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California Method of Assigning Diverted Traffic to Proposed Freeways

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California has developed a set of curves showing percent of freeway usage as a function of both time and distance differentials. The primary features of this chart are that it shows: (a) as long as some time is saved, there will be some users of the freeway route no matter how far out of direction they must go; (b) as long as some distance is lost, there will be some "non-users", no matter how much time is saved; (c) in between there is a gray area where people do not know how much time or distance is saved or lost, or whether it is saved or lost.

The area between the limiting boundaries described in (a) and (b) was filled by a systematic set of usage curves and the coefficients were determined by observation of two existing freeways; i.e., by interviewing the users and comparing with total interzone transfers. The chart was then tested against the Shirley Highway data reported by D. L. Trueblood in HRB Bulletin 61, and was found to fit relatively well. At least the California curves fit the Shirley data far better than the time-ratio curves fit the California data.

In California, whenever a route study involves new location or more than one alternate solution, a complete economic analysis is made, showing user costs for the common set of trips whether made via any one of the proposed alternates or via remaining roads. This work is done in conjunction with the assignment, by punch card machines. The manual coding necessary consists of coding the distance via existing network for each interzone transfer, the distance to and from each freeway alternate for each interzone transfer, and the distance between access points along the line of each freeway alternate. The assignment curves are expressed as a formula,

$$P = 50 + \frac{50(d+\frac{1}{2}t)}{\sqrt{(d-\frac{1}{2}t)^2+4.5}}$$

for the purpose of machine manipulation.

● MOST of the cities in California lie on principal state highways that are being projected as freeways. The larger cities, of course, will be served by several freeways in each.

Whenever a route study or project report for one of these freeways involves alternate locations, an economic analysis accounting for road-users' operating costs and benefits as well as highway costs is made. The economic analysis takes into consideration those items that can be reduced to financial terms with a minimum amount of surmise or opinion, but often there are other factors which cannot be stated in dollars which might outweigh the formal analysis. These must be resolved by judgment.

Many engineers are prone to regard economic analyses as "theoretical", using the word in a manner that implies that theory is antithetic to practice. These engineers are reminded that whenever one says "this line will do the most good for the money," he has made an economic analysis. Whether it is formalized and computed or merely based on a mental process involving long experience, judgment, and art, the analysis is made. The difference is that when a formal analysis is made, it can be laid down in black and white for all to see, and the engineer can say "these are the facts". This is a very valuable thing to be able to say if controversy arises regarding a route location, and the other man says "this is my opinion."

For many years, in California practice, trips were assigned to a proposed route on the basis of least cost (1). In this method, the cost per trip, including time value, was computed via the proposed route and via the remaining road network, and the whole transfer between zones was assigned to the route resulting in the least cost per trip. This method usually produced results which looked reasonable from a subjective point of view, and had a distinct advantage in that trips which would "lose money" by using

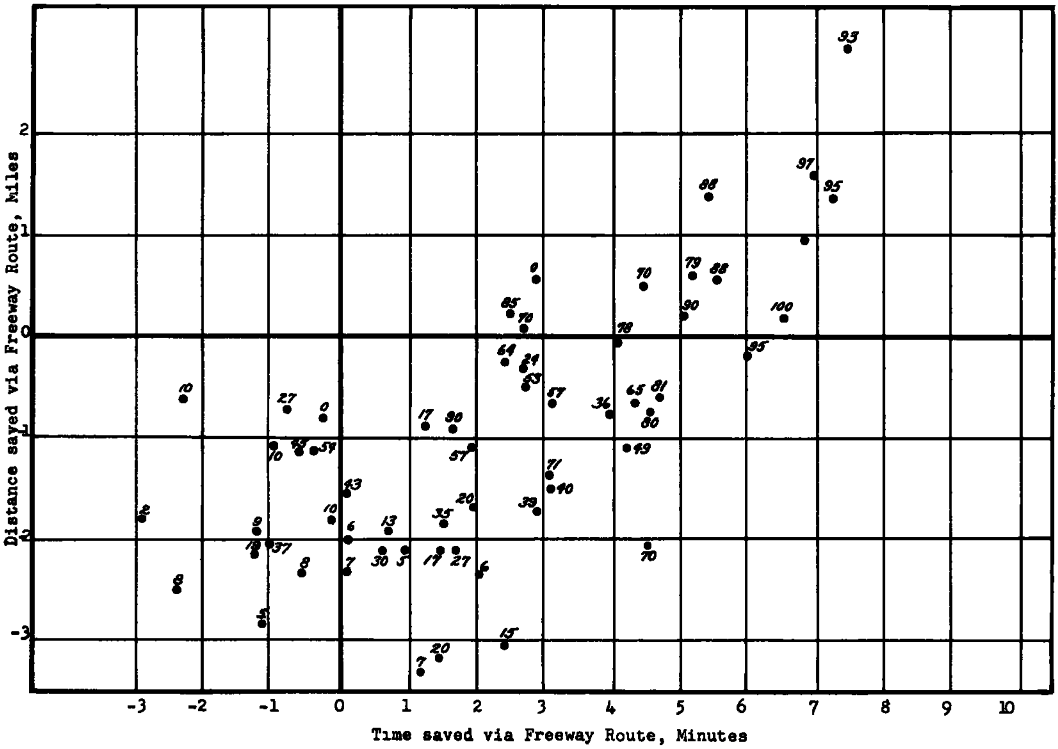


Figure 1. Percent usage related to time saved and distance saved-Alvarado Expressway.

the freeway were not assigned to it, thereby reducing its benefits. The reason for putting "lose money" in quotations here is that, if the proper values are assigned to time saved, and to driver's preference, he does not lose by choosing one route or the other. He may spend more, but he gets what he considers his money's worth, or he would have gone the other way. Inasmuch as a practical method of assigning different values to time for various individual users of a facility has not come to our attention, the "least cost" procedure has considerable merit.

It was known, that all of the drivers involved in a given transfer would not choose the same route, but it was hoped that the overs would offset the unders. In 1953, however, this procedure was revealed to have some serious flaws.

In one city, moving a proposed access point from H Street to J Street changed the ADT on the freeway by about 40 percent. In another city, the far bypass alternate which skirted the town about 1½ miles from the main intersection, was found to have practically the same projected traffic volume as the near by-pass. This was because trips destined to the central business district saved a bare fraction of a cent by using the freeway in the case of the far by-pass, and although the saving per trip was much greater on the near by-pass, all of the trips involved in this large transfer were assigned to both alternates.

In a third city (San Diego), a similar situation arose but here there was a completed expressway upon which an origin-destination survey had just been completed. To obviate the difficulty, which was caused by the assumption that either 100 percent or none of a given transfer would use the proposed facility, it was decided that a curve of graduated percent usage would be used. The time-ratio curve in D. L. Trueblood's paper "Effect of Travel Time and Distance on Freeway Usage" (2) was tested against the known data on the Alvarado expressway. It was found that this curve would result in assigning 39,000 trips per day to the expressway, whereas only 24,000 trips a day were using the expressway. It was then decided to do some independent analysis of the San Diego Origin-Destination data in conjunction with known usage of the two freeways in that city.

DEVELOPMENT OF ASSIGNMENT CURVES

Driver preference for one route or another is a function of many factors. The simplest ones to measure and express numerically are travel-time and travel-distance. It is believed that orientation, or sense of direction, in itself is also extremely important. It is very difficult to persuade a motorist to start out in a northerly direction when he knows his destination in southerly. Fortunately, nearly all trips which are out of direction in this sense involve extra travel distance, which can be measured.

From Trueblood (2) was derived the idea of plotting time, distance, and percent usage on one graph. It was thought that some iso-usage curves could be developed by interpolation or smoothing of the values observed. If distance is of no weight, the iso-usage curves would come out parallel to the time ordinates. The results of observations on the two expressways in San Diego are shown in Figures 1 and 2, and in Tables 1 and 2. It was practically impossible to discern a pattern, and so deductive reasoning was resorted to. This reasoning went like this:

1. There are other factors besides time and distance, but they will be ignored because they can't be measured and because they cannot be forecast.

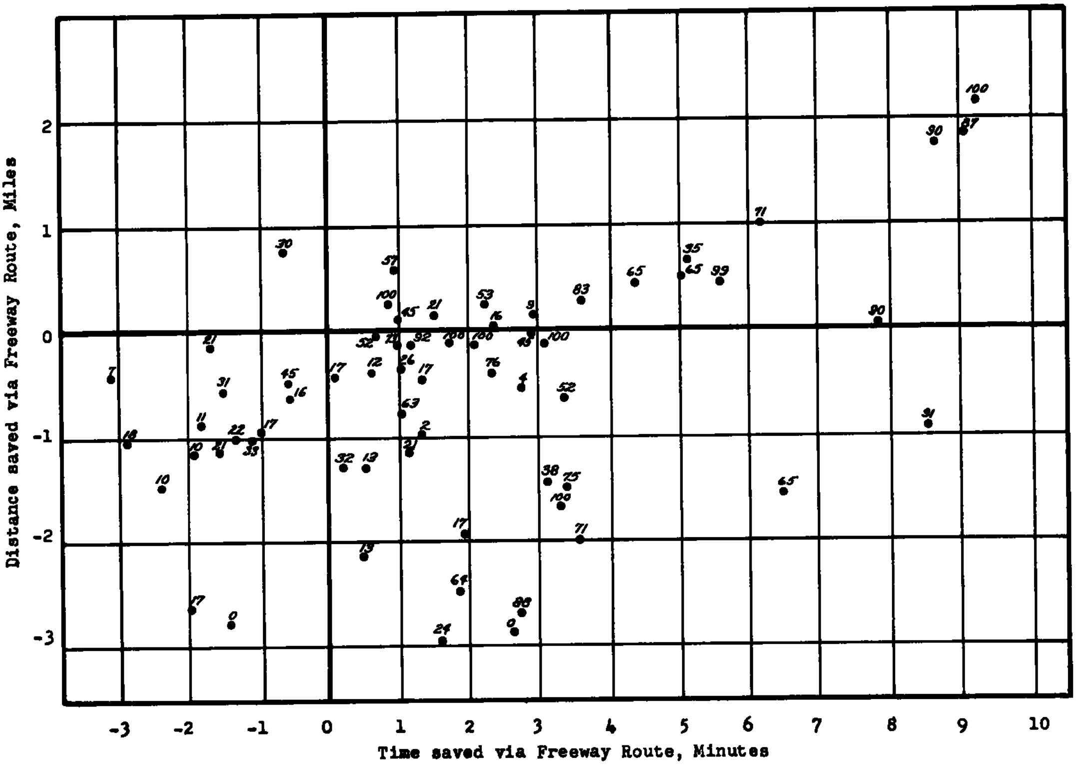


Figure 2. Percent usage related to time saved and distance saved-Cabrillo Freeway.

2. For the purpose of forecasting, it is essential that a systematic, or regular, pattern be used. If idiosyncrasies of a particular route or street system affect the pattern, they are impossible to extrapolate from the observed case or cases to the problem at

TABLE 1

ALVARADO-MISSION VALLEY EXPRESSWAY USE STUDY

From Zone	To Zone	Total Trip Transfer Between Zones	No. of Trips on Expressway	Percent of Trips on Expressway	Time Via Expressway (Min.)	Time Via Alternate Route (Min.)	Distance Via Expressway (Miles)	Distance Via Alternate Route (Miles)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
76	51	1323	1126	85	11.39	18.13	8.37	9.31
51	76	1125	912	81	11.39	18.13	8.37	9.31
76	52	260	249	96	18.61	24.68	12.25	12.04
52	76	271	255	94	18.61	24.68	12.25	12.04
76	53	874	651	74	12.62	16.90	9.40	8.28
53	76	775	533	69	12.62	16.90	9.40	8.28
76	54	293	224	76	12.62	16.90	9.40	8.28
54	76	279	169	61	12.62	16.90	9.40	8.28
76	55	423	389	92	11.39	18.13	8.37	9.31
55	76	337	312	93	11.39	18.13	8.37	9.31
76	56	558	386	69	12.62	16.90	9.40	8.28
56	76	501	266	53	12.62	16.90	9.40	8.28
76	57	807	515	64	12.62	16.90	9.40	8.28
57	76	867	470	54	12.62	16.90	9.40	8.28
76	58	2212	1196	54	18.08	20.71	12.07	10.32
58	76	1861	959	52	18.08	20.71	12.07	10.32
76	59	523	130	25	19.38	19.41	12.57	9.82
59	76	581	137	24	19.38	19.41	12.57	9.82
76	60	301	33	11	11.89	10.66	7.32	5.19
60	76	278	36	13	11.89	10.66	7.32	5.19
76	61	513	95	18	12.47	13.16	8.34	6.39
61	76	578	132	23	12.47	13.16	8.34	6.39
76	62	1004	263	26	11.89	10.66	7.32	5.19
62	76	1157	271	23	11.89	10.66	7.32	5.19
76	63	73	41	56	9.92	12.63	6.50	6.01
63	76	65	50	77	9.92	12.63	6.50	6.01
75	51	156	133	85	9.95	15.51	7.37	7.92
51	75	225	177	79	9.95	15.51	7.37	7.92
75	52	40	37	93	17.17	22.06	11.25	10.65
52	75	23	19	83	17.17	22.06	11.25	10.65
75	53	172	66	38	11.18	14.28	8.40	6.89
53	75	117	52	44	11.18	14.28	8.40	6.89
75	54	82	20	24	11.18	14.28	8.40	6.89
54	75	37	13	35	11.18	14.28	8.40	6.89
75	55	76	76	100	9.95	15.51	7.37	7.92
55	75	101	94	93	9.95	15.51	7.37	7.92
75	56	138	55	40	11.18	14.28	8.40	6.89
56	75	135	35	26	11.18	14.28	8.40	6.89
75	57	169	67	40	11.18	14.28	8.40	6.89
57	75	126	50	40	11.18	14.28	8.40	6.89
75	58	507	138	27	19.36	21.30	12.38	10.69

TABLE 1 (Cont'd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
58	75	532	116	22	19.36	21.30	12.38	10.69
75	59	100	12	12	20.66	20.00	12.88	10.19
59	75	113	23	20	20.66	20.00	12.88	10.19
75	60	68	6	9	14.20	12.07	8.01	5.15
60	75	53	0	0	14.20	12.07	8.01	5.15
75	61	125	19	15	11.03	10.54	7.34	5.00
61	75	165	7	4	11.03	10.54	7.34	5.00
75	62	381	47	12	10.45	8.04	6.32	3.80
62	75	368	36	10	10.45	8.04	6.32	3.80
75	63	28	3	11	8.48	10.01	5.50	4.62
63	75	21	13	62	8.48	10.01	5.50	4.62
74	51	251	199	79	11.39	18.13	8.37	9.31
51	74	288	235	82	11.39	18.13	8.37	9.31
74	52	50	32	64	25.06	29.56	15.22	14.54
52	74	33	22	67	25.06	29.56	15.22	14.54
74	53	255	54	21	12.62	16.90	9.40	8.28
53	74	247	58	23	12.62	16.90	9.40	8.28
74	54	117	7	6	23.33	25.36	13.81	11.48
54	74	102	6	6	23.33	25.36	13.81	11.48
74	55	84	82	98	11.39	18.13	8.37	9.31
55	74	86	73	85	11.39	18.13	8.37	9.31
74	56	143	63	44	12.62	16.90	9.40	8.28
56	74	130	56	43	12.62	16.90	9.40	8.28
74	57	213	42	20	18.90	20.43	12.99	9.79
57	74	188	38	20	18.90	20.43	12.99	9.79
74	58	607	36	6	21.38	17.95	13.52	9.26
58	74	700	75	11	21.38	17.95	13.52	9.26
74	59	184	3	2	22.68	16.65	14.02	8.76
59	74	214	6	3	22.68	16.65	14.02	8.76
74	60	59	0	0	15.19	12.35	8.77	6.98
60	74	79	3	4	15.19	12.35	8.77	6.98
74	61	147	7	5	12.47	13.16	8.34	6.39
61	74	109	3	3	12.47	13.16	8.34	6.39
74	62	304	38	13	11.89	10.66	7.32	5.19
62	74	244	30	12	11.89	10.66	7.32	5.19
74	63	27	9	33	9.92	12.63	6.50	6.01
63	74	31	9	29	9.92	12.63	6.50	6.01
73	51	211	152	72	10.14	12.69	6.89	6.63
51	73	200	131	65	10.14	12.69	6.89	6.63
73	52	43	31	72	19.15	23.82	12.18	10.12
52	73	60	40	67	19.15	23.82	12.18	10.12
73	53	215	51	24	13.34	15.76	9.47	6.40
53	73	181	39	22	13.34	15.76	9.47	6.40
73	54	71	9	13	13.34	15.76	9.47	6.40
54	73	102	6	6	13.34	15.76	9.47	6.40
73	55	76	58	76	11.93	16.07	8.30	8.25
55	73	44	36	82	11.93	16.07	8.30	8.25
73	56	196	39	20	13.16	14.84	9.33	7.22
56	73	148	23	16	13.16	14.84	9.33	7.22

TABLE 1 (Cont'd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
73	57	202	33	16	13.16	14.84	9.33	7.22
57	73	206	76	37	13.16	14.84	9.33	7.22
73	58	711	68	10	18.62	16.30	12.00	8.37
58	73	641	47	7	18.62	16.30	12.00	8.37
73	59	184	2	1	19.92	15.00	12.50	7.87
59	73	164	3	2	19.92	15.00	12.50	7.87
73	60	70	3	4	16.88	10.70	10.10	6.09
60	73	91	3	3	16.88	10.70	10.10	6.09
73	61	211	9	4	15.21	12.47	8.32	4.92
61	73	206	17	8	15.21	12.47	8.32	4.92
73	62	467	7	1	12.43	8.60	7.25	4.13
62	73	377	6	2	12.43	8.60	7.25	4.13
73	63	13	3	23	9.86	11.17	6.14	5.24
63	73	28	3	11	9.86	11.17	6.14	5.24
72	51	219	166	76	9.95	15.51	7.37	7.92
51	72	169	137	81	9.95	15.51	7.37	7.92
72	52	48	33	69	17.17	22.06	11.25	10.65
52	72	58	46	79	17.17	22.06	11.25	10.65
72	53	188	51	27	11.18	14.28	8.40	6.89
53	72	165	58	35	11.18	14.28	8.40	6.89
72	54	67	36	54	11.18	14.28	8.40	6.89
54	72	53	23	43	11.18	14.28	8.40	6.89
72	55	59	59	100	9.95	15.51	7.37	7.92
55	72	92	74	80	9.95	15.51	7.37	7.92
72	56	140	40	29	11.18	14.28	8.40	6.89
56	72	76	27	36	11.18	14.28	8.40	6.89
72	57	197	52	26	11.18	14.28	8.40	6.89
57	72	152	45	30	11.18	14.28	8.40	6.89
72	58	403	73	18	16.64	18.09	11.07	8.93
58	72	308	77	25	16.64	18.09	11.07	8.93
72	59	136	23	17	17.94	16.79	11.57	8.43
59	72	89	7	8	17.94	16.79	11.57	8.43
72	60	52	3	6	10.45	8.04	6.32	3.80
60	72	39	3	8	10.45	8.04	6.32	3.80
72	61	142	13	9	11.75	10.54	6.94	5.00
61	72	153	13	9	11.75	10.54	6.94	5.00
72	62	409	13	3	10.45	8.04	6.32	3.80
62	72	382	12	3	10.45	8.04	6.32	3.80
72	63	53	10	19	7.88	10.61	5.21	4.91
63	72	35	10	29	7.88	10.61	5.21	4.91
71	51	144	132	92	9.12	16.34	6.98	8.31
51	71	117	113	97	9.12	16.34	6.98	8.31
71	52	17	17	100	16.34	22.89	10.86	11.04
52	71	26	26	100	16.34	22.89	10.86	11.04
71	53	104	88	85	10.35	15.11	8.01	7.28
53	71	63	58	92	10.35	15.11	8.01	7.28
71	54	40	31	77	10.35	15.11	8.01	7.28
54	71	31	26	84	10.35	15.11	8.01	7.28
71	55	39	39	100	9.12	16.34	6.98	8.31

TABLE 1 (Cont'd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
55	71	41	37	90	9.12	16.34	6.98	8.31
71	56	61	50	82	10.35	15.11	8.01	7.28
56	71	60	41	68	10.35	15.11	8.01	7.28
71	57	75	61	81	10.35	15.11	8.01	7.28
57	71	73	64	88	10.35	15.11	8.01	7.28
71	58	285	222	78	15.81	18.92	10.76	9.32
58	71	211	151	72	15.81	18.92	10.76	9.32
71	59	42	28	67	17.11	17.62	11.26	8.82
59	71	45	29	64	17.11	17.62	11.26	8.82
71	60	35	0	0	9.62	8.87	5.93	4.19
60	71	49	13	27	9.62	8.87	5.93	4.19
71	61	57	22	39	10.92	11.37	6.55	5.39
61	71	38	19	50	10.92	11.37	6.55	5.39
71	62	142	56	39	9.62	8.87	5.93	5.19
62	71	127	69	54	9.62	8.87	5.93	5.19
70	51	120	100	83	8.59	14.21	5.91	7.30
51	70	108	91	84	8.59	14.21	5.91	7.30
70	52	51	45	88	15.81	20.76	9.79	10.03
52	70	43	39	91	15.81	20.76	9.79	10.03
70	53	84	50	60	9.82	12.98	6.94	6.27
53	70	83	65	78	9.82	12.98	6.94	6.27
70	54	33	16	49	9.82	12.98	6.94	6.27
54	70	17	6	35	9.82	12.98	6.94	6.27
70	55	50	46	92	8.59	14.21	5.91	7.30
55	70	38	29	76	8.59	14.21	5.91	7.30
70	56	54	24	44	9.82	12.98	6.94	6.27
56	70	57	19	33	9.82	12.98	6.94	6.27
70	57	114	66	58	9.82	12.98	6.94	6.27
57	70	91	45	49	9.82	12.98	6.94	6.27
70	58	338	172	51	12.80	16.79	9.08	8.31
58	70	247	111	45	12.80	16.79	9.08	8.31
70	59	66	14	21	14.10	15.49	9.58	7.81
59	70	50	16	32	14.10	15.49	9.58	7.81
70	60	54	0	0	9.09	6.74	4.86	3.18
60	70	51	0	0	9.09	6.74	4.86	3.18
70	61	126	6	5	10.39	9.24	5.48	4.38
61	70	101	13	13	10.39	9.24	5.48	4.38
70	62	210	39	19	9.09	6.74	4.86	3.13
62	70	187	9	5	9.09	6.74	4.86	3.13
69	51	431	237	55	10.11	12.69	6.58	6.63
51	69	365	194	53	10.11	12.69	6.58	6.63
69	52	68	39	57	17.33	19.24	10.46	9.36
52	69	62	36	58	17.33	19.24	10.46	9.36
69	53	321	19	6	11.34	11.46	7.61	5.60
53	69	246	30	12	11.34	11.46	7.61	5.60
69	54	106	4	4	11.34	11.46	7.61	5.60
54	69	67	0	0	11.34	11.46	7.61	5.60
69	55	120	103	86	10.11	12.69	6.58	6.63
55	69	106	83	78	10.11	12.69	6.58	6.63

TABLE 1 (Cont'd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
69	56	335	33	10	11.34	11.46	7.61	5.60
56	69	336	23	7	11.34	11.46	7.61	5.60
69	57	456	27	6	11.34	11.46	7.61	5.60
57	69	382	42	11	11.34	11.46	7.61	5.60
69	58	1041	53	5	14.32	15.27	9.75	7.64
58	69	979	88	9	14.32	15.27	9.75	7.64
69	59	252	5	2	15.62	13.97	10.25	7.14
59	69	272	4	1	15.62	13.97	10.25	7.14
69	60	140	4	3	10.61	5.22	5.53	2.51
60	69	170	0	0	10.61	5.22	5.53	2.51
69	61	310	6	2	11.91	7.72	6.15	4.57
61	69	330	0	0	11.91	7.72	6.15	4.57
69	62	934	0	0	10.61	5.22	5.53	2.51
62	69	835	10	1	10.61	5.22	5.53	2.51
69	63	75	0	0	8.04	7.79	4.42	3.62
63	69	60	0	0	8.04	7.79	4.42	3.62
68	51	922	467	51	10.14	12.69	6.89	6.63
51	68	892	457	51	10.14	12.69	6.89	6.63
68	52	222	57	26	24.16	24.76	14.18	12.06
52	68	258	79	31	24.16	24.76	14.18	12.06
68	53	835	52	6	13.00	13.83	8.68	5.40
53	68	785	62	8	13.00	13.83	8.68	5.40
68	54	349	6	2	22.43	20.56	12.77	9.00
54	68	317	20	6	22.43	20.56	12.77	9.00
68	55	354	267	76	10.14	12.69	6.89	6.63
55	68	388	262	68	10.14	12.69	6.89	6.63
68	56	542	28	5	11.37	11.46	7.92	5.60
56	68	487	38	8	11.37	11.46	7.92	5.60
68	57	882	14	2	18.00	15.63	11.95	7.31
57	68	782	20	3	18.00	15.63	11.95	7.31
68	58	2888	26	1	20.48	13.15	12.48	6.78
58	68	2838	45	2	20.48	13.15	12.48	6.78
68	59	1110	14	1	21.78	11.85	12.98	6.28
59	68	995	20	2	21.78	11.85	12.98	6.28
68	60	449	0	0	18.74	7.55	10.58	4.50
60	68	459	3	1	18.74	7.55	10.58	4.50
68	61	757	17	2	14.87	10.54	7.53	3.92
61	68	839	7	1	14.87	10.54	7.53	3.92
68	62	1802	14	1	10.64	5.22	5.84	2.51
62	68	1548	7	0	10.64	5.22	5.84	2.51
68	63	123	4	3	8.07	7.79	4.73	3.62
63	68	134	10	7	8.07	7.79	4.73	3.62
67	51	512	109	21	10.03	10.05	5.90	4.35
51	67	509	131	26	10.03	10.05	5.90	4.35
67	52	80	15	19	23.60	19.36	12.72	8.94
52	67	86	23	27	23.60	19.36	12.72	8.94
67	53	416	9	2	11.44	8.64	7.07	3.18
53	67	390	3	1	11.44	8.64	7.07	3.18
67	54	130	9	7	21.87	15.16	11.31	5.88

TABLE 1 (Cont'd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
54	67	97	0	0	21.87	15.16	11.31	5.88
67	55	156	101	65	10.03	10.05	5.90	4.35
55	67	159	92	58	10.03	10.05	5.90	4.35
67	56	243	13	5	11.26	8.82	6.93	3.32
56	67	222	20	9	11.26	8.82	6.93	3.32
67	57	353	0	0	14.24	10.23	9.07	4.19
57	67	278	0	0	14.24	10.23	9.07	4.19
67	58	1118	7	1	16.72	7.75	9.60	3.66
58	67	1159	3	0	16.72	7.75	9.60	3.66
67	59	420	0	0	16.72	7.75	9.60	3.66
59	67	499	0	0	16.72	7.75	9.60	3.66
66	51	703	285	40	8.90	8.57	5.53	4.61
51	66	664	284	43	8.90	8.57	5.53	4.61
66	52	132	42	32	16.12	15.12	9.41	7.34
52	66	122	50	41	16.12	15.12	9.41	7.34
66	53	551	22	4	10.13	7.34	6.56	3.58
53	66	492	35	7	10.13	7.34	6.56	3.58
66	54	157	0	0	10.13	7.34	6.56	3.58
54	66	156	3	2	10.13	7.34	6.56	3.58
66	55	156	106	68	8.90	8.57	5.53	4.61
55	66	238	156	66	8.90	8.57	5.53	4.61
66	56	500	31	6	10.13	7.34	6.56	3.58
56	66	496	28	6	10.13	7.34	6.56	3.58
66	57	647	12	2	10.13	7.34	6.56	3.58
57	66	678	22	3	10.13	7.34	6.56	3.58
66	58	1686	33	2	15.59	12.08	9.23	5.45
58	66	1528	39	3	15.59	12.08	9.23	5.45
66	59	461	7	2	16.89	10.78	9.73	4.95
59	66	414	3	1	16.89	10.78	9.73	4.95
65	51	108	77	71	7.54	9.93	4.95	5.19
51	65	69	47	68	7.54	9.93	4.95	5.19
65	52	19	19	100	14.76	16.48	8.83	7.92
52	65	17	13	77	14.76	16.48	8.83	7.92
65	53	50	0	0	8.77	8.70	5.98	4.16
53	65	44	0	0	8.77	8.70	5.98	4.16
65	55	5	5	100	7.54	9.93	4.95	5.19
55	65	16	13	81	7.54	9.93	4.95	5.19
65	56	74	8	11	8.77	8.70	5.98	4.16
56	65	65	13	20	8.77	8.70	5.98	4.16
65	57	107	4	4	8.77	8.70	5.98	4.16
57	65	78	3	4	8.77	8.70	5.98	4.16
65	58	282	7	2	14.23	13.44	8.65	6.03
58	65	223	16	7	14.23	13.44	8.65	6.03
65	59	38	0	0	15.53	12.14	9.15	5.53
59	65	47	0	0	15.53	12.14	9.15	5.53
64	51	491	439	89	4.98	12.49	3.72	6.42
51	64	579	535	93	4.98	12.49	3.72	6.42
64	52	72	72	100	12.20	19.04	7.60	9.15
52	64	71	66	93	12.20	19.04	7.60	9.15

TABLE 1 (Cont'd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
64	53	69	45	65	6.21	11.26	4.75	5.39
53	64	91	53	58	6.21	11.26	4.75	5.39
64	54	11	11	100	6.21	11.26	4.75	5.39
54	64	10	10	100	6.21	11.26	4.75	5.39
64	55	146	134	92	4.98	12.49	3.72	6.42
55	64	137	132	96	4.98	12.49	3.72	6.42
64	56	119	78	66	6.21	11.26	4.75	5.39
56	64	194	117	60	6.21	11.26	4.75	5.39
64	57	102	66	65	6.21	11.26	4.75	5.39
57	64	84	63	75	6.21	11.26	4.75	5.39
64	58	194	102	53	11.67	15.07	7.42	7.43
58	64	132	75	57	11.67	15.07	7.42	7.43
64	59	36	12	33	12.97	13.77	7.92	6.93
59	64	23	6	26	12.97	13.77	7.92	6.93
64	60	55	7	13	5.48	5.02	2.67	2.30
60	64	48	6	13	5.48	5.02	2.67	2.30
64	61	191	29	15	4.88	5.62	2.38	2.59
61	64	201	28	14	4.88	5.62	2.38	2.59
64	62	234	46	20	5.48	5.02	2.67	2.30
62	64	257	45	18	5.48	5.02	2.67	2.30
64	63	26	7	27	2.91	4.26	1.56	2.05
63	64	13	6	46	2.91	4.26	1.56	2.05
		103,333	23,913					

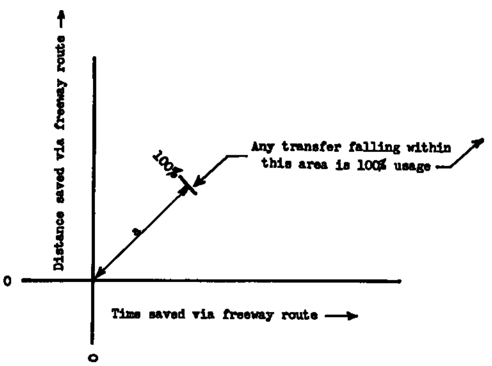


Figure 3.

hand. Regularity is assured if the shape of the curve is expressed by a mathematical equation.

3. The more time saved, the greater will be the percent usage.

4. The more distance saved (or the less that is lost), the greater will be the percent usage.

5. When either time or distance saved is small, there will be doubt in the motorists' minds as to whether it is saved or lost, and some motorists will resolve it one way and some the other.

6. Some motorists will drive any amount of distance to save time, and a few motorists will choose the shortest route no matter how much time this route consumes.

100 Percent Usage Boundary

Starting with the above reasoning, the upper right-hand quadrant of the graph was examined first (see Figure 3). Any trip which plots in this quadrant saves both time and distance. As a first approximation it might be said that the axes of zero distance and zero time would be the 100 percent usage boundary.

However, near the origin the time and distance differences are so small that many motorists in planning a trip will think that the trip lies in another quadrant; i.e., they will not know that the freeway route saves both time and distance or either. This applies even to habitual users (commuters), since they seldom record the actual time or

TABLE 2

CABRILLO FREEWAY USE STUDY

From Zone	To Zone	Total Trip Transfer Between Zones	No. of Trips on Expressway	Percent of Trips on Expressway	Time Via Expressway (Min.)	Time Via Alternate Route (Min.)	Distance Via Expressway (Miles)	Distance Via Alternate Route (Miles)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2	17	440	40	9	12.29	9.19	5.24	4.81
	18,19	440	160	36	4.09	5.14	2.57	2.19
	23	260	80	31	5.97	7.20	2.84	2.39
	25	1120	0	0	13.15	11.86	7.05	4.27
	27	380	380	100	11.60	17.21	6.05	6.96
	28	540	500	92	7.03	8.20	3.22	3.06
	29	400	280	70	4.45	5.46	3.12	2.35
	30	280	120	43	4.45	5.46	3.12	2.35
	31	480	160	33	11.70	10.22	5.78	5.19
	32	100	100	100	10.47	13.50	6.98	6.84
	33	180	140	78	18.09	20.87	12.45	9.75
	34	280	240	86	19.88	23.53	13.38	11.39
3	17	820	80	10	12.29	9.19	5.24	4.81
	18,19	840	260	31	4.09	5.14	2.57	2.19
	20	180	100	56	5.03	6.14	2.28	2.39
	21	180	100	56	3.49	5.74	2.27	2.49
	22	160	20	13	5.08	5.80	2.09	1.69
	23	420	40	10	5.97	7.20	2.84	2.39
	25	1700	220	13	12.24	12.73	6.77	4.60
	27	580	520	90	10.14	18.67	5.63	7.38
	28	440	440	100	6.01	8.00	2.95	2.79
	29	720	480	67	4.45	5.46	3.12	2.35
	30	700	400	57	4.45	5.46	3.12	2.35
	31	1760	660	37	11.70	10.22	5.78	5.19
	32	180	180	100	10.47	13.50	6.98	6.84
	33	220	200	91	18.09	20.87	12.45	9.75
	34	620	420	68	19.88	23.53	13.38	11.39
4	19	380	80	21	6.83	6.33	3.26	2.64
	21	180	100	55	6.23	6.93	2.96	2.94
	23	120	100	83	5.15	8.02	2.63	2.60
	25	840	400	48	10.90	14.00	6.37	4.91
	26	100	100	100	7.17	12.13	3.60	4.14
	27	460	460	100	9.74	19.07	5.42	7.59
	28	500	500	100	5.19	8.82	2.74	3.00
	29	780	200	26	5.47	4.44	3.25	2.22
	30	380	180	47	9.86	10.08	5.06	3.73
	31	1120	240	21	12.35	9.57	6.03	4.94
	32	400	300	75	10.87	13.10	7.10	6.72
	33	100	20	20	19.02	20.82	12.68	9.74
	34	480	300	63	20.81	22.60	13.61	11.16
5	21	80	40	50	7.03	6.51	3.21	2.91
	23	360	160	44	5.15	8.02	2.63	2.60
	25	280	100	36	10.90	14.00	6.37	4.91
	27	180	180	100	9.74	19.07	5.42	7.59

TABLE 2 (Con'td.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	28	240	180	75	5.19	8.82	2.74	3.00
	29	200	20	10	5.47	4.44	3.25	2.22
	31	480	80	17	13.65	8.27	6.53	4.44
6	21	320	160	50	7.03	6.51	3.21	2.91
	25	1340	340	25	10.90	14.00	6.37	4.91
	27	500	500	100	9.74	19.07	5.42	7.59
	28	680	540	80	5.19	8.82	2.74	3.00
	29	380	60	16	5.47	4.44	3.25	2.22
8	23	260	80	31	5.15	8.02	2.63	2.60
	25	240	180	75	10.90	14.00	6.37	4.91
	27	160	160	100	9.74	19.07	5.42	7.59
	28	660	480	73	5.19	8.82	2.74	3.00
9	21	220	120	55	5.29	4.72	2.87	2.36
	23	140	140	100	2.94	4.60	2.05	1.92
	25	640	360	56	8.66	11.98	5.84	4.33
	27	320	320	100	7.26	16.59	4.89	7.06
	28	260	260	100	2.98	5.40	2.16	2.42
	29	440	160	36	5.47	4.44	3.25	2.22
	30	360	40	11	9.72	7.89	4.41	3.06
	31	660	160	24	11.82	10.13	5.56	5.41
10	17	800	320	40	11.08	10.40	4.66	5.39
	18,19	1460	240	16	4.09	5.14	2.57	2.19
	20	480	140	29	2.82	4.42	1.70	1.83
	21	640	340	53	3.49	5.74	2.27	2.49
	23	920	180	20	3.67	3.87	2.26	1.81
	24	900	20	2	7.29	8.54	3.83	2.85
	25	3540	600	17	9.39	11.25	6.05	4.11
	26	800	40	5	6.09	9.74	3.23	3.45
	27	780	680	87	7.84	17.09	5.05	6.90
	28	1160	820	71	3.71	4.67	2.37	2.21
	29	1380	940	68	4.45	5.46	3.12	2.35
	30	1400	1040	74	4.45	5.46	3.12	2.35
	31	2460	1600	65	10.49	11.43	5.20	5.77
	32	420	380	90	8.26	14.05	6.40	6.44
	33	600	360	60	16.88	23.08	11.87	10.33
	34	960	760	79	17.50	26.01	12.85	11.92
11	17	420	100	24	11.08	10.40	4.66	5.39
	18,19	460	60	13	4.09	5.14	2.57	2.19
	25	1940	0	0	11.65	8.99	6.52	3.64
	26	360	40	11	7.68	8.15	4.28	2.98
	27	400	280	70	9.43	15.50	5.52	6.43
	28	460	380	83	3.71	4.67	2.37	2.21
	29	600	280	47	4.45	5.46	3.12	2.35
	30	600	420	70	4.45	5.46	3.12	2.35
	31	1180	440	37	10.49	11.43	5.20	5.77
	32	500	460	92	8.26	14.05	6.40	6.44
	33	200	160	80	16.88	23.08	11.87	10.33
	34	680	680	100	17.50	26.01	12.85	11.92
13	18	420	40	10	6.07	4.20	3.28	2.10
	23	580	60	10	4.92	2.62	2.76	1.31
	25	940	180	19	10.64	8.89	6.55	3.91
	27	440	280	64	9.69	14.06	5.85	6.29
	28	620	120	19	4.96	3.42	2.87	1.71

TABLE 2 (Cont'd.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	29	360	20	6	6.43	5.38	3.83	2.69
	30	600	160	27	6.43	5.38	3.83	2.69
	31	840	220	26	6.43	5.38	3.83	2.69
	32	180	100	56	10.24	13.45	7.11	6.47

distance used. The time also varies from day to day, and besides this, the assumed time for the particular interzone transfer can be wrong for an individual trip which begins within a zone at some distance from the centroid of that zone. Therefore, the 100 percent boundary is to be plotted at some distance, a, from the origin. The distance will be determined experimentally.

The next question is what direction the 100 percent boundary will take starting from the point established in Figure 3. In Figure 4 are shown four possibilities. Line (1) would be the boundary if distance is ignored. Lines (2) and (3) imply that a given sum of time and distance saved (i.e., $ax+by=C$) will insure 100 percent usage. But even Line (3) says that if a certain amount of time is saved, not just most, but all drivers will go out of their way to use the freeway. This violates rule No. 6, "a few motorists will choose the shortest route no matter how much time this route consumes". These motorists are called freeway-haters. In order to allow for them, the 100 percent boundary cannot cross the zero-distance axis. However, it is clear that as the time saved becomes larger and larger, it becomes harder and harder to hate the freeway and the number of non-users will decrease.

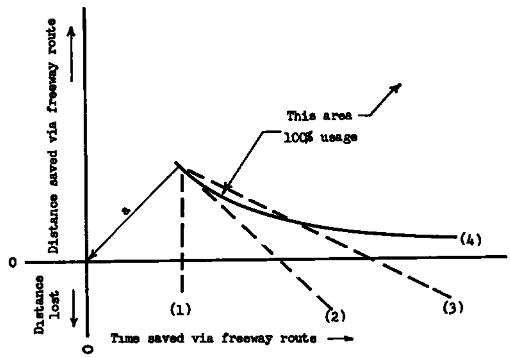


Figure 4.

Curve (4) answers these stipulations: it approaches the zero-distance axis closer and closer as time saved becomes greater, but it never crosses it. In other words, it is asymptotic to the zero-distance axis. One of the simplest curves which has asymptotes is a hyperbola. It was therefore decided to use a hyperbola.

0 Percent Usage Boundary

Next, the lower left-hand quadrant was examined. The planner of any trip which falls in this quadrant would be foolish to use the freeway route, but near the origin it is not certain, in the mind of the motorist, that his trip does fall in the quadrant. Furthermore, it has been stipulated that no matter how much distance is lost by traveling on the freeway, there will always be a few drivers who will use it provided they can save some time. That is to say, the boundary of the zero usage line cannot cross the zero time axis, but comes asymptotic to it as the excess distance increases. This gives us the other branch of the hyperbola set up for the 100 percent boundary (see Figure 5).

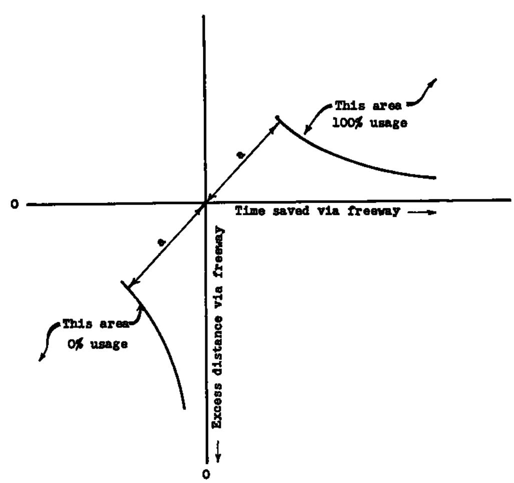


Figure 5.

Filling in Between the Boundaries

Rule No. 2 says that the pattern must be systematic if it is to be worth anything for prognosticating purposes. In other words, if the observed data on existing freeways results in an irregular pattern because of local idiosyncrasies, they must be regularized for use elsewhere, where these idiosyncrasies do not exist.

It was decided that a family of hyperbolas with a common conjugate axis would be the simplest systematic way of filling in the surface between the boundaries.

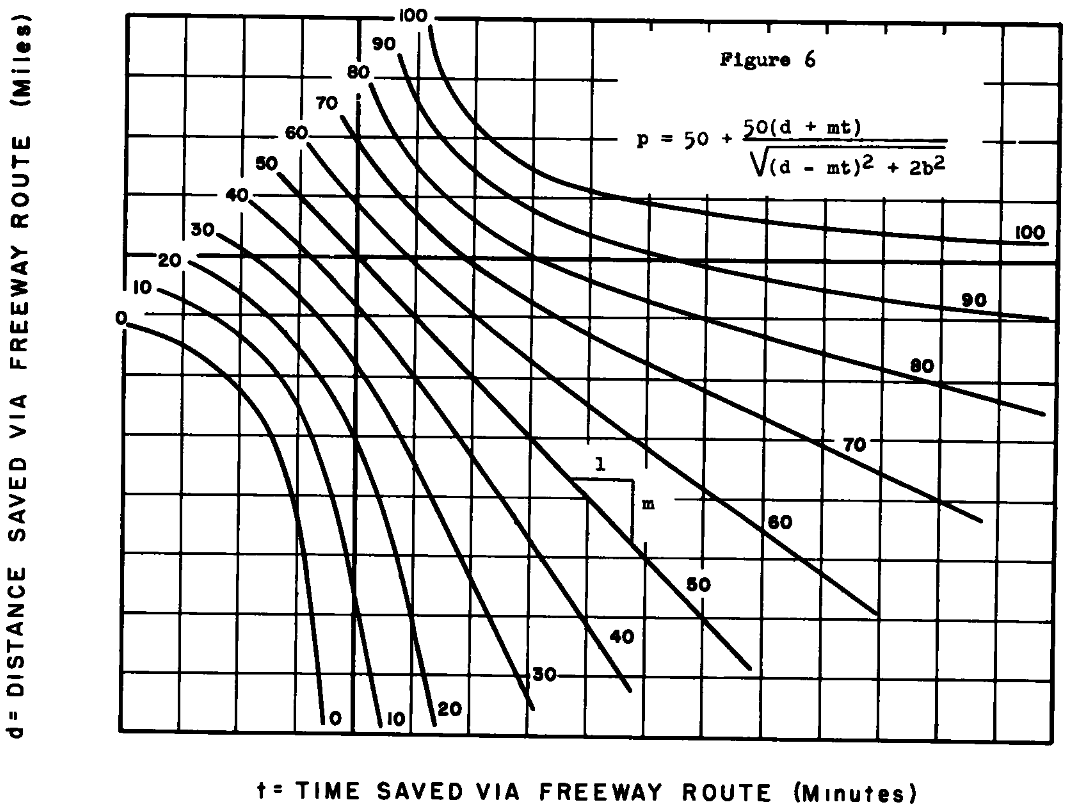


Figure 6.

This set of curves is shown in Figure 6. The equation is $P = 50 + \frac{50(d + mt)}{\sqrt{(d - mt)^2 + 2b^2}}$

Where p = percent usage,
d = distance saved in miles,
t = time saved in minutes,
m = a coefficient relating the value of a mile saved to a minute lost; in other words, a scale value for the x ordinate for a given scale on the y ordinate,
and b = a coefficient determining how far the vertices of the 100 percent and 0 percent boundaries are from the origin.

Having developed a rational framework, it remained to determine experimentally the values of m and b which would result in the "best fit". This probably could have been done by the method of least squares, but the partial derivatives of the expression are somewhat awkward to work with, and a trial-and-error method was used instead.

For the Cabrillo and Alvarado freeways in San Diego it was found that for b = 1.5, the best value of m is between 0.4 and 0.5. It was also found that for various values of m, b = 1.5 is pretty fair, although the results are much more sensitive to changes in m than in b.

It will be noted that m is the slope of the 50 percent usage line, or, put in another way, m is the number of extra miles which 50 percent of the drivers will go in order to save one minute of time. It had previously been determined by the California Division of Highways, using AASHO(3) values for passenger car operating costs at various

TABLE 3

RESULTS OBTAINED BY VARIOUS ASSIGNMENT FORMULAS

Fig	Formula	Alvarado Expressway: Trips assigned by formula	Alvarado Expressway: Ratio as'gd vol to obs'd vol	Alvarado Expressway: Std. error, percent (n=154)	Cabrillo Freeway: Trips assigned by formula	Cabrillo Freeway: Ratio as'gd vol. to obs'd vol.	Cabrillo Freeway: Std. error, percent (n=105)	Shirley Highway: Trips assigned by formula	Shirley Highway: Ratio as'gd vol. to obs'd vol	Shirley Highway: Std error percent (n=87)
	Observed Usage	23,868 trips per day			28,400 trips per day			8,152 trips per day		
6.	$p = 50 + \frac{50(d+mt)}{\sqrt{(d-mt)^2+4\ 5}}$									
	where m=0 4	24,628	1.03	17 1	28,909	1.02	23.2	6,730	0 83	15.3
	where m=0.5	25,403	1 07	17.8	29,880	1 05	23.2	6,695	0 82	15.1
	where m=0.55	26,084	1 09	18.1	30,202	1 07	23 3	6,726	0 83	15 1
	where m=0 67				31,380	1.10	23.6			
7.	$\overset{100}{\underset{0}{p}} = 50 + 6\ 25(2.6t + 4\ 7d)$	24,661	1 03	21.8	30,020	1.06	27 2	6,508	0 80	19.0
8	$p = 0$ $p = 100$ 0> (2.6t+4.7d) > 0	24,375	1 02	31 3	30,020	1.06	44 0	6,133	0.75	30 9
9.	Trueblood time ratio curve	39,007	1.64	29.0	38,379	1.35	28.0	8,258	1 01	9.4

speeds, that the median driver spends 2.6 cents for every minute he saves by driving 53 mph. for 4.7 cents per mile, i.e. the value he places on a minute is 0.55 of that which he spends on a mile. This means that if the 50 percent line were drawn so that m = 0.55, 50 percent of the potential customers would go each way when the "cost" per

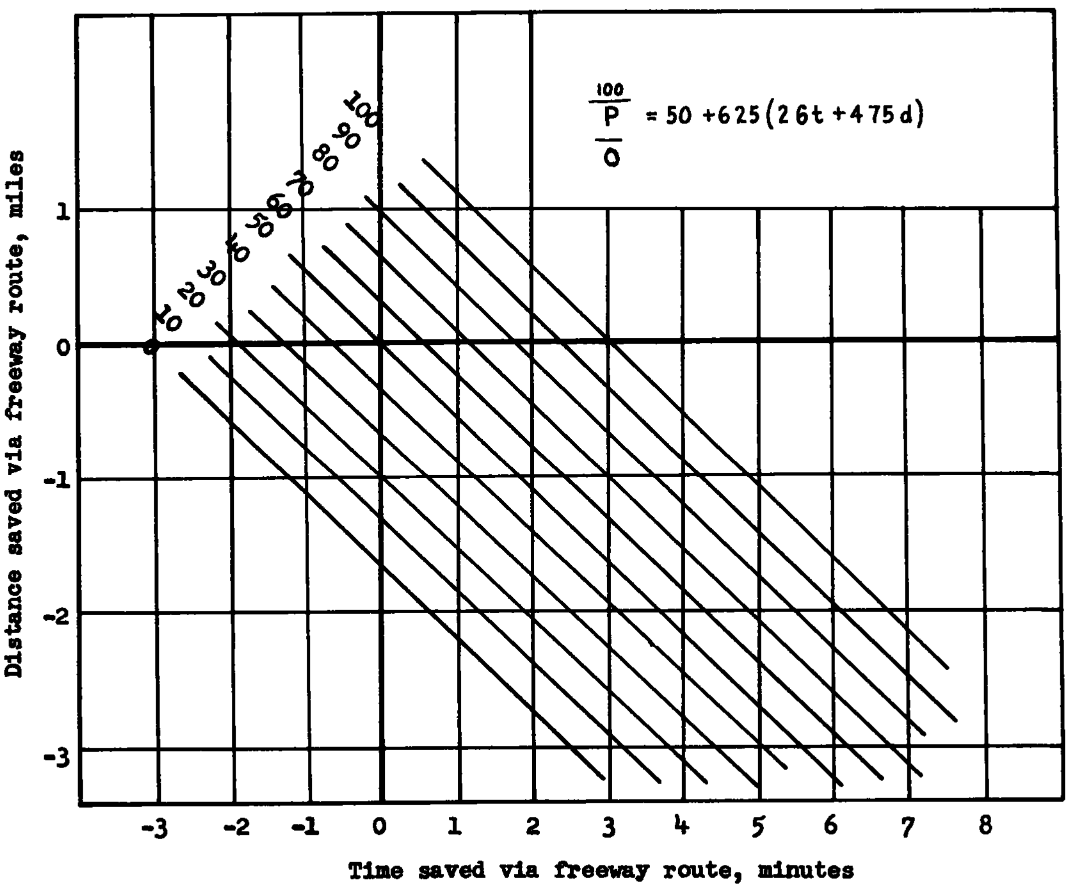


Figure 7.

trip (operating cost plus time value) was equal on either route. This would be a convenient thing for the purpose of computing the economic benefits of a proposed route.

TABLE 4

INTERZONE TRIP DATA - OCEANSIDE-CARLSBAD

From Zone (1)	To Zone (2)	Total Trip Transfer Between Zones (3)	No of Trips on Expressway (4)	Percent of Trips on Expressway Actual (5a)	Percent of Trips on Expressway Theoretical (5b)	Time Via Expressway (Min) (6)	Time Via Alternate Route (Min.) (7)	Distance Via Expressway (Miles) (8)	Distance Via Alternate Route (Miles) (9)
3	N	700	584	83	85	2.18	3.63	1.12	1.77
5	N	219	11	5	20 (0)	3.52	2.80	1.77	1.12
6	N	278	2	1	0	4.23	1.59	2.03	0.86
7	N	1338	105	8	25 (8)	3.40	2.42	1.73	1.16
8	N	48	25	52	42 (37)	3 00	2.82	1.53	1.36
9	N	119	32	27	42 (37)	3.67	3.50	1.81	1.61
10	N	386	23	6	25 (8)	4.33	3 35	2.08	1.51
11	N	345	43	12	25 (8)	5.77	4.79	2.64	2.07
12	N	54	40	75	100	2.93	7.94	2.49	3.31
13	N	71	63	89	90	3.70	7.17	2.78	3.02
14	N	62	56	90	60	4.63	6.90	3.13	2 92
15	N	299	82	27	50	4.80	6.07	3.20	2.60
16	N	98	40	41	63	4.94	7.25	3.78	3.25
17	N	43	29	68	87	4.24	7.95	3.43	3.60
18	N	32	24	75	100	3.70	8.49	3 16	3.87
19	N	32	32	100	100	4.17	10.28	3.58	4.69
20	N	33	21	64	63	6.32	8.63	4.47	3.94
21	N	14	11	79	85	5.42	9.03	4.11	4.16
22	N	31	19	61	100	5.44	11 98	4.12	5.41
23	N	62	45	74	92	5 66	10.35	4.52	4.73
24	N	103	45	44	63	6 48	9.53	4.86	4.39
25	N	62	53	85	68	7 68	10.73	5.48	5.01
26	N	53	44	83	92	6.56	11.25	4.89	5 10
27	N	54	45	83	100	5.91	12 22	4.71	5 60
28	N	43	37	86	100	5 84	12.76	5.06	5.87
29	N	23	17	74	72	7.39	11 21	5.71	5.22
S	N	5160	5000	97	95	8 35	14 85	7.38	7.46
1	S	69	46	46	73	9.55	13.50	7.28	6 84
2	S	26	23	88	85	8.67	13.38	6.87	6.82
3	S	185	169	91	94	7.68	13.24	6.65	6.80
4	S	5	5	100	90	7.91	12.94	6.55	6.65
5	S	71	39	55	75	8.74	12 85	6.96	6.55
6	S	95	57	60	68	9.48	13.03	7.22	6.58
7	S	485	227	47	68	8.65	12.20	6.92	6.28
8	S	50	42	84	80	8.25	12.60	6.72	6.48
9	S	51	35	68	48	10.29	11.45	6.66	6.01
10	S	157	51	33	48	9.86	11.01	6.48	5.83
11	S	193	91	47	48	8.68	9.83	6.02	5.37
12	S	50	42	84	100	5.19	9.39	4.49	5.04
13	S	23	21	91	75	5.57	9.01	4.65	4.88
14	S	28	28	100	68	6.10	8.48	4.87	4.66
15	S	189	104	55	44	6.58	8.00	5.07	4.46
16	S	61	42	69	48	6.00	7.15	4.85	4.20
17	S	24	22	92	78	5.30	7.85	4.50	4.55
18	S	25	23	92	98	4.90	8.25	4.30	4.75
20	S	52	9	17	35	6.08	6.22	4.25	3.52
21	S	13	7	54	73	5.03	7 10	3.74	3.81
22	S	18	13	72	95	3 74	6.76	3.20	3.67
23	S	142	78	55	58	4.36	6.14	3.46	3.41
24	S	128	18	14	35	5.18	5.32	3.80	3.07
25	S	45	8	18	32	4.59	4.42	3.09	2.56
26	S	46	36	78	68	4.18	6.21	2.94	3.27
27	S	35	32	91	89	4.24	6.61	2.94	3.47
28	S	36	27	75	89	2.74	5.11	2.32	2.85
N	S	6175	5860	95	87	8.35	14.35	7.38	7.20

Usage curves which depend on time ratio, disregarding distance, have a tendency to assign "money-losing" trips to a freeway and thus reduce the benefits, or even wipe them out.

Starting with a value for m of 0.67 (based on the 1948 California values of 3 cents per mile and 2 cents per minute) and working through 0.55 (based on current values) down to 0.4, trials were made with results shown in Table 3. The item called "Standard Error" in this table was computed as follows:

$$S.E. = \sqrt{\frac{\Sigma d^2}{n}}$$

where d = p - p'
(p = computed percent usage for a given interzone transfer
(p' = observed percent usage for the same transfer
and n = number of interzone transfers

Table 3 also shows results obtained by other formulas. Graphs of these other formulas are shown in Figures 7, 8 and 9.

It was decided that a coefficient of 0.5 would be as close to right as the data warrant, and that formula was adopted. The final graph is shown in Figure 10. This graph appears in the California Planning Manual, Part 8 (Traffic).

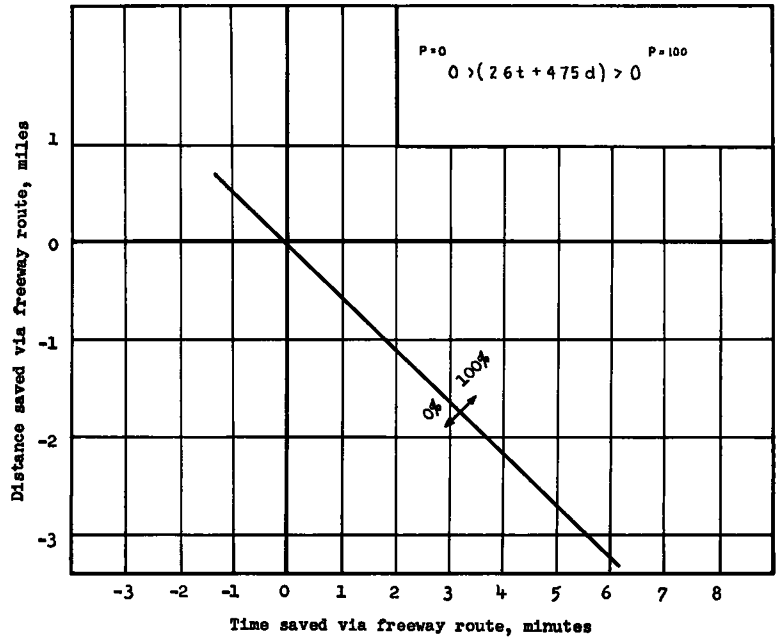


Figure 8.

USAGE OF SMALL CITY BY-PASSES

Origin and destination surveys were made in two small cities in California, Oceanside-Carlsbad (population 25,541), and Tulare (population 13,253), where freeway by-passes had been built. All of the external-internal traffic was interviewed, whether using the freeway or the old road. The through traffic was not interviewed, and internal traffic was interviewed only when it used the freeway. The internal traffic using other streets was not interviewed and it is therefore not known what percentage usage obtained for these transfers.

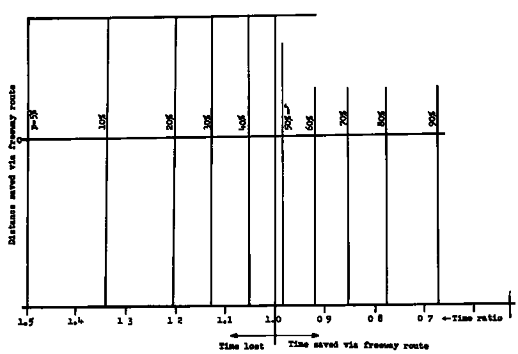
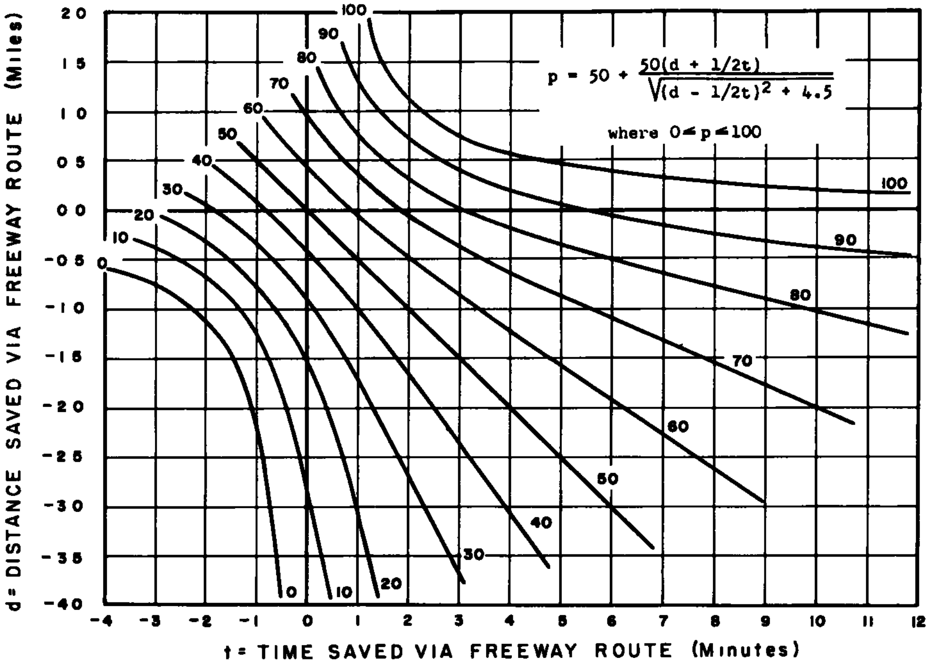


Figure 9. Trueblood time ratio curve.

The results of the Oceanside survey are

shown in Table 4 and those of the Tulare survey in Table 5. The column headed "Theoretical percent usage" shows the percent that would be read directly from Figure



PROCEDURE FOR USE OF THE CHART

1. a. Determine distance between points by best available freeway route (d_f) and by best available alternate (d_a). The distance saved, d, is d_a minus d_f.

b. Determine travel time between points by best available freeway route (t_f) and by best available alternate route (t_a). The time saved, t, is t_a minus t_f.

When determining d_a and t_a, do not overlook the fact that when the freeway obliterates part of the existing road net, d_a and t_a may include some freeway travel. In this case, the "non-users" will be users of the freeway for the portions of the trip where no alternate route is available.

2. Enter chart at appropriate values of d and t and read p, the percentage of trips between the given points which will use the freeway route.

3. Multiply p by the number of trips between the given points. Assign this number of trips to the appropriate portion of the freeway. Assign the balance to the alternate route.

4. When $p < 50$ and $L < 2.0$ miles, the following modification should be applied:

$$p_1 = p + (p - 50)\times(1.5 - 0.75L)$$

where
p_1 = modified percent assignment
p = original percent assignment
L = Length of freeway (between points of choice of trip routing) used via the best available freeway route (d_f)

5. When both ends of a trip are on the freeway, as in the case of a through trip, then assign 100% to the freeway.

Figure 10, Percent of traffic diversion to freeway in relation to time and distance saved.

10 for each interzone transfer. In parentheses are shown the percent usage after applying a secondary formula which is explained below. With this adjustment, the theoretical and actual usage compare as shown in Table 6.

Adjustment for Short Trips

In developing the hyperbolic curves, it was reasoned that when the time and distance differences were small, there would be doubt in the minds of trip planners which route saves time or distance and which loses. It was for this reason that transfers plotting

TABLE 5

INTERZONE TRIP DATA (TULARE)

From Zone	To Zone	Total Trip Transfer Between Zones	No. of Trips on Expressway	Percent of Trips on Expressway: Actual	Percent of Trips on Expressway: Theoretical	Time Via Expressway (Min.)	Time Via Alternate Route (Min.)	Distance Via Expressway (Miles)	Distance Via Alternate Route (Miles)
(1)	(2)	(3)	(4)	(5a)	(5b)	(6)	(7)	(8)	(9)
				%	%				
5	N	414	15	4.0	0	7.22	5.25	4.93	3.64
N	5	367	16						
6	N	152	27	14.0	14	6.72	5.75	4.78	3.79
N	6	110	9						
7	N	44	13	33	61	5.64	6.83	4.34	4.24
N	7	44	16						
20	N	256	234	92	93	4.75	7.62	3.98	4.60
N	20	250	232						
5	S	394	16	4.0	13	7.10	6.25	4.88	3.64
S	5	404	16						
6	S	208	20	9.5	31	6.61	6.75	4.73	3.79
S	6	141	13						
9	S	50	25	42.0	83	5.30	8.05	4.14	4.38
S	9	57	20						
10	S	45	4	20.0	60	5.70	7.65	4.46	4.06
S	10	56	16						
11	S	115	4	2	13	7.10	6.25	4.88	3.64
S	11	96	0						
14	S	28	5	21	57	6.60	8.00	4.70	4.39
S	14	39	9						
20	S	471	418	90	100	4.37	9.10	3.87	4.60
S	20	550	502						
N	S	4,000	3,940	98.4	-a	8.20	11.50	7.54	7.29
S	N	4,075	4,000						

a Would be assigned 100 percent by virtue of being a through trip.

TABLE 6

RESULTS AS APPLIED TO EXTERNAL-INTERNAL TRIPS ON SMALL CITY BY-PASSES

	Oceanside Trips	Oceanside S.E. (Percent)	Tulare Trips	Tulare S.E. (Percent)
Actual Usage	2823		244	
Parabolic Formula (Modified)	3137	16.3	516	25.9
Time Ratio Curve	3840	22.5	892	39.7
All or Nothing (Least Cost)	3295	32.8	363	48.0

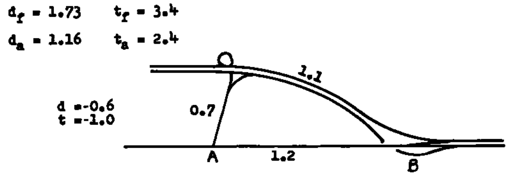


Figure 11.

near the intersection of the zero distance and zero time axes were made other than 100 percent or 0 percent. However, in a geographic situation like that shown in Figure 11, there can be no doubt which is the better route from A to B. The parabolic chart would show 25 percent users of the freeway because the differences are small, and this is obviously an error.

The case shown in Figure 11 is likely to arise in small city by-passes, and did arise at Oceanside. It was necessary to develop a systematic way of taking care of this situation.[1] It was decided that the correction should be a function of the length of ride on the freeway, and that it should apply only to ridiculous trips. Now obviously a ridiculous trip will not plot more than 50 percent usage. Therefore the correction where p=50 would be zero, increasing to a maximum at p=0. This statement is expressed

$$p_1 \Big|_{0}^{50} = p \Big|_{0}^{50} + a(p - 50),$$ where p_1 is the adjusted percent usage.

For determining "a", several graphs were drawn in the shape of Figure 12 and the one which gave the best results was chosen. This was the one showing

$$a = 1.5 - \tfrac{3}{4}L$$

The adjusted formula for short trips (where $L < 2.0$ miles) is then,

$$p_1 = p + (1.5 - \tfrac{3}{4}L)(p - 50),$$ where L is length of freeway ride, and must be less than 2.0, and $p < 50$.

This formula reduces the percent usage of transfer A - B in Figure 11 from 25 percent to 8 percent. Strangely enough, 8 percent of the people in Oceanside going from A to B do use the freeway route.

Reasons for Choice of Route

In connection with the Oceanside and Tulare surveys, an attempt was made to determine the subjective factors which influence individual motorists in choosing one route or the other.

This information was obtained by having the interviewer asking as a last question

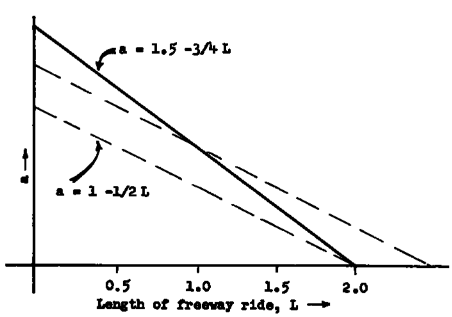


Figure 12.

[1] The time-ratio curve would show 8 percent users. It may have been noted that the question of time or distance ratio vs time or distance difference has been avoided. It is not proposed to open that question here. Good reasons were had for using the difference form.

"Why did you choose the freeway instead of the old road to reach your destination?" The phrasing of the question, of course, depended on the location of the interview station. When the interviewing was on the old road the question was reversed and drivers

ROUTE COMPARISON CARD

TS 91

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Alternate	Trip type	Card No	Between Zones: Low No	Between Zones: High No	No of Trips (year) 1955 ADT	Access Points Used: Low No	A or B	L or R	High No	A or B	L or R	Distance approaching (miles) at Speed 1	at Speed 2	at Speed 3	Distance leaving (miles) at Speed 1	at Speed 2	at Speed 3
X	1		01	15	5,750							4.50					
A	2		01	15		01			02		R				325		
A	3		01	15		01			03		R				1.50		
B	2		01	15		01			02		R				450		
B	3		01	15		01			03		R				175		

NOTES

1. The figures in this form and in form TS 9 2 refer to the example in Fig. 8-321.2. The notes for that figure are also pertinent to this form.

2. Trip type codes are.
   1 - existing system
   2 - "Basic" (non-user) route for comparison with user route.
   3 - Freeway user route.

   Where trip type 2 is identical to trip type 1, trip type 2 need not be shown.

3. Card No. - Where more than one freeway is used additional lines (cards) must be used to describe a routing. Each line or card must be numbered. 1 for the first line, 2 for the second and so on. In the example all routings can be described on one line hence this column is left blank.

4. "Number of trips" need be entered for the existing routing only. The A or B designation need not be entered since the Low number access point will always be A and the High number access point will be B.

5. Three speeds will be allowed for surface street travel. They should be noted on the first page. No particular order in listing routings is required. It may be desirable to list all trip type 3 on one set of sheets, trip type 2's on another and so on.

Figure 13.

were asked why they used the old road instead of the freeway. The interviewers were instructed to leave the question open-ended; that is, not to put answers in the drivers' mouths. The interviewer entered a code number in the appropriate column of the interview sheet depending on the response. The numbers used in the field were:

1. Because of signs
2. Because it's shorter (closer)
3. Because it's faster
4. Have no reason, or don't know
5. Didn't know about freeway or unfamiliar with the area
6. Other (to be written in, time permitting)
7. The only way out.

The interviewers were encouraged to write in as many of the respondents' remarks as possible. In the following analyses the first answer was always used. After the survey other code numbers were assigned to some of the more commonly used reasons and this information was put on punch cards.

The question surprised and seemed to stun a lot of people judging from the number of blank looks. It had one unexpected usefulness in that the driver usually left smiling.

A common reply was an answer which indicated that the driver made a stop in addition to the one he previously gave as his last stop. There would be answers such as "I went this way to get gas" and "To go to the drugstore." This would necessitate changing the last stop on the interview sheet and re-asking the question as to choice of route from the last stop. This type of interview consumed a lot of time and the correct answer to choice of route was not always obtained.

In general, people that used the freeway knew why they went that way and had a ready answer. The people interviewed on the old highway were usually the ones who had to think about why they went that way. The non-users had many varied reasons for choosing their routing in contrast to the few reasons given by freeway users.

In addition to trips discussed in this analysis there were several thousand trips on the Oceanside freeway that were internal trips. That is, they would enter the freeway but leave before they reached the end. These were left out of previous analyses since the non-user portion of the internal traffic was unknown. An interesting occurrence was the high praise the freeway received, especially from the internal traffic on the

TABLE 7

NUMBER OF PEOPLE GIVING VARIOUS REASONS FOR USING EITHER THE FREEWAY ROUTE OR THE OTHER ROUTE (OCEANSIDE-CARLSBAD)

Reasons given when asked why you used the freeway instead of the old road (or vice versa)		Type of trip from engineer's viewpoint: Distance saved via freeway / Time saved via freeway	Over 1/2 mile / Over 5 minutes		Up to 1/2 mile / Up to 5 minutes		Lose up to 1/2 mile / Save more than 2 minutes		Lose more than 1/2 mile / Save up to 2 minutes		Lose both distance and time		Through Traffic (non-stop)		Totals other than through traffic	
		Type of trip from users' and non-users' viewpoints	Obviously save both time and distance	Obviously lose both time and distance	Obviously save time Probably save distance too	Obviously lose time Maybe lose distance too	Lose some distance, but definitely save time	Gain some distance but probably lose time	obviously lose distance Probably save some time	Obviously save distance Maybe lose time	Obviously lose distance Maybe lose time	Obviously save distance Probably save time	Dist fwy. 7 38 / old rd 7 20 / lose 0 18 mi; Time fwy. 8 35 / old rd 14 35 / gain 6 00 min			
			Users	Non-Users	Users	Non-Users	Users	Non-Users	Users	Non-Users	Users	Non-Users	Users	Non-Users	Users	Non-Users
Orientation	1	Signing	0	6	0	3	16	19	2	18	0	160		38		
	2	Only way	4	12	2	20	7	31	3	71	13	775		16		
	3	Best way, logical	3	0	C	0	3	0	0	5	0	6		0		
	4	Required route	2	0	0	0	0	10	2	6	0	5		0		
	5	Habit	0	2	0	0	6	27	0	58	6	58		11		
	6	Meant to stop but didn't	0	0	0	0	0	0	0	0	0	0		2		
	7	See city or scenic	1	10	0	0	0	65	0	62	0	15		168		
	8	Lost or missed freeway	0	2	0	2	3	8	0	11	1	12		31		
	9	Unfamiliar	3	2	0	0	6	63	0	38	4	119		68		
		Subtotal	13	34	2	25	41	223	7	269	24	1,150		334	87	1,701
Distance	10	Shorter	122	31	30	14	86	125	55	245	53	729		23		
	11	Direct Route	2	0	0	0	6	10	2	11	2	34		2		
		Subtotal	124	31	30	14	92	135	57	256	55	763		25	358	1,199
Time	12	Faster	239	8	160	2	405	26	359	54	118	188		21		
	13	Shorter and Faster	34	0	16	0	20	2	12	0	2	0		0		
		Subtotal	273	8	176	2	425	28	371	54	120	188		21	1,365	280
Comfort and Convenience	14	Less Congestion	6	0	5	0	12	0	5	0	2	3		0		
	15	Less Traffic	22	0	7	0	21	5	16	5	6	12		4		
	16	No stops or signals	4	0	3	0	21	0	11	2	2	0		0		
	17	Easier, simpler	3	0	2	0	20	5	5	25	4	38		2		
	18	Convenient, handier	14	0	3	0	5	6	2	16	6	65		6		
	19	Just like it better	3	0	0	0	6	3	3	5	2	0		2		
	20	Safer	9	0	2	0	13	0	9	3	4	0		0		
	21	Better road	4	0	2	0	0	0	5	0	2	6		0		
	22	Don't like freeways	0	0	0	0	0	8	0	10	0	0		6		
		Subtotal	65	0	24	0	98	27	56	66	28	124		20	271	217
Least Cost	23	Cheaper	2	0	0	0	0	0	0	0	0	0		0	2	0
	24	Don't know why	2	16	6	3	8	20	8	31	8	131		15		
	25	Other	5	2	2	0	8	8	11	15	4	36		14		
	26	Didn't ask or interviewer error	55	11	2	25	17	75	1	70	2	145		46		
		Subtotal	62	29	10	28	33	103	20	116	14	312		75	139	588
		Total	539	102	242	69	689	516	511	761	241	2,537	10,860	475	2,222	3,985
		Actual percent usage	85		78		57		40		9		96		36	
		Chart percent usage	90 to 100		60 to 92		60 to 85		35 to 58		0 to 35				42	

freeway. There was almost no adverse comment, except for some that were afraid to drive on the freeway, and some complaining about signing. Many in Oceanside or Carlsbad were trying to find US 395. Many of the non-users even commented on how nice it

TIME AND DISTANCE BETWEEN ACCESS POINTS

Barstow Study   Feb 19 55   TS 92 Page 1 Alternate A

Access points		Distance * (miles)	Time * (minutes)	Access points		Distance * (miles)	Time * (minutes)
Low No	High No			Low No	High No		
01	02	1.35	1.91				
	03	405	497				

* Includes penalty time and distance where applicable

Figure 14.

was to drive on the old road now that the freeway was there. This attitude is in marked contrast to the extreme pressure applied in 1948 to have the freeway built a considerably greater distance to the east of Oceanside and by-pass the city completely. If the Oceanside freeway had been built at that location, there would be no local traffic using it.

The results are given in Table 7. There are six general categories, but the original 26 reasons are reproduced here to avoid unconscious bias on the part of the author.

The table speaks for itself. It is obvious that both time and distance are considered, although it is probable that when both time and distance are favorable to one route, the word "shorter" covers both. The large number of respondents saying "it's the only way" when they would lose both time and distance if they went the other way indicates that a time-ratio curve should come close to showing no usage when the time ratio is greater than 1.0. In fact, except for scattering exceptions, the only people who use a freeway when they lose time are those who mistakenly believe they are saving time (or distance). This "only way" response also indicates that people are map conscious. The most logical way of providing for this phenomenon is to record the extra distance incurred by the round-about route.

ASSIGNMENT PROCEDURE

Data are coded for punched cards unless specific approval for manual tabulation is obtained from Headquarters Traffic Department. The reasons for this are: (a) although it sometimes seems quicker and simper to hand-tally the trips into the few groups necessary for one localized problem, it frequently happens that they need to be regrouped for another alternate or problem; (b) once the data are on cards, much tedious sorting, regrouping, calculating and summation can be done mechanically; (c) machine tabulations provide a systematic way of filing the calculations and furnishing copies where needed. (d) if the machine makes a mistake in handling one item, it makes the same mistake in every item. Additionally, internal checks are usually available in the machine process. On the other hand, spot checks of manual calculations may show that the method is correct, but among hundreds or even thousands of repetitive calculations it is very hard to spot a mistake. (e) Much labor is saved and engineering personnel may be utilized to a better advantage on other needed projects.

For convenience in this discussion, trips will be classified in two categories: users and non-users. Users are defined as those trips who find it desirable to use a proposed freeway line in preference to other routes. Non-users are those who, when they have a choice, decide not to use the freeway. Under certain circumstances, non-users do use short portions of freeway where the old road is obliterated by new construction.

Since upon completion of construction there will be only one plan available to the road user, the question of which trips will use which portions of the proposed plan is answered by comparison with the remaining streets and highways available for travel (not by comparison with alternative plans). The streets and highways available for travel by non-users upon completion of any proposed improvement will be called the basic system. The streets and highways over which the trips are now being made will be called the existing system. The only difference between the existing system and the basic system will be where portions of the existing system are obliterated by the proposed improvement.

Whether based on an O & D survey of any type, or upon other methods of estimating traffic movements, the set of trips is first broken down into transfers between zones, or points of choice. Each transfer is then subject to the following treatment. (a) Time and distance via the existing system are determined; (b) time and distance via basic system are determined; (c) time and distance via Plan A are determined; (d) access points and quadrants for the freeway portion of the transfer are recorded for later summation; (e) based on a comparison of items (b) and (c), a percent usage is determined; (f) the number of users is determined by multiplying the percent usage by the number of trips in the whole transfer. The number of non-users is recorded for later use in the economic comparison. (g) The number of users for this transfer is added to the users for all other transfers having a common access point and quadrant. This is done twice: once for each of the two access points used by any one trip.

Steps (b) to (g) are repeated for each alternate being studied. Steps (f) and (g) are repeated for future traffic if the several transfers have different growth factors.

In order to accomplish the above steps on punch card machines, the original data, consisting of the distance of various speeds for each interzone transfer, are entered on forms T.S. 9.1 and T.S. 9.2 (Figures 13 and 14).

The lettered steps in the preceding paragraph are then accomplished by electric business machines for each interzone transfer, as follows: (a) time and distance via existing system. Distance is key-punched from T.S. 9.1, time is computed according to distance in each speed column; (b) time and distance via basic system (trip type 2).

If this is different from (a), the distance on freeway is picked up by merging corresponding access points with cards T.S. 9.2, then total time and distance via basic system are computed and punched. (c) Time and distance via plan A. The distance on city streets from each zone centroid to and from the freeway is key-punched. Time is computed and punched in electric computing machine. Distance and time on freeway are ganged from merged T.S. 9.2 cards. Total distance and time then computed and punched; (d) access point numbers and quadrants were key punched from T.S. 9.1. (e) A new card is made showing (b) and (c) on same card. p is then computed in electronic calculating machine, using formula. If L on freeway is less than 2.0 miles and p is less than 50, a "modified percent" is computed by second formula; (f) the p or p_1 determined in step (e) is multiplied by number of trips in transfer (this was key-punched from T.S. 9.1). The result is automatically punched in the "freeway card" and marked U (for user). The difference is punched into the "basic card" and marked N (for non-user); (g) cards are sorted down by entry access point and the number of trips entering freeway at each access point is tabulated. Then they are sorted by exit access point and the number of trips exiting at each access point is tabulated. The traffic engineer takes these tables and prepares a flow diagram by algebraic addition of trips entering and leaving freeway at each point.

Since the data are also to be used for economic comparisons of alternate routes, the number of vehicle-miles and vehicle-minutes, both users and non-users, for each alternate is also multiplied out on the electronic calculator, punched, and tabulated in the same tabulations.

Further information, including punch card forms, wiring diagrams and instructions to machine operators, is contained in a "Manual of Procedure for Punched Card Processing of Freeway Traffic Assignment Studies" by the California Division of Highways, Highway Planning Survey (June 29, 1955).

WORK TO BE DONE

Some experimenting with a procedure that does not require hand coding of each transfer, but only each zone, has been done. In a large metropolitan area with several freeways, there are so many access points available to each zone, depending on where the other zone of the transfer is, that it is quite prolix to have the machines select the proper access points for each transfer. It is hoped that this can still be done, however, and at the same time maintain some human control of where the trips go. Physical controls such as bridges and "only route available" situations are hard to systematize for machine processing.

In the Alvarado study, the alternate route used for determining distance and time differences was the "best" city street route, "best" being determined by eyeball inspection of the map. However, in working with the data it was noted that drivers use many routes in going between a given pair of zones. A good method of selecting which street route to use for the basic routing has not been developed. The preferred solution would be to develop an assignment curve which would not compare just two routes, but would compare all available routes and assign a percentage to each. This does not seem very practical, but it is important nonetheless.

When two or three freeway routes are available in addition to the surface street route, our procedure has been: (a) Compute p for each freeway with respect to "eyeball best" surface route. The freeway having highest p is considered the best freeway route. (b) Assign (100 - p) to the surface route, where p is the highest p in step (a). (c) Recompute p for the best freeway with respect to the second-best freeway. Divide the users between the two freeways according to this split. (d) Repeat (c) for best and third best, etc. This procedure is tiresome, complex, and leaves much to be desired. Perhaps the best way is to adopt the practical rules: If it is in a metropolitan area, make it eight lanes. In small areas, the short route is always the best route, and in metropolitan areas the straight routes are the best.

ACKNOWLEDGMENT

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Survey. G.T. McCoy is State Highway Engineer, J.W. Vickrey Deputy State Highway Engineer, and George M. Webb, Traffic Engineer. Special mention is made of the contributions of M.H. West, District Traffic Engineer in the San Diego District, Leonard Newman of the Headquarters Traffic Department, and Sam Osofsky, Walker Ayres, and L.H. Dunigan of the Planning Survey.

References

1. "Assignment of Traffic to Expressways" by J.C. Young. Presented to American Association of State Highway Officials, 1950.

2. "Effect of Travel Time and Distance on Freeway Usage," by D. L. Trueblood, Highway Research Board Bulletin 61, (1952).

3. "Road User Benefit Analyses for Highway Improvements," (Informational Report). Committee on Planning and Design Policies, AASHO (1952).

A Mechanical Method for Assigning Traffic To Expressways

E. WILSON CAMPBELL, Chief Traffic Engineer
Detroit Metropolitan Area Transportation Study

This paper describes the coding techniques and machine procedures worked out to facilitate a rapid assignment o expressways in the Detroit area. Using this assignment method 23,50ſ ;one-to-zone movements were assigned to a network of expressways anc' -›nnecting arterials totaling 375 miles in slightly less than three weeks.

Features of this assignment procedure are that alternate distances can be rapidly and accurately estimated by a machine technique. Second, is a method of treating expressway trips in parts and matching parts together to form trips thus eliminating the necessity of reviewing and coding each zone-to-zone transfer individually. Finally, the adaptability of this procedure to high speed computing and summarizing techniques makes possible a tremendous conservation of time and manpower.

PART I: INTRODUCTION

● TRAFFIC assignment serves several useful purposes. One of the most important of these is in testing new route proposals for their ability to serve the traffic needs of an area. Traffic assignment can provide a very reasonable estimate of the demand for usage of new route proposals. It can point out locations where impossible overloads might develop or where traffic loads are not sufficient to justify expressway or freeway type construction.

Ideally a plan should be based on the traffic pattern developed from origin and destination information. After the plan is carefully worked out then it should be subjected to test by traffic assignment. This test might indicate that some rearrangement of routes is necessary or that new routes should be added or perhaps others dropped from the plan. Based on the test the plan should be revised and then tested again by assignment. This process should be continued within the limits of time until a suitable plan is devised. The best plan from a traffic service standpoint would be the one which served the most trips with more vehicle miles travelled on the routes of the plan (thus relieving existing streets) and had the most even or balanced distribution of traffic loads throughout the system.

This system of testing and revision is highly desirable but it had not been possible in the past due to the time required to complete an assignment. Measurements of distance and time via a proposed and alternate route for each zone-to-zone movement and calculation of ratios and allocation of traffic have been done manually. In addition to the time involved assignment has been subject to considerable human error. In the last decade the summary and tabulation has been mechanized to a certain extent, by the use of electronic tabulation and data processing equipment. Even so, the traffic assignment was still time consuming, tedious and subject to human error which was almost impossible to prevent or detect. In one city even with the aid of electronic data processing equipment the assignment took over a year to complete. The analysis and assignment took so long that the basic traffic pattern was considered outdated due to the rapid suburban growth and increase in vehicle registration.

The Staff of the Detroit Study was faced with the problem of assigning 23,500 transfers between zones (actually over 47,000 zone-to-zone transfers) to over 230 miles of proposed new routes. The time allotted for this job in the work program was six weeks. A manual assignment with an individual inspection of each zone-to-zone movement was out of the question.

To solve the assignment problem a highly mechanized procedure was developed which systematized the coding operation and eliminated many repetitive computations. This procedure made a complete assignment possible within three weeks with a small amount of manual work required. This included all necessary coding, keypunching,

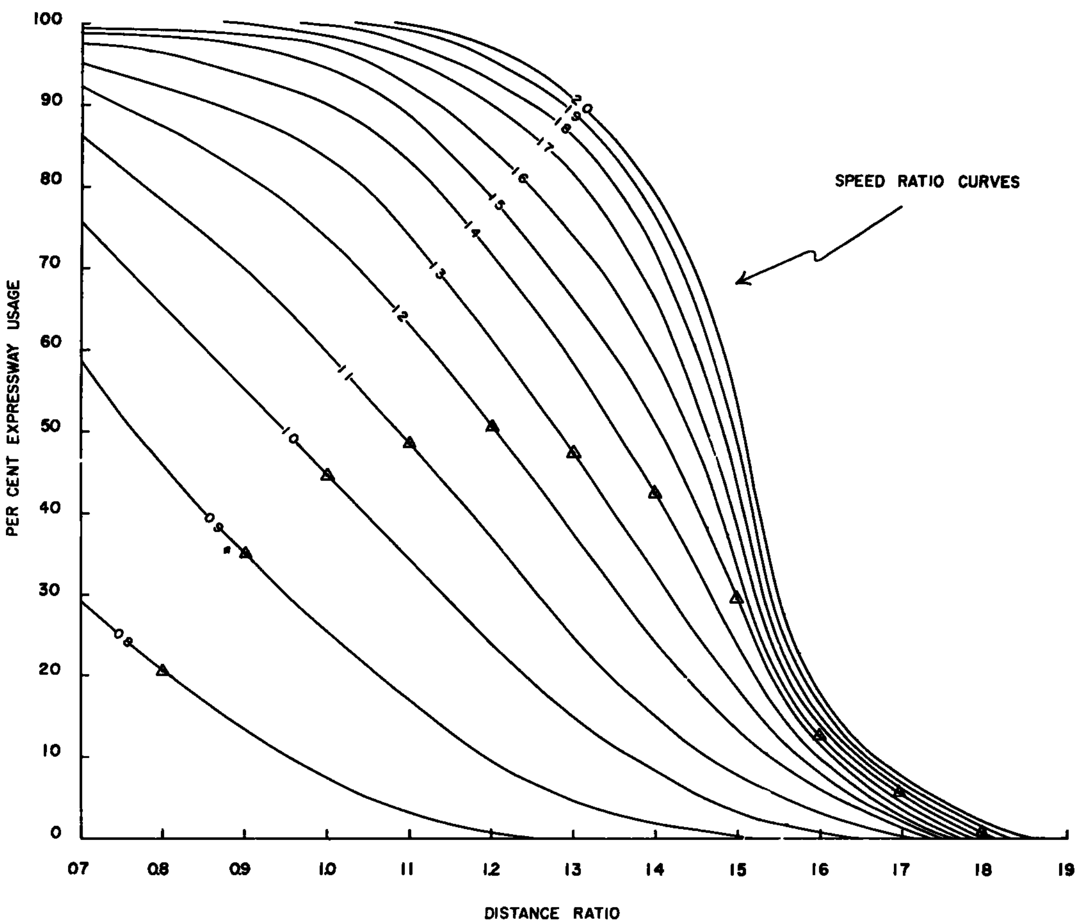


Figure 1. Expressway usage as related to speed and distance ratios.

data processing and tabulation of assigned volumes. The tabulation listed the volumes of all turning movements through every interchange and also the volumes approaching and leaving each leg of all interchanges. The assignment was done for 1953 traffic data as well as 1980 traffic data. While this procedure is highly mechanized it still permits the exercise of engineering judgement in selecting and coding travel routes for all transfers.

The purpose of this report is to present the method of assignment as worked out by the Detroit Staff. The report is organized as follows: Part II presents the basis for the assignment and describes the mechanical procedure in great detail; Part III presents the results and analysis of the assignment including a discussion of assignment versus flow, and suggestions for further research.

PART II: ASSIGNMENT PROCEDURES

Basis for Assignment

The assignment to expressways in Detroit was based on combinations of comparative distance and speed for an expressway and an alternate route. A family of distance and speed-ratio curves previously developed and made the subject of a paper presented at the Highway Research Board in January 1955 (See Bulletin 119, Highway Research Board, Washington, D.C.) was used to allocate trips to expressways. These curves are shown on Figure 1. To utilize these curves, distance and speed-ratios had to be calculated for the alternate and express routes. It was shown in the report referenced above that with an assumption of the ratio of speed on expressways to speed for city street travel the ratio of average speeds could be calculated using only distance measures. The formula for obtaining the overall speed-ratio when a 2:1 ratio of expressway speed to city street speed is assumed is as follows:

$$\text{Speed Ratio} = \frac{\text{Total expressway trip distance}}{\text{One-half of the distance on the expressway} + \text{distance between expressway and zone centers.}}$$

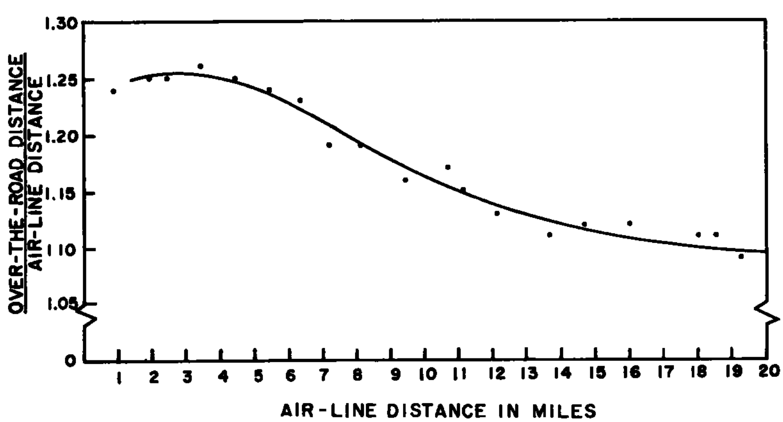
Therefore, both the speed and distance ratios can be calculated using only distance measurements and an assumption of the ratio of speed on expressways to speed on city streets. This assumption of the ratio of speed on expressways to speed on city streets for some future date is just as logical as the assumption of actual speeds and measurement of travel time for individual streets in the future. In addition to being logical this technique eliminated the need for making speed runs over many streets for use in determining travel times.

This method of determining speed and distance-ratios made the basic measurements easier but there was still the problem of comparing two routes for each of the many individual transfers between zones. In Detroit there were 264 analysis zones including 10 external station groups with possibilities of each having interchange with all others. There actually were slightly over 23,500 individual two-way transfers between zones out of the 34,800 possible.

The Approach to the Problem

The approach to the problem of developing a procedure for making a rapid assignment of traffic was one of breaking the problem into its simplest parts and trying to find an answer to each problem in turn. For example, the assignment problem can be broken into three basic parts as follows:

1. Measuring and recording distance for the most convenient (shortest) route of travel via city streets for a traffic volume transfer between two zones.



(PLOTTED POINTS ARE GROUP MEANS BY MILES INCREMENTS)

Source: The Relationship Between Over-The-Road and Geometric Measures of Trip Distance for the Detroit Area. (Detroit Metropolitan Area Traffic Study. 1955).

Figure 2. Comparison of distance factor and airline distance.

2. Measuring and recording distances for the same transfer via a route utilizing expressways. This second step was divided into two parts. First, distances were recorded between zone centers and expressway ramps and second, distances and turning

movements were coded for the expressway route. The distance travelled on the expressway and the distance getting to and from expressways were tabulated separately so speed ratios could be determined.

3. Comparing the route measurements obtained in step 1 and 2 above and the calculation of speed and distance-ratios and from these ratios determining the allocation of trips to expressways. The procedure used in working out each of these problems is detailed below.

Measurement of Alternate Route Distance

This problem was approached with the idea that there is a predictable relationship between "straight line" or "airline" distance between two points and the actual "over-the-road" distance. If the street system were a pure grid then the "over-the-road" distance would be the same or very near the same as the "right-angle" distance. However, streets in the Detroit area were not laid out in a simple grid pattern, and there were many diagonal and radial streets. Therefore, to determine the relationship between "airline" and "over-the-road" distance a random sample of over 200 individual zone-to-zone movements was selected for testing. The "airline" distance was calculated between each pair of zones, and the distance via the best arterial route was measured. From a comparison of "airline" versus "over-the-road" distance the curve shown in Figure 2 was constructed and a mathematical relationship was determined.[1] The relationship had a 0.993 correlation ratio. For the sample used, a very accurate approximation of city street distance was obtained from converting "airline" distance by a factor dependent on the trip length. Therefore, if the "airline" distance between two zones is known, a close approximation of average alternate city street distance can be determined by using this curve.

The question then is how can the "airline" distance be calculated for the various pairs of zones exchanging trips. This problem was solved by overlaying and keying a half-mile grid pattern to the Study Area. Then the coordinates of the geographic center of each zone were determined. "Airline" distance between two zones was calculated by an electronic calculator (IBM604). This distance was simply the hypotenuse of right triangle. Given the coordinates of the zone centers it was a simple calculation for the 604. In the same operation the 604 applied an appropriate factor as determined from Figure 2 to the "airline" distance to approximate the "over-the-road" distance. These distances were punched into the zone to zone transfer cards. (Card 089—see appendix for card layout). This measurement technique made possible a tremendous time saving in calculating city street distance. The 604 does calculations at the rate of 6,000 an hour; so all the distances were determined in less than five hours after the cards were prepared and instructions wired into the 604. The whole process of coding, punching and tabulation takes one person about two days. This again is to compute alternate route distance for all 23,500 transfers.

The second problem was one of tracing and recording a route using expressways for a movement between two zones. The Detroit solution to this problem is described below.

Tracing the Expressway Routing

The expressway routing was an entirely different problem from the alternate routing and its solution was not as simple. Since turning movements and expressway mileage were required for the expressway route it appeared that some manual coding would be necessary. Therefore, efforts were directed toward devising a simple and systematic method of manually coding routes so that a minimum amount would be sufficient. Many zonal pairs have similar routings for a portion of the trip between them. For example, in Figure 3 the route from Zone A to the expressway ramp might be the same when Zone C, D or X is the destination zone. Likewise, the routing over the expressway network might be the same for many pairs of zones. In Figure 2 the route from B to C, D, or X is the same over the expressways as the route from A to these zones. Thus

[1] For complete discussion see "The Relationship Between Over-The-Road and Geometric Measures of Trip Distance for the Detroit Area," 8pp. mimeo., September, 1955.

much of the routing for these six transfers in the example is duplicated. It is possible that a routing between an expressway ramp and a particular zone center could have been used 263 times since there are 263 other zones with which this zone could exchange trips. If sections of routes could be coded once and then used over and over again whenever they appear as part of an expressway trip, the coding would then be much simpler. The foregoing hypothesis provided the basis of the expressway route tracing procedure developed by the staff.

There are three things which should be pointed out for an understanding of the coding system. First, all zone-to-zone transfers used in the assignment are two-way, all-vehicle totals, representing interchange between zones. Second, even though the transfers are two-way totals all traffic was considered to move from west to east. Therefore, for a particular zone-to-zone movement the zone having the smallest X coordinate for its geographic center was always considered as the origin zone. Third, existing individual zone-to-zone transfers were not considered in this coding method. Whole expressway trips from origin to destination were never coded as such. Instead these trips were coded in parts and by a system of master carding and machine matching fashioned together to make a complete trip via the expressway network.

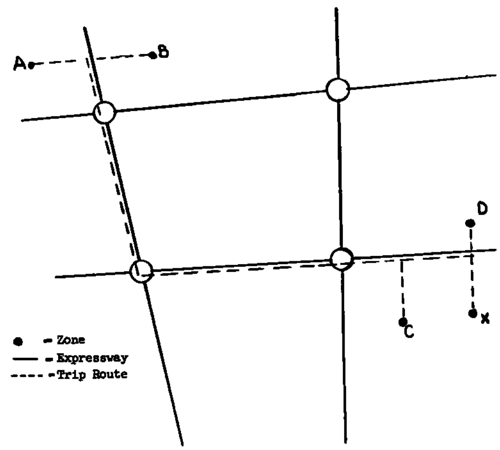


Figure 3. Illustration showing how various zone to zone transfers can have the same trip routing.

The first part involved coding a route and measuring distance between zone centers and the first or last interchange used in getting to or from the zone. The second step was to determine routings between all possible combinations of first and last interchanges. Routings obtained from these two steps are then combined as various zones match together as origins and destinations of trips and the expressway trip is determined.

To illustrate, consider a particular zone and see how the expressway trip would be coded. If this zone is an origin then the destination must be east of it. For a transfer between this zone and zones in a particular sector east of it there will be a particular expressway ramp which would provide the best routing via expressways. These trips, all moving in the same direction will pass through the same first interchange of the expressway network and approach it on the same leg. If this zone is a destination zone the best exit-ramp and the last interchange the trips could pass through could be determined for a group of transfers between it and origins in a specified direction. This routing is done for all zones as origins and again for all zones as destinations and punched into IBM master cards. The second coding operation is to code routing between each interchange and every other interchange so that routings are known between all possible combinations of one interchange used as a first and another used as a last interchange. As part of this coding operation turning movements are recorded for each interchange which lies on the expressway route between the first and last interchange.

To illustrate how the expressway routing is obtained consider a transfer between Zones A and B. Routing from Zone A to the expressway and to the first interchange is given on the master card coded in step one above for A as an origin zone. Likewise the routing from the last interchange to Zone B will be shown on the master card coded for B as a destination in step one. The route on the expressways between the first and last interchanges is determined from the coding in the second step which gives the routing between all interchanges. Controlling on first and last interchange the routing card from step two is matched with the cards from step one to form a complete routing by expressway.

Determining Turns in First and Last Interchanges. Thus far the coding and matching of cards results in obtaining all the information needed for the expressway route except the turns in the first and last interchanges. It should be obvious that these turns cannot be recorded in the original coding of the routings between zones and interchanges, because it is not known which zones will match up to make trips. For a particular zone all transfers will approach the first interchange or leave the last in the same direction, but some may turn right, left, or go straight through depending on what the destination zone is and where the last interchange is. To get around this problem a system of interchange leg codes (called approach and leave codes) and turning movement codes were devised. These codes are different from the usual codings in that the turns can be obtained by adding the approach or leave codes. For example, in Figure 4 a vehicle approaching on leg 1 and leaving on leg 3 must make a 4 turn (1 + 3 = 4). In the same manner any turning movement can be obtained by adding appropriate approach and leave codes. Incidentally, the number 2 was left out of the leg numbering because it would result in two number 5 turning movements (i.e., 1 + 4 and 2 + 3.)

How then does this help in solving the problem of turns in the first and last interchange? In coding the route from origin to first interchange the approach leg number is coded, and in coding the route between last interchange and destination zone the leaving leg of the last interchange is coded. Then in routing trips between first and last interchanges the leaving leg of the first interchange and approach leg of the last interchange are coded. By adding the approach and leaving codes for the first and last interchange, the appropriate turns are obtained.

Use of Travel Direction Code. There is still one other basic step which must be explained. It is true that for zones lying in a particular known direction from an origin or destination one particular route to an expressway ramp and interchange can be picked. Consider again an origin zone. All destinations must be east of it. However, there is a sector of almost 180° from just east of north to just east of south within which these destination zones can fall. It is not likely therefore that there would be only one best route between a zone and an expressway for all trips leaving that zone. To narrow the range of choice of expressway ramps for any zone, all trips were classified into one of eight direction groups depending upon their slope. Although not always necessary this allowed eight choices of route between a zone and the expressway. In coding it was found that for some zones one route served all eight travel directions. Thus, the number of routes and ramp choices needed varied from one to eight with few zones requiring all eight.

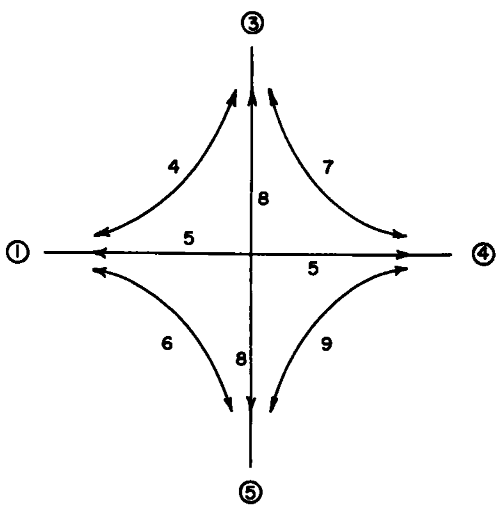


Figure 4.

To summarize, route coding was done abstractly in parts and matched together as various combinations of origins and destinations occurred, to form a complete trip. Routing for all zones between zone center and first expressway interchange is coded for eight possible directions of leaving when the zone is an origin. Each zone is coded in the same manner for possibilities as a destination. Routing between each expressway interchange and every one having a higher number is also coded. All codings are transferred to punched cards and trips are constructed by machine matching of master cards to produce expressway routings for all zone-to-zone combinations. The coding operation for the 264 analysis zones in the Detroit area took about a week and a half, with six people coding. This included a complete recoding as a check. The success of this kind of assignment depends a great deal on the accuracy of coding, since one master card may be used many times and any errors are duplicated each time it is used.

This paper so far has discussed in general the technique of coding and card matching used in assignment. A detailed explanation of the procedure is presented next so that it will be thoroughly understood.

Map Preparation and Expressway Numbering. A necessary first step before the coding can be started is the preparation of maps and coding instruments. Several map

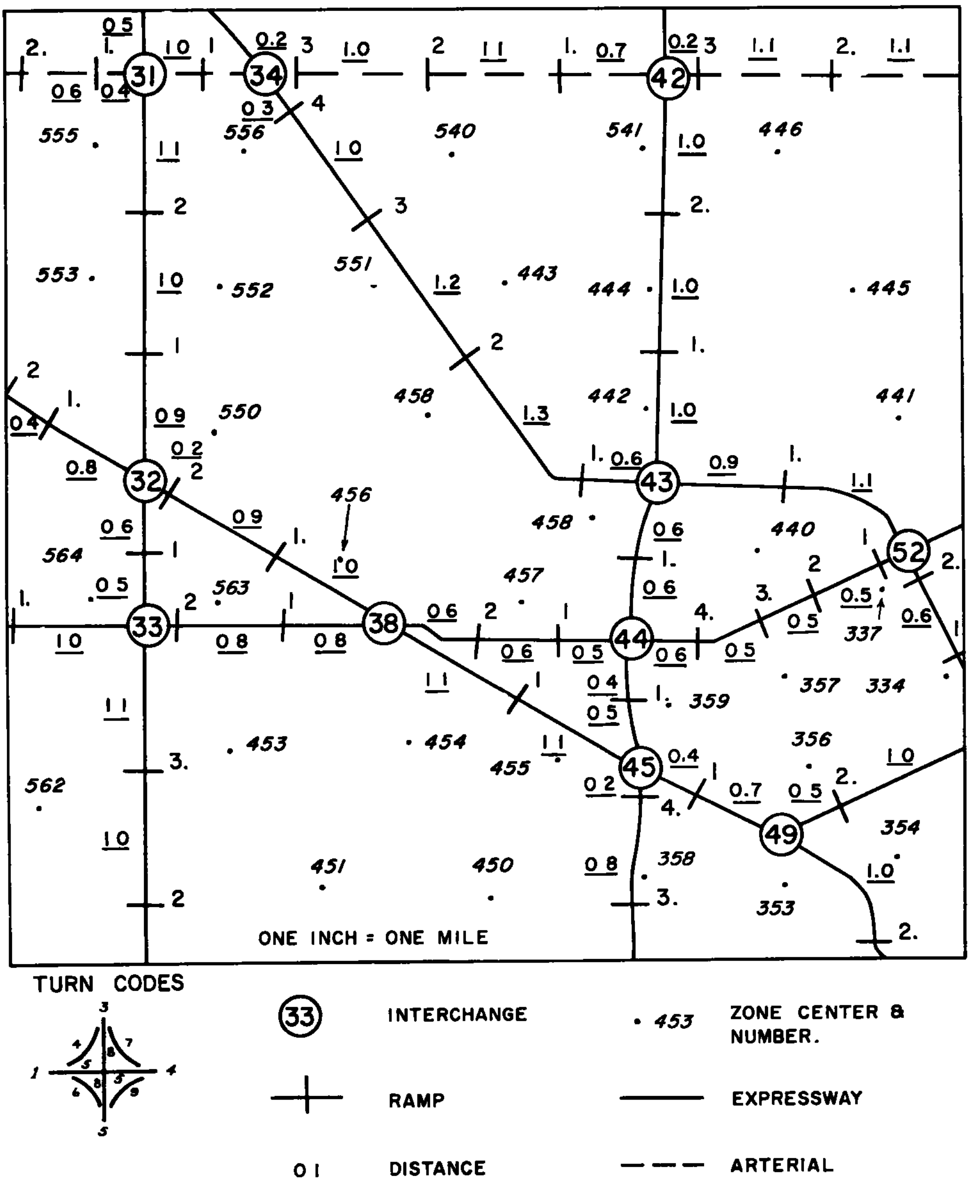


Figure 5. Section of expressway assignment coding map.

preparations are required before one can begin coding. First the proposed expressway network must be plotted and all ramps, interchanges and expressway sections located and designated in a systematic manner for easy reference. Since the street system is not essential to this coding operation, the expressway network can be plotted on a blank overlay, keyed to the street map. When the network has been plotted and interchanges numbered, copies of the map should be reproduced for use in coding the routing between the first and last interchanges. All that is needed for this is the interchange number and the distance between the interchanges. Detail required for coding the routing between expressways and zone centers, can then be plotted on the original tracing. For this map, ramps must be located and numbered and all geographic zone centers plotted and numbered. It would be desirable to show all zone boundaries on this map also. Distances between all ramps and between ramps and interchanges must also be measured and posted. Distances were measured and checked with a map meter.

Figure 5 is an inset from the coding map which was used for assignment in Detroit. The map scale is 1 inch equals 1 mile. This map is identical to the map the Detroit coders used except for two details. First, the zone boundaries were shown on the coders map in light colored pencil. Second, to insure that all coders recorded correct approach and leaving codes for interchanges, the leg numbers of all interchanges were designated with a colored pencil.

The expressway interchanges were numbered from north to south and west to east in sequential number as nearly as possible. Sections between interchanges were designated by the numbers of the interchanges it lay between, always listing the low interchange number first. For example, the section between interchanges 33 and 38 on Figure 5 is designated 3338. Ramps are identified by the section number plus the number of the ramp on the section. On section 3338 there are two ramps designated 33381 an 33382.

One other feature of the map should be explained. The system as shown includes expressways and connecting high type arterials. Expressways are designated by a solid line and the arterials by a dashed line. These connecting arterials were conceived as not quite as good as expressways in terms of service and capacity, but much better than ordinary surface arterials. By traffic engineering techniques and some construction these areterials could be improved to afford much better service than other arterials. To account for the differential service provided, a 10 percent additional increment was added to the arterial distance measures. This added distance increased the distance ratio thus decreasing assignment to arterials as compared to expressways.

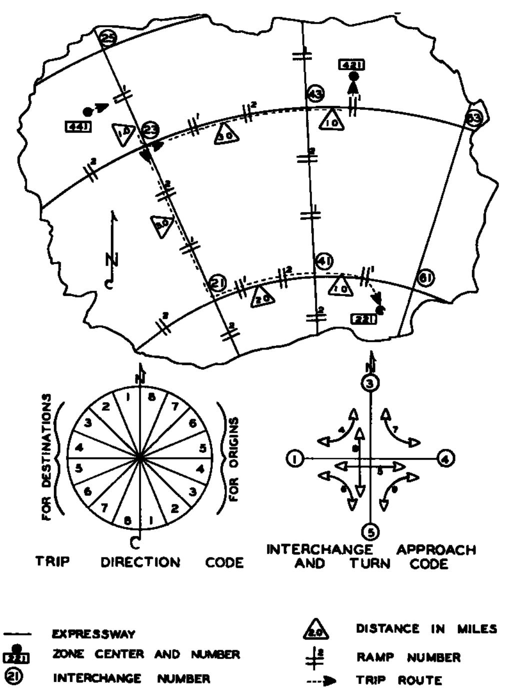


Figure 6. Illustration used to demonstrate trip routing via an expressway.

In addition to the map preparation, it is necessary to prepare a template showing the eight trip direction sectors for origins and destinations. (See Figure 6 and refer to trip direction code). This template is used as a guide by the person coding the routing between zones and expressways. The center of the template is placed over the zone center and the coder can then determine which zones have the possibility of exchanging trips with the zone being coded for any direction of travel. The coder can then select the best route to get to or from the expressway in serving trips between the zone being coded and all other zones falling in the direction sector, for eight direction possibilities.

These preliminary steps are followed by the preparation of Tables 1 and 2.

Preparation of Coding Table 1. The items recorded in the assignment Table 1 are shown below in heading form.

TABLE 1

Zone No.	Zone is O or D	Direction Code	Ramp of Entrance or Exit	Number of First or Last Interchange	Approach or Leaving Code	Airline Distance Zone to Ramp	Dist. Ramp to Interchange

Items are recorded in this table for every zone as an origin and destination possibility and for eight travel directions. This amounts to coding routes between zones and expressways sixteen times for every zone. However, about 70 percent of the coding is duplicated, since routing is often the same for 2 or more travel directions at a particular zone. Coding for origins is done separately and independent of coding for zones as destinations. It is best to have one person code all origin possibilities and another code all destination possibilities. After coding is completed and checked the data should be punched into IBM cards (card 087) and kept as two separate decks, one of origins, the other of destinations.

The first column in Table 1 is zone number. This, of course, is the number of the zone for which the routing is being coded. Zones are taken in rotation by numerical order. A list of zones ranked numerically is a handy check list to insure all zones are coded. In the second column (1) or (2) is entered to indicate that the zone is being considered as an origin (1) or a destination (2). The third column is used to show the travel direction being coded, of the eight possible. It is this step in coding where the template described earlier, is used. The ramp of entrance if the zone is an origin, or ramp of exit if the zone is being considered as a destination is recorded in column four. Column five is used to show the number of the first interchange for origin zones or the last interchange for destination zones. The number of the leg used in approaching the first interchange or in leaving the last interchange is entered in column six. Next the airline distance from the zone to the indicated ramp is entered. This distance in most cases will not be the distance from zone center to ramp, but will be an estimated average distance to the ramp from any place in the zone. Zone boundaries are necessary to obtain an accurate judgment of this distance, and that is why the boundaries are shown on the coding map. The last entry in this table is the distance between the indicated ramp and interchange. This distance is read from the map since distance was previously posted for the expressway system.

The "airline" distance between the zone and ramp (now in card 087) is multiplied by a constant 1.25 factor to convert it to equivalent arterial mileage. This calculation is made by the IBM 604. In addition the 604 adds a constant 0.1 mile to each zone to ramp distance to account for travel on the ramps in getting from surface streets to expressways. This final street distance is punched into the 087 cards.

This completes the coding required to fill in Table 1. The other coding operation is the designation of routing between the first and last interchanges. This routing is recorded in Table 2.

Preparation of Coding Table 2. Table 2 was set up to record the expressway routing and turning movements between the first and last interchanges. The layout of Table 2 is shown below.

TABLE 2

ROUTING OF EXPRESSWAY TRIPS BETWEEN INTERCHANGES

First Interchange	Leaving Code	Last Interchange	Approach Code	INTERCHANGE TURNING MOVEMENTS — Interchange Numbers 1 2 3 4 5 6 7 ... 30 31 32 33	Distance Between Interchanges

Since the first and last interchanges are dependent upon the origin and destination of a trip, any combination of one first interchange with another last interchange may be involved. Therefore, it was necessary to code the route between each interchange and all others. This requires a total of n (n-1) codes where n is the number of interchanges in the system. The actual coding can be cut in half by coding each interchange to all interchanges with higher numbers. The route between any interchange and all other interchanges with lower numbers is obtained by reversing the first and last interchange numbers and approach and leaving codes and duplicating these cards. The routes and turns between interchange 32 and 51 is the same as the route and turns between 51 and 32.

In filling out this table the coder started with the lowest numbered interchange as the first, and coded routes between it and every interchange with a higher number in

TABLE 3

Zone No.	Zone is O or D	Direction Code	Ramp of Entrance or Exit	Number of First or Last Interchange	Approach or Leave	Airline Distance Zone to Ramp	Dist. Ramp to Interchange
441	1	5	23,251	23	3	0.4	1.0
441	1	3	23,251	23	3	0 4	1.0
421	2	5	43,631	43	4	0.4	1.0
221	2	3	41,611	41	4	0.4	1.0

numerical order. Then the interchange with the second highest number was taken as the first interchange and routes between it and every higher numbered interchange coded. This procedure was followed until all interchanges had been considered as a first interchange and routes designated between them and every interchange with a higher number.

The completion of Table 2 was the most difficult of the coding jobs. Nevertheless, three people were able to complete the coding and completely check every code twice in about 7 days. Only two coding errors were uncovered by the second check, and when they were corrected the coding was letter perfect.

Column one in Table 2 is used to record the number of the first interchange. The leg which would be used in leaving the first interchange was coded in column two. Column three was used for recording the number of the last interchange and column four for recording the leg number which would be used in approaching the last interchange. The next group of columns under the heading "Interchange Turning Movements" were used to indicate the movement through any interchange which might be on the expressway route between the first and last interchanges. This is done by entering the appropriate movement number in the column having the same number as the interchange. The last column in the table is used to record the distance on expressways between interchanges.

The basis for determining routing within the expressway system was that all trips were routed over the shortest distance between interchanges. When two routes had the same distance the one having fewer turns was selected.

When all the possible routings have been coded and recorded in Table 2 and completely checked, the information is transferred to IBM cards (No. 088).

With completion of basic coding, one can match any origin zone with any destination, and trace a trip via the expressway, at the same time recording the necessary distances and turns. This procedure is best illustrated with an example.

Examples of Procedure for Tracing an Expressway Trip

Figure 6 represents part of a hypothetical expressway system. Zone 441 in this illustration is an origin and zones 421 and 221 are destinations. A trip from 441 to 421 would fall in travel direction 5 of the eight possible, whereas a trip from 441 to 221 would be in the 3 direction. These zones would have been coded and routings determined for origin and destination possibilities in eight travel directions. For this illustration only the routings for the 5 and 3 travel directions for the respective transfers are needed. Having the zone to zone movements indicated above, the problem is to match the first, middle and last parts of the route together to form a complete trip via expressways. The coding for the three zones as it would have been done in Table 1 is shown in Table 3.

The first and last parts of the expressway trip can be determined from the Table 1 entries. The middle part of the trip must be obtained from Table 2. For this example Table 2 would have been coded as shown in Table 4.

For the transfers between 441 and 421 the following procedure is used in determining the expressway routing. The first entry from Table 1 shown above is matched with the third entry in Table 1. This gives the entrance ramp as 23251 and the exit ramp as 43631. The first interchange the vehicle would pass through would be 23 and the last

TABLE 4

First Interchange	Direction Leaving	Last Interchange	Direction Approach	TURNS THROUGH INTERCHANGE 21	23	41	42	Distance Between Interchange
23	4	43	1	-	-	-	-	3.0
23	5	41	1	7	-	-	-	5.0

would be 43. By comparing entries from Tables 1 and 2 one can see that the vehicles approach 23 from direction 3 and leave in direction 4. Adding the approach and leave codes results in a 7 turn through interchange 23. This would be a turn from the north leg to the east leg which is correct. The vehicles then approach interchange 43 from the 1 direction and leave in the 4 direction. The approach and leaving result in a 5 movement which is a straight through movement from west to east and is the correct movement for this transfer.

For the trip between 441 and 221 the second and fourth entries from Table 1 are matched with the second entry in Table 2. Results of this matching show the first ramp as 23251 and the last as 41611. The first interchange is 23 and the last is 41 and the vehicle passes through 21 with a 7 movement in making the trip. By adding the interchange approach and leaving codes an 8 movement is obtained for interchange 23 and a 5 movement for interchange 41 which are the correct turns.

Distances for both transfers, via expressways, can be obtained by adding the distance from origin zone to entrance ramp, entrance ramp to first interchange, first interchange to last interchange, last interchange to exit ramp and exit ramp to destination zone. The "airline" distance between zones and ramps must be increased by a factor of 1.25 to convert it to arterial mileage and in addition a tenth of a mile added for each ramp.

Now that the procedure for routing and measuring expressway and city street trips has been described, the remaining basic problem is to compare the two routes and allocate a percent of trips to expressways. The solution to this problem is described next.

Method for Comparison of Routes and Allocation of Trips

As stated at the beginning of this chapter, the allocation of trips to expressways was based on combinations of distance and speed ratios. Therefore, these ratios had to be calculated for each group of zone-to-zone trips. The easiest way to make this calculation, utilizing electronic equipment, was to summarize the pertinent route information for the expressway and alternate route onto one punched card. Card number 089 is the card which is used to summarize the route information and to calculate the speed and distance ratios and percent and number of vehicles assigned to expressways. The layout of this card may be seen in the appendix.

The first three columns of card 089 contain the card number. Columns 4 through 19 contain the number of the origin and destination zone and the number of trips between them for 1953 and 1980. Columns 4 through 19 are obtained from the cards used in making the C and D trip transfer tables. The alternate distance columns 20, 21, and 22 are calculated as described earlier in this paper. The "airline" distance and direction code (column 23) were available from a deck of zone-to-zone cards used in making "Trip Desire Charts."[2]

Columns 24 through 36 are obtained by matching the origin columns and trip direction columns on card 089 with the origin and direction code for the 087 origin deck of cards, and transfer-punching the information from card 087 onto card 089.

Columns 37 through 49 are obtained in the same manner by matching the destination and direction codes for the two cards and again transfer-punching the 087 information into the 089 card.

Columns 50 through 54 are obtained as a result of matching the 088 card with the 089 card and transferring information. The control for this matching operation is the first and last interchange number, which appears in both sets of cards. From the 088 cards the distance between the first and last interchange is transferred into columns 50, 51 and 52. The first and last turns recorded in columns 53 and 54 are obtained by adding approach and leave codes for the first and last interchange. The 604 does this automatically after reading one code from one card and the other code from the second card.

At this point all the basic information necessary for calculating speed and distance

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[2] See paper, "Construction of Trip Desire Charts", Detroit Metropolitan Area Traffic Study, June 28, 1955.

ratios has been transferred to the 089 card. Information for the remaining columns on Card 089 is obtained by manipulating data already punched in the card. The next item, distance on the expressway, was obtained by adding distance ramp to interchange (cols. 32, 33, 34), distance interchange to ramp (45, 46, 47), and distance interchange to interchange (50, 51, 52). The total expressway trip is calculated by adding the entry in columns 35, 36 and 48 and 49 which are the distances between zones and ramps, to the distance on the expressway. Distance-ratio is obtained by dividing the total expressway trip distance (cols. 58, 59, 60) by the distance on the alternate (cols. 20, 21, 22). Speed-ratio is determined by dividing the total expressway trip distance by half the distance on the expressway plus the zone-to-ramp distances.

A deck of master cards showing the percent assigned for the various combinations of distance and speed ratios was made up for use in determining the percent assigned for card 089. These cards were match-merged with the 089 cards and the percent assigned, punched into the 089 cards. The 1953 and 1980 vehicles assigned were determined by multiplying the 1953 total transfer (col. 10-14) and the 1980 transfer (col. 15-19) by the percent assigned. This whole procedure except for the initial coding can be done by high speed electronic calculators and tabulators.

After the number of vehicles assigned is calculated and punched into the cards the interchange turns and section volumes can be summarized and plotted on maps. Details of the summarizing procedure can be seen from the step by step machine procedure in the appendix.

Chapter Summary

In this paper the coding techniques and machine procedures worked out by the Detroit Staff to facilitate a rapid machine assignment were presented. The reasoning and approach to the problems were shown and the coding technique and machine procedures were explained in great detail.

Several features contribute to the speed and workability of this system. First, is that alternate distances can be rapidly and accurately estimated by a machine technique. Second, is that the concept of treating an expressway trip in parts and matching parts together to form trips eliminates the necessity of reviewing each zone to zone transfer and makes coding vastly simpler. Finally, the adaptability of this procedure to high speed computing and summarizing makes possible a tremendous conservation of time.

One hundred zone-to-zone transfers were pulled at random to check the expressway routing, resulting from the coding and matching technique. The 100 transfers were coded for the best expressway route and compared to the routing which resulted from this assignment procedure. Less than five percent of the routings were different. Even for the ones which differed, the percent assigned was only slightly different. Therefore, it appears that this procedure is not only fast but accurate as well.

Using this assignment method 23,500 zone to zone transfers were assigned to a network of expressways and connecting arterials in the Detroit Metropolitan Area totaling 370 miles in slightly less than three weeks.

PART III: RESULTS AND ANALYSIS OF ASSIGNMENT

Need for Two-Variable Assignment Curves

After the assignment in Detroit was completed, it was possible to summarize the distance and speed-ratios which occurred. Figure 7 illustrates the range of speed and distance-ratios which were obtained. The unshaded areas are ones where speed and distance-ratios did not occur. Values of speed and distance-ratios were obtained throughout the shaded area. This pretty clearly shows the range of possible distance and speed-ratio combinations and demonstrated the need for a two-variable solution to the assignment problem.

Table 5 gives a comparison of the assignment using the speed and distance-ratio-curves to the assignment using curves developed for the Shirley Highway.[3] This com-

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[3] Trueblood, Darel L., "Effect of Travel Time and Distance on Freeway Usage". Bulletin 61, Highway Research Board, Washington, D.C.

parison was made possible by converting all the various combinations of distance and speed-ratio to equivalent time-ratios. Equivalent time-ratio is determined by dividing distance-ratio by speed-ratio. Trips were then summarized by equivalent time-ratios showing total assigned and total trips for 1953 and 1980. Knowing the total trips for each time-ratio it was possible to apply assignment percentages based on the Shirley time-ratio curve, and thus determine the amount of trips which would have been assigned by the Shirley time-ratio curve.

From Table 5 it can be seen that the total trips assigned by the distance-speed-ratio curves was 1,534,914. The Shirley curve assigned 96,774 more to make a total

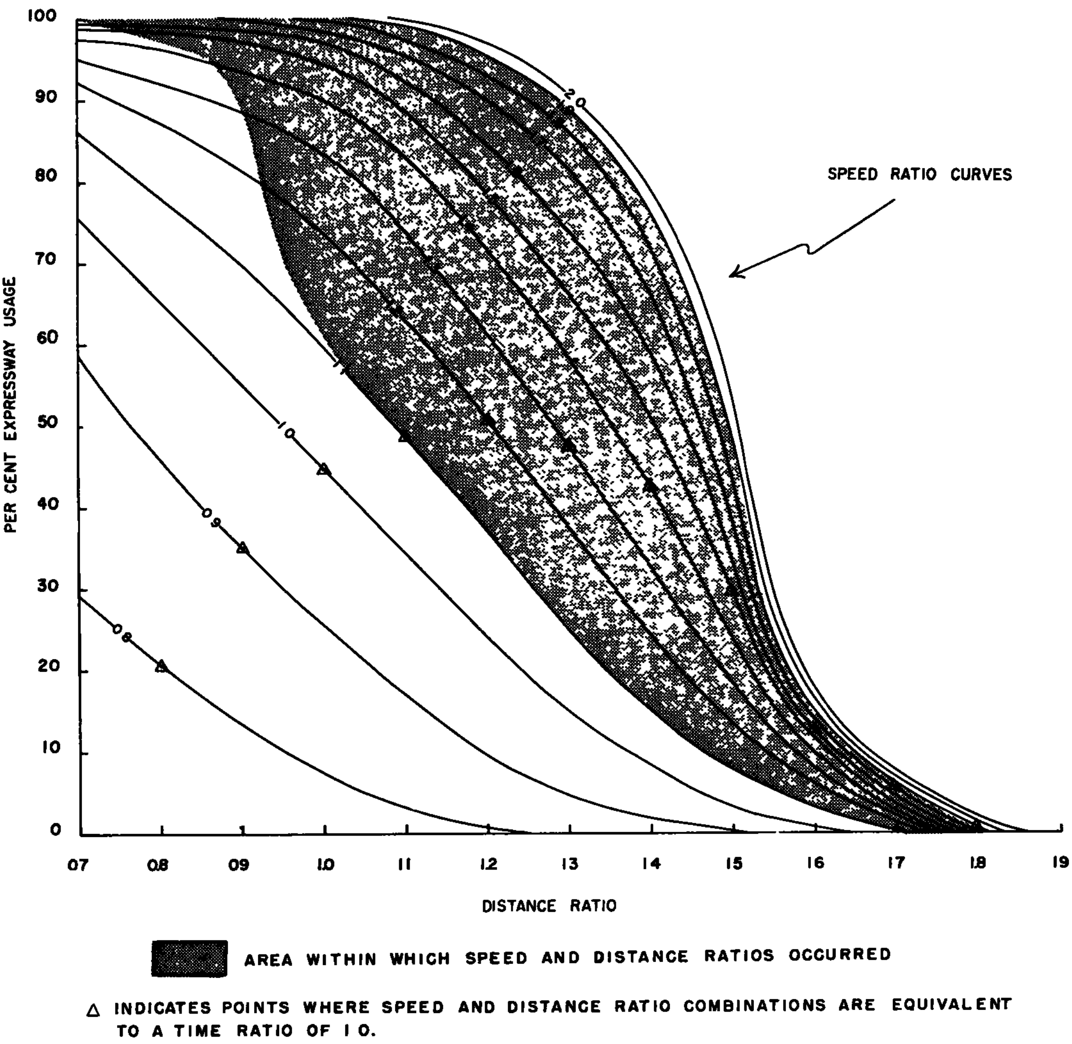


Figure 7. Expressway usage as related to speed and distance ratios.

of 1,631,688 trips. The difference in total assignment is not critical. However, the difference in the number assigned for certain individual time-ratios is critical. Assignment by the two curves was very close for time-ratios up through 0.8. However, for time-ratios higher than 0.9 the Shirley curve assigned much higher percentage-wise. At a time-ratio of 0.9 the Shirley curve assigned 13.9 percent higher; for time ratios of 1.0 it assigned 40.5 percent more and at 1.1 it assigned 98 percent more. From ratios of 1.2 and above the assignment was more than doubled by using the single-variable time-ratio curve. It is true that more than half of the transfers had time-ratios less than 0.9. However, there is still a substantial difference in the number assigned for time ratios of 1.0 and 1.1.

The apparent reason for this differential in assignment is that equivalent time-ratios of 1.0, 1.1, etc. are the result of combinations of high distance and speed-ratios as well as low ones. A low assignment would be expected for these combinations involving high distance-ratios. The Shirley time-ratio curve or any time-ratio curve cannot take these variations into account since it can only assign one value for every time-ratio and this value represents a mean based on the characteristics of trips found in the Shirley Study. The Shirley trips involved slower speeds and smaller distance disadvantages for time-ratios of 1.0 and higher; therefore, its proportinate use should be higher.

The expressway network designed for the Detroit Area afforded a definite time advantage for the average trip assigned. The mean time-ratio was 0.76. Most of the

TABLE 5

COMPARISON OF ASSIGNMENT BY SPEED AND DISTANCE-RATIO CURVES TO ASSIGNMENT BY SHIRLEY TIME-RATIO CURVE

Time Ratio	1953 Total Trips	Number Assigned by Speed-Distance	Number Assigned by Shirley Curve	Difference	Percent of Difference
0.4	159	157	159	+ 2	1.3
0.5	51,912	51,377	50,874	- 503	1.0
0.6	422,047	409,297	400,945	- 8,352	2.0
0.7	443,671	402,715	385,994	- 16,721	4.2
0.8	455,059	350,114	350,395	+ 281	0.8
0.9	316,352	172,130	196,138	+ 24,008	13.9
1.0	283,651	96,933	136,152	+ 39,219	40.5
1.1	185,042	30,841	61,064	+ 30,223	98.0
1.2	143,156	14,762	30,063	+ 15,301	103.7
1.3	112,487	5,120	13,498	+ 8,378	163.6
1.4	47,235	1,334	3,779	+ 2,445	183.3
1.5	62,451	134	2,498	+ 2,364	1,764.2
1.6	5,544	0	111	+ 111	- -
1.7	1,842	0	18	+ 18	- -
TOTAL		1,534,914	1,631,688	96,774	

trips fell in the range where they had high assignment by both the speed-distance-ratio curves and the time-ratio curve. The fact that most of the trips fell in this range was due to the high speed-ratios obtained. The high speed-ratios were due to the layout of the expressway network, which made it possible for a large portion of the average trip via expressways to be on the expressway itself. The assumption of a 2:1 ratio between expressway and city street speeds was also a factor.

Assignment to an expressway network, having more trips in the high distance-high speed-ratio ranges, would be quite a bit higher using the time-ratio curve as opposed to the distance-speed-ratio curves. These kinds of speed and distance-ratios would be possible in a network which, due to its high speed potential, caused trips to divert from greater distances, thus causing high distance and speed-ratios. Since it is almost impossible to determine the kind and range of trips which will occur in a given expressway network, it seems logical to use a series of curves which are flexible and can take a greater range of activities into account. Such are the distance-speed-ratio curves.

Assignment vs. Flow

Traffic assignment does not always provide the planner with an accurate description of flows on expressways. Actual flows are dependent upon capacity. It is possible that volumes could be assigned to an expressway which could not possibly be handled, due to capacity limitations. Therefore, assignment and flow are not necessarily synonomous.

Even though flows are not always accurately predicted, traffic assignment provides the planner with the kind of information he is seeking. For example, a good approximation of expressway demand, if each trip could be made on most convenient route, is obtained. The demand based on any criteria can be estimated with reasonable accuracy. In general the traffic assignment provides the planner with a tool which can be used to test the effectiveness of a plan from the standpoint of traffic service. For example an assignment of very high loads might indicate a defect in the plan which could be better corrected by adding another expressway or a shift in location rather than the addition of more lanes. An assignment of small volume raises a doubt as to the necessity of providing the amount of capacity in the plan.

Traffic assignment was a very useful tool in arriving at a final expressway plan for the Detroit Area. One plan was devised and tested by assignment. The assigned traffic resulted in some impossible over-loads and a general uneven distribution of the traffic load. Based on the assignment a new plan was devised and tested. The second plan proved much better than the first. The assigned loads were more evenly distributed and 200,000 more trips (9.2 percent more) were carried. The total vehicle mileage travelled by all trips in the area was almost identical for both plans. Therefore, based on the information gained from the traffic assignment a plan was devised which carried more trips, distributed the load more evenly and kept the total vehicle miles the same and with only a slight addition in the expressway mileage of the system. Based on the second assignment a few minor changes were made and a final plan was laid out. The process of assignment, plan revision, reassignment and final revision required about four months.

Suggestions for Additional Research and Development

Some additional work is necessary to determine whether or not the speed and distance-ratio curves have universal application. Exploration might reveal other variables which could serve as a better predictor of expressway use. Refinement of the assignment procedure through improved coding and machine techniques would be desirable.

A real contribution could be made with the development of basic flow theories, so that traffic flow could be simulated. A field barely touched awaits the researcher in traffic simulation with high speed computors. A traffic simulation model would be very useful in estimating flows on arterial streets, under different and changing conditions. It seems entirely possible that a model could be developed whereby flows could be estimated on an expressway and street system at the same time. By changing the locations or capacities of proposed facilities the whole traffic load would be automatically and instantaneously rearranged. With this kind of a model and a given set of traffic requirements the effects of alternate kinds of solutions can be determined and weighed. Solutions to problems of this order have already been worked out for hydraulic systems and electrical networks. Some experimentation and research along these lines might prove profitable in developing a flow theory for urban traffic volumes.

It is true that this kind of approach to urban traffic is for the future but how long in the future depends upon the curiosity and ingenuity of the researcher.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the Policy Committee of the Detroit Metropolitan Area Traffic Study for permitting him to prepare this paper. He also wishes to thank the many persons who helped and advised him in its preparation, particularly J. Douglas Carroll, Jr., Director of the Study, Darel Trueblood of the Bureau of Public Roads, and M. Earl Campbell of the Highway Research Board. The assistance of Robert Vanderford, Tabulation Supervisor for the Study in working out the details of the assignment procedure is also gratefully acknowledged.

Appendix

Step by Step Machine Procedures

Robert E. Vanderford

From previous procedures there should be available a set of cards with the inter-zonal traffic at present volumes and expected volumes at some future date - in this case, 1953 and 1980. The street distance from zone center to zone center must be punched in the cards along with the code for direction travel. Following is a step by step outline of the machine procedure:

1. Sort the inter-zone cards (089) to direction within zone of origin and selective merge behind zone to ramp master cards (087).
2. Intersperse gang punch ramp number, first interchange, approach code, distance ramp to interchange, and distance zone to ramp.
3. Sort the inter-zone cards (089) to direction within zone of destination and selective merge behind ramp to zone master cards (087).
4. Intersperse gang punch ramp number, last interchange, leave code, distance-interchange to ramp, and distance ramp to zone.
5. Run inter-zone cards (089) through collator pulling all cards where section (first four digits of ramp) of origin equals section of destination. Run equal section cards through again pulling equal ramps. Discard equal ramps as non-expressway trips. Hold equal section cards for step No. 13.
6. Sort the inter-zone (089) cards to last interchange within first interchange and selective merge behind interchange to interchange master cards (088). The unmatched are set aside.
7. Intersperse gang punch distance interchange to interchange into inter-zone cards (089) using the 604 Electronic Calculator. On the same pass, add first interchange leave code from the master card (088) to first interchange approach code from the inter-zone card (089). Punch as first interchange turn code into the inter-zone cards. Add last interchange approach code from the master card (088) to last interchange leave code from the inter-zone card (089). Punch as last interchange turn code into the inter-zone cards (089).
8. Check unmatched from Step No. 6 to make sure that first and last interchanges are the same. Put through 604 and add first interchange approach to last interchange leave. Punch as first interchange turn. As the trip passes through only one interchange, distance-interchange to interchange, the last interchange turn are left blank.
9. Because the expressway system is quite complex there are trips that double back at the first or last interchange, as a result to the coding and matching procedure. One example of these is shown in Figure A.

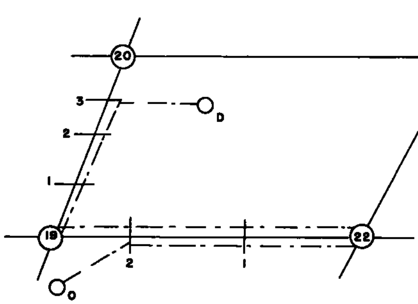


Figure A.

In coding O as an origin for the travel direction of a trip between O and D, ramp 19223 would be selected and 22 would be coded as the first interchange. The coding for D as a destination in this travel direction would show ramp 19203 as the last ramp and 19 the last interchange. Matching with an interchange routing card would result in the section between ramp 19223 and interchange 22 being duplicated in the trip. These double-back trips can easily be detected because the approach and leave codes for interchange 22 are the same, or to say it another way, the turn in interchange 22 is double the approach or leave code. Therefore, sort all inter-zone cards, except equal-section, on first turn. The two's and ten's are obviously doubled back. The five's, seven's and nine's cannot be doubled. Since there is no approach code two, there will not be any doubled back trips in the four's.

There are other kinds of doubled back trips but they are all detected by sorting on the turns and checking to see if the turn is twice the approach or leaving code.

10. All doubled back at origin trips should be reproduced using the opposite first interchange and approach from the one punched in the card. First turn code and distance interchange to interchange must be dropped and repunched as in step No. 6, using the new first and last interchange.

11. All inter-zone cards must be put through steps 9 and 10 again for last interchange turn and leave code and doubled at destination trips corrected. Less than 2 percent of the trips will have portions doubled back.

12. After all doubled back trips have been corrected, all inter-zone cards except equal section trips are put through the 604. Distance ramp to interchange, distance interchange to interchange, and distance interchange to ramp are totaled and punched as distance on expressway. On the same pass distance zone to ramp, and distance ramp to zone are added to distance on expressway and punched as total expressway trip.

13. Sort the equal section cards from step No. 5 the last interchange within first interchange. Selective merge behind interchange to interchange master cards. Set unmatched aside.

14. Put merged cards from above through 604. Add distance ramp to interchange to distance-interchange to ramp from the equal section card. Subtract distance-interchange to interchange and change sign to plus if answer is negative. Punch as expressway distance. Add distance-zone to ramp and distance-ramp to zone to expressway distance and punch as total expressway trip.

15. Put unmatched from step No. 13 through 604. Subtract distance-ramp to interchange from distance-interchange to ramp. Change sign to plus if negative and punch as expressway distance. Add distance-zone to ramp and distance-ramp to zone to expressway distance and punch as total expressway trip.

16. Put all inter-zone cards from steps 12, 14 and 15 through 604. Divide total expressway trip by distance on alternate route. Carry result to two decimal positions and punch as distance-ratio. Divide total expressway trip by one half the expressway distance plus the zone to ramp and ramp to zone distances. Carry result to one decimal position. Punch as speed-ratio.

17. Sort above cards to speed-ratio within distance-ratio and merge behind percent assignment master cards.

18. Make a 604 pass intersperse gang punching percent assignment and extending 1953 and 1980 traffic volumes in each card by percent assignment. Punch as 1953 and 1980 vehicles assigned.

19. Summarize interchange turns and section and ramp volumes. Sort first turn within first interchange. Blanks in first turn are held for ramp summary.

20. Cut a summary card for each turn at each interchange with 1953 and 1980 volumes assigned.

21. Sort inter-zone cards from above to last turn within last interchange. Blanks in last turn are set aside for ramp summary.

22. Cut a summary card for each turn at each interchange with 1953 and 1980 volumes assigned.

23. Sort inter-zone cards from above to last interchange within first interchange.

24. Cut a summary card for each pair of interchanges. Set inter-zone cards aside for ramp summary.

25. Sort interchange to interchange master cards to last interchange within first interchange. Match against interchange pair summary cards from step No. 24.

26. Reproduce 1953 and 1980 assigned volumes from interchange pair summary cards into matching interchange to interchange master cards.

27. Sort interchange to interchange master cards on the column reserved for turns through the lowest numbered interchange, in this case, column 20. Cut a summary card for each turn code showing interchange number, turn code, 1953 and 1980 vehicles. Use 604 or 402-519.

28. Sort on next interchange, column 21. Cut summary cards as above.

29. Continue above until last column in interchange to interchange card has been sorted and summarized.

30. Combine summary cards from above with summary cards from steps 20 and 22. Sort to turn code within interchange number.

31. Run a tabulation showing interchange number, turn code, and total vehicles assigned 1953 and 1980. Post figures to map of expressway system.

32. Sort all inter-zone cards to interchange approach code within ramp of origin.

33. Cut a summary card for each approach code at each ramp. Show 1953 and 1980 assigned vehicles.

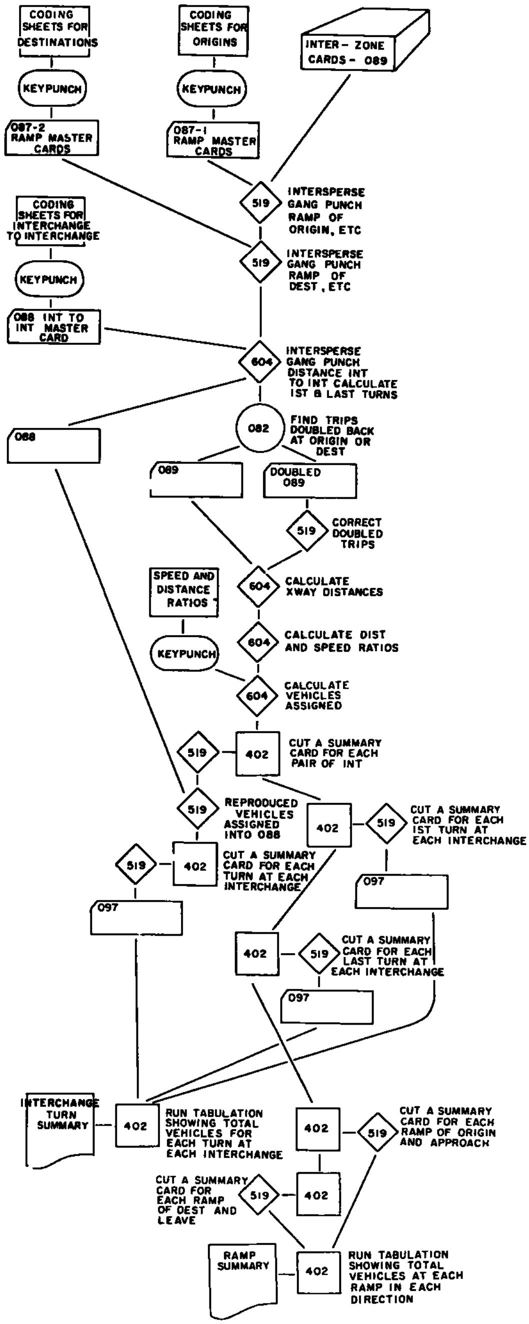
34. Sort all inter-zone cards from above to interchange leave code within ramp of destination.

35. Cut summary cards as in step 33.

36. Combine summary cards from steps 33 and 35. Sort the approach-leave code within ramp number.

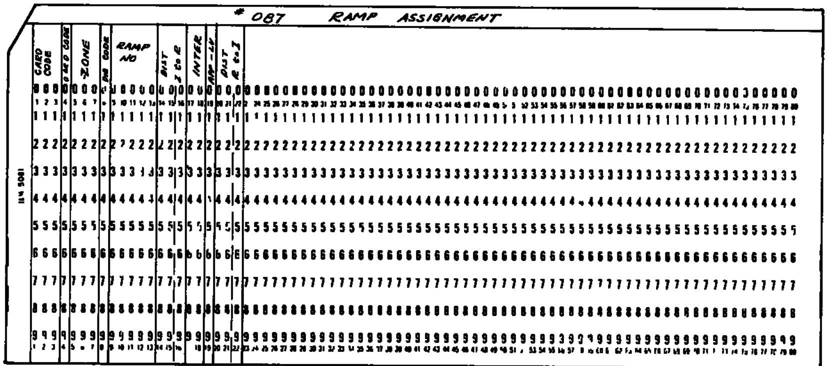
37. Run a tabulation showing ramp number, approach-leave code, 1953 and 1980 vehicles assigned. Post figures to map of expressway system.

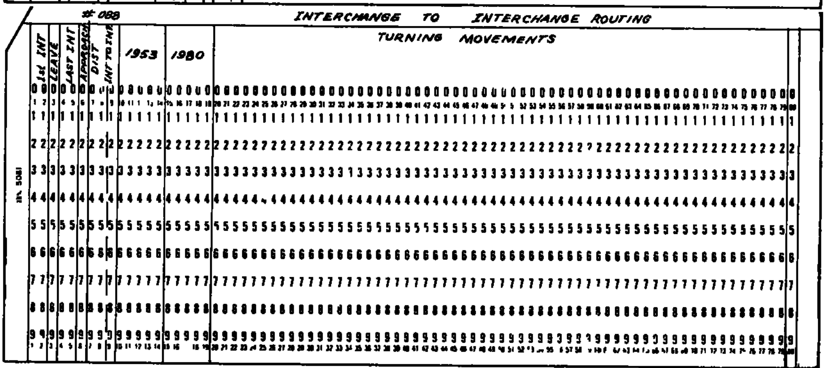
Flow Diagram for Machine Traffic Assignment

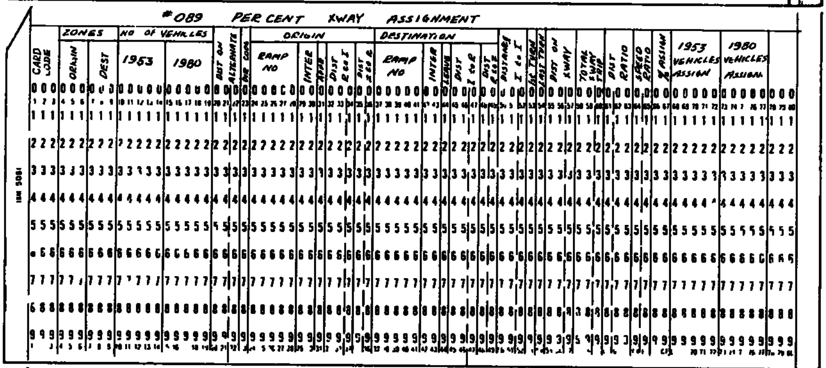


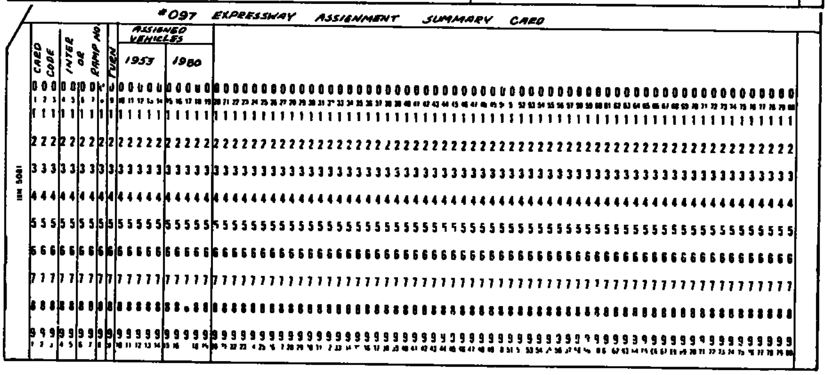
EXPRESSWAY ASSIGNMENT FLOW DIAGRAM

Card Layouts









Traffic Assignment Using IBM Computations And Summation

R. M. BROWN, and
H. H. WEAVER, Indiana State Highway Department

Any traffic assignment problem from orgin -destination data involves two basic operations: the determination of the percent of usage for each of two more routes for each separate O-D movement and the summation of a usage for each segment of each route. IBM machines can remove the dudgery and human errors from both of these operations. Given the governing criteria in numeric values and the computation formulas to apply to these criteria, they can make the computations with amazing speed and almost infallible accuracy. They cannot, however, exercise engineering judgment nor can they get right answers from erroneous criteria.

This report deals with the probable distribution of traffic on the arterial street systems of Lafayette and West Lafayette, Indiana which could be expected to follow the construction of a new bridge across the Wabash River.

River crossings were assigned to the new and present bridges by a formula of our own development using both the time ratio between terminals via the new bridge and whichever of the present bridges now carries the largest segment of the specific movement and the present ratio of usage of existing bridges by that movement.

All movements within or through the area on either side of the river (including river crossings) were assigned to the arterial street system on the basis of the time ratio between points of choice via the two most reasonable yet substantially different routes.

Assigned volumes to each segment of the arterial street systems were developed from suitable summary and tabulation of the computed cards.

● ANY problem of traffic assignment, from origin-destination data, involves two principal operations. First is the basic individual assignment, or numeric distribution, of each O-D movement to the routes of choice available to that movement. Second is the summation of these individual assignments in terms of total flow on each segment of each route and of turning movements at principal intersections.

IBM machines can remove the drudgery and human errors from both of these operations. Given the governing criteria in numeric values and codes, and the "instructions" as to the use of those values and codes, they can make the computations with amazing speed and almost infallible accuracy.

The "instructions" to the machine evolve from prior decisions of engineering judgment and proceedural detail. Those decisions include:

1. Selection of the basis for comparison of one route with another. Will it be travel-time, distance, weighted combination, or others?
2. Maximum number of routes of choice to be considered for any one movement.
3. The mathematical formula for application to the selected criteria to determine route usage ratios.
4. The statistical-card layout that will provide for most efficient performance of the several proceedural steps of assignment and summation.

With those of us who work with traffic assignment, there remains minor uncertainty and difference of opinion as to the relative effect of travel-time, distance and other factors on the driver's choice of routes. Each assignment problem involves special conditions of facility and traffic characteristics. The nature and extent of factual data available to the assignment engineer is not always the same. For these reasons, it would be presumptuous for us to describe one single assignment procedure and say, "This is it", for any and all circumstances. Rather we propose to narrate what was actually done in one assignment problem; what compromises were made between precision and expedience, and what conclusions were reached as to the end result.

The Situation

For this purpose we have chosen our Lafayette - West Lafayette traffic survey of 1952. This was not a large study, as O-D surveys go (metropolitan population of about 50,000), but it is the one on which our most comprehensive, and most extensively mechanized, traffic assignment operation was performed. Lafayette, the business and industrial city, and West Lafayette, the university city, are separated by the Wabash River.

There now exists two good bridges across the river. The Main Street bridge is centrally located at the west edge of the Lafayette business district and leads directly to the south part of the Purdue University Campus. The US 52 by-pass bridge is about two miles upstream at the extreme north edge of the urban area. A third bridge, Brown Street, is quite close to the Main Street bridge. It is structurally obsolete with a very low load limit. Its location is unsuitable for a replacement structure.

The major highway of the area is US 52, the Indianapolis-Chicago route. It is a dual highway to the northwest and southeast and skirts the north and east edges of the urban area on a two-lane by-pass. The east leg of this by-pass has degenerated to complete inadequacy for its primary function from lack of entrance control in the development of abutting property.

The analysis of our O-D Survey showed the need for two major unrelated facilities and their respective connections, as well as other improvements of lesser importance.

A new bridge was proposed at a site six blocks north of Main Street. Its east approa would be a one-way pair of existing streets extending eastward. This approach would be connected with a one-way pair southward to and across the business district for highway connections to the south. Its west approach would be a new four lane facility leading to a one-way pair of existing streets and thence to the north part of the Purdue Campus. This approach would connect, via improved existing streets, with US 52 to the northwest to divert traffic, between that highway and the Lafayette business district, from its present route alongside the Campus.

Relocation of the US 52 by-pass as a dual highway was proposed on a line one-half mile east of the present east leg and meeting approximately the present alignment near the northeast corner of the area.

State route 43 now enters the area from the north on the West Lafayette side, crosse the river at Main Street and thence proceeds southward to the area limits. A relocation of this highway north of the city was proposed from a point about three miles north of US 52 to enter and traverse the urban area entirely on the east side of the river. This relocation would shorten the route and, more important, would permit direct interchange with US 52 which is not now possible because of the terrain of the present route.

The Assignment Problem and Available Data

The assignment problem was to determine the redistribution of traffic, not only on the proposed and improved facilities, but also on the entire arterial street system of the urban area and the highway approaches at its perimeter. It was also desired to deter mine turning movements at all important intersections, and to handle SR 43 movements in such a way as to trace the effect of its relocation throughout the entire pattern.

The survey data available for application to the problem included:

1. O-D survey summary cards in which were punched, (a) terminal codes of the movement (Points of perimeter crossing were coded as terminals), (b) trips between terminals by vehicle type, direction and total, (c) distance between terminals, (d) travel-time between terminals.

2. Travel-time data on sufficient numbers and kinds of arterial streets and highways to permit reasonable projection to the whole.

3. Travel-time contour maps centered on each present and proposed bridge (except the Brown Street bridge which, for assignment purposes, was considered identical with the Main Street bridge.)

4. Tabulations of screen line (Wabash River) interviews showing the number of each O-D movement crossing at each existing bridge.

The Assignment Operation

The total trips, terminal codes, travel-time for each movement within or through the area and other data had previously been reproduced from the survey summary cards to standard 27-column mark-sense cards (card columns 1-42). These cards, which were used for two unrelated purposes, were titled "Major Desire Line and Bridge Assignment Cards". (See Appendix — Figure "A"). The cards were first used for major desire line development (mark-sense columns 1-6 and punch columns 43-48).

A manual analysis and reassignment for the relocation of SR 43 to the north was made. A second assignment card was prepared for each movement which would be increased or decreased by this proposed relocation. These cards were identified for mechanical distinction from the main or regular deck.

The first step of the primary assignment operation was the redistribution of river-crossing movements to the proposed and existing bridges, a three way choice. It was decided to make the assignment on the basis of the travel-time between terminals, comparing the route via the proposed bridge with that via the existing bridge now carrying the greater portion of the specific movement. This comparison would fix the ratio of usage between the proposed and the presently most used bridge for that movement. The completion of the three-way assignment depended upon our hypothesis that, no matter what portion of a total movement is diverted to a new facility, the residue of that movement will continue to divide itself over existing facilities in the same ratios as the total movement was previously divided.

The mechanics of this assignment involved:

1. Selection of the cards of river crossing movements.
2. Mark-sense coding of travel-time between terminals via the proposed bridge.
3. Mark-sense coding of the present usage-factor for the bridge now most used by that movement and the identification code for that bridge.
4. Mark-sense punching of these items. (Punch columns 49-55).
5. Computation and punching of the distribution of the movement to the three bridges of choice. This was done in two passages through the computer at 100 cards per minute (two more passages for checking). The separate steps within the computation included: (a) compute (and punch in 56-58) the usage-factor for the proposed bridge from a formula using the two travel-time values and the present usage-factor of the best alternate bridge. (b) This usage-factor was applied to total trips to determine (and punch in 59-62) the number of trips assigned to the new bridge. (c) The usage-factor of the best alternate bridge was applied to trip residue to determine and punch the trips assigned to that bridge. (d) The residue then remaining was punched and assigned to the second alternate bridge.

The second step of the primary assignment was the distribution of all trips, both river-crossings and non-crossings, to the arterial street systems on each side of the river. For this operation certain decisions of judgment and choices between precision and expedience were necessary. Those decisions and choices were:

1. The three bridges, to which assignments were made in the first step, would be treated as terminals and each river-crossing trip would thus become two trips, one on each side of the river.
2. Not more than two routes of choice, one the fastest reasonable route and the other the fastest yet substantially different alternate, would be considered for any one movement.
3. Assignment would be based on travel-time between points of choice.

In addition to these decisions and choices, certain mechanical and manual preparations were necessary prior to the actual assignment task:

1. A second assignment-card layout titled, "Traffic Assignment — Arterial Streets", (See Appendix — Figure "B") was designed to apply to the standard 27-column mark-sense card.
2. Trip terminal codes, kind of trip and number of trips were reproduced in these cards (columns 66-84) from the Major Desire Line and Bridge Assignment cards for non-crossing trips. The same data for river-crossing trips were placed in cards of the new deck by summary punching the redistribution to bridges as made in the first step.

(It will be noted that this card provides two total-trip fields, one for the present and one for the proposed route of SR 43).

3. A skeleton layout of the arterial street system was prepared. Each intersection was assigned a two-digit number and the terminal codes of perimeter-crossing and river-crossing points were shown. (See Appendix — Figure "C"). The location and code of internal terminals and the travel-time in minutes and hundredths for each segment between intersections were added to the work print. (Total time to the nearest tenth was used in assignment).

4. The 27-column mark-sense capacity of the card made it necessary to limit the definition of each route to the intersection of entry, not more than 3 intersections of turning and the intersection of exit. Although each card actually represented a two-way movement, it was presumed, for assignment purposes, to be a one-way movement from the first to the second terminal.

5. Classification codes (column 1) were defined to indicate: (a) the movement would use some part of the arterial street system; (b) the movement would cross but not use the arterial street system; (c) the movement would not use or cross the arterial street system.

6. Other codes were defined to indicate only one route of choice and similar details to facilitate computations and tabulations.

The actual assignment procedure then involved decisions of judgment with respect to each movement, the coding of these decisions and subsequent mechanical procedures: (It is imperative that the assignment personnel be personally familiar with the area involved, yet sufficiently objective to disregard pure personal prejudice or opinion as to route desirability).

1. The first decision was whether or not the specific movement would use the arterial street system. By definition, usage implied that at least a major part of the movement would traverse at least one segment of the system between numbered intersections. This decision was coded and, if there were no usage, the card was segregated without further processing prior to final tabulations.

2. For a movement with usage of the system, the next decision was selection of the fastest reasonable route and of the fastest yet substantially different alternate; determination of respective travel-times between points of choice, and the appropriate coding of these items.

3. The mark-sense coding was punched into the cards. Appropriate mechanical check were made as to completeness and intra-card consistency of the coding.

4. Cards were processed to compute and punch the usage-factor and the distribution of the movement between the two routes by that factor.

This completed the actual assignment and there remained only the mechanical summation by means of intermediate summary cards to develop the flow pattern by street segments, the turning movements at important intersections, and the affect, on each of these, of the proposed relocation of SR 43. Because of the coding space limitations of the assignment card, it was necessary to do some manual summation in lieu of more extensive (and expensive) mechanical summation. For example, by reference to the arterial street system diagram, the full total for the 51-52 segment would be a summation of the mechanical totals for the 49-52, 49-53, 49-54, 50-52, 50-53 50-54, 51-52, 51-53 and 51-54 segments and their reversals. Similarly, the 46-51-52 turning movement would be a summation of the tabulated 44-51-52, 44-51-53, 44-51-54, 46-51-52, 46-51-53 and 46-51-54 movements and their reversals. In the actual operation, each tabulated item was written in on a large scale working diagram opposite each separate segment to which it applied. A scaled flow map was subsequently prepared from this working diagram. (See Appendix — Figure "D").

Completeness of the overall assignment was verified by comparison of the assignment flow-map with the existing flow-map developed from actual traffic counts. Total crossings of certain strategic lines were found to check within acceptable tolerance limits (8 percent). Substantial changes of traffic pattern were consistent with the purposes of the proposed improvement program.

Formulae

The basic formula used in this assignment job was a mathematical approximation of published experience curves.[1] It was simplified in the belief that such simplification was necessary for more efficient machine computation. Later experience proved that a more refined formula such a $U = \frac{1}{1+\left(\frac{A}{B}\right)^6}$ could very well have been used.

1. Definitions

A = travel-time via study route.

B = travel-time via the only or best alternate route.

P = fractional part of the total movement carried by the best alternate in the absence of the study route and in the presence of one or more lesser alternates.

U = usage-factor of the study route or the fraction of the whole to be assigned to that route.

2. Formulae

(a) Only two routes of choice

$$U = 0.5 + 2.5\,\frac{B-A}{B+A}$$

(b) Three or more routes of choice

$$U = \frac{PX}{1+PX-X} \text{ in which } X = 0.5 + 2.5\,\frac{B-A}{B+A}$$

CONCLUSIONS

1. The time required to determine and record numeric values of travel-time and other governing criteria is the same for either manual or IBM computations but, in the latter case, it is not necessary to transcribe number of trips and other known values from a tabulation to a computation sheet with the consequent chance of human error.

2. The mechanical computation of usage-factors has decided advantages over manual computations. (a) It is faster to the point of there being no real comparison. (b) It is infallibly accurate so long as the data is correctly supplied. (c) No human errors of estimating or interpolating from a graph are involved. (d) The record of the computation remains for future review or check.

3. By IBM methods, it is more difficult to detect errors in original criteria. Such errors produce answers that would be ridiculous to the human operator but not to the machine, because the machine cannot go back of the data which it is given.

4. For the tabulations of traffic flow, subsequent to the assignment of movements, the IBM card method again has distinct advantages. (a) It is more accurate; (b) it is faster and cheaper; (c) it is more flexible, in that rapid regrouping for trial situations is possible. (d) Human errors of erroneous entry to line or column are eliminated.

5. The statistical-card method has the very valuable advantage of being a separate record for each movement, capable of mechanical rearrangement and regrouping, to take off, at later dates, details or data not originally contemplated.

6. Economically, the choice of methods hinges on the number of repetitive computations to be made and whether the fixed costs of IBM methods are spread over a sufficient volume. This same basic condition governs the decision between statistical-card and manual methods, whether in traffic assignment or any other field.

7. Subject only to these economic considerations, we expect to continue the use of the basic principles involved. There will be variations, of course, to meet the special features of specific assignment problems. The assignment formula will be changed as our knowledge of the subject increases. And, finally, we expect, from experience, to be able to devise procedural refinements to take further advantage of the statistical card possibilities.

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[1] See Highway Research Board Bulletin 61.

Appendix

Figure A shows a sample survey summary card for the movement between internal tract 036 (one of three comprising the Lafayette business district) and perimeter station 105 (US 52 to the northwest). Its punching and interpreted values are apparent from the printed captions.

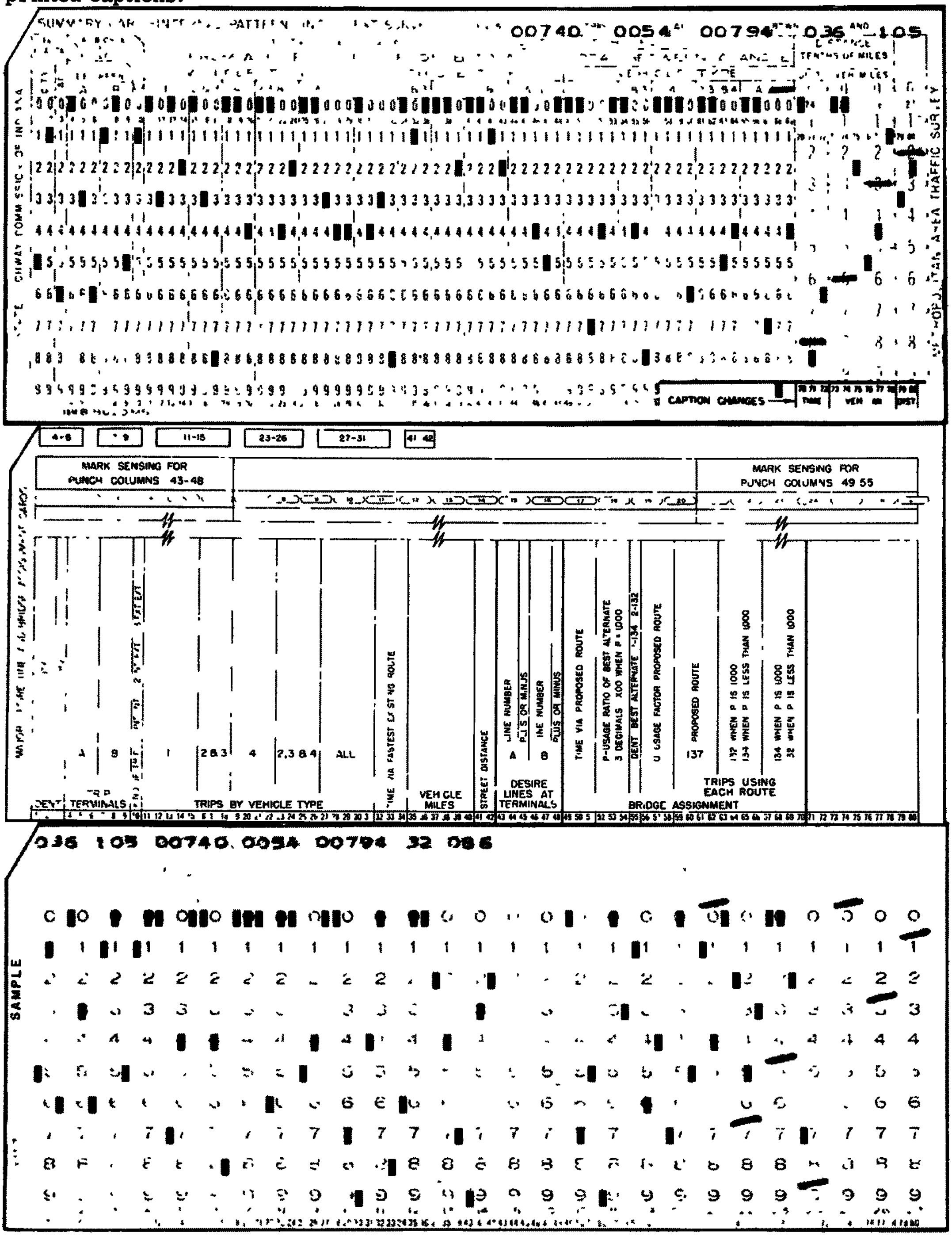


Figure A. Major desire line and bridge assignment cards.

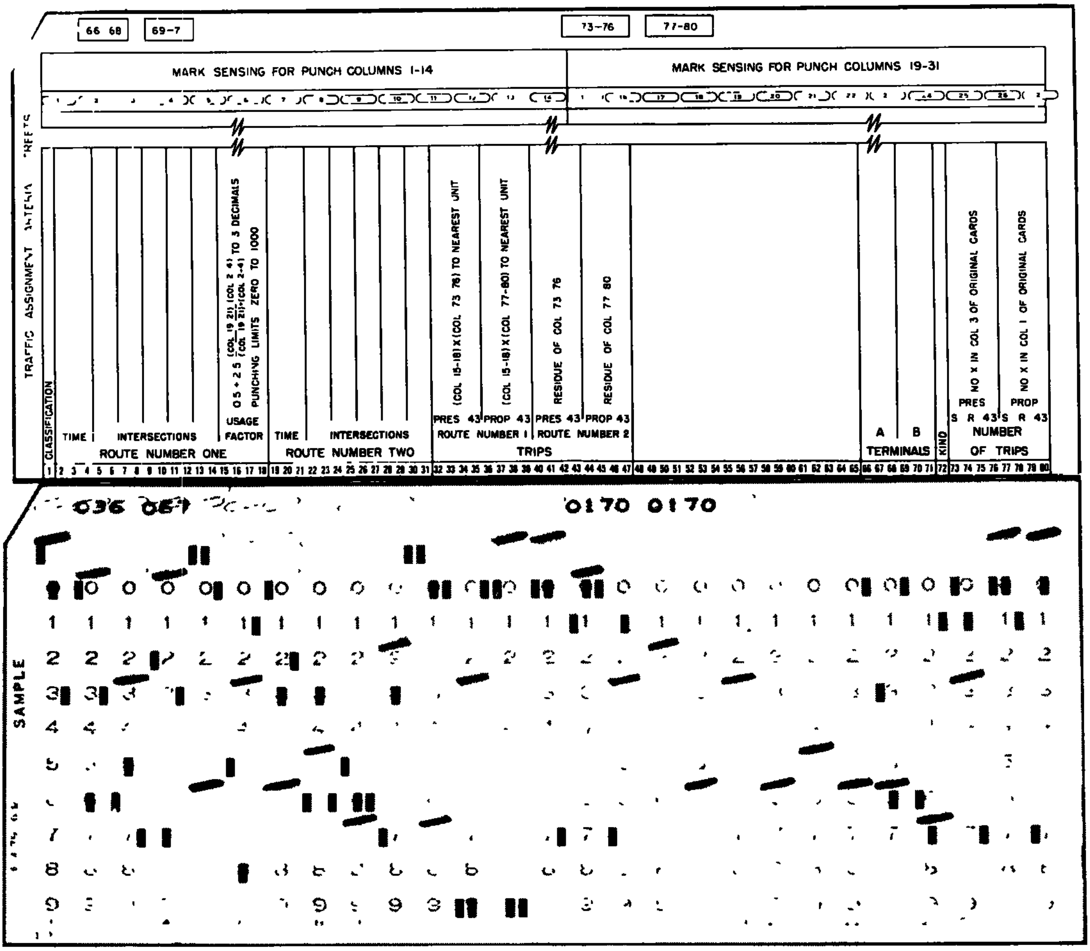


Figure B. Traffic assignment - arterial streets.

Second on this figure is the layout diagram and, third, an actual sample of the Major Desire Line and Bridge Assignment Card. The sample is for the same movement as that of the summary card sample. Columns 1-9 and 11-42 of the assignment cards were reproduced from appropriate fields of the summary cards. Column 10 was punched by emitter at the same time in accordance with prior sorting of the summary cards. Cards were interpreted according to the layout diagram.

Major desire line usage of the card (columns 43-48) is omitted from the sample since it is not pertinent to this discussion.

Travel-time via the proposed bridge (7.5 minutes for this sample and coded 075) was determined from a time contour working map and marked in mark-sense columns 21-23. Screen line interviews showed a volume of 750 for this movement with 677 via Main and Brown Streets. The value of $P(\frac{677}{750} = .903)$ was computed by calculator and marked as 903 in mark-sense columns 24-26. The code of the Main Street Bridge as the best alternate for this movement was marked as 1 in mark-sense column 27.

This completed the placing of controlling criteria in or on the cards. All subsequent computations and summations to complete the redistribution of each movement to the three bridges of choice was by IBM machines.

Figure B shows the layout diagram and an actual sample of the arterial street system assignment card. The movement selected for the sample is between internal tracts 036 and 067 with a two-way volume of 170 trips.

In actual performance of the mark-sense coding operation, the individual card was placed on a hard surface with a top and left edge-guide and captions above the card po-

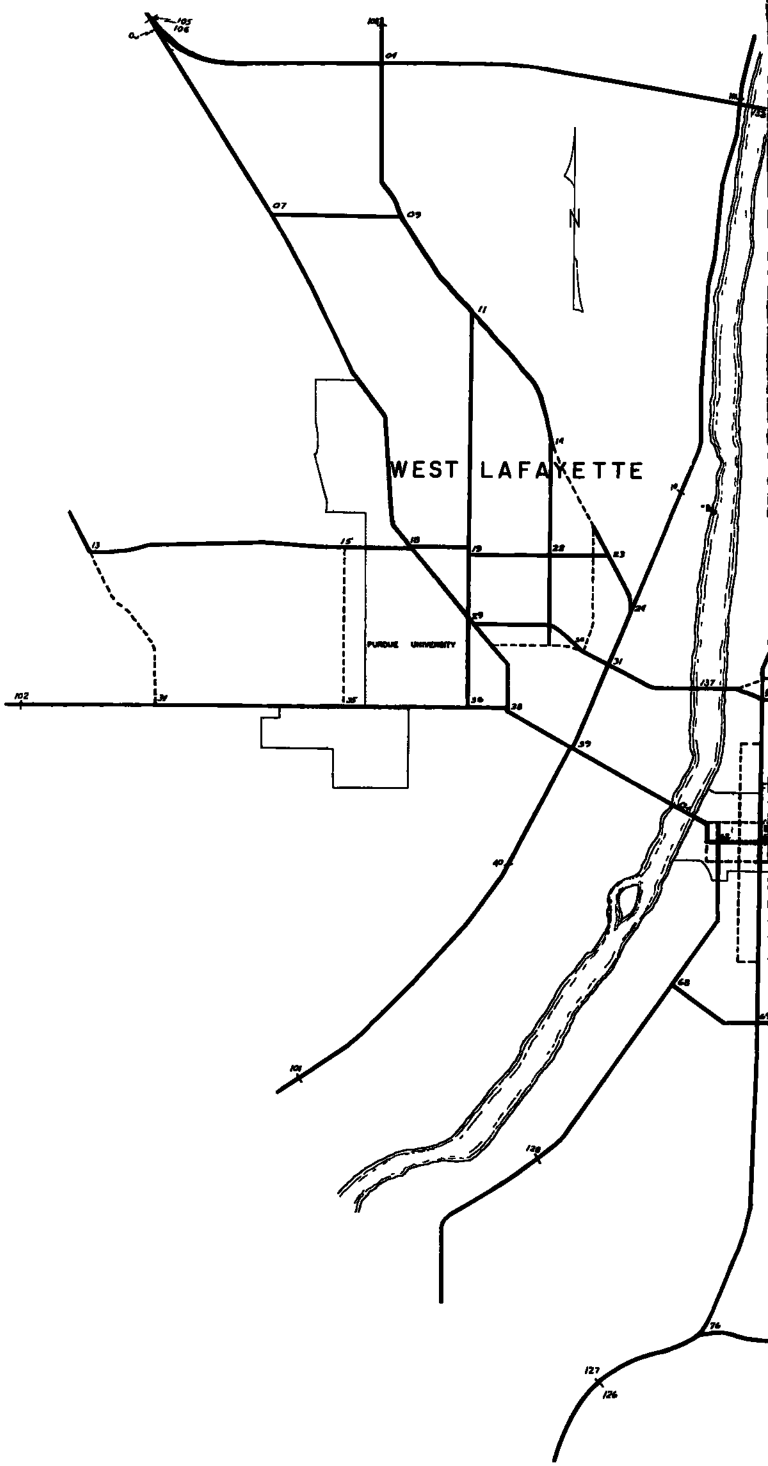
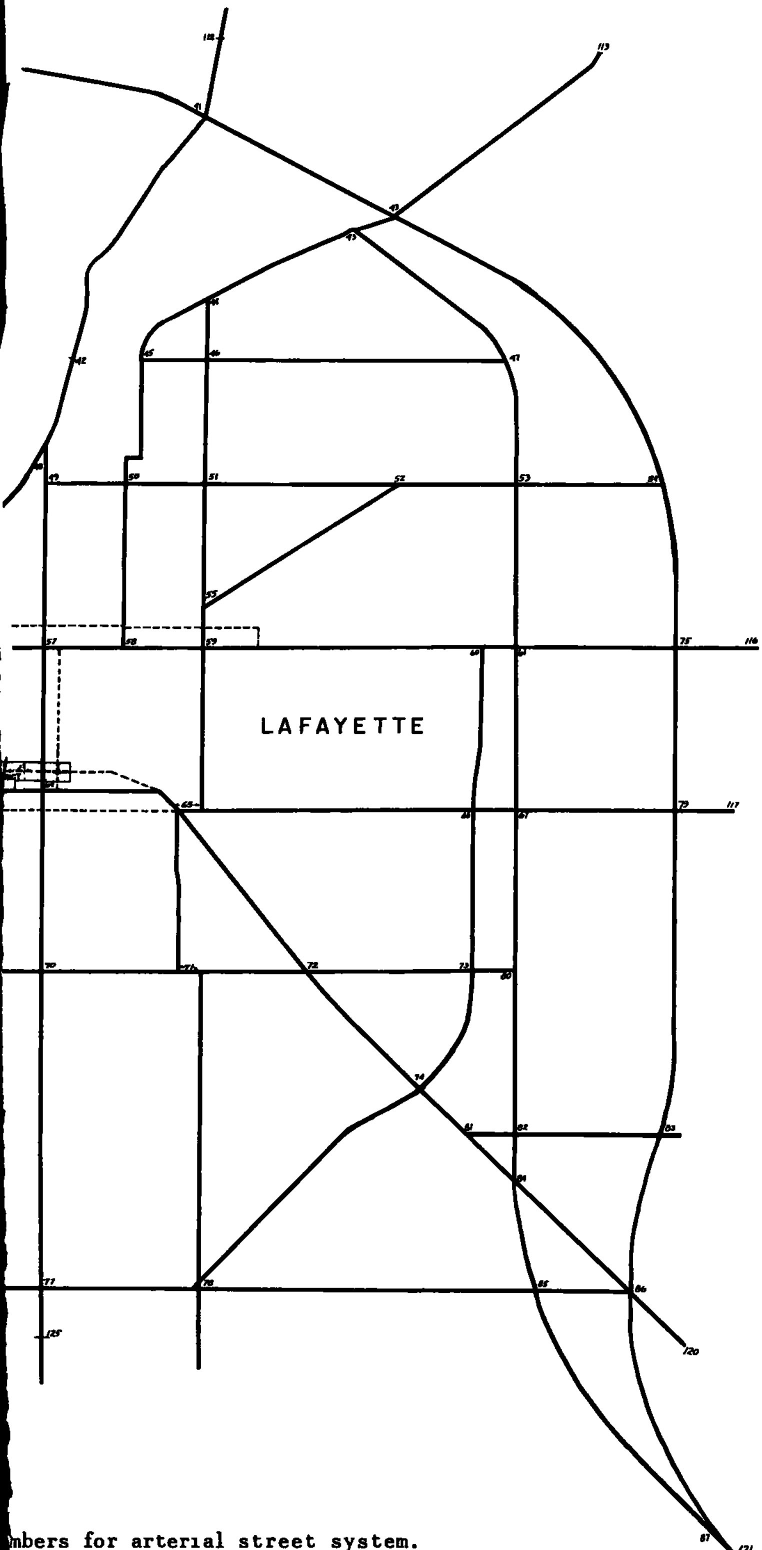
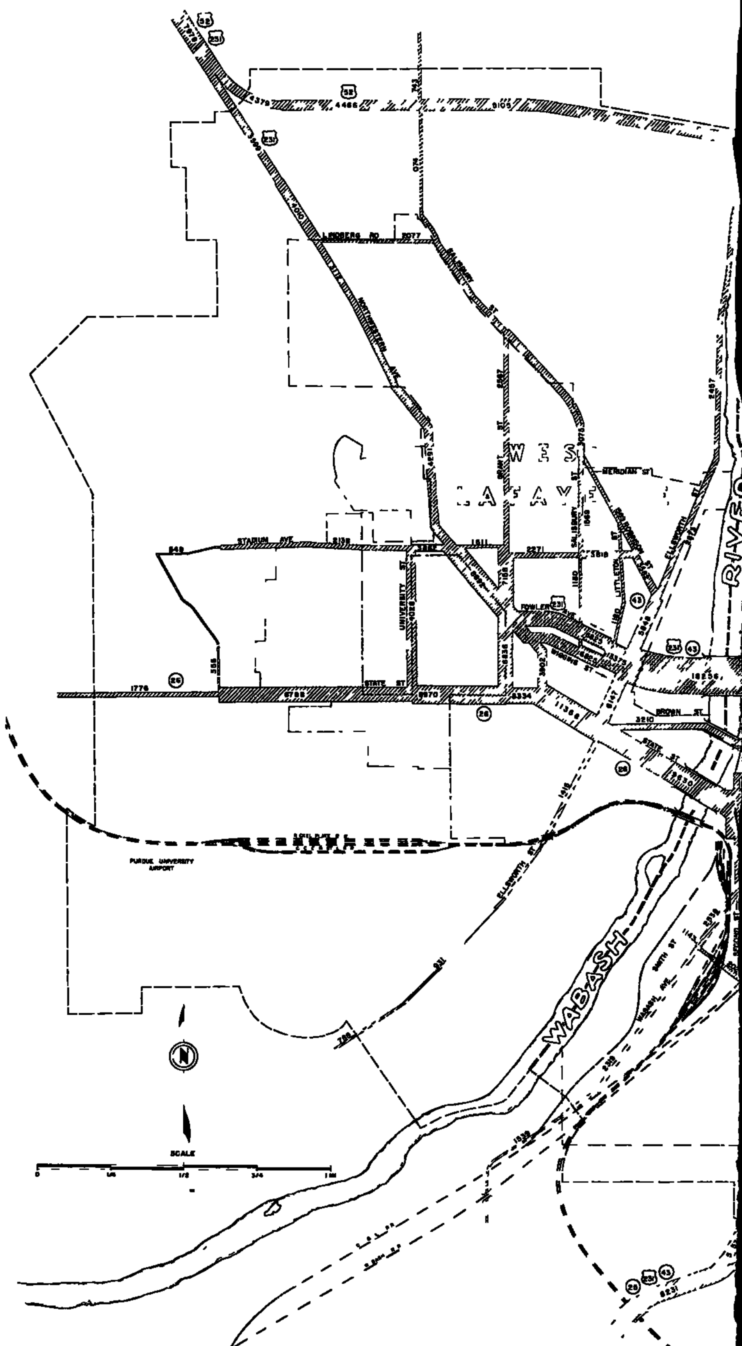


Figure C. Terminal and perimet



mbers for arterial street system.



SCOPE OF TRAFFIC ASSIGNMENT

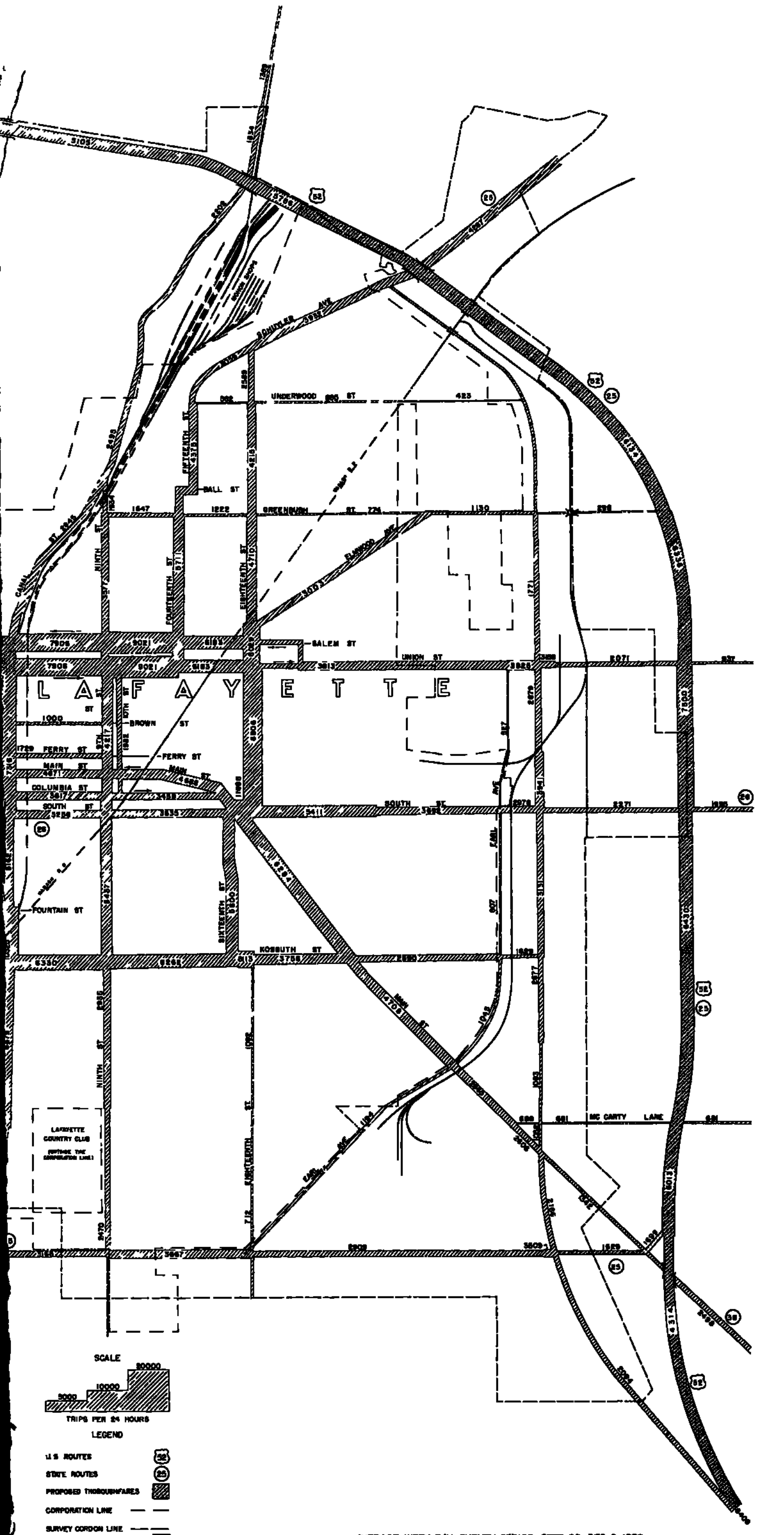
	ASSIGNED	% OF TOTAL	NOT ASSIGNED	TOTAL
RIVER CROSSINGS	36207	100	0	36207
NON CROSSINGS	87400	89	10706	98106
ALL TRIPS	123607	92	10706	154313

TRIPS NOT ASSIGNED WERE OF SHORT RANDOM PATTERNS WITH LITTLE OR NO USAGE OF ARTERIAL STREETS

METHOD OF ASSIGNMENT

RIVER CROSSINGS WERE DISTRIBUTED TO PRESENT AND PROPOSE BRIDGES ON THE BASIS OF TIME RATIOS BETWEEN TERMINALS WITHIN THE EAST AND WEST SIDES SEPARATELY ASSIGNMENT TO THE ARTERIAL STREET SYSTEM WAS BASED ON THE TIME RATIO BETWEEN POINTS OF CHOICE WITH EACH INDIVIDUAL MOVEMENT DIVIDED BETWEEN ONLY TWO ROUTES

Figure D. Lafayette-West Lafayette, Indiana predicted traffi



lumes on existing and proposed state and city thoroughfares.

sition. This enabled the coder to make entries in proper fields more readily and with less error as to position on the card. The mark-sense coding of the sample card indicates:

1. The movement will use the arterial street system (column 1).

2. For its fastest route, it will converge from the first terminal (036) to intersection number 63 (column 5-6); will proceed thence to intersection 65 (column 7-8); thence to 72 (column 9-10); thence to 73 (column 11-12) and thence disperse to the second terminal (067).

3. Its second fastest route is by way of intersections 63, 65, 66 and 73.

4. The respective travel-times between points of choice (intersections 65 and 73) are 3.0 and 3.2 minutes.

5. The "XX" coding of mark-sense fields 13-14 and 26-27 indicates that these fields were not needed for complete route descriptions. This was both insurance against human error and an aid in later tabulations.

Subsequent machine computations and punching indicate, for this sample, that:

1. The usage factor for route number one is 0.581.

2. This usage factor applied to the total trips of the movement places 99 trips on route number one and 71 trips on route number two.

The mechanics of summary and tabulation are too involved for brief description and would be of interest only to an IBM technician. Having been told the meaning of codes and values in the cards and the end result desired, a competent technician would prefer to work out his own procedures.

Figure C is reduced reproduction of the skeleton map of the arterial street system. The Wabash River, the central business district of Lafayette and the Purdue Campus were added for purposes of this presentation.

Several prints were used for different purposes in the actual work. The most important was the one on which the assignment data were shown, which consisted of:

1. Internal tract centers and code numbers in green ink.

2. Travel-time for segments between consecutive intersections in red ink.

3. Pencil indications of total travel-time for recurring sections of two or more segments.

4. Other pencil notes for time saving and accuracy with respect to recurring conditions and considerations.

Figure D is the complete traffic flow map depicting flows on present and proposed facilities, as developed from this assignment.

...echanized Procedure for Assignment of Traffic to a New Route

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These machine methods developed for assigning traffic to a proposed new highway route are believed to be initial and simple steps easily adaptable even by those with no business machine installation. If a simple business machine installation is already available the automatic calculating equipment which is required can be used on a loan, and as available, basis from agencies equipped with such machines or from business machine service bureaus at very nominal cost.

If conducted without the benefit of automatic machines, the assignment of traffic volumes to proposed new routes is an extremely time-consuming procedure. Each and every zone-to-zone travel movement intercepted during an Origin and Destination Traffic Survey must be studied individually. In the larger urban areas where the number of zones tends to be quite large, the analysis of the many traffic movements which would be affected by the construction of a new route becomes extremely cumbersome since the number of individual zone-to-zone movements increases as the square of the number of zones being dealt with.

All of the essential route analysis steps have been converted to a machine operation except for the initial stages of procedure which require a manual measurement of the distance of travel between the zones being studied both for the existing and the proposed routes of travel. The distance measurements are segregated according to the various average travel speed ranges which exist along the route of travel. This data is then punched into cards with the subsequent steps of converting distance to travel time being performed automatically. The machines also compute the travel-time ratio for each zone-to-zone movement by comparing the travel time which would exist if the proposed new facility were used in comparison to the existing city streets. The machine determines from the travel-time ratio the percentage of the total zone-to-zone movement which would use the new facility and multiplies the total volume by this percentage.

When the entire series of computations are completed for all traffic movements affected, a summary tabulation is machine prepared showing the total volume traveling between each ramp of access and each point of egress. The information which is punched on the cards permits tabulations to be made of the vehicle mile savings in travel distance and the vehicle minute savings in travel time which would be provided by the proposed new facility. This, together with estimated costs for each of the routes being studied, permits the computation of a benefit-cost ratio for each.

A further advantage of having the information on punch cards is the ease of expanding present day travel movements to predicted travel based upon predictions of zonal growth. This expansion can be performed by machine.

The conversion to machine methods of analysis has not only provided a saving in personnel time and analysis cost, but has at the same time yielded far more information than it was possible to obtain when the analyses were being performed manually. This additional information permits an evaluation of various proposed routings on a benefit-cost basis, as well as on an average travel speed improvement basis. These items of information should prove extremely valuable in indicating to responsible authorities, as well as the public in general, the value of providing improved highway facilities and also the factual basis upon which any particular choice of route has been made.

THE State of Washington's first major application of traffic assignment procedures was performed in the analysis of the 1946 Seattle origin and destination traffic survey. Totals of five separate routes were analyzed as freeways with definite interchange points assumed. In determining the number of trips to be assigned to the proposed routes a travel-time ratio system was used. Where assumed interchanges were quite close together no assignments were made to single route sections, as it was assumed motorists would probably not choose to travel through two interchanges in order to use a short section of new freeway.

At that time route analysis procedures and methods were not yet formalized but it was decided that a travel-time ratio method probably would prove the most accurate and reliable system of assignment. Individual zone-to-zone travel movements were studied, and distance measurements made between common points for travel via existing streets and the proposed new route. These were converted to travel times by applying the findings of trial speed runs on the existing streets and a simple ratio computed of travel-time via the freeway versus travel-time on the existing street system. The scale of traffic assignments which was used was based upon a study of all of the literature and research available at that time on the subject. Interestingly enough the scale is not too greatly different from typical travel-time ratio curves in use today. It can be seen that for simplicity the assignments were broken in even 10 percent ranges as it was not believed that any further refinement could be justified on the basis of the limited information available.

Such a method of analysis was used virtually unchanged for several years for the urban surveys subsequently analyzed by the State. The only modifications were quite slight and consisted primarily of lifting the percentage assignments in the central regions. At the same time assignments were discontinued at the lower end of the scale. This was a result of a study of completed route analyses which revealed that quite substantial distance losses would be incurred in utilizing proposed freeway routes when the travel-time ratios were greater than 1.05. This ratio meant the trip via the freeway would not only take longer in time but also be farther in distance. Trip assignments at the lower end of the scale were, therefore, no longer made as it was not believed that any significant number of motorists would choose a route of travel which would result in a loss in travel-time and distance. The only exception to this rule was applied when it was believed that signing might promote such usage. Completed analyses also showed that, in general, there were not a great number of motorists who would be involved in assignments to the proposed route if assignments were made when travel-time ratios were larger than 1.05.

In still later analyses assignments were not made if the travel-time ratio was larger than 1.00. This was done, in part, to possibly compensate for over-assignments occurring because of the use in the analysis of travel speeds found on existing streets before freeway construction. Because of the traffic relief which a freeway would provide, these assumed speeds on the existing system might be much too conservative. The remaining street system might, therefore, be more attractive than travel-time studies made at the time of the traffic survey would indicate. A factor of this sort is generally not evaluated in "after" studies since the new route is then in operation and travel-time comparisons are then made on the basis of the relieved existing street system. Assignments in the lower percentage ranges were also not made because of the possibility that the route could or would not be built to as high standards as that assumed in the analysis, and also because the time involved in traveling through interchanges is not fully accounted for in the analysis.

Free route analyses made in recent years have not been changed except in details of procedure, with the assignment scales remaining virtually unchanged. There has not been sufficient reason for abandoning the travel-time ratio method of trip assignments in favor of other assignment methods as most recent research studies have verified this method as probably being at least as good a measure as the best of the alternate methods. In our own state we have not been fortunate enough to be able to obtain motorist interviews in making "after" studies of new facilities. However, traffic count studies have been made on several new rural facilities and, in particular, on two urban freeway facilities. In the case of the Alaskan Way Viaduct and the connecting

Battery Street Subway in Seattle, which provide a downtown bypass, traffic counts indicated a very good agreement with the predicted volumes from the travel-time ratio analysis. In the case of the Vancouver Freeway, however, usage thus far has been somewhat below that predicted. This is believed to be primarily because of the high degree of relief the Freeway has provided the paralleling city streets. A contributing factor is that the facility has been in use for less than one year and usage does not seem to have stabilized. In contrast, traffic growth has been more rapid in Seattle and the reservoir of demand so great that the Viaduct's removal of over 40,000 vehicles per day from the parallel downtown streets has not substantially changed travel speeds on these streets from that found during the traffic survey in 1946.

As the number of route analyses being conducted by the State became greater, the need for improvement of methods became obvious. Not only was the need for personnel time savings becoming imperative but a greater flexibility of data was thought at least equally necessary. After initial route studies are completed and the quite nebulous proposals for freeways come closer to reality and design studies are made, the need for reanalyses inevitably comes up. A revision in interchange location, a slight shifting of route location, a revision in access provisions — each requires additional and cumbersome restudy. If conducted manually the assignment of traffic volumes to proposed new routes is extremely time-consuming. Necessary reanalyses are equally time-consuming. Since each and every zone-to-zone travel movement intercepted during an origin and destination traffic study must be studied individually, studies in the larger urban areas where the number of zones is quite large become quite unmanageable since the number of individual zone-to-zone traffic movements increases as the square of the number of zones being dealt with.

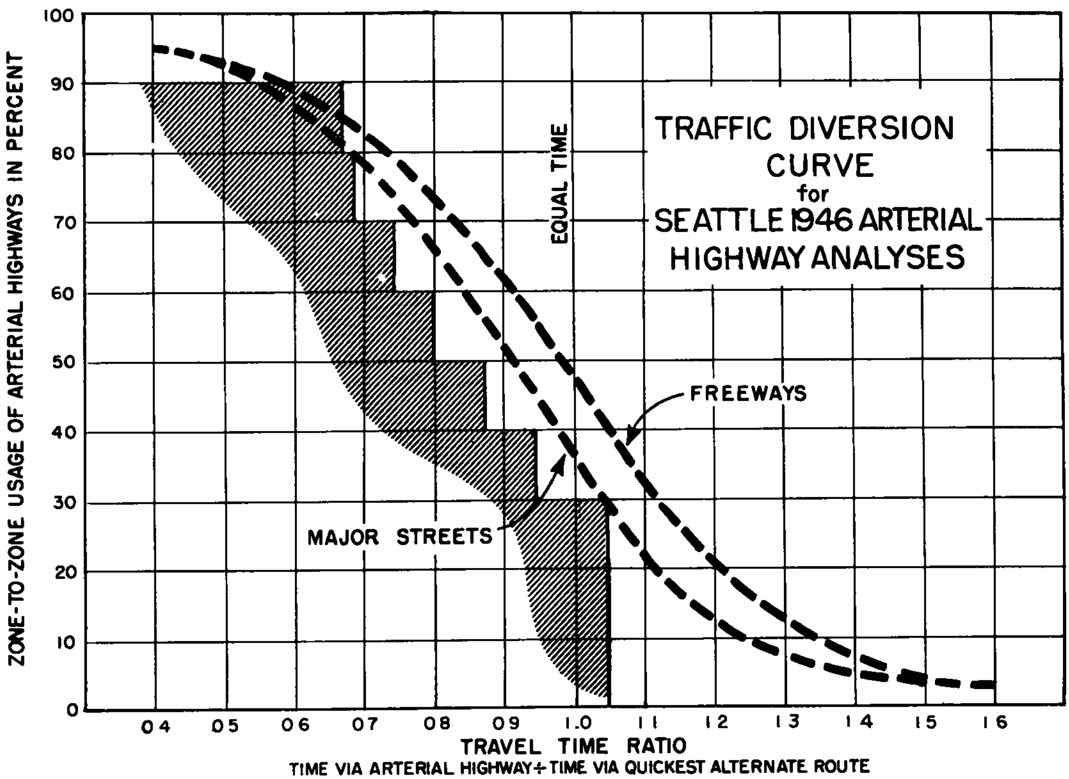

Figure 1.

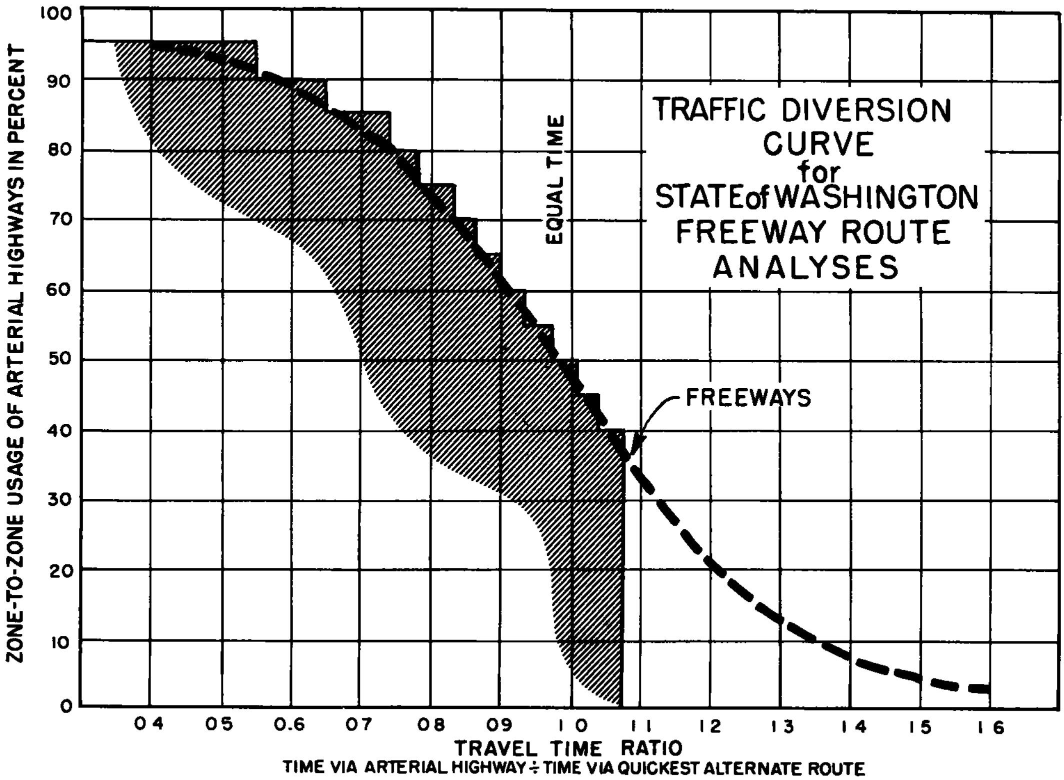

Figure 2.

Development of Machine Methods

Primarily because of personnel time considerations and the need for greater flexibility of data, business machine methods were developed by the State of Washington for assigning traffic to proposed freeways. The method is simple and easily adaptable by even those with access to a minimum business machine installation. Automatic business machine calculators can oftentimes be used on an "as available" basis from other agencies which have such equipment, or, at a very nominal cost, from business machine service bureaus. In any event, the necessary machine time is moderate and inexpensive.

All of the essential route analysis steps have been converted to machine operations except for the initial steps which still require a manual measurement of the distance of travel between the zones being studied both for the existing and the proposed routes of travel. No longer, however, is it necessary for the analyst to convert the individual distance measurements to time measurements in accordance with the particular travel speed found on each section of the route of travel. The analyst now merely lists the distance at each travel speed in the appropriate columns of prepared forms. He notes down the ramps of access and egress for the route of freeway travel. After this information is punched into cards, all subsequent operations are machine conducted.

The first machine operation is the conversion of the distance measurements into minutes of travel-time. The factors inserted into the machine to make this conversion are a function of the scale of the map used in the analysis of the travel distances and the speed of travel for each of the measured distances. The factors are, therefore, generally different for each series of route analyses as map scales are chosen to best suit the particular area being studied. The machine computes the travel times and then totals them for each individual zone-to-zone movement by summing up the time of travel at each travel speed. These travel-time totals are then machine compared and a travel-time ratio automatically computed—the travel-time via the proposed new route being divided by the travel-time via existing streets, the result being punched in the card.

Determination of Assignment Percentages

At this point the automatic calculating equipment available for use would have permitted determining the exact percentage assignment which a conventional time-ratio assignment curve would indicate appropriate. However, it was not considered that the time necessary to compute the appropriate equations to insert into the machine was warranted as the basic data is of insufficient accuracy to justify such exactitude in analysis methods. Assignments to the nearest 5 percent seems sufficiently exact and moreover, the machine operations are thereby simplified. The machine compares the computed travel-time ratio with the predetermined scale of assignments, punches the corresponding assignment percentage into the card, multiplies the total zone-to-zone movement volume by this percentage, and punches the answer in the card.

This results in the cards containing: (1) the total number of trips traveling between the individual pair of zones; (2) the distance each trip between these zones would travel at each of various operating speeds if the trip were made via the existing street system; (3) the corresponding distances if the trip were made via the proposed new route; (4) the ramps of access and egress to the proposed new route; (5) the travel times for each of the speeds for which travel distance was incurred in items 2 and 3 above; (6) the total travel-time and the total travel distance between origin and destination via existing routes and via the proposed route; (7) the travel-time ratio; (8) the percentage assignment for this travel-time ratio; (9) the assigned traffic volume.

The cards are then summarized, the result being a tabulation showing the proposed route's individual ramp to ramp volumes, from which the entire route's expected usage can be obtained. Formerly each of the outlined steps was done manually, and besides being extremely time consuming, unwieldy, and tedious, the procedure was subject to human error at each step.

Further Advantages of Machine Method

Any route modification can now easily be handled in reanalyses by simply machine extracting all of the ramp or route section movements which will be affected by the change. The necessary changes can be machine applied and a new summary tabulation prepared. This flexibility of data is believed to be a prime advantage of such a machine method of operation for any organization that will be developing a series of route studies which will eventually culminate in design and construction. Route refinements may take place right up to construction contract letting and intelligent decisions of the effect of such changes cannot be reached without traffic analyses. Oftentimes the initial analysis of a route proves to be the minor part of the overall continuing study culminating in the route's construction.

An added advantage of having the traffic analysis on punch cards is the ease with which predicted growth rates can be applied to zone-to-zone traffic movements to permit developing predicted future traffic flows. In some instances the growth factors can be applied to an entire ramp's volume. However, in most instances they are applied to the individual zone or to the separate zone-to-zone movements and the ramp volumes recalculated for the year desired. This is an extremely rapid calculation in comparison to manual expansion methods.

Frequently it has been necessary to make analyses to indicate the relative value of several alternate proposed routes through a particular area. Before machine methods of analysis were developed decisions on route choice could not be based upon any more than general considerations such as estimated costs, available funds, estimated overall traffic attraction, and possible time and distance advantages conferred upon certain large individual traffic movements.

Computing Benefit-Cost Ratio Values

It was readily apparent in developing the machine procedures that they would permit

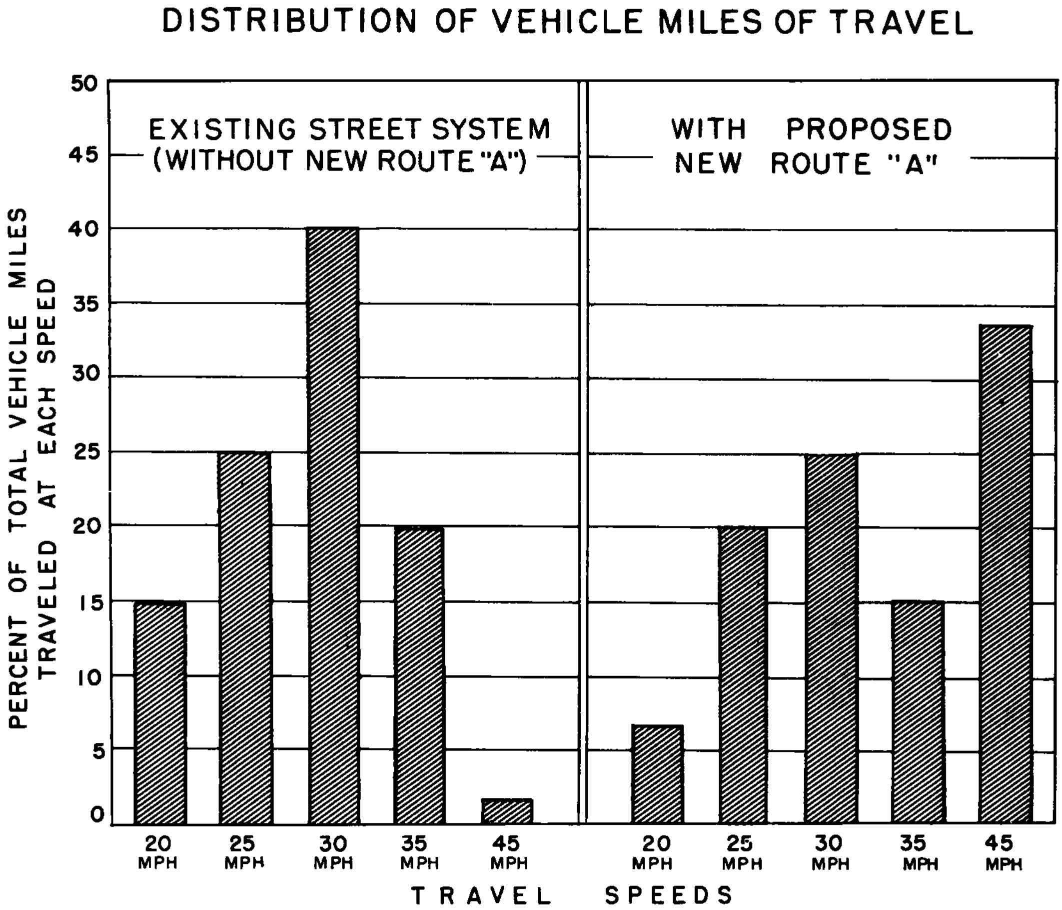

Figure 3.

machine computations to be made of vehicle miles and vehicle minutes for those zone-to-zone movements which the analysis indicates would use the proposed route. Such computations permit the determination of benefit-cost ratios for the various alternate new routes being considered. Although these computations are somewhat complicated in comparison to traffic volume assignment procedures they are nonetheless relatively easy to apply. In contrast, manual methods would tend to be entirely too extended to warrant making the study.

The total time saved by those motorists assigned to a proposed new route should be determined as this represents an actual money saving. This is done by computing the overall travel-time assuming it to be performed via the new route, then assuming it to be done on the existing street system, the difference being the time savings which would be gained from provision of the new route. A monetary value can be placed on the time savings by utilizing values found in the American Association of State Highway officials' publication entitled "Road User Benefit Analyses for Highway Improvements." [1]

Distance savings are more difficult to evaluate since the cost of operating a vehicle is not only dependent upon the type of vehicle and the distance which it is operated, but also the speed of operation and the type of operation, specified as so-called free,

[1] "Road User Benefit Analyses for Highway Improvements," Committee on Planning and Design Policies, American Association of State Highway Officials, Washington, D. C., 1952.

normal, or restricted, depending upon the degree of congestion experienced in the flow. Monetary values obtained from the AASHO publication on Benefit Analyses are applied to the vehicle miles of operation found to exist at each operating speed. The trips assigned to the proposed new route are assumed to be traveling the existing street system, and the cost of the vehicle miles of travel computed. This is repeated for the assumption that these trips travel via the proposed route. The difference in costs reveals the possible benefits bestowed on motorists in terms of operating costs. In actual usage it has been found that because of the higher operating speeds, the proposed freeway routes in urban areas will usually bring about higher overall motorist operating costs which are, however, far and away over-shadowed by the much greater value of time savings. The negative operating cost benefit due to increased operating speeds (as determined from the application of the AASHO publication values) is borne out by actual "in-the-field" measurements of improved routes in actual operation[2].

The net monetary saving to motorists from the time and distance computations is easily inserted into a benefit-cost calculation, the result being an easily understood and quite reliable comparative measure of the worth of alternate proposed new routes.

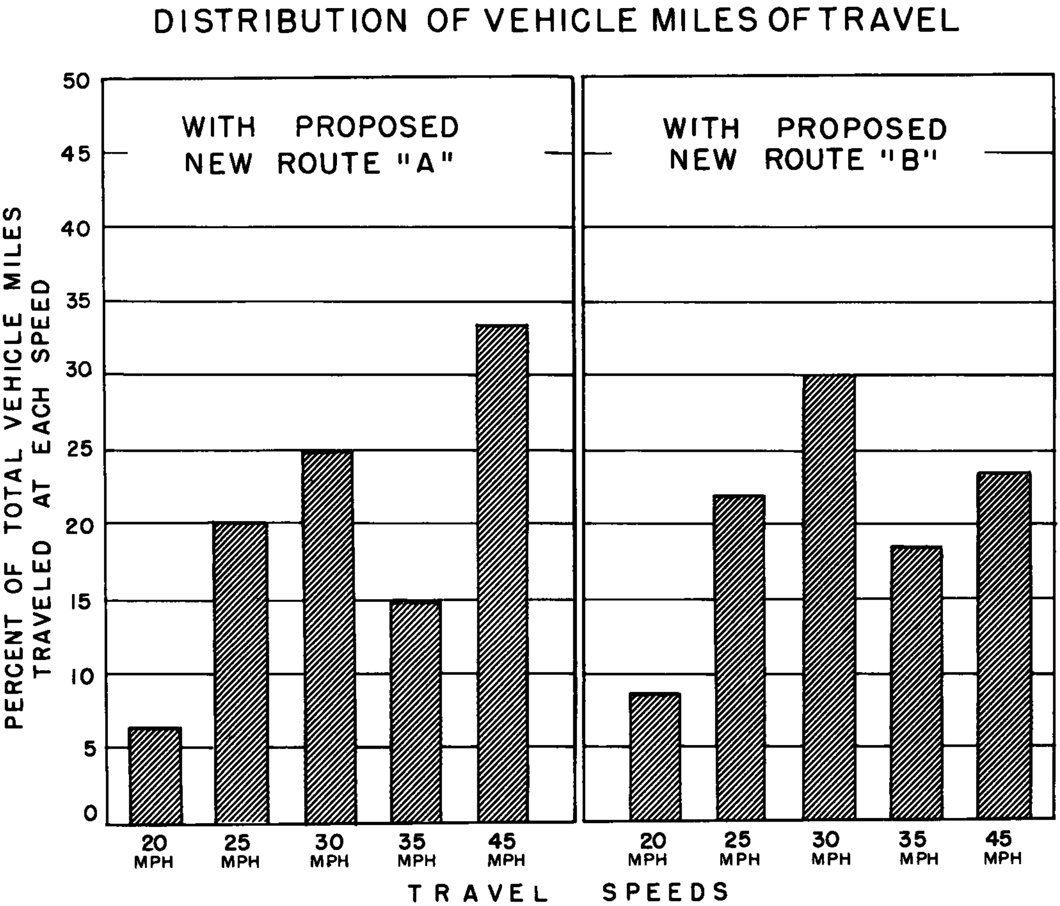

Figure 4.

Such benefit-cost ratio calculations are being relied upon more and more by responsible policy makers as a valuable tool in the making of decisions as to choice of route

[2] "Vehicle Operation as Affected by Traffic Control and Highway Type," Highway Research Board Bulletin 107, Washington D.C., 1955.

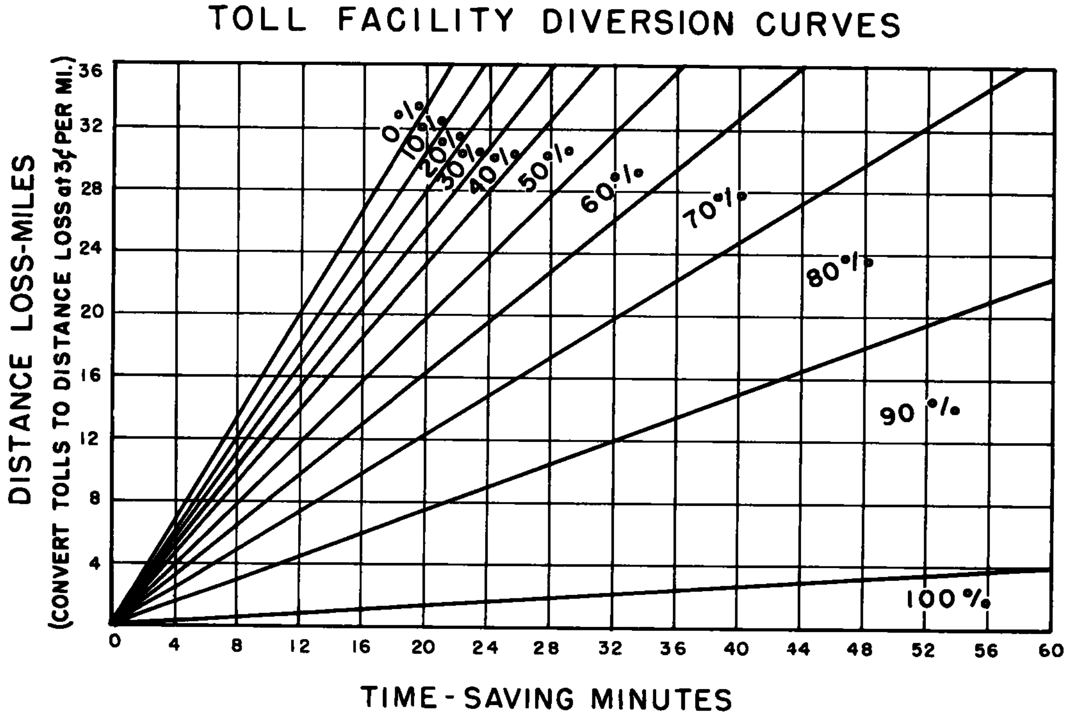

Figure 5.

to construct. This is especially true in urban areas where costs are high, and decisions are difficult to make because of the complexity of the problems involved and the difficulty of properly evaluating the many factors which must be considered. Of course, the benefit ratio is only a tool and not an absolute determinant. However, not only does it permit departmental decisions to be made on a more factual basis, but contacts with local agencies and groups are on a firmer footing when such factual information is available for use in discussing the alternate routes being considered.

Another easily understood pictorial representation of the value of various routes is a comparison of what any particular new facility will provide in the way of improved travel from an up-grading of the operating speed of the vehicle miles of travel performed in the area served by the route. The illustrations are typical of those which can be prepared to show not only the improvement which a new route will provide over existing facilities but also the relative degrees of improvement which various proposed alternates will provide.

Other Assignment Methods Used

The State has not used travel-time ratio assignment methods exclusively. In the analysis of proposed toll facilities it was found necessary to depart from a time ratio method of assingment in order to permit including the effect of tolls on the motorist's choice of route. One of the prime considerations in such analyses was to obtain an estimated traffic volume from analysis methods acceptable to bonding houses that might be called in on the necessary revenue bond issue.

A review of a number of reports on proposed toll facilities by nationally recognized consulting firms revealed that a so-called "cost per minute saved" method was widely used. In this method the cost of the trip via the toll facility is calculated in cents, including the toll charge as a cost and also the possible distance losses which are converted to cents at a rate of 3 cents per mile. The time savings in minutes are divided into the thus calculated trip cost, the result being the so-called "cost per minute saved" which determines the assignment percentage. For a fixed toll rate this can be more easily put in terms of time savings and distance losses, as shown on the accompanying graph. It must be emphasized that the values shown have been derived from a study of analysis methods reported by consultants on many large toll projects. Inasmuch as there has been no known published research study on the validity of such an assignment method, there may be some doubt attached to its use. The value placed on mileage and time also appears to be arbitrary, lacking factual data to the contrary. Moreover it is obvious that at the low end of the time and distance scales, the curves are difficult to apply. One other aspect of the method is that regardless of the length of trip a unit of time saving has an equal value. It is believed, however, that time savings should probably assume importance in an inverse relation to overall trip time rather than as a unit value. This appears to be borne out by the studies which show that travel time ratios are a superior method of assignment. However, the "cost per minute saved" assignment method not only appears to be generally accepted for toll facility revenue bond issue projects, but also is admirably suited to business machine operations.

In studying toll facilities traffic assingments have also been made by consulting firms by assigning a money value to a unit minute saving and a unit mileage saving and balancing this against the toll charge. The percentage assignment is then frequently taken as a straight line function of the net monetary saving. This system of assignment is also admirably suited to business machine calculating and summarizing. However, some of the same considerations seem to apply to this method as to the "cost per minute saved" method. In studying a proposed toll bridge facility in competition with ferry routes, time and distance savings or losses were found to be quite large. It seemed logical to assume that as the savings of time became greater that motorists would tend to attach an increasing value to time. A modification was, therefore, attempted by the

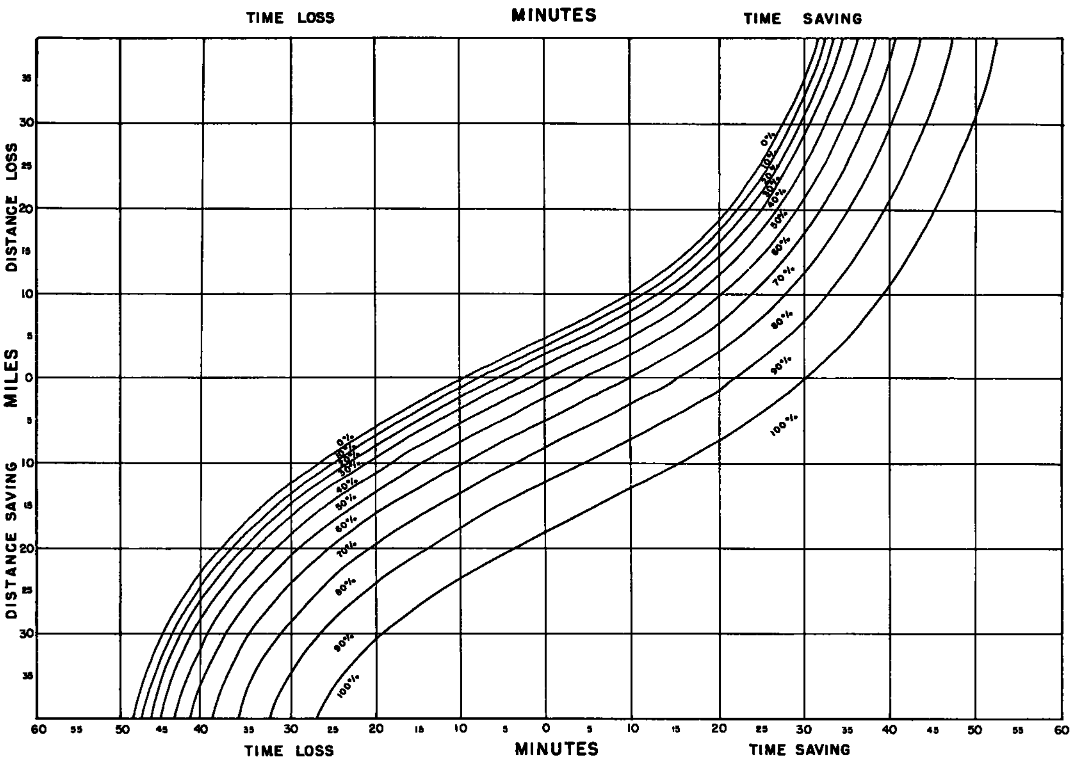

Figure 6.

State of Washington by increasing the value of time as time savings increased. This is shown on an accompanying graph. However, without factual studies such curves are known to be of doubtful validity. It would be desirable to restudy available data from actual surveys of new facilities to attempt to set up such curves and test their value in relation to the more generally accepted time-ratio assignment method.

Mechanical Methods of Traffic Assignment

M. A. CONNER, Engineer of Traffic and Planning, and
S. H. HILLER, Assistant Engineer of Traffic
State Road Department of Florida

Two general kinds of digital computation problems are very amenable to machine computations. The first kind is the performing of highly repetitive calculations for a mass of data. An example of this is the application of the traffic diversion curves to the assignment of traffic using O & D trip information. The second kind of computation is the performance of a great number of sequential calculations starting from a single set of data. An example of this is the distribution of individually forecasted zone trip frequencies by successive approximation.

Some of the advantages of punched card machine computations are greater speed, greater accuracy, freeing of technical personnel from routine calculations and the solution of problems that would otherwise be impossible or so time consuming as to never be attempted.

The amount of computation involved in the assignment of traffic to a selected line can be very great. The number of theoretically possible movements is the combination of zones and stations taken two at a time or $\frac{N!}{(N-2)!\ 2!}$; in which "N" is the number of zones or stations.

Machine computations on an IBM-602A enable the work to be done in ½ to ⅓ the time required using desk calculators. More advanced type calculators such as the Remington Rand "File Computor" or an "IBM-650" would permit a much greater time saving. The advanced computors have an added feature of internal automatic checking.

Alternate route possibilities are measured using map meters. This information for each zone-to-zone movement is key punched and verified. The time ratios are then computed by machine using assumed arterial street speeds and assumed expressway speeds. The cards are then collated with a rate deck and diversion percentages reproduced. The cards are then run through the calculator again to find the estimated expressway usage. The final step is to make an "on-off" tabulation from which the assigned traffic is entered on the expressway line. A specific application is cited and a number of additional machine applications are mentioned.

TWO types of computational problems lend themselves readily to punched card machine solutions.

The first kind is the performing of highly repetitive calculations for a mass of data. This would include problems such as $\frac{(a + b - c)\ d}{e}$ in which sets of values for (a, b, c, d, e) occur in very great numbers. An example of this is application of the traffic diversion curve to the assignment of traffic using O & D trip information.

The second kind of computation is the performance of a great number of sequential calculations starting from a single set or a restricted number of sets of values. An example of this is the distribution by successive approximation of individually forecasted zone-to-zone O & D trip frequencies. One solution of this problem is the use of an inverted matrix.

There are some obvious advantages to the use of machines for computations. They are faster. They make fewer errors and make possible the tackling of problems whose magnitude or complexity are either very burdensome or insurmountable by ordinary desk machines. One of the most important advantages is the freeing of trained personnel for "thinking" work rather than wasting them on routine calculations.

The use of machine methods in the assignment of traffic could only be developed after predictable relationships could be established for driver route selection. The development of the empirical traffic diversion curves provided one of the most sought after and needed tools for the traffic engineer. Only someone who querulously and

CONTROL	ZONE TO ZONE		STREET TRIP TIME T_A	EXPRESSWAY TIME					FORECASTED FREQUENCY
	ORIGIN	DESTINATION		TIME TO T_{x1}	INTERCHANGE ON	TIME ON T_{x2}	INTERCHANGE OFF	TIME FROM T_{x3}	

Figure 1. Work Sheet.

prayerfully guessed his way through a traffic assignment in those days prior to the diversion curve development can fully appreciate the changes they have wrought. While it is recognized that relationships exist between diverted traffic and measurable factors other than "time saved", the time factor only is used in this paper for the sake of simplicity.

The number of movements to be considered when using O & D data to make a traffic assignment to a selected expressway line in a large metropolitan area can become very large indeed. For example: The City of Miami was broken up into 104 zones and external stations. The number of theoretically possible movements is equal to the number of combinations of internal zones and external stations taken two at a time. The number of movements is as follows:

$$\frac{N!}{(N-2)!\;2!} = \text{total possible movements}$$

Where:

$N!$ = total number of zones and stations factorially

$2!$ = two factorially

In the case of Miami there were 5,356 total possible origin to destination movements. Many of the theoretically possible movements never took place, were inconsequential in volume or "obviously" would not use the projected facility. Nevertheless, the number of calculations involved would be very large if only half that number of movements were deemed within the domain of possible usage yield.

The number of calculations involved in making the assignment for one movement is dependent upon the number of facilities to be utilized during the trip and the kind of data available. We shall consider only the problem of assignment to a single line which would only be traveled once during a trip.

There are two possible situations involving the availability of time data. The first situation is that in which time runs have been made along all the arterial streets. The second is that in which time field data are not available. The first case is not necessarily the more accurate. In most instances in which a comprehensive analysis is done, part of the program will be the improvement of a high type arterial street network along with an expressway. It may be that synthetic times derived from assumed arterial speeds may be preferable. In the second case, where time information is not available, synthetic times have to be used.

Either case is amenable to machine calculation with the main difference being some additional calculations done by machine.

The number of calculations to be performed is the same whether the work is done by hand on desk machines, slide rules or on punched card machines. An examination of the calculations involved in making one assignment will make it possible to clearly show the punched card approach.

First, consider the case where time data are available. The following relationships exist and the calculations must be performed:

1. $R = \frac{T_x}{T_a} = \frac{T_{x_1} + T_{x_2} + T_{x_3}}{T_a}$
2. From calculated R, one determines D from the curve
3. D x F = Volume of traffic diverted to expressway

Where:
R = time ratio
T_x = total time for trip from origin to destination via expressway
T_a = total time for trip from origin to destination via arterial streets
T_{x_1} = time from origin to expressway
T_{x_2} = time from interchange "on" to interchange "off"
T_{x_3} = time from expressway to destination
D = decimal equivalent traffic usage from diversion curve
F = total forecasted trip frequency

There are a total of four calculations plus one curve reading to be performed.

Now consider the case where the time field data are not available. Working from a map, the following calculations are made:

$$R = \frac{\left(\frac{K\, d_{a_2}}{V_a} + \frac{d_x}{V_x} + \frac{d_{a_3}}{V_a}\right)}{\frac{K\, d_{a_1}}{V_a}} = \frac{T_x}{T_a}$$

From calculated R, one determines D from the curve.
D x F = volume of traffic diverted to expressway

Where:
R = time ratio
d_{a_1} = distance via arterial streets in inches
d_{a_2} = distance via arterial streets in inches to expressway
d_{a_3} = distance via arterial streets in inches from expressway
d_x = distance via expressway in inches
v_a = arterial velocity in feet per minute
v_x = expressway velocity in feet per minute
K = map scale in feet per inch
D = decimal equivalent traffic usage from diversion curve

It can be seen that this would entail a minimum of nine separate calculations plus one curve reading.

In a city the size of Miami with 104 zones and stations and 5,356 theoretically possible movements, the number of calculations becomes quite large if a single assignment is made to only one line. If only half the theoretical movements (2,678) were considered there would be a total of 10,712 calculations in the first case or 24,102 calculations in the second case.

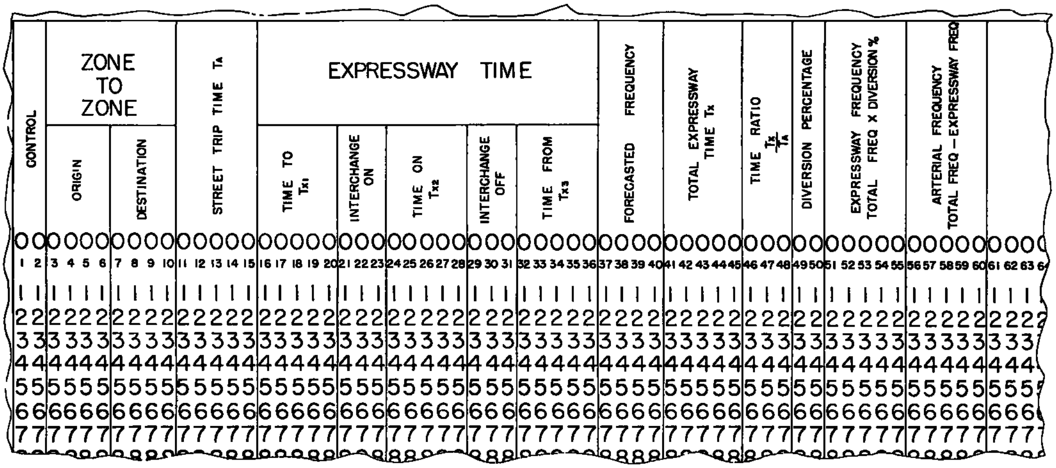

Figure 2. Layout form for punched cards.

In order to estimate doing the calculations by hand, assume that a rate of two calculations per minute could be maintained including recording and curve reading. In the first case a little over eleven man days would be necessary and in the second case about 25 man days would be necessary.

The use of punched card methods and an IBM 602-A calculating punch would enable the job to be done in less than half the time. It should be pointed out again that technical personnel are not involved in the machine calculating time.

At this point in the operation the hand calculation would have produced results in a form that would necessitate tabulating "ons" and "offs" by hand. In order to speed up the process, add accuracy and have the results in an easily usable form, it would be necessary to use punched card methods to obtain the final results. This would entail key-punching and key-verifying of the hand calculated results.

The machine calculated results, however, are already on cards at the end of the calculation cycle and are ready to be tabulated. In addition, the estimated time using machine methods in the example cited is based on slow performance rates for both people and machines. For example: the key punching and verifying time estimate was based on an average of 5,000 key strokes per hour. Rates of 6,000 to 10,000 strokes are common. The 602-A time was based on the simplest step by step programing; optimum programing might also save time in this step.

In any case, the 602-A calculating punch is a relatively slow machine with limited storage capacity. In comparison with an IBM 650 or a Remington Rand File Computer it is like finger counting compared to an automatic desk calculator.

The whole process of machine calculation is very flexible and expandable over the previous two cases mentioned. The arterial street network could be broken into sections of different speeds. Ramp travel could be handled separately and expressway speeds might be varied by location. In all such cases, the only difference would be to add extra terms to the numerator and the denominator of the time ratio fraction and add some extra machine steps.

The methods developed to date can be illustrated by reference to the forms, flow chart card layouts and machine procedures that could be used with O & D trip information and where time data are available. As pointed out previously, the methodology is easily expandable.

Figure 1 is a reproduction of the basic work sheet. The first step is to enter all the origins and destinations on the work sheet. In order to insure proper control of the operation, we found it best to enter all of the theoretically possible movements and let the diversion curve do the selecting as well as the assigning.

Next, the time for each trip using the arterial streets from origin to destination is entered. There are a number of ways of organizing the time data so as to make it readily accessible and usable.

Then the time segments must be entered for the same trip using the expressway. The time from the origin to the nearest interchange is entered and also the "ON" interchange number. We have been using a three digit code for the interchange numbers. The first two digits represent the interchange number and the third digit the direction of approach or leaving. This permits ramp assignments and ramp end turning movements to be created.

The next entry is the time on the expressway. This is the time from the interchange where the trip gets on the expressway line to the interchange where it gets off. Naturally this would be a calculated time from an assumed speed or speeds on the expressway. The "OFF" interchange is entered next followed by the forecasted zone to zone trip frequency.

From this point, the process becomes a normal punched card operation. Figure 2 is a layout for the punched card. The work sheets are first key punched and key verified and any punching errors corrected.

The cards are now ready for the calculation cycles. Our machine installation has an IBM 602-A calculating punch. The cards are run through the 602-A. During this run several steps take place. First the three pieces of expressway time are summed

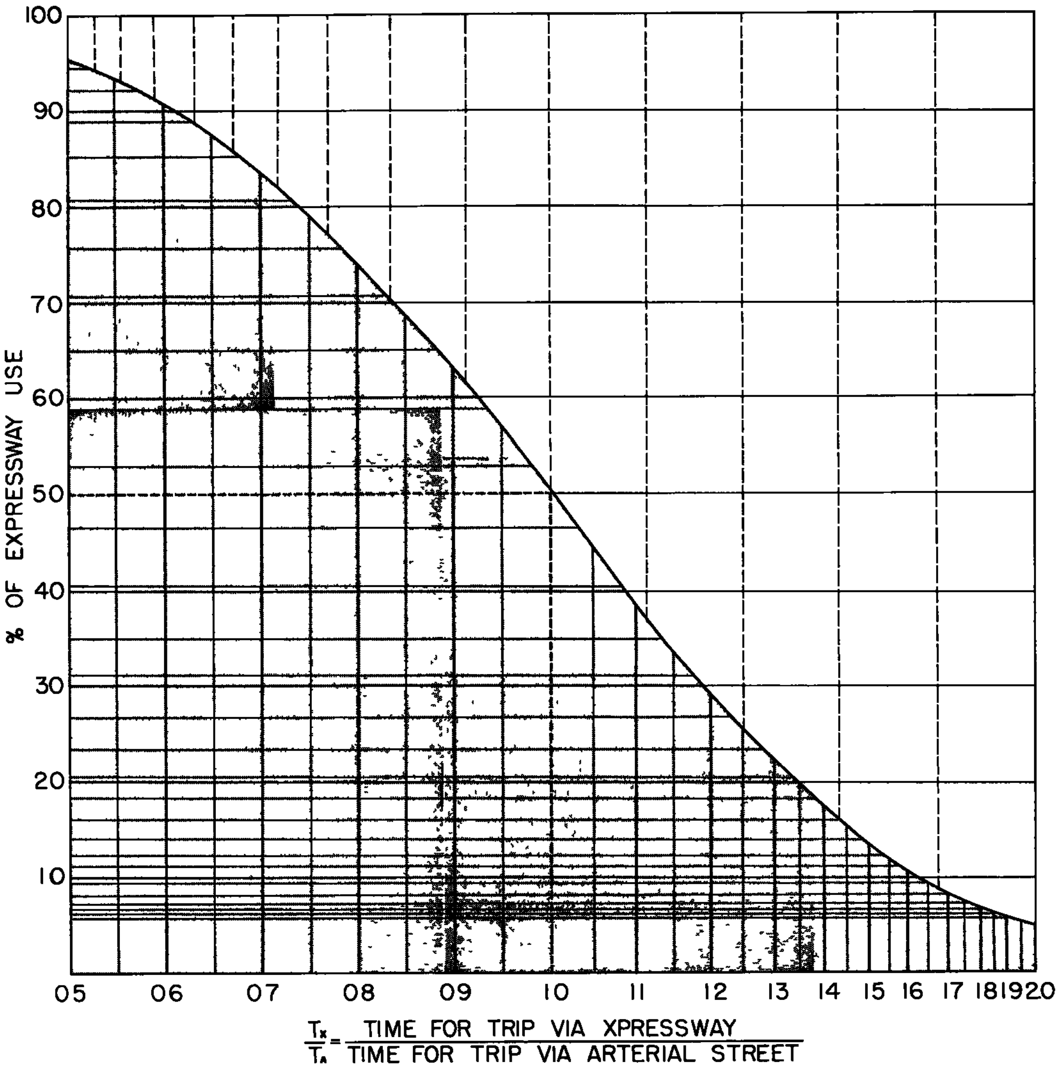

Figure 3. Curve determining percentage of expressway use.

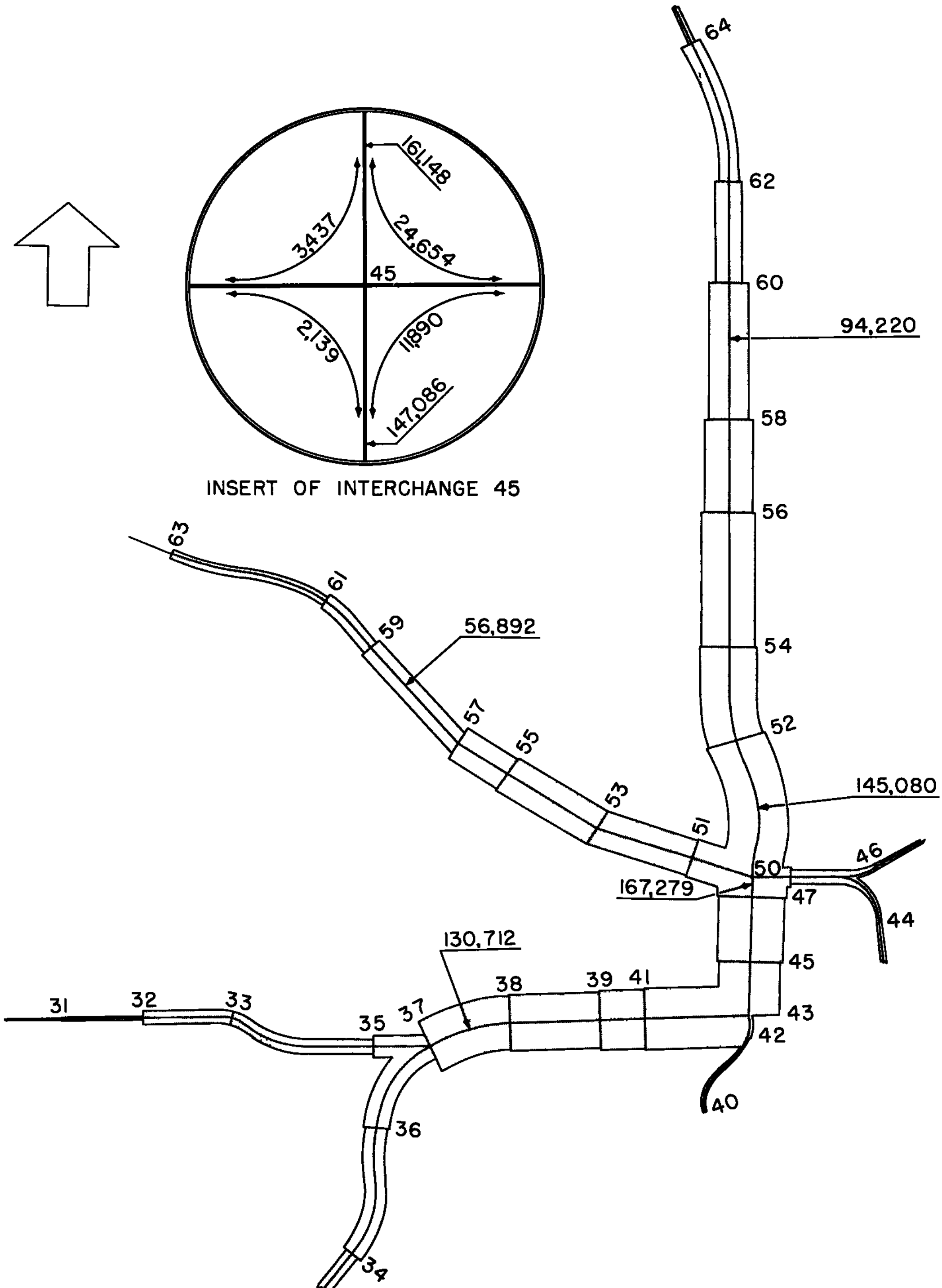

Figure 4. 24 hour assigned traffic volumes.

and the total punched in the proper columns. Secondly, the time ratio is calculated and the result punched.

Figure 3 is a representative diversion curve. We have broken the abscissa into 27 intervals with a five-hundreths range. The next step is to match the calculated time ratio to the proper diversion percentage. A master deck of cards was previously punched with time ratios and equivalent diversion percentages. The master deck is placed in front of the detail cards and sorted by time ratio. This groups the detail cards behind the proper master card. The combined deck is then run through a reproducing punch to gang punch the diversion curve decimal equivalents into the detail cards.

The final pass through the 602-A is then made. The diversion decimals are multiplied by the trip frequency and the volume assigned to the expressway is obtained. During the same pass, the expressway volume is subtracted from the total volume and the remainder or arterial volume is punched.

The detail cards are then ready to be sorted in the sequences necessary for the "ON-OFF" tabulations. Figure 4 is a sample flow map illustrating graphically the final results. The insert shows the manner of entering volumes on and off at an interchange. In actual use, the volumes themselves and not bands are utilized since the primary purpose is design data.

Initial success with the use of machines has led the authors to investigate their utilization in major facility location, sufficiency rating calculations, signs, signals and pavement marking inventory. It is quite obvious that only a beginning has been made in traffic engineering utilization of digital and analogue computers. Much more remains to be done.

General Discussion

J. DOUGLAS CARROLL, JR., Director
Detroit Metropolitan Area Traffic Study

These five papers illustrate the importance attached to traffic assignment techniques. The assignment of traffic provides an acid test of route location. Assigning traffic has always been a time-consuming and tedious process, so that new ideas on ways to economize by use of machines are welcomed by all traffic planners.

Traffic planning is fast becoming a specialized field. Many of the data used by the traffic planner are supplied by origin-destination surveys. To use the results of these surveys in planning both new traffic facilities and improvements for existing routes requires detailed manipulation of the trip data, especially use of these data in making traffic assignments.

Origin-destination trip movements have historically been represented by desire lines. Yet, desire lines show only the shortest airline distance between the terminal points of trips. The problem facing the planner is that of routing these trips over existing and/or proposed new facilities. To achieve this, it has been amply demonstrated that a formula is necessary whereby potential traffic is split between competing routes. From desire lines it is possible to estimate where new facilities should go. But until vehicle trips have been assigned it will not be possible to appraise the value of such locations nor to design the new facilities properly. Traffic assignment, then, is the tool whereby the traffic planner reviews the effective demand for usage of a given facility or set of facilities. It is a means whereby desire lines are regrouped for further inspection of route locations.

These five papers present the work of advance thinkers on this subject. It is a tribute to the Highway Research Board that they can assemble five persons working quite independently, who have all sought to mechanize these procedures as much as possible. The authors come from Florida, Indiana, Michigan, Washington and California.

Moskowitz has described a mathematical formulation for determining the percentage split of traffic between competing routes. This entire calculation is done by machine once the measurements are in the trip cards. Moreover, he has shown that two alternate possible routes can have assignments made at thesame time. Finally, he has shown that California is able to compute economic benefits on these new routes at the same time the traffic assignment is computed.

Brown and Weaver have shown how Inidana has tackled this problem. Here they have used the mark sense card system to great advantage. Also, they have developed an interesting formula which considers the effects of multiple alternate routes. Of particular interest is the fact that their assignment of traffic is actually made to an entire arterial street network.

In Seattle, Mladinov has shown that they have made several interesting innovations They have calculated the effect of tolls on assignment of traffic, and they have considered the need for continual re-assignments during stage construction. They utilize vehicle mileage comparisons in analyzing the value of alternate routes. Mladinov has also raised the provocative question as to whether these running times should be used on alternate routes when such times will quite conceivably be different when the new facility is in place and traffic volumes are re-distributed.

Campbell's paper was interesting because he has presented a method for shortening the time-consuming process of dealing with each zonal transfer. Instead, he has suggested the "one end" coding method which greatly reduces the coding time, thus making possible assignment to more than one route or group of routes in a short time period. He has also advanced a method for reducing the number of measurements required to obtain the comparison between two routes. He allows the punched card equipment to calculate alternate arterial travel distances from coordinate point codes of the trip origin and destination.

Conner and Hiller have raised the next question which all traffic planning personnel will have to deal with — the use of the more complex, high speed, electronic computers.

They have pointed out that these machines are well adapted to making many of the serial calculations and decisions involved in this process.

Looking ahead, it is possible to see further refinements in assignment techniques. Traffic assignment is presently made to a facility with the assumption of no final design and, therefore, no capacity limits. Future methods will be evolved whereby actual flows can be simulated. Thus, where assignment techniques indicate probable demand, flow simulation will show actual estimated usage when (or if) completed. Assignment is essential to achieve optimum location patterns, but flows tell more about traffic management problems and the effects of new facilities on existing arterials. Thus it may be considered that in the future traffic assignment will be used to test route locations and to pin-point locations of need. However, simulating of flows will be necessary for preparing final design criteria, locating ramps, and planning traffic management during stage construction.

Looking ahead, once more, it is also possible to anticipate greatly increased mechanization of these processes as the normal behavior of travelers is organized into increasingly precise predictive equations. It seems inescapable that there will be high-speed computers able to remember an entire urban street network and capable of distributing all zonal interchanges to these routes, either for assignment or for actual flows.

These papers have indicated many different attacks designed to eliminate the drudgery of assigning traffic to proposed new routes. They give an idea of important improvements to come which will then put an essential and valuable tool in the traffic planner's bag, that of classifying origin-destination data in such a way as to increase knowledge of future traffic movements on new facilities. This should increase the quality and precision of route planning and will provide the design engineer with the information which is essential in avoiding design errors. Finally, such techniques greatly increase the general usefulness of data gathered in origin-destination studies.