factors for Flexible Pavement (2).

Axle Load	Traffic Equivalency Factor		Number of Axles		A18 Kip EAL's
Single Axles	P = 2.5, SN = 5				
Under 3,000	0.0002	X	0	=	0.000
3,000 - 6,999	0.0050	X	1	=	0.005
7,000 - 7,999	0.0320	X	6	=	0.192
8,000 - 11,999	0.0870	X	144	=	12.528
12,000 - 15,999	0.3600	X	16	=	5.760
26,000 - 29,999	5.3890	X	1	=	5.3890
Tandem Axle Groups					
Under 6,000	0.0100	X	0	=	0.000
6,000 - 11,993	0.0100	X	14	=	0.140
12,000 - 17,999	0.0440	X	21	=	0.924
18,000 - 23,999	0.1480	X	44	=	6.512
24,000 - 29,999	0.4260	X	42	=	17.892
30,000 - 32,000	0.7530	X	44	=	33.132
32,001 - 32,500	0.8850	X	21	=	18.585
32,501 - 33,999	1.0020	X	101	=	101.202
34,000 - 35,999	1.2300	X	43	=	52.890
18 Kip EAL's for all trucks wieghed				=	255.151

$$\text{Truck Load Factor} = \frac{\text{18 Kip EAL's for all trucks weighed}}{\text{Number of trucks weighed 1654}} = \frac{255.151}{165} = 1.5464$$

Figure 10. Computation of the Truck Load Factor for 5-Axle or Greater Trucks on Flexible Pavement (2).

One-Way ADT	2 Lanes (One-Direction) Inner	2 Lanes (One-Direction) Outer	3+ Lanes (One-Direction) Inner*	3+ Lanes (One-Direction) Center	3+ Lanes (One-Direction) Outer
2,000	6**	94	6	12	82
4,000	12	88	6	18	76
6,000	15	85	7	21	72
8,000	18	82	7	23	70
10,000	19	81	7	25	68
15,000	23	77	7	28	65
20,000	25	75	7	30	63
25,000	27	73	7	32	61
30,000	28	72	8	33	59
35,000	30	70	8	34	58
40,000	31	69	8	35	57
50,000	33	67	8	37	55
60,000	34	66	8	39	53
70,000	--	--	8	40	52
80,000	--	--	8	41	51
100,000	--	--	9	42	49

* Combined inner one or more lanes.

** Percent of all trucks in one direction (note that the proportion of trucks in one direction sums to 100 percent).

Figure 5. Truck Distribution for Multiple-Lane Highways (129 Counts in 6 States, 1982-83) (6).

◎ AASHO Road Test
Brief Description of the AASHO Road Test (1958-1960)

Handouts:

Highway Research Board, "The AASHO Road Test," Report 5, Pavement Research, Special Report 61E, Publication No. 954, National Research Council, Washington, D.C., 1962.

◎ ESAL Concept and Calculations

- Development of the AASHTO Equations for Flexible and Rigid Pavements
- ESAL Concept
  18-Kip ESAL, 18仟磅單軸軸重當量數
- ESAL Calcualtion
  ESAL = 365*(ADT)*(%TRK)*(DD)*
  (LD)*(TF)*((1+g)^n -1)/g)

Handouts:

(Same as above)

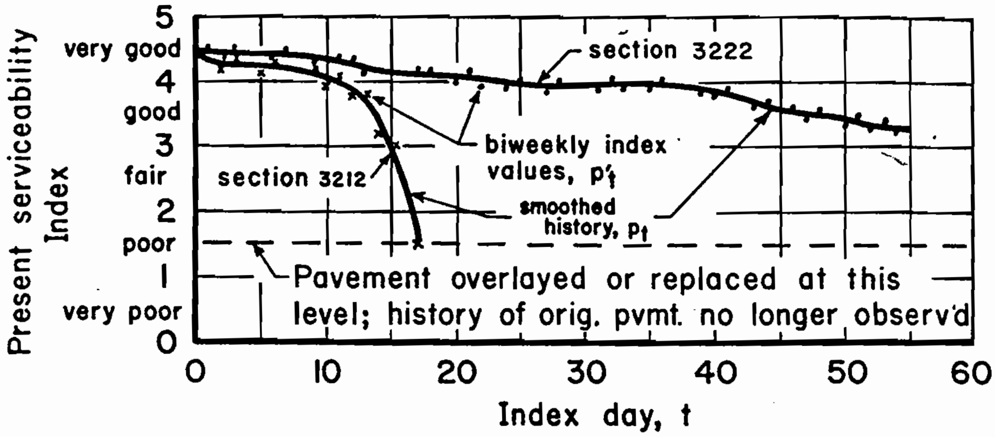


Figure 1–G. Present serviceability histories for two illustrative pavement sections.

Although theories* and procedures exist for dealing with mixtures of axle loads, reference in this paper to any particular number of applications implies that each application represents the same axle weight. For the illustration, Figure 2–G gives both the number of axle load applications between successive index days and the accumulated number of applications for any index day. The respective notation for these two quantities is n_t and N_t. If more than one traffic lane is represented by n_t and N_t, it is assumed that lane to lane variation in n_t is negligible and n_t is averaged for all lanes before the accumulation, N_t. Whenever it is necessary to evaluate accumulated applications between index days, linear interpolation is performed between successive values of N_t.

Before specifications are given for performance data, one more history is discussed—a history that is associated with the general state of environmental conditions at any particular time. This history is called a seasonal weighting function. Relative to a specified norm, or base, it may be supposed that the conditions at any time or location are either normal, better than normal, or worse than normal. It is considered that the seasonal weighting function reflects serviceability loss potential, and that any particular section may or may not lose serviceability during a period when the weighting function is high. No specific formula for a weighting function will be given in this paper, but it is supposed that such a formula has been evolved to give values, q_t, for every index period (Fig. 3–G). This function presumably depends in general on changes in moisture-temperature states, and has the value $q_t = 1.0$ for normal conditions. A value of zero is considered to be a lower bound at which no serviceability-loss potential exists for any pavement-load combination.

The seasonal weighting function (Fig. 3–G) averages about 1.0, so that environmental conditions for the two years average normal even though there is much seasonal variation. Relative to the selected location, this index might not average 1.0 at a second location, whether

* Scrivner, F. H., "A Theory for Transforming the AASHO Road Test Pavement Performance Equations to Equations Involving Mixed Traffic." HRB Special Report 66 (1961).

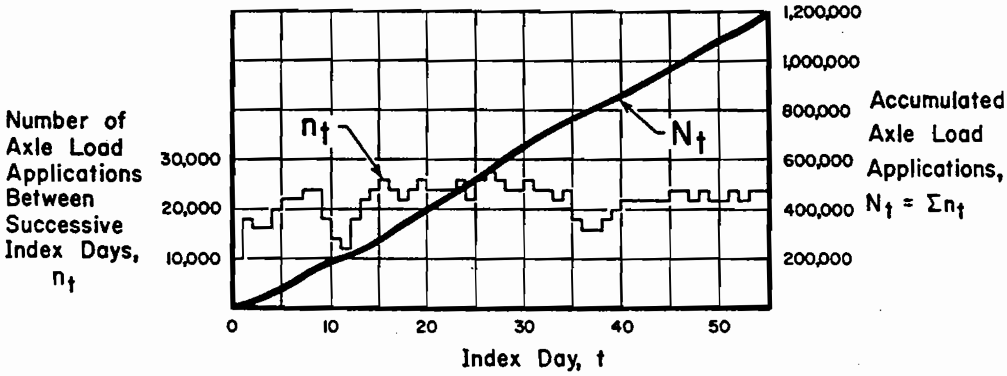


Figure 2–G. Axle load application history for the illustration.

relation indexes are given as 0.48 and 0.70 for unweighted and weighted applications, respectively, and corresponding root mean square residuals are 0.36 and 0.31.

The general nature of the over-all Δ log W distribution (except for Loop 2, lane 1) is indicated by the fact that about 60 percent of all Δ log W is contained within one mean absolute residual and about 90 percent within two mean absolute residuals. The distributions support the statement that in about nine out of ten cases, observations agree with corresponding performance equation estimates to within plus or minus two mean residuals. In other words there is approximately 90 percent confidence (Table 11 includes root mean square residuals, twice whose value can be used to set limits with approximately 95 percent confidence.) that log W will be observed between $\log \hat{W} \pm 0.54$ for unweighted applications and between $\log \hat{W} \pm 0.46$ for weighted applications. In terms of the thickness index, D, these bands correspond approximately to $\hat{D} \pm 0.14\ (\hat{D} + 1)$ for unweighted applications and to $\hat{D} \pm 0.11\ (\hat{D} + 1)$ for weighted applications, where $\hat{D}$ is obtained by entering the appropriate performance equation (or curve) with fixed W and calculating D. For relatively heavy designs, the uncertainty represented by two mean residuals in log W is approximately $0.18\hat{D}$ using the unweighted applications formulas and approximately $0.14\hat{D}$ using the weighted application formulas. All confidence limits such as these are relative to the Road Test conditions and range of variables.

The last part of Table 11 summarizes log W and p differences observed between replicate test sections. In all there were 32 pairs of replicate sections in Design 1, and the mean replicate difference is 0.46 for p, 0.15 for unweighted log W differences and 0.17 for weighted log W differences. In those pairs where one section was out of test before the second, replicate differences were provided at the missing points by assuming that the remaining differences would be as large as when the first section went out of test.

For whatever reasons two replicate sections do not show the same performance, it can be expected that the performance data will deviate from any fitted equation. For a particular lane a satisfactory model and fitting procedure should result in residuals that average about the same as deviations of replicate observations from their own mean. For two replicates, then, estimation errors should average to be about one-half the replicate differences if the fit is to be judged adequate. Since the performance equations were developed across lanes and loops it is expected that the average residual will be more than one-half the average replicate difference, but how much greater cannot be determined in the absence of replicate lanes and loops. In the Road Test performance analyses it has been supposed that a satisfactory model and fit is indicated whenever mean absolute residuals are about equal to replicate mean differences. Table 11 gives this comparison for unweighted applications to be 0.53 vs 0.46 for p and 0.27 vs 0.15 for log W. For weighted applications the comparison is 0.46 vs 0.46 for p and 0.23 vs 0.17 for log W. It is quite possible that other models and fitting procedures may do equally well, and that some will represent better the long-time performance of highways in actual service.

2.2.2.1.1 Seasonal Weighting Function.—The concept of a seasonal weighting function to allow for changing load effects in a changing environment was discussed in Section 1.3.4. The weighting function, q_t, used in flexible pavement analyses is given by

$$q_t = \left[\frac{2d_t - d_{t-1}}{\bar{d}}\right]^2 \qquad (23)$$

in which d_t is an estimate of the average deflection under a 6-kip wheel load of eight sections in Loop 1 (the non-traffic loop) during index period t. Deflections were generally taken twice during each index period and averaged, then a 3-point moving average was used to smooth the deflection history of the eight sections. The deflection d_{t-1} is the smoothed deflection for index period $t - 1$.

Division by $\bar{d}$, the 2-yr average of d_t, makes q_t a unitless factor and also makes the weighting function relative to the Road Test conditions. Whenever $d_t = d_{t-1} = \bar{d}$, then $q_t = 1$, so that the weighting function is unity if deflections in Loop 1 are unchanging and are at the 2-yr average value.

The exponent 2 in Eq. 23 has been assumed as an appropriate factor for increasing the amplitude of q_t in periods of high increasing deflection relative to periods of low constant deflection. Data and values for q_t are given in Appendix B.

In Table 11, the use of the seasonal weighting function increased the correlation index from 0.48 to 0.70 and reduced the mean residuals in log W from 0.27 to 0.23.

2.2.2.2 Paved Shoulder Studies.—A study of the effectiveness of paved shoulders (Design 2) was included in the Road Test. A total of 48 test sections was provided in this study.

Unfortunately, the pavements selected for the tests were underdesigned to the extent that 42 of the sections failed during the first spring of traffic operation and little information of value was disclosed by the experiment. An attempt was made to obtain additional information by studying the differences in performance of the outer and inner wheelpaths of the test sections of the main experiment.

The results of these studies pointed to the fact that the pavement needed to maintain a or not the same seasonal variation occurred at the two locations.

For any index period, the product of the weighting function value with axle load application is assumed to be w_t, the number of weighted applications for the period; therefore, $w_t = q_t n_t$ can be obtained by multiplication of index day ordinates from Figures 2–G and 3–G. Also, W_t is assumed to be the accumulation of weighted axle load applications through any index day. Graphs for both w_t and W_t are shown in Figure 4–G. If the weighting function were taken to be 1.0 on every index day, then the curve in Figure 3–G would be horizontal at unit height, and Figure 4–G would be identical with Figure 2–G. Thus, N_t is a special case of W_t if q_t is always 1.0. In all the discussion that follows accumulated axle load applications are represented by W but any difference between W and N depends on the values prescribed for q_t.

All of the variables have values that are observed and computed at points in time. If smoothed serviceability values for a pavement section are plotted against accumulated axle applications rather than against time, the resultant curve is called the section's serviceability trend. Coordinates of points on the serviceability trend are denoted by p and W, and the trend of p with W is defined to be the pavement's performance. In other words, serviceability trends are considered to be performance curves that show how pavements are affected by applied loads.

Trend plots for the two sections of Figure 1–G are shown in Figure 5–G for the case when applications are not weighted; that is, when $v_t = 1$. Coordinates for the trend curves in Figure 5–G were obtained from ordinates of Figures 1–G and 2–G on common index days. Similarly Figure 6–G shows trend curves for the same sections when the seasonal weighting function of Figure 3–G is used to obtain W. That is, coordinates for Figure 6–G were obtained from ordinates of Figures 1–G and 4–G on common index days.

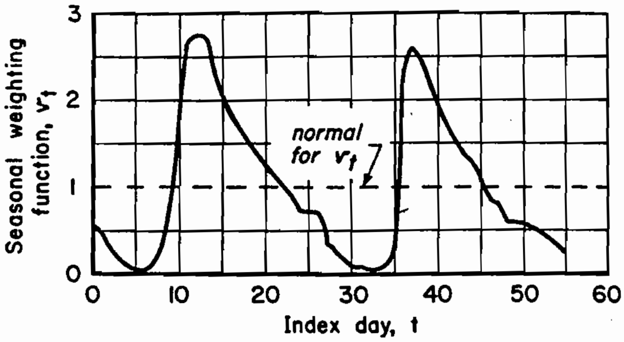


Figure 3–G. Seasonal weighting function.

Summarizing the definitions of the various serviceability-time-applications relationships:

Serviceability history is the plot of observed values of serviceability p_t' on a time scale;

Smoothed serviceability history is the plot of the 5-point moving average of the serviceability history values on a time scale and smoothed history values are designated by p_t;

Serviceability trend is the plot of smoothed serviceability history values p on an accumulated axle application scale W where axle applications may be weighted or unweighted; and the

Performance of a pavement is given by its serviceability trend.

The final step in the specification of performance data is to assume that for numerical analysis a small number of pairs of coordinates from any trend curve can be selected to represent satisfactorily the curve. In the Road Test rationale five pairs of coordinates were selected from every trend. If the trend was complete (*i.e.*, p had fallen to 1.5) then the trend was represented by five values that spanned the range of p. Specifically, W was noted when p was 3.5, 3.0, 2.5, 2.0, and 1.5. In the case of incomplete serviceability trends (p at the end of the Road Test was greater than 1.5) the observations were spanned by noting pairs of

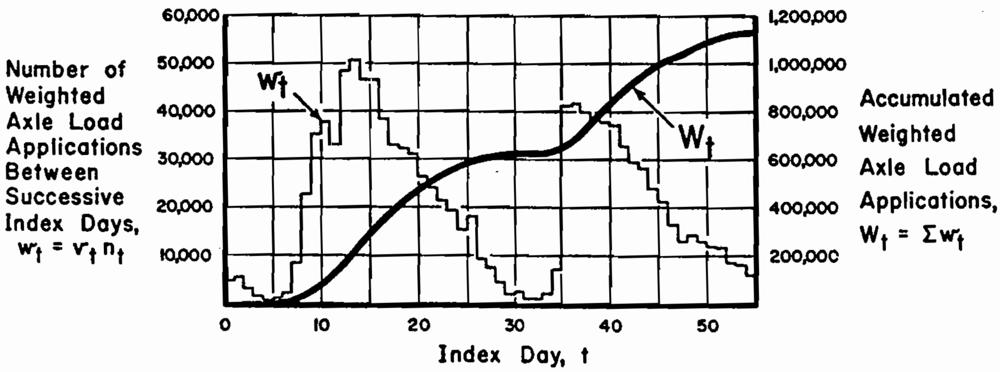


Figure 4–G. Weighted axle load applications for the illustration (seasonal weighting function from Fig. 3–G).

Truck Class	Interstate Rural		Other Rural		All Rural		All Urban		All Systems	
	Percent Trucks									
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Single-unit trucks										
2-axle, 4-tire	39	17-64	58	40-80	47	23-66	61	33-84	49	26-67
2-axle, 6-tire	10	5-15	11	4-18	10	4-16	13	4-26	11	5-20
3-axle or more	2	1-4	4	1-6	2	1-4	3	1-7	3	1-5
All single-units	51	30-71	73	50-88	59	36-77	77	55-94	63	36-81
Multiple unit trucks										
3-axle	1	<1-2	1	<1-3	1	1-3	1	<1-4	1	<1-2
4-axle	5	1-10	3	<1-8	4	1-10	4	1-13	4	1-10
5-axle or more**	43	24-59	23	8-40	36	16-57	18	5-37	32	15-56
All multiple-units	49	31-71	27	13-50	41	23-66	23	6-44	37	20-67
All trucks	100		100		100		100		100	

*Compiled from data supplied by the Highway Statistics Division, U.S. Federal Highway Administration.
**Including full-trailer combinations in some states.

Figure 2. Distribution of Trucks on Different Classes of Highways (3).

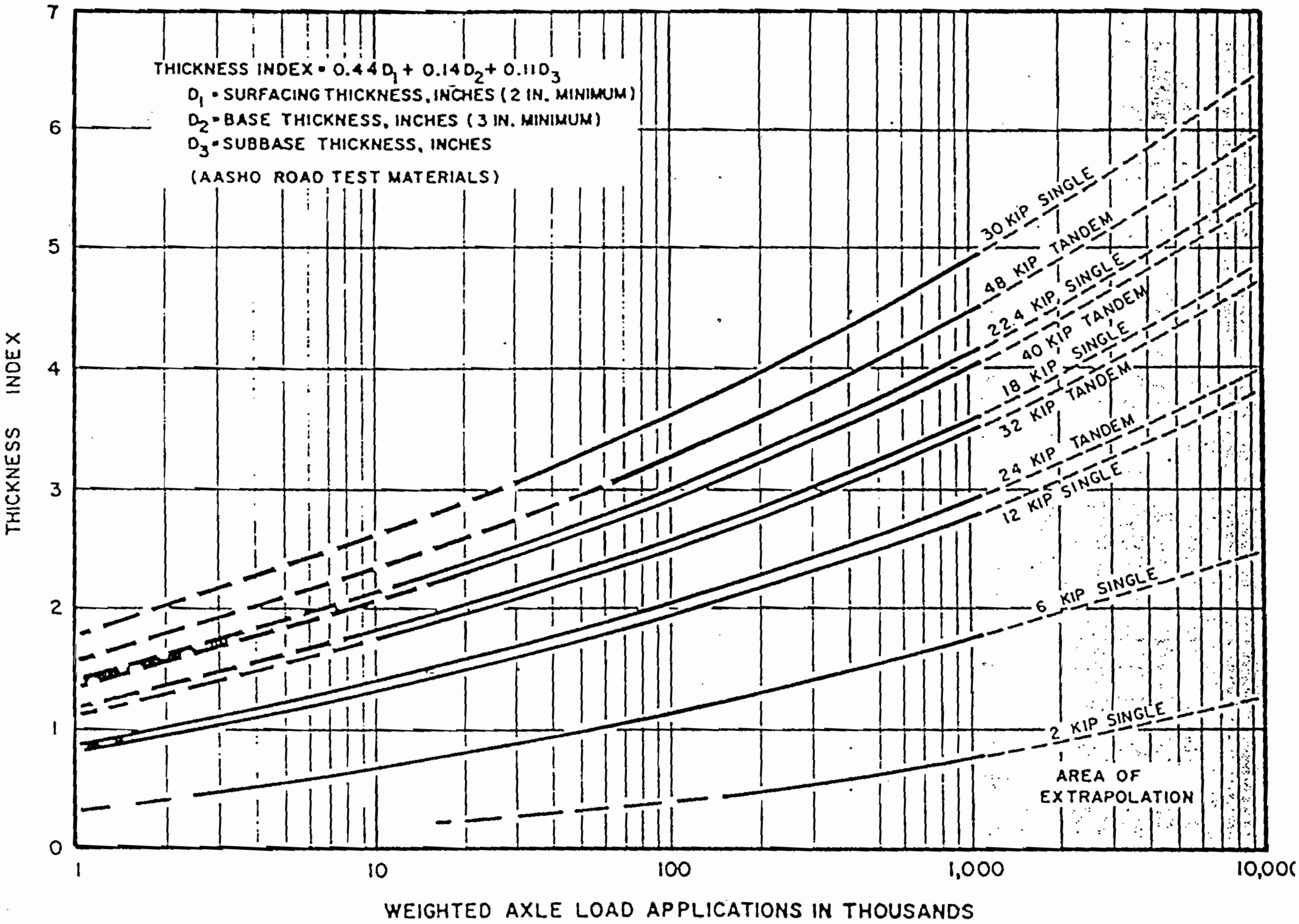


Figure 23. Main factorial experiment, relationship between design and axle load applications at $p = 1.5$ (from Road Test equations).

significant effects. Thus this and similar analyses of variance all pointed to the use of a thickness index as given by Eq. 16.

The third part of Tables 9 and 10 shows within loop estimates for a_1, a_2, and a_3 that were obtained from the variance analyses. Weighted averages of these estimates gave the values shown in Eqs. 19 and 22. The last part shows the results of within lane regression analyses that were used to determine values for A_1 in Eq. 15. In the logarithmic form, A_1 is the coefficient of log $(a_1D_1 + a_2D_2 + a_3D_3 + 1)$, and estimates for this coefficient are shown for each lane at the bottom of the table. Weighted average values for A_1 are 9.36 and 8.94 for the two cases represented by Eqs. 18 and 21. The remaining constants in Eqs. 14 and 15 were determined by applying procedures described in Appendix G to the performance data of Appendix A.

If W represents weighted applications obtained through the use of seasonal weighting

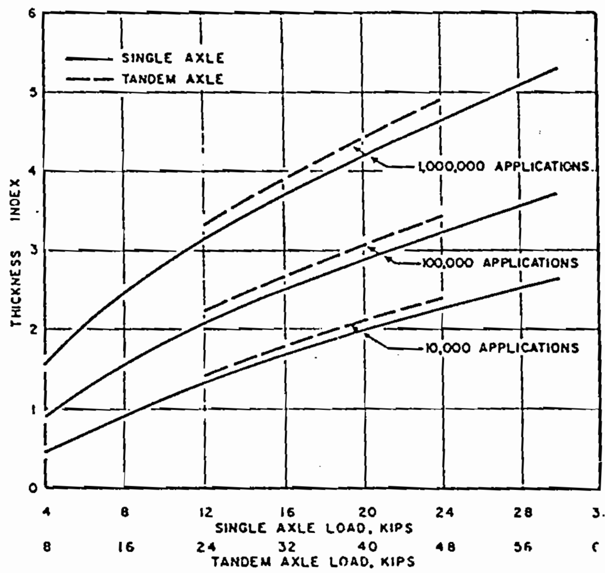


Figure 24. Main factorial experiment, relationship between design and load at $p = 2.5$.

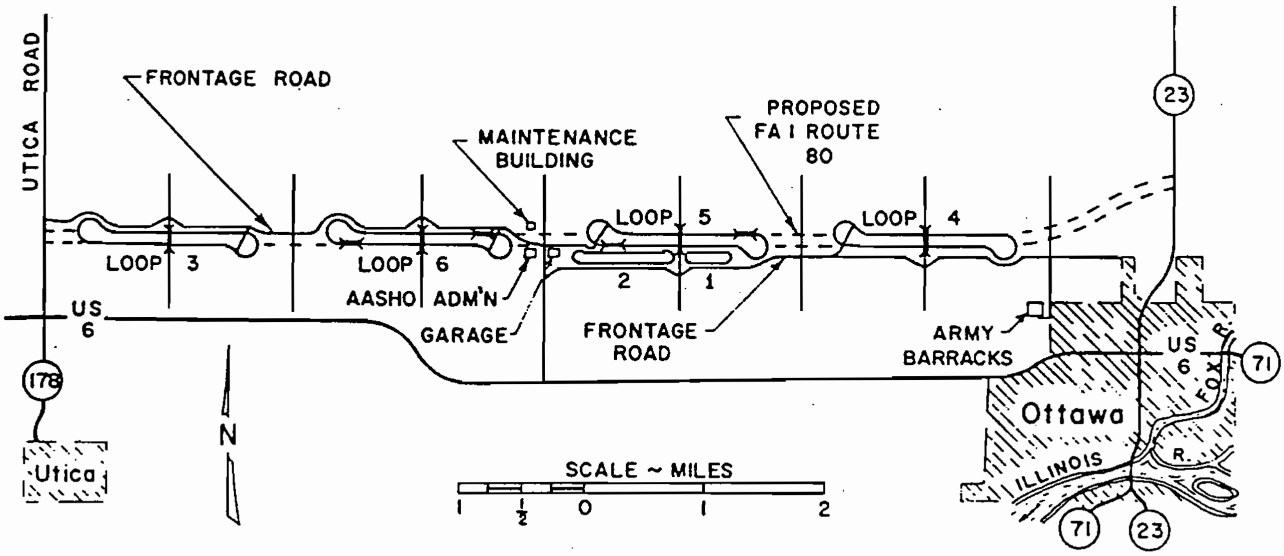


Figure 2. Layout of AASHO Road Test.

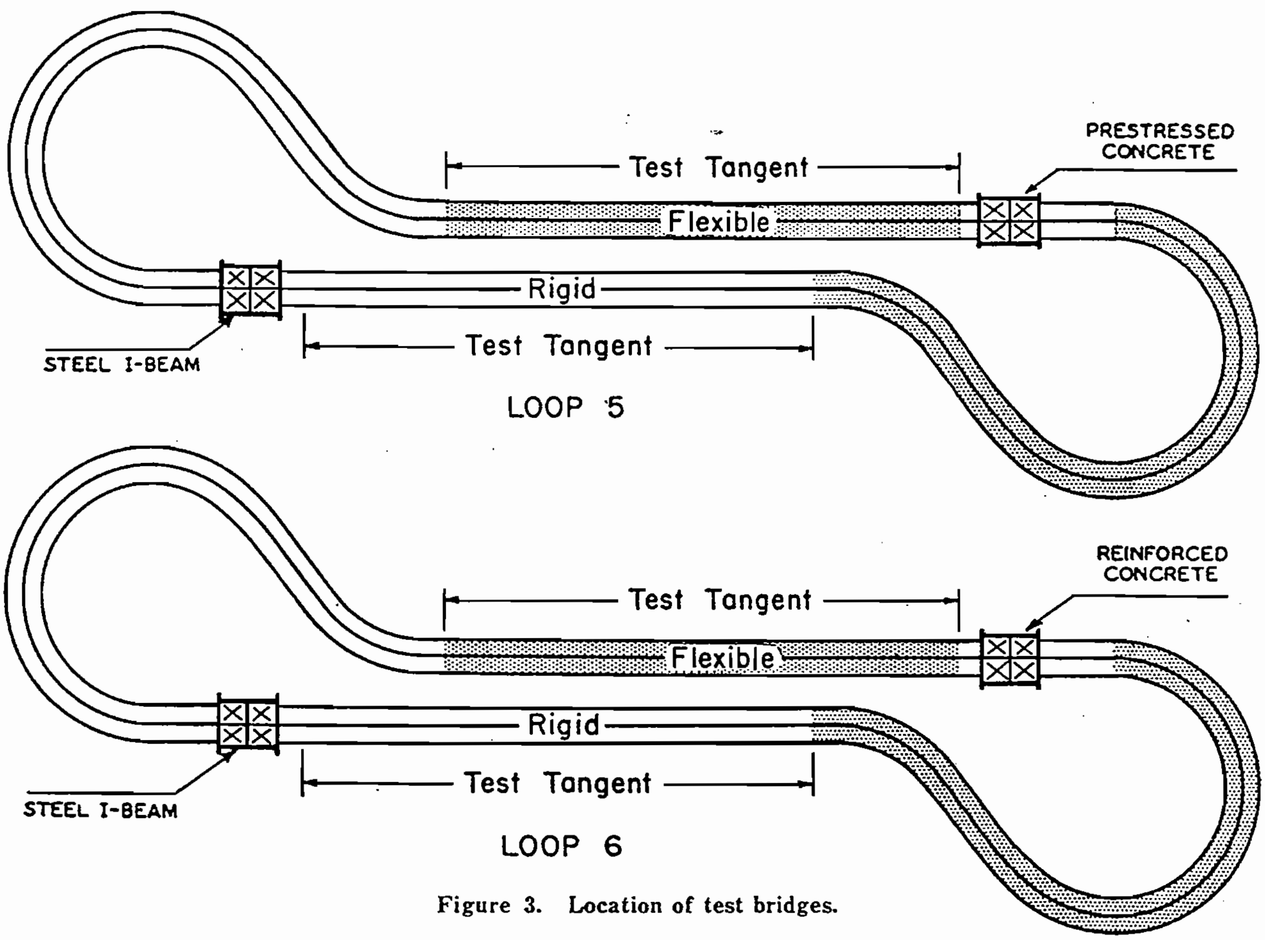


Figure 3. Location of test bridges.

Analysis Period = 20 Years

Location Example 1

Assumed SN or D = 9"

Vehicle Types	Current Traffic (A)	Growth Factors (B)	Design Traffic (C)	E.S.A.L. Factor (D)	Design E.S.A.L. (E)
		2%			
Passenger Cars	5.925	24.30	52,551,787	.0008	42,041
Buses	35	24.30	310,433	.6806	211.280
Panel and Pickup Trucks	1,135	24.30	10,066,882	.0122	122,816
Other 2-Axle/4-Tire Trucks	3	24.30	26,609	.0052	138
2-Axle/6-Tire Trucks	372	24.30	3,299,454	.1890	623,597
3 or More Axle Trucks	34	24.30	301.563	.1303	39,294
All Single Unit Trucks					
3 Axle Tractor Semi-Trailers	19	24.30	168,521	.8646	145,703
4 Axle Tractor Semi-Trailers	49	24.30	434,606	.6560	285,101
5 + Axle Tractor Semi-Trailers	1,880	24.30	16,674,660	2.3719	39,550,626
All Tractor Semi-Trailers					
5 Axle Double Trailers	103	24.30	913,559	2.3187	2,118,268
6 + Axle Double Trailers	0	24.30			
All Double Trailer Combos.					
3 Axle Truck-Trailers	208	24.30	1,844,856	.0152	28,042
4 Axle Truck-Trailers	305	24.30	2,705,198	.0152	41,119
5 + Axle Truck-Trailers	125	24.30	1,108,688	.5317	589,489
All Truck-Trailer Combos.					
All Vehicles	10,193		90,406,816	Design E.S.A.L.	43,772,314

Figure 11. Worksheet for Calculating 18-kip Equivalent Single-Axle Load (ESAL) Applications (2).

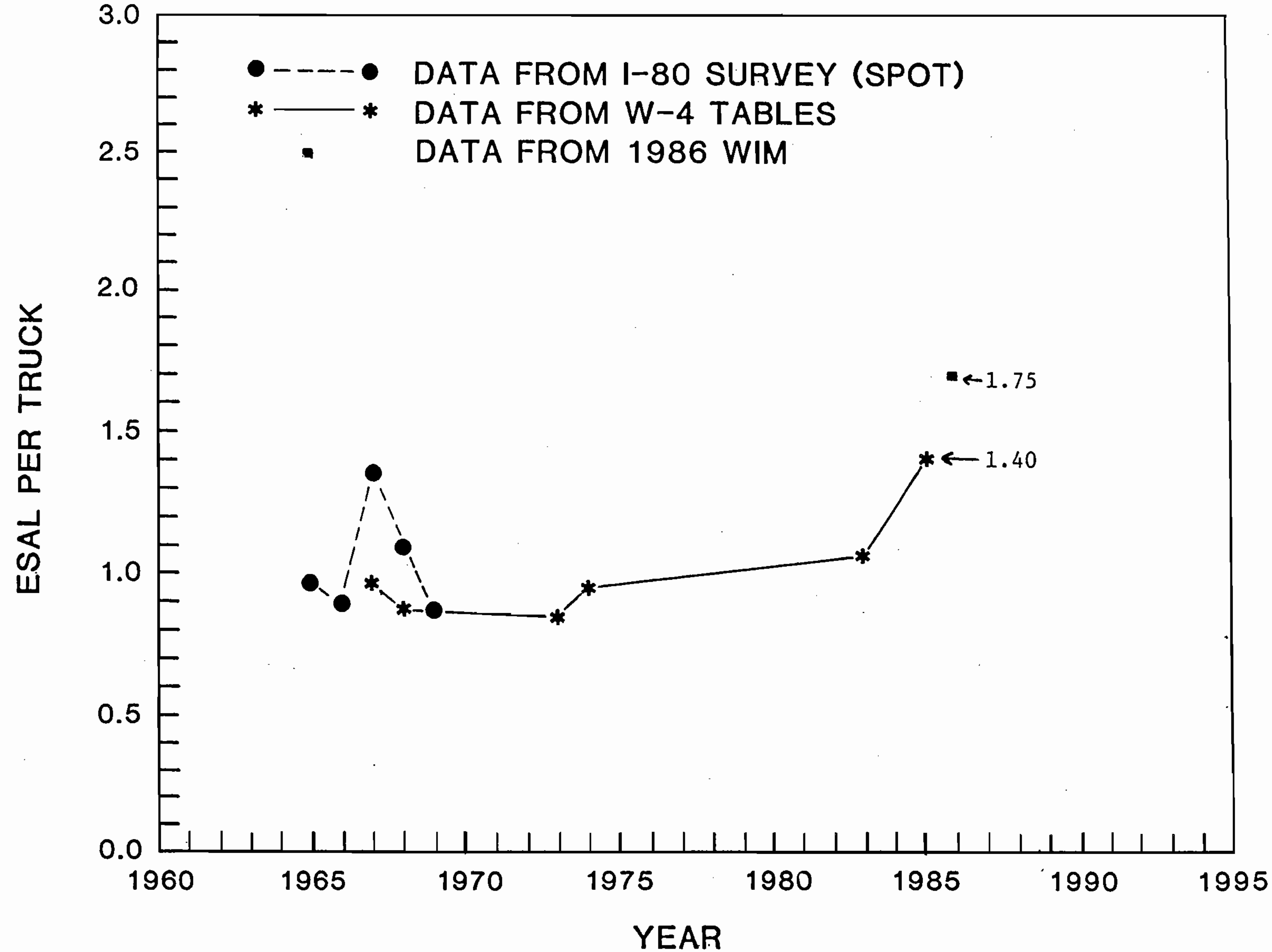


Figure 9. ESALs Per Truck Calculated from W-4 Tables, with WIM Data Indicated in 1986.

Vehicle Type	Truck Factors									
	Rural Systems						Urban Systems		All Systems	
	Interstate Rural		Other Rural		All Rural		All Urban			
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Single-unit trucks										
2-axle, 4-tire	0.02	0.01-0.06	0.02	0.01-0.09	0.03***	0.02-0.08	0.03***	0.01-0.05	0.02	0.01-0.07
2-axle, 6-tire	0.19	0.13-0.30	0.21	0.14-0.34	0.20	0.14-0.31	0.26	0.18-0.42	0.21	0.15-0.32
3-axle or more	0.56	0.09-1.65	0.73	0.31-1.57	0.67	0.23-1.53	1.03	0.52-1.99	0.73	0.29-1.59
All single-units	0.07	0.02-0.16	0.07	0.02-0.17	0.07	0.03-0.16	0.09	0.04-0.21	0.07	0.02-0.17
Tractor semi-trailers										
3-axle	0.51	0.30-0.86	0.47	0.29-0.82	0.48	0.31-0.80	0.47	0.24-1.02	0.48	0.33-0.78
4-axle	0.62	0.40-1.07	0.83	0.44-1.55	0.70	0.37-1.34	0.89	0.60-1.64	0.73	0.43-1.32
5-axle or more**	0.94	0.67-1.15	0.98	0.58-1.70	0.95	0.58-1.64	1.02	0.69-1.69	0.95	0.63-1.53
All multiple units	0.93	0.67-1.38	0.97	0.67-1.50	0.94	0.66-1.43	1.00	0.72-1.58	0.95	0.71-1.39
All trucks	0.49	0.34-0.77	0.31	0.20-0.52	0.42	0.29-0.67	0.30	0.15-0.59	0.40	0.27-0.63

Compiled from data supplied by the Highway Statistics Division, U.S. Federal Highway Administration.
**Including full-trailer combinations in some states.*
***See Article 4.05 for values to be used when the number of heavy trucks is low.*

Figure 8. Distribution of Truck Factors for Different Classes of Highways and Vehicles in the United States (9).

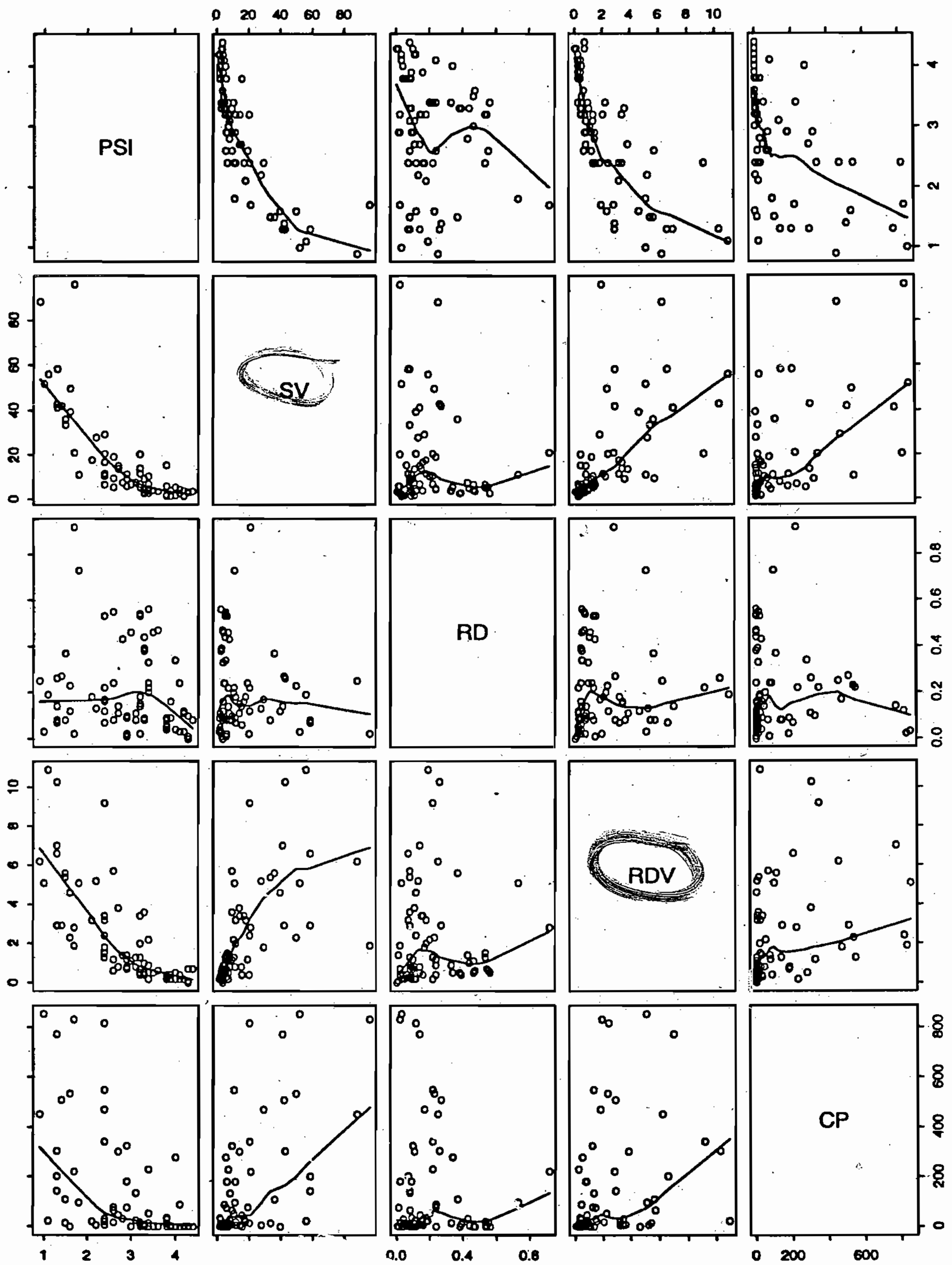


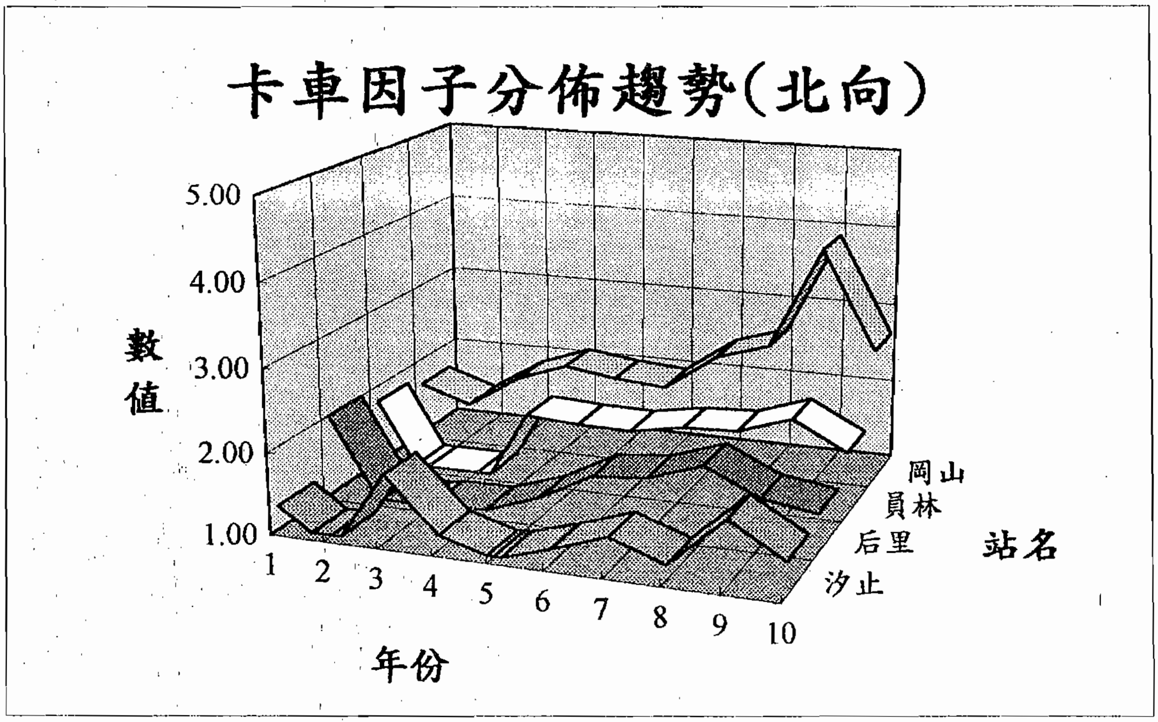
Figure 3.4 - Using Scatterplot Smoother (lowess) on the Scatter Plot Matrix

各站之TF值(北向)

年度\站名	汐止	后里	員林	岡山	平均
70	1.28294	1.99182	1.79620	1.66052	1.68287
71	0.82935	0.91712	0.73090	1.44614	0.98088
72	1.81488	1.02673	0.70082	1.85465	1.34927
73	1.17328	1.02688	1.81813	2.09390	1.52805
74	0.97371	1.25037	1.77454	2.00173	1.50009
75	1.17576	1.60636	1.76216	1.95284	1.62428
76	1.40749	1.66493	1.87759	2.41035	1.84009
77	1.17294	1.89006	1.90699	2.61529	1.89632
78	1.78024	1.57651	2.12938	3.89897	2.34627
79	1.38461	1.47839	1.78861	2.67640	1.83200
平均	1.29952	1.44292	1.62853	2.26108	1.65801

各站之 TF 值(南向)

年度\站名	汐止	后里	員林	岡山	平均
70	3.1088	1.2598	1.2461	0.6545	1.5673
71	1.7769	1.2372	0.6916	0.6792	1.0962
72	2.8092	0.9631	0.7910	0.6096	1.2932
73	2.0559	1.0521	0.6646	0.7345	1.1268
74	2.0176	0.9982	0.8722	0.9264	1.2036
75	1.8361	1.6129	0.9604	1.0354	1.3612
76	2.7124	1.1785	1.3642	1.0808	1.5840
77	2.6762	1.5207	1.3589	1.5638	1.7799
78	2.9583	1.5089	1.8692	1.9978	2.0836
79	1.8864	1.6639	1.5600	1.7465	1.7142
平均	2.3838	1.2995	1.1378	1.1029	1.4810


卡車因子分佈趨勢(北向)
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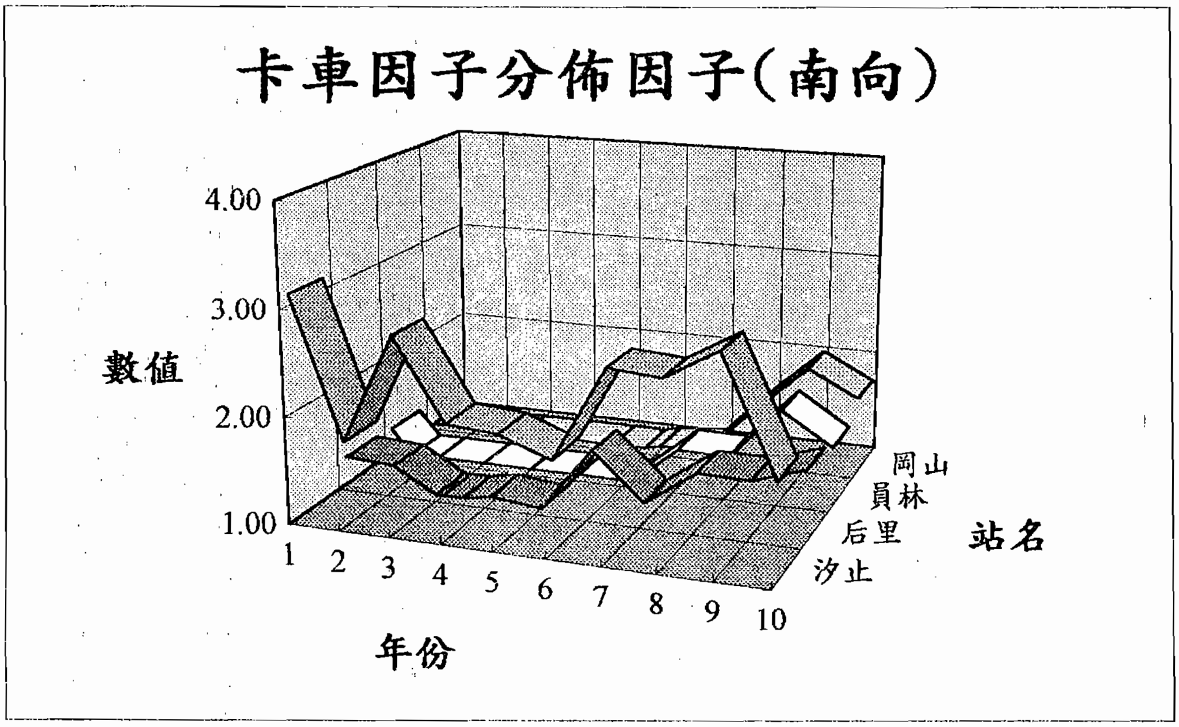
后里
汐止
站名


卡車因子分佈因子(南向)
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年份
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后里
汐止
站名