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.

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

Note: Shaded sections are replicates

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

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
[illegible]	[illegible]	[illegible]	[illegible]	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]	[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

Table 2 Designs for Flexible

section. Figures 19, 20 and 21 are examples of these charts as they may be found for each section in DS 4199.

Basic data relative to the performance of the factorial sections for both weighted and unweighted application are given in Appendix A. Data for a present serviceability level of 1.5 and 2.5, are also given in Tables 5, 6, 7 and 8. Load applications for each design of pavement are given for those sections that were removed from the test and p values for those sections that survived the test.

2.2.2 *Performance as a Function of Design and Load*

This subsection gives relationships between flexible pavement performance and variables that describe load and pavement design. Performance data, models, and analytical procedures described in Section 1.3 are used to obtain specific performance-design-load equations for the factorial experiments. This section also includes associations of performance with design and load variables for the paved shoulder studies and for the special base type studies.

2.2.2.1 Main Factorial Experiments (Design 1).—This subsection contains the results of the major Road Test flexible pavement analysis, the pavement performance analysis, and develops the relationships for flexible pavement sought in the first objective. These relationships have been reduced to four equations containing terms for the variables included in the test. Eqs. 13, 17, 18, and 19 are for the case where load applications have been adjusted by the seasonal weighting function; similar equations are given for unweighted applications.

Graphs and tables were constructed from the equations for use in the study of performance over the wide range of designs and loads included in the Road Test.

A convenient presentation of the relationships for the axle loadings of the Road Test is shown in Figure 22. For example, to determine what pavement structure would have survived a million 22.4-kip single axle loads at the Road Test before its serviceability level dropped to 2.5, the chart is entered at 1,000,000 applica-

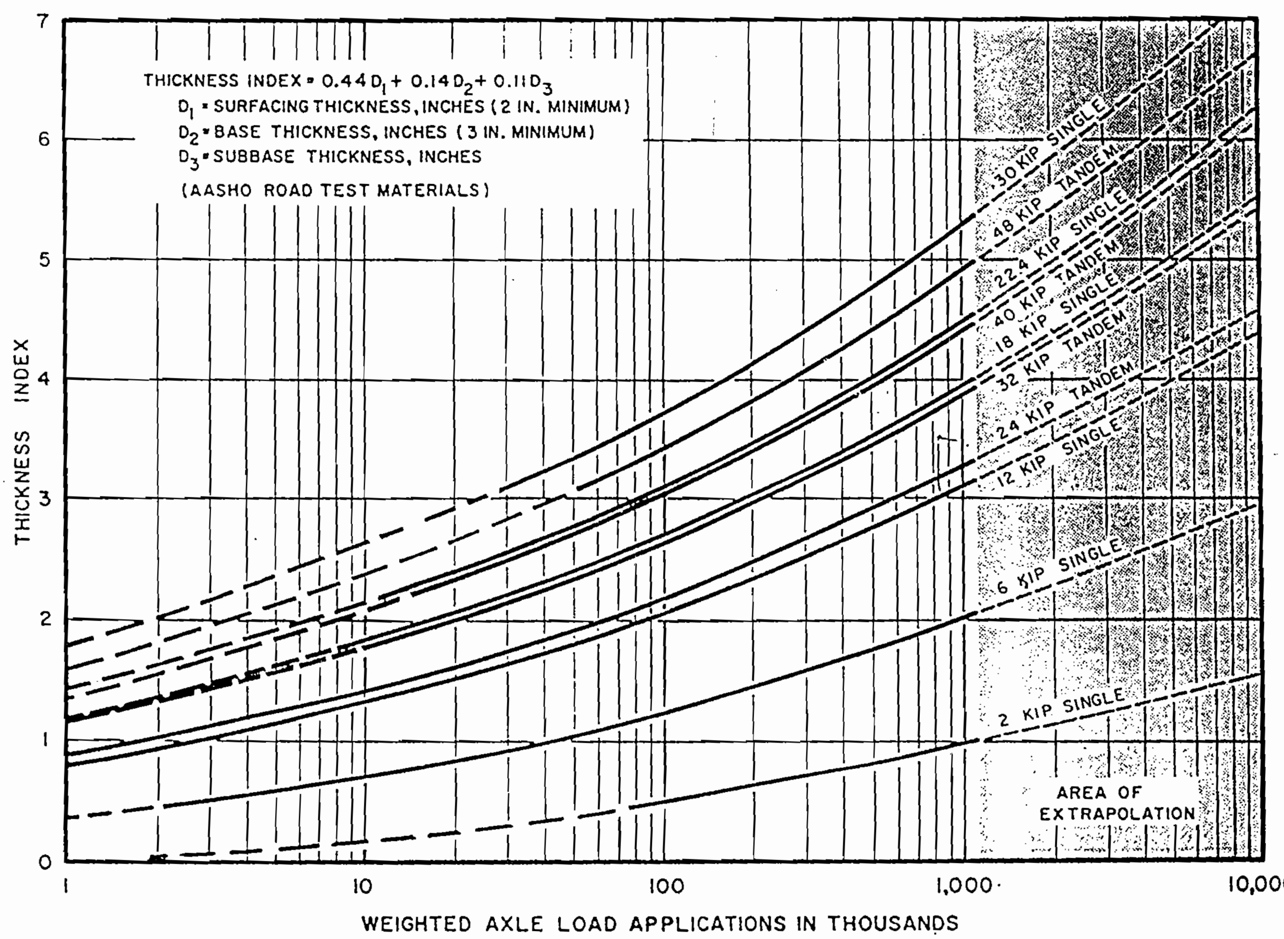

Figure 22. Main factorial experiment, relationship between design and axle application at $p = 2.5$ (from Road Test equations).

tions on the abscissa and the thickness index (4.5) is read on the ordinate scale. Asphaltic concrete surfacing, base and subbase may be combined in any combination for an index of 4.5, provided it meets the conditions for use of the thickness index equation stated on the chart. Many combinations of structural layers will meet these conditions. One, for example, is 4 in. of surfacing, 10 in. of base and 12 in. of subbase.

Since these equations represent serviceability trend data observed in the test, some Road Test sections failed sooner and some later than indicated by the smooth curves. Thus, some allowance should be made for the scatter of the data as shown, for example, in Figure 25. Through a residual analysis it was found that the scatter corresponds to approximately ±14 percent of the thickness index values given by the curves. If comparisons are made with observed performance of actual highways in service, additional allowance should be made to account for differences between the Road Test and the actual highway in materials, environment, and loading history.

These relationships are not intended to be design equations. However, they can serve as a basis for design procedures in which variables not included in the Road Test, such as soil type, are considered.

Tables and discussion are included to show the basis for determining the significance or nonsignificance of the various effects. Correlation indexes show the degree of correlation found in the relationships; mean residuals, the degree of scatter of the observed performance data from the predictions of the performance equations.

The thickness index found to apply to Road Test flexible pavements is of interest in itself. For the weighted applications case the thickness index equation (Eq. 19) indicates that an inch of surfacing was about three times as effective as an inch of base and four times as effective as an inch of subbase in improving pavement performance within the range of design studied.

The use of the seasonal weighting function on axle load applications was found to increase the correlation index from 0.48 to 0.70 and to reduce the mean residuals by 15 percent.

The general model used to represent pavement performance was Eq. 4. For flexible pavement test sections in the factorial experiments the average initial serviceability trend value was $c_0 = 4.2$, and since $c_1 = 1.5$, $c_0 - c_1 = 2.7$, and the trend curves are represented by

$$p = 4.2 - 2.7 \left(\frac{W}{\rho}\right)^{\beta} \qquad (12)$$

Both β and ρ are positive functions of the design variables, D_1 (surfacing thickness, in.), D_2 (base thickness, in.), and D_3 (subbase thickness, in.), and of the load variables, L_1 (nominal axle load, kips*) and L_2 (1 for single axles or 2 for tamdem axles).

The function β determines the general shape of the serviceability trend with increasing axle load applications, W. If $\beta = 1$, the trend is a straight line; if $\beta > 1$, the serviceability loss rate increases with applications; and if $\beta < 1$, the loss rate decreases with axle load repetitions. Graphs of the performance data for flexible pavements in Appendix A indicated that designs failing early in the Road Test tended to have an increasing rate of serviceability loss ($\beta > 1$), while more adequate designs as a rule had a decreasing loss rate ($\beta < 1$). Estimates of β were obtained from the performance data of a number of sections that experienced relatively little serviceability loss in the Road Test. The average of these values was approximately 0.4, and this value was assigned to β_0, the assumed minimum value for β in Eq. 6.

The function ρ is equal to the number of load applications at which $p = 1.5$, and is assumed to increase as design increases and to decrease as load increases. The over-all aim of the performance analysis is to arrive at formulas for β and ρ in terms of D_1, D_2, D_3, L_1 and L_2 so that Eq. 12 may be used to predict the value of p after a specified number of applications, W. Or if Eq. 12 is solved for log W,

$$\log W = \log \rho + \frac{\log\left(\frac{4.2 - p}{2.7}\right)}{\beta} \qquad (13)$$

then Eq. 13 may be used to predict the number of applications required to reduce p to a specified value.

For the flexible pavements, β and ρ are given by particular cases of Eqs. 6 and 7 of Section 1.3.5, as follows:

$$\beta = 0.4 + \frac{B_0(L_1 + L_2)^{B_2}}{(D + 1)^{B_1} L_2^{B_3}} \qquad (14)$$

$$\rho = \frac{A_0(D + 1)^{A_1} L_2^{A_3}}{(L_1 + L_2)^{A_2}} \qquad (15)$$

in which D is a thickness index given by

$$D = a_1 D_1 + a_2 D_2 + a_3 D_3 \qquad (16)$$

If the coefficients a_1, a_2 and a_3 in Eq. 16 are each assigned a value of one, D is the total structure thickness. In the Road Test analyses,

* For example, for single axle loads of 18 or 22.4 kips, L_1 = 18 or 22.4; for tandem axle loads of 32 or 40 kips, L_1 = 32 or 40.

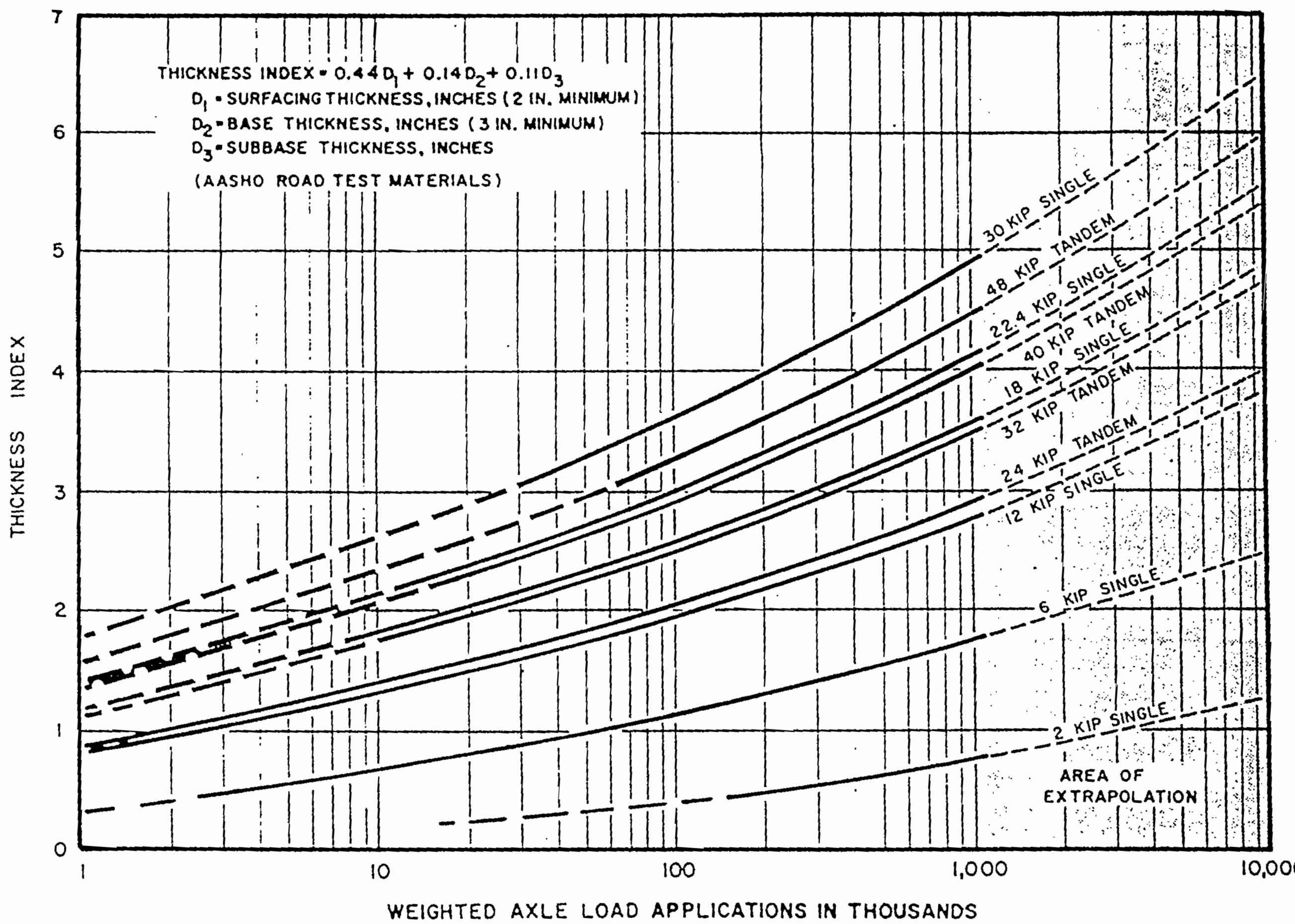

Figure 23. Main factorial experiment, relationship between design and axle load applications at $p = 1.5$ (from Road Test equations).

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

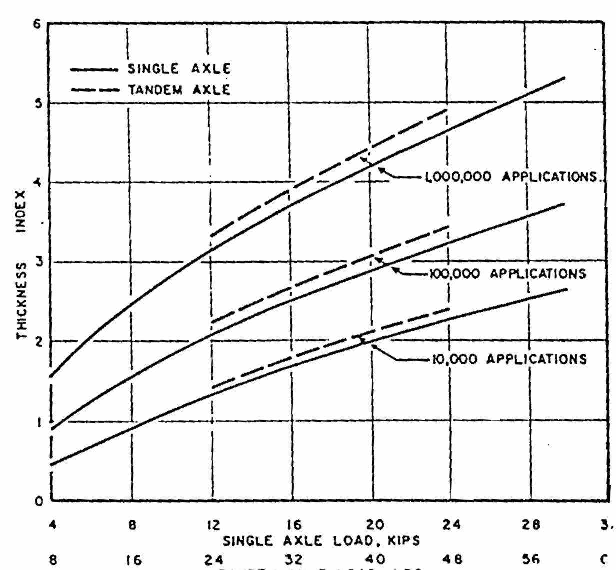

Figure 24. Main factorial experiment, relationship between design and load at $p = 2.5$.

function described in Section 2.2.2.1.1, then the analysis gives the following equations:

$$\beta = 0.4 + \frac{0.081\,(L_1 + L_2)^{3.23}}{(D + 1)^{5.19}\,L_2^{3.23}} \qquad (17)$$

$$\rho = \frac{10^{5.03}\,(D + 1)^{9.36}\,L_2^{4.33}}{(L_1 + L_2)^{4.79}} \qquad (18)$$

$$D = 0.44D_1 + 0.14D_2 + 0.11D_3 \qquad (19)$$

If the applications are unweighted, then the performance equations are as follows:

$$\beta = 0.4 + \frac{0.083\,(L_1 + L_2)^{4.87}}{(D + 1)^{8.73}\,L_2^{4.87}} \qquad (20)$$

$$\rho = \frac{10^{6.16}\,(D + 1)^{8.94}\,L_2^{4.17}}{(L_1 + L_2)^{4.54}} \qquad (21)$$

$$D = 0.37D_1 + 0.14D_2 + 0.10D_3 \qquad (22)$$

Thus for a particular pavement design and axle load, either Eqs. 17, 18 and 19 or Eqs. 20, 21 and 22 give values for β and ρ that may be substituted in Eq. 12 if p is to be estimated from W, or in Eq. 13 if W is to be estimated when p is given. Figures 22 and 23 show how W varies with D in Eq. 13 when p is fixed at 2.5 and 1.5, respectively. Each figure has ten curves, one curve for each test load used in the Road Test.

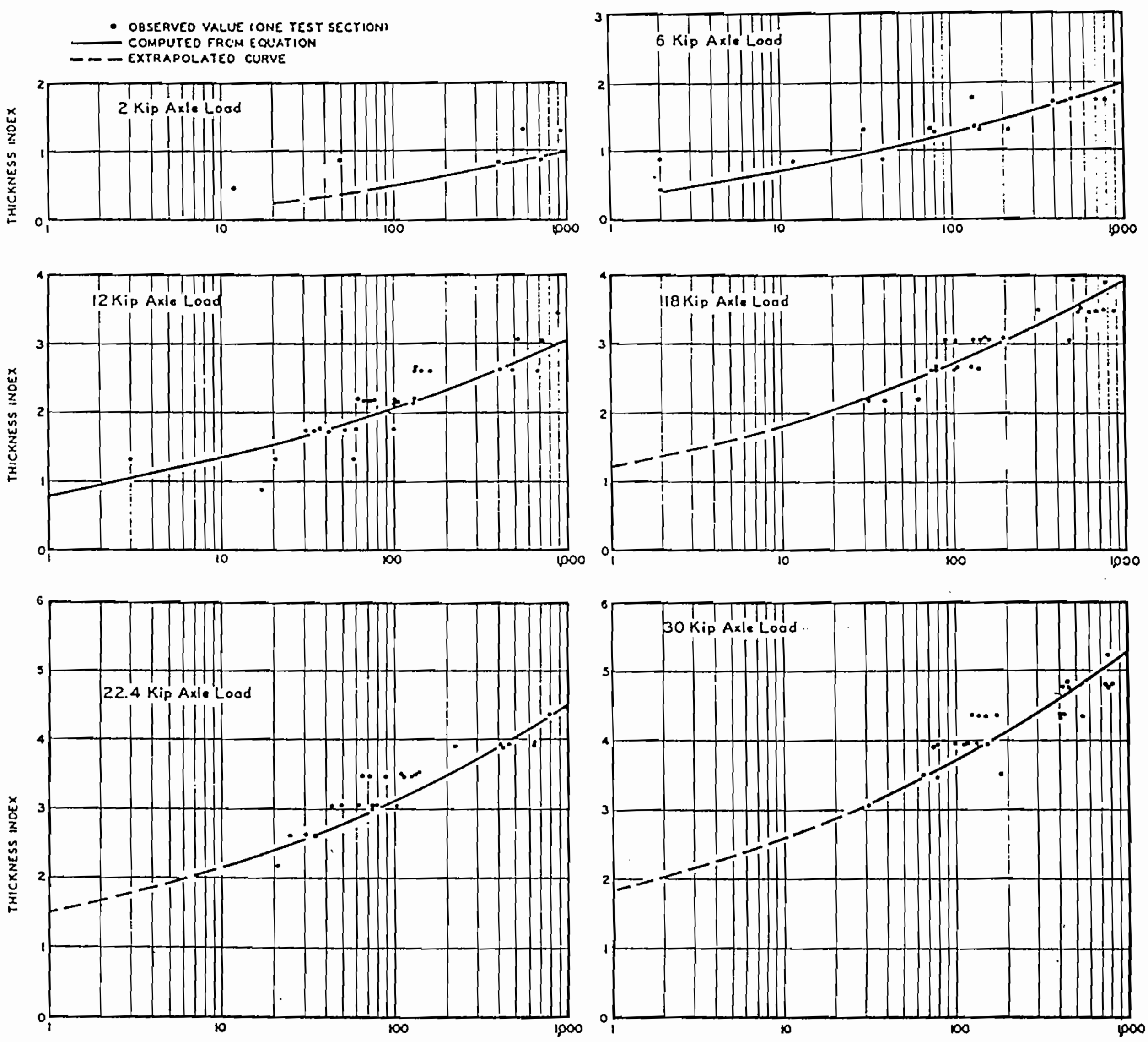

Figure 25. Main factorial experiment, relationship between design and single axle load applications at p = 2.5.

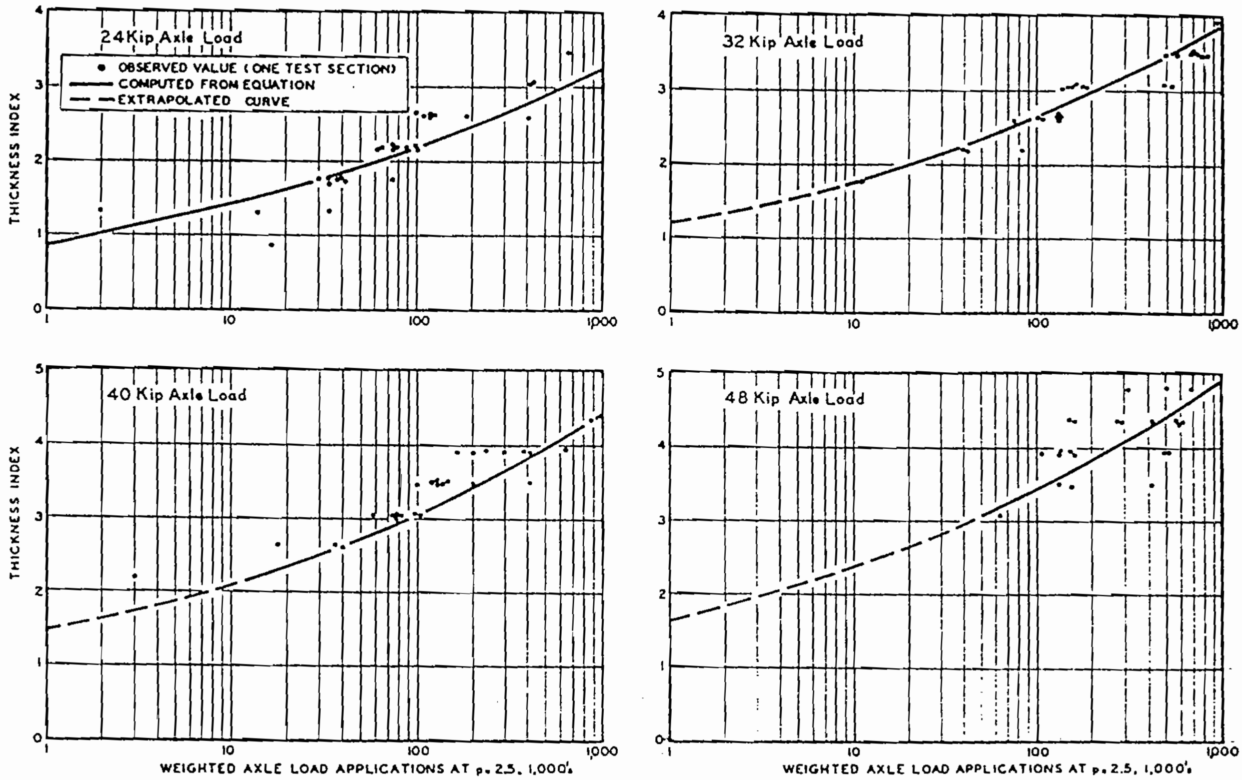

Figure 26. Main factorial experiment, relationship between design and tandem axle load applications at $p = 2.5$.

Figure 24 shows design requirements when the final serviceability value is $p = 2.5$ for a range of single and tandem axle loads at three levels of load applications. In this and the remaining graphs for flexible pavement performance (Figs. 24, 25 and 26), the final serviceability level is $p = 2.5$. The choice of 2.5 for final serviceability was arbitrary. The level of serviceability at which states actually perform major maintenance will be established by a survey of pavements scheduled for overlay or reconstruction.

Figures 25 and 26 show the correspondence between the individual curves of Figure 22 and performance data from Appendix A for each of the ten traffic lanes. Each point represents the observed number of weighted applications at which the serviceability of a test section was 2.5. Horizontal deviations of the points from the curves represent prediction errors or residuals when Eqs. 13, 14, 15, and 16 are used to predict the life of a section (to $p = 2.5$) whose design and load values are specified.

Points shown (Figs. 25 and 26) represent only those sections whose serviceability fell to 2.5 by the end of the test. All remaining sections would be represented by points whose abscissas are to the right of 1,114,000 applications. The number of such sections for any lane can be found by subtracting the number of points shown from 22 in Loop 2 and from 30 in all remaining loops. Although these sections do not appear in the graphs, their performance data were used in the development of the performance equations.

The performance data in Appendix A, Design 1, give a minimum of 5 and a maximum of 10 (p, log W) pairs for each test section. When p is fixed at 3.5, 3.0, 2.5, 2.0 and 1.5 there can be as many as 5 log W observations, and when log W is fixed at $t = 11, 22, 33, 44$ and 55 index days there can be as many as 5 observed values for p. Corresponding to each observation, log W or p, is a calculated value, $\log\hat{W}$ or $\hat{p}$, obtained from the performance equations. Differences between calculated and observed values are the residuals $\Delta \log W = \log\hat{W} - \log W$ and $\Delta p = \hat{p} - p$. Absolute values of these residuals are summarized in the first part of Table 11 which shows for each lane the number of residuals of each type as well as mean absolute residuals. Mean absolute values for Δ log W in Loop 2, lane 1 were found to be extreme relative to the other lanes and were omitted from the grand means. Table 11 thus shows that mean values for Δp and Δ log W were 0.53 and 0.27 for unweighted applications, and 0.46 and 0.23 for weighted applications.

Log W residuals are horizontal deviations from the performance equation curves and are thus of special interest in the use of these curves. The second part of Table 11 shows a further summary of log W residuals. The cor-

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	25.6	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.	55.

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.[illegible]
90	17.1	15.8	13.2	11.3	11.6	12.[illegible]

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

Huang (1968b) compared the ESWL based on equal contact radius with that based on equal contact pressure for a variety of cases. He found that unless the pavement is extremely thin and the modulus ratio close to unity, the differences between the two methods are not very significant.

Two-layer interface deflections based on equal contact pressure were also used by the Asphalt Institute to compute the ESWL for full-depth asphalt pavements. This procedure is applicable to aircraft having less than 60,000 lb (267 kN) gross weight. By the use of Figure 2.19, simplified charts were developed for determining the ESWL for dual wheels based on the CBR of the subgrade (AI, 1973).

6.3 EQUIVALENT AXLE LOAD FACTOR

An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the axle in question relative to the damage per pass of a standard axle load, usually the 18-kip (80-kN) single-axle load. The design is based on the total number of passes of the standard axle load during the design period, defined as the equivalent single-axle load (ESAL) and computed by

$$\mathrm{ESAL} = \sum_{i=1}^{m} F_i\, n_i \tag{6.19}$$

in which m is the number of axle load groups, F_i is the EALF for the ith-axle load group, and n_i is the number of passes of the ith-axle load group during the design period.

The EALF depends on the type of pavements, thickness or structural capacity, and the terminal conditions at which the pavement is considered failed. Most of the EALFs in use today are based on experience. One of the most widely used methods is based on the empirical equations developed from the AASHO Road Test (AASHTO, 1972). The EALF can also be determined theoretically based on the critical stresses and strains in the pavement and the failure criteria. In this section, the equivalent factors for flexible and rigid pavements are discussed separately.

6.3.1 Flexible Pavements

The AASHTO equations for computing EALF are described first, followed by a discussion of equivalent factor based on the results obtained from KENLAYER.

AASHTO Equivalent Factors

The following regression equations based on the results of road tests can be used for determining EALF:

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79 \log(18 + 1) - 4.79 \log(L_x + L_2) + 4.33 \log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \tag{6.20a}$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \tag{6.20b}$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(\mathrm{SN} + 1)^{5.19} L_2^{3.23}} \tag{6.20c}$$

in which W_{tx} is the number of x-axle load applications at the end of time t; W_{t18} is the number of 18-kip (80-kN) single-axle load applications to time t; L_x is the load in kip on one single axle, one set of tandem axles, or one set of tridem axles; L_2 is the axle code, 1 for single axle, 2 for tandem axles, and 3 for tridem axles; SN is the structural number, which is a function of the thickness and modulus of each layer and the drainage conditions of base and subbase; p_t is the terminal serviceability, which indicates the pavement conditions to be considered as failures; G_t is a function of P_t; and β_{18} is the value of β_x when L_x is equal to 18 and L_2 is equal to one. The method for determining SN is presented in Section 11.3.4. Note that

$$\mathrm{EALF} = \frac{W_{t18}}{W_{tx}} \tag{6.21}$$

Equation 6.20 can be used to solve EALF. The effect of p_t and SN on EALF is erratic and is not completely consistent with theory. However, under heavy axle loads with an equivalent factor much greater than unity, the EALF increases as p_t or SN decreases. This is as expected because heavy axle loads are more destructive to poor and weaker pavements than to good and stronger ones. A disadvantage of using the above equations is that the EALF varies with the structural number, which is a function of layer thicknesses. Theoretically, a method of successive approximations should be used because the EALF depends on the structural number and the structual number depends on the EALF. Practically, EALF is not very sensitive to pavement thickness and a SN of 5 may be used for most cases. Unless the design thickness is significantly different, no iterations will be needed. The AASHTO equivalent factors with $p_t = 2.5$ and $\mathrm{SN} = 5$ are used by the Asphalt Institute, as shown in Table 6.4. The original table has single and tandem axles only but the tridem axles are added based on the AASHTO design guide (AASHTO, 1986). Tables of equivalent factors for SN values of 1, 2, 3, 4, 5, and 6 and p_t values of 2, 2.5, and 3 can be found in the AASHTO design guide.

Example 6.7:

Given $p_t = 2.5$ and $\mathrm{SN} = 5$, determine the EALF for a 32-kip (151-kN) tandem-axle load and a 48-kip (214-kN) tridem-axle load.

Solution: For the tandem axles, $L_x = 32$ and $L_2 = 2$, from Eq. 6.20, $G_t = \log(1.7/2.7) = -0.201$, $\beta_x = 0.4 + 0.081\,(32 + 2)^{3.23}/[(5 + 1)^{5.19}(2)^{3.23}] = 0.470$, $\beta_{18} = 0.4 + 0.081\,(18 + 1)^{3.23}/(5 + 1)^{5.19} = 0.5$, and $\log(W_{tx}/W_{t18}) = 4.79 \log 19 - 4.79 \log (32 + 2) + 4.33 \log 2 - 0.201/0.47 + 0.201/0.5 = 0.067$, or $W_{tx}/W_{t18} = 1.167$. From Eq. 6.21, $\mathrm{EALF} = 0.857$, which is exactly the same as that shown in Table 6.4.

For the tridem axles, $L_x = 48$, $L_2 = 3$, from Eq. 6.20, $\beta_x = 0.4 + 0.081(48 + 3)^{3.23}/[(5 + 1)^{5.19}(3)^{3.23}] = 0.470$, and $\log (W_{tx}/W_{t18}) = 4.79 \log 19 - 4.79 \log (48 + 3) + 4.33 \log 3 - 0.201/0.47 + 0.201/0.5 = -0.0139$, or $W_{tx}/W_{t18} = 0.968$. From Eq. 6.21, $\mathrm{EALF} = 1.033$, as shown in Table 6.4.

√(7)設計當量軸次:各車輛設計當量軸次相加之和。

√(8)範例:列於 3.2.8 節。

5. 交通量指數(TI)公式

$TI = 9.0 \times (80kN\ ESAL/10^6)^{0.119}$.......... 公式 3.2.(3)

87/7/21

3.2.4 貨車因素 (TF) 與軸重當量因素

1. 貨車因素:每一部車輛或每一組群車輛每行駛一次,作用於路面之軸重當量值(80kN ESAL),以貨車因素表示之,其求法為:

(1)可查出貨車因素者:

從主管道路機構查出貨車因素者,如高速公路收費站等資料。

√(2)參考相關資料予以應用或修正之,如表 3.2.(1)

台灣地區與美國地區貨車因素比較表[302]

√ 表 3.2.(1)台灣地區與美國地區貨車因素(卡車因子)比較表

美國地區			台灣地區		
車　種	鄉村系統	都市系統	車　種	楊梅 WIN	中山高
單組車					
2 軸 4 輪	0.003-0.017	0.006-0.015			
2 軸 6 輪	0.19-0.41	0.13-0.24	前單後單	1.79	0.93
3 軸或以上	0.45-1.26	0.61-1.02	前單後雙	1.44	0.99
平　均	0.03-0.12	0.04-0.16	平　均	1.73	0.94
複組車					
4 軸或以下	0.37-0.91	0.4-0.98	單-單-雙	5.04	5.46
5 軸	1.05-1.67	0.63-1.17	單-雙-雙	2.57	5.88
6 軸或以上	1.04-2.21	0.64-1.19			
平　均	0.97-1.52	0.53-1.05	平　均	4.99	5.54