Saturation Flow: Do We Speak the Same Language?

S. TEPLY AND A. M. JONES*

Saturation flow is the basis for the determination of traffic signal timings and for the evaluation of intersection performance. Most current analysis and design methods are based on some form of the critical lane technique, in which the critical lane, or group of movements, is determined from the relationship between the volume it carries and its saturation flow. The general descriptions of saturation flow presented in the *Highway Capacity Manual*, the *Canadian Capacity Guide for Signalized Intersections*, and an Australian Road Research Board special report on traffic signal capacity and timing analysis are more or less identical for similar, close-to-ideal intersection conditions. Nevertheless, the definitions implied by the recommended survey techniques are significantly different. Moreover, saturation flow values reported by some researchers in the past have been based on measurement methods that differ from all three documents. The differences in the meaning of saturation flow, as understood in different regions and by different authors, are discussed. The implications are illustrated using the three documents and a set of 1989 Edmonton surveys as examples. It is found that values reported in the literature may not be directly comparable and that saturation flows measured with the assistance of one document may not be compatible with calculation techniques taken from another.

Saturation flow is the basis for the determination of traffic signal timings and for the evaluation of intersection performance. Most current analysis and design methods are based on some form of the critical lane technique, in which the critical lane, or group of movements, is determined from the relationship between the volume it carries and its saturation flow.

A small change in the saturation flow value may result in a relatively large change in the calculated cycle time and the duration of the necessary green intervals. The impact becomes especially critical in situations in which volumes are just below or exceed capacity.

Because saturation flow represents a major factor in the determination of measures of effectiveness used in traffic engineering practice, its value also influences the performance evaluation of signalized intersections. Almost all computer programs for design and analysis of individual intersections, signal progression, or network operations use saturation flow as one of the principal input parameters. The accuracy of these programs is usually sensitive to saturation flow estimates.

Most documents for the design and analysis of signalized intersections, such as the *Highway Capacity Manual* (HCM) (*1*), *Canadian Capacity Guide for Signalized Intersections* (CCG) (*2*), or Australian Road Research Board (ARRB) Report 123 (*3*), recommend the use of measured saturation flows, rather than the default values provided in these documents or in many computer programs.

Nevertheless, although the general descriptions of saturation flow are more or less identical for similar, close-to-ideal intersection conditions, the definitions implied by the recommended survey techniques are not. To make the issue more complicated, saturation flow values reported by some researchers in the past have been based on measurement methods that differ from all three documents.

The differences in the meaning of saturation flow, as understood in different regions and by different authors, are discussed. The implications are illustrated using the three documents and a set of 1989 Edmonton surveys as examples. The objective is to make researchers and practitioners aware that values reported in the literature may not be directly comparable and that saturation flows measured with the assistance of one document may not be compatible with calculation techniques taken from another.

CONCEPT OF SATURATION FLOW

The HCM (*1*) describes the saturation flow rate as the flow, in vehicles per hour per lane, that can be accommodated by the lane assuming that the green phase is always available to the approach.

The CCG (*2*) defines saturation flow as the rate of queue discharge from the stop line of an approach lane, expressed in passenger-car units per hour of green (pcu/hr green).

ARRB Report 123 (*3*) defines saturation flow as the maximum constant departure rate from the queue during the green period, expressed in through-car units per hour (tcu/hr).

These definitions do not mean that there is a continuous hour of green, but imply the usual stopping and moving operation for the normally used range of cycle times and green intervals; thus, saturation flow reflects the uniform service rate used in most applications of queueing theory for the problem of intersection capacity.

All three general definitions are based on the conventional graphical representation of saturation flow shown in Figure 1. The solid line in the figure shows the traditional concept, which assumes that the discharge rate from a stop line remains constant after some initial period. Canadian experience (*2*) has indicated that the discharge begins to decline after 30 to 50 sec of green time. Both interpretations are based on demand at or above capacity.

This traditional concept assumes that, after an initial hesitation immediately following the beginning of the green interval, traffic discharges at a constant rate (the saturation flow

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*Winners of the 1991 D. Grant Mickle Award for outstanding paper in the field of operation, safety, and maintenance of transportation facilities.

Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2G7.

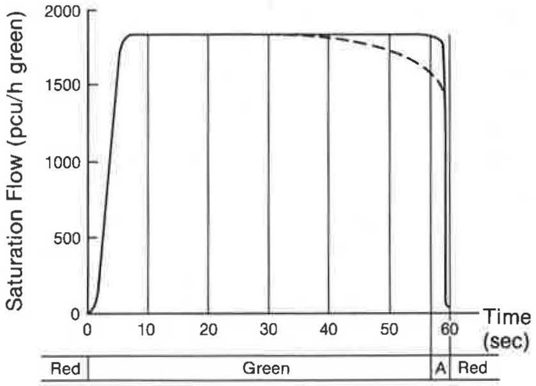

FIGURE 1 Saturation flow concept.

rate) until the queue is exhausted or until shortly after the beginning of amber, when a sharp drop in the flow occurs. The departure rate is lower during the first few seconds, while vehicles accelerate to normal running speed, and after the end of the green interval, as the flow of vehicles declines.

The HCM, CCG, and ARRB report agree on the great variability in saturation flows caused by different urban conditions and various geometric and traffic configurations. Factors used to modify the saturation flow of a given lane or approach generally include the urban environment; local driver behavior; lane width; turning radius; gradient; pedestrian interference; parking or transit interference; interaction with priority, opposing or adjacent flows; and limited queueing or discharge space. The CCG also allows the user to consider weather conditions and the duration of the green interval.

There is a major difference among the three documents in their treatment of traffic composition (i.e., cars, trucks, and buses). The CCG notes that it is convenient to represent all flows as homogeneous entities, therefore suggesting conversion of all volumes of individual vehicle categories to passenger-car units. The values of pcu equivalents have been determined from surveys in several Canadian cities, both in summer and in winter conditions, using a least squares optimization technique (*4*).

Both the HCM and the ARRB report consider the basic saturation flow in vehicles/hr green, applying a traffic composition adjustment along with the adjustment factors based on geometric and other traffic conditions. All three documents include calculation procedures involving the special effect of turning vehicles on the operation of single lanes that carry different movements (shared lanes).

Although there are many similarities in the saturation flow adjustments recommended in these three documents, actual procedures differ. The Canadian concept of the so-called "basic" (or ideal) saturation flow has been adopted for use here. Basic saturation flow is defined as the number of pcu that can discharge across the stop line of an intersection approach lane 3.0 to 3.5 m wide, with no slope or curves. Traffic is moving straight ahead without any additional traffic friction (i.e., no bus stops, pedestrians, parking, or other limiting factors are present), under ideal weather conditions and during an optimum duration of the green interval.

For consistency in this comparison, traffic composition adjustments have been applied to all measured results according to the following rules:

- *HCM.* The percentage of heavy vehicles (defined as vehicles with more than four tires on the road) was derived from the surveyed data, and the corresponding heavy vehicle adjustment factor (f_{HV}) was taken from Table 9–6 of the HCM. The basic saturation flow was then divided by this factor to increase the flow, accounting for the traffic composition in a manner similar to the pcu conversion in the CCG.
- *CCG.* All surveyed vehicles were converted to pcu before processing of the data, using the pcu equivalents suggested by the CCG.
- *ARRB Report 123.* The traffic composition factor (f_c) is a weighted average determined by the proportions of various vehicle types in combination with turning movements. Because only straight-through flows were surveyed, the through-car-unit equivalent values were limited to 1 for cars and 2 for all heavy vehicles. Heavy vehicles are defined as vehicles having more than two axles or having dual tires on the rear axle. The average tcu/vehicle was multiplied by the basic saturation flow to convert the flow to tcu/hr green. Naturally, for the basic (i.e., straight-through) saturation flows, pcu and tcu are directly comparable.

METHODS OF MEASURING SATURATION FLOW

Much of the background work on saturation flow took place at the end of the 1950s and in the 1960s, although the pioneering work by Greenshields (*5*) started much earlier.

One of the major problems with the body of literature on saturation flow is that many authors do not report the details of their survey techniques. As a result, the transferability of the values is questionable. Even when potential users are aware of the range of possible fluctuations in saturation flows, these flows are difficult to compare. The following section attempts to illustrate this problem.

It is assumed that there are no gross mistakes, which are sometimes found in practical applications. A typical example of this category when applying the HCM method is a wrong determination of the average headway by starting the time count at the passage of the fifth vehicle (the HCM clearly recommends use of the time of the fourth vehicle). The error can be compounded by dividing the duration of the surveyed period by the number of vehicles and not by the number of gaps. Such large mistakes, however, can easily be spotted because they usually result in saturation flow values well over 2,000 cars or vehicles/hr green/lane. Although such values are possible, they are unusual.

In essence, there are two major categories of saturation flow surveys, as follows.

The first group of techniques is based on the successive times (not necessarily true headways) of vehicle discharge at a specified reference line. Stop lines, nearside crosswalk boundaries, nearside intersection boundaries, or other nearside points (such as the cross section at which a nearside signal is located) have been used to that end, although farside intersection boundaries or farside crosswalk lines have also been used. Vehicles have been considered discharged when their front bumpers, front wheels, rear wheels, or rear bumpers have passed the reference line. As can be seen, a large number of possible combinations of reference lines and vehicle discharge criteria exists.

The second group of techniques, which count the number of vehicles passing the reference line during short portions of the green interval, is best represented by one of the first reports on the subject, published by the (then) Road Research Laboratory (RRL) and titled *A Method for Measuring Saturation Flow at Signalized Intersections* (*6*). In principle, the CCG also applies this basic technique.

Nevertheless, although both the RRL and CCG methods designate the stop line as the reference line, there is a difference in the identification of the point in time at which a vehicle is considered discharged. In the RRL report, discharge is given by the moment when the vehicle fully clears the stop line; the report recommends the use of the time at which the rear wheels cross the stop line. The CCG uses the passage of the front bumper over the stop line as the time of discharge, primarily because it is consistent with the usual definition of a headway (time differential between the passage of front parts of consecutive vehicles over a fixed cross section).

The HCM and ARRB report are, in fact, combinations of both basic groups of techniques because they are based on the determination of the average headways during a specifically defined portion of the green interval. This portion starts with the passage of the fourth vehicle in the HCM method and after 10 sec of green in the ARRB technique. The CCG survey method includes the entire initial period of flow.

The HCM, CCG, and ARRB report also demonstrate the different preferences in the identification of the reference cross-section line and the part of the vehicle that is considered representative of its discharge.

As an additional consideration, Branston and Van Zuylen (*7*) reported on a comparison of asynchronous and synchronous counting periods as defined by Haight (*8*), applied to saturation flow measurement. Although the synchronous technique starts and terminates observations at the instant of a vehicle departure (however defined), as in the HCM, the asynchronous method starts and terminates at arbitrary points in time, as in the CCG or ARRB report. Branston and Van Zuylen found some advantages of the synchronous method, although both techniques seem to be consistent if the data are manipulated correctly.

Greenshields (*5*) pioneered the headway method. He measured headways of passenger cars as their front parts passed the line connecting the nearside intersection curbs and found that, after the passage of the fifth vehicle, the headways stabilized at 2.1 sec. This value corresponds to about 1,715 vehicles per hour of green per lane.

Headway-based methods have been popular in Continental Europe, although the definitions of the reference line, and the part of the vehicle that defines discharge, vary (*7,9–16*). The use of the intersection exit as a reference line is less popular but has recently been used in Canada in a study of the effects of winter maintenance on traffic flow (*17*).

Many current saturation flow surveys still use the 1963 RRL method (*4,6,18–21*). Axhausen et al. (*16*) apparently used it to supplement headway measurements.

Although most of the British work consistently applies the 1963 method (which uses the passage of the rear axle for time reference), recent work by the British Transport and Road Research Laboratory (*22*) on the values of pcu equivalents defined the headways as "the time elapsed between the front of a vehicle crossing the stopline and the front of the following vehicle crossing the stopline."

Some of the differences in the headway values and their sequence that are caused by the various reference points in space and time can be explained with the assistance of Figures 2 and 3. Figure 2 shows, in a time-space diagram, a perfectly

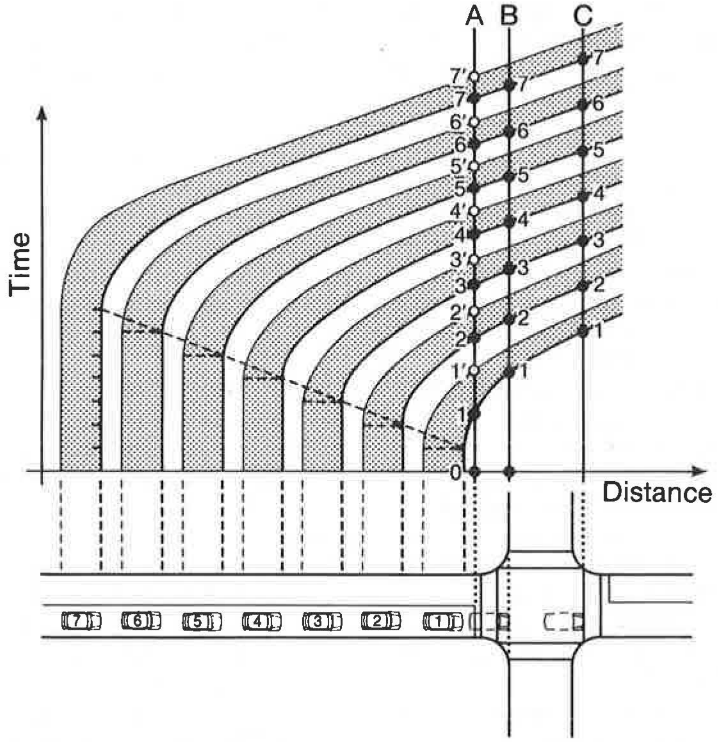

FIGURE 2 Perfectly regular discharge from standing queue, with uniform acceleration.

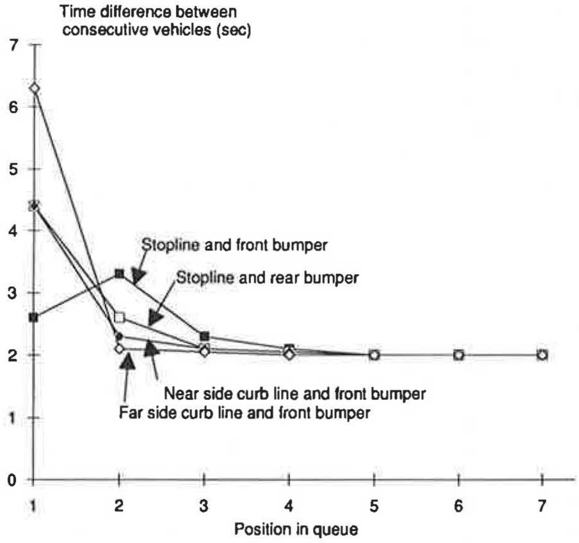

FIGURE 3 Variation in time difference between consecutive vehicles from Figure 2 for combinations of reference point and vehicle discharge criteria.

regular discharge of passenger cars from a standing queue with all cars accelerating uniformly at the same rate from the stopped position to a constant speed. Three reference lines are identified in the figure, which allows for the following combinations:

A. Stop line + front bumper,
A′. Stop line + rear bumper,
B. Nearside curb line + front bumper, and
C. Farside curb line + front bumper.

The trajectories of the vehicles intersect the vertical lines, which identify the reference lines in space. Figure 3 shows that the headways (or their rear-end equivalents) for the leading four or five cars vary not only in absolute values but also in the shape of the graph. The two basic shapes are easily recognizable, as follows:

1. The greatest time difference represents the time needed by the first vehicle, and
2. The greatest time difference occurs for the second vehicle.

The first case is typical for the Greenshields intervals; the second for many Continental European studies. The diagram attempts to illustrate that what is sometimes interpreted as a regional difference may merely be a result of a different measurement method. Naturally, the practical problem is more complex because of such factors as different vehicle lengths, rates of acceleration, acceleration noise of individual vehicles, and, consequently, the increased randomness that occurs at the far end of the intersection rather than at the stop line.

Some of the true regional factors that influence the derivation of saturation flows depend on traffic engineering practices and legal requirements. For example, the period immediately preceding the beginning of the green interval is identified in some countries by a short display of the amber signal in addition to the red signal. This practice may have a significant impact on the discharge during the first part of green (especially when motorcycles are present). Another factor that increases the international variability of flow, and influences the practice of defining the reference line and discharge, is the standard application of nearside or farside signals, or a combination of both.

An important factor related to the use of the surveyed data on headways or saturation flows is the well-known concept of the effective green interval and how this concept is introduced in design and analytical practice. Theoretically, it can either mitigate or increase the extent of inconsistencies caused by the application of a survey method that has not been meant for the calculation procedure at hand. Figures 2 and 3 illustrate the problem: the initial lag (start-up lost time) is significantly longer for methods that use reference points downstream of the stop line and rear parts of the vehicle. Figure 1 shows that such an increase may not be fully compensated for by the time gained after the end of the green interval.

COMPARATIVE SURVEYS

The main objective of the comparative research described here was to examine the relationship among the three saturation flow survey methods as described in the CCG, HCM, and ARRB report. By comparing the three methods, some insight might be gained as to the reliability of the surveyed results for further use in design or analysis computations. In the course of this study, variations in survey techniques used by several other researchers were also identified.

A total of 10 saturation flow surveys were conducted during the summer of 1989 in Edmonton, Alberta, Canada. More than 4,800 vehicles were observed during 325 signal cycles. The survey locations were as follows (see Figure 4):

1. St. Albert Trail/137 Avenue,
2. St. Albert Trail/Yellowhead Trail,
3. 127 Street/Yellowhead Trail,
4. 97 Street/137 Avenue,

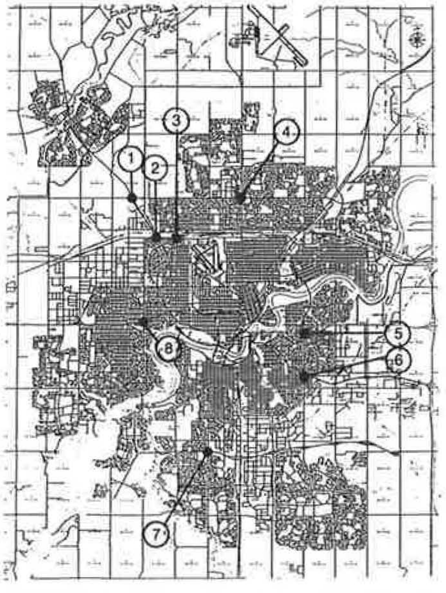

FIGURE 4 Survey locations within city of Edmonton.

5. 75 Street/98 Avenue,
6. 75 Street/Whyte Avenue,
7. Whitemud Drive/111 Street, and
8. 142 Street/Stony Plain Road.

These locations were carefully selected to conform with the general definition of basic saturation flow as designated by the CCG. The High Geometric Standard/Low Activity intersection approach category was chosen, meaning primarily divided arterial roadways with low activity levels for pedestrian and other adjacent land uses. This designation corresponds to ARRB Class A: ideal or nearly ideal conditions for free movement of vehicles (both approach and exit sides), good visibility, few pedestrians, and almost no interference because of loading and unloading of goods vehicles or parking turnover. The selected sites were also chosen to give the observer an unobstructed view of the surveyed lane and its stop line, and, hence, to maximize the accuracy of the results. The location shown in Figure 5 represents a typical intersection representative of basic saturation flow in Edmonton. In the figure, Site 1 was the observed lane for Survey 1 and Site 2 was the observed lane for Surveys 2 and 10.

Each survey consisted of 30 valid cycles with adequately saturated portions of the green interval of longer than 20 sec. For this reason, only the busier morning and afternoon peak periods were used. Several surveyed cycles had to be discarded due to unusual circumstances, such as the presence of emergency vehicles or stalled vehicles.

The surveys were conducted using a cassette recorder. Events in the observed lane were noted as they occurred (i.e., the beginning of the green interval, the length of the queue, the passage of the front bumper and rear axle of each passing vehicle over the reference point, the end of saturated flow, and the end of the green interval). Although the recording process required a great deal of concentration, no major problems were encountered with the ability to correctly identify the series of events.

The major benefit of using the same sample for all three techniques—simultaneously recording all data necessary for each of them—was that each of the methods could be applied to the same set of events. As a result, a direct and reliable comparison of the results was possible. In addition, if there were any inconsistencies due to the observer's perception of an event, they were equally reflected in all three methods.

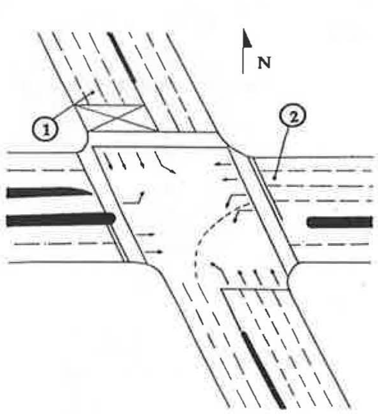

FIGURE 5 Typical survey site (Location 1): St. Albert Trail and 137 Avenue.

The survey methods used are described in detail in the source documents (CCG, HCM, and ARRB Report 123). Raw data were transcribed to field data sheets for each survey in the formats suggested by the individual manuals. The following section briefly outlines the three procedures.

CCG

The CCG survey method is designed for application to a single observed lane (similar to the HCM and ARRB report). A 15-sec time check just before and after each survey was recorded to calibrate the speed of the cassette recorder. The following vehicle categories were used: passenger cars, vans and pickup trucks, single-unit trucks, multiunit trucks, buses, and motorcycles.

Vehicles were considered to be discharged when their front bumpers had passed the reference point (stop line). The end of the platoon also included vehicles that joined the queue and proceeded as part of the lineup after the start of green. Because of the short duration of some green intervals, a 5-sec time slice was used in the data transcription. A comparison with the use of a 10-sec time slice showed that the choice of duration made little difference to the final basic saturation flow.

Saturation flow was computed as the average number of pcu per valid (fully saturated) time slice, multiplied by 3,600 and divided by the duration of the slice.

The results are illustrated in two formats (see Figure 6):

1. As a conventional saturation flow graph, with the flow for each 5-sec time slice plotted directly and the average flow calculated from all the values; and
2. As a cumulative average graph, with the average flows calculated from the beginning of green to the end of the given time slice (i.e., 0 to 5, 0 to 10, 0 to 15 sec, etc.). The curve climbs asymptotically to the eventual constant saturation flow rate as the effect of the initial loss becomes less pronounced for longer green intervals. Thus, the saturation flow is the asymptotic value to which the graph converges or, in the event that the rate starts declining, the peak of the graph, usually occurring at 30 to 40 sec of elapsed green time. Such a decline has been identified in Canada (*2*) and elsewhere (*18*).

The cumulative representation is favored by the CCG because it reflects the true flow from the onset of the green interval to any desired period (i.e., the saturation flow for any selected green interval includes the initial time period, during which the flow is lower). Moreover, for statistically significant samples, the cumulative graph exhibits a great degree of consistency. Consequently, it can be used for an initial assurance that the sample is valid and for a quick estimation by extrapolation of the basic saturation flow value in cases where the saturated flow does not persist long enough to be measured beyond, say, 10 sec.

The average saturation flow calculated using both formats is 1,840 pcu/hour green. The difference between the basic saturation flow determined from the two formats is generally negligible.

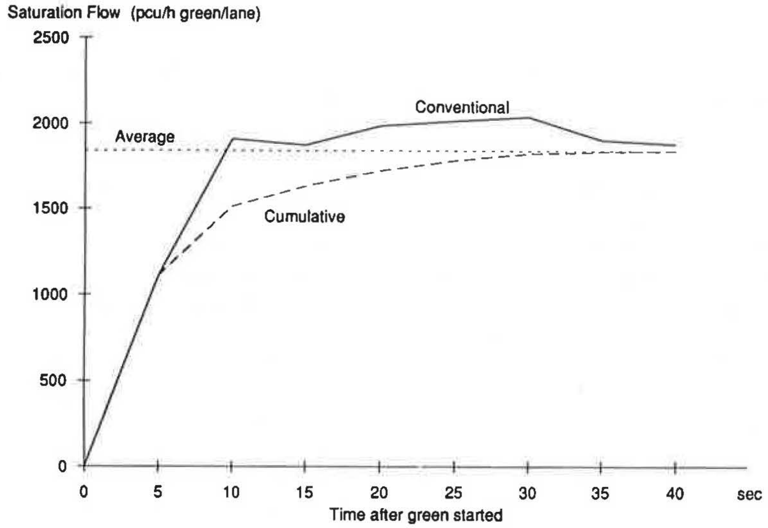

FIGURE 6 Basic saturation flow in conventional and cumulative formats for Survey 10.

HCM

This method differs from the CCG method in that a vehicle is considered discharged when its rear axle crosses the stop-line reference point. The period of saturation flow begins when the fourth vehicle in the queue crosses the reference point and ends when the last queued vehicle crosses the same point. Thus, unlike the CCG, the initial period of hesitant flow is not included. It is therefore to be expected that the HCM will yield a higher saturation flow than the CCG.

Flows were calculated by dividing 3,600 sec by the average headway for the saturated portion of the green interval (after the fourth queued vehicle). The flows calculated for each of the 30 surveyed cycles were averaged, and the heavy vehicle adjustment factor was then applied to obtain the basic saturation flow, consistent with the CCG for comparison.

ARRB Report 123

The time surveyed during each cycle was divided into three separate periods as follows:

1. The first 10 sec of green,
2. The remainder of the green period while saturated, and
3. The period after the end of green, including both amber and red.

The saturated time is considered to be the time to clear the vehicles that are stopped during the red interval, as well as those that arrive and join the back of the queue during the green interval (i.e., Intervals 1 and 2). Discharging vehicles were recorded as their front bumpers crossed the stop line.

This method stipulates that the saturation flow is calculated on the basis of the average headway of vehicles discharging only during Period 2 (i.e., not including the first 10 sec of green). The initial period of lower saturation flow is disregarded. As a result, it can be expected that the ARRB method would yield a higher saturation flow than the CCG method. Further, this saturation flow will likely be higher than that measured by the HCM method as well because, under normal circumstances, the passage of four passenger cars uses a period shorter than 10 sec (i.e., HCM discounts a smaller portion of the initial flow).

Saturation flow was then multiplied by the traffic composition factor to obtain a flow in through-car units, which, because only straight-through lanes were surveyed, is comparable to the CCG's passenger car units.

PCU Program

To have a generic basic saturation flow value to compare with the values found using the previously described methods, the computer program known as "PCU" was used. This program was developed by the University of Alberta (*4*) and was based on an older procedure suggested by Fischer (*9*). The main assumption is that, under equal conditions and for homogeneous traffic flow, the number of passenger-car units crossing the stop line of a single lane of an intersection approach should be constant during green intervals of equal duration. Variations are therefore attributed to differences in the behavior of individual vehicle categories. The PCU program finds the values of the pcu equivalents using a least squares optimization technique to minimize the variations in the number of pcu discharging for green intervals of equal duration. This method of data manipulation is similar to the application of linear regression described elsewhere (*7*). Because the PCU program calculates its own pcu equivalents, it is not biased with respect to the three documents (CCG, HCM, and ARRB Report 123). Nevertheless, its application includes the start-up lag as in the CCG.

The data input to the program are in time slices, before pcu conversion. The output may be in either the conventional or cumulative formats; again, the cumulative format was assumed to be the most reliable and was therefore chosen to serve as the basis for the comparisons.

RESULTS

Table 1 presents the results of the 10 surveys conducted in Edmonton, with the saturation flows calculated using the PCU cumulative format, the CCG cumulative format, and the HCM and ARRB procedures. All flows are in units adjusted for the presence of heavy vehicles in the traffic stream. Figure 7 shows these results graphically for easier comparison.

The difference between the results of the PCU program and the CCG is negligible; on average, the CCG method yields flows only 0.13 percent higher than those derived from the PCU method. The correlation between the two methods was expected because of the flow at the start of green. Moreover, the pcu equivalents used by the CCG were derived in previous research with the assistance of the PCU program.

The ARRB method yields saturation flows up to 23 percent higher than the PCU flows—the range is 5 to 23 percent. This result corresponds to the expectation of higher values because of the exclusion of the first 10 sec of the green interval, which leaves only the most stable flow in the evaluation (see Figure 2).

The HCM values are in most cases higher than the PCU results. Surveys 5, 9, and 10 for the PCU program and the HCM are, however, quite comparable. Overall, the magnitude of the difference between the PCU and HCM values ranges from 0.3 to 11 percent. The variability, and the low range of the difference, is somewhat surprising because the first part of the flow is omitted, more or less similarly to the ARRB method, and the HCM and ARRB values were expected to be similar. This finding seems to be true only for Surveys 1, 3, and 6.

There seems to be no immediately identifiable consistent relationship between any factor and the magnitudes of the differences among the three basic methods. Initially, it was thought that the differences might be attributed to different pcu conversions in combination with the share of heavy vehicles. Nevertheless, Figure 7, which presents the surveys in the order of increasing percentage of heavy vehicles, does not confirm that hypothesis. As a result, it appears that it is not possible to determine the saturation flows for one method from the measurements based on another.

Because it has been shown that saturation flow exhibits a great degree of consistency over time (*4*), it was judged feasible to check the accuracy and consistency of the surveys by repeating one of the surveys under identical conditions after a short period of time. The survey at Location 1 (see Figure

TABLE 1 SATURATION FLOW SURVEY RESULTS AND PERCENTAGE OF HEAVY VEHICLES FOR 10 EDMONTON SURVEYS

Survey # / Location	Direction / Peak	Saturation Flow				% Heavy Vehicles
		PCU	CCG	HCM	ARRB	
1. St. Albert Trail / 137 Avenue	Southbound / A.M.	1890	1900	2100	2140	2.9
2. St. Albert Trail / 137 Avenue	Westbound / A.M.	1900	1910	2000	2190	3.3
3. St. Albert Trail / Yellowhead Trail	Northbound / P.M.	1710	1730	1900	1930	3.5
4. 137 Avenue / 97 Street	Westbound / P.M.	1600	1640	1710	1970	8.1
5. 142 Street / Stony Plain Road	Eastbound / A.M.	1800	1730	1810	1900	1.9
6. 98 Avenue / 75 Street	Northbound / P.M.	1690	1710	1850	1900	3.5
7. 127 Street / Yellowhead Trail	Westbound / P.M.	1790	1810	1880	2060	5.1
8. Whyte Avenue / 75 Street	Southbound / P.M.	1670	1670	1780	1910	4.3
9. Whitemud Drive / 111 Street	Eastbound / A.M.	1630	1650	1640	1720	12.2
10. St. Albert Trail / 137 Avenue	Westbound / A.M.	1890	1840	1960	2020	4.2

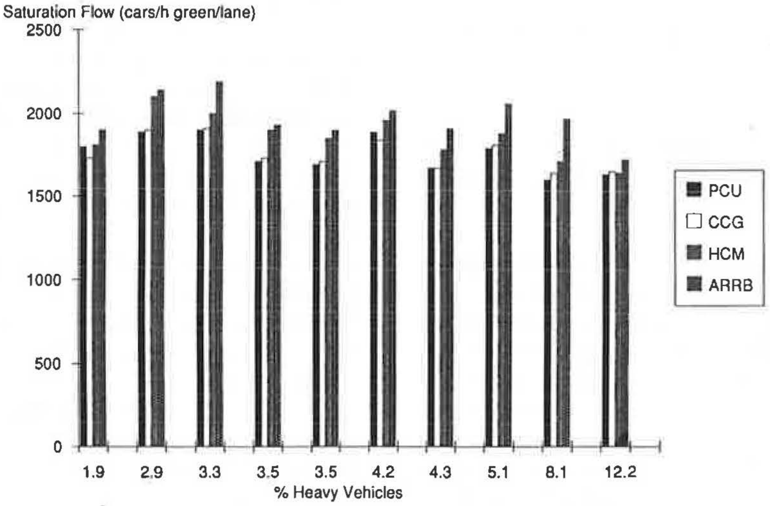

FIGURE 7 Comparison of surveyed saturation flows according to survey method and percentage of heavy vehicles.

4) was selected and repeated exactly 2 weeks after the initial survey (i.e., Survey 10 was designed to duplicate Survey 2). The PCU results for the two surveys indicate only a 0.58 percent difference (i.e., 1,900 versus 1,890 pcu/hour green), which can be considered insignificant. Consequently, the accuracy of the surveys appears to be adequate.

OTHER RESULTS

The CCG suggests that the passenger-car-unit equivalents for individual vehicle categories may vary regionally. Because the PCU program also calculates appropriate pcu equivalents, it was possible to compare these equivalents with those in the CCG. The results are presented in Table 2 and indicate a good fit, considering that the surveys described represent a small sample compared with the magnitudes of the survey efforts for the CCG. The CCG recommended values are a composite of summer and winter measured passenger-car-unit equivalents.

Vehicle headways were calculated from a number of randomly selected surveyed cycles, and the results are shown in Figure 8. For the reasons explained in connection with Figure 2, the traditional Greenshields curve (*5*) is not supported by the initial portion of the graph (the first two to three vehicles), but the average headway of 2.12 sec calculated here for the fifth and successive vehicles closely corresponds to Greenshields' reported value of 2.1 sec. Although not subject to this study, previous headway studies for Edmonton winter conditions exhibited patterns identical to that of Greenshields, even though headways were measured as front bumpers crossed the stop line (see Figure 9). Similar patterns for stop lines and front bumpers are frequently observed in regions with high degrees of red signal violations. A cautious entry by the first driver of the queue into the intersection is a likely explanation of this phenomenon and, perhaps, an added reason for survey consistency and careful interpretation of results.

Finally, the CCG reports a value of 1,650 pcu/hour green as the basic saturation flow in Edmonton for intersections of the type described in this discussion (for 1978 to 1984). The survey results presented are often significantly higher, ranging from 1,600 to 1,900 pcu/hour green. The average morning peak flow is 1,820 pcu/hour green (as calculated by PCU), whereas the average afternoon peak flow is 1,690 pcu/hour green, as shown in Figures 10 and 11. Higher saturation flows for morning periods with a more homogeneous and more aggressive driver population are mentioned in the CCG.

TABLE 2 COMPARISON OF PASSENGER-CAR-UNIT EQUIVALENTS

Vehicle Category	Passenger Car Unit Equivalent			
	Surveyed (PCU)	CCG	HCM	ARRB
Passenger Cars, Vans, Pick-Ups	1	1	1	1
Single-Unit Trucks	1.32	1.5	2	2
Multi-Unit Trucks	2.24	2.5	2	2
Buses	1.93	1.75	2	2
Motorcycles	0.75	0.5	1	1

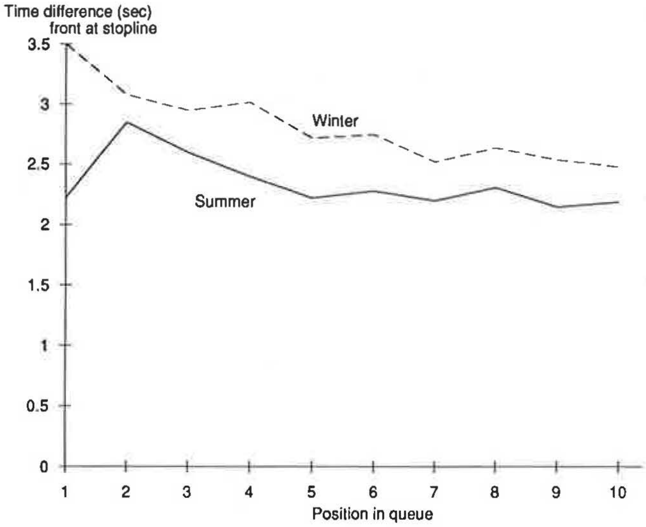

FIGURE 9 Comparison of vehicle headways for typical summer and winter conditions in western Canada.

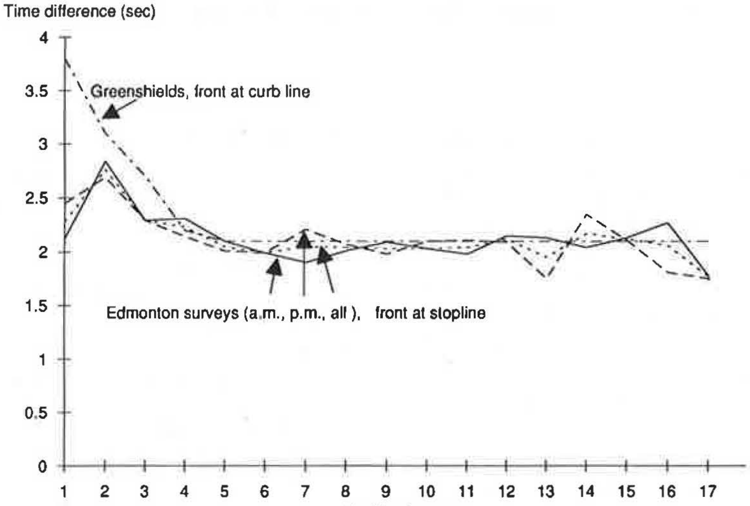

FIGURE 8 Vehicle headways calculated from 10 Edmonton surveys.

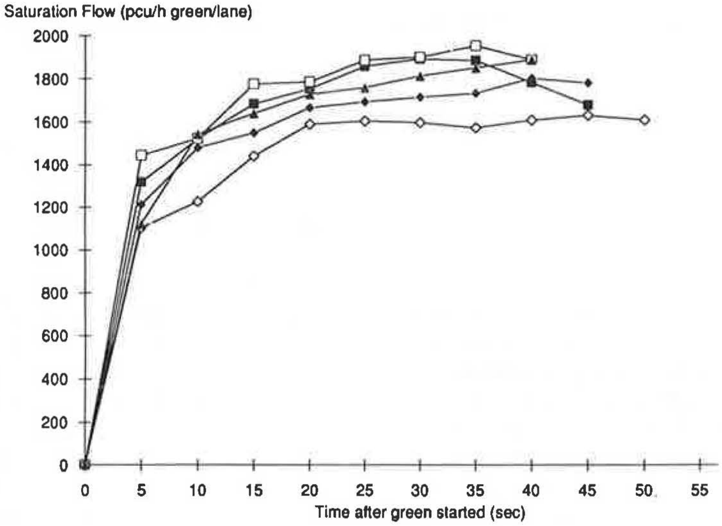

FIGURE 10 Morning peak saturation flows calculated by PCU program for five Edmonton surveys in cumulative format.

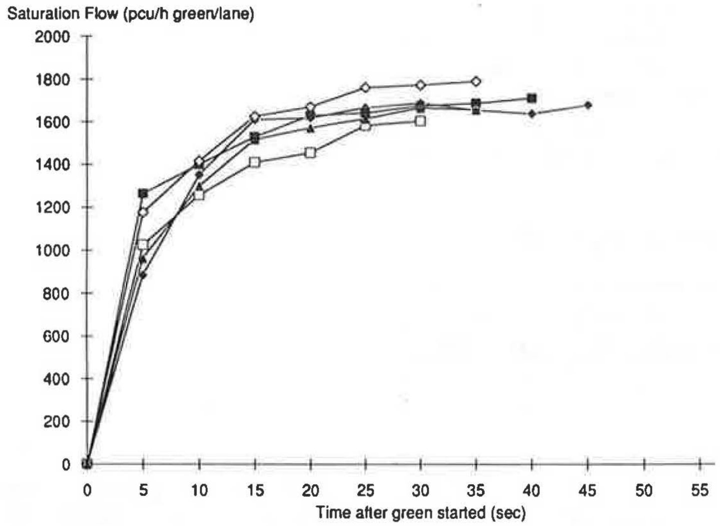

FIGURE 11 Afternoon peak saturation flows calculated by PCU program for five Edmonton surveys in cumulative format.

An increase in saturation flows over the past several years, and a corresponding increase in intersection capacity, has been observed by the city of Edmonton traffic engineering staff and in several smaller communities in the commuter shed. A logical explanation can be found in improved economic conditions in recent years. On the other hand, saturation flows in Calgary, which shares much of Alberta's economic prospects, remained unchanged. This finding emphasizes the value of periodic field saturation flow surveys in providing the most accurate and up-to-date basis for the analysis and design of signalized intersections.

As an additional observation, a tendency for calculated saturation flows to decrease over time for longer green intervals has been identified during the surveys (see Figure 8).

CONCLUSIONS

All sources suggest that accurate saturation flow measurements are necessary for reliable analysis and design of signalized intersections.

The deliberations during this study, and the results of the surveys presented, illustrate that the value of such surveys greatly depends on the method applied. The three methods commonly used in North America differ significantly with respect to use of the following attributes:

1. Roadway reference point,
2. Reference point on the vehicle that denotes discharge,
3. Start time for measurement and analysis, and
4. Heavy vehicle conversions.

The problem is compounded because the relationship among the values determined by various techniques is not consistent. Consequently, a method taken from one document cannot be reliably converted to the values needed for the calculation procedures used by another document.

The implications bear not only on the values of saturation flow itself but also on the applications of lost time, effective green interval, and effective red interval. As a result, care should be taken, both in practice and research, to correctly interpret the methodology used in the measurement of saturation flows.

This research study also confirmed some of the previous Canadian findings, such as the values of pcu equivalents for the basic vehicle categories and the consistency of saturation flows over shorter time spans. Although the consistency makes saturation flow an excellent basis for analysis and design of intersection signalization, saturation flow also exhibits longer trends that can only be detected by periodic surveys, which, naturally, must use methods commensurate with design and analysis practices in the region.

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