Capacity of Traffic Signals and Traffic Signal Timing

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● SIMILAR CONDITIONS on a road produce similar behavior among motor vehicle users of that road. The principal research problem is to recognize and isolate the conditions and then measure traffic behavior under these conditions. Having done this for a sufficient number of varying conditions, practical application can be made covering other varying but similar conditions.

Although traffic on the open road may travel at random, traffic signals regiment this traffic into narrow bands of variation.

TABLE 1

US 1, SOUTHBOUND, AT AVENEL STREET

$$T_p = 1.2N + \frac{.95}{52}\sqrt{\left\{D + 25(N-1)\right\}\left\{D + 25(N-1) + 676\right\}}$$

PASSENGER CARS

	D = 55 FEET				D = 381 FEET				D = 629 FEET			
N	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.
1	225	4.45	4.87	+.42	213	12.62	12.80	+.18	206	17.01	17.75	+.74
2	182	6.59	6.89	+.30	167	14.73	14.51	-.22	167	19.69	19.45	-.24
3	130	8.62	8.83	+.21	123	16.86	16.22	-.64	120	21.08	21.12	+.04
4	102	10.64	10.72	+.08	90	18.60	17.92	-.68	92	22.66	22.81	+.15
5	72	12.68	12.56	-.12	60	20.36	19.63	-.73	64	24.16	24.49	+.33
6	56	14.59	14.38	-.21	45	21.87	21.32	-.55	48	26.27	26.16	-.11
7	48	15.72	16.16	+.44	35	22.06	23.03	+.97	38	26.99	27.84	+.85
8	28	18.74	17.95	-.79	13	25.08	24.73	-.35	21	30.05	29.53	-.52
9	14	20.97	19.70	-1.27	5	26.60	26.40	-.20	11	31.93	31.22	-.71
10	8	23.58	21.45	-2.13	2	27.45	28.10	+.65	6	34.18	32.91	-1.27
11	6	25.53	23.19	-2.34	1	32.50	29.80	-2.70	4	36.53	34.59	-1.94
12	5	27.30	24.93	-2.37	1	32.50	31.49	-1.01	3	40.33	36.26	-4.07
13	7	28.01	26.67	-1.34					3	36.23	37.93	+1.70
14	6	29.73	28.38	-1.35					2	36.45	39.59	+3.14
15	4	32.05	30.09	-1.96								
16	4	35.05	31.80	-3.25								

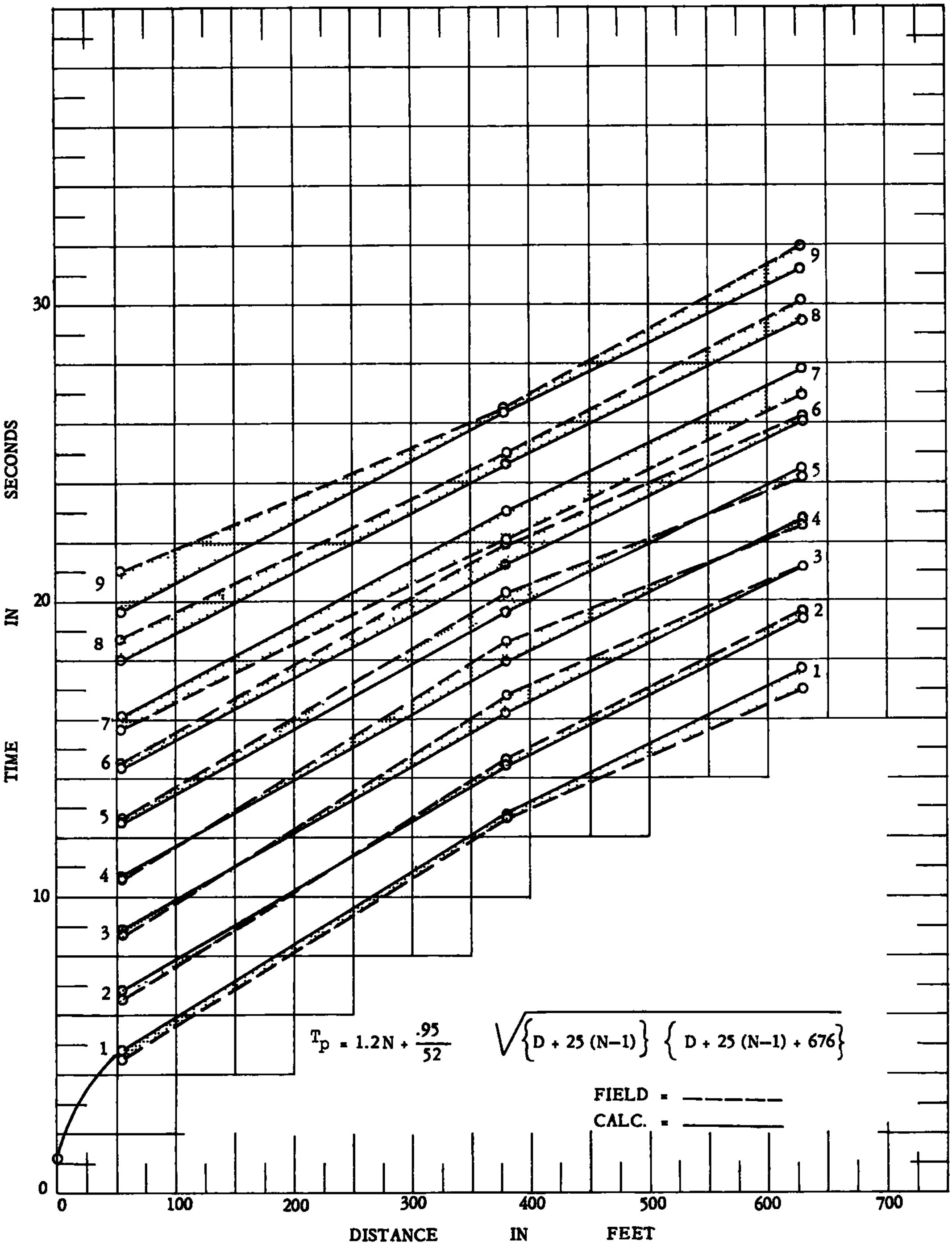


Figure 1. US 1, southbound, at Avenel Street—passenger cars.

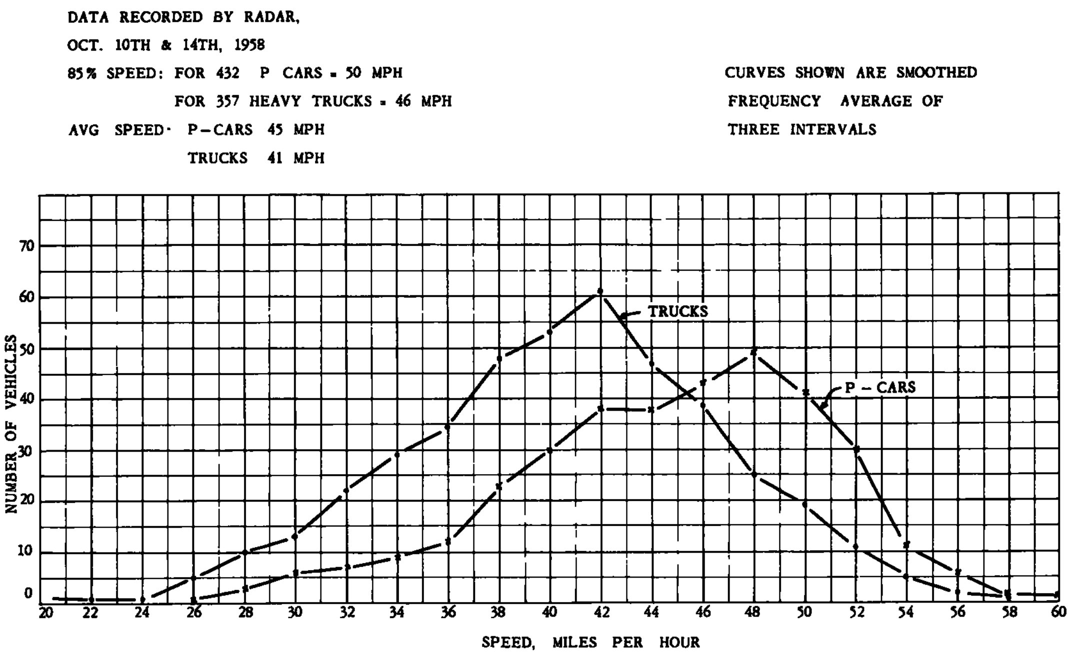


Figure 2. Smoothed frequency diagram, US 1, northbound, at Avenel Street.

The behavior of vehicles responding to the green signal, after waiting during the red signal can be described by:

$$T = PN + \frac{K}{S}\sqrt{\left\{D + C(N-1)\right\}\left\{D + C(N-1) + \frac{S^2}{4}\right\}} \quad (1)$$

in which T = time, in seconds, after the beginning of the green signal, to arrive at the distance D;

T_p = passenger car reaction time;
T_t = truck reaction time;
P = perception and reaction time, in seconds;
N = Nth vehicle stopped in line (single line);
K = constant of acceleration;
S = speed limit (real), in miles per hour;
D = distance in feet measured from the stop line of the first car; and
C = spacing in feet measured front to front of standing vehicles.

The perception and reaction time P for the first car is the time between the beginning of the green signal and the beginning of the vehicles forward motion. It includes the time for the first driver in line to perceive that the signal has turned green, the mental and physical reaction time of the driver to start the vehicle in motion, and the time for the mechanics of the vehicle to overcome inertia. The perception and reaction time for other drivers following is similar except that each driver must perceive that the vehicle immediately ahead has started its forward motion rather than perceive that the signal has turned green.

The constant K varies with the acceleration capabilities of the vehicle, within the desirable limits of the driver. Passenger car drivers seldom exercise the maximum or close to maximum capability of the vehicle.

The speed limit S is that speed limit which is reasonable. Where the posted speed limit is based on the 85 percentile method this speed limit is S but where the posted speed limit is higher or lower than the 85 percentile, the 85 percentile is used.

COMPARISON OF EQ. 1 WITH FIELD DATA

Table 1 and Figure 1 show a comparison of field data with calculated data on US 1, southbound at Avenel Street, Woodbridge, N.J. Field data were collected by a five man party pressing telegraph keys wired to an Eaterline—Angus 20 pen. recorder during the summer of 1958. US 1 has 37,000 cars per average day with 10 percent heavy trucks and 25 percent total trucks. The posted speed limit is 50 mph for 8 mi to the

TABLE 2

US 1, NORTHBOUND, AT AVENEL STREET

$$T_p = 1.2N + \frac{.95}{48}\sqrt{\left\{D + 25(N-1)\right\}\left\{D + 25(N-1) + 576\right\}}$$

PASSENGER CARS

	D = 52 FEET				D = 153 FEET				D = 222 FEET			
N	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.
1	159	4.74	4.78	+.04	24	8.62	7.81	-.81	72	10.29	9.53	-.76
2	111	6.84	6.83	-.01	5	9.28	9.64	+.36	17	11.68	11.33	-.35
3	69	8.90	8.81	-.09					3	16.43	13.10	-3.33
4	46	10.63	10.72	+.09								
5	29	12.61	12.59	-.02								
6	17	14.18	14.42	+.24								
7	11	16.15	16.24	+.09								
8	11	18.02	18.05	+.03								
9	1	21.90	19.84	-2.06								
10	1	25.20	21.62	-3.58								
11	1	27.40	23.39	-4.01								

$$T_t = 2.25N + \frac{1.32}{48}\sqrt{\left\{D + 50(N-1)\right\}\left\{D + 50(N-1) + 576\right\}}$$

TRUCKS

1	117	6.38	7.23	+.85	32	10.89	11.45	+.56	103	13.59	13.83	+.24
2	63	10.88	11.74	+.86	17	14.95	15.39	+.44	60	18.02	17.70	-.32
3	28	14.97	15.91	+.94	10	18.83	19.34	+.51	32	21.72	21.55	-.17
4	14	19.00	19.89	+.89	5	22.90	23.19	+.29	16	25.86	25.34	-.52
5	6	23.33	23.79	+.46	3	26.20	26.99	+.79	8	29.52	29.10	-.42
6	3	26.83	27.65	+.82					2	33.05	32.82	-.23
7	3	30.63	31.65	+1.02								

TABLE 2

US 1, NORTHBOUND, AT AVENEL STREET (Cont'd)

$$T_p = 1.2N + \frac{.95}{48}\sqrt{\left\{D + 25(N-1)\right\}\left\{D + 25(N-1) + 576\right\}}$$

PASSENGER CARS

	D = 237 FEET				D = 471 FEET				D = 685 FEET			
N	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.
1	110	10.00	9.89	-.11	155	15.00	15.09	+.09	19	19.77	19.59	-.18
2	90	12.08	11.68	-.40	96	16.98	16.83	-.15	5	24.36	21.32	-3.04
3	72	13.90	13.46	-.44	69	18.98	18.56	-.42				
4	52	15.63	15.21	-.42	49	20.55	20.30	-.25				
5	30	16.82	16.98	+.16	30	21.48	22.01	+.53				
6	19	18.54	18.74	+.20	17	23.44	23.75	+.31				
7	12	20.80	20.47	-.33	10	25.12	25.46	+.34				
8	11	22.76	22.23	-.53	7	26.50	27.17	+.67				

$$T_t = 2.25N + \frac{1.32}{48}\sqrt{\left\{D + 50(N-1)\right\}\left\{D + 50(N-1) + 576\right\}}$$

TRUCKS

N	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.
1	44	13.67	14.35	+.68	99	20.73	21.56	+.83	43	25.96	27.82	+1.86
2	19	18.49	18.18	-.31	56	25.33	25.29	-.04	18	30.72	31.48	+.76
3	4	22.88	22.00	-.88	30	28.78	29.00	+.22	4	33.95	35.23	+1.28
4	2	24.20	25.80	+1.60	16	33.65	32.70	-.95				
5					8	36.68	36.40	-.28				
6					2	39.45	40.08	+.63				

south and 1.5 mi to the north. Beyond these points the posted speed limit is 45 mph. The highway is level and tangent with 32 ft of concrete pavement on each side of a 16-ft raised median. The pavement is lane lined for three lanes in each direction. There are very few pedestrians but some marginal friction exists because of frequent gas stations, etc. Data collected were for passenger cars in the left-hand lane.

Field data shown are the average time for the number of samples; that is the sum of the individual times divided by the number of samples. A frequency speed diagram is shown in Figure 2.

For 100 percent passenger cars not affected by turning vehicles, the perception and reaction time P is found, by experiment, to be 1.2 and to be the same for the Nth car as for the first car. This value is found to increase as the speed decreases and to be different for trucks and passenger cars. For heavy trucks the value is 2.25.

The value for K for passenger cars is found to be 0.95 and for heavy trucks, 1.32. These values satisfy the test samples observed. The passenger car value seems to be constant for all locations. This is probably true because there is very little difference in the average passenger car at different locations. If all passenger cars were small low priced cars at one location and large high priced cars at another location, there probably would be a difference. The value for trucks undoubtedly varies from location to location. Predominantly loaded trucks will give a different value than unloaded trucks and there is a wide variation in performance ability of different makes and models of trucks.

Figure 3. US 1 at Avenel Street, Woodbridge (looking north).

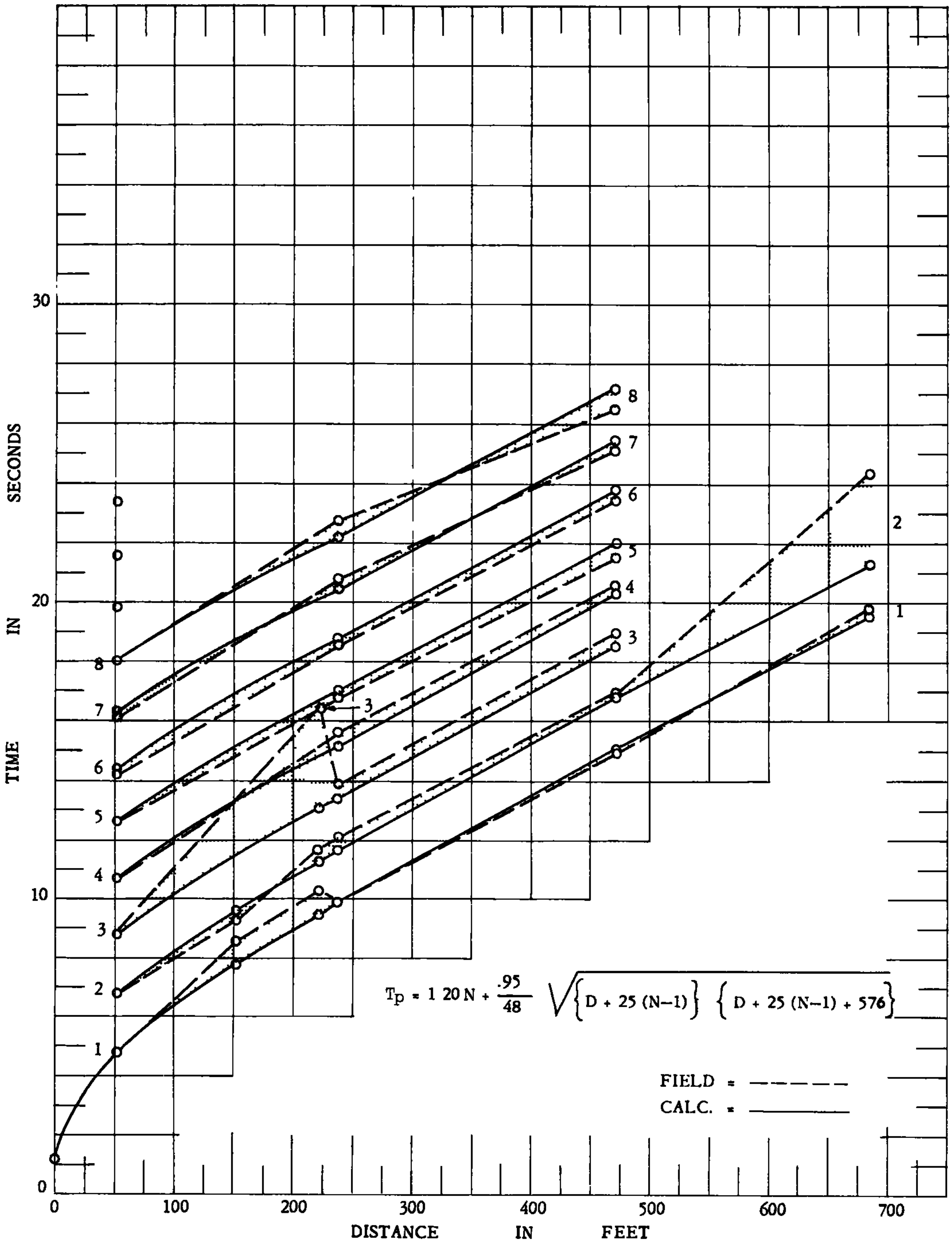


Figure 4. US 1, northbound, at Avenel Street—passenger cars.

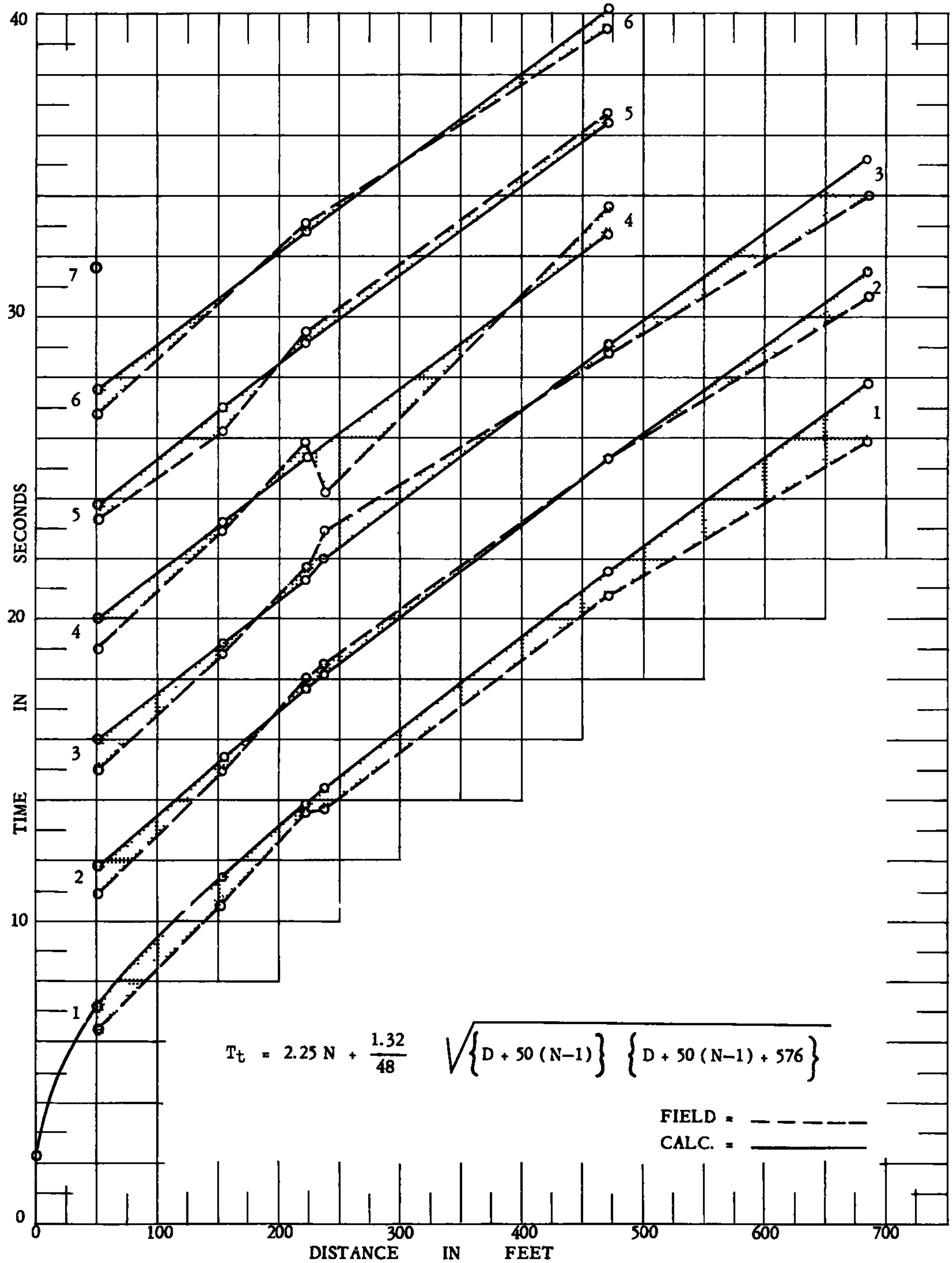


Figure 5. US 1, northbound, at Avenel Street—trucks.

TABLE 3

CALHOUN STREET, SOUTHBOUND, AT INGHAM AVENUE

$$T_p = 2N + \frac{.95}{29} \sqrt{\left\{D + 25(N-1)\right\} \left\{D + 25(N-1) + 210.25\right\}}$$

PASSENGER CARS

N	D = 30 FEET				D = 240 FEET				D = 441 FEET			
	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.
1	64	4.48	4.72	+.24	62	12.22	12.78	+.56	52	19.11	19.56	+.45
2	42	7.48	7.96	+.48	42	15.17	15.63	+.46	34	22.69	22.38	-.31
3	19	11.47	10.98	-.49	18	18.34	18.48	+.14	16	25.24	25.23	-.01
4	8	13.69	13.96	+.27	8	21.41	21.33	-.08	7	28.07	28.05	-.02
5	2	15.85	16.88	+1.03	2	23.45	24.28	+.83	2	30.40	30.87	+.47

TRUCKS

1	9	4.07			8	13.96			8	22.30		

The value of C for passenger cars is 25 ft. This consists of the length of the average passenger car measured from bumper to bumper plus the average spacing between standing vehicles measured from the rear bumper of one vehicle to the front bumper of the vehicle immediately in back. The length of the average passenger car is taken as 17 ft and the space between as 8 ft.

The C for heavy trucks is 50 ft for the US 1 location and assumed to be the same for locations with similar types of trucks. The 50 ft is taken as composed of 42 ft for the length of vehicle and 8 ft for the space between vehicles. It is possible that this is in error in that the average heavy truck may be less than 42 ft long and the space between trucks may be longer than 8 ft.

US 1 northbound, at Avenel Street (Fig. 3), data are given in Table 2 and shown in Figures 4 and 5. Samples selected from field data include only 100 percent samples. That is, the Nth truck was preceded by N-1 trucks. Passenger cars were selected similarly. Where the Nth vehicle was preceded by some trucks and some passenger cars, data were tabulated but not included in this part of the study.

Calhoun Street northbound, at Ingham Avenue, in Trenton has one moving lane with parked vehicles along the curb. It is an urban location close to the central business district with a legal speed limit of 25 mph. Comparative data are shown in Table 3 and Figure 6.

Brunswick Avenue southbound, at Olden Avenue, in Trenton (Fig. 7), is an urban area similar to the Calhoun Street location. Comparative data are shown in Table 4 and Figure 8.

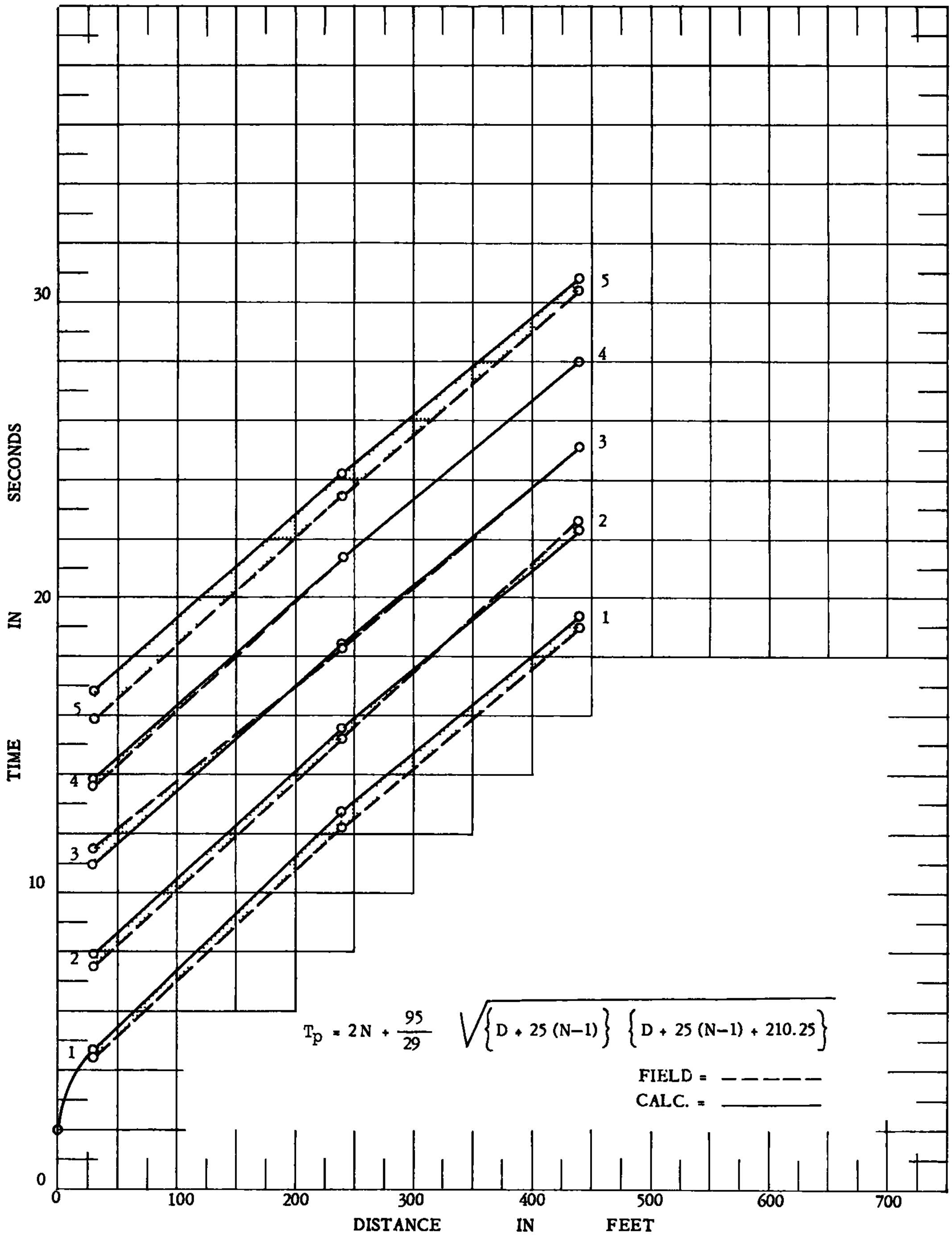


Figure 6. Calhoun Street, northbound, at Ingham Avenue—passenger cars.

TABLE 4

BRUNSWICK AVENUE, SOUTHBOUND, AT OLDEN AVENUE

$$T_p = 2N + \frac{.95}{30}\sqrt{\left\{D + 25(N-1)\right\}\left\{D + 25(N-1) + 225\right\}}$$

PASSENGER CARS

	D = 40 FEET				D = 400 FEET				D = 485 FEET			
N	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.	Samples	Field	Calc.	Diff.
1	49	5.51	5.26	-.25	47	17.25	17.83	+.58	44	19.51	20.59	+1.08
2	21	9.19	8.34	-.85	21	20.98	20.66	-.32	20	23.40	23.38	-.02
3	11	11.99	11.32	-.67	11	23.48	23.45	-.03	10	25.90	26.20	+.30

TRUCKS

1	13	6.22			12	19.44			11	21.63		
2	4	12.25			2	22.30			2	24.55		

TRAFFIC SIGNAL CAPACITY AND SIGNAL TIMING

Free flowing traffic on an open highway has time intervals between successive vehicles which vary according to laws of probability. Figure 9 shows the maximum number of vehicles approaching in short time intervals for given hourly volumes of approach traffic based on Poisson's theory of probability. Part vehicles are dropped off and it is limited to one such hour. Theoretically a million such hours would give a larger maximum number per short time interval than that shown.

Figure 10 shows the number of seconds required to pass a given maximum number of vehicles per short time cycle in accelerating from a stopped position as occurs under traffic signal control. At a traffic signal the number of vehicles arriving during a traffic signal cycle of red, amber and green, must be passed during the green period of that cycle in order to avoid backing up and requiring vehicles to wait during more than one red period. This figure applies for uninterrupted passenger cars on a road where the real speed limit is 50 mph. It can be used to determine the signal timing and cycle required for design hour volumes or to determine the capacity of a given cycle and timing.

A traffic signal can carry the maximum number of cars during each cycle which results in the absolute capacity but this occurs when the signal is greatly over-loaded and traffic is backed up for a long distance with vehicles must waiting for many changes of signal before passing through. This is a degree of congestion to be avoided. The signal timing should be such that the maximum number of vehicles per cycle occurs only once during the design hour. This is the design capacity of the signal timing.

Figures 11, 12, 13 show similar charts for use on 40-, 30- and 20-mph roads for passenger cars on level grades and with normal daylight and weather conditions.

Figure 14 is a similar chart for heavy trucks on a 50-mph road on level grades and with normal daylight and weather conditions.

Figure 7. Brunswick and Olden Avenues, Trenton.

These charts are developed from the use of Eq. 1 with the following variables:

	S	P	K	C
Passenger Cars	50	1.2	0.95	25
Passenger Cars	40	1.6	0.95	25
Passenger Cars	30	2.0	0.95	25
Passenger Cars	20	2.4	0.95	25
Heavy Trucks	50	2.25	1.32	50

Figure 15 shows the timing required for each of the above charts for ease of comparison of the effect of speed and vehicle type. Also included are cycle lengths up to 300 sec. Some of this is extended beyond the limits of practical application but this is done for analytical purposes only. Certainly to have 70 heavy trucks in line go through a signal cannot be expected but this should have a bearing on possible application for a short cut method of signal timing on the bases of percentage of trucks to total hourly volume.

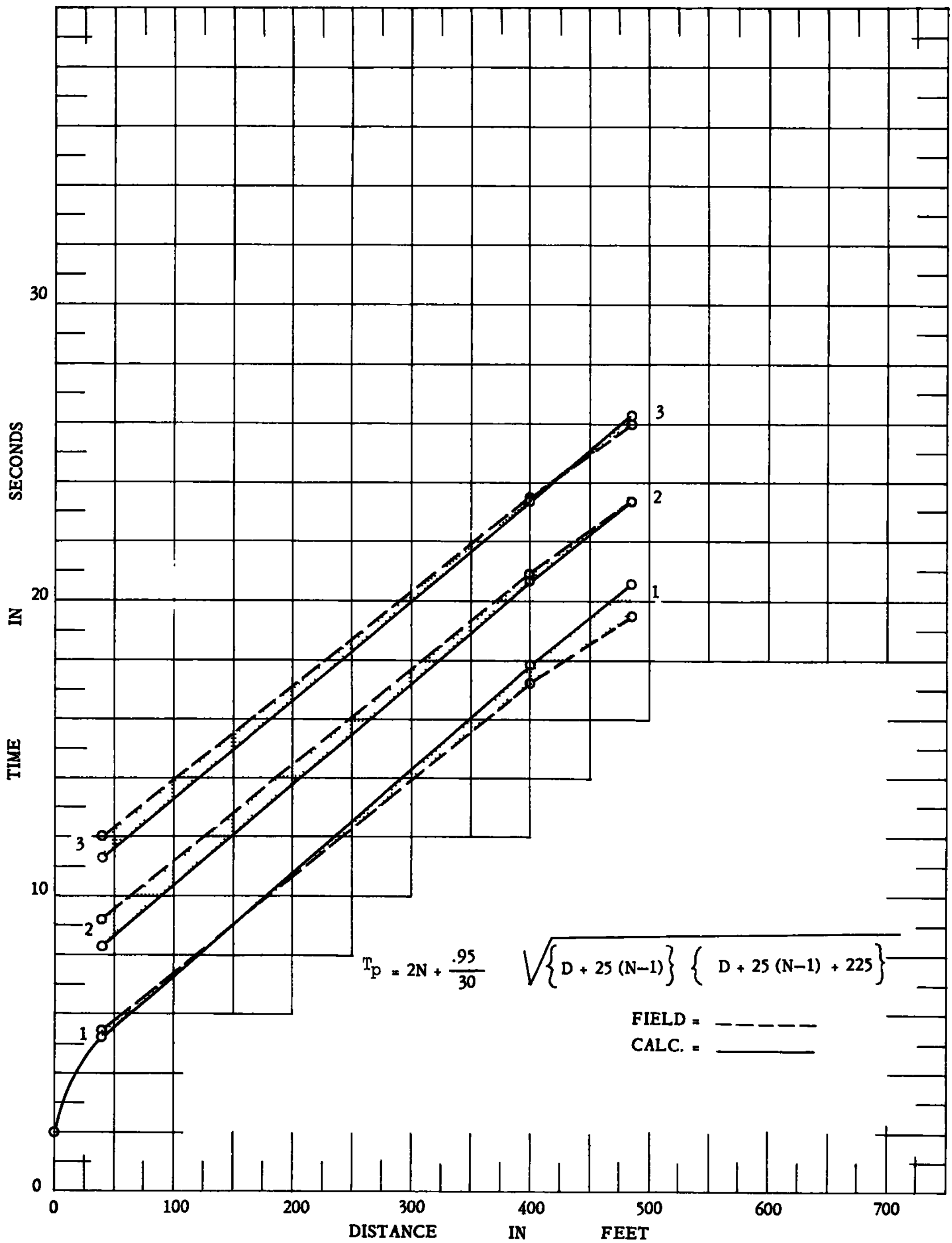
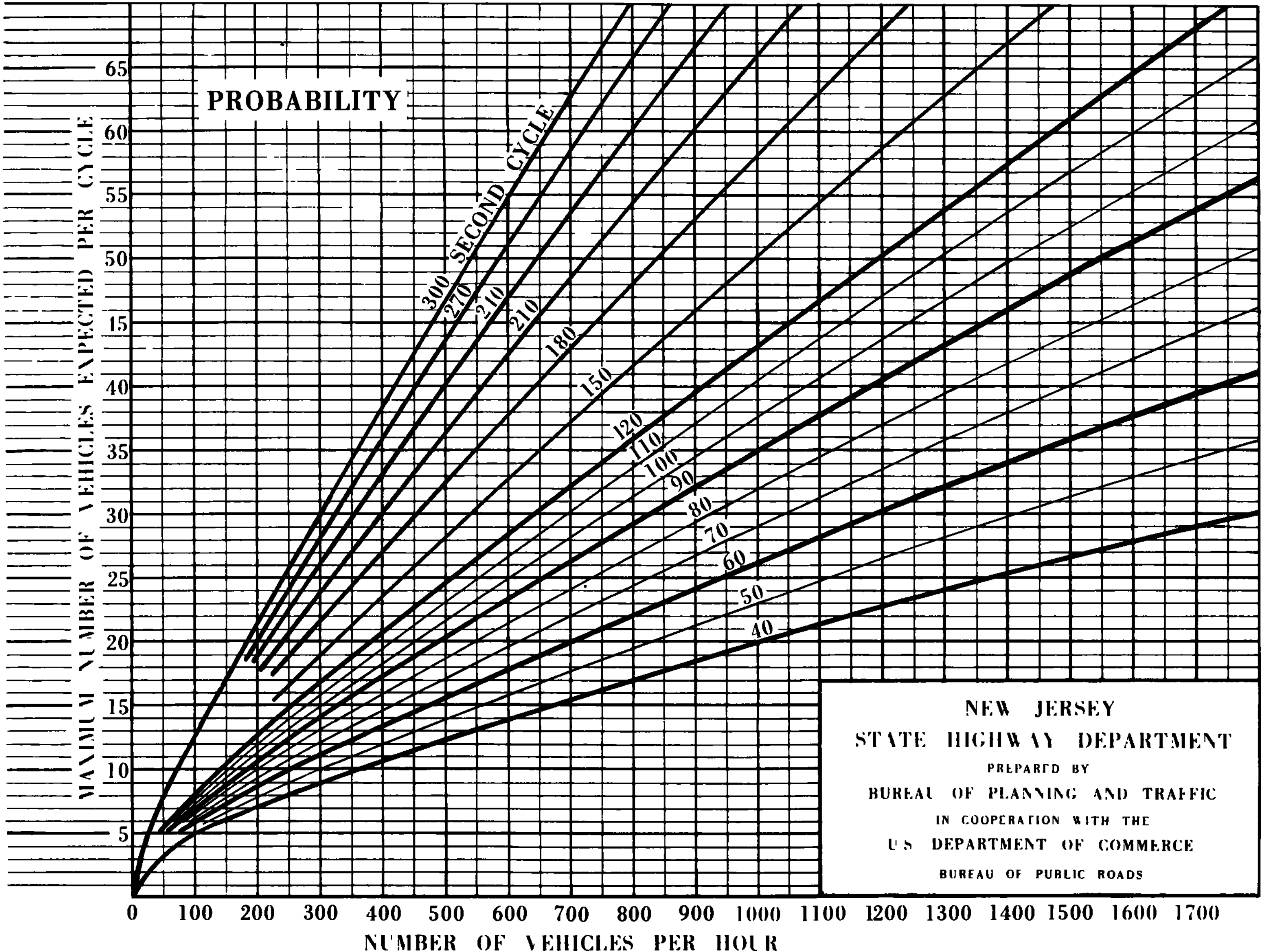


Figure 8. Brunswick Avenue, southbound, at Olden Avenue—passenger cars.

It is planned to continue this study to include the effect of upgrade, downgrade, nighttime and rainy weather.

It is also planned to extend this study to include the effect of closely spaced signalized locations, such as experienced in high type complex channelization.


PROBABILITY
300 SECOND CYCLE
270
210
210
180
150
120
110
100
90
80
70
60
50
40
MAXIMUM NUMBER OF VEHICLES EXPECTED PER CYCLE
NUMBER OF VEHICLES PER HOUR
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700
5 10 15 20 25 30 35 40 45 50 55 60 65
NEW JERSEY
STATE HIGHWAY DEPARTMENT
PREPARED BY
BUREAU OF PLANNING AND TRAFFIC
IN COOPERATION WITH THE
U.S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

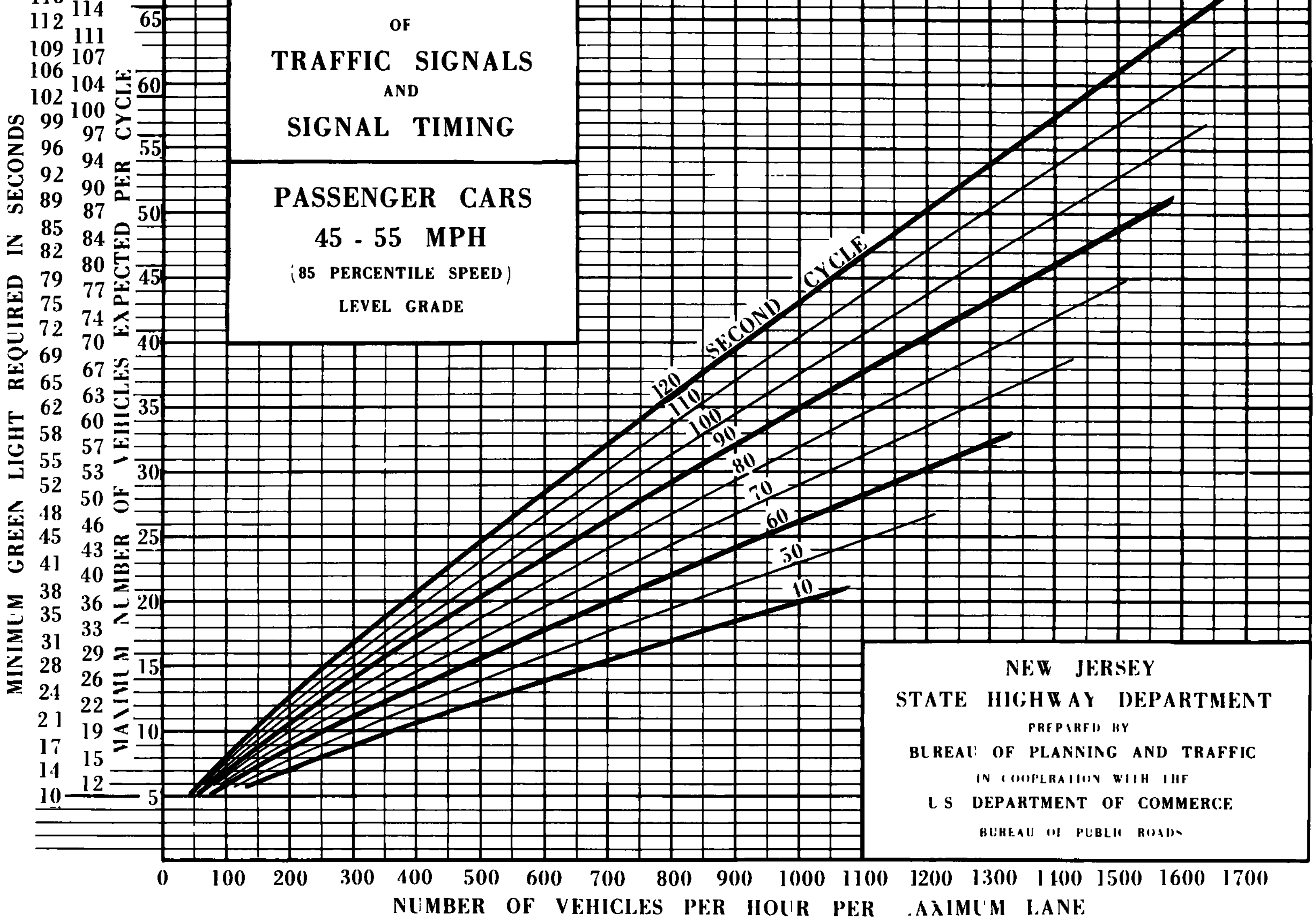
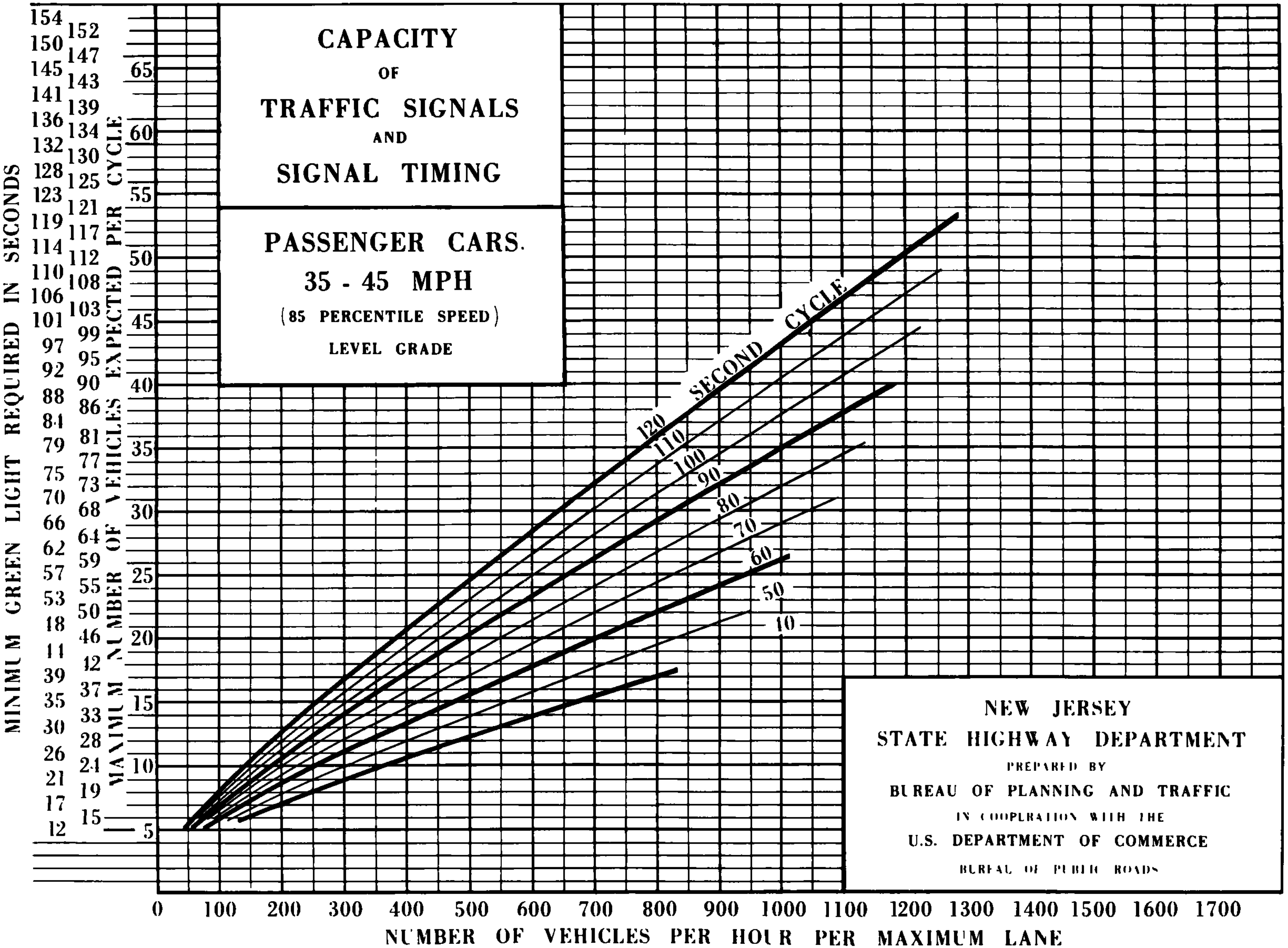

OF
TRAFFIC SIGNALS
AND
SIGNAL TIMING
PASSENGER CARS
45 - 55 MPH
(85 PERCENTILE SPEED)
LEVEL GRADE
NEW JERSEY
STATE HIGHWAY DEPARTMENT
PREPARED BY
BUREAU OF PLANNING AND TRAFFIC
IN COOPERATION WITH THE
U S DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS
120 SECOND CYCLE
110
100
90
80
70
60
50
40
MINIMUM GREEN LIGHT REQUIRED IN SECONDS
MAXIMUM NUMBER OF VEHICLES EXPECTED PER CYCLE
NUMBER OF VEHICLES PER HOUR PER MAXIMUM LANE
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700

Figure 10.


CAPACITY
OF
TRAFFIC SIGNALS
AND
SIGNAL TIMING
PASSENGER CARS.
35 - 45 MPH
(85 PERCENTILE SPEED)
LEVEL GRADE
120 SECOND CYCLE
110
100
90
80
70
60
50
40
MINIMUM GREEN LIGHT REQUIRED IN SECONDS
MAXIMUM NUMBER OF VEHICLES EXPECTED PER CYCLE
NUMBER OF VEHICLES PER HOUR PER MAXIMUM LANE
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
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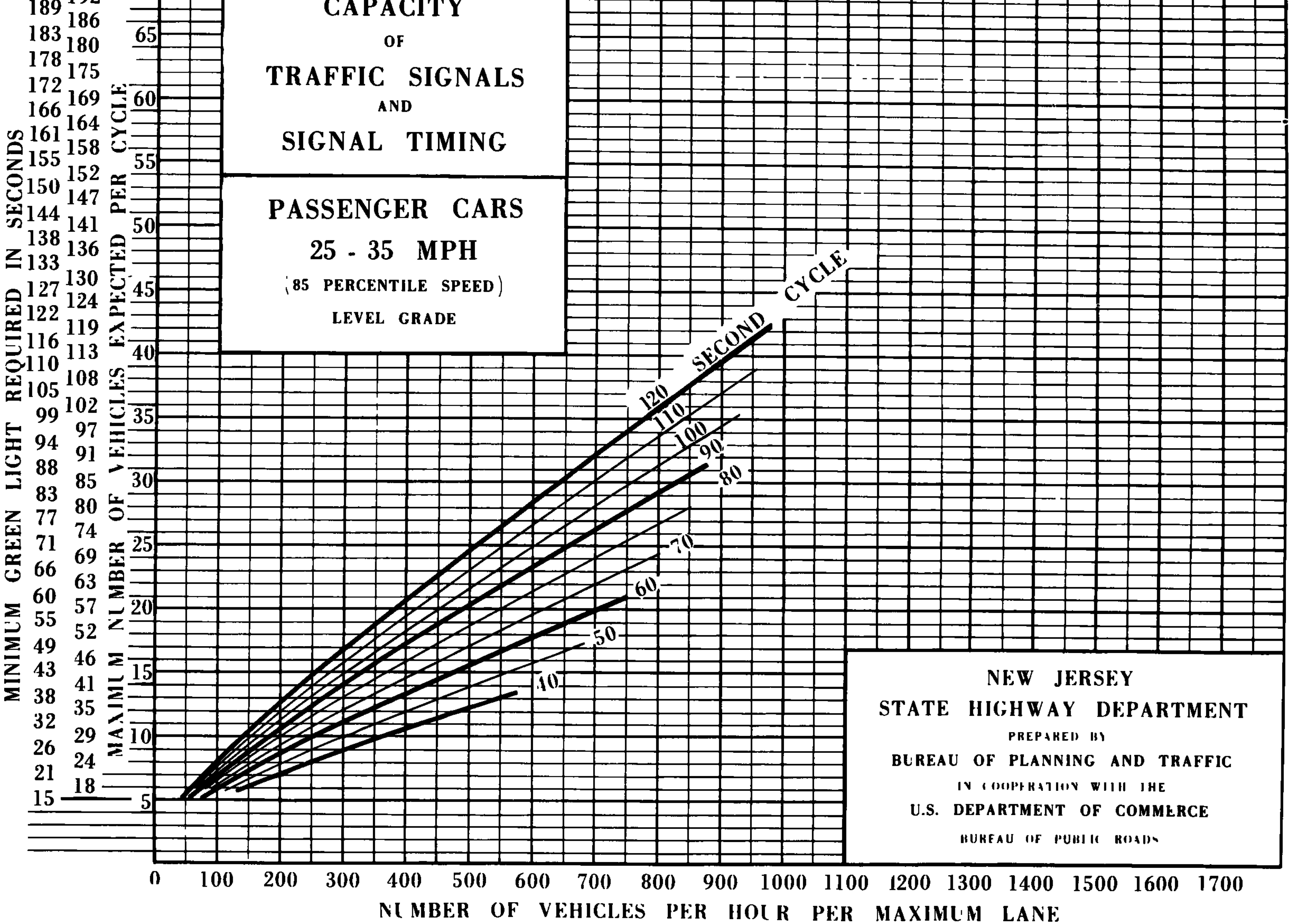
CAPACITY
OF
TRAFFIC SIGNALS
AND
SIGNAL TIMING
PASSENGER CARS
25 - 35 MPH
(85 PERCENTILE SPEED)
LEVEL GRADE
120 SECOND CYCLE
110
100
90
80
70
60
50
40
MINIMUM GREEN LIGHT REQUIRED IN SECONDS
MAXIMUM NUMBER OF VEHICLES EXPECTED PER CYCLE
NUMBER OF VEHICLES PER HOUR PER MAXIMUM LANE
NEW JERSEY
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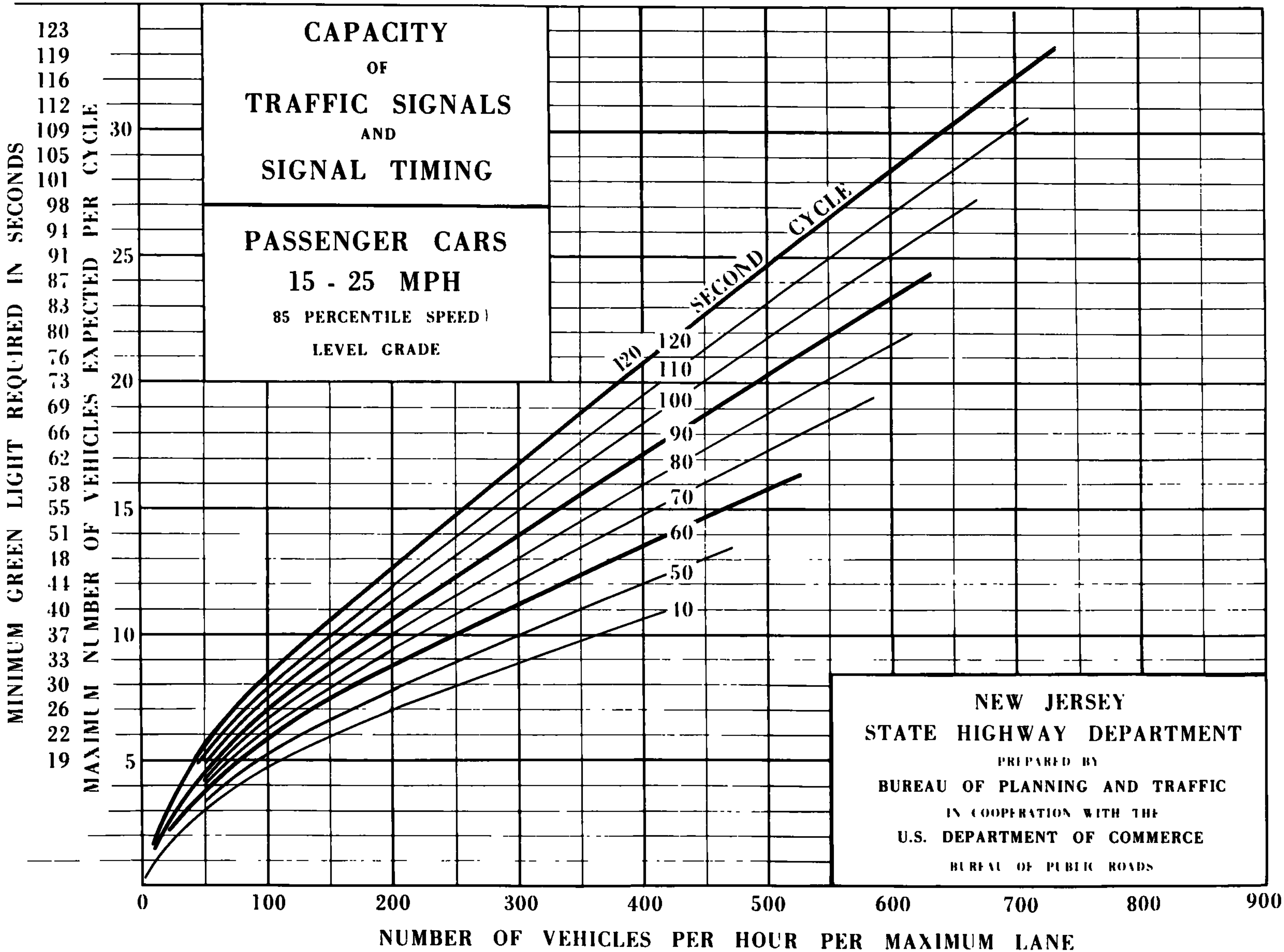
Figure 12.


CAPACITY
OF
TRAFFIC SIGNALS
AND
SIGNAL TIMING
PASSENGER CARS
15 - 25 MPH
85 PERCENTILE SPEED)
LEVEL GRADE
120 SECOND CYCLE
120
110
100
90
80
70
60
50
40
MINIMUM GREEN LIGHT REQUIRED IN SECONDS
123 119 116 112 109 105 101 98 94 91 87 83 80 76 73 69 66 62 58 55 51 48 44 40 37 33 30 26 22 19
MAXIMUM NUMBER OF VEHICLES EXPECTED PER CYCLE
30 25 20 15 10 5
0 100 200 300 400 500 600 700 800 900
NUMBER OF VEHICLES PER HOUR PER MAXIMUM LANE
NEW JERSEY
STATE HIGHWAY DEPARTMENT
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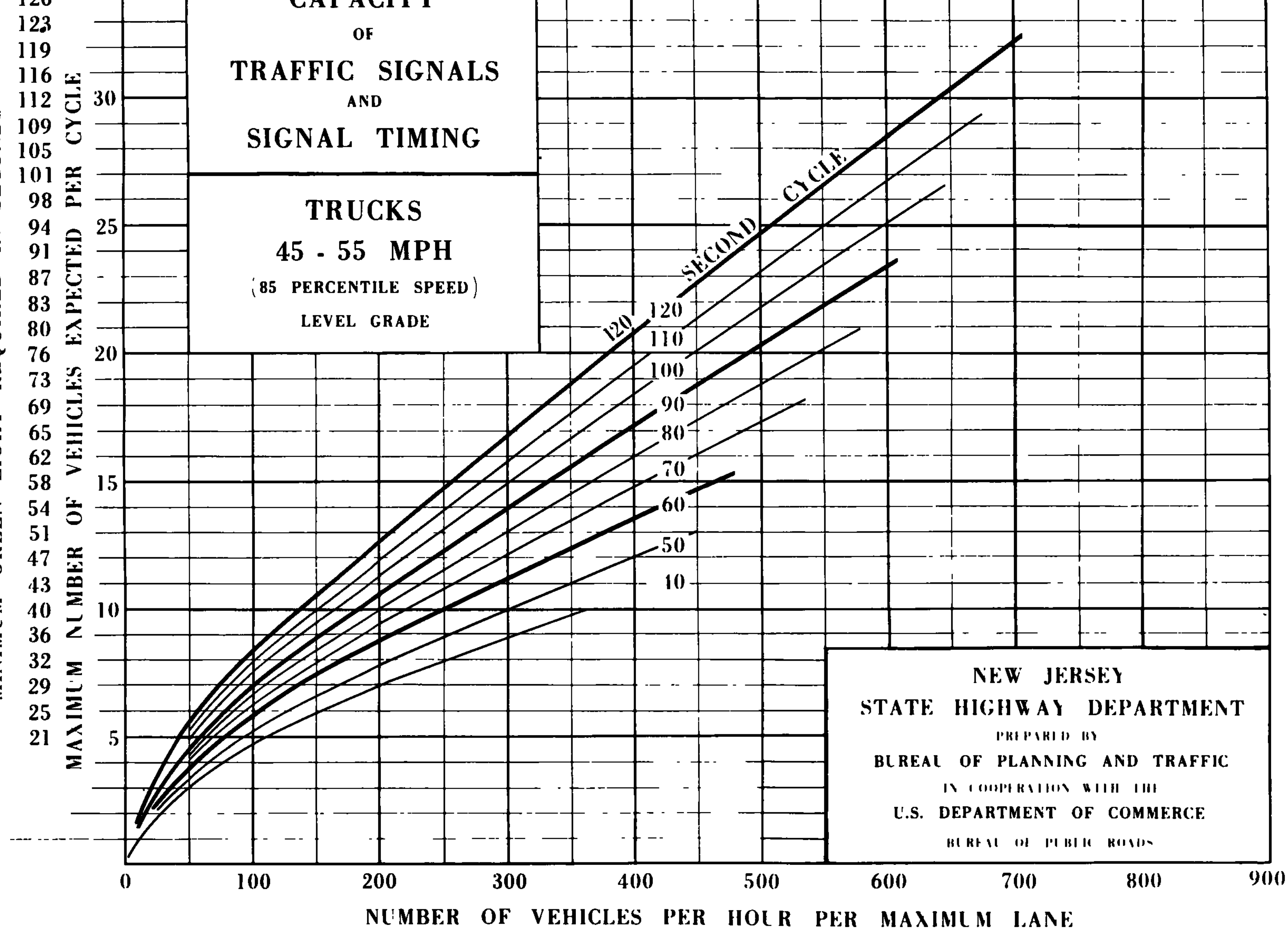
OF
TRAFFIC SIGNALS
AND
SIGNAL TIMING
TRUCKS
45 - 55 MPH
(85 PERCENTILE SPEED)
LEVEL GRADE
120 SECOND CYCLE
120
110
100
90
80
70
60
50
10
MINIMUM GREEN LIGHT REQUIRED IN SECONDS
MAXIMUM NUMBER OF VEHICLES EXPECTED PER CYCLE
NUMBER OF VEHICLES PER HOUR PER MAXIMUM LANE
NEW JERSEY
STATE HIGHWAY DEPARTMENT
PREPARED BY
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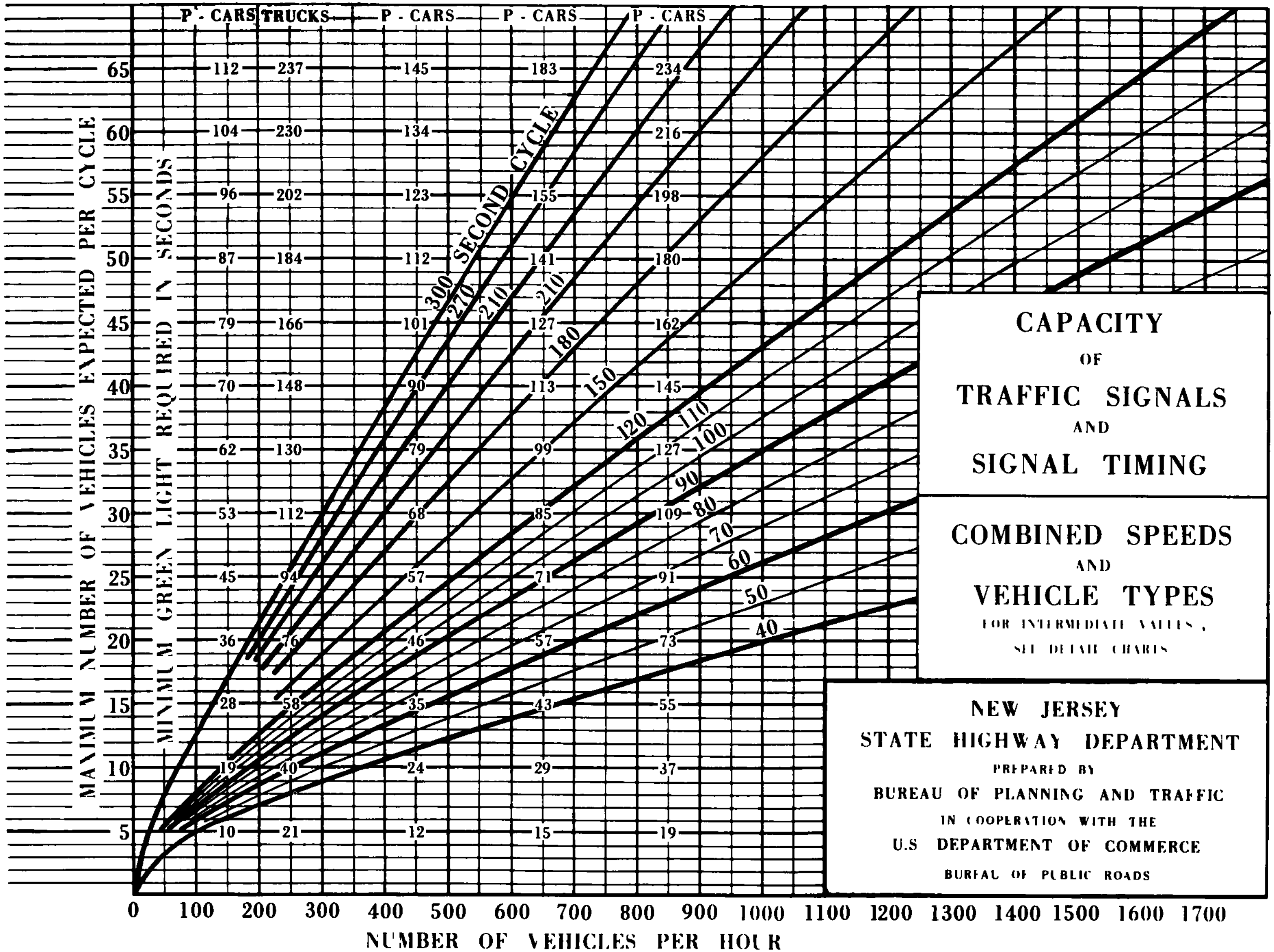
BUREAU OF PUBLIC ROADS

Figure 14.


CAPACITY
OF
TRAFFIC SIGNALS
AND
SIGNAL TIMING
COMBINED SPEEDS
AND
VEHICLE TYPES
FOR INTERMEDIATE VALUES,
SEE DETAIL CHARTS
NEW JERSEY
STATE HIGHWAY DEPARTMENT
PREPARED BY
BUREAU OF PLANNING AND TRAFFIC
IN COOPERATION WITH THE
U.S DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS
MAXIMUM NUMBER OF VEHICLES EXPECTED PER CYCLE
MINIMUM GREEN LIGHT REQUIRED IN SECONDS
NUMBER OF VEHICLES PER HOUR
P - CARS
TRUCKS
P - CARS
P - CARS
P - CARS
300 SECOND CYCLE
270
240
210
180
150
120
110
100
90
80
70
60
50
40
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
5
10
15
20
25
30
35
40
45
50
55
60
65

Appendix

After having the benefit of comments by the Division of Traffic Operations of the Bureau of Public Roads, the Department of Traffic and Operations of the Highway Research Board, and others, the author wishes to add the following:

Although the paper makes no reference to the methodology utilized to derive the acceleration equation (Eq. 1), the experienced researcher realizes that there was much preliminary work. It may be possible, with the given field data, to arrive directly at the desired equation, but not so with this researcher.

The first attempt to write this paper included a description of the procedures and methods used but this seemed useless. The only useful part is the equation and its application. It would have been easy for highly rated mathematicians to "prove" that the procedure was wrong (and most of it was) even though the conclusions had practical value. Possibly the author did not care to display his ignorance compared to some of the fancy mathematics floating around these days.

The method used was "trial and success." Different basic mathematical equations were tried for fit with field data. Much field data were collected, most of which was finally treated as pilot studies. Assuming that Eq. 1 receives widespread application (as the author hopes) very few, if any, individuals will really care how it was derived.

Reference is made to adding feet and speed squared under the radical—which it seems is not "cricket." The author has no reply except that this was necessary to make a close fit.

Consideration was given to vehicles anticipating the green signal and accelerating before the signal changed. This behavior is included in these data collected. Some cars did start before the green signal and some were caught napping. Reference is made to an apparent disagreement with a paper "Starting Delay and Time Spacing of Vehicles Entering Signalized Intersections" by Bartle, Skoro and Gerlough, in HRB Bul. 112. It is quite possible that the two papers are in agreement, with the variables different but interpreted as the same. The value of P in the equation was not assumed; it was determined by trial and success to fit these data and gives the same value for the first car as for the Nth car.

A question has been raised as to how the capacity charts were developed from the acceleration equation. On the probability chart, the time for each maximum number of vehicles expected per cycle to arrive at the 50-ft point beyond the stop line after the beginning of the green signal was placed along side each corresponding maximum number of vehicles expected per cycle. These times were determined from Eq. 1 substituting 50 ft for D and applicable values for each of the other variables. Having done this the chart plotting is reduced to the applicable ranges.

The author cannot explain the unit values of K. It developed from the trial and success method to make a fit.

In the text S has been defined as equal to the speed limit (real). In the equation S is the speed reached after completing acceleration. This is a limit and in this sense each car has its speed limit. The value of S was determined by trial and success for each test location for a fit with these field data. The values for fit did not equal the legal speed limit or the 85 percentile speed. For US 1 southbound passenger cars S was 52: for US 1 northbound passenger cars it was 48, for US 1 northbound trucks it was 48. Here the posted speed limit is 50 mph based on the 85 percentile test. For Calhoun Street passenger cars S was 29 and for Brunswick Ave. passenger cars it was 30 and the posted speed limit is 25 mph. It so happens that the speed in the equation and the posted speed limit (if real) are reasonably close and, therefore, in the use of the charts the 85 percentile speed is used. Where the posted speed limit is based on the 85 percentile speed, the posted speed limit is used. Where it is known that the posted speed limit is not reasonable a reasonable speed should be used. At the Calhoun St. and the Brunswick Ave. locations the posted speed limits are 25 mph. A knowledge of the location would show that this is on the low side although justified rather than a speed limit of 30 mph. For these locations the 25 to 35 mph chart would be used rather than the 15 to 25 mph chart.

The application of speed to traffic is a very easily confused factor. When a posted speed limit is needed what should it be? Certainly it should be a speed somewhere between the lower limit and the upper limit of the individual speeds. For enforcement purposes it was agreed that it should be higher than the average or the mean so it was set at the 85 percent point as determined during off hours. It could have been 80 percent, 90 percent, 95 percent or other. At 85 percent the posted speed limit will be exceeded by 15 percent of the drivers who may very well be among the best citizens but all made to look like law breakers. All 85 percentile speed determined on a Sunday, weekday or Saturday could vary widely. It could differ if determined in the a.m. or p.m. or by hours. Morning commuters travel faster than midafternoon traffic. Hot or cold weather makes a difference. There are many influencing factors but the aim is to arrive at an acceptable, reasonable and enforceable speed limit. For some other applications it is better to use the average speed. In clocking speeds of all cars on a multilane one-way roadway, through a distance, it is found that speeds are highly variable even where acceleration is not a factor. The speed of the same car varies through the distance; the speed of, even, successive cars varies; and the speeds in different lanes vary. The best that can be done is to arrive at a speed which is representative and usable for the purpose at hand. Very confusing observations have been made in attempting to apply speed to traffic problems but they are too complex to discuss here.

It so happens that the S in Eq. 1 is reasonably close to the speed limit as determined by the 85 percentile method and this provides a convenient value to use in the application of the signal charts.

It has been suggested that the S be made equal to the 85 percentile speed and compensate for this with a constant. The 85 percentile speed is not conveniently available but the posted speed limit very often is available. If the posted speed limit is used there is no constant to take care of the change. From data available there is no constant to equate S to an 85 percentile speed.

USE OF THE CHARTS

Example 1.—Given; a 60-sec cycle with 27 sec green in an area where the posted speed limit, as determined by the 85 percentile method, is 30 mph; find the capacity per maximum lane. Solution: on the 25-35 mile per hour chart (Fig. 12) find 27 sec minimum green light required. Here we must use 26 seconds which is the next lower time given. The use of 27 interpolated would give $9\frac{1}{3}$ cars during the maximum cycle. Only whole cars can be used. From this 26-sec point go to the right horizontally to an intersection with the 60-sec cycle line and then go down vertically to obtain 210 passenger vehicles per hour per maximum lane as the design capacity per maximum lane. To find the absolute capacity per maximum lane: from the 26 sec go to the right and find 9 as the maximum number of vehicles expected per cycle. Multiply 9 times the number of cycles in an hour or (3,600 sec divided by 60 sec) 60 to obtain 540 passenger cars which is the absolute capacity per maximum lane.

Example 2.—Given a design hour of 400 passenger cars per hour per maximum lane in an area where the posted speed is 40 mph determined by the 85 percentile method; find a signal timing that will have a design capacity of the 400 passenger cars per maximum lane per hour. Solution: On the 35 to 45 mph passenger car chart (Fig. 11) find 400 vehicles per hour per maximum lane then go up vertically to intersect a cycle length line; then go horizontally to the left to find the minimum green light required. If a 60-sec cycle had been selected, a green time of 33 sec would be required. The 31 sec matches $13\frac{1}{3}$ cars so the 33 sec must be used to avoid the part car. With 3-sec ambers this would give 21 sec on the crossroad. It may be desirable to have equal greens on the crossroads. In this case an 80-sec cycle, or longer, will satisfy. Using an 80-sec cycle start at 400 vehicles per hour per maximum lane and go up to in-

tersect with the 80-sec cycle line, then to the left to read 37-sec minimum green light required. Adjacent to the 37 sec is 16 as the maximum number of cars per cycle, so 16 times 3,600 sec divided by 80 sec equals 720 cars as the absolute capacity.