SIMULTANEOUS MEASUREMENT OF SATURATION FLOW AND PCU VALUES AT SIGNALISED INTERSECTIONS WITH MIXED FLOWS

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abstract : This paper describes the development of program PASS which is an easy and quick method to determine saturation flow and related passenger car unit values, simultaneously, at the stop line of a signalised intersection. The method is aimed at cities of developing countries with mixed driver and vehicle characteristics. The program is based on manipulation of the straight (saturated) part of the cumulative flow curve. Tryouts have shown that the method is reliable and easy to operate. Full automation of the original manual manipulation process has improved the reliability and shortened the analysis time for selected conditions to a few seconds.

1. INTRODUCTION

Saturation flow and passenger car unit (pcu) values are main variables for determining signal settings at signalised intersections. These values tend to vary with vehicle and driver characteristics and also from site to site ; preferably these values should be measured on site whenever possible, rather than taken from design manuals which give overall average values.

Saturation flow and pcu values can be determined separately or simultaneously. When determined separately, one is assumed to be known and the other is calculated by using actual flow data. For simultaneous determination a regression analysis is normally done in the office and this requires a certain amount of effort, comprising field data collection, compilation and analysis.

The condition at intersections in developing countries is often different from those in developed countries. The recent standard procedures for signal calculations, which come from developed countries, are based on a lane by lane, or by lane group analysis ; this is often difficult to apply

in developing countries because of lack of lane markings, or lane discipline. The vehicle mix and vehicles themselves are also different, e.g. high number of motorcycles, higher mass to power ratios, smaller sized vehicles and presence of slow vehicles in developing countries.

Thus there is a need for appropriate methods to determine saturation flow and pcu values which are applicable to the specific conditions. Program PASS was developed by the author to fill this need.

2. DEVELOPMENT OF METHODOLOGY

The methodology is a result of a mixture of influences. Part of the idea came from the headway ratio method for determining pcu values of heavy vehicles (Salter, 1976). Then there is a report by Wood (1986) who automated the time-slice-method (Road Note 34) by utilising the accurate internal clock of the Epson HX-20 micro computer. Shanteau (1988) converted average passage times from several cycles into cumulative data to obtain saturation flow, starting lost time and ending lost time simultaneously, but did not derive pcu's. The methodology of PASS is described briefly next.

The discharge of cars past the stop line during a green period can be presented with a cumulative curve. The relationship between the total number of cars passing the stop line and the elapsed time will form a typical S-curve with each point representing a certain car. See Figure 1. The slope of tangents along the S-curve indicate the respective flow rates. At the early part of the green, time headways between successive cars are gradually decreasing as the first cars accelerate across the stop line. Later, when the queue has discharged, or at the end of the green period, time headways increase as less cars cross the stop line.

Program PASS is based on the assumption that the straight sloping part of this S-curve represents the saturated part of the green period and that the slope itself represents the saturation flow rate. It is also assumed that this sloping part has to be straight when representing a steady state saturated flow condition.Consequently the saturated period extends from the start to the end of this sloping part, and need not be identified in the field.

For a mixture of vehicle types the straight sloping part of the S-curve will show a scatter of points. This is caused by the fact that non-cars discharge across the stop line with different time headways ; the larger the headways, the larger the scatter.

A straight line with minimum scatter can be obtained by assigning pcu values to the respective vehicle types and changing the vertical scale of the S-curve from total vehicles into total pcu's. Each point now represents the passage of a certain vehicle across the stop line and consequently the elapsed time has to be based on the instant the rear end of the vehicle passes the stop line.
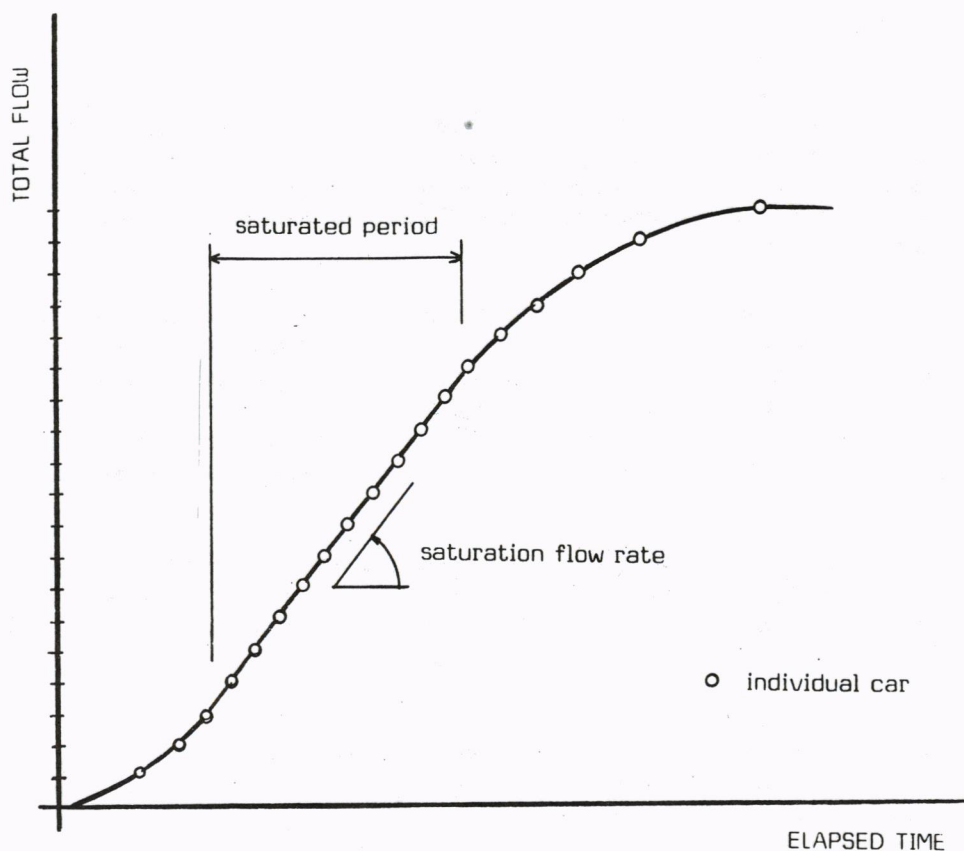
Figure 1 Typical Cumulative Flow of Cars, Discharging Across A Stop Line
During A Green Phase with Saturated Period

So the saturation flow and pcu values for a mixed flow of vehicle types are obtained from a unique condition of the straight slope of the S-curve. Pcu values are determined through a trial and error process; a change of pcu values will change the total (cumulative) number of pcu's and this causes a change in the S-curve and therefore a change in saturation flow value. In line with above assumption that a steady state saturated flow condition is indicated by a straight slope on the cumulative curve, a true saturated condition for mixed flows is achieved when the scatter of points at this straight slope is minimum. The pcu values that produce this specific condition are thus the true values which produce a true saturation flow value.

3. PROGRAM 'PASS'

PASS is an abbreviation of " Pengukuran Arus Jenuh dan Satuan Mobil Penumpang Sekaligus ,"
or, simultaneous measurement of saturation flow and pcu values. It is a purposely developed
program which is based on the methodology described briefly above. The objective is to utilise
the powerful computing and graphics capabilities of a modern 486 notebook computer, with
color monitor, in the field.

Program PASS utilises the internal clock of the computer and is based on very small time
slices to obtain an accurate discharge pattern. To synchronise the elapsed time in seconds with
the computer clock a time slice of 2/18.2 seconds or about 0.11 seconds is used. When
compared with the average time headway of about 2 seconds for a saturated condition , the
small time slices give near exact representations on the cumulative graph. The computer
will keep track of the elapsed time and so an observer does not have to look at a watch during
field observations.

The use of very small time slices will result in many empty slices, during which no vehicle
passages are recorded. PASS is based on an analysis of the cumulative curve, where these empty
slices will not affect the curve. As a comparison, Wood (1986), who automated the time-slice
method of Road Note 34, kept the 6-second time-slices on the frequency curve, possibly to avoid
empty or quiet slices.

To operate the program, first the types of vehicles and their descriptions are entered. The
program has the ability to differentiate nine types of vehicles. Each type of vehicle is
given a particular pcu value, color and symbol. The appropriate key of the keyboard has to be
pressed when the rear end of the observed vehicle passes the stop line. One green period
produces one data set and no observations need to be recorded by an observer.

The analysis by the program will produce a diagram of total number of pcu's against elapsed
time in seconds, based on the initial pcu values. A typical S-shape with a scatter of colored
symbols will appear ; all recorded vehicles are shown individually. This method can be applied
on a lane by lane basis, or by approach width.

For manipulation of this cumulative curve, to obtain true saturation flow and pcu values,
attention should be focused on the straight sloping part of the curve. Based ont he assumption
that the saturated flow of vehicles is steady, the scatter of symbols should be minimum. If
certain colored symbols are predominantly below the sloped line, it means that a too low pcu
value has been assigned ; conversely, if certain colored symbols are above the sloped line, a too
high pcu value has been assigned. This trial and error process is evaluated by eye until a true
condition is reached.

This true S-curve is based on true pcu values and will give a true saturation flow value. The
true pcu values can be read off the screen as the prevailing values used to produce the S-curve.
The true saturation flow is the slope of the straight portion.To determine this slope a reference

line is moved to overlap exactly with the sloping line; the true saturation flow can now be read off the screen too. The development of an early version of PASS is described by Tumewu and Hidayat (1992) in an unpublished research report. A sample output of Program PASS is shown in Figure 2.
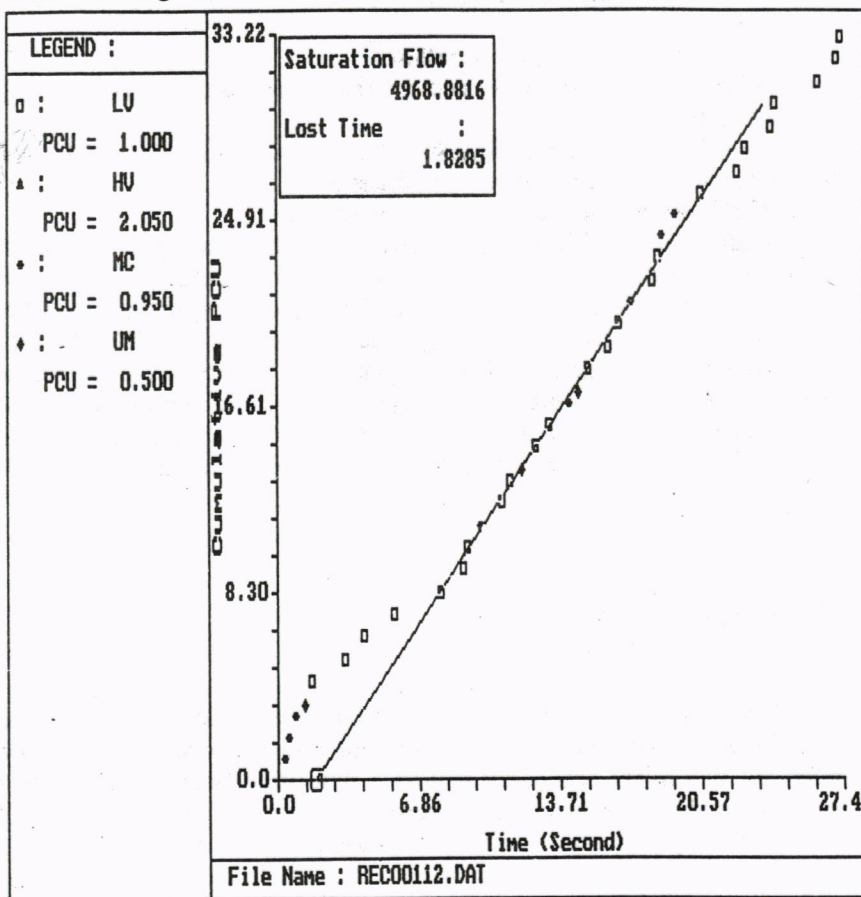
Figure 2   Sample Output of Program PASS

4. EVALUATION OF 'PASS'

Program PASS was applied by Budhiaty (1994) on long greens of a major signalised intersection in Jakarta. This intersection had been analysed by the Indonesian Highway Capacity Manual Project and she selected video recordings with smooth, unobstructed, straight through flows, at one approach for five long greens (of about 120 seconds) and five shorter greens (of about 60 seconds). The results were compared with those of the project.

The observed approach was 13.3 meters wide and produced a saturation flow in the order of 10.000 pcu/hour. The traffic flow comprised about 55 % light vehicles, 2 % heavy vehicles and 43% motorcycles with less than 1 % of unmotorised vehicles (which were excluded). The motorcycles were mainly in the outer side ; PASS was applied to the whole approach width.

Some conclusions of the evaluation study are as follows :
1. For the heavy traffic two operators were needed, one for motorcycles and one for light vehicles and heavy vehicles.
2. Pcu values were consistent with 1.0 for light vehicles, 0.5 for motorcycles and 1.5 for heavy vehicles. The IHCM values were respectively 1.0, 0.2 and 1.3.
3. The coefficient of variation for saturation flow values was 8.56 %.
4. Saturation flow results were reliable when operated by technicians. The mean coefficient of variation between seven repeated viewings by the same technician pair was 0.22 % and the mean coefficient of variation between 14 different operator pairs was also 0.22 %.
5. Saturation flows from the study were 32 % higher than those from the IHCM Project. Partly (10 %) this was caused by the slightly higher true pcu values and partly(22 %) because the study was done on selected ideal cycles, as compared to the large number of cycles used by the Project. (Note : Shanteau (1988) has also indicated that the cumulative method gives higher saturation flow values, compared to previously published estimates : 1900 - 2100 vs 1700 - 1800 vph).

5. FURTHER DEVELOPMENTS

The main criticism of this manual procedure was that the manipulation to obtain the least scatter by varying the pcu values was very subjective. For instance, one microstep of change in slope of reference line might change the saturation flow value some 50 units. Some formal way of optimisation would make the program more accurate and reliable , although careful manual manipulation already gave a low coefficient of variation.

Automisation of the manipulation process involves the calculation of total deviation of points from its regression line, for the straight portion of the S-curve. A true condition is defined as the condition which gives a minimum total deviation ; this optimum condition was found to be unique, ie there is only one optimum condition. Computing time with a 486 notebook computer varied from a few seconds to a minute, depending on the number of vehicle types.

On wide intersection approaches with a large vehicle mix, observations have to be made by stream (or by lane if appropriate). The reason is that one observer has only a limited capacity of recording ; also, the streams do not give similar results. See Table, which gives results of consecutive cycles of a major intersection in Bandung.

The Table shows a large variation of saturation flow values. Careful review of the respective traffic conditions (which were video tapes from the IHCM project) showed that several

DATA ANALYSIS RESULT

JUNCTION NAME   : KOPO – SOEKARNO HATTA
APPROACH   : KOPO (NORTH)
RECORD NAME   : KOPO–A – KOPO–B – KOPO–C

NO	RECORD NUMBER	LEFT STREAM				CENTER STREAM				RIGHT STREAM			
		SATURATION FLOW	PCU-VALUE			SATURATION FLOW	PCU-VALUE			SATURATION FLOW	PCU-VALUE		
			HV	MC	UM		HV	MC	UM		HV	MC	UM
1	REC000 1 . DAT	1498.8052	1.2	0.5	0	1684.5284	1.1	0	0	1638.3997	0	0.7	0
2	REC000 2 . DAT	1616.9860	0	0.2	0	1154.5231	0.5	2.7	0	1400.1780	0.2	3.1	0.3
3	REC000 3 . DAT	1532.0266	0	0.2	0	2158.5378	0.3	3.8	0	2210.2065	1.4	0.5	0
4	REC000 4 . DAT	1989.6458	0	0.6	1.3	2068.9285	0	1	0	2237.3143	0	1.1	0
5	REC000 5 . DAT	1538.3707	1.2	0.2	0.3	1258.9849	0	0.3	0	2296.6780	0	0.4	0
6	REC000 6 . DAT	1621.0866	0	0.5	0.4	1942.9271	1	0.4	0	1741.2519	0	0	0
7	REC000 7 . DAT	2522.3035	0	0.4	0	1991.0547	2.2	0	0	2114.2997	0	0.4	0
8	REC000 8 . DAT	3735.2973	0	0.7	0.8	1365.8279	0.8	0.4	0.4	1716.0686	0	0.4	0
9	REC000 9 . DAT	1588.3273	0	0	0.6	1668.4411	1.2	0.2	3.7	1527.4219	0	0.3	2.1
10	REC000 10 . DAT	2258.6767	0	0	1.2	2149.7257	0	0.7	0	1512.4220	0	0.5	0
11	REC000 11 . DAT	1142.5827	0	0.2	0.2	1944.9731	1.8	0.4	0	2047.0948	0	0.5	0
12	REC000 12 . DAT	2380.4156	0	0.4	0.7	2197.5689	3.9	0	0	2032.0286	1.5	0.5	0
13	REC000 13 . DAT	2308.8437	0	0.3	0.3	1604.5833	0	0.7	0	1853.0261	3.7	0.8	0
14	REC000 14 . DAT	1889.4271	1.1	0.5	0.6	1970.4010	0	0.5	0	2453.4835	1.5	0.8	0
15	REC000 15 . DAT	1400.4413	0	0.2	0.5	1210.0461	0	0	0	1774.0112	0.7	0.3	0
16	REC000 16 . DAT	1676.4113	0	0.1	0.5	1716.5119	0	0.4	0	2763.1565	0	0.9	0
17	REC000 17 . DAT	1402.3890	0	0.5	0.9	1568.3096	0	0	0	1766.1526	0	0	0
18	REC000 18 . DAT	2024.9326	0	0.1	1.1	1769.4136	1.7	0	0	2188.8550	0	0.6	0.6
19	REC000 19 . DAT	1649.4763	0	0.4	0	1602.0955	0	0.5	0	1890.8326	0	0.5	0
20	REC000 20 . DAT	1428.4752	0	0.2	0	1431.2535	0.5	0.7	0.4	1995.1048	0	0.6	1
21	REC000 21 . DAT	2401.1470	0	0.8	0	1240.8125	0	0.3	0	1989.0224	0	0.7	0
22	REC000 22 . DAT	2140.8186	0	0.5	0.7	2795.7112	1.5	3.8	0	2010.7458	0	0.3	0
23	REC000 23 . DAT	1790.8075	0	0.3	1.3	2275.2397	0	0.4	0	1973.2075	0	3.7	0
24	REC000 24 . DAT	1870.1421	0	0.6	1.3	2235.4397				1464.6997	0	3.3	4
25	REC000 25 . DAT	1411.2020	0	0	0.9	2285.3455	0	0.7	0	2929.2984	0	0.6	0
26	REC000 26 . DAT	1594.8660	0	0	0.3	1773.0176	0	0.4	0	2154.4895	0	0.2	0
27	REC000 27 . DAT	1674.3240	1.5	0	1.1	1406.1425	1.1	0.1	0	2362.0688	0	0.6	0
28	REC000 28 . DAT	1638.0000	0	0.3	0	1617.4087	2.2	0.4	0	1493.3152	0	0.4	0
29	REC000 29 . DAT	1249.8537	0	0.1	1	1681.2169	0.8	0.7	0	2005.0326	0.5	0.4	0
30	REC000 30 . DAT	2700.8189	2.2	0.7	1.1	2831.0424	0	0.8	0	1689.7338	0	1	1.7
31	REC000 31 . DAT	1826.0506	0	0.4	0	2164.8563	2.1	0.4	3.2	1503.2521	1.4	0	0.1
32	RECOC0 32 . DAT	1665.1696	0	0.1	2.7	1963.1733	1.8	0	0.9	1937.1255	0	0.3	3.4
33	REC000 33 . DAT	1754.7915	1.9	0.2	0.4	1331.3960	0	0.4	0	1841.3166	0	0.1	0
34	REC000 34 . DAT	1788.9160	1.2	0.2	0.1	2886.0880	2.2	0.5	0	2595.5562	0	0.8	0
35	REC000 35 . DAT	2068.6306	0	0.5	0.5	1536.6650	1.7	0	0	1965.1466	0	0.3	0
36	REC000 36 . DAT	1488.9841	0	0.2	0	1743.9522	0	0.3	0	2284.4211	1.2	0.8	0
37	REC000 37 . DAT	2580.6219	0	0.7	3	2445.2391	1.1	0.2	0	1893.8405	0	0.6	0
38	REC000 38 . DAT	2513.9880	0	0.5	0.8	1715.0615	0	0.5	0	1600.9408	0	3.7	0
39	REC000 39 . DAT	1426.4212	0	0.2	0.4	1602.9811	1.2	0	0	1523.3113	0.8	0.8	0
40	REC000 40 . DAT	1543.1087	0	0.2	0.2	1385.3858	0	0.2	0	1868.2388	0.9	0.8	0
41	REC000 41 . DAT	2000.1704	0	0.4	0.4	2456.6824	0	1	0.7	1833.8488	0	0.4	1.2
42	REC000 42 . DAT	1864.7281	0.6	0.4	0.9	1534.2816	0	0.8	0	2217.7928	0	0.6	0
43	REC000 43 . DAT	1789.7006	0	0.2	0	1773.3315	1.7	0.2	0	2333.3229	0	0.6	0
44	REC000 44 . DAT	1463.2953	1.1	0.3	0.7	1590.5164	1.3	0.6	0	2161.2205	1.7	0	0.4
45	REC000 45 . DAT	1388.2179	0	0.2	0	1346.7269				1908.9778	0	0.2	0
46	REC000 46 . DAT	2071.0087	2.6	0.3	0.5	2118.9863	0	0.8	0.2	2295.8062	1.2	0.3	1.2
47	REC000 47 . DAT	1975.3461	0	0.3	0.3	1276.2353	1.5	0	0	2072.2276	2.2	0.4	0
48	REC000 48 . DAT	2013.0084	0	0.6	0.2	1983.6443	0	1.4	0	1803.4351	1.2	0.1	0
49	REC000 49 . DAT	1696.2980	0	0.3	0	1681.4566	1	0.3	0	1925.4438	0	0.4	0.5
50	REC000 50 . DAT	1901.4479	0	0.4	0.5	1793.4493	0.7	0.1	0	3582.4203	0	0.8	0
51	REC000 51 . DAT	2188.4176	1.2	0.7	0	1752.7164	0.2	0.4	0	1840.8493	0	0.3	0
52	REC000 52 . DAT	1181.5343	0	0.3	0	1946.9648	0.1	2.1	0	1634.8061	0	0	0
53	REC000 53 . DAT	1387.7188	0	0.1	0.6	1439.8066	0	0	0	1896.5606	0	0	0
54	REC000 54 . DAT	1702.0211	0	0.4	0.2	1803.7770	0	1	1.1	1740.6616	0	0.6	0.4
55	REC000 55 . DAT	1855.3668	0	0.8	0.9	1614.8754	0	0.6	0	2091.2651	0	0.4	0
56	REC000 56 . DAT	1091.6147	0.3	0	0.4	1499.2526	0.8	0.5	0	2225.7748	0	0.5	0
57	REC000 57 . DAT	1719.2833	0.9	0.5	1.2	1826.9496	0	0.8	0	1629.3337	2.2	0.2	0
58	REC000 58 . DAT	2114.3748	0	0.2	1	1517.9800	0.3	2.7	0	2267.0880	0	0.4	0.3
59	REC000 59 . DAT	2474.7632	0	0.6	0.9	1784.8843	0	1.5	1.4	2170.8434	0	0.5	0
60	REC000 60 . DAT	1760.3946	0	0.5	1.3	2977.1077	0	0.9	1.4	1827.0716	2.6	0.3	0.6
61	REC000 61 . DAT	2002.5351	0	0.5	0.5	1885.7144	0	3.1	0.4	1883.7679	0	0.5	0
62	REC000 62 . DAT	1523.0847	0.4	0.3	0	1988.7414	0	0.4	3.6	1730.7165	0	0.2	3.6
63	REC000 63 . DAT	1901.4166	0	0.3	0.1	2968.7462	0	0.5	0	1534.8016	0	0.4	0.3
64	REC000 64 . DAT	2622.3475	1.6	0.4	0.5	1255.9156	0.5	0.6	0.6	1763.6543	0	0.3	0.7

conditions were not smoothly flowing. Obstructions were caused by down stream conditions, by stopping or stalling vehicles, or by some bad vehicle manoeuvers. Extreme results were also obtained when only one or two of a vehicle type were in the stream.

Subject to more extensive evaluation, it was postulated that smoothly flowing conditions across the stopline are characterised by a proper S-shaped curve, because extreme values were obtained from non-S-shaped curves. This selection of S-curves can be done before the optimisation process, by looking at the curves based on initial pcu values. This selection process is not done systematically with the other methods of pcu and satflow determination ; this may explain the higher saturation flow values obtained with the cumulative method.

6. CONCLUSIONS

a. The collection of data for program PASS by technicians produced reliable results, as shown by the low coefficient of variation.
b. The manual manipulation of cumulative curves to obtain saturation flow and passenger car unit values simultaneously gave consistent results for a given approach, and these results compared well with those from a standard method ; the 22 % difference in saturation flow value is probably caused by the criteria for selecting acceptable traffic conditions.
c. There is no need to identify the saturated period during data collection ; the S-curve will show the saturated period.
d. On wide intersection approaches, with a large vehicle mix, observations have to be made by stream ; there is an indication that saturation flows vary along the stop line.
e. Full automation of the manipulation process has made the analysis less prone to subjective interpretation and thus more reliable, PASS can be run in the field with a notebook computer.
f. In general the method is now easy, quick and reliable but should not be applied on interrupted conditions or where a vehicle type is not well represented. The method can easily identify the acceptable cycles.

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