EVALUATION OF DELAY ON UNSIGNALIZED INTERSECTIONS

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Abstract: In this study, empirical models of capacity and delay and warrant for signalization or improvement had been developed for some types of two-way STOP controlled intersections. The capacity model states that the maximum flow of the minor street is a function of the total conflicting flow. The delay model states that at 100 vph reserved capacity, the average service time tends to remain at a nearly constant level and average service time is a function of total conflicting flow and reserved capacity being fixed. The delay-based warrant states that the intersection is efficient at a combination below the curve of the capacity minus the threshold value of 100 vph reserved capacity. Comparison shows that the MUTCD and the locally used TEC warrants is an overestimate of the Philippine situation of unsignalized intersection efficiency.

The abovementioned models and the established warrant are preliminary for reason of limited survey sites and data. In this context, the author understands the necessity for further study to come up with reliable conclusions.

1. INTRODUCTION

Intersections are the most critical elements in the highway transportation system. Their main function is to facilitate the transfer of vehicles from one route to another efficiently by minimizing delay. In the transfer maneuver, vehicles may either merge or cross the paths of the conflicting traffic stream thus the necessity of intersection control to solve conflict is necessary.

Unsignalized intersections controlled by STOP or YIELD signs are the most common type of intersections in urban streets and rural roads. The universal adoption of these types of control to solve conflicts on intersections with relatively low traffic volumes has imposed to the cross street drivers to merge or cross a priority stream using gaps or lags in one or more conflicting traffic streams. This condition gives the gap acceptance theory to play a role on the analysis of this type of intersections.

Capacity of unsignalized intersections is usually limited. A measure of this capacity is usually the practical capacity with its corresponding threshold value of delay of the minor street vehicles. At volumes beyond this limiting value of capacity, the average delay increases with only small increase in volume. In this case, the intersection is said to be warranted for signalization or improvements.

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The Philippines has no local standard guidelines on when to signalize intersections. There are local studies made but the models established are only the result of validations of those on the foreign studies thus, it is almost the same as forcing these models to fit on the local situation of the country. Particularly in Metro Manila, Traffic Engineering and Management Office (TEAM) usually referred to as Traffic Engineering Center (TEC) which is under the Department of Public Works and Highways (DPWH), is having its guidelines of the warrants for signalization established with the assistance of consultant Pak-Poy and Associates. But these guidelines are based on the model established in 1978 on its fourth revision by the Manual on Uniform Traffic Control and Devices (MUTCD) of the U.S. Department of Transportation and Federal Highway Administration.

The Philippine has a unique situation such that forcing the use of foreign models might overestimate or maybe underestimate the local situation of the intersections. It is in this belief that this study is conducted aimed to produce useful tool for the analysis of unsignalized intersection based on the country's local situation

The fact that the country has no local standard for unsignalized intersections analysis and the warrants for signalization, most of the engineers in the country resort to using foreign models like that of the 1985 U.S. HCM and the MUTCD and fit them by brute force in the local situation. Doing so may result to degrading the quality of service of the intersections because this may end up to adopting improper and inadequate traffic controls. The reason is that, the fact that the models are calibrated by the data outside the Philippine situation makes the problem because of the most possible disparity on the road users attitude, i.e., the drivers capability on accepting or rejecting the gaps on the priority stream for their crossing or merging maneuver and the traffic characteristic as well. Thus, the traffic situation might be overestimated or underestimated.

The abovementioned lack of local guidelines leads the engineers in the country to use blindly the foreign models and fit them by brute force on the local situation. It is in this context that this study is conducted of which objectives are a) establish some values for critical gap for Philippine situation, b) establish empirical models of delay and actual capacity of minor street vehicles, and c) come up with a basis to distinguish intersection into efficient or inefficient on their functions. The latter could serve as warrant for improvement or signalization of unsignalized intersections.

Due to some constraints, only four intersections are covered, two of which are T-intersections and two four-legged intersections. The effect of intersection geometry is excluded except the number of lanes of both legs and a general observation of sight distances or view across corners.

The data is limited only on that obtain from a conducted field survey from 6:30 A.M. to 1:00 P.M. one setting per intersection.

Intersections under study are only STOP - controlled intersections.

Delay considered is service time delay and the delay incurred in the queue before reaching the stopline or the queue time delay is not included in the analysis.

Furthermore, the study is exploratory in nature such that the resulting output is not guaranteed reliable. Instead this will serve as initial basis for further study by validating the output to as many intersections as possible to come up with a precise conclusion and tool that will fit the Philippine situation.

2. DATA COLLECTION

The primary data are traffic volumes on each of the movements, delay per vehicle at the minor street movements, gap accepted and rejected by the minor street drivers from the available gaps on the major street, the number of lanes of both approaches and general observation of the sight distances across corners. The gathering of all these data per intersection was done in one sitting.

2.1 Traffic Volumes

Traffic volumes were gathered by enumerators using hand counters from 6:30 A.M. to 1:00 P.M. Volumes on all movements and per lane were recorded in 5-minutes interval. For Roces Avenue-Magsaysay Avenue and Mother Ignacia-Sgt. Esguerra Intersections, there were 12 movements recorded, for C.P. Garcia-to Teacher's Village 6 movements, and for University Avenue-C.P. Garcia 10 movements. Vehicles were classified into cars, buses, jeepneys, and trucks. Although conversion of vehicles to passenger cars may not be necessary, equivalent PCU was still taken using Traffic Engineering Center (TEC) conversion factor shown in Table 4-1 below for use in the future direction expected in this study.

Table 4-1.Passenger Car Unit Conversion Factors

Movement	Car	PUJ (jeepney)	Bus / Truck
left - turn	1.0	1.4	2.2
through	1. 0	1.4	2.2
right - turn	1.4	2.0	2.8

Source: Traffic Engineering Center

2.2 Delay per Vehicle

Using video camera mounted on strategic location so that every movement on the minor street can be observed, a video footage was taken. In the laboratory, these were encoded using a computer program to record time the vehicle in each movement in the minor street spent while waiting for a gap in the major street. This was accompanied by the use of a video player on television to view the footage taken.

The encoding is done by taking samples randomly per 5-minute interval and getting the average per interval gives the necessary data for the analysis.

2.3 Accepted and Rejected Gap

The use of video camera mounted on a car was employed here. The car was positioned in such a way that the whole view of the intersection could be seen so that intersections of vehicles can be easily observed. Using a computer program to record the gap accepted or rejected by the drivers and accompanied by a video player and a television, the encoding was done. The gap referred to here is the distance between arrivals of vehicles at the major street with respect to a reference expressed in time which is either accepted or rejected by the drivers for maneuver in crossing or merging at the intersection. So that time is no biased, a driver could only accept or reject one gap. If a vehicle arrive at the intersection and there is available gap, the recording is either that of gap rejected or gap accepted. Other actions after this gap by the vehicle is ignored and thus another vehicle will be considered again for another data.

2.4 Speed of the Major Street

Using video camera mounted on strategic location so that at least 50 meters section of the roadway near the intersection could be seen, a footage was taken per direction of the major traffic stream. Trap length method was used using a trap length of 40 meters. The encoding was done using the spot speed computer program (by Dr. R.G. Sigua) and video player and television taking sample speeds at random. Average is then calculated to represent average speed of the major street per direction.

2.5 Physical Characteristics

Physical characteristics were gathered on a general observation, and these were the number of lanes of both legs which was done by simply counting them and the sight distances across corners which was done by classifying them generally as poor, fair, and good. This was done so because of the fact that the effect of geometry is outside the scope of this study, but because of the belief that in the process, the kind of observations stated above would help in the discussion gives the reason for their inclusion.

3.0 RESULTS OF ANALYSIS

The output this study had achieved were somw critical gap values for Philippine intersection, delay models , capacity models and warrant for signalization or improvement of some types of unsignalized intersections.

3.1 Established Critical Gap Values

Shown below is a tabulated established critical gap values of some of the minor street movements of unsignalized intersections in Metro Manila in relation to the number of lanes and the average speed of the major street.

Table 9-2. Established Critical Gap Values

Vehicle Maneuver and Type of Control	Critical Gap in Seconds			
	Average Speed on the Major Street			
	27kph	33kph		38kph
		Case 1	Case 2	Case 3
	Number of Lanes on the Major Street			
	2	2	2	6
RT from Minor Street				
STOP				
NO CONTROL	3.2			
Cross Major Street				
STOP		3.9	4	
NO CONTROL				
LT from Minor Street				
STOP		4.4	4.8	6.2
NO CONTROL				

3.2 Actual Capacity / Maximum Flow Models

Intersections were classified into Case 1, Case 2, and Case3 types. The characteristics with the corresponding capacity models are shown below. As shown in Fig. 1,2 and 3, the capacity decreases as the total conflicting flow increases.

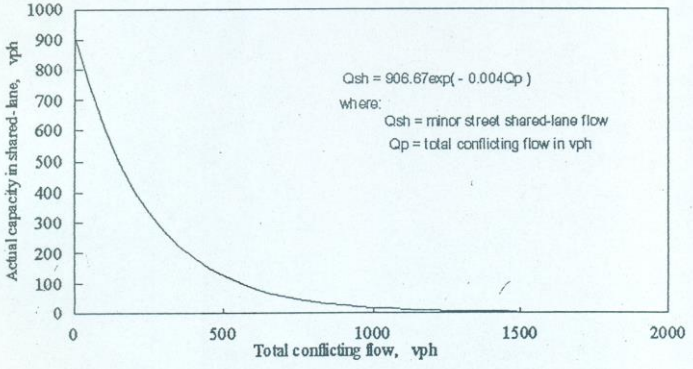

Fig. 1. Case 1: Minor Street Actual Capacity Model of STOP-controlled 4-leg intersection with wide approach, both legs two lanes and good corner vissibility (the Case of Mother Ignacia St. - Sgt. Esguerra St. Intersection).

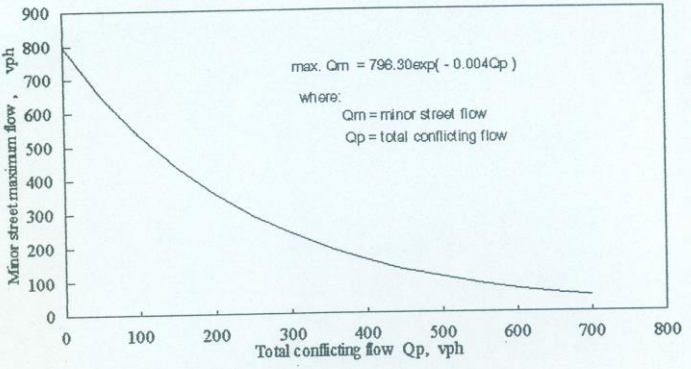

Fig. 2. Case 2: Minor Street Actual Capacity Model of STOP-controlled 4-leg intersection with narrow approach, with humps on the minor legs, poor corner vissibility and both legs two lanes (the case of Roces Ave.-Magsaysay Ave. Intersection).

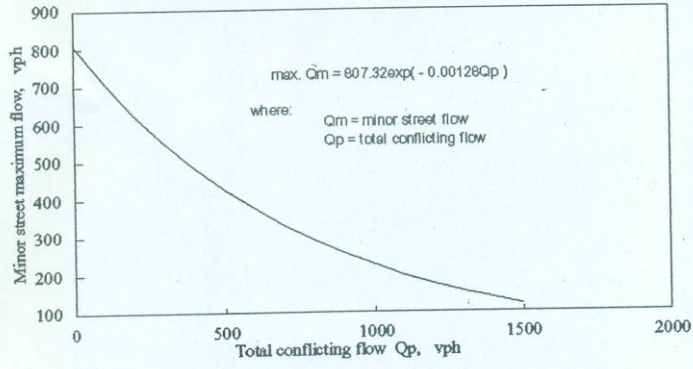

Fig. 3. Case 3: Minor Street Actual Capacity of STOP-controlled T-intersection with wide approach, 2-lane-2-way minor street and 6-lane-2-way major street, with median in the major street and with good corner vissibility (the case of University Ave.-C.P. Garcia Ave. Intersection)

3.2.1 The Effect of Critical Gap Size on Actual Capacity

The only actual capacity model that can be used to established the effect of critical gap size on actual capacity are that of Case 1 and Case 2 models. As shown in Fig. 4 below, the actual capacity decreases as the critical gap increases.

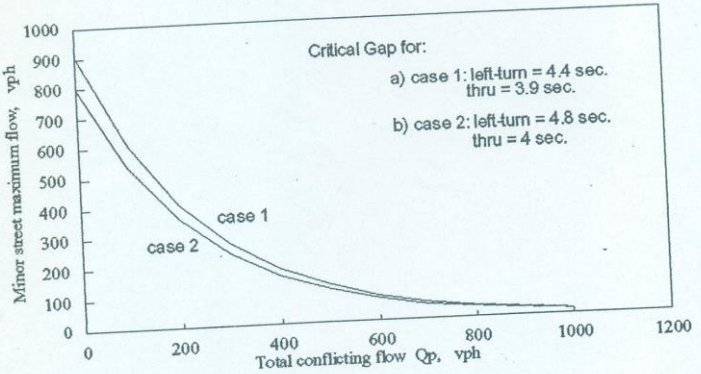

Fig. 4. The Effect of Critical Gap Size on Actual Capacity

3.3 Established Delay Models

The delay models by movement per type of intersection is a linear function of total conflicting flow and the reserved capacity being fixed and are shown below.These were established based on the zero reserved capacity curve or the actualcapacity curves mentioned above.

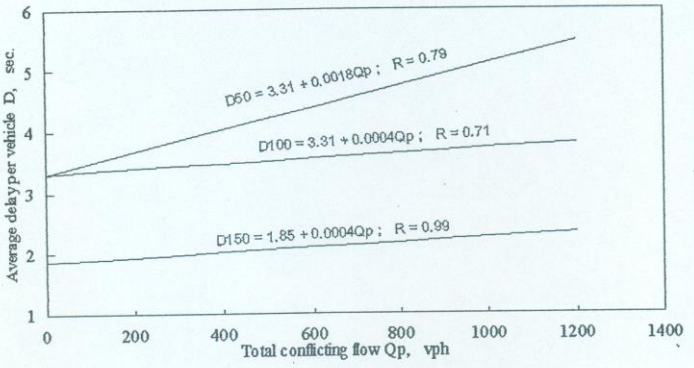

Fig. 5. Average Delay of Minor Street Left-turn of Case 1 type of Intersections (the case of Mother Ignacia Street - Sgt. Esguerra Street Intersection).

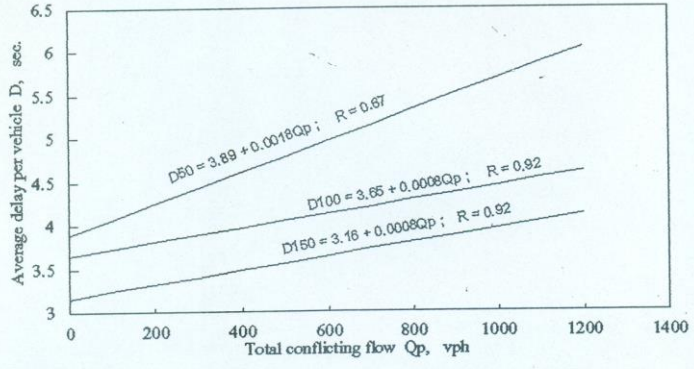

Fig. 6. Average Delay of Minor Street Left-turn of Case 2 type of Intersections (the case of Roces Avenue-Magsaysay Avenue Intersection).

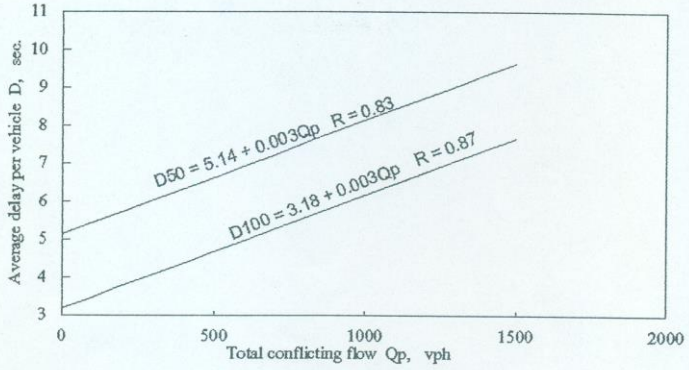

Fig. 7. Average Delay of Minor Street Left-turn of Case 3 type of Intersections (the case of University Avenue - C.P. Garcia Avenue Intersection).

3.4 Warrant for Intersection Improvement /Signalization

Based on the delay analysis , the reserved capacity of 100vph will be adopted in this study as the limiting reserved capacity. With reference to the actual capacity models established and the basic concept for an efficient unsignalized intersection, warrants are established as follows:

1. Case 1 intersection is only efficient if **$q < 906.67\exp(-0.004Qp) - 100$** where **q** is the flow of the minor street subject movement and **Qp** is the corresponding total conflicting flow.
2. Case 2 intersection is only efficient if **$q < 796.30\exp(-0.004Qp) - 100$** where **q** is the flow of the minor street subject movement and **Qp** is the total conflicting flow corresponding to **q**.

The figures below shows the graphical representation of the two cases mentioned above. The area below the curve of either of the two figures is the area where the solution set of the corresponding inequality cited on item (1) and (2) above holds true thus ,any combination of the flow of minor street subject movement and its corresponding total conflicting flow that falls on this area , the intersection condition does not warrant for signalization or improvement. Otherwise, if this combination falls on or above the curve, the intersection is warranted for signalization or improvement.

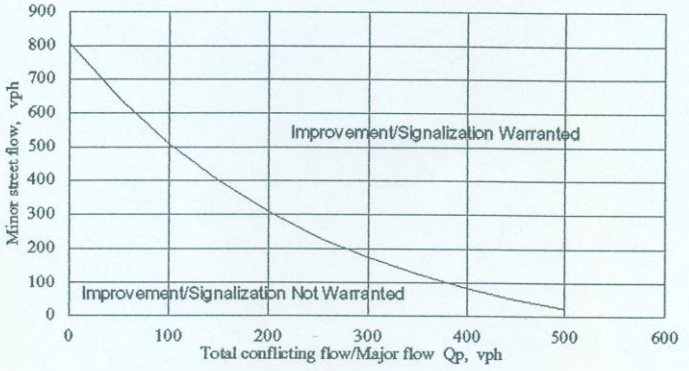

Fig. 8. Warrant for Signalization/Improvement of Case 1 type of Intersections

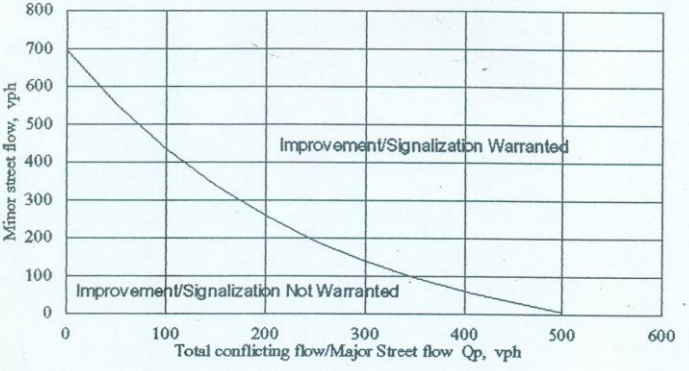

Fig. 9. Warrant for Signalization/Improvement of Case 2 type of intersections

4. COMPARISON OF THE ESTABLISHED MODELS TO SOME EXISTING MODELS

The question of whether the use of some existing models fit, overestimate or underestimate the condition of intersections in the country is an important question this paper is aimed to answer. On the use of capacity models, the 1985 U.S. HCM is widely used in the country whilie on the used of warrants for signalization/improvement of intersections, that of the MUTCD and TEC's (assisted by its consultant Pak-poy and Associates) warrants are popular. Below are comparisons of the established models to the abovementioned existing models.

4.1 Established Capacity Models vs. 1985 U.S. HCM Capacity Model

The 1985 U.S. HCM capacity model is a relationship of the potential or basic capacity as a function of the total conflicting flow including half of the right turners. This study does not include the effect of the right turn movement but as observed this movement is very minimal that if this was included, the result is approximately the same. Potential capacity as it is used by the 1985 U.S. HCM is that capacity with the assumptions that no movement impede the minor street subject movement or impedance effect neglected and that major street traffic does not block the minor street. In the selection of datapoints for establishing the capacity model on this study, they were so selected in such a way that besides the consideration of continuous demand and interaction, free flow on the movements was also an important consideration (no blocking of movements by a stop or a crawling speed). In this context, the capacity established in this study is comparable to that of the 1985 U.S. HCM (on no impedance condition). Shown below are Figures 10, 11 and 12 stating that generally Case 1 and Case 2 types of intersections lower capacity compared to that of the 1985 U.S. HCM except for Case 3 type of intersections which is generally true between the 6 sec. and 7 sec. 1985 U.S. HCM capacity curves.

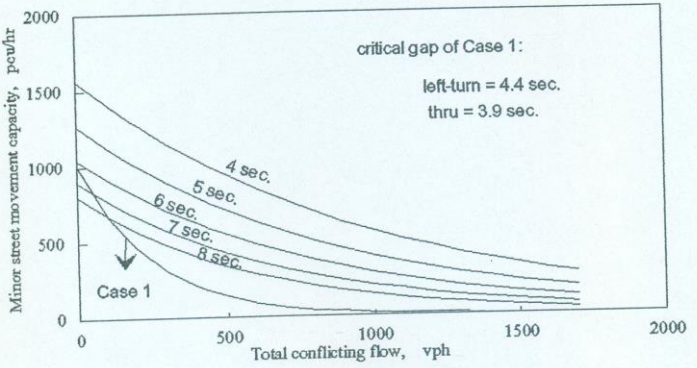

Fig. 10. Capacity of Case 1 type of intersections compared to that of the 1985 U.S. HCM showing that generally this type is of lower values.

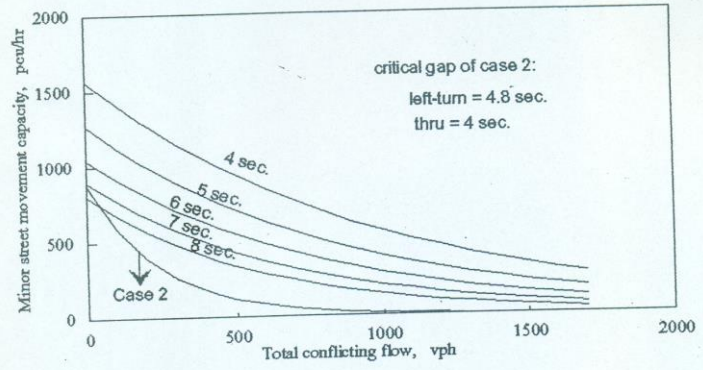

Fig. 11. Capacity of Case 2 type of intersections compared to the 1985 U.S. HCM capacity model showing that this type is generally of lower value.

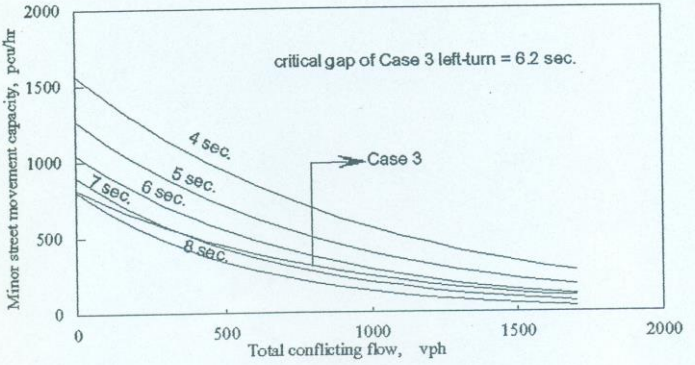

Fig. 12. Capacity of Case 3 type of intersections compared to the 1985 U.S. HCM capacity model showing that this type generally holds true between the 6 sec. and 7 sec. curves of the latter.

4.2 Established Warrants vs. MUTCD Warrant

Fig. 13 shows the comparison of the MUTCD warrant and the established warrants of Case 1 and Case 2 types of intersections. The graph states that the use of the former is an overestimate of the local situation of intersections.

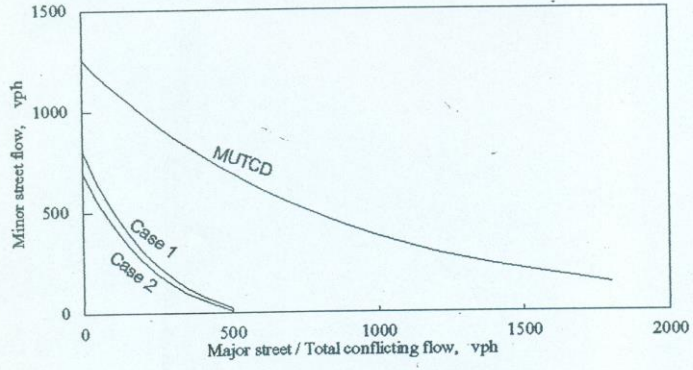

Fig. 14. Warrants for Case 1and Case 2 types of intersections compared to the MUTCD showing that the use of the latter is an overestimate.

4.3. Established Warrants vs. TEC Warrant

The only warrant that could be compared to the TEC is that of the Case 2 for reason that volumes of the through movement on either approach of the minor street of the intersection observed was found minimal. Fig. 15 below shows the comparison.

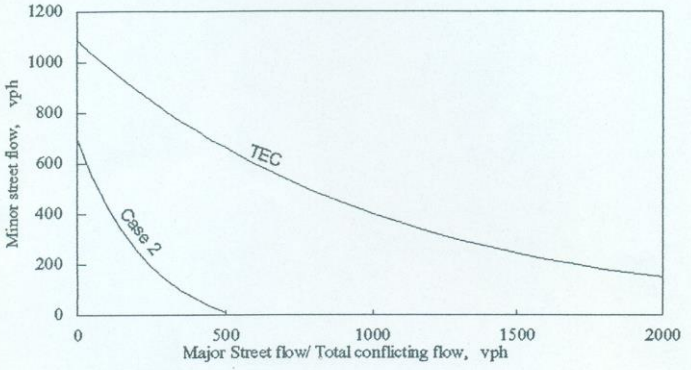

Fig. 15. Warrant for Case 2 type of intersections compared to TEC warrant showing that the later is an overestimate of the local situation of intersections.

5. SUMMARY OF FINDINGS

In this study, values of critical gap and preliminary models to estimate the maximum flow or actual capacity and average delay at selected STOP controlled intersections has been developed. Warrant for intersection signalization based on average service time delay and a threshold reserved capacity has also been established. Some findings relating to these are as follows:

1) The basic traffic flow theories presented in Chapter 3 were confirmed to be true in this study.
2) At a constant reserved capacity of 100 vph, the delay at urban unsignalized intersections in the country tends to remain constant beyond which the said intersection is saturated.
3) The use of the values of critical gap in the 1985 U.S. HCM for local situation in the country will overestimate intersection capacity and the local drivers capability of accepting safe gap for maneuver except for some type of intersection such as Case 3 intersection.
4) The use of the MUTCD warrant for signalization will overestimate tthe efficiency of the local intersections.

5) TEC warrant for signalization was found out to be an overestimate of some type of intersection like Case 2 as referred to in this study.

The above findings are preliminary for reasons of limited sites and data. As this is the first study of this type conducted in the country, reliability is not a guarrantee. Furthermore, several studies reveal that critical gap is local in nature, that it is possible that certain values obtain are only true on the place where gap acceptances and rejections data were gathered. In this context, the values of critical gap obtain on this study may be a representative only of the intersections selected.

6. SOME PROBLEMS AND RECOMENDATIONS FOR FURTHER DIRECTIONS

One problem encountered was on the selection of field survey sites where the input data needed were gathered. One of the site selected was found to be too congested that almost no relationship could be possibly established. For the other three intersections some minor street subject movements were found having very low traffic demand that establishing the actual capacity or maximum flow model is impossible. With these, it is recomended that preliminary observations and investigations of the characteristics of the selected unsignalized intersections will be conducted first not only once but as much as possible several times before gathering the final data for the analysis. This requires a large amount of time and money but this is one way of obtaining good data and reliable results.

On the traffic count, one problem encountered is the efficiency and reliability of the hired enumerators. Athough briefings were conducted before they were sent to the field, still it was not avoided that unbelievable data were reflected on their tally sheets. In this connection, it is recomended that the collection of traffic flow data will be done using video camera rather than hiring enumerators. Again, this requires large amount of money, time and effort. On the other hand, it was found out that not only morning characteristic of traffic flows will be considered .The afternoon flow characteristics must also be included to define well the pattern of increase and decrease of flows and the maximum flow as well and this will be done not only a day but as much as possible in the whole week to come up with a good generalization on the flow characteristics.

The presence of jeepney stop near the intersection selected is also found a problem as this was observed altering the intersection operation in which vehicles slow down or stop upon seeing park jeepneys on the stop box. The selection of safe gap of minor street drivers was found also affected on this situation. Thus for the further direction of this study, this must be avoided.

The platoon movement of the vehicles both in the minor and major street was observed apparent in so many intervals (if not all) of the whole duration of the field survey on all intersections selected. In this case it is recomended that instead of analyzing this intersection as two-way STOP intersection, it will be analyze as four-way STOP intersection to compensate the effect of platoon movement.

Another important observation was the case where most of the minor street drivers prefer lag for their maneuver rather than gap. In this cnnection, it is recomended that in the further

direction of this study, lag will be considered instead of gap thus establishing critical lag size instead of critical gap.

Finally, further validations of the results of this study to as many intersections as possible must be made to come up with concrete conclusions regarding Philippine unsignalized intersections .

ACKNOWLEDGMENTS

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