OL. 30, NO. 9 AUGUST 1959

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

Recently completed East Bridge of the MacArthur Causeway which joins Miami Beach and Miami, Fla. (Miami Beach in the foreground)

UBLISHED
IMONTHLY BY THE
UREAU OF
UBLIC ROADS,
.S. DEPARTMENT
F COMMERCE,
VASHINGTON

Public Road

A JOURNAL OF HIGHWAY RESEARC

Published Bimonthly

Vol. 30, No. 9 *August 195*

C. M. Billingsley, *Editor*

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Use of funds for printing this publication has been approved by th Director of the Bureau of the Budget, March 28, 1958.

IN THIS ISSUE

U.S. DEPARTMENT OF COMMERCE

FREDERICK H. MUELLER, Acting Secretary

BUREAU OF PUBLIC ROADS

BERTRAM D. TALLAMY, Administrator
ELLIS L. ARMSTRONG, Commissioner

Properties of Highway Asphalts—Part I, 85-100 Penetration Grade

BY THE DIVISION OF PHYSICAL RESEARCH
BUREAU OF PUBLIC ROADS

Reported[1] by J. YORK WELBORN, Chief, Bituminous and Chemical Branch, and WOODROW J. HALSTEAD, Head, Bituminous Materials and Chemical Section

This article is the first of a series of a general study of asphalts produced for highway purposes. A total of 323 samples from 105 refineries were collected by the States for test purposes. Of this number, 146 samples were of the 85–100 penetration grade. This article includes the commonly determined test characteristics of the materials of this penetration grade as well as the results of some of the better known special tests.

The data presented are believed to be valuable as an indication of the range of test characteristics of asphalts that might normally be expected in all regions of the country, as an indication of the usefulness of various specification requirements, and also as a guide for further research directed toward the establishment of "quality" tests for asphalts.

A discussion of the suitability of some of the special quality requirements that have been suggested and used in some specifications is included. No overall conclusions have been drawn since the need for more complete data is apparent.

THIS REPORT catalogs the properties of asphalt cements of the 85–100 penetration grade produced in the United States for use in highway construction. The information presented here is the first report of a comprehensive study of asphalt undertaken by the Division of Physical Research in 1954. Reports on other phases of this study will be published at a later date.

The results of a similar study conducted by the Division of Physical Research in the late thirties were published in 1940 and 1941, and followed by another report published in 1946 (*1–3*).[2] These studies proved useful in that they showed the conformity of the asphalts to specification requirements and presented the general range in test characteristics. Values for the standard tests and also for a large number of special tests either in use or proposed at that time were included.

The present survey provides similar up-to-date information on a national scope, including the properties of asphalts produced from various crude sources and methods of refining in current use in the United States.

Sources of Samples

The samples of asphalt cement for the current study were obtained for the Division of Physical Research by the regional offices of the Bureau of Public Roads. The States within each region cooperated to the fullest extent by collecting representative samples from the producers supplying their material. Although it is likely that some producers are not represented, the materials received are a relatively complete sample of asphalt cements produced and used during 1954 and 1955. New producers, crude sources, and changes in refinery techniques instituted since that time naturally are not reflected in the properties of these materials. However, it is believed that the materials received are essentially the same as those in use today.

Some of the samples of asphalt were obtained by State highway departments from actual construction projects, and others were obtained at the refineries. At the time of sampling, information concerning the source of the crude petroleum and the general refinery method used to manufacture the asphalt was requested from the producers and received from most of them.

Initially the Bureau's regional offices were requested to collect samples of only the 60–70, 85–100, and 120–150 penetration grades. When it was found that other penetration grades were used extensively by some States, the selection of grades was left to the discretion of each Regional Engineer.

A total of 323 samples from 105 refineries were received. The penetration grades and the number of samples of each grade were as follows: 60–70 grade, 59 samples; 70–85 grade, 33; 85–100 grade, 146; 100–120 grade,7; 120–150 grade, 62; and 150–200 grade, 16.

Nearly all producers supplying asphalt for this study included one or more samples in the 85–100 penetration range. Since this group of samples is considered the most representative of all asphalt cements now produced and used in the United States, it was selected for the initial study. It is planned that subsequent reports will include the properties of the other grades as well as more intensive study of selected types or particular characteristics of asphalts.

The data in this report include only those test characteristics in general use as specification requirements or those that are being used by some agencies in an effort to obtain better materials. All testing was performed according to ASTM or AASHO standard methods of test.

The results of the tests on the 146 samples of 85–100 penetration asphalt are tabulated in tables 1 and 2. The data in the tables are grouped according to regions.

There was some duplication of samples within a region because some of the States collected material from a particular refinery using the same crude source and refining method. When this occurred only one sample is included in table 1 and the others are included in table 2. However, in some cases where a particular refinery supplied an asphalt to more than one region, as represented by different samples, data for that asphalt are included in each region. In most cases the test results indicated that the materials were essentially the same, but in a few cases there were significant differences. The variations in test characteristics generally occurred in samples from those refineries which reported the use of more than one type of crude or blends of crudes. Since samples from different regions were taken at different times, it is likely that there were actual differences in the crudes. This would account for asphalts having different characteristics.

Tables 1 and 2 show the refinery by a code number, the source of the crude or crudes used, and the general method of producing the asphalt. Although in many cases more specific information was given as to the crude source and refinery processes, only the basic information that generally characterizes the material is included. It is recognized that differences can and do exist within the range of the geographical location of the crude sources indicated, and also within the meaning of the general terms used to describe the method of refining.

Of the 119 samples included in table 1, 73 were reported to be refined by vacuum and/or steam distillation, 15 by vacuum and/or steam distillation with some blowing, 3 by vacuum and/or steam with fluxing, and

[1] This article was presented before the Association of Asphalt Paving Technologists, Denver, Colo., January 1959.

[2] Italic numbers in parentheses refer to the list of references on p. 207.

511782—59——1

Table 1.—Test characteristics of 85–100 penetration grade asphalts

B.P.R. region [1]	Sample identification [2]	Source of crude	Method of refining [3]	Penetration			Ductility		Softening point	Furol viscosity at 275° F.	Specific gravity at 77° F.	Flash point		Soluble in CCl_4	Standard oven test at 325° F., 5 hours			Thin-film oven test, ⅛-inch film at 325° F., 5 hours				
				100 g., 5 sec. at 77° F.	200 g., 60 sec. at 39.2° F.	Penetration ratio, 39.2°/77° F.	5 cm. per minute at 77° F.	1 cm. per minute at 39.2° F.				Pensky-Martens closed cup	Cleveland open cup		Loss	Penetration of residue: Value	Penetration of residue: Percent of original	Loss [4]	Tests on residue: Softening point	Tests on residue: Ductility, 5 cm. per min., 77° F.	Tests on residue: Penetration at 77° F.	Tests on residue: Percent of original penetration
							Cm.	Cm.	° F.	Sec.		° F.	° F.	Pct.	Pct.			Pct.	° F.	Cm.		
Region 1	1 (2)	Venezuela	V, S	87	30	34	195	14.5	120	239	1.031	450	530	99.86	0.07	76	87	0.23	131	194	52	60
	2 (4)	do	V, S	88	32	36	225	99.5	118	137	1.018	370	455	99.93	.58	66	75	2.04	131	250+	33	38
	3 (22)	Mexico	S	87	39	45	248	51.5	121	318	1.037	445	500	99.92	.12	77	89	.55	134	138	52	60
	4 (22)	Venezuela	S	87	37	43	158	71.0	120	250	1.034	435	485	99.98	.16	76	87	.75	132	200	48	55
	5 (22)	Venezuela, Mexico	S	95	34	36	212	36.0	117	247	1.034	435	495	99.84	.12	81	85	.59	131	212	53	56
	6 (30)	Colombia		86	30	35	180	79.0	115	200	1.005	525	580	99.75	.07	81	94	+.10	122	250+	61	71
	7 (32)	Venezuela	V	91	31	34	233	62.5	115	178	1.024	510	550	99.90	.02	83	91	.10	124	243	58	64
	8 (77)			91	37	41	217	18.5	117	213	1.020	425	545	99.87	.18	78	86	.50	127	188	53	58
	9 (77)	Venezuela, Texas	V, S, O	93	35	38	150	22.3	116	198	1.022	415	540	99.92	.20	80	86	.50	130	226	53	57
	10 (86)	Coastal	V	91	35	38	204	16.0	117	214	1.017	520	595	99.91	.00	83	91	.02	123	250+	61	67
	11 (90)	Venezuela	V	85	35	41	250+	14.5	118	202	1.016	475	555	99.92	.07	75	88	.14	130	208	54	64
	12 (110)		S	85	33	39	177	27.0	117	202	1.020	475	575	99.89	.03	75	88	.01	125	250+	56	66
Region 2	13 (1)	Venezuela		89	32	36	175	18.3	120	255	1.033	480	530	99.85	.03	79	89	.18	132	175	55	62
	14 (3)	do	V, S	92	32	35	185	29.5	117	232	1.030	440	490	99.85	.13	82	89	.70	130	182	52	57
	15 (9)	do	S	96	34	35	189	33.5	118	249	1.036	420	490	99.88	.13	80	83	.64	132	176	53	55
	16 (13)	Illinois	V, S	83	30	36	187	6.5	118	169	1.005	495	625	99.82	.06	71	86	.01	129	154	53	64
	17 (14)			93	34	37	196	63.0	116	166	1.022	535	565	99.95	.01	81	87	+.04	123	205	61	66
	18 (17)			87	40	46	116	7.3	124	239	.992	425	630	99.89	.07	75	86	.08	135	29	57	66
	19 (31)	Venezuela	V	94	37	39	205	15.5	116	209	1.025	510	570	99.89	.00	82	87	.03	126	148	58	62
	20 (70)			87	31	36	199	47.0	117	204	1.019	510	590	99.96	.01	78	90	.01	125	229	59	68
	21 (81)			91	40	44	197	7.0	117	207	1.009	540	620	99.78	.00	84	92	+.07	130	125	61	67
	22 (82)			95	35	37	154	9.8	119	191	.994	545	630	99.96	.00	85	89	+.05	124	169	66	69
	23 (87)	Gulf Coast	V	81	37	46	190	11.3	119	198	1.016	530	585	99.87	.03	75	93	.04	127	208	57	70
Region 3	24 (6)	Venezuela, Mississippi	V, S, B	94	36	38	200	32.5	120	251	1.032	460	500	99.87	.07	87	93	.36	131	156	57	61
	25 (10)	Venezuela, Mexico	S	95	40	42	171	35.5	120	298	1.036	440	505	99.96	.12	80	84	.56	134	160	54	57
	26 (11)	Texas	S	87	37	43	231	13.3	118	219	1.028	375	590	99.93	.15	73	84	.19	129	250+	51	59
	27 (33)	Venezuela	V, S	93	34	37	195	88.0	113	153	1.025	495	545	99.88	.02	82	88	.13	123	221	61	66
	28 (33)		S	89	31	35	184	152.0	116	172	1.023	385	540	99.90	.10	77	87	.21	125	250+	53	60
	29 (42)	Mississippi, Alabama	V, S	89	37	42	177	9.8	119	259	1.036	445	550	99.92	.07	78	88	.16	129	183	55	62
	30 (63)	Mississippi	S	91	46	51	222	9.3	123	265	1.029	440	505	99.90	.11	79	87	.45	137	70	53	58
	31 (65)			93	46	49	155	11.0	119	247	1.019	450	520	99.65	.08	78	84	.33	136	77	52	56
	32 (69)	Venezuela		94	36	38	250+	76.5	117	200	1.018	500	580	99.97	.03	85	90	.04	125	250+	57	61
	33 (83)	Mississippi	V, S	96	42	44	180	13.5	119	244	1.033	470	530	99.95	.03	88	92	.12	131	117	59	61
	34 (102)	do	S	87	45	52	140	8.3	124	268	1.031	390	490	99.96	.20	74	85	.73	140	40	47	54
	35 (103)	do	S	92	46	50	197	18.5	122	262	1.029	420	495	99.72	.18	76	83	.59	137	71	50	54
Region 4	36 (1)	Venezuela	V, S	87	34	39	218	19.3	120	264	1.034	450	525	99.92	.03	75	86	.14	130	184	52	60
	37 (7)	Texas	V	80	37	46	136	7.3	125	195	1.029	490	575	99.88	.02	73	91	.00	136	68	53	66
	38 (8)	Midcontinent	V, O	90	32	36	170	6.3	120	189	1.000	510	605	99.76	.02	79	88	.00	129	120	56	62
	39 (13)			88	27	31	193	13.3	116	188	1.001	460	675	99.98	.02	77	87	.02	124	234	59	67
	40 (15)	Wyoming	V	83	27	33	185	10.8	118	169	1.027	435	585	99.89	.05	72	87	.11	126	250+	50	60
	41 (31)		V, S	93	36	39	202	25.0	116	192	1.018	510	590	99.83	.00	82	88	+.05	123	250+	59	63
	42 (44)	Canada		82	20	23	190	5.0	123	110	.999	570	660	[5] 98.00	.01	67	82	+.08	131	160	50	61
	43 (44)	do		83	18	22	176	5.8	118	108	1.009	545	620	99.62	.04	73	88	.01	126	157	49	59
	44 (45)	Wyoming	V	81	26	32	150	15.8	117	193	1.026	450	630	99.90	.03	71	88	+.06	126	239	49	60
	45 (46)	Arkansas	V, S	90	26	29	212	6.3	115	220	1.020	545	670	99.91	.01	78	87	.17	125	200	60	67
	46 (59)	Texas	S, O	89	36	41	207	9.5	117	222	1.007	470	580	99.95	.07	80	90	.14	124	205	60	67
	47 (59)	Wyoming, Texas	S, O	94	34	36	137	10.0	116	140	1.019	505	565	99.91	.02	83	88	.00	126	124	59	63
	48 (60)	Midcontinent	V, S, O	90	39	43	138	6.8	120	207	.997	415	620	99.74	.09	77	86	.10	134	37	53	59
	49 (64)	Wyoming, Texas	V, O, B	93	26	28	169	6.3	117	133	1.014	535	630	99.89	.00	80	86	.11	126	180	55	59
	50 (67)	North and West Texas	V, O, B	98	29	30	140	8.0	114	135	1.015	435	610	99.88	.06	78	80	.09	125	166	51	52
	51 (70)	Venezuela	V, S, B	89	36	40	224	78.0	118	206	1.017	475	555	99.92	.03	78	88	.06	128	215	56	63
	52 (74)	Wyoming, Oklahoma	V	85	22	26	222	5.0	115	146	1.016	440	630	99.75	.05	70	82	.02	127	250+	45	53
	53 (89)	Midcontinent	V, O	86	34	40	151	7.3	119	195	.995	545	635	99.88	.01	79	92	+.03	126	150	59	69
	54 (93)	Wyoming	V	83	29	35	182	8.5	117	162	1.027	550	595	99.92	.04	71	86	.03	128	250+	48	58
Region 5	55 (7)			86	31	36	197	10.3	112	244	1.027	510	605	99.97	.02	76	88	.00	127	198	55	64
	56 (12)	Kansas	V	86	33	38	166	4.8	121	180	1.004	525	665	99.70	.01	75	87	+.03	139	13	53	62
	57 (25)	do	V	94	38	40	220	7.5	118	200	1.001	495	650	99.93	.09	79	84	.10	132	40	58	62
	58 (36)	do	V, B	87	35	40	153	6.0	119	205	1.005	500	610	99.81	.02	77	89	.00	133	55	54	62
	59 (39)	Wyoming	V	98	32	33	160	27.0	112	133	1.034	435	530	99.90	.15	79	81	.37	126	211	48	49
	60 (46)			92	28	32	210	8.5	115	216	1.029	610	680	99.94	.00	76	83	+.09	124	200	59	64
	61 (47)	Canada	V	88	19	22	151	5.3	116	99	1.012	585	625	99.89	.01	71	81	+.12	126	184	50	57
	62 (55)	Kansas, Oklahoma, Texas.	V, P, B	85	28	33	161	6.8	118	211	1.004	480	660	99.88	.01	74	87	.16	126	184	56	66
	63 (61)			84	31	37	149	9.8	118	171	1.013	460	580	99.88	.05	74	88	.10	130	153	52	62
	64 (76)	Kansas	V, S	97	37	38	155	8.0	117	201	1.004	420	630	99.86	.04	80	82	.00	130	76	58	60
	65 (78)	do	V, S, B	90	38	42	153	5.5	121	229	.998	465	615	99.80	.02	79	88	.02	130	82	60	67
	66 (107)	do	V	90	34	38	129	6.5	120	231	.998	485	635	99.95	.02	77	86	.00	130	80	58	64

Table 1.—Test characteristics of 85–100 penetration grade asphalts—Continued

B.P.R. region [1]	Sample identification [2]	Source of crude	Method of refining [3]	Penetration: 100 g., 5 sec. at 77° F.	Penetration: 200 g., 60 sec. at 39.2° F.	Penetration: Penetration ratio, 39.2°/77° F.	Ductility: 5 cm. per minute at 77° F.	Ductility: 1 cm. per minute at 39.2° F.	Softening point	Furol viscosity at 275° F.	Specific gravity at 77° F.	Flash point: Pensky-Martens closed cup	Flash point: Cleveland open cup	Soluble in CCl_4	Standard oven test at 325° F., 5 hours: Loss [4]	Standard oven test: Penetration of residue: Value	Standard oven test: Penetration of residue: Percent of original	Thin-film oven test, ⅛-inch film at 325° F., 5 hours: Loss [4]	Thin-film: Tests on residue: Softening point	Thin-film: Tests on residue: Ductility, 5 cm. per min., at 77° F.	Thin-film: Tests on residue: Penetration at 77° F.	Thin-film: Tests on residue: Percent of original penetration
							Cm.	Cm.	° F.	Sec.		° F.	° F.	Pct.	Pct.			Pct.	° F.	Cm.		
	67 (7)	Texas	V	90	34	38	201	20.8	122	243	1.029	460	575	99.78	0.05	78	87	0.08	129	192	55	61
	68 (21)	do	V, S, O	89	30	34	178	6.3	117	153	1.009	485	585	99.61	.03	77	87	.05	130	70	50	56
	69 (23)	do	V, S	87	20	23	112	12.5	116	120	1.029	535	585	99.67	.01	77	89	+.02	125	178	53	61
	70 (27)	Midcontinent	V, S, O	87	28	32	150	6.8	120	208	1.005	510	635	99.82	.01	75	86	+.03	127	250+	53	61
	71 (28)	do	V, P, B	87	26	30	200	112.0	116	190	1.010	525	630	99.82	.00	79	91	+.08	121	190	61	70
	72 (29)	Oklahoma	V, P, O, F	95	47	49	139	7.5	121	203	1.008	455	520	99.77	.06	82	87	.28	135	35	58	61
	73 (35	Texas	V, S	93	33	35	234	10.3	116	239	1.025	465	625	99.82	.01	83	89	.05	125	209	60	64
	74 (41)	do	V, P, O	94	22	23	250+	4.3	117	263	1.005	525	640	99.73	.01	81	86	+.03	127	181	64	68
	75 (46)	Arkansas	V, S	88	26	30	215	6.5	117	228	1.018	600	675	99.90	+.01	80	91	+.01	125	219	52	59
	76 (48)	Oklahoma	V, O	93	48	52	107	7.5	125	257	1.002	425	475	99.81	.14	82	88	.70	138	20	57	61
	77 (49)	Arkansas	V, S, B, O	94	35	37	213	9.8	117	238	1.016	550	635	99.93	.00	85	90	.06	124	185	65	69
Region 6	78 (54)	Mississippi	S	92	48	52	139	9.3	122	240	1.030	400	490	99.84	.12	78	85	.42	138	36	53	58
	79 (57)	Gulf, Midcontinent	V, P, B, O	90	23	26	145	6.0	118	123	1.001	485	565	99.53	.07	80	89	.20	127	114	63	70
	80 (65)	Mississippi	S	90	47	52	180	17.0	114	246	1.030	445	520	99.83	.07	81	90	.20	128	102	57	63
	81 (72)	Texas, Kansas	V, P, O	91	32	35	120	3.5	119	303	.984	550	655	99.48	+.01	84	92	+.08	128	80	63	69
	82 (85)	Mexico, Gulf	V	91	30	33	160	9.3	115	142	1.027	465	530	99.72	.00	85	93	.05	122	182	60	66
	83 (87)	Gulf Coast	V	93	34	37	184	79.5	115	207	1.027	530	605	99.73	.01	82	88	+.03	124	250+	60	65
	84 (92)	Texas	V, O	99	33	33	162	160+	113	85	1.011	450	495	99.65	.09	88	89	.31	118	232	69	70
	85 (95)	do	V, S, O	90	37	41	132	6.3	118	167	1.000	480	590	99.88	.05	80	89	.03	127	127	58	64
	86 (97)	Oklahoma	V	85	27	32	207	8.8	118	238	1.001	525	680	99.51	.01	73	86	.08	124	192	55	65
	87 (104)	do	V, S	88	34	39	166	12.3	118	180	1.012	515	570	99.86	.00	77	88	+.05	128	162	55	63
	88 (106)	do	V, B	81	32	40	172	5.3	122	213	.995	540	645	99.95	.06	69	85	.07	132	104	48	59
	89 (111)	Arkansas	V	89	30	34	138	11.0	116	236	1.021	560	660	99.91	.00	81	91	+.09	124	160	64	72
	90 (24)	California	V, S	92	36	39	237	49.0	117	210	1.028	435	480	99.88	.15	83	90	.88	129	120	51	55
	91 (40)	do	V, S, B, O	87	27	31	218	109	111	109	1.017	480	575	99.59	.05	78	90	.05	119	190	56	64
	92 (58)	do	V, S	91	30	33	178	132	113	148	1.020	455	520	99.86	.13	77	85	.42	124	242	50	55
Region 7	93 (66)	do	V, S, F	89	27	30	216	160+	111	90	1.014	515	565	99.87	.02	82	92	.02	118	250+	58	65
	94 (84)	do	V, S	91	29	30	245	13.8	118	196	1.032	440	480	99.92	.16	75	82	.76	131	160	46	51
	95 (99)	do	S, F	86	31	35	200	14.8	119	210	1.029	450	495	99.86	.10	77	90	.40	131	192	48	55
	96 (5)	do	V, S	93	23	25	190	8.8	113	104	1.011	470	520	99.93	.05	82	88	.09	120	250+	56	60
	97 (5)	do	V, S	94	24	26	180	250+	113	114	1.017	395	460	99.82	.29	80	85	1.62	128	250+	43	46
Region 8	98 (38)	Wyoming	V	96	31	32	220	10.3	116	140	1.033	505	570	99.92	.05	84	88	.03	125	250+	57	59
	99 (43)	do	V	86	24	28	202	44.5	116	196	1.028	465	555	99.91	.05	76	88	.07	125	159	53	62
	100 (100)	California	S	88	29	33	245	26.0	120	228	1.031	410	450	99.69	.27	74	84	1.03	136	125	43	49
	101 (105)	Montana	V	93	26	28	198	6.3	117	154	1.022	430	590	99.86	.07	82	88	.08	125	170	57	61
	102 (23)	Texas	V, S	92	25	27	121	12.3	116	112	1.031	480	570	99.85	.05	76	83	.06	124	174	57	62
	103 (24)	California	V, S	91	29	32	176	6.8	120	214	1.029	400	440	99.93	.34	75	82	1.63	139	61	39	43
	104 (37)	Wyoming	V	80	25	31	241	7.0	117	170	1.031	495	585	99.90	.02	69	86	.00	126	250+	46	58
	105 (39)	do	V	93	30	32	214	9.3	115	154	1.034	430	515	99.92	.12	75	81	.30	129	235	47	51
	106 (43)	do	V	92	27	32	206	27.0	115	191	1.029	510	560	99.91	.02	74	80	.00	124	240	55	60
	107 (50)			89	20	23	135	5.5	113	123	1.017	455	625	99.91	.04	78	88	.01	123	205	52	58
	108 (52)	Wyoming	V, S	89	29	33	250+	6.3	115	181	1.031	520	585	99.92	.01	75	84	+.07	125	219	54	61
	109 (56)	Colorado	V	87	26	30	195	4.3	118	100	1.019	530	670	[5] 98.42	.00	74	85	+.10	129	63	50	57
	110 (59)	Texas, Wyoming		87	25	29	205	9.3	116	137	1.028	515	580	99.94	.01	74	85	+.03	125	208	50	57
Region 9	111 (52)	Wyoming	V, S	89	31	35	250+	11.5	116	151	1.034	535	590	99.90	.01	76	85	+.12	128	214	51	57
	112 (60)	Midcontinent		86	36	42	125	5.0	123	240	.997	530	620	99.78	.01	75	87	+.06	134	39	57	66
	113 (61)	Midcontinent, Wyoming, Texas.		90	27	30	183	11.8	117	169	1.015	465	540	99.88	.07	76	84	.10	128	210	54	60
	114 (62)	Wyoming	V	94	29	31	190	32.0	114	158	1.030	505	605	99.90	.01	80	85	+.05	125	192	53	56
	115 (72)	Texas, Kansas	P, O	88	21	24	110	4.0	121	263	.988	510	650	99.75	.02	74	84	.07	128	71	57	65
	116 (75)	Wyoming	V	86	21	24	220	14.8	115	98	1.024	490	590	99.50	.02	71	83	.00	124	204	45	52
	117 (79)	do	V, F	86	27	31	250+	19.5	115	158	1.026	385	580	99.88	.15	70	86	.20	127	167	48	56
	118 (91)	do	V, B	82	26	32	250+	36.0	116	164	1.032	505	585	99.92	.02	72	88	+.11	128	250+	50	61
	119 (101)	Colorado	P, F	92	25	27	238	9.0	116	123	1.031	400	450	99.97	.43	72	78	2.18	129	250+	35	38

[1] For States included in each of the Bureau of Public Roads regions, see inside front cover.
[2] Numbers in parentheses indicate code designation of refinery.
[3] V=vacuum distillation, S=steam distillation, O=blowing (oxidation), B=blending (different grade asphalts), P=propane fractionation, and F=fluxing (heavy oils).
[4] Plus values represent gains rather than losses.
[5] Sample No. 42, soluble in CS_2=98.74; sample No. 109, soluble in CS_2=98.86.

Table 2.—Test characteristics of supplemental samples of 85–100 penetration grade asphalts

B.P.R. region [1]	Sample identification [2]	Source of crude	Method of refining [3]	Penetration: 100 g., 5 sec. at 77° F.	Penetration: 200 g., 60 sec. at 39.2° F.	Penetration: Penetration ratio, 39.2°/77° F.	Ductility: 5 cm. per minute at 77° F.	Ductility: 1 cm. per minute at 39.2° F.	Softening point	Furol viscosity at 275° F.	Specific gravity at 77° F.	Flash point: Pensky-Martens closed cup	Flash point: Cleveland open cup	Soluble in CCl_4	Standard oven test at 325° F., 5 hours: Loss	Standard oven test: Penetration of residue: Value	Standard oven test: Penetration of residue: Percent of original	Thin-film oven test, ⅛-inch film at 325° F., 5 hours: Loss [4]	Thin-film: Tests on residue: Softening point	Thin-film: Tests on residue: Ductility, 5 cm. per min., 77° F.	Thin-film: Tests on residue: Penetration at 77° F.	Thin-film: Tests on residue: Percent of original penetration
							Cm.	Cm.	° F.	Sec.		° F.	° F.	Pct.	Pct.			Pct.	° F.	Cm.		
Region 1	2a (4)			87	31	36	242	150+	113	145	1.018	360	440	99.94	0.59	67	77	2.08	132	250+	33	38
	9a (77)	Venezuela, Texas	V, S, O	90	35	39	169	23.5	117	210	1.021	410	525	99.92	.22	78	87	.47	127	238	50	56
	9b (77)	do	V, S, O	89	32	36	158	22.3	116	210	1.020	415	525	99.87	.22	76	85	.68	128	213	48	54
	11a (90)	do	V	87	38	44	206	14.8	119	195	1.012	460	565	99.91	.07	76	87	.12	128	250+	55	63
Region 2	13a (1)	Venezuela		86	29	34	250+	89.5	120	240	1.033	480	490	99.92	.07	75	87	.33	131	153	52	60
	14a (3)	do	V, S	91	36	40	180	33.5	119	280	1.034	435	495	99.88	.05	80	88	.81	131	109	52	57
	15a (9)	do	S	86	35	41	230	12.3	120	315	1.039	435	510	99.88	.14	75	87	.70	133	99	47	55
	19a (31)	do	V	94	37	39	239	75.0	115	202	1.018	510	560	99.74	.01	85	90	+.02	141	105	61	65
	19b (31)	do	V	92	30	33	175	40.0	116	165	1.022	535	570	99.76	.00	81	88	+.03	124	242	60	65
	19c (31)	do	V	92	32	35	212	22.5	116	189	1.023	510	565	99.89	.00	81	88	+.06	124	250+	58	63
Region 3	33a (83)	Mississippi	V, S	84	42	50	202	6.5	124	-----	1.004	510	600	99.84	.02	75	89	.04	134	33	58	69
Region 4	36a (1)	Venezuela	V, S	89	38	43	199	29.0	119	254	1.033	475	520	99.91	.05	80	90	.25	130	162	55	62
	47a (59)	Wyoming, Texas	S, O	88	28	32	202	24.0	118	160	1.021	515	575	99.84	.03	74	84	.03	126	190	52	59
	53a (89)	Midcontinent	V, O	92	37	40	171	8.5	119	192	.994	515	620	99.81	.00	84	91	+.04	127	150	65	71
	54a (93)	Wyoming	V	89	26	29	250+	4.0	116	215	1.024	480	590	99.94	.05	75	84	.02	127	202	51	57
Region 5	57a (25)	Kansas	V	95	36	38	153	7.0	120	222	.999	435	665	99.70	.03	82	86	.01	131	62	59	62
	62a (55)	Kansas, Oklahoma, Texas.	V, P, B	91	32	35	207	15.5	116	196	1.006	580	645	99.84	.17	80	88	.28	126	181	57	63
	66a (107)	Kansas	V	96	34	35	152	9.5	119	198	.999	555	620	99.85	.04	85	89	.03	131	105	59	61
Region 6	68a (21)	Texas	V, S, O	87	34	39	166	6.8	120	165	1.004	485	580	99.69	.05	72	83	.08	132	22	50	57
	89a (111)	Arkansas	V	85	28	33	152	8.5	119	241	1.021	575	665	99.71	.00	79	93	.07	125	166	61	72
Region 7	90a (24)	California	V, S	97	35	36	205	14.5	118	200	1.026	410	425	99.88	.21	88	91	1.33	131	65	49	51
	91a (40)	do	V, S, B, O	87	24	28	157	146	112	97	1.016	480	580	99.67	.05	77	89	.00	120	197	57	66
	92a (58)	do	V, S	89	21	24	215	45.0	112	101	1.017	510	540	99.92	.03	77	87	.10	123	250+	50	56
	93a (66)	do	V, S	100	27	27	171	250+	111	84	1.015	505	545	99.85	.03	88	88	.16	119	248	62	62
	95a (99)	do	S	87	27	31	207	11.5	119	206	1.031	450	475	99.88	.14	75	86	.70	132	160	46	53
Region 8	99a (43)	Wyoming	V	84	----	----	189	-----	115	-----	1.030	455	560	99.85	.08	74	88	.14	125	167	52	62
Region 9	107a (50)	New Mexico	V	77	20	26	179	5.5	118	125	1.019	480	645	99.88	.05	64	83	.00	127	230	44	57

[1] For States included in each of the Bureau of Public Roads regions, see inside front cover.
[2] Numbers in parentheses indicate code designation of refinery.
[3] V=vacuum distillation, S=steam distillation, O=blowing (oxidation), B=blending (different grade asphalts), and P=propane fractionation.
[4] Plus values represent gains rather than losses.

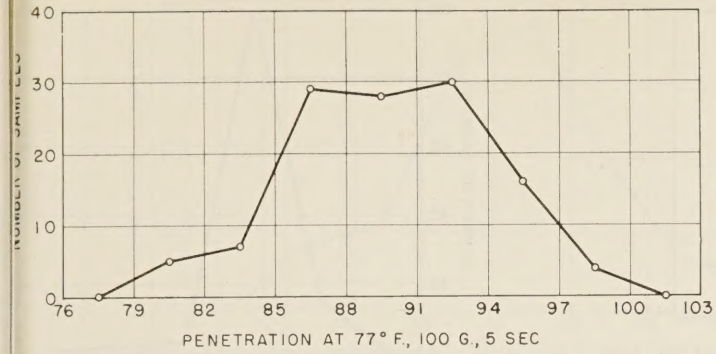

Figure 1.—Distribution of penetration results.

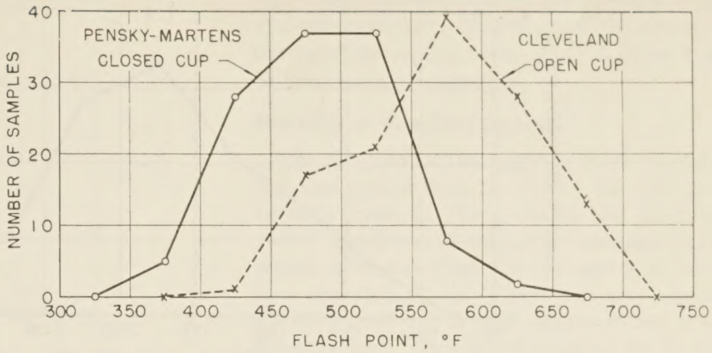

Figure 2.—Distribution of flash point results.

by propane solvent extraction together with arious combinations of distillation, blowing, lending and/or fluxing. Information perinining to the source of crude used was not iven for 14 asphalts, and information on ie refining method was not furnished for 20 sphalts.

Since the primary purpose of this report ; to present the survey results of the characeristics of asphalt cements produced in the 'nited States, it was believed that the large iass of data could best be shown by graphs. 'requency distribution graphs in the form of requency polygons were selected for this urpose. The results of each test made on ie 119 samples given in table 1 were grouped ito class intervals. The number of test alues in each class interval were then plotted t the midpoint of the respective class interal and connected to form the polygon.

The results shown in table 2 are not inluded in this analysis since they are esentially a duplication of values given in table . Their inclusion therefore would have iven an improper representation on the basis f the general production of refineries. The esults in table 2 are given principally to iake the report complete with respect to amples submitted. The numerical identifiation number for samples corresponds to the umber of the replicate sample included in able 1.

Figures 1–15 show the frequency polygons or both the standard specification tests and pecial tests such as the thin-film oven test, igh temperature viscosity, and others that re now being used in specifications by some f the States or other agencies. The requency polygons for the various tests show onsiderable variation. Some have a fair mount of symmetry but others show a coniderable amount of skewness. The disperion of results also varies considerably for he different tests.

Results of Tests

The following brief discussion of each requency distribution polygon points out cerain variations in test characteristics and eviations from specification requirements vhere applicable.

'enetration at 77° F.

The values for the penetration test at 77° '. ranged from 80 to 99 (fig. 1). Although ll 119 samples were supposed to conform to he 85–100 penetration grade, 12 asphalts had values below the minimum requirement of 85; none exceeded the upper limit of 100.

Flash point

Figure 2 shows the distribution of flash points determined by both the Cleveland open cup and Pensky-Martens closed cup. As shown in table 1, the flash point determined by the Cleveland open cup ranged from 440° to 680° F. with one sample flashing below 450° F. State specifications have minimum requirements ranging from 347° to 450° F. Thus, only one asphalt which flashed at 440° F. would fail the most restrictive specification.

Some States have replaced the Cleveland open cup method for determining flash point with the Pensky-Martens closed cup method. Specifications now in force require minimum flash points of either 440° or 450° F. Twenty-six of the 119 asphalts flashed at temperatures less than 440° F., and 33 were less than 450° F. As is normally expected, the Pensky-Martens flash point is lower than that obtained in the Cleveland open cup method. However, there is no definite correlation between Pensky-Martens and Cleveland open cup test values. This is illustrated by the shapes of the polygons in figure 2.

Specific gravity at 77/77° F.

The specific gravity of all asphalts ranged from 0.984 to 1.037 (fig. 3). Eleven samples had values less than 1.00. The two lowest

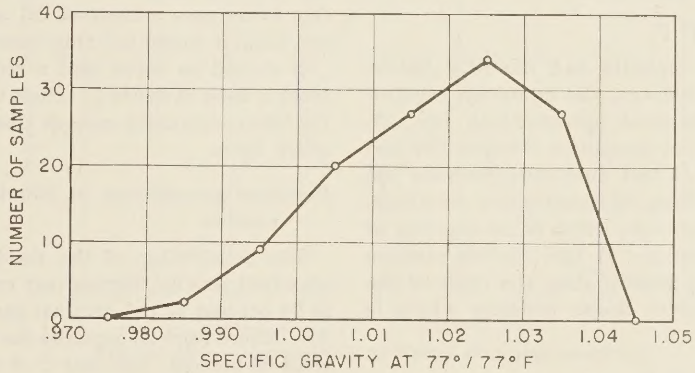

Figure 3.—Distribution of specific gravity results.

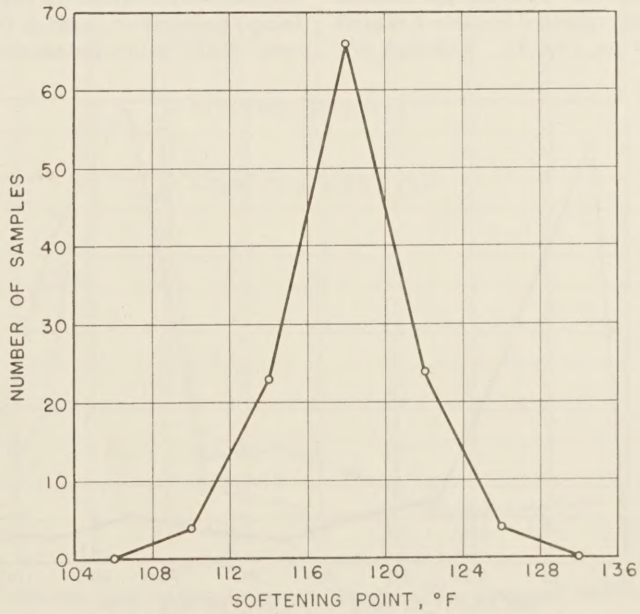

Figure 4.—Distribution of softening point results.

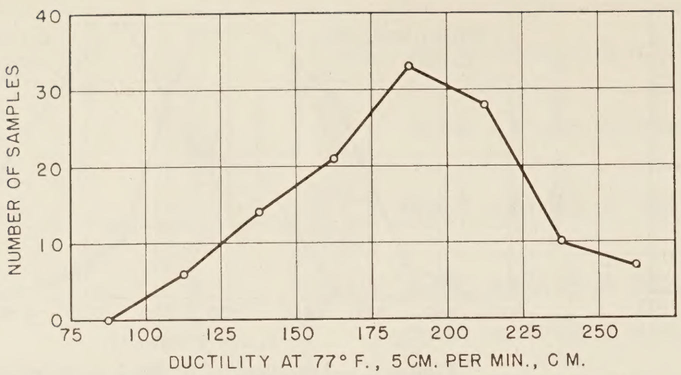

Figure 5.—Distribution of ductility results at 77° F.

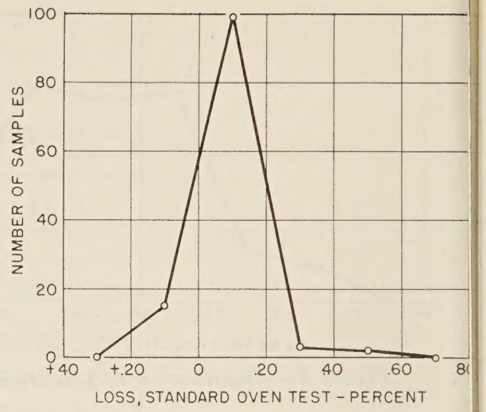

Figure 7.—Distribution of loss during standard oven test.

values 0.984 and 0.988 were asphalts shipped to different regions from one refinery and were manufactured by a propane method using midcontinent crudes. The peak of the distribution curve is between 1.02 and 1.03.

Softening point

The softening point values for the asphalts ranged from 111° to 125° F., with 66 samples falling in the range of 116° to 119° F. (fig. 4). Only a few States include softening point requirements in their specifications. The most restrictive limits are 100° to 125° F. and 113° to 140° F. Only four asphalts had softening points less than 113° F., and none had values above 125° F.

Ductility at 77° F.

All of the asphalts had ductility values greater than 100 cm., the minimum requirement found in most specifications (fig. 5). Six asphalts had ductilities between 100 and 124 cm., and 14 had ductilities between 125 and 149 cm. Thus, 99 samples had ductilities of 150 cm. or greater, which is the capacity of most machines now in use. Seven samples had ductilities greater than the limit of the Bureau of Public Roads machine which is 250 cm.

Ductility at 39.2° F.

The ductility at 39.2° F., 1 cm. per minute, for the 119 samples reported in table 1 ranged from 3.5 to 250+ cm. (fig. 6). Although low temperature ductility is not widely used, there are specifications which require a ductility of not less than a numerical value of 10 percent of the penetration at 77° F. Forty-three asphalts would fail this requirement. Fifty-five asphalts had values less than 10 cm.

Loss on heating at 325° F., standard test

The change in weight during heating at 325° F. for 5 hours using the standard test ranged from a gain of 0.01 percent to a loss of 0.58 percent (fig. 7). The loss in weight of 115 of the 119 samples was less than 0.20 percent. Most State specifications allow up to 1.0 percent loss. Thus none of the asphalts had loss values even approaching this limit. One State uses a limit of 0.5 percent. Only one asphalt would fail this requirement.

It should be noted that a reduced vertical scale is used in figure 7. Thus, the peak value for this test greatly exceeds that found in the other tests.

Retained penetration of standard oven test residue

The penetration of the residues from the standard loss on heating test ranged from 75 to 94 percent of the original penetration (fig. 8). There were 25 asphalts that retained less than 85 percent, and only 2 of these retained less than 80 percent. Various State specifications include minimum requirements for retained penetration ranging from 50 to 80 percent. Only two materials would fail the most restrictive specification (in effect in tw States). As in figure 7, the vertical scale reduced in this polygon.

Penetration ratio

The ratio of the penetration at 39.2° F 200 g., 60 sec., to the penetration at 77° F 100 g., 5 sec., ranged from 22 to 52 (fig. 9 A number of agencies now use this ratio their specifications. The minimum requir ments range from 25 to 35. Eight of the 1 asphalts had penetration-ratio values le than 25, 19 had values less than 30, and had values less than 35. A minimum requir ment of 33 used in one State specificati could not be met by 39 asphalts.

As measured by the penetration ratio, the is a general trend for asphalts from the wes ern regions to have greater temperatur viscosity susceptibility than those from t eastern regions. The central areas general fall in the intermediate range. For exampl in Regions 1–3, principally the Eastern State only 6 percent (2 out of 35) of the asphal had penetration ratios less than 35 and the had values of 34. For Regions 4–6, princ pally the Central States, 43 percent (23 out 54) of the asphalts had penetration ratios le than 35; and in Regions 7–9, the Weste States, 87 percent (26 out of 30) had rati less than 35. For Regions 4–6, 9 values we less than 30, and 4 were less than 25. F Regions 7–9, 10 values were less than 30, a 3 were less than 25.

Furol viscosity at 275° F.

The Furol viscosity at 275° F. ranged fro 85 to 318 seconds for the 119 asphalts (fig. 10

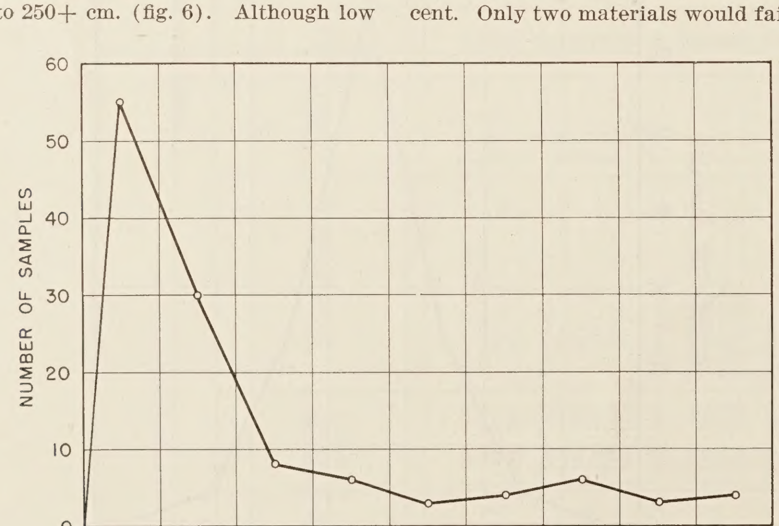

Figure 6.—Distribution of ductility results at 39.2° F.

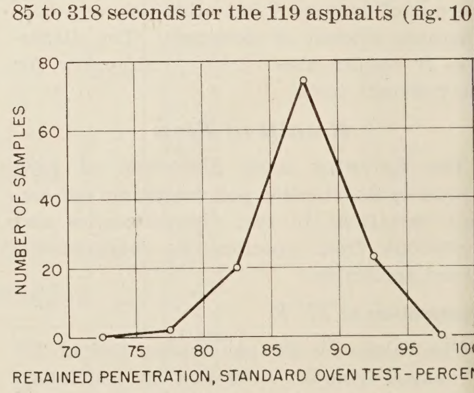

Figure 8.—Distribution of retained penetr tion of standard oven test residues.

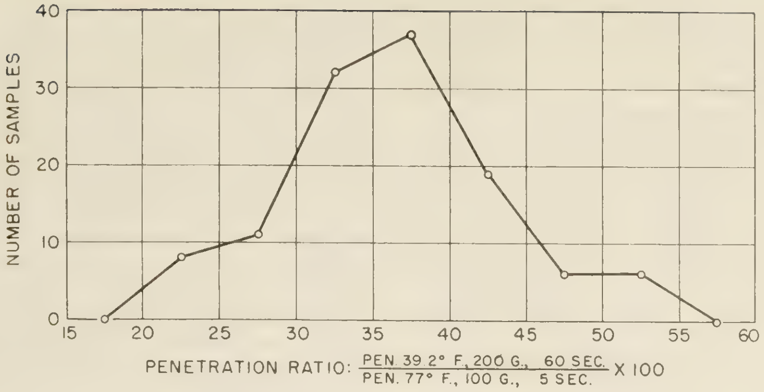

Figure 9.—Distribution of the penetration ratio results.

Four asphalts had viscosity values less than 100 seconds, and two asphalts had values exceeding 300 seconds. The viscosity of 81 asphalts was within the range of 150 to 250 seconds, inclusive. Agencies using Furol viscosity as a specification test have specified minimum requirements of 85 seconds. None of the 119 asphalts failed this requirement. The maximum limit of these specifications is 260 seconds. Six asphalts were over this requirement. The general trend for greater viscosity-temperature susceptibility for asphalts in the West as compared with those in the East is also indicated by the generally lower viscosities for asphalts from the Western States.

Thin-film oven test, loss in weight

The change in weight during the heating of the asphalts in the ⅛-inch film for 5 hours at 325° F. ranged from a gain of 0.12 percent to a loss of 2.18 percent (fig. 11). Twenty-seven asphalts gained in weight during heating, 10 asphalts showed no change, and 16 asphalts lost more than 0.50 percent. Specifications now in effect require loss in weight of either not more than 0.75 or not more than 0.85 percent. Only 7 of the 119 asphalts failed the 0.75 percent requirement and 6 of these indicated losses of more than 0.85 percent.

The greater spread of values for the thin-film losses is illustrated in figure 11, the range being approximately four times that for the standard oven losses. This difference also indicates the lack of a definite relation between the loss results for the two tests.

Retained penetration, thin-film residues

The percentage of the original penetration retained by the residues from the thin-film oven test ranged from 38 to 72 (fig. 12). Of the 119 samples, 13 were less than 55 percent and of these 6 were less than 50 percent. Specifications now in effect in several States specify 47 or 50 percent retained penetration. Only 4 asphalts were less than 47 percent.

Comparison of oven tests

A comparison of the distribution of results of retained penetration after the standard and thin-film oven tests is shown in figure 13. This graph has a different grouping from that used in figure 12, in order to show both groups of data on the same basis. The appreciably greater amount of hardening that occurred in the thin-film oven test is indicated. The range in values for the thin-film residues was approximately twice that for the standard test.

Softening point of thin-film residues

The softening point of the residues from the thin-film oven test ranged from 118° to 140° F. (fig. 14). A comparison with the results for the original softening points, which are also shown, indicates the generally higher values and wider spread for the softening point of the thin-film residues. The range in the values of the residues is approximately 1.7 times that of the original materials.

Ductility of thin-film residues

The ductility of the residues from the thin-film test ranged from 13 to 250+ cm. (fig. 15). Initially none of the asphalts had ductility values less than 100 cm. After heating, 22 asphalts were less than 100 cm. and 9 of these were less than 50 cm. There was also a trend for some asphalts to show higher values after the oven test. This was accounted for by the fact that the reduction in penetration or the hardening during heating for these asphalts put them in the range of consistency for optimum ductility. There was much greater dispersion of ductility values for the thin-film residues than for the original asphalts.

Comparison of properties of asphalts

The 85–100 penetration asphalts included in the 1940 and 1941 reports are believed to be generally representative of the asphalt production during the midthirties (*1–2*). A comparison of test properties of those asphalts with the asphalts produced in the mid-

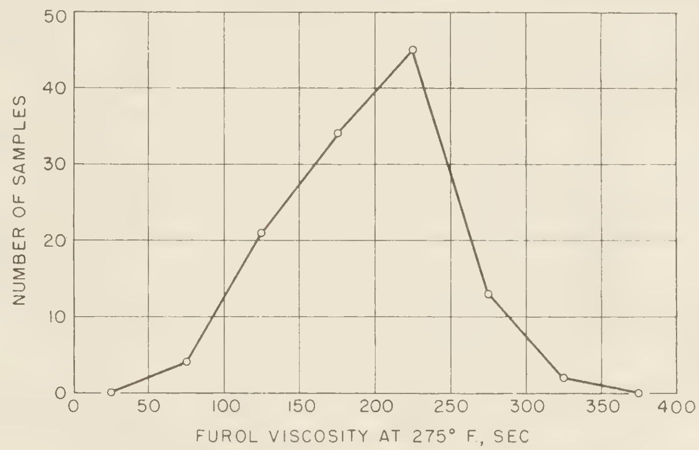

Figure 10.—Distribution of Furol viscosity results.

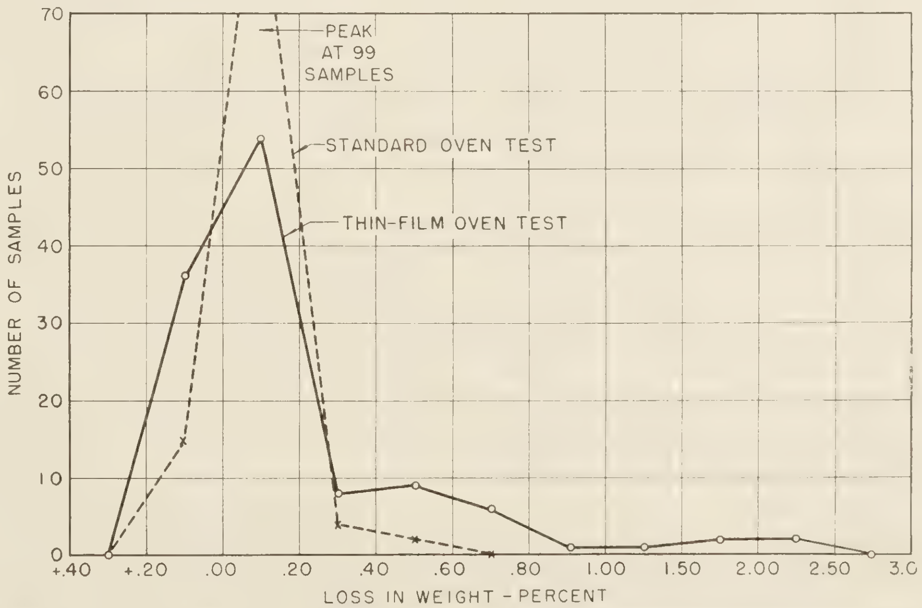

Figure 11.—Distribution of loss in weight for thin-film oven test and comparison with loss in standard test.

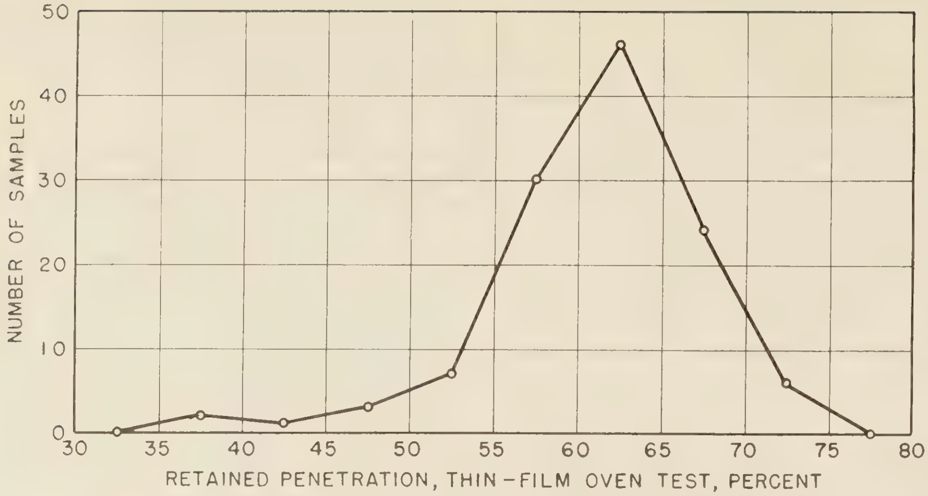

Figure 12.—Distribution of retained penetration of thin-film residues.

fifties should be of interest. Therefore, the results of several tests from the two surveys are presented here in frequency distribution polygons. For discussion purposes the two groups of asphalts are designated as 1935 and 1955 asphalts.

Since there were 40 samples of 1935 asphalts and 119 samples of 1955 asphalts, the results falling in each class interval are shown as a percentage of the total number of samples. Only comparisons are shown for those tests that are being used or considered as measures of quality.

Loss on heating at 325° F., standard test

A comparison of the frequency distribution polygons representing the loss in weight in the standard oven test for the 1935 and 1955 asphalts is shown in figure 16. Except for a slightly larger spread in results for the current asphalts, the distribution for the loss in weight values was essentially the same. In both periods the majority of the samples lost less than 0.20 percent.

Retained penetration of standard oven test residue

A comparison of the results of the penetration retained by the residues from the stand-the standard oven test for the 1935 and 1955 asphalts is shown in figure 17. There was a considerable difference in the amount of retained penetration for the two series of asphalts. Twenty percent of the 40 asphalts in the 1935 series had less than 75 percent retained penetration. None of the 119 asphalts in the 1955 series retained less than 75 percent penetration. The peak of the distribution was between 75 and 80 percent for the 1935 asphalts and between 85 and 90 percent for the 1955 asphalts. This difference resulted chiefly from the general absence of highly cracked asphalts in the 1955 series. Nearly all of those asphalts retaining less than 75 percent of their original penetration were cracked asphalts.

Thin-film oven test

Figure 18 shows the distribution of the results of the change in weight during the thin-film oven test for the asphalts produced in 1935 and 1955. The main differences in the asphalts were the greater percentage of the 1935 materials having loss values between 0.40 and 0.60 percent and the larger percentage of 1955 asphalts having losses greater than 0.80 percent. The secondary peak is caused by five samples, or 12.5 percent of the 1935 asphalts with loss values between 0.40 and 0.60 percent, that were from Mexican crude sources. Only one asphalt known to be from this source was included in the 1955 survey and it had a loss in the same range.

The percentage of penetration retained by the residues from the thin-film oven test on the 1935 and 1955 asphalts is compared in figure 19. In general, the 1955 asphalts were more resistant to hardening in the thin-film test than were those produced in 1935. However, only a few asphalts showed excessive loss in penetration during this heat test.

Comparisons of the distribution of the ductility of the 1935 and 1955 asphalts before and after heating in the thin-film test are shown in figures 20 and 21. The frequency distribution polygons of the asphalts produced for the two periods as shown in figure 20 are essentially the same with a slight trend for the more recent asphalts to have higher ductility. Figure 21 shows a definite trend toward higher ductility for the residues from the 1955 asphalts. Of the 1935 asphalts, 37.5 percent had ductility values less than 100 cm. as compared with approximately 18.5 percent of the 1955 asphalts.

Penetration ratio

The ratio of the penetration at 39.2° F. to the penetration at 77° F. is coming to be

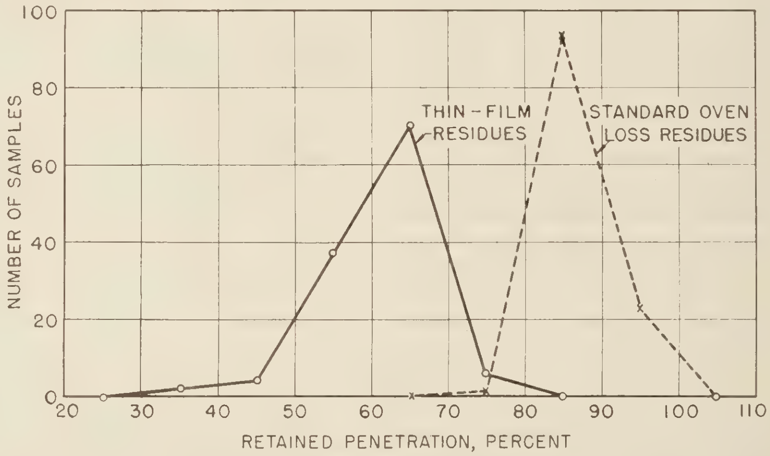

Figure 13.—Comparison of the results of retained penetration after standard and thin-film oven tests.

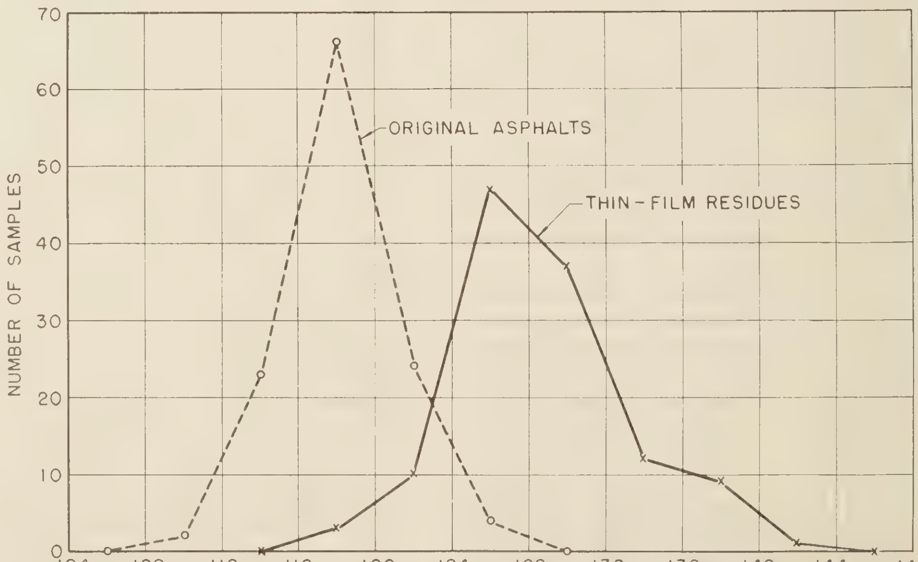

Figure 14.—Comparison of softening points of thin-film residues and original values.

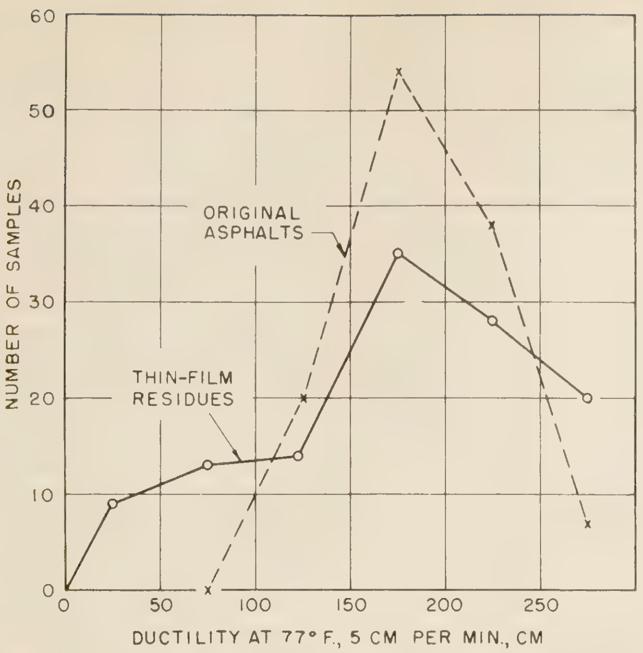

Figure 15.—Comparison of ductility of thin-film residues and original values.

more generally used as a specification test (fig. 22). None of the asphalts produced in 1935 had penetration ratios less than 25 as compared with 6.7 percent of those produced in 1955. However, 21.1 percent of the 1935 asphalts had values between 25 and 29 as compared with 9.2 percent of the 1955 samples. Here, the larger percentage of 1935 asphalts is due essentially to the results of four California asphalts and two highly cracked asphalts falling in the 25 to 29 range.

Furol viscosity at 275° F.

A comparison of the Furol viscosity at 275° F. of the asphalts produced in 1935 and 1955 is shown in figure 23. In general, the viscosity of the 1955 asphalts was higher than the 1935 asphalts. The secondary peak of the 1935 asphalts, between 50 and 100 seconds, was caused by the four California and two highly cracked asphalts.

Oliensis spot test

In the 1940 report (*1*) it was shown that 15 of the 40 asphalt cements tested had a positive reaction to the Oliensis spot test, and that the degree of heterogeneity as measured by the xylene equivalent was high for some of them, 7 having values higher than 12. The spot test using standard naphtha on the 1955 asphalts indicated negative results for 105 of the 119 samples. The remaining 14 samples showed a positive spot, but most of these had relatively low xylene equivalents as indicated in table 3. Samples 42 and 109 are unusual in that they showed positive spots with 100-percent xylene. However, both of these samples contain unusually high amounts of organic insoluble in carbon disulfide. This insoluble material most likely produces the spot. Sample 69 has a 12–16 xylene equivalent, and this asphalt is known to be refined from a West Texas crude that produces a positive spot asphalt even when vacuum or steam refining is used. One asphalt of the 1935 group was from the same producer and crude source and had a xylene equivalent of 16–20. All of the other positive spot materials had a xylene equivalent less than 12.

Thus it is indicated that very few of the present day asphalts would fail to pass spot test requirements in specifications, particularly if the standard solvent contains some increment of xylene as is often specified.

General Discussion of Data

The test values reported here are considered important as a group in that they provide needed information concerning what may be considered normal values for specific test characteristics, and also what the expected relation between various associated characteristics may be. The general differences in asphalts produced in different areas of the country are also considered to be of interest. It is believed that such information is needed for a proper evaluation of present specification requirements and as a guide to the acceptability of new tests and requirements. The data should also be helpful to those engaged in asphalt research.

From the standpoint of specification requirements it is shown that very few of the 85–100 penetration grade asphalts failed to meet the standard specifications that are used by a large number of States. Although 12 asphalts failed to fall within the proper penetration range, only 3 would fail any of the other standard AASHO requirements. Sample 103 had a Cleveland open cup flash point of 440° F., 10 degrees below the required 450° F. However, this value would be acceptable in all but 17 States. Samples 42 and 109 would fail the requirement for the amount of insoluble matter in carbon tetrachloride in all States using this test. Both samples would also fail the usual requirement for carbon disulfide insoluble.

The asphalt specifications in most general use fail to measure the relative quality of

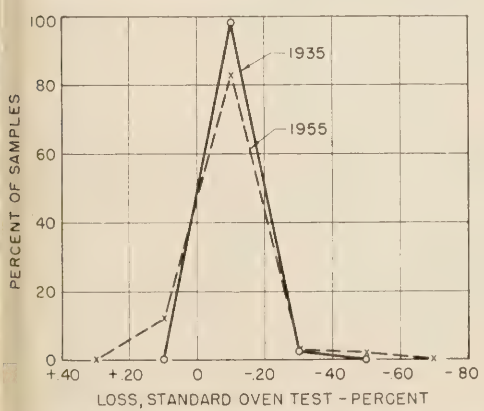

Figure 16.—Distribution of loss in standard oven test, 1935 and 1955.

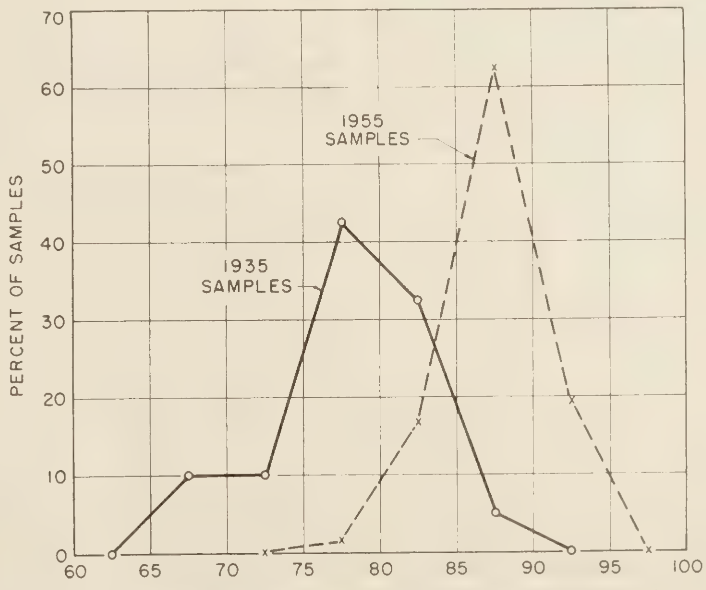

Figure 17.—Distribution of results of retained penetration, 1935 and 1955.

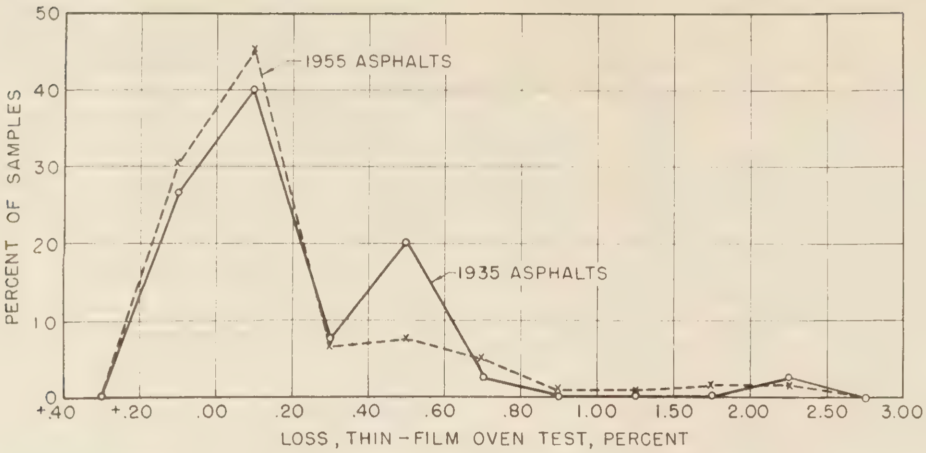

Figure 18.—Distribution of loss in thin-film test, 1935 and 1955.

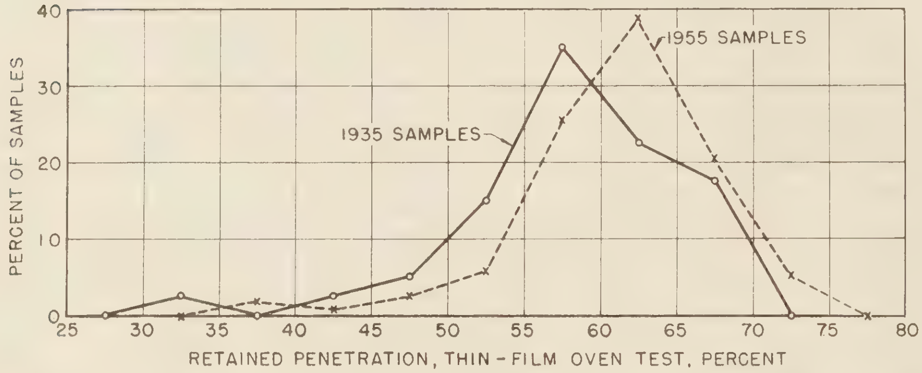

Figure 19.—Distribution of retained penetration after thin-film oven test, 1935 and 1955.

different materials, and some materials meeting present day specifications may actually show poor service characteristics. Consequently, a number of agencies, including the Bureau of Public Roads, are conducting research directed toward the establishment of more direct measures of quality. Several States have adopted special tests designed to raise the overall quality of the asphalts being furnished them. The most extensive effort along these lines has been the adoption, on a trial basis, of a so-called quality specification

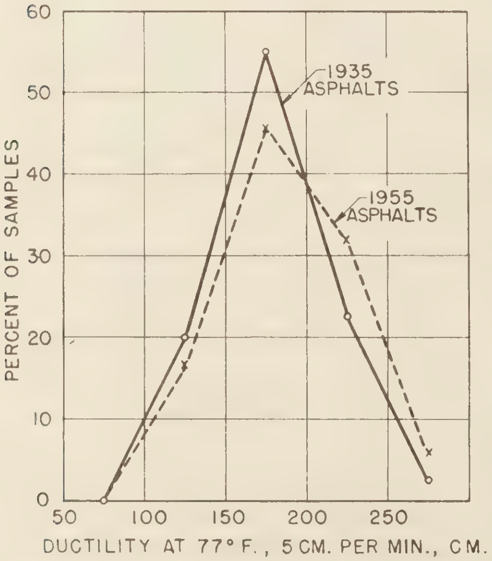

Figure 20.—Distribution of ductility results, 1935 and 1955.

by a number of Western States. This specification contains several features not usually a part of standard specifications. A general discussion of these requirements with respect to the data reported in this series of tests and the effect of their application on a nationwide basis is believed to be of interest.

The western quality specification substitutes the Pensky-Martens closed cup apparatus for the Cleveland open cup as the means for determining the flash point. Several States use a limit of 450° F., whereas that recommended by a conference of western producers and consumers in 1957 was 440° F. While such limits may be useful in these States, the tests reported here show that 33 asphalts, most of them of apparently good quality, would fail the requirement of 450° F. if applied on a national basis. The principal reason for including flash point requirements in specifications is to indicate the temperature to which asphalt may be safely heated. Therefore the use of a limit more restrictive than necessary to accomplish this objective can be justified only if correlation with service or laboratory tests for quality is indicated.

Although one State has reported some correlation of Pensky-Martens flash point with service records of asphalts used in that State, such a correlation is apparently not general for asphalts all over the country. These tests show no specific correlation of the flash point values by either method with volatility or the tendency of the material to harden in laboratory tests. There is also no definite relation between the values obtained by the two methods. Apparently certain asphalts contain a small trace of volatile material that is sufficient to give a closed cup flash at a relatively low temperature, but the quantity is insufficient to produce a flash in the open cup apparatus. Losses in weight in both the standard and thin-film oven tests show that some of the asphalts having low Pensky-Martens flash points have relatively low amounts of volatile matter.

A second special test is the penetration ratio, that is, the penetration at 39.2° F., 200 g., 60 sec., divided by the penetration at 77° F., 100 g., 5 sec., multiplied by 100. This test was first proposed for use by an Eastern State with a limiting value of 35. As previously discussed, such a limit would not be applicable on a nationwide basis as it would eliminate almost 90 percent of the asphalts available in the far Western States. The application of the test with a limit of 25, however, serves to eliminate only those materials with unusually high temperature susceptibility, and therefore the test does serve a useful purpose in the western area of the country.

Another feature of the quality specification that serves to limit the viscosity-temperature relation is the Furol viscosity at 275° F. This value is of interest not only as a specification requirement but also as a means of determining the proper mixing temperature. The western specification has limits of 85 to 260 seconds for the 85–100 penetration grade asphalt. None of the asphalts in this series had viscosities lower than 85 seconds, but some of the less susceptible good quality asphalts in the Eastern States had viscosities greater than 260 seconds. Thus again, the same limits could not be applied all over the country.

The substitution of the thin-film oven test (⅛-inch film) for the standard loss test is believed to be a definite step forward. The data in this report show the standard test to be of little or no value. The usual limit of 1 percent loss is unrealistic in that no asphalt being produced today even approaches this limit, even though some of them apparently contain a much greater amount of volatile matter than is consistent with good engineering practice. Of even more importance is the failure of the test to indicate the amount of hardening that is likely to occur in the mixing process.

On the other hand, early investigations

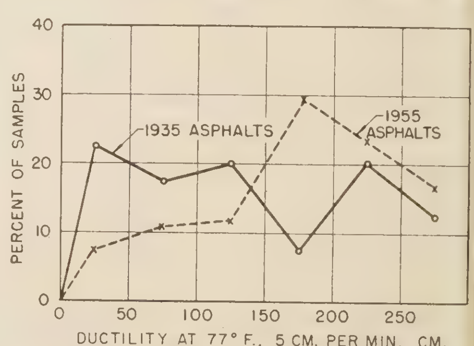

Figure 21.—Distribution of ductility results of thin-film residues, 1935 and 1955.

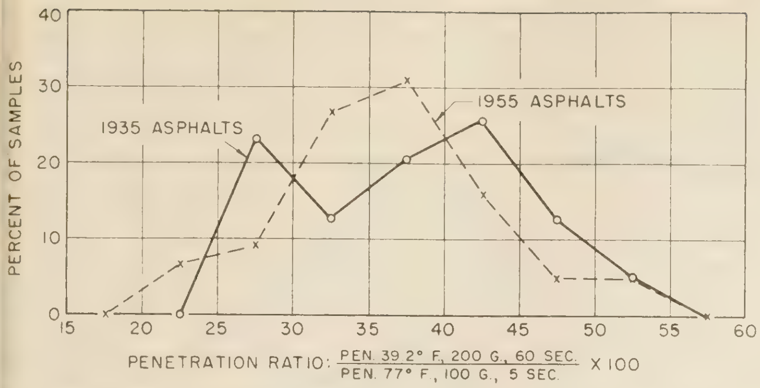

Figure 22.—Distribution of penetration ratios, 1935 and 1955.

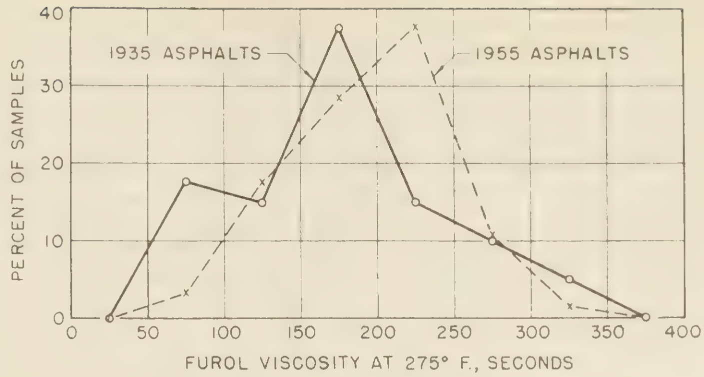

Figure 23.—Distribution of Furol viscosity tests, 1935 and 1955.

have shown that the correlation of the hardening that occurs in the thin-film oven test with the hardening that occurs in normal mixing seems to be generally good for all asphalts. The relation between various tests for hardening was discussed in an article by Pauls and Welborn (*4*). These authors concluded that a good relation existed between the results of the thin-film oven test and a number of other tests for hardening such as the Shattuck test, an abrasion test on oven-weathered Ottawa sand mixtures, and accelerated outdoor exposure. It was also pointed out that the thin-film oven test is the most suitable for use in specifications because it requires less time, it measures the hardening of the asphalt directly, and it does not require extraction and recovery of the asphalt as in the case of those tests in which an asphalt-aggregate mixture is used. Continuing studies in the Bureau of Public Roads laboratories since that report have not produced any evidence contrary to the conclusions drawn at that time.

Table 3.—Xylene-naphtha equivalents of positive spot asphalts produced in 1955

Sample identification	Xylene-naphtha equivalent
42	[1] 100
43	8–12
56	4–8
59	4–8
69	12–16
79	8–12
90	0–4
95	0–4
98	0–4
102	8–12
103	0–4
109	[1] 100
111	8–12
116	4–8

[1] Positive spot in xylene.

The proper specification limits to be applied to the thin-film oven test to eliminate those asphalts likely to be excessively damaged during mixing without being too restrictive have been the subject of considerable debate. These tests show that the limit of 0.75 percent loss most generally used is not unduly restrictive for any area. The results also indicate that a value of 50 percent used by some States for the amount of retained penetration is also suitable and would be preferable to the 47 percent limit now included in the western quality specification. The minimum value of 75 cm. for ductility as used by the Western States appears suitable for that region. However, this limiting value may be somewhat severe for asphalts from the midcontinent area that normally have lower ductility on the original material. A better evaluation of this limit may be made after the other penetration grades of asphalt collected for this study have been analyzed.

As stated earlier, this is a progress report. The data reported indicate generally the differences in test characteristics that exist and those asphalts that have unusual characteristics. While certain trends and relations are evident, no attempt is made to discuss such relations or to draw definite conclusions at this time. It is believed that the completion of the tests for all grades of asphalts and a survey of the performance of some of the more unusual materials will provide a basis for a better evaluation.

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(1) Lewis, R. H., and Welborn, J. Y. *The physical and chemical properties of petroleum asphalts of the 50–60 and 85–100 penetration grades.* Public Roads, vol. 21, No. 1, March 1940; also Proceedings of the Association of Asphalt Paving Technologists, vol. 11, Jan. 1940, pp. 86–157.

(2) Lewis, R. H., and Welborn, J. Y. *The properties of the residues of 50–60 and 85–100 penetration asphalts from oven tests and exposure.* Public Roads, vol. 22, No. 2, April 1941; also Proceedings of the Association of Asphalt Paving Technologists, vol. 12, Dec. 1940, pp 14–68.

(3) Lewis, R. H., and Halstead, W. J. *Behavior of asphalts in the thin-film oven test.* Public Roads, vol. 24, No. 8, April-May-June 1946.

(4) Pauls, J. T., and Welborn, J. Y. *Studies of the hardening properties of asphaltic materials.* Public Roads, vol. 27, No. 9, Aug. 1953; also Proceedings of the Association of Asphalt Paving Technologists, vol. 21, Jan. 1952, pp. 48–75.

Maximum wind speeds (miles per hour) at 3

ound for 50-year mean recurrence interval.

North Dakota's Use of Aerial Inventory for County General Highway Maps

By E. THOMAS BOWEN, CHARLES J. CRAWFORD
North Dakota State Highway Department, and
JOHN B. KEMP, Bureau of Public Roads

North Dakota's topography is particularly adaptable to the aerial method of road inventory. The flat and rolling terrain, the section-line road pattern, and the sparsely populated areas make it possible to quickly identify road and cultural features from the air.

North Dakota, being the first State to institute aerial inventory operations, has in its initial 3 years produced better inventory data in much less time and at less cost than the conventional ground inventory method. Formerly, it was necessary for inventory crews to travel by automobile over every road and street in the State. Since North Dakota is the sixth ranking State in total mileage, the ground inventory method was both costly and time consuming. Under the present inventory method, most of the data can be recorded from the air.

The average inventory costs in 1958, based on the combined use of aerial and ground methods, amounted to approximately 27½ percent of the cost of the ground inventory method used in 1955.

ONE of the principal activities of the State highway planning surveys since their beginning in the midthirties has been inventory and mapping. Probably the principal use of inventory data has been for the preparation of county general highway maps. A number of methods for collecting the inventory data have been developed by the several States.

The North Dakota Highway Planning Survey has instituted an aerial method for collecting most of the field data. During the past 3 years all 53 counties in the State have been inventoried, an area of about 70,000 square miles and including approximately 115,000 miles of roads and streets.

Inventory Operations

The inventory operations in North Dakota involve essentially a combination of the following activities: office preparation of a work map showing roads and cultural data obtained from aerial photographs; verification or revision of the work map based on field observations from the air; estimation and classification from the air of such information as road surface types and widths, and types and sizes of drainage structures; and collection, by ground crews, of structural and other inventory data in incorporated places. Of necessity, certain horizontal control information must also be obtained by a ground crew.

A print of the most current county general highway map, having a scale of 1 inch equals 1 mile, serves as a base for the work map. Information such as road identification numbers, map segment numbers, and other data which serve to orient the air crew are indicated on the base map. Available aerial photographs are then examined for the purpose of updating the base map to the extent possible. The work maps are cut into segments of convenient size for ease in handling within the aircraft.

The work map is then taken aloft and each road is studied. The roads in North Dakota generally follow the north-south or east-west section-line land grids. The road and cultural data that appear on the work map are identified from the air by a check mark on the map. Features not shown on the work map are added by color code, and conversely, features shown on the map but found to be nonexisting are crossed out. Also, incorrect map data are adjusted to conform with observed conditions.

Aerial Classification of Roads

Most of the roads located off the Federal-aid primary system in North Dakota are gravel-surfaced or dirt roads, and for these a satisfactory visual grouping of three width classes has been used: narrow, under 20 feet; middle, 20–26 feet; and wide, over 26 feet. Widths from construction plans are available for practically all surface-treated and higher type roads.

The narrow earth and gravel-surfaced roads under 20 feet are characterized by a single pair of tracks; the middle class, with seldom meeting traffic, is characterized by three tracks; and the over 26-foot widths generally have two pairs of tracks or four clearly defined wheel tracks (fig. 1).

Minor structures, 10 to 20 feet in length, are classified according to size and type from the air. On the basis of test runs, it was found that an experienced air crew could estimate road surface widths and structure size and type information to better than 95-percent accuracy.

Ground Crew Activities

The ground crew and air crew activities are well coordinated to prevent duplication of effort. The aerial inventory is made first,

[1] This article was presented at the 38th Annual Meeting of the Highway Research Board, Washington, D.C., January 1959. Authors' titles are as follows: Mr. Bowen, Assistant Highway Planning Survey Engineer; Mr. Crawford, Highway Planning Survey Engineer; and Mr. Kemp, District Engineer.

Figure 1.—Aerial classification of low type or unsurfaced road widths: (left) narrow class, single pair of tracks; (center) middle class, three tracks; and (right) wide class, two pairs of tracks.

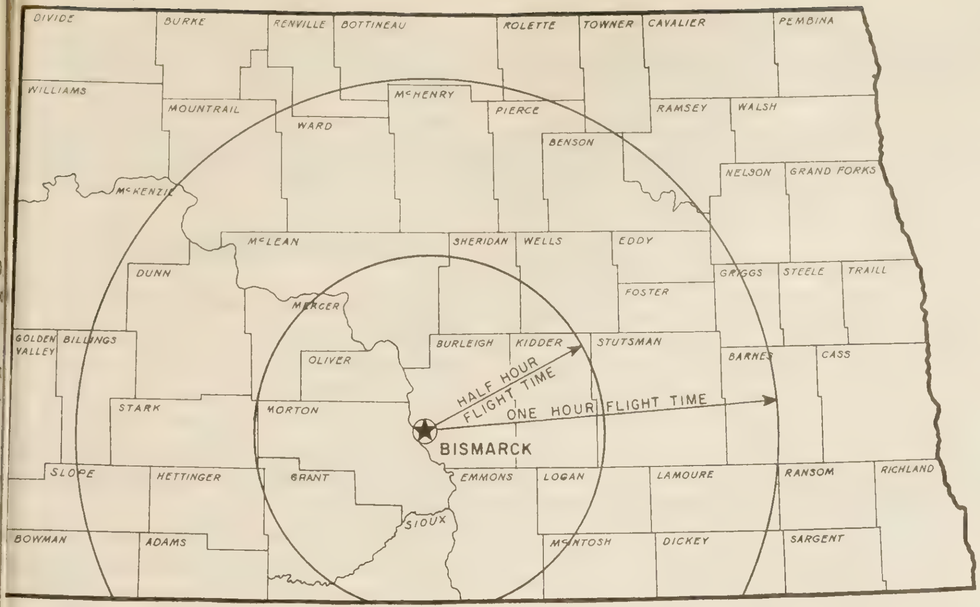

Figure 2.—One-hour flight time from Bismarck covers 58 percent of North Dakota.

and all possible data are collected by this method. The remainder is handled by the ground crew.

In areas where there is inadequate coverage of triangulation stations, the ground crew takes the aerial photographs into the field, locates enough section corners to give adequate horizontal control data for mapping, and pin pricks the section corner locations on the aerial photographs. It should be noted that the collection of this horizontal control information by the ground crew is a one-time operation and it has been completed.

For structures with over 20-foot clear span, the ground crew records type, width, length, and related data. Since most of this information has been obtained, future reinventory operations will include only the structures built, replaced, or destroyed since the previous inventory. Such structures can be readily identified by the air crew. Inventory data for structures built on the Federal-aid systems can be taken from the construction plans.

The air crew has inventoried the smaller unincorporated compacts by the checkoff method, working from photocopy enlargements of the aerial photographs. In a few of the larger unincorporated compacts, especially those with over 500 population, some assistance from the ground crew was needed.

Equipment, Personnel, and Operation

The aerial inventory is accomplished in a four-place aircraft equipped with all-weather instruments including a directional gyro compass. The aircraft is leased from a privately owned corporation exclusively for the inventory operation. The rental rate is $12 per hour without pilot; there is no fixed minimum charge for limited use. A new airplane of this general type so equipped would cost from $10,000 to $15,000.

The State has full control of all operations and maintenance. Whenever repairs and maintenance are deemed necessary, whether it be a new motor or a small screw, the State Highway Department initiates the work orders and the corporation pays the bill.

There is strict adherence to FAA safety regulations, both in maintenance and in flight. The corporation carries insurance on damage to the airplane, property damage, and liability coverage for all State and Federal personnel using the craft.

The air crew consists of a pilot and a recorder. The State Highway Department employs a pilot on an annual salary, which includes an increment for flight time. When not engaged in flying activities, particularly during the winter months, he is assigned office duties. A number of State employees hold commercial pilot licenses which qualify them for this type of work. The recorder is one of the regular draftsmen in the Inventory and Mapping Section. Several draftsmen have been trained for this duty.

Three-fourths of the counties in North Dakota are within 1 hour's flight time from the State Capitol in Bismarck (fig. 2), which is the base of operations for the air activities. This saves subsistence and quarters allowances and is convenient in assigning office duties during inclement weather.

In working the outlying counties the air crew collects inventory data in intermediate counties enroute. By the time the inventory of the outlying counties is completed, a major portion of the work in the intermediate counties has been completed also. By proper scheduling of the counties for inventory in any given year, little time is lost in "deadheading".

In rough terrain, such as the badlands, high level reconnaissance at 2,000 to 5,000 feet (above the ground) is necessary for orientation. After completion of the high level reconnaissance, the flight altitude is reduced to less than 1,000 feet for detailed road information.

In flat or gently rolling terrain the high level reconnaissance is employed only in the more congested urban areas. In rural areas the section lines are usually well defined, in many instances with a road or trail. Orientation presents no special problem in such areas and the inventory data can be collected by low level flights. These flights generally are made at an altitude of 200 to 500 feet, and at an air speed of about 80 miles per hour. FAA and North Dakota low flight waivers are required.

The low level county-wide flight runs are made covering one section line at a time and, depending upon the wind direction on a given day, either north-south or east-west section lines are flown. Occasional circling and reruns are necessary if features are not clearly identifiable on the first run. For instance, it may be difficult to ascertain whether a dwelling unit in a grove of trees is occupied. Also, a cluster of houses tends to pass from view too quickly at low altitudes. If the culture is quite dense, it may be necessary to climb to a higher altitude to get a better overall view.

Comparative Costs

As shown in table 1, the area of the average county in North Dakota is 1,324 square miles. During 1955, the last year the ground inventory method was used, the inventory operations in an average county cost $6,104 or $4.61 per square mile. The cost in previous years approximated this amount.

In 1956, the first year of the aerial inventory, the average cost per county was $2,118 or $1.60 per square mile. In 1958, the average costs per county and per square mile were $1,681 and $1.27, respectively. Field inventory costs should be further reduced during subsequent reinventory operations.

Table 1.—Comparison of aerial and ground inventory costs in North Dakota, 1955–58, based on an average of 1,324 square miles per county

Cost basis	1955 (=100) [1]	1956		1957		1958	
		Actual cost	Adjusted cost [1]	Actual cost	Adjusted cost [1]	Actual cost	Adjusted cost [1]
Cost per county:							
Aerial inventory	--------	$1,165	$1,095	$966	$899	$807	$751
Ground inventory	$6,104	953	896	914	849	874	813
Total	6,104	2,118	1,991	1,880	1,748	1,681	1,564
Cost per square mile:							
Aerial inventory	--------	0.88	0.83	0.73	0.68	0.61	0.57
Ground inventory	4.61	.72	.67	.69	.64	.66	.61
Total	4.61	1.60	1.50	1.42	1.32	1.27	1.18

[1] Cost indexes: 1955=100, 1956=106.4, 1957=107.5, and 1958=107.5. Changes in index values reflect primarily increases in salaries and aircraft operating costs.

Future Operations

Reinventory operations will be continued on a 3-year cycle. This cycle is considered reasonable from the standpoint of efficient inventory and mapping operations, and in view of the need for current data. Under this plan, one-third of the roads and streets would be inventoried each year.

Every effort is being made to transfer ground crew inventory activities to the air crew. In the past, the ground crew has inventoried all incorporated places primarily to identify corporate limits. New methods of obtaining this information by other than a direct visit are under consideration. Also under consideration is the purchase of a camera and appropriate enlarging, developing, and reproduction equipment to permit aerial inventory of areas having relatively heavy cultural development.

Within a short time, it is anticipated that all incorporated places under 500 population, which represent about 70 percent of all incorporated places in North Dakota, will be inventoried by the aerial method without assistance from a ground crew. Ground crew activities will then be limited to inventorying streets in cities over 500 population and to measuring and classifying structures.

Maximum Wind Speeds to Consider in Designing Highway Signs

In cooperation with the Bureau of Public Roads, the U.S. Weather Bureau has prepared the map shown on pages 208–209 which presents wind speeds throughout the United States.

The specific purpose of the map is to provide highway engineers with wind speed values that can be used in the design of highway signs, especially overhead signs. For the first time, the wind data compiled by the Weather Bureau were developed from observations at airport stations instead of locations within cities. A comparison made between city and airport stations in the same locality showed that winds were considerably higher, in most cases, at airports.

Wind speeds shown on the map at an elevation of 30 feet above ground are for the 50-year mean recurrence interval, and take into account thunderstorms and hurricanes. Tornadoes are not subject to prediction by the method used in compiling the map data, and have such extreme wind speeds with a low probability of occurrence that design for their loads is not economically warranted. The map does not show wind direction; hence, the term speed is used instead of velocity.

Adequate guide and destination signs fo the Interstate System have been estimated t cost nearly $1/2 billion. The greater dimer sions of the new signs and their positionin along the roadway to provide highway clea ance and legibility make the sign supportin structure an important engineering problem

Highway Statistics, 1957

The Bureau's *Highway Statistics, 1957*, th thirteenth of the bulletin series presentin annual statistical and analytical tables o general interest on the subjects of motor fue motor vehicles, highway-user taxation, Stat and local highway financing, road and stree mileage, and Federal aid for highways, is nov available.

The 200-page publication, which include special tables on State legal and administra tive provisions regarding motor-fuel taxation motor-vehicle registrations, and operator' licenses, may be purchased from the Super intendent of Documents, U.S. Governmen Printing Office, Washington 25, D.C., at $1.2 a copy. The series of annual bulletins tha are available from the Superintendent o Documents are indicated on the inside bacl cover of Public Roads.

Characteristics of Traffic Entering and Leaving the Central Business District

BY THE DIVISION OF HIGHWAY PLANNING
BUREAU OF PUBLIC ROADS

Reported by DAVID A. GORMAN, Highway Research Engineer, and
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The prosperity of the central business district depends to a great extent upon a transportation system capable of carrying the huge volumes of traffic destined to the central area and upon vehicle storage capacity. Knowledge of the movement of traffic entering and leaving the central business district, including its volume and composition, and the ability to estimate these traffic characteristics are prerequisites for good city planning.

The central business district is but one terminus of many trips in an urbanized area. The other major terminus is outside the central business district in the various zones or sections of the urbanized area. This article discusses only one area of the study of urban traffic, the central business district. With the development of more accurate relationships between population, land use, and automobile and transit trips generated outside the central business districts, more reliable predictions of the volume and distribution of travel from the various zones to the central business district should be possible.

The traffic volume data presented here should be considered carefully before applying to any particular city. The wide variations in numbers of vehicles entering and leaving the central business district of cities within a population group demonstrates the need for precaution in making generalizations, except in the case of averages for population groups. Nevertheless, the data do have considerable value as a measure of traffic that can be expected to enter and leave the central business districts in cities of different sizes.

BETWEEN 1945 and 1955, parking surveys were conducted in the central business districts of 91 cities. The surveys consisted of two phases: parking and traffic. In many of these surveys, because of a limited budget, both phases were studied only between 10 a.m. and 6 p.m., hours when parking and traffic problems were most evident. For this reason and for comparative purposes, all data, except when otherwise noted, are presented for this time period.

The 10 a.m. to 6 p.m. period, although desirable for the study of parking, has its shortcomings from the traffic standpoint because of the omission of the morning peak hours of inbound traffic. Since the 10 a.m. to 6 p.m. period included the daily peak hours of outbound traffic and since late afternoon peaks are usually greater than morning peaks, preference was given in the analysis to the outbound traffic volumes as the basis for comparing traffic volumes among cities. This, however, is not intended to detract from the usefulness of the inbound traffic data shown in the tables. Inbound traffic data can also be used for comparing traffic volumes among cities and population groups.

Vehicles Entering and Leaving the Central Business District

The central business district with its concentration of commercial, business, financial, and governmental activities is one of the principal destinations of traffic in an urbanized area.[1] Table 1 shows the number of vehicles entering and leaving the central business district between 10 a.m. and 6 p.m., and the relation between traffic volumes and urbanized area population for each of the 91 cities. From this table it is possible to compare traffic volumes of one city with another, since the data pertain to the same period of the day and were obtained by the same procedure. Table 2 is a summary showing the averages of these data for cities within each population group.

Five types of traffic entered the central business district: (1) Vehicles passing through without parking, 10 a.m.–6 p.m.; (2) vehicles arriving after 10 a.m. and leaving before 6 p.m.; (3) vehicles arriving before 10 a.m. and leaving after 6 p.m.; (4) vehicles arriving after 10 a.m. and leaving after 6 p.m.; and (5) vehicles arriving before 10 a.m. and leaving before 6 p.m. Vehicles in groups 1 and 2 were counted as they entered and again as they left. Vehicles in group 3 were missed entirely; those in group 4 were counted inbound only; and those in group 5 were counted outbound only.

The ratio of outbound vehicles to inbound vehicles between 10 a.m. and 6 p.m. tended to increase with population size, (tables 1 and 2), which shows that more vehicles of group 5 entered the central business district of the larger cities than vehicles of group 4. This seems to indicate that the proportion of employees in the inbound traffic stream increases with population size. This is significant because of the bearing it has upon the type of parking space that is required in the larger cities in contrast to that which is required in the smaller cities. Employees as a group are long-time parkers, whereas persons on business and shopping trips are generally short-time parkers.

Figure 1 shows the number of vehicles by urbanized area population that left the central business district between 10 a.m. and 6 p.m., and the number per thousand population. According to this graph, the number of vehicles leaving the central business district in proportion to population decreased as cities became larger. The slope of the curve for the number of vehicles leaving the central business district approaches the horizontal for cities of about 800,000 or more population which indicates the probability that further increases in population produce only very minor increases in the number of vehicles leaving the central business district.

It should be noted that the curves apply only to averages for cities within population groups and not to individual cities. Using averages for cities within a population group greatly reduced the influence of factors responsible for the variations of the individual cities. It has not yet been possible to identify all of these factors nor to measure them satisfactorily.

Traffic Volumes Compared on Per Capita Basis

The traffic problem is not confined to large cities. On a per capita basis, the central business districts in the smaller cities are greater traffic magnets than those in the larger cities. Thirteen times as many vehicles per thousand population entered the central business district in the average city of the 10,000–25,000 population group as in the over 1 million population group. This large difference is probably due in part to the fact that the area of central business districts increases very slowly in relation to population. The average city in the over 1 million

[1] *Parking Guide for Cities*, Bureau of Public Roads, Washington, 1956, fig. 31, p. 115.

Table 1.—Passenger cars, trucks, and buses entering and leaving the central business district in 91 cities

Population group and city	Year of study	Urbanized area population, 1950	Vehicles entering CBD, 10 a.m.–6 p.m.		Vehicles leaving CBD, 10 a.m.–6 p.m.		Ratio: vehicles leaving/vehicles entering	Vehicles leaving CBD during peak ½ hour			Ratio: peak ½ hour/average ½ hour	Trucks and buses leaving CBD, 10 a.m.–6 p.m.[1]		
			Number	Per 1,000 population	Number	Per 1,000 population		Number	Per 1,000 population	Percentage of all vehicles leaving 10 a.m.–6 p.m.		Number	Per 1,000 population	Percentage of all vehicles leaving 10 a.m.–6 p.m.
5,000–10,000:														
Paris, Ky	1955	6,912	9,716	1,406	9,783	1,415	1.01	934	135	10	1.53	2,116	306	22
Decatur, Ind	1948	7,271	5,918	814	6,134	844	1.04	582	80	9	1.52	1,131	156	18
Seymour, Ind	1948	9,629	10,594	1,100	10,752	1,117	1.01	914	95	9	1.36	2,345	244	22
10,000–25,000:														
Wabash, Ind	1948	10,621	9,961	938	10,549	993	1.06	973	92	9	1.48	1,982	187	19
Coatesville, Pa	1951	13,826	15,087	1,091	15,342	1,110	1.02	1,296	94	8	1.35	2,949	214	19
Lewistown, Pa	1952	13,894	14,271	1,027	14,834	1,068	1.04	1,230	89	8	1.33	2,806	209	19
Hanover, Pa	1954	14,048	17,480	1,244	18,090	1,288	1.03	1,925	137	11	1.70	3,335	237	18
Frankfort, Ind	1948	15,028	11,244	748	11,577	770	1.03	1,096	73	9	1.51	1,891	126	16
Huntington, Ind	1948	15,097	14,431	956	15,007	994	1.04	1,423	94	9	1.52	2,485	165	17
West Chester, Pa	1949	15,168	14,961	986	15,211	1,003	1.02	1,461	96	10	1.54	3,149	208	21
Jeannette, Pa	1953	16,172	8,819	545	9,553	591	1.08	814	50	9	1.36	1,679	104	18
Stevens Point, Wis	1947	16,564	9,755	589	10,213	617	1.05	975	59	10	1.53	1,684	102	16
Carlisle, Pa	1953	16,812	17,495	1,041	17,760	1,056	1.02	1,830	109	10	1.65	3,334	198	19
Greensburg, Pa	1952	16,923	20,613	1,218	21,297	1,258	1.03	2,221	131	10	1.67	4,319	255	20
Chambersburg, Pa	1954	17,212	17,639	1,025	18,297	1,063	1.04	1,860	108	10	1.63	3,630	211	20
Martinsville, Va	1949	17,251	10,987	637	11,299	655	1.03	989	57	9	1.40	--------	-----	------
Clovis, N. Mex	1950	17,318	16,312	942	16,749	967	1.03	1,501	87	9	1.43	3,509	203	21
Bradford, Pa	1953	17,354	12,940	746	13,472	776	1.04	1,399	81	10	1.66	2,498	144	19
Monessen, Pa	1953	17,896	9,054	506	9,452	528	1.04	944	53	10	1.60	1,585	89	17
Columbus, Ind	1948	18,370	12,613	687	13,387	729	1.06	1,336	73	10	1.60	2,489	135	19
Portsmouth, N. H	1946	18,830	12,906	685	12,591	669	.98	1,076	57	9	1.37	2,143	114	17
Meadville, Pa	1948	18,972	16,398	864	17,117	902	1.04	1,318	69	8	1.23	2,287	121	13
Oil City, Pa	1954	19,581	14,518	741	15,508	792	1.07	1,686	86	11	1.74	2,507	128	16
Anderson, S.C	1947	19,770	16,854	853	17,267	873	1.02	1,365	69	8	1.26	2,906	147	17
Uniontown, Pa	1950	20,471	21,546	1,053	21,696	1,060	1.01	2,032	99	9	1.50	5,086	248	23
Pottstown, Pa	1949	22,589	20,363	901	20,830	922	1.02	1,674	74	8	1.29	4,214	187	20
Butler, Pa	1951	23,487	20,582	876	21,539	917	1.05	2,042	87	9	1.52	3,987	170	19
Pottsville, Pa	1953	23,640	18,877	799	19,607	829	1.04	1,652	70	8	1.35	3,168	134	16
Walla Walla, Wash	1946	24,102	15,658	650	16,291	676	1.04	1,631	68	10	1.60	3,072	127	19
25,000–50,000:														
New Kensington, Pa	1954	25,146	19,365	770	20,024	796	1.03	2,059	82	10	1.65	3,268	130	16
Roswell, N. Mex	1950	25,738	20,937	813	21,303	828	1.02	2,108	82	10	1.58	4,514	175	21
Washington, Pa	1952	26,280	21,142	804	22,585	859	1.07	2,137	81	9	1.51	3,879	148	17
Lebanon, Pa	1953	28,156	23,291	827	24,372	866	1.05	2,524	90	10	1.66	4,956	176	20
Fond du Lac, Wis	1950	29,936	18,172	607	19,056	637	1.05	2,009	67	11	1.69	3,147	105	17
Biddeford-Saco, Maine	1950	31,160	18,489	593	20,003	642	1.08	1,831	59	9	1.46	3,576	115	18
Reno, Nev	1949	32,497	30,141	928	30,768	947	1.02	3,104	96	10	1.61	--------	-----	------
Bristol, Tenn.-Va	1950	32,725	22,022	673	23,145	707	1.05	2,147	66	9	1.49	--------	-----	------
Lafayette, La.[2]	1955	33,541	20,202	602	21,526	642	1.07	--------	-----	------	------	3,995	119	19
Owensboro, Ky	1955	33,651	20,353	605	21,703	645	1.07	2,333	69	11	1.72	3,664	109	17
Boise, Idaho	1948	34,393	24,605	715	25,781	750	1.05	2,657	77	10	1.65	4,786	139	19
Alexandria, La	1947	34,913	16,363	469	16,849	483	1.03	1,418	41	8	1.35	4,021	115	24
Easton, Pa	1948	35,732	24,445	684	24,513	686	1.00	2,006	56	8	1.31	5,211	146	21
Steubenville, Ohio	1952	35,872	18,107	505	18,640	520	1.03	1,539	43	8	1.32	4,155	116	22
Eugene, Oreg	1952	35,879	37,756	1,052	37,515	1,046	.99	3,908	109	10	1.67	--------	-----	------
Independence, Mo	1950	36,963	14,903	404	15,240	412	1.02	1,291	35	8	1.36	2,723	74	18
Norristown, Pa	1949	38,126	27,937	733	28,413	745	1.02	2,573	67	9	1.45	7,170	188	25
Monroe, La	1947	38,572	19,462	505	20,400	529	1.05	1,805	47	9	1.42	4,317	112	21
Kokomo, Ind	1948	38,672	19,547	505	20,192	522	1.03	1,753	45	9	1.39	3,560	92	18
Lake Charles, La	1947	41,272	17,154	416	18,306	444	1.07	1,771	43	10	1.55	3,594	87	20
Newport News, Va	1954	42,358	18,688	441	21,982	519	1.18	3,028	71	14	2.20	--------	-----	------
Williamsport, Pa	1954	45,047	21,697	482	23,922	531	1.10	2,336	52	10	1.56	4,018	89	17
Anderson, Ind	1948	46,820	24,412	521	24,424	522	1.00	2,700	58	11	1.77	3,702	79	15
Lynchburg, Va	1948	47,727	17,372	364	19,330	405	1.11	2,085	44	11	1.73	--------	-----	------
New Castle, Pa	1952	48,834	25,305	518	27,086	555	1.07	2,303	47	9	1.36	4,961	102	18
50,000–100,000:														
Ogden, Utah	1952	57,112	31,166	546	32,101	562	1.03	3,481	61	11	1.74	4,517	79	14
Lancaster, Pa	1954	76,280	45,729	599	47,974	629	1.05	5,203	68	11	1.74	8,884	116	19
Lexington, Ky	1952	76,497	45,902	600	46,929	613	1.02	4,068	53	9	1.39	--------	-----	------
Pawtucket, R.I	1945	81,436	26,197	322	26,728	328	1.02	2,373	29	9	1.42	4,854	60	18
Topeka, Kans	1951	89,104	48,114	540	51,860	582	1.08	6,763	76	13	2.09	8,909	100	17
Albuquerque, N. Mex	1949	96,815	32,359	334	33,976	351	1.05	3,371	35	10	1.59	6,606	68	19
Lincoln, Nebr	1950	99,509	35,741	359	38,761	390	1.08	4,748	48	12	1.96	3,127	31	8
100,000–250,000:														
Portland, Maine	1949	113,499	32,769	289	35,604	314	1.09	3,607	32	10	1.62	8,210	72	23
Corpus Christi, Tex	1947	122,956	26,082	212	26,966	219	1.03	2,520	20	9	1.50	4,544	37	17
New Bedford, Mass	1954	125,495	35,393	282	37,463	299	1.06	--------	-----	------	------	5,375	43	14
Gary, Ind	1949	133,911	33,979	254	34,786	260	1.02	3,439	26	10	1.58	5,955	44	17
Evansville, Ind	1949	137,573	32,699	238	35,154	256	1.08	3,753	27	11	1.71	7,213	52	21
Charlotte, N.C	1947	140,930	48,422	344	51,200	363	1.06	5,000	35	10	1.56	--------	-----	------
Allentown, Pa	1948	145,145	32,252	222	33,712	232	1.05	2,724	19	8	1.29	6,883	47	20
Knoxville, Tenn	1946	148,166	33,304	225	34,786	235	1.04	2,847	19	8	1.31	6,086	41	17
Reading, Pa	1947	154,931	34,458	222	35,553	229	1.03	2,955	19	8	1.33	8,872	57	25
Chattanooga, Tenn	1947	167,764	35,715	213	37,892	226	1.06	3,567	21	9	1.51	7,264	43	19
Harrisburg, Pa	1946	169,646	34,701	205	36,983	218	1.07	3,275	19	9	1.42	8,394	49	23
Spokane, Wash	1947	176,004	49,383	281	54,982	312	1.11	6,462	37	12	1.88	11,740	67	21
Wichita, Kans	1947	194,047	46,011	237	48,552	250	1.06	5,369	28	11	1.77	7,952	47	16
Tulsa, Okla	1954	206,311	63,469	308	66,819	324	1.05	8,084	39	12	1.94	11,681	57	17
250,000–500,000:														
Richmond, Va	1948	257,995	46,457	180	54,816	212	1.18	5,007	19	9	1.46	--------	-----	------
Honolulu, T.H	1947	286,928	48,637	170	52,916	184	1.09	5,410	19	10	1.64	11,356	40	21
Omaha, Nebr	1948	310,291	58,549	189	62,967	203	1.08	7,651	25	12	1.94	--------	-----	------
Toledo, Ohio	1947	364,344	60,047	165	64,452	177	1.07	5,554	15	9	1.38	12,387	34	19
Memphis, Tenn	1950	406,034	51,357	126	55,721	137	1.09	--------	-----	------	------	--------	-----	------
Miami, Fla.[2]	1951	458,647	78,152	170	77,969	170	1.00	6,915	15	9	1.42	12,689	28	16
Louisville, Ky	1951	472,736	79,037	167	83,788	177	1.06	8,285	18	10	1.58	--------	-----	------
500,000–1,000,000:														
Atlanta, Ga	1945	507,887	64,885	128	64,982	128	1.00	6,377	13	10	1.57	14,122	28	22
Portland, Oreg	1946	512,643	75,475	147	84,264	164	1.12	9,359	18	11	1.78	17,969	35	21
Dallas, Tex	1950	538,924	87,766	163	96,340	179	1.10	10,840	20	11	1.80	17,988	33	19
Providence, R.I	1945	583,346	55,789	96	57,548	99	1.03	5,296	9	9	1.47	11,061	19	19
Seattle, Wash	1946	621,509	84,833	136	91,505	147	1.08	9,709	16	11	1.70	14,752	24	16
Houston, Tex	1953	700,508	114,328	163	125,255	179	1.10	14,170	20	11	1.81	24,278	35	19
Over 1,000,000:														
Baltimore, Md	1946	1,161,852	82,461	71	86,836	75	1.05	8,817	8	10	1.62	20,595	18	24
Cleveland, Ohio	1951	1,383,599	97,518	70	108,803	79	1.12	13,326	10	12	1.96	21,896	16	20
St. Louis, Mo	1950	1,400,058	76,448	55	91,948	66	1.20	11,229	8	12	1.95	24,079	17	26

[1] Commercial vehicles were not reported separately in 10 cities; and in two cities (Louisville and Lexington, Ky.) data were omitted because taxicabs could not be separated.
[2] Adjusted from 9 a.m.–5 p.m. study period to 10 a.m.–6 p.m. period.

Table 2.—Summary of vehicles entering and leaving the central business districts by population groups

Population group	Number of cities	Average urbanized area population, 1950	Vehicles entering CBD, 10 a.m.–6 p.m.[1]		Vehicles leaving CBD, 10 a.m.–6 p.m.		Ratio: vehicles leaving/vehicles entering	Vehicles leaving CBD during peak ½ hour			Ratio: peak ½ hour/average ½ hour	Trucks and buses leaving CBD, 10 a.m.–6 p.m.			
			Average number per city	Per 1,000 population	Average number per city	Per 1,000 population		Average number per city	Per 1,000 population	Percentage of all vehicles leaving 10 a.m.–6 p.m.		Number of cities	Average number per city	Average per 1,000 popula-	Percentage of all vehicles leaving 10 a.m.–6 p.m.
5,000–10,000	3	7, 900	8, 700	1, 107	8, 900	1, 125	1. 02	810	103	9	1. 47	3	1, 864	235	21
10,000–25,000	26	17, 700	15. 100	860	15, 600	889	1. 04	1, 450	83	9	1. 49	25	2, 908	167	18
25,000–50,000	25	36, 000	21, 700	621	22. 700	650	1. 05	2, 230	64	10	1. 56	20	4, 161	121	19
50,000–100,000	7	82, 400	37, 900	471	39, 800	494	1. 05	4, 290	53	11	1. 70	6	6, 150	76	16
100,000–250,000	14	152. 600	38, 500	252	40, 700	267	1. 06	4, 120	26	10	1. 57	13	7, 690	50	19
250,000–500,000	7	365. 300	60, 300	167	64, 700	180	1. 08	6, 470	19	10	1. 57	3	12, 144	34	19
500,000–1,000,000	6	577, 500	80, 500	139	86, 600	149	1. 07	9, 290	16	11	1. 69	6	16, 695	29	19
Over 1,000,000	3	1, 315, 200	85, 500	65	95, 900	73	1. 12	11, 120	9	11	1. 84	3	22, 190	17	23

[1]Excludes vehicles already within the central business district at 10:00 a.m.

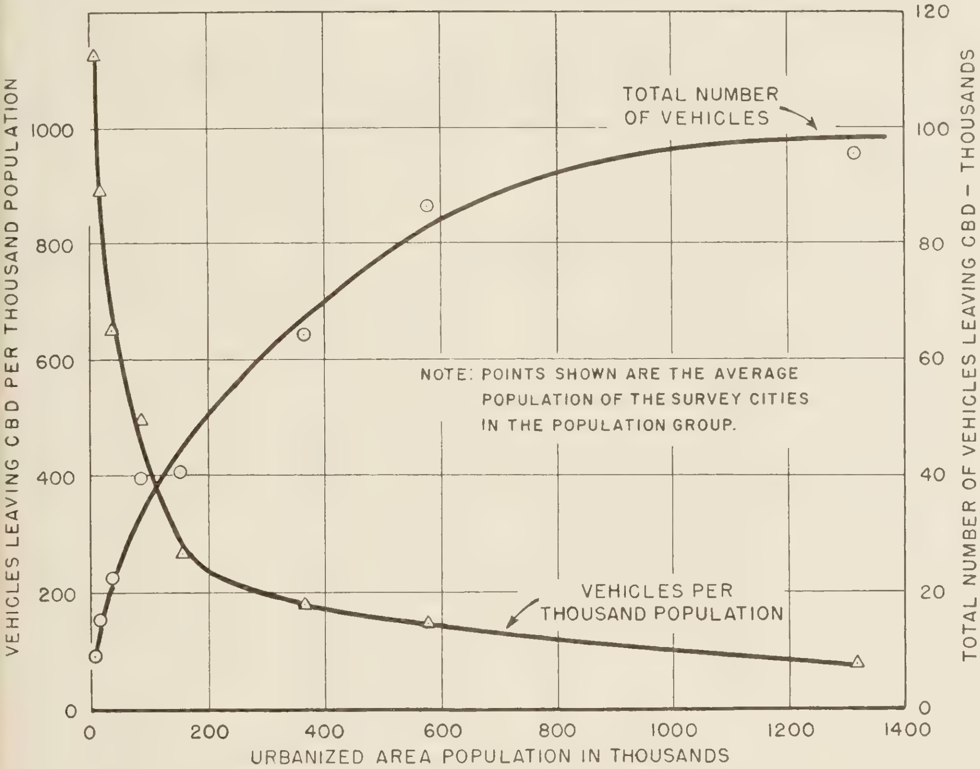

Figure 1.—Vehicles leaving the central business district, 10 a.m.–6 p.m.

population group had only one-ninth as much ground area per capita as the average city in the 10,000–25,000 population group[2]. This does not permit as great a per capita use of the automobile in central business districts of urbanized areas of over 1 million population. The availability of mass transit, the small number of parking spaces in relation to population, the greater proportion of other than downtown destinations in the larger cities[3], and the greater frequency of downtown trips in smaller cities are important contributing factors to the large difference in the per capita ratio of vehicles entering the central business districts of these two population groups. The declining number of vehicles entering the central business districts per thousand population with increasing city size reflects the decreasing relative importance of the central business district in the large urbanized areas as a traffic generator in comparison with total traffic generated in the entire urbanized area.

As shown in table 3, the average number of vehicles entering the central business districts of cities with over 1 million population was only 15 percent greater than the number entering the central business districts of cities in the 500,000–1,000,000 population group. This is in striking contrast to an average population difference of 138 percent. Fewer vehicles entered the central business districts of Baltimore and St. Louis than entered those of Dallas and Seattle, despite the fact that the former are considerably larger cities. The average city of the 1 million or more population group had 74 times the population of the average city in the 10,000–25,000 population group, but only 6 times the number of vehicles entering and leaving between 10 a.m. and 6 p.m. (table 2 and fig. 1).

Variations Among Cities of Same Population Group

The average volume of traffic entering the central business district for the group of cities comprising a population group increased with each progressively larger group, although not in direct proportion. This trend is natural and one that should be expected. The large variations within cities of each population group and the reasons for these variations are probably more significant than the averages for the population groups.

Although population is a very important factor, the variations cannot be fully explained by population alone. Other factors may be just as important in explaining why some cities within the same population group, such as Reno, Nev., and Eugene, Oreg., in the 25,000–50,000 population group and Houston, Tex., in the 500,000–1,000,000 population group, had more vehicles entering the central business district than other cities in the same group. The geographical location of the central business district with respect to the arterial and regional highway system, mass-transit use, economic characteristics of the city, degree of centralization of commercial and industrial facilities, and many other characteristics are all very significant factors that affect the volume of traffic entering the

Table 3.—Comparison of urbanized area populations, areas of central business districts, and vehicles entering CBD in selected cities of the two largest population groups

Comparison	Ratio, population	Ratio, area of CBD	Ratio, vehicles entering CBD
Cleveland/Dallas	2. 57	1. 75	1. 11
Cleveland/Seattle	2. 23	1. 60	1. 15
St. Louis/Dallas	2. 60	2. 02	. 86
St. Louis/Seattle	2. 25	1. 85	. 89
Average city over 1,000,000/average city 500,000–1,000,000 [1]	2. 38	1. 99	1. 15

[1] Cities over 1,000,000 population: Baltimore, Cleveland, and St. Louis. Cities included in 500,000–1,000,000 population group: Atlanta, Portland, Dallas, Providence, and Seattle.

[2] *Parking Guide for Cities.* Table 2, p. 11.

[3] *Parking Guide for Cities.* Figures 5 and 31, pp. 19 and 115.

central business district. These factors are as significant in explaining the variations in traffic volumes of cities within the same population group as they are in accounting for the differences between population groups.

Until the reasons for these variations can be adequately explained and mathematically measured, it probably will not be possible to forecast with confidence the traffic volumes entering central business districts. For example, Monessen, Pa., a coal mining community located along a river, had only 528 vehicles leaving the central business district per 1,000 population during the 8-hour period, whereas Chambersburg, a city having practically the same population in a more highly developed agricultural area of Pennsylvania, had twice as many vehicles leaving the central business district per 1,000 population.

Traffic Volumes Compared on a Square Mile Basis

Vehicle density or the volume of vehicles per square mile of central business district area has an important influence on traffic behavior. Vehicle densities in places where congestion is already acute provide an approximate measure of the maximum number of vehicles that can be accommodated in the central business district under prevailing conditions.

The structural character of the central business district in the old and mature cities, represented by the urbanized areas of 500,000 population and over, crystallized in a period long before the advent of the motor vehicle. Consequently, the central business district inherited a system of streets generally inadequate for the huge volumes of traffic thrust upon it. As a result, although the population continues to grow and the central business district continues to expand both vertically and laterally, there can be only a relatively small increase in the number of vehicles entering the central business district.

Vehicle densities tend to become greater as cities increase in population. Even with a greatly reduced per capita usage of vehicles in the central business districts of the large cities, the vehicle densities in the urbanized areas over 500,000 population were double those in cities under 25,000 population (tables 4 and 5). The greatest density of vehicles in the 91 cities surveyed was 34,000 vehicles per square mile in Dallas, Tex. This included both vehicles parked and in motion.

The peak cordon accumulation (greatest number of vehicles present within the central business district at any time) increased with population size. There were approximately 14 times as many vehicles in the central business district of the average urbanized area of over 1 million population as were found in the average city of 10,000–25,000 population at the moment of peak cordon accumulation (table 5).

Tables 4 and 5 show the peak cordon accumulation divided by the area of the central business district and also by the urbanized area population. Placing all cities on an

Table 4.—Accumulation of vehicles in the central business district in relation to area and population

Population group and city	Urbanized area population, 1950	Area of CBD, square miles	Accumulation of vehicles in CBD, 10 a.m.–6 p.m.			Peak accumulation of vehicles			
			Peak	Average	Ratio of peak to average	Per square mile	Per 1,000 population	Per square mile per 1,000 population	Time of occurrence
5,000–10,000:									
Paris, Ky	6,912	0.0679	1,023	830	1.23	15,066	148	2,180	4:30
Decatur, Ind	7,271	.0445	951	636	1.50	21,371	131	2,939	4:30
Seymour, Ind	9,629	.1280	1,125	844	1.33	8,789	117	913	4:30
10,000–25,000:									
Wabash, Ind	10,621	------	955	773	1.24	------	90	------	4:00
Coatesville, Pa	13,826	.1340	1,178	1,094	1.08	8,791	85	636	2:00
Lewistown, Pa	13,894	.2639	1,650	1,452	1.14	6,252	119	450	3:30
Hanover, Pa	14,048	.2411	1,889	1,599	1.18	7,835	134	558	3:00
Frankfort, Ind	15,028	.0559	1,167	904	1.29	20,877	78	1,389	4:00
Huntington, Ind	15,097	.0773	1,036	944	1.10	13,402	69	888	2:30
West Chester, Pa	15,168	.1195	1,483	1,267	1.17	12,410	98	818	3:00
Jeannette, Pa	16,172	.1324	1,589	1,403	1.13	12,002	98	742	3:00
Stevens Point, Wis	16,564	.0725	934	766	1.22	12,883	56	778	3:30
Carlisle, Pa	16,812	.3545	2,216	2,038	1.09	6,251	132	372	2:30
Greensburg, Pa	16,923	.2746	2,562	2,396	1.07	9,330	151	551	2:30
Chambersburg, Pa	17,212	.2616	1,954	1,766	1.11	7,469	114	434	10:30
Martinsville, Va	17,251	.1410	1,382	1,194	1.16	9,801	80	568	5:00
Clovis, N. Mex	17,318	.1167	1,287	1,128	1.14	11,028	74	637	4:00
Bradford, Pa	17,354	.2498	1,791	1,655	1.08	7,170	103	413	11:00
Monessen, Pa	17,896	.1197	1,419	1,284	1.11	11,855	79	662	3:00
Columbus, Ind	18,370	.1025	1,467	1,201	1.22	14,312	80	779	4:00
Portsmouth, N.H	18,830	.1135	1,704	1,392	1.22	15,013	90	797	5:00
Meadville, Pa	18,972	.1419	1,557	1,387	1.12	10,973	82	578	4:00
Oil City, Pa	19,581	.1974	2,160	1,951	1.11	10,942	110	559	2:30
Anderson, S.C	19,770	.1277	1,778	1,515	1.17	13,923	90	704	11:00
Uniontown, Pa	20,471	.1948	2,796	2,416	1.16	14,353	137	701	4:00
Pottstown, Pa	22,589	.2049	1,709	1,560	1.10	8,341	76	369	4:00
Butler, Pa	23,487	.2219	2,386	2,138	1.12	10,753	102	458	------
Pottsville, Pa	23,640	.2863	2,140	1,970	1.09	7,475	91	316	10:30
Walla Walla, Wash	24,102	.1806	1,729	1,501	1.15	9,574	72	397	3:00
25,000–50,000:									
New Kensington, Pa	25,146	.2583	3,055	2,579	1.18	11,827	121	470	3:00
Roswell, N. Mex	25,738	.1313	1,703	1,467	1.16	12,970	66	504	5:00
Washington, Pa	26,280	.3858	2,902	2,537	1.14	7,522	110	286	11:00
Lebanon, Pa	28,156	.4282	2,632	2,317	1.14	6,147	93	218	11:00
Fond du Lac, Wis	29,936	.1645	1,888	1,592	1.19	11,477	63	383	3:30
Reno, Nev	32,497	.3016	5,521	4,970	1.11	18,110	170	557	3:00
Bristol, Tenn.-Va	32,725	.1848	2,127	1,856	1.15	11,510	65	352	10:00
Owensboro, Ky	33,651	.1515	2,579	2,271	1.14	17,023	77	506	1:30
Boise, Idaho	34,398	.3214	4,298	3,888	1.11	13,373	125	389	3:30
Alexandria, La	34,913	.1345	1,819	1,577	1.15	13,524	52	387	2:30
Easton, Pa	35,732	.1902	2,165	1,873	1.16	11,383	61	319	3:00
Steubenville, Ohio	35,872	.2164	2,157	1,967	1.10	9,968	60	278	2:00
Eugene, Oreg	35,879	.3228	5,882	5,173	1.14	18,222	164	508	2:30
Independence, Mo	36,963	.0807	1,491	1,284	1.16	18,476	40	500	4:30
Norristown, Pa	38,126	.1628	2,194	2,015	1.09	13,477	58	353	11:00
Monroe, La	38,572	.1621	2,043	1,763	1.16	12,603	53	327	10:00
Kokomo, Ind	38,672	.1584	1,808	1,507	1.20	11,414	47	295	4:30
Lake Charles, La	41,272	.2107	1,980	1,658	1.19	9,397	48	228	10:30
Newport News, Va	42,358	(1)	2 7,548	2 6,496	1.16	------	2 178	------	4:00
Williamsport, Pa	45,047	.3476	3,797	3,373	1.13	10,923	84	242	11:00
Anderson, Ind	46,820	.1492	3,226	2,262	1.43	21,622	69	462	4:30
Lynchburg, Va	47,727	.2164	3,524	3,154	1.12	16,285	74	341	12:00
New Castle, Pa	48,834	.1596	3,259	2,834	1.15	20,420	67	418	11:00
50,000–100,000:									
Ogden, Utah	57,112	.2318	3,645	3,330	1.09	15,725	64	275	4:45
Lancaster, Pa	76,280	.4864	6,077	5,642	1.08	12,494	80	164	2:30
Lexington, Ky	76,497	.3806	4,776	4,154	1.15	12,549	62	164	3:00
Pawtucket, R. I	81,436	.1096	2,081	1,842	1.13	18,987	26	233	3:00
Topeka, Kans	89,104	.4941	6,804	6,048	1.13	13,770	76	155	3:00
Albuquerque, N. Mex	96,815	.2796	3,689	3,360	1.10	13,194	38	136	11:00
Lincoln, Nebr	99,509	.4781	7,526	6,859	1.10	15,741	76	158	2:30
100,000–250,000:									
Portland, Maine	113,499	.3110	7,727	7,155	1.08	24,846	68	219	11:00
Corpus Christi, Tex	122,956	.3160	4,705	4,374	1.08	14,889	38	121	3:30
New Bedford, Mass	125,495	------	4,460	3,739	1.19	------	36	------	2:00
Gary, Ind	133,911	.3299	3,272	2,894	1.13	9,918	24	74	12:30
Evansville, Ind	137,573	.5287	6,764	6,240	1.08	12,794	49	93	1:30
Charlotte, N.C	140,930	.3766	7,275	6,773	1.07	19,318	52	137	11:30
Allentown, Pa	3 145,145	.2589	2,401	2,082	1.15	9,274	17	64	2:00
Knoxville, Tenn	148,166	.380	5,739	5,069	1.13	15,103	39	102	2:00
Reading, Pa	154,931	.3527	4,831	4,340	1.11	13,697	31	88	3:00
Chattanooga, Tenn	167,764	.48	7,315	6,621	1.11	15,240	44	91	2:00
Harrisburg, Pa	169,646	.3666	5,079	4,532	1.12	13,854	30	82	3:00
Spokane, Wash	176,004	.6345	11,278	10,208	1.10	17,775	64	101	2:00
Wichita, Kans	194,047	.52	10,850	9,691	1.12	20,865	56	108	3:00
Tulsa, Okla	206,311	.3301	7,898	7,091	1.11	23,926	38	116	1:30
250,000–500,000:									
Richmond, Va	257,995	.560	12,372	10,858	1.14	22,093	48	86	11:00
Honolulu, T. H	286,928	.3392	6,630	5,315	1.25	19,546	23	68	11:30
Omaha, Nebr	310,291	.5356	11,519	10,632	1.08	21,507	37	69	12:15
Toledo, Ohio	364,344	.5237	12,865	11,360	1.13	24,566	35	67	2:00
Memphis, Tenn	406,034	.6303	9,603	8,410	1.14	15,236	24	38	1:00
Miami, Fla	458,647	.8803	19,414	17,144	1.13	22,054	42	48	3:00
Louisville, Ky	472,736	.6600	13,057	11,397	1.15	19,783	28	42	1:30
500,000–1,000,000:									
Atlanta, Ga	507,887	.5406	11,837	10,031	1.18	21,896	23	43	3:30
Portland, Oreg	512,643	.8956	21,294	19,741	1.08	23,776	42	46	2:00
Dallas, Tex	538,924	.5905	20,161	18,065	1.12	34,142	37	63	2:00
Providence, R.I	583,346	.3354	10,856	10,078	1.08	32,367	19	55	2:30
Seattle, Wash	621,509	.6454	16,041	14,543	1.10	24,854	26	40	2:00
Houston, Tex	700,508	.7331	22,735	20,126	1.13	31,012	32	44	12:00
Over 1,000,000:									
Baltimore, Md	1,161,852	.7558	14,172	12,681	1.12	18,751	12	16	2:00
Cleveland, Ohio	1,383,599	1.0306	28,644	24,707	1.16	27,794	21	20	2:00
St. Louis, Mo	1,400,058	1.1943	26,636	23,331	1.14	22,303	19	16	1:00

[1] Not available. [2] Influence of U.S. Navy Yard. [3] Estimated.

Table 5.—Summary of accumulation of vehicles in the central business district in relation to population and area

Population group	Number of cities	Average area of CBD, square mile	Peak and average accumulation of vehicles per city in the CBD, 10 a.m.–6 p.m.			Average peak accumulation of vehicles per city in the CBD		
			Peak	Average	Ratio of peak to average	Per square mile	Per 1,000 population	Per square mile per 1,000 population
5,000–10,000	3	0.08	1,030	770	1.35	15,100	132	2,011
10,000–25,000	26	.18	1,690	1,490	1.15	10,900	96	622
25,000–50,000 [1]	22	.22	2,820	2,450	1.16	13,500	80	378
50,000–100,000	7	.35	4,940	4,460	1.11	14,600	60	184
100,000–250,000	14	.40	6,400	5,770	1.11	16,300	42	107
250,000–500,000	7	.59	12,210	10,730	1.15	20,700	34	60
500,000–1,000,000	6	.62	17,150	15,430	1.12	28,000	30	49
Over 1,000,000	3	.99	23,150	20,240	1.14	22,900	17	17

[1] Newport News, Va., excluded.

equivalent area basis permits a more equitable comparison within each population group.

Changes in Supply of Parking Spaces

A study of the changes in supply of parking space in 37 cities revealed that the average annual increase in parking spaces over the 9-year period from 1947 to 1956 was only 2 percent in central business districts of urbanized areas with over 1 million population.[4] All of the gain came from offstreet parking spaces where turnover is relatively low, averaging about 1.6. On the other hand, many curb spaces were eliminated where turnover is relatively large, averaging about 4.4. The net result has been a decrease in available parking space.

The difference in the slopes of the upper curves in figures 1 and 2 for cities between 650,000 and 1,300,000 population is a reflection of the longer parking durations and lower turnover rates in the central business districts of the very large population groups. As urbanized areas increase in population, a greater proportion of motorists park offstreet where the turnover, as previously mentioned, is much less than at the curb. The overall turnover rate in the average central business district of the population group over 1 million is about half that of the population groups under 100,000.[5] This results in a considerably larger buildup of vehicle accumulation in the central business districts of the larger urbanized areas. In the larger cities a greater proportion of all vehicles entering were present at the time of peak accumulation. Approximately 60 percent more storage space was required for every 100 vehicles leaving the central business district of the urbanized areas over 500,000 population as that required by the same number of vehicles leaving the central business district in cities under 100,000 population (tables 6 and 7). An average of 880 vehicles per 100 parking spaces left the central business district in cities under 100,000 population, whereas 550 vehicles per 100 parking spaces left the central business district in cities of over 500,000 population (table 7).

The longer parking durations and the resultant high peak accumulation in cities with over 1 million population have an important bearing on the question of the economic feasibility of providing sufficient parking space for all who desire to park in the large cities. They are also important contributing factors in restricting the number of vehicles that can be accommodated during the day both in storage and in movement.

Outbound Traffic Volumes

The daily peak exodus of vehicles from the central business district usually occurred between 5 and 5:30 p.m. In the urbanized areas of over 1 million population, an average of about 11,000 vehicles left between 5 and 5:30 p.m. (table 2 and fig. 3). The maximum peak half-hour traffic volume observed leaving a central business district was 14,200 vehicles in Houston, Tex.

The outbound traffic volumes for the 91 cities during the peak half-hour of traffic flow exceeded that of the average half-hour between 10 a.m. and 6 p.m. by about 60 percent (table 2). The ratio generally increased with population.

Through Traffic Volumes

The major arterial routes of an urban area almost invariably radiate from the central business district. Between 48 and 63 percent of the drivers that entered between 10 a.m. and 6 p.m. did not stop to park (table 7); many entered only because of the pattern of the highway and street system. The percentages in table 7 probably include some vehicles which had passed through the central business district and were parked just outside, with the central business district as the ultimate destination of the drivers. Also, because of the manner in which observations were made, the percentages included vehicles in service stations and garages being serviced or repaired.

The percentages shown in table 7 were computed without regard to trip origins of parkers because trip origin data were not available in most parking reports. Had trip origins of parkers been taken into account, the resulting percentages of the vehicles that entered and did not stop to park would have been greater than those shown in table 7, although only by a small amount, since some parkers had come from other parking places inside the central business district.

During the peak half-hour of traffic movement, usually between 5 and 5:30 p.m., as many as 98 percent of the vehicles in one of the cities in the 500,000–1,000,000 population group passed through the central business district without parking (table 6). In many cities, a large proportion of this traffic might have been more satisfactorily diverted around

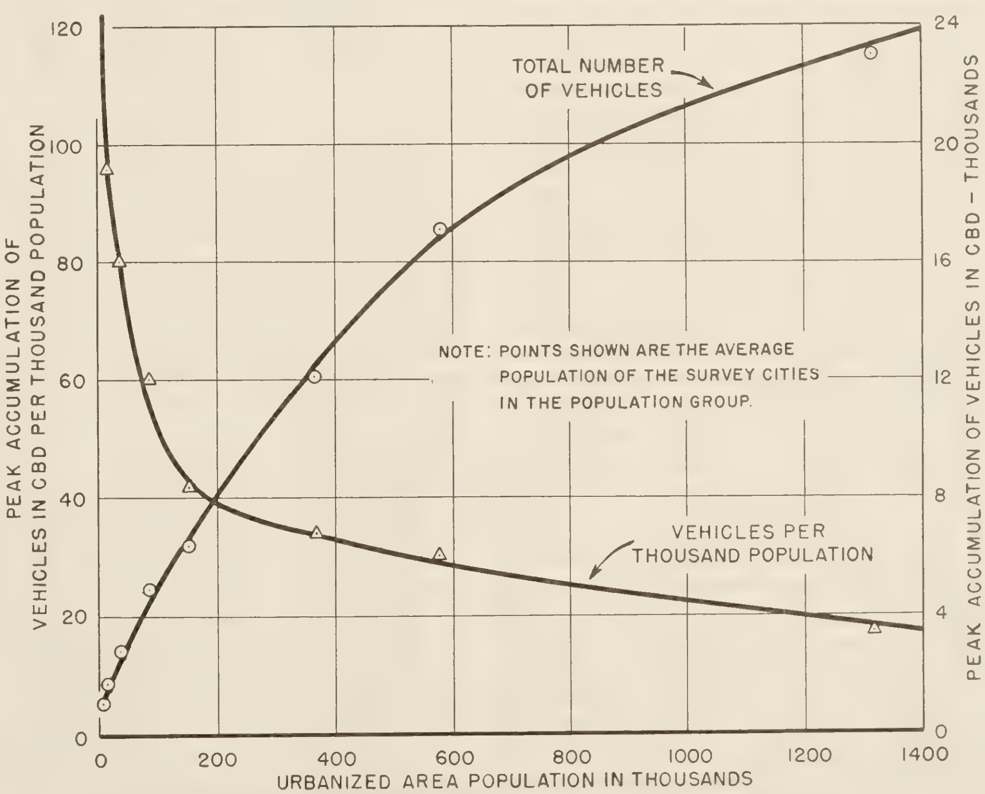

Figure 2.—Maximum accumulation of vehicles in the central business district.

[4] *Changes in supply of parking space,* by David A. Gorman. Highway Research Abstracts, Highway Research Board, vol. 26, No. 6, June 1956, pp. 19–22.

[5] *Parking Guide for Cities.* Table 27, p. 30.

the central business district. The proportion of traffic that entered during the peak half-hour of traffic movement and did not stop to park tended to increase with the size of the city. The development of employment centers in sections of the city other than the central business district creates a large movement of population twice a day going to or coming from work. Much of this movement is across town and through the central business district.

There was little difference in the proportion of traffic passing through the central business district without parking during the business day (10 a.m.–6 p.m.) in cities of different population groups (table 7). This substantiates the need for and the general practice of locating and designing street arterials based on peak-hour volumes of traffic.

Truck and Bus Travel in Central Business Districts

The average number of trucks and buses leaving the central business districts from 10 a.m. to 6 p.m., and the average number per 1,000 population, are shown in table 2 for cities of various sizes. Trucks and buses constituted about 20 percent of all vehicles leaving the central business districts, the range being 16 to 23 percent for the 8 population groups. This relatively narrow range for population groups generally applied to individual cities as well.

The number of trucks and buses leaving the central business district in urbanized areas of over 1 million population was only 7 times as great as the number leaving the central business district in cities of 10,000–25,000 population. This may be compared with a population ratio of 74 to 1 for the same groups.

On a per capita basis, 10 times as many trucks and buses left the central business district in cities of 10,000 to 25,000 population as left the central business districts in urbanized areas of over 1 million population. The declining ratio of trucks and buses per thousand population leaving the central business district with increasing size of city may be attributed to the influence of decentralization of industry and business in the larger cities, and also to the provision of bypass routes for trucks around the central business districts of the larger cities. Generally the street pattern in the smaller cities is such that much of the through truck traffic as well as other types of traffic must pass directly through the central business district.

Trip Purposes

There were many reasons why motorists came to the central business district. About half of them entered because the layout of the street system or highway network compelled them to pass through the central business district on their way to some other destination. Of those who stopped and parked, the trip purposes were as shown in table 8. The percentage distribution of trip purposes varied with population. As population increased, a

Table 6.—Passenger cars, trucks, and buses leaving CBD per 100 parking spaces, ratio of peak accumulation to outbound traffic, and percentage of through traffic

Population group and city	Total available parking spaces	Vehicles leaving CBD per 100 parking spaces		Ratio: peak accumulation/peak ½ hour outbound traffic	Percentage of vehicles entering and not stopping to park		Peak accumulation as a percentage of total vehicles leaving CBD
		10 a.m.–6 p.m.	Peak ½ hour		10 a.m.–6 p.m.	Peak ½ hour	
5,000–10,000:							
Paris, Ky	960	1,012	97	1.1	67	72	10
Decatur, Ind	624	866	66	1.6	57	68	16
Seymour, Ind	969	1,003	94	1.2	64	68	10
10,000–25,000:							
Wabash, Ind	1,016	1,038	96	1.0	48	54	9
Coatesville, Pa	1,329	1,154	98	.9	63	73	8
Lewistown, Pa	2,343	633	52	1.3	33	41	11
Hanover, Pa	2,830	639	68	1.0	57	73	10
Frankfort, Ind	852	1,208	102	1.3	56	50	10
Huntington, Ind	1,054	1,265	115	.9	59	61	7
West Chester, Pa	1,137	1,338	128	1.0	62	67	10
Jeannette, Pa	1,581	604	51	2.0	35	40	17
Stevens Point, Wis	1,267	806	77	1.0	49	54	9
Carlisle, Pa	3,317	535	55	1.2	37	53	12
Greensburg, Pa	2,663	800	83	1.2	53	69	12
Chambersburg, Pa	2,631	695	71	1.1	55	67	11
Martinsville, Va	1,558	725	63	1.4	59	69	12
Clovis, N. Mex	2,104	796	71	.9	45	49	8
Bradford, Pa	2,185	617	64	1.3	32	45	13
Monessen, Pa	1,444	655	65	1.5	28	33	15
Columbus, Ind	1,274	1,051	105	1.1	48	52	11
Portsmouth, N.H	1,056	1,192	102	1.6	68	76	13
Meadville, Pa	1,987	861	66	1.2	48	54	9
Oil City, Pa	2,558	606	66	1.3	31	45	14
Anderson, S.C	2,137	808	64	1.3	42	42	10
Uniontown, Pa	3,136	692	65	1.4	56	69	13
Pottstown, Pa	2,503	832	67	1.0	55	62	8
Butler, Pa	2,850	756	72	1.2	51	62	11
Pottsville, Pa	2,641	742	63	1.0	58	68	11
Walla Walla, Wash	1,569	1,038	104	1.1	43	61	11
25,000–50,000:							
New Kensington, Pa	2,754	703	75	1.5	51	63	15
Roswell, N. Mex	1,648	1,293	128	.8	46	49	8
Washington, Pa	3,841	588	56	1.4	40	46	13
Lebanon, Pa	3,494	698	72	1.0	42	59	11
Fond du Lac, Wis	2,659	717	76	.9	48	59	10
Biddeford-Saco, Maine	3,060	654	60	--------	50	52	--------
Reno, Nev	4,525	680	69	1.8	41	47	18
Bristol, Tenn.-Va	1,794	1,290	120	1.0	65	70	9
Owensboro, Ky	1,937	1,120	120	1.1	70	78	12
Boise, Idaho	5,199	496	51	1.6	43	50	17
Alexandria, La	1,965	857	72	1.3	59	63	11
Easton, Pa	1,932	1,269	104	1.1	58	64	9
Steubenville, Ohio	2,397	778	64	1.4	43	51	12
Eugene, Oreg	5,779	649	68	1.5	52	61	16
Independence, Mo	1,203	1,267	107	1.2	58	52	10
Norristown, Pa	2,395	1,186	107	.9	68	77	8
Monroe, La	2,243	909	80	1.1	59	65	10
Kokomo, Ind	1,641	1,230	107	1.0	59	62	9
Lake Charles, La	2,214	827	80	1.1	52	68	11
Newport News, Va. [1]	7,426	296	41	2.5	5	8	34
Williamsport, Pa	4,427	540	53	1.6	51	60	16
Anderson, Ind	1,975	1,237	137	1.2	77	90	13
Lynchburg, Va	3,006	643	69	1.7	33	33	18
New Castle, Pa	4,403	615	52	1.4	52	59	12
50,000–100,000:							
Ogden, Utah	4,563	704	76	1.0	50	60	11
Lancaster, Pa	6,918	693	75	1.2	50	65	13
Lexington, Ky	4,739	990	86	1.2	60	70	10
Pawtucket, R.I	1,823	1,466	130	.9	66	79	8
Topeka, Kans	6,901	751	98	1.0	40	57	13
Albuquerque, N. Mex	4,321	786	78	1.1	43	53	11
Lincoln, Nebr	7,402	524	64	1.6	25	37	19
100,000–250,000:							
Portland, Maine	4,654	765	78	2.1	53	64	10
Corpus Christi, Tex	6,355	424	40	1.9	47	59	17
New Bedford, Mass	5,930	632	--------	--------	63	--------	12
Gary, Ind	3,714	937	93	1.0	67	78	9
Evansville, Ind	5,912	595	63	1.8	33	58	19
Charlotte, N.C	7,299	701	69	1.5	65	80	14
Allentown, Pa	3,158	1,068	86	.9	61	74	7
Knoxville, Tenn	4,060	857	70	2.0	75	77	16
Reading, Pa	4,202	846	70	1.6	57	63	14
Chattanooga, Tenn	6,393	593	56	2.1	55	58	19
Harrisburg, Pa	4,765	776	69	1.6	62	76	14
Spokane, Wash	8,726	630	74	1.7	47	56	21
Wichita, Kans	9,613	505	56	2.0	23	37	22
Tulsa, Okla	9,119	733	89	1.0	63	80	12
250,000–500,000:							
Richmond, Va	9,170	598	55	2.5	34	47	23
Honolulu, T.H	6,914	765	78	1.2	62	74	13
Omaha, Nebr	9,793	643	78	1.5	56	64	18
Toledo, Ohio	11,002	586	50	2.3	53	70	20
Memphis, Tenn	11,968	466	--------	--------	59	69	17
Miami, Fla	18,563	420	37	2.8	57	81	25
Louisville, Ky	13,793	607	60	1.6	64	81	16
500,000–1,000,000:							
Atlanta, Ga	11,456	567	56	1.9	69	79	18
Portland, Oreg	11,662	723	80	2.3	30	53	25
Dallas, Tex	17,923	538	60	1.9	51	74	21
Providence, R.I	8,089	711	65	2.0	59	98	19
Seattle, Wash	15,855	577	61	1.7	58	83	18
Houston, Tex	19,226	651	74	1.6	59	74	18
Over 1,000,000:							
Baltimore, Md	12,279	707	72	1.6	64	84	16
Cleveland, Ohio	29,120	374	46	2.1	54	72	26
St. Louis, Mo	29,332	313	38	2.4	38	66	29

[1] Values show influence of U.S. Navy Yard.

Table 7.—Summary of vehicles leaving CBD per 100 parking spaces, ratio of peak accumulation to outbound traffic, and percentage of through traffic

Population group	Number of cities	Average number of available parking spaces	Average number of vehicles leaving CBD per 100 parking spaces		Ratio: peak accumulation/peak ½ hour outbound traffic	Percentage of vehicles entering and not stopping to park		Peak accumulation as a percentage of total vehicles leaving CBD
			10 a.m.–6 p.m.	Peak ½ hour		10 a.m.–6 p.m.	Peak ½ hour	
5,000–10,000	3	850	960	86	1.3	63	69	12
10,000–25,000	26	1,960	849	78	1.2	49	57	11
25,000–50,000	24	3,080	856	82	1.3	51	58	13
50,000–100,000	7	5,240	845	87	1.1	48	60	12
100,000–250,000	14	5,990	719	70	1.6	55	66	15
250,000–500,000	7	11,600	584	60	2.0	55	69	19
500,000–1,000,000	6	14,040	628	66	1.9	54	77	20
Over 1,000,000	3	23,580	465	52	2.0	52	74	24

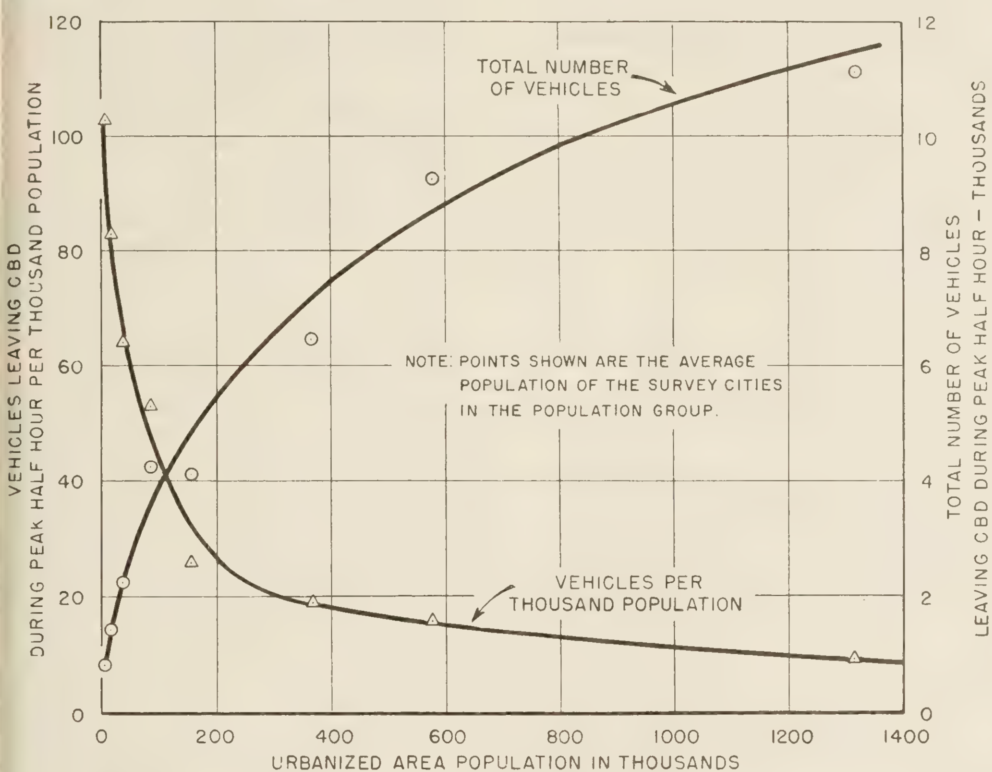

Figure 3.—Vehicles leaving the central business district during peak half hour.

greater proportion of the trips were made for work and a smaller proportion for shopping.

Vehicles in Motion

The wide variations in the number and proportion of vehicles in motion, shown in table 9, limit the usefulness of these data, and the averages are presented here merely for the purpose of shedding some light on the approximate volume and proportion of vehicles in motion within the central business district at an average moment between 10 a.m. and 6 p.m. and also at 5 p.m. The number of vehicles in motion was determined by subtracting the parking accumulation from the cordon accumulation. Disregarding population considerations entirely, the standard deviation of the percentage of vehicles in motion in 87 cities, assuming a normal distribution, was 12 percent around a mean of 25 percent. According to statistical theory, one could expect to find for two-thirds of the time the percentage of vehicles in motion would be between 13 and 37 percent of the cordon accumulation and 95 percent of the time, between 1 and 49 percent.

Generally, the number of vehicles in motion increased as cities became larger. There were 290 vehicles in motion in the average central business district of cities in the 5,000–10,000 population group as compared with 3,210 vehicles in motion in the average central business district of cities in the 500,000–1,000,000 population group. The low figure of 1,910 vehicles in motion in the population group of over 1 million is at variance to the trend and perhaps could indicate a reversal in trend for the largest cities. It may be due to the large percentage of worker-parkers in this population group.

The number and percentage of vehicles in motion at 5 p.m. is also of interest, though of limited value because of the wide variations in the data from which the averages were derived.

Traffic Pattern at Periphery of Central Business District

The cordon traffic data from many cities of various population groups were analyzed in an attempt to discover, if possible, the underlying basic traffic pattern at the periphery of the central business district common to all cities of similar physical characteristics. It is possible that data, such as those presented in table 10 for a 10-hour period (8 a.m. to 6 p.m.), could be useful in forecasting traffic volumes resulting from population growth and in allocating them to a properly designed street system within and around the central business district. They are not adequate for making precise forcasts of traffic volumes and their distribution pattern, and are merely presented as an indication of what can be expected with population increase. Because of the limited information available and the many factors that must be considered, such as type of street, method of operation (whether one-way or two-way), number of lanes, and other traffic controls, these data cannot give the complete answer, but do shed some light upon a most complex subject for which an answer is sought.

The number of streets leading into the central business district is related to the size and geographical location of the central business district. In cities under 25,000 population, there are about 25 street entrances (table 10), whereas cities with over 1 million population have 42 street entrances at the periphery of the central business district.

In cities of 10,000–50,000 population, the street with the greatest inbound traffic volume carried about 19 percent of all vehicles entering the central business district in the 10-hour period between 8 a.m. and 6 p.m. In the larger urbanized areas, a smaller difference among the five most heavily traveled streets was observed in the percentage of

Table 8.—Vehicle trips with known trip purposes, involving parking in the central business district

Population group	Number of cities [1]	Percentage distribution, according to purpose				
		Shopping	Business	Work	Other	Total
5,000–10,000	2	27	32	15	26	100
10,000–25,000	27	31	28	18	23	100
25,000–50,000	23	29	30	18	23	100
50,000–100,000	7	27	31	16	26	100
100,000–250,000	14	25	39	17	19	100
250,000–500,000	8	16	42	21	21	100
500,000–1,000,000	7	17	42	20	21	100
Over 1,000,000	4	12	32	36	20	100

[1] Includes 87 of the cities listed in table 1 and 5 additional cities for which trip purpose data were available.

Table 9.—Average number and percentage of vehicles in motion in the central business district, by population group, during 8-hour period and at 5 p.m.

Population group	8-hour period, 10 a.m.–6 p.m.				5 p.m.		
	Number of cities	Average cordon accumulation	Average number of vehicles in motion	Percentage of average cordon accumulation in motion	Number of cities	Average number of vehicles in motion	Percentage of average cordon accumulation in motion
5,000–10,000	3	770	290	37	3	520	51
10,000–25,000	26	1,510	370	24	23	480	31
25,000–50,000	22	2,450	640	25	18	890	33
50,000–100,000	4	5,000	730	14	4	1,080	21
100,000–250,000	16	5,470	1,580	28	14	1,920	35
250,000–500,000	7	10,730	2,810	26	7	3,810	38
500,000–1,000,000	6	15,430	3,210	24	5	4,370	32
Over 1,000,000	3	20,240	1,910	9	3	2,860	17

Table 10.—Summary of traffic volumes to and from the central business district

Population group [1]	Traffic entering CBD, 8 a.m.–6 p.m.					Traffic leaving CBD, 10 a.m.–6 p.m.				
	Number of cities	Average number of street entrances	Number of streets carrying one-half of traffic	Number of vehicles entering: On all streets	Number of vehicles entering: Greatest number on 1 street	Number of cities	Average number of street entrances	Number of streets carrying one-half of traffic	Number of vehicles leaving: On all streets	Number of vehicles leaving: Greatest number on 1 street
10,000–25,000	16	25	4	20,360	4,210	3	21	4	13,410	2,180
25,000–50,000	13	25	4	26,060	4,630	3	20	4	20,180	3,670
50,000–100,000	1	42	6	56,160	6,080	2	32	6	41,980	5,070
100,000–250,000	3	31	6	47,360	5,250	7	27	6	43,330	4,870
250,000–500,000	-----	-----	-----	------	------	2	26	6	74,180	7,820
Over 1,000,000	1	42	7	102,640	12,230	1	41	8	86,840	8,040

[1] No inbound traffic data available for 250,000–500,000 population group. No data available for 500,000–1,000,000 population group.

inbound traffic carried by each street at the central business district cordon.

The largest inbound traffic volume carried on a single street between 8 a.m. and 6 p.m. was 12,230 vehicles which occurred in the population group of over 1 million (table 10). This was 2.9 times as great as the largest inbound traffic volume of 4,210 vehicles entering on a single street in the 10,000–25,000 population group. The population ratio for the two groups was about 74 to 1. In the single city in the population group over 1 million for which data were available, 102,640 vehicles entered between 8 a.m. and 6 p.m. compared with an average of 20,360 vehicles in cities of 10,000–25,000 population, a traffic volume ratio of 4.9 to 1 on only 1.7 times as many street entrances.

Fifteen percent of the streets crossing the central business district cordon carried 50 percent of the inbound vehicles and one-half of the streets carried 90 percent of the inbound vehicles. Of the remaining streets, none carried more than 2 percent of the inbound traffic and many carried less than 1 percent. Similarly, 19 percent of the streets at the central business district cordon carried 50 percent of the outbound vehicles, and one-half of the streets at this cordon carried 85 percent of the outbound vehicles.

These findings, supplemented by a more detailed examination of actual local street conditions, might be especially useful in cities under 50,000 population. Consideration could be given to the feasibility of closing some of the streets to through traffic at the periphery of the central business district and converting them to street parking areas with angle parking. Curb parking might then be entirely eliminated from the few streets with the highest traffic concentration, particularly during the morning and evening rush hours. The increased traffic carrying capacity of these streets would accommodate vehicles displaced from the closed streets.

Since most of the streets at the periphery of the central business district in cities over 100,000 population carry significant volumes of traffic, the closing of any of these streets would be less feasible since a large number of motorists might be inconvenienced.

Application of Data to Emergency Evacuation

Parking and traffic data provide a broad perspective of the scope of the traffic problem involved in evacuating persons and vehicles from the central business districts in an emergency. The data can aid in determining the feasibility of an evacuation plan and in devising various ways and means for its implementation.

As shown in table 6, the ratio of the peak accumulation of passenger cars, trucks, and buses to the peak half-hour outbound traffic volume varied from 0.8 to 2.8, increasing generally with population. Considering only present usage of the street capacity and present traffic-operating conditions, it would require from slightly less than ½ hour to about 1½ hours to evacuate all vehicles from the central business district at the time of the peak vehicle accumulation at a rate equal to the outbound traffic flow occurring daily during the peak half-hour. This evacuation time could obviously be reduced by making most, if not all, streets radiating from the central business district one-way outbound, eliminating crossing movement of traffic and interference from pedestrians, and substituting police control for fixed traffic signals.

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