

**DEVELOPMENT OF UNSIGNALISED INTERSECTION ANALYSIS
PROCEDURE FOR THE MALAYSIAN HIGHWAY CAPACITY MANUAL**

by

MOHD ERWAN BIN SANIK

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LIST OF SYMBOLS

t_c	Critical gap
t_f	Follow-up time
V_c	Conflicting volume
C_n	Capacity of non-priority stream
v_p	Priority flow rate
C_{sh}	Capacity of shared-lane
V_l	Volume of left-turn movement in shared-lane
V_r	Volume of right-turn movement in shared-lane
C_{ml}	Movement capacity of left-turn movement in shared lane
C_{mr}	Movement capacity of right-turn movement in shared lane
C_R	Reserve or unused capacity
$t_{c,x}$	Critical gap for movement x
$t_{c,base}$	Base critical gap
$t_{c,G}$	Adjustment factor for grade
$t_{c,T}$	Adjustment factor for each part of a two-stage gap acceptance process
$t_{3,LT}$	Adjustment factor for intersection geometry
$t_{c,HV}$	Adjustment factor for heavy vehicle
P_{HV}	Proportion of heavy vehicle

G	Percent grade divided by 100
$t_{f,x}$	Follow-up time for minor movement x
$t_{f,base}$	Base follow-up time
$t_{f,HV}$	Adjustment factor for heavy vehicle
$C_{p,x}$	Potential capacity of minor movement x (U.S. HCM 2000)
$v_{c,x}$	Conflicting flow rate for movement x
$P_{p,x}$	Impedance Factor for Pedestrians for movement x
Q_{95}	95 th -percentile queue
T	Analysis time period
d	Control delay
L	Maximum likelihood function
a_i	Logarithm of the accepted gap of driver i
r_i	Logarithm of the largest rejected gap of driver i
$F (...)$	Cumulative distribution function for the normal distribution
μ	Mean of the gap acceptance distribution
σ^2	Variance of the gap acceptance distribution
q	Flow rate of vehicles
A_x	Adjustment factor for movement x
$t_{c,all}$	Critical gap for all vehicle
$t_{c,car}$	Critical gap for passenger car
P_M	Proportion of motorcycle
$\alpha_{c,M}$	Estimated coefficient for motorcycle of critical gap
$\beta_{c,HV}$	Estimated coefficient for heavy vehicle of critical gap
$\alpha_{f,M}$	Estimated coefficient for motorcycle of follow-up time
$\beta_{f,HV}$	Estimated coefficient for heavy vehicle of follow-up time
D	Average total delay
$t_{d,i}$	Time when i^{th} vehicle departed the stop line

$t_{s,i}$	Time when i^{th} vehicle stopped at the end of a queue
$P_{O,j}$	Probability that conflicting Rank 2 movement j will operate in a queue-free state
$C_{emc,j}$	Estimated movement capacity for movement j
$C_{p,j}$	Potential capacity for movement j
C_{omc}	Observed movement capacity
$C_{mp,x}$	Potential capacity for movement x (MHCM)
H_0	Null hypothesis
H_1	Alternate hypothesis

LIST OF ABBREVIATION

U.S. HCM	United States Highway Capacity Manual
TRB	Transportation Research Board
MHCM	Malaysian Highway Capacity Manual
RTMaj	Right turn from major
LTMin	Left turn from minor
RTMin	Right turn from minor
LOS	Level of service
vph	Vehicle per hour
pcph	Passenger car per hour
mph	Mile per hour
TWSC	Two-way stop-controlled
PHF	Peak-hour factor
veh	Vehicle
TDC-8	Traffic Data Collector – 8
AAR	Ascending accepted-rejected gap
AAcc	Ascending accepted gap

ARej	Ascending largest rejected gap
SD	Standard deviation
Acc	Accepted gap
Rej	The largest rejected gap

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- Appendix D Regression Analysis for Critical Gap (Input and output)

LIST OF PUBLICATIONS & SEMINARS

Mohd Erwan S., Wan Hashim W.I. (2006). Study of Critical Gap and Follow-up Time Based on Malaysian Road Condition, 1st Civil Engineering Colloquium, School of Civil Engineering, Universiti Sains Malaysia.

Wan Hashim Wan Ibrahim and Mohd Erwan Sanik, Overview of Capacity Estimation at Unsignalised Intersection, Technical Notes 9, Paper 2, Highway Planning Unit, Ministry of Works, Malaysia

Wan Hashim Wan Ibrahim and Mohd Erwan Sanik, Estimation of Capacity at Priority Junction, Technical Notes 10, Paper 2, Highway Planning Unit, Ministry of Works, Malaysia

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PEMBANGUNAN PROSEDUR ANALISIS PERSIMPANGAN KEUTAMAAN BAGI MANUAL KAPASITI LEBUH RAYA MALAYSIA

ABSTRAK

Tesis ini membincangkan pembangunan prosedur analisis persimpangan keutamaan untuk Manual Kapasiti Lebuh Raya Malaysia (MHCM 2006). Persimpangan keutamaan memainkan peranan yang penting dalam menentukan kapasiti suatu rangkaian jalan terutamanya untuk kawasan bandar dan pinggir bandar. Pada masa ini, Malaysia menggunakan kaedah yang diambil daripada United States Highway Capacity Manual 1985 sebagai prosedur untuk menilai persimpangan keutamaan dan dikenali sebagai Arahan Teknik (Jalan) 11/87.

Untuk membangunkan prosedur berdasarkan keadaan lalu lintas di Malaysia, United States Highway Capacity Manual 2000 telah disesuaikan dengan parameter masukan yang ditentukan berdasarkan data tempatan. Parameter-parameter masukan yang ditentukan ialah ruang genting, masa kemajuan dan faktor pelarasan untuk kapasiti dengan mengambil kira komposisi kenderaan dan jenis geometri persimpangan. Walau bagaimanapun, hanya kereta dan motosikal yang terlibat memandangkan data untuk kenderaan berat adalah sedikit dan tidak mencukupi.

Dalam kajian ini, sebanyak 33 persimpangan telah digunakan. Cerapan data melibatkan kawasan bandar dan pinggir bandar sepanjang pantai barat Semenanjung Malaysia. Prosedur baru untuk Malaysia adalah penyesuaian daripada bahagian kawalan-berhenti dua-hala dalam United States Highway Capacity Manual 2000 untuk persimpangan tiga cabang atau persimpangan-T, yang mana persimpangan yang paling banyak terdapat di kawasan kajian. Ruang genting tidak boleh ditentukan secara langsung daripada lapangan tetapi data ruang diterima dan ruang ditolak boleh

dicerap dan dianalisa. Data ruang ini dicerap menggunakan kamera video dan beberapa peralatan lain. Dalam penentuan ruang genting, kaedah maximum likelihood telah digunakan. Masa kemajuan boleh diperhatikan secara langsung semasa di lapangan tetapi dalam kajian ini ia diperhatikan dan dihitung dalam aliran lalu lintas di persimpangan yang dirakam oleh kamera video. Dalam pengiraan faktor pelarasan, peralatan daripada JAMAR Technology telah digunakan untuk mencerap data kelengahan di persimpangan.

Keunikan prosedur analisis ini adalah dengan mengambil kira motosikal dalam pengiraan ruang genting, masa kemajuan dan kapasiti. Nilai-nilai ruang genting dan masa kemajuan untuk persimpangan lorong tunggal dan pelbagai masing-masing dalam julat 3.2 hingga 4.2 saat dan 1.9 hingga 2.4 saat. Faktor pelarasan adalah berbeza mengikut jenis geometri persimpangan.

Prosedur analisis berdasarkan keadaan lalu lintas di Malaysia ini dibangunkan untuk membantu jurutera-jurutera, penyelidik-penyelidik dan perancang-perancang untuk mendapatkan penilaian kapasiti dan aras perkhidmatan yang tepat untuk persimpangan. Kajian ini boleh diteruskan di masa akan datang untuk memperbaiki nilai-nilai parameter masukan dan juga membangunkan prosedur analisis untuk persimpangan empat-cabang dan bulatan bukan sahaja untuk kawasan bandar dan pinggir bandar, malah untuk kawasan luar bandar juga.

DEVELOPMENT OF UNSIGNALISED INTERSECTION ANALYSIS PROCEDURE FOR THE MALAYSIAN HIGHWAY CAPACITY MANUAL

ABSTRACT

This thesis discusses the development of unsignalised intersection analysis procedure for the Malaysian Highway Capacity Manual (MHCM 2006). Unsignalised intersection plays an important role in determining the capacity of a road network especially in urban and suburban areas. Currently, Malaysia has been adopting the United States Highway Capacity Manual 1985 (U.S. HCM 1985) as the procedure to evaluate unsignalised intersections and known as the Arahan Teknik (Jalan) 11/87.

In order to develop a procedure based on Malaysian traffic condition, the United States Highway Capacity Manual 2000 is adopted with the input parameters which are determined based on local data. The input parameters that are estimated are critical gap, follow-up time and adjustment factor for capacity with respect to vehicle composition and type of intersection. However, only passenger car and motorcycle are involved since the data of heavy vehicle is less and not adequate.

There are thirty three intersections being investigated in this study. The data collection involves urban and suburban area along west coast of Peninsular Malaysia. The new Malaysian procedure is the adaptation of the two-way stop-controlled procedure based on the United States Highway Capacity Manual 2000 for three legs junction or T-junction, which is the most available unsignalised intersection in the study area. Critical gap can not be determined directly from field but data of accepted and rejected gaps can be collected and analysed. Data of gaps were collected using video camera and other several equipments. The maximum likelihood method is used in the determination of critical gap. Follow-up time can be observed directly from the field but

in this study, it is observed and estimated from the traffic flow at the intersection which was recorded by the video camera. In the estimation of adjustment factor, equipment from JAMAR Technology was used to collect delay at intersection.

The uniqueness of this analysis procedure is the consideration of motorcycle in the estimation of critical gap, follow-up time and capacity. The values of critical gap and follow-up time for single and multi-lane vary from 3.2 to 4.2 seconds and 1.9 to 2.4 seconds respectively. The adjustment factor varies according to type of intersection.

The analysis procedure is developed with respect to Malaysian traffic conditions to help engineers, researchers and planners to obtain accurate assessments of capacity as well as the level of service of intersections. This study can be continued in the future in order to improve the values of input parameters and also develop the analysis procedure for four-leg intersection and roundabout not only for urban and suburban areas, but also for rural area.

CHAPTER 1 INTRODUCTION

1.1 Background of Study

The rapid development of Malaysia increases the cost of living of the citizen. It influences the travel pattern of the community from their origin to any destination. Transportation system is also affected by the development as shown by the annual increase in the number of vehicles on roads. Referring to Table 1.1, the statistic shows that the number of vehicles has increased every year (JKR, 2005). This obvious increase causes road congestion especially during peak hour. Traffic congestion is also influenced by the road network. In a road network, the intersection is a major cause of bottlenecks thus contributing to congestion. Various types of intersection are at-grade intersection, signalized and unsignalised intersection, and roundabout. However the scope of this study is to carry out analysis for the unsignalised intersection only.

Table 1.1: Motor Vehicle Registration Malaysia - By Vehicle Types From 1986 – 2005
(JKR, 2005)

Year	Motorcycle	Car	Taxi	Bus	Lorry & Van	Hire Car	Trailer	Other	Total
1989	2,848,717	1,658,567	26,078	24,828	349,737	4,725	26,807	132,327	5,071,786
1990	3,035,930	1,811,160	28,811	26,803	380,330	5,666	27,348	146,730	5,462,778
1991	3,251,289	1,970,934	31,842	28,229	411,149	6,181	27,998	159,554	5,887,176
1992	3,473,643	2,107,005	34,178	30,013	442,401	6,791	28,744	172,733	6,295,508
1993	3,703,838	2,255,420	36,458	33,358	466,871	7,586	29,077	179,871	6,712,479
1994	3,977,047	2,426,546	40,088	34,771	495,736	10,279	28,788	196,834	7,210,089
1995	3,564,756	2,532,396	27,276	35,224	430,716	28,969	No data	183,038	6,802,375
1996	3,951,931	2,886,536	49,485	38,965	512,165	9,971	No data	237,631	7,686,684
1997	4,328,997	3,271,304	51,293	43,444	574,622	10,826	No data	269,983	8,550,469
1998	4,692,183	3,452,852	45,643	54,590	599,149	10,142	No data	269,983	9,124,542
1999	5,082,473	3,787,047	55,626	47,674	642,976	10,020	No data	304,135	9,929,951
2000	5,356,604	4,145,982	56,152	48,662	665,284	10,433	No data	315,687	10,598,804
2001	5,592,150	4,528,490	56,464	49,669	688,367	10,053	No data	327,369	11,252,562
2002	5,825,960	4,974,850	57,920	51,008	711,738	10,107	No data	344,058	11,975,641
2003	6,164,958	5,428,774	60,723	52,846	740,482	10,210	No data	361,275	12,819,268
2004	6,572,366	5,911,752	65,008	54,997	772,218	10,661	No data	377,835	13,764,837
2005	6,604,042	5,960,253	65,504	55,231	775,021	10,971	No data	380,627	13,851,649

Unsignalised intersection is a common type of intersection used to control traffic movement. They play an important role in determining overall capacity of road networks. A poorly operating unsignalised intersection may affect adjacent signalized intersection. Therefore, it is important to make sure that the intersection is designed appropriately to prevent either under or over designing of the facility. Analysis procedure with respect to Malaysian road condition is needed to design the unsignalised intersection so the capacity is always greater than traffic demand.

The evaluation of capacity at unsignalised intersection is practically measured using the gap acceptance approach and the empirical regression approach. In this study, the gap acceptance approach is used for unsignalised intersection procedure. The critical gap and the follow-up time are two major parameters needed for various gap acceptance capacity models. Currently, Malaysia has been adopting the United States Highway Capacity Manual 1985 (U.S. HCM 1985) (TRB, 1985) as the procedure to analyse the capacity for unsignalised intersection. The parameters used are obviously based on the United States road condition and this study will determine whether these parameters are suitable for Malaysia.

1.2 Problem Statement

The current procedure to evaluate the operational performance of an unsignalised intersection is adopted directly from the United States Highway Capacity Manual. Such procedure would lead to inaccurate interpretations of the results of the analysis as all parameters and variables used are not based on local traffic characteristics. As a result, planning for improvements and resources would not be reliable. Therefore, it is very important to re-develop the procedure to incorporate various local traffic characteristics for accurate analysis. Two aspects of the input parameters that require revision are the motorist's critical gap and follow-up time.

These two parameters influence the results of the performance analysis as well as the composition of traffic. This study is carried to address this issue.

The previous study of Asmi (2003) in his master's dissertation is to determine appropriate value of critical gap and follow-up time based on Malaysian road condition. The Maximum Likelihood method was selected for Asmi's study to obtain critical gap value and is continued in this study. Estimated value of follow-up time is measured directly from the field. Asmi (2003) has emphasized the importance of values for motorcycle since motorcycle composition is high on Malaysian roads as proven in Table 1.2. Table 1.2 shows the percentage of vehicle composition on Malaysian road at 15 selected stations in 2004 (JKR, 2006).

In this study, the data of critical gap and follow-up time have been revised and analysed with several consideration. In addition, regression model was selected to find the relationship of vehicle compositions especially passenger car and motorcycle. New values of critical gap and follow-up time are introduced.

Using the U.S. HCM 2000 as the standard reference, the existing potential capacity formula is used for calculation. However, it has to come with an adjustment factor to be practically used for Malaysian Highway Capacity Manual. The adjustment factor A is determined by analyzing the relationship of movement capacity calculated from control delay and potential capacity formula. The detailed methodology is discussed in Chapter 3. In order to observe the effect of critical gap, follow-up time and adjustment factor's value to the movement capacity and control delay, variation of these values are tested on the formula. It is carried out by changing the parameters' value for every 5 percent. The detailed sensitivity analysis is discussed in Chapter 5.

Table 1.2: Traffic Composition (%) by Type of Vehicles at 15 Selected Stations, Malaysia, 2004 (JKR, 2006)

No	Station	16-hour Traffic	Percentage (%) Vehicles Composition											
			April-04						October-04					
			Car/Taxi	Light Lorry	Medium Lorry	Heavy Lorry	Bus	Motorcycle	Car/Taxi	Light Lorry	Medium Lorry	Heavy Lorry	Bus	Motorcycle
Peninsular Malaysia														
1	AR 301	22,557	55.0	7.1	12.8	7.5	2.4	15.3	53.9	7.7	12.1	6.9	2.3	17.1
2	BR 805	169,972	73.2	4.9	4.3	0.8	1.0	15.9	77.1	4.7	3.6	0.7	0.8	13.1
3	CR 805	11,004	63.9	9.0	10.2	6.7	1.7	8.5	48.8	12.0	12.9	9.7	1.3	15.2
4	CR 902	7,031	52.8	13.3	13.0	11.7	1.2	8.1	52.6	14.1	12.9	9.8	1.4	9.2
5	DR 802	14,109	56.7	14.0	9.0	3.5	1.0	15.7	60.5	13.0	9.1	2.4	1.1	14.0
6	JR 203	44,437	61.0	12.3	9.6	5.0	2.7	9.5	58.1	10.6	10.9	7.0	1.8	11.7
7	JR 501	13,225	52.0	7.4	7.6	3.2	0.9	29.0	54.6	7.0	7.0	2.5	0.9	27.9
8	KR 501	18,156	50.4	9.3	10.0	4.9	1.1	24.3	53.1	8.8	8.9	4.6	1.1	23.5
9	NR 501	12,718	59.5	9.4	11.6	3.4	1.4	15.3	No data	No data	No data	No data	No data	No data
10	PR 115	33,596	50.8	7.7	9.3	4.1	1.1	27.0	50.7	7.4	10.0	3.8	1.1	27.1
11	TR 402	No data	No data	No data	No data	No data	No data	No data	61.4	7.9	4.9	1.9	1.5	22.4
Sabah														
12	HR 201	3,078	48.6	25.2	11.8	5.9	0.7	7.8	48.5	25.0	13.4	5.2	1.3	7.1
13	HR 501	18,757	19.6	20.8	19.6	14.6	12.9	12.5	19.5	20.6	19.5	14.7	3.2	12.6
Sarawak														
14	SR 103	30,717	48.5	12.9	10.7	5.7	1.9	20.3	46.8	12.5	8.9	6.9	0.9	23.7
15	SR 402	6,041	38.2	25.4	15.8	9.7	2.5	8.4	42.0	15.8	18.5	17.1	13.2	3.5

1.3 Objectives

The objectives of this research are as follows:

1. To develop critical gap and follow-up time for Malaysian road condition to take into consideration of vehicle compositions.
2. To develop capacity formulation for unsignalised intersection with respect to Malaysian road condition.
3. To analyse the effect of variation in parameters to the performance of unsignalised intersection calculated using the proposed procedure.

1.4 Scope of Study

In this thesis, study locations are selected among single lane and multi-lane T-junctions. This type of intersection is the most common type of unsignalised intersection in Malaysia especially for urban and suburban area. Several study location in the West Coast of Peninsular Malaysia were selected to conduct the study.

Figure 1.1 shows the illustration of a typical T-junction in this study and also the ranks of the movements. Ranks of movement are the discipline of the movements at T-junction which have the right of way according to priority. In this study, only the critical movements are analysed. These movements are represented by number 4, 9 and 7 which are right turn from major road (RTMaj), left turn from minor road (LTMin) and right turn from minor road (RTMin), respectively.

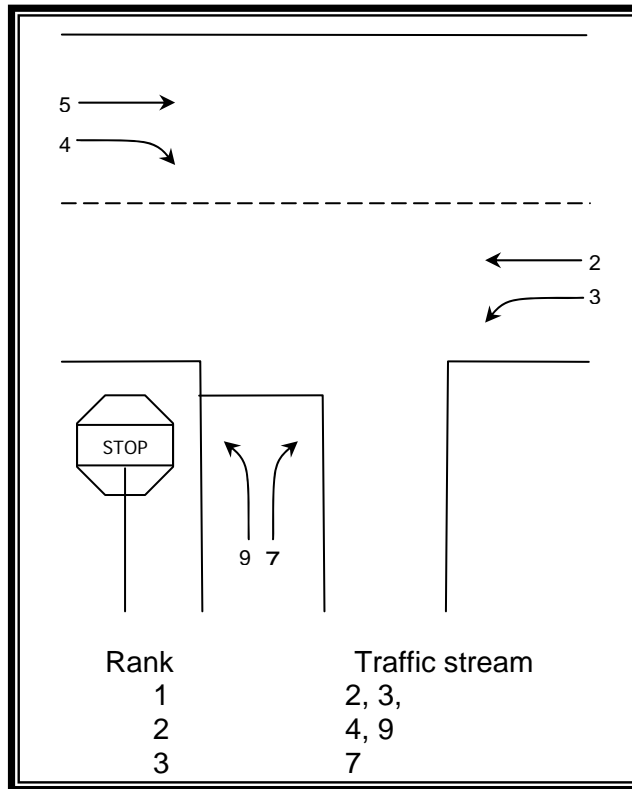


Figure1.1: Illustration of a typical T-junction in Malaysia

1.5 Thesis Organisation

The first chapter of this thesis gives a general introduction of the overall thesis content and the general background of parameters involved in the analysis of unsignalised intersection. The second chapter reviews the relevant literatures related to gap acceptance parameter and capacity studies. Subsequently, Chapter 3 discusses the study methodology carried out for this study. Chapter 4 is the data analysis and discussion. Chapter 5 discusses the sensitivity analysis and comparison of a junction evaluation between the MHCM and the U.S. HCM 2000. Finally, Chapter 6 concludes this thesis.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

In Chapter 1, overall contents of this study were discussed from the problem statement, objectives, and the scope. In order to understand this study, the literature reviews on several procedures and the discussion on the parameters are carried out in this chapter. In this chapter, current literatures on the unsignalised intersection analysis procedures in Malaysia, United States of America, Indonesia, United Kingdom and Poland are reviewed in section 2.2. In section 2.3, the definition of critical gap and follow-up time is specified. In section 2.4, estimation procedure for gap acceptance and follow-up time as carried out by Asmi (2003) is reviewed. Finally, section 2.5 summarizes this chapter.

2.2 Capacity Analysis Procedures

2.2.1 Malaysian Approach

Malaysian approach of capacity analysis procedure is based on the Arahan Teknik (Jalan) 11/87. The estimation of capacity for unsignalised intersection as proposed by the Arahan Teknik (Jalan) 11/87 is based on The Highway Capacity Manual, Special Report 209, 1985. The outline of unsignalised intersection analysis procedure based on the Arahan Teknik (Jalan) 11/87 is as illustrated in Figure 2.1. Referring to Figure 2.1, the procedure being used can be categorized as follows:

- a) The definition of the existing geometric and volume conditions for the intersection under study.
- b) The determination of the “conflicting traffic”.
- c) The determination of the size of the gap in the conflicting traffic stream.
- d) The determination of the potential capacity.

- e) The Adjustment of the potential capacities by taking into account for impedance and the use of shared-lanes.
- f) The estimation of reserve capacity and determine LOS.

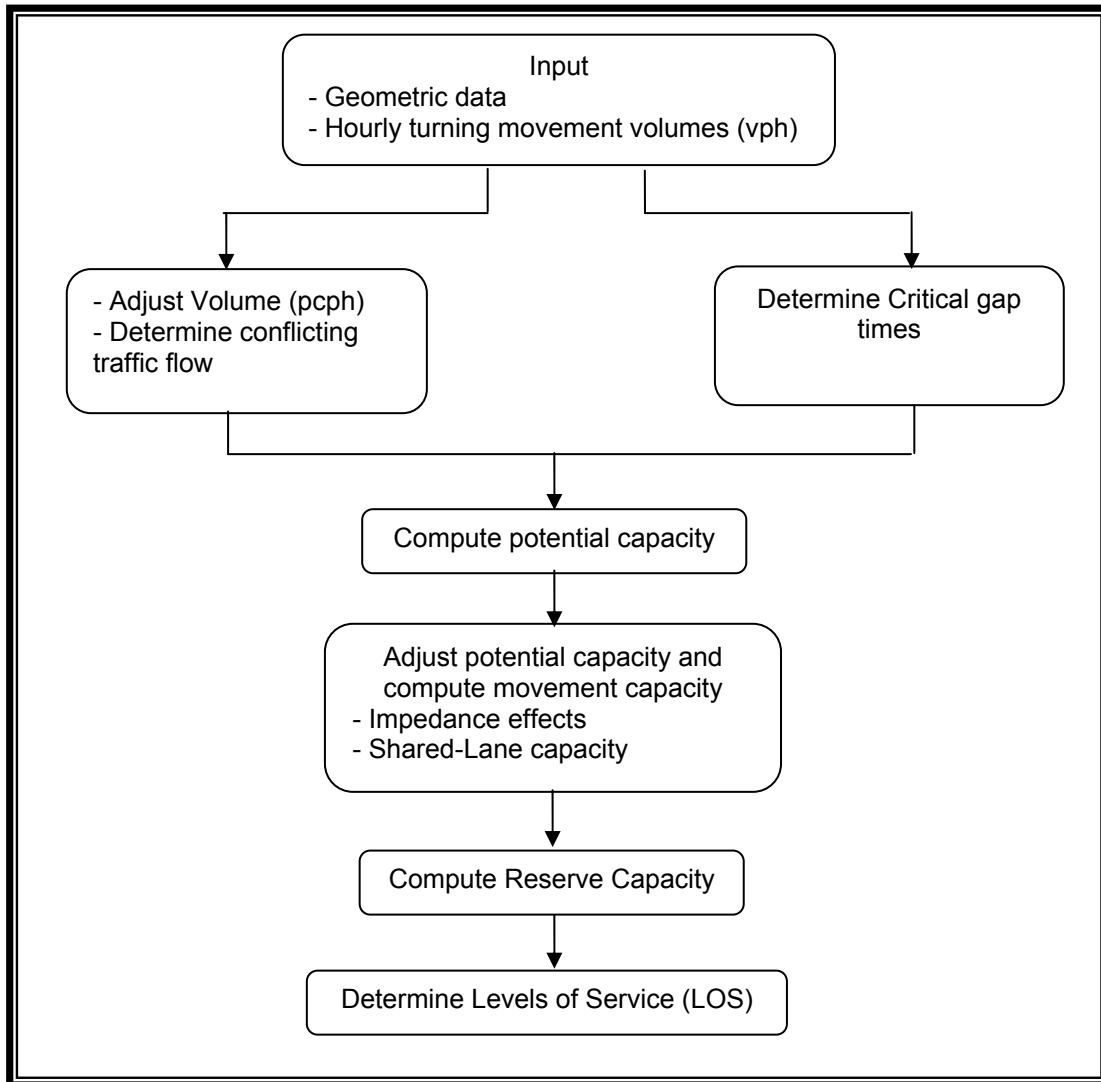


Figure 2.1: Outline of unsignalised intersection analysis procedure based on Arahan Teknik (Jalan) 11/87 (JKR, 1987)

Key geometric factors being considered in the Arahan Teknik (Jalan) 11/87 are number of lanes, lane usage, channelization, percent grade, curb radii, approach angle, and sight distance. Each of these factors is assumed to have substantial impact on how gaps are utilized, and on the size of the gap that is required by the various

movements. Conversion of vehicles per hour to passenger car per hour is accomplished using the passenger-car equivalent values given in Table 2.1.

Table 2.1: Passenger-Car Equivalent for Unsignalised Intersection (JKR, 1987)

Type of Vehicle	Grade (%)				
	-4%	-2%	0%	+2%	+4%
Motorcycles	0.3	0.4	0.5	0.6	0.7
Passenger Cars	0.8	0.9	1.0	1.2	1.4
SU/RV's ^a	1.0	1.2	1.5	2.0	3.0
Combination Veh.	1.2	1.5	2.0	3.0	6.0
All Vehicles ^b	0.9	1.0	1.1	1.4	1.7

^a Single-unit trucks and recreational vehicles.

^b If vehicle composition is unknown, these values may be used as an approximation.

The nature of conflicting movements at an unsignalized intersection is relatively complex. The conflicting volume defines as V_{ci} , the conflicting volume for movement i , that is, the total volume which conflicts with movement i , expressed in vehicles per hour. The computation of conflicting traffic volumes is as shown in Figure 2.2.

The gap acceptance theory requires an understanding of availability of major stream gaps, the usefulness of each gap, and the relative hierarchy of the traffic streams at the intersection. It assumes random arrivals on the major street and minor stream driver behaviour that is both consistent and homogenous in accepting and rejecting major stream gaps (Kyte et al., 1996).

Subject Movement	Conflicting Traffic, V_{ci}	Illustration
1. LEFT TURN from minor street	$\frac{1}{2}(V_r)^{**} + V_t^*$	
2. RIGHT TURN from major street	$V_r^{***} + V_t$	
3. THROUGH MVT from minor street	$\frac{1}{2}(V_{ra})^{***} + V_{ta} + V_{la} + V_{rb} + V_{tb} + V_{lb}$	
4. RIGHT TURN from minor street	$\frac{1}{2}(V_{ra})^{**} + V_{ta} + V_{la} + V_{rb}^{***} + V_{tb} + V_{lb} + V_o + V_{or}$	

* V_i include only volume in the left hand lane

** where a left-turn lane is provided on major street, eliminate V_r or V_{ra}

*** where the left-turn radius into minor street is large and/or where these movements are STOP/YIELD-controlled, eliminate V_r (case 2), and V_{ra} and/or V_{rb} (case 4), V_{rb} may also be eliminated on multilane major streets.

Figure 2.2: Definition and computation of conflicting traffic volumes (JKR, 1987)

The values of basic critical gap for passenger cars are as shown in Table 2.2.

The critical gap depends on a number of factors, including:

1. The type of maneuver being executed.

2. The type of minor street control (STOP or YIELD).
3. The average running speed on the major street.
4. The number of lanes on the major street.
5. The geometric and environmental conditions at the intersection.

Table 2.2: Critical gap criteria for unsignalised intersection (JKR, 1987)

Basic critical gap for passenger cars, s				
Vehicle maneuver and Type of control	Average running speed, major road			
	30 mph		55 mph	
	Number of lanes on major road			
	2	4	2	4
LT from minor				
Stop	5.5	5.5	6.5	6.5
Yield	5.0	5.0	5.5	5.5
RT from major	5.0	5.5	5.5	6.0
Cross major				
Stop	6.0	6.5	7.5	8.0
Yield	5.5	6.0	6.5	7.0
RT from minor				
Stop	6.5	7.0	8.0	8.5
Yield	6.0	6.5	7.0	7.5
Adjustments and modifications to critical gap, s				
Condition			Adjustment	
LT from minor street: curb radius > 50 ft Or turn angle < 60°			- 0.5	
LT from minor street: acceleration lane provided			- 1.0	
All movements: population ≥ 250,000			- 0.5	
Restricted sight distance. *			Up to + 1.0	

Notes: Maximum total decrease in critical gap = 1.0

Maximum critical gap = 9.5 s

For values of average running speed between 30 and 55 mph, interpolate.

* This adjustment is made for the specific movement impacted by restricted sight distance.

The potential capacity is defined as the “ideal” capacity for a specific subject movement, assuming the following conditions (TRB, 1985; JKR, 1987):

1. Traffic on the major roadway does not block the minor road.
2. Traffic from nearby intersections does not back up into the intersection under consideration.
3. A separate lane is provided for the exclusive use of each minor street movement under consideration.
4. No other movements impede the subject movement.

The capacity formulation adopted by the Arahan Teknik (Jalan) 11/87 is as shown by equation (2.1).

$$C_n = \frac{v_p e^{-(v_p/3600)(t_c - t_f)}}{e^{v_p t_f / 3600} - 1} \quad (2.1)$$

where,

C_n = the capacity of non-priority stream in veh/hr

v_p = priority flow rate in veh/hr

t_c = critical gap in seconds

t_f = follow-up time in seconds

When traffic becomes congested in a high-priority movement, it can impede the potential capacity. These impedance effects can be derived by multiplying the potential capacity to the series of impedance factor for every impeded movement (JKR, 1987).

Frequently two or three movements share a single lane on the minor approach. When this event occurs, vehicles from different movements do not have simultaneous access to gaps, nor can more than one vehicle from the sharing movements utilize the same gap. Equation (2.2) is used to compute the capacity of the shared lane for T-Junction:

$$C_{sh} = \frac{v_l + v_r}{\left[v_l / c_{ml} \right] + \left[v_r / c_{mr} \right]} \quad (2.2)$$

where,

C_{sh} = capacity of shared-lane (pc/h)

v_l = volume of left-turn movement in shared-lane (pc/h)

- V_r = volume of right-turn movement in shared-lane (pc/h)
- C_{ml} = movement capacity of left-turn movement in shared lane (pc/h)
- C_{mr} = movement capacity of right-turn movement in shared lane (pc/h)

The computation described above results in a solution for the capacity of each lane on the minor approaches to a STOP- or YIELD-controlled intersection. Level of service criteria for this methodology are stated in very general terms, and are related to general delay ranges. The criterion for LOS for unsignalised intersection is given in Table 2.3, and are based on the reserve, or unused, capacity of the lane in question. The reserve capacity is computed using equation (2.3).

$$C_R = C_{SH} - v \tag{2.3}$$

where,

- C_R = reserve or unused capacity of the lane (pc/h)
- C_{SH} = shared-lane capacity of the lane (pc/h)
- v = total volume or flow rate using the lane (pc/h)

Table 2.3: Level of service for unsignalised intersection (JKR, 1987)

Reserve capacity (pcph)	Level of service (LOS)	Expected delay to minor street traffic
≥ 400	A	Little or no delays
300 – 399	B	Short traffic delays
200 – 299	C	Average traffic delays
100 – 199	D	Long traffic delays
0 – 99	E	Very long traffic delays
*	F	*

2.2.2 American Approach

The Transportation Research Board had released a new edition of the Highway Capacity Manual in late 2000. This document was written to fulfill the needs of a much wider audience of transportation professionals, including designers, operation engineers, etc. Unsignalised intersection is performed in chapter 17 of the U.S. HCM 2000 (TRB, 2000). In the chapter, unsignalised intersection is divided into 3 parts; Two-way stop-controlled (TWSC), all-way stop-controlled, and roundabout. In this section, only the discussion on the TWSC is described.

The outline of TWSC analysis procedure is as illustrated in Figure 2.3. Referring to Figure 2.3, the structure of the procedure is as follows:

1. The definition of existing geometric, control and volume conditions for the intersection under study.
2. The determination of the “conflicting traffic”.
3. The determination of the size of the gap in the conflicting traffic stream.
4. The determination of the potential capacity.
5. The adjustment of the potential capacities so found to account for impedance, the use of shared-lanes, effects of upstream signals, two-stage gap acceptance process and flared minor-street approaches.
6. The determination of queue lengths, control delay and LOS.

The U.S. HCM 2000 is the latest and update version of the Highway Capacity Manual in the United State of America, so it has significant differences with the Arahan Teknik (Jalan) 11/87 which is adopted from the U.S. HCM 1985. Instead of using pcu/h in the unit of flow rate, the U.S. HCM 2000 uses veh/h, so it is unnecessary to have any conversion to take into consideration different vehicle composition.

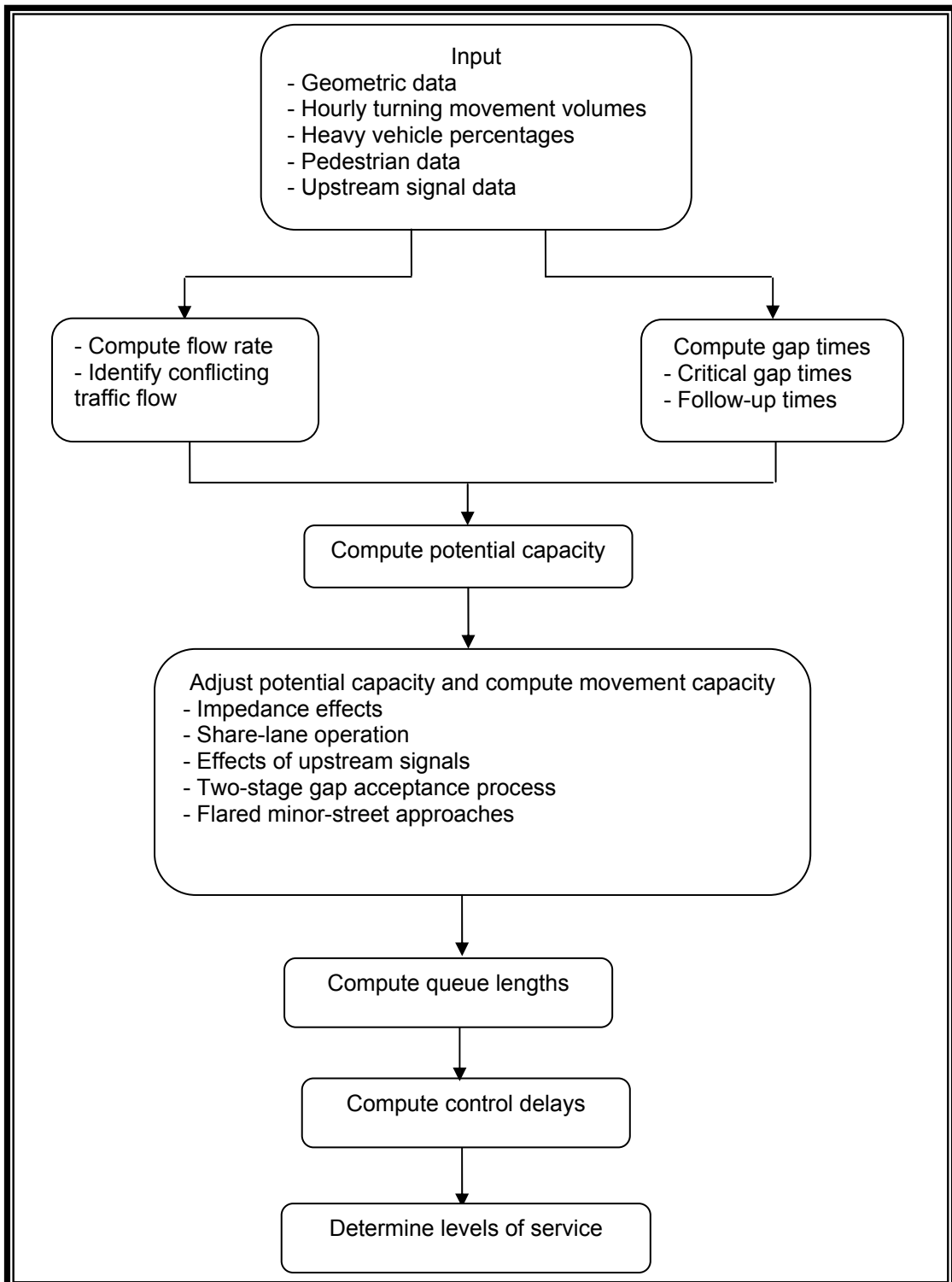


Figure 2.3: Outline of unsignalised intersection analysis procedure based on the U.S HCM 2000 (TRB, 2000)

In the U.S. HCM 2000 analysis procedure, the parameter of heavy vehicle, gradient, two-stage gap acceptance process and type of geometry are already considered in the calculation of critical gap and follow-up time. Additional factors such

as the effects of upstream signals, two-stage gap acceptance process and flared minor-street approaches are also considered in the adjustment of potential capacity. In the determination of LOS, the reserve capacity is used in the Malaysian approach as the measure of effectiveness while control delay is used in the U.S. HCM 2000 or American approach.

2.2.2.1 Input data requirement

Detailed descriptions of the geometrics, control, and volumes at the intersection are needed. Key geometric factors include number and use of lanes, channelization, two-way left-turn lane or raised or striped median storage (or both), approach grade, and existence of flared approaches on the minor street. Volumes must be specified by movement. For the analysis to reflect conditions during the peak 15 minutes, the analyst must divide the full hour volumes by the peak-hour factor (PHF) before beginning computations. By convention, subscripts 1 to 6 define vehicle movements on the major street, and subscripts 7 to 12 define movements on the minor street. Subscript 13 to 16 define the pedestrian movements. The presence of traffic signals upstream from the intersection on the major street will produce nonrandom flows and affect of capacity of the minor street approaches if the signal is within 0.4 km of intersection.

2.2.2.2 Priority of stream

Figure 2.4 and 2.5 showed the priority of stream for four legs and three legs intersection of TWSC with the subscripts mentioned in the previous section. The figures are according to the traffic system of the United States of America which is based on the left-hand drive.

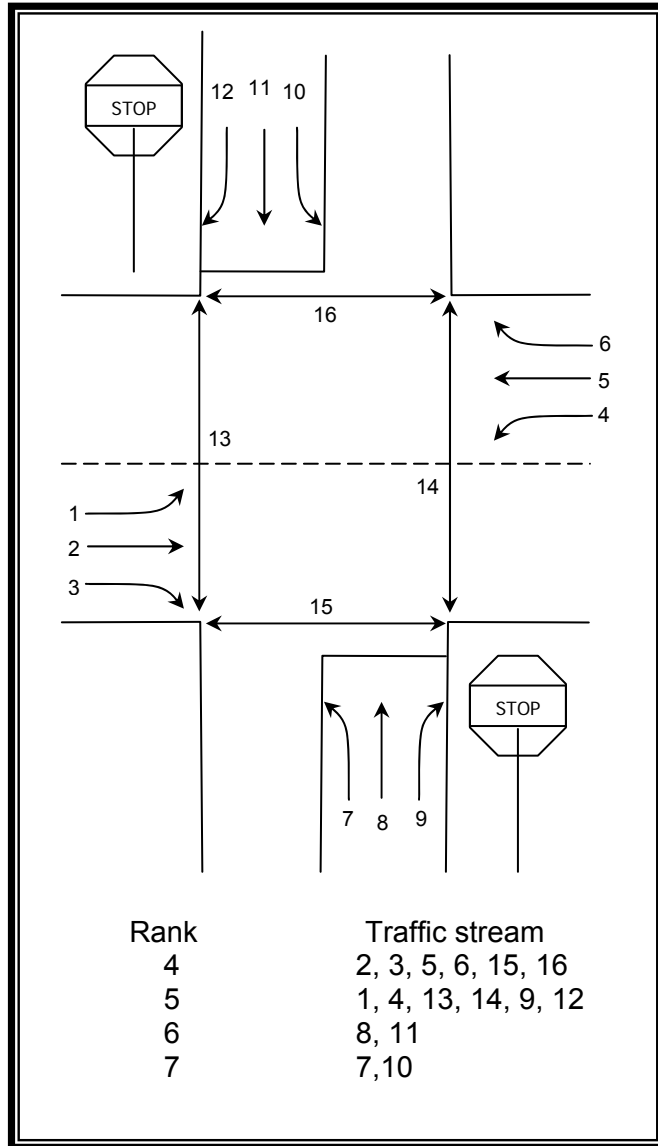


Figure 2.4: Traffic stream at a TWSC four leg intersection (TRB, 2000)

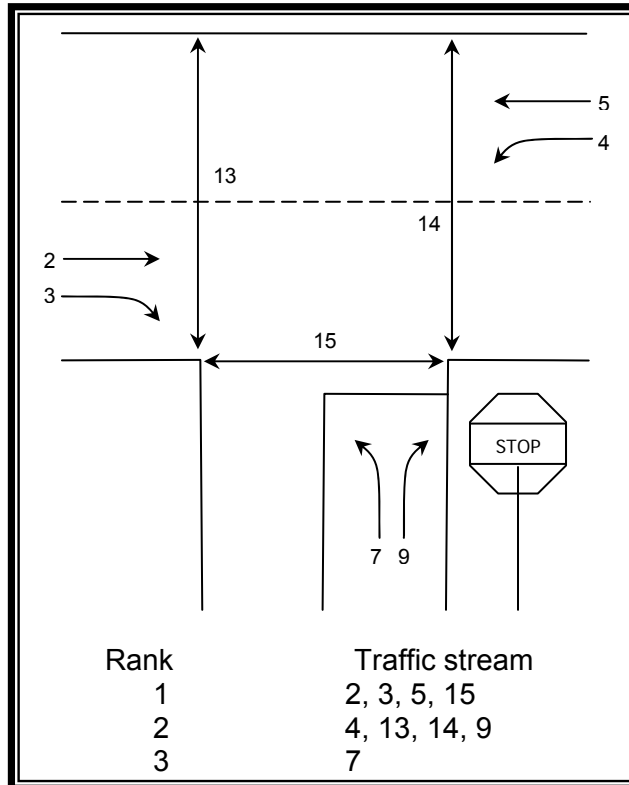
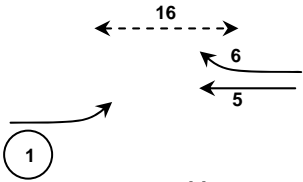
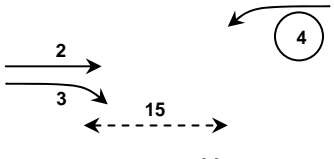
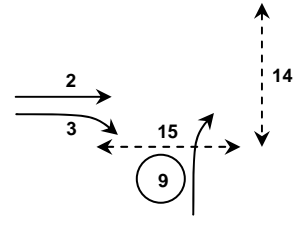
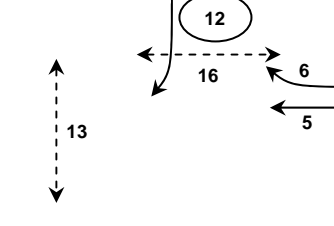
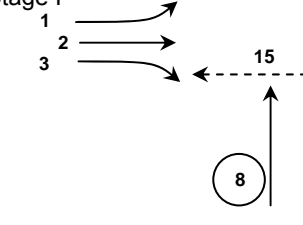
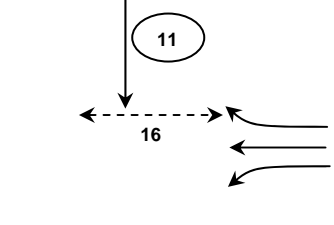
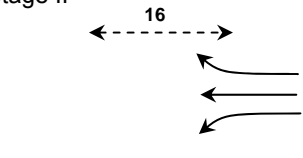
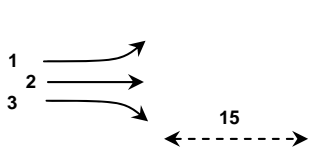
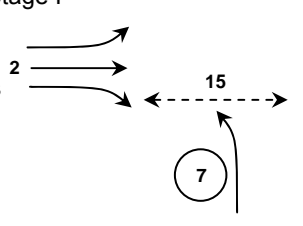
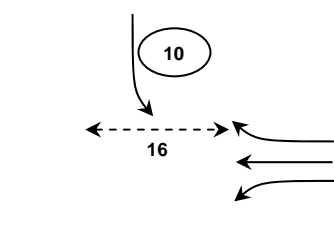
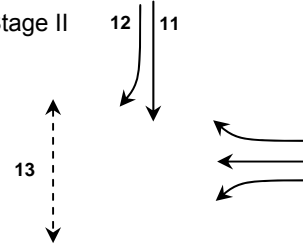
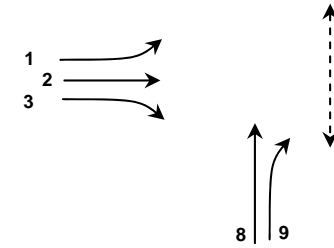


Figure 2.5: Traffic stream at a TWSC three leg intersection (TRB, 2000)

2.2.2.3 Conflicting traffic

Each movement at a TWSC intersection faces a different set of conflicts that are related to the nature of movement. These conflict is shown in Figure 2.6, which illustrates the computation parameter $v_{c,x}$, the conflicting flow rate for movement x, that is, the total flow rate that conflicts with movement x (veh/h).

Subject Movement	Subject and Conflicting Movements Conflicting Traffic Flows, $V_{c,x}$	
Major LT (RT in Malaysia) (1,4)	 $V_{c,1} = v_5 + v_6^{[a]} + v_{16}$	 $V_{c,4} = v_2 + v_3^{[a]} + v_{15}$
Minor RT (LT in Malaysia) (9,12)	 $V_{c,9} = v_2^{[b]}/N + 0.5v_3^{[c]} + v_{14} + v_{15}$	 $V_{c,12} = v_5^{[b]}/N + 0.5v_6^{[c]} + v_{13} + v_{16}$
Minor TH (8,11)	<p>Stage I</p>  $V_{c,I,8} = 2v_1 + v_2 + 0.5v_3^{[c]} + v_{15}$	 $V_{c,I,11} = 2v_4 + v_5 + 0.5v_6^{[c]} + v_{16}$
	<p>Stage II</p>  $V_{c,II,11} = 2v_6 + v_5 + v_6^{[a]} + v_{16}$	 $V_{c,II,11} = 2v_1 + v_2 + v_3^{[a]} + v_{15}$
Minor LT (RT in Malaysia) (7,10)	<p>Stage I</p>  $V_{c,I,7} = 2v_1 + v_2 + 0.5v_3^{[c]} + v_{15}$	 $V_{c,I,10} = 2v_4 + v_5 + 0.5v_6^{[c]} + v_{16}$
	<p>Stage II</p>  $V_{c,II,7} = 2v_4 + v_5/N + 0.5v_6^{[d]} + 0.5v_{12}^{[e,f]} + 0.5v_{11} + v_{13}$	 $V_{c,II,10} = 2v_1 + v_2/N + 0.5v_3^{[d]} + 0.5v_9^{[e,f]} + 0.5v_8 + v_{14}$

- [a] If right-turning traffic from the major street is separated by a triangular island and has to comply with a yield or stop sign, v_6 and v_3 need not be considered.
[b] If there is more than one lane on the major street, the flow rates in the right lane are assumed to be v_2/N or v_3/N , where N is the number of through lanes. The user can specify a different lane distribution if field data are available.
[c] If there is a right-turn lane on the major street, v_3 or v_6 should not be considered.
[d] Omit the farthest right-turn v_3 for Subject Movement 10 or v_6 for Subject Movement 7 if the major street is multilane.
[e] If right-turning traffic from the major street is separated by a triangular island and has to comply with a yield or stop sign, v_6 and v_{12} need not be considered.
[f] Omit v_9 and v_{12} for multilane sites, or use one-half their values if the minor approach is flared.

Figure 2.6: Definition and computation of conflicting flows (TRB, 2000)

2.2.2.4 Critical gap and follow-up time

Base values of t_c and t_f for passenger cars are given in Table 2.4. The values are based on studies throughout the United States and are the representative of a broad range of condition (TRB, 2000). Adjustments for critical gap are made to account for the presence of heavy vehicles, approach grade, T-intersections, and two-stage gap acceptance. Adjustments for follow-up time are made for the presence of heavy vehicle. The computation of critical gap and follow-up time are as shown in equation (2.4) and (2.5), respectively (TRB, 2000).

$$t_{c,x} = t_{c,base} + t_{c,HV}P_{HV} + t_{c,G}G - t_{c,T} - t_{3,LT} \quad (2.4)$$

where,

$t_{c,x}$ = critical gap for movement x (sec)

$t_{c,base}$ = base critical gap from table 2.4 (sec)

$t_{c,HV}$ = adjustment factor for heavy vehicle (1.0 for two-lane major street and 2.0 for four lane major street) (sec)

P_{HV} = proportion of heavy vehicle for the minor movement

$t_{c,G}$ = adjustment factor for grade (0.1 for movements 9 and 12 and 0.2 for movements 7,8,10 and 11) (sec)

G = percent grade divided by 100

$t_{c,T}$ = adjustment factor for each part of a two-stage gap acceptance process (1.0 for first and second stage; 0.0 if only one stage) (sec)

$t_{3,LT}$ = adjustment factor for intersection geometry (0.7 for minor-street left-turn (right-turn in Malaysia) movement at three-leg intersection; 0.0 otherwise) (sec)

$$t_{f,x} = t_{f,base} + t_{f,HV}P_{HV} \quad (2.5)$$

where,

$t_{f,x}$ = follow-up time for minor movement x (sec)

$t_{f,base}$ = base follow-up time from table 2.4 (sec)

$t_{f,HV}$ = adjustment factor for heavy vehicle (0.9 for two-lane major street and 1.0 for four lane major street) (sec)

P_{HV} = proportion of heavy vehicle for the minor movement.

Table 2.4: Base critical gap and follow-up times for TWSC intersection (TRB, 2000)

Vehicle Movement	Base Critical Gap, $t_{c,base}$ (s)		Base Follow-up Time, $t_{c,base}$ (s)
	Two-Lane Major Street	Four-Lane Major Street	
Left turn (Right turn in Malaysia) from major	4.1	4.1	2.2
Right turn (Left turn in Malaysia) from minor	6.2	6.9	3.3
Through traffic on minor	6.5	6.5	4.0
Left turn (Right turn in Malaysia) from minor	7.1	7.5	3.5

2.2.2.5 Potential capacity

The gap acceptance model used in this method computes the potential capacity for two-way stop controlled of each minor traffic stream in accordance with equation (2.6).

$$C_{p,x} = V_{c,x} \frac{e^{-v_{c,x}t_{c,x}/3600}}{1 - e^{-v_{c,x}t_{f,x}/3600}} \quad (2.6)$$

where,

$C_{p,x}$ = potential capacity of minor movement x (veh/h)

$V_{c,x}$ = conflicting flow rate for movement x (veh/h)

$t_{c,x}$ = critical gap for minor movement x (sec)

$t_{f,x}$ = follow-up time for minor movement x (sec)

The potential capacity of a movement is denoted as $c_{p,x}$ (for movement x) and is defined as the capacity for a specific movement, assuming the following base conditions:

1. Traffic from nearby intersections does not back up into the subject intersection.
2. A separate lane is provided for the exclusive use of each minor-street movement.
3. An upstream signal does not affect the arrival pattern of the major-street traffic.
4. No other movements of other rank impede the subject movement.

The potential capacity of minor-street movements is given in Figure 2.7 for two-lane streets and Figure 2.8 for four-lane streets.

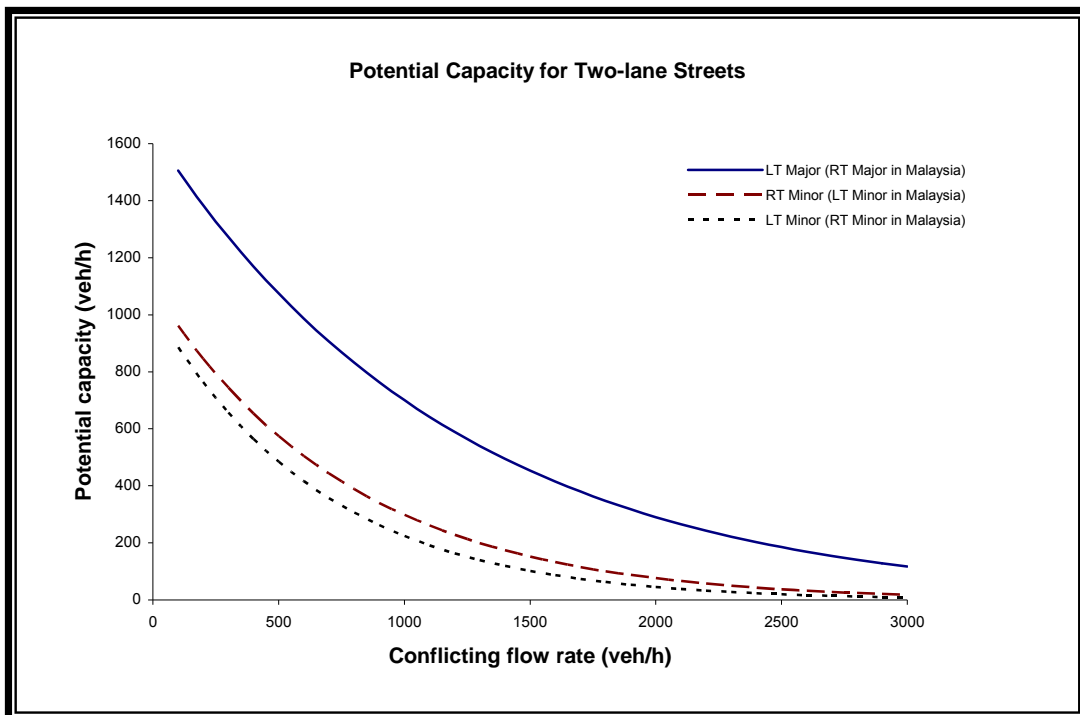


Figure 2.7: Potential capacity for two-lane streets of TWSC unsignalised intersection (TRB, 2000)

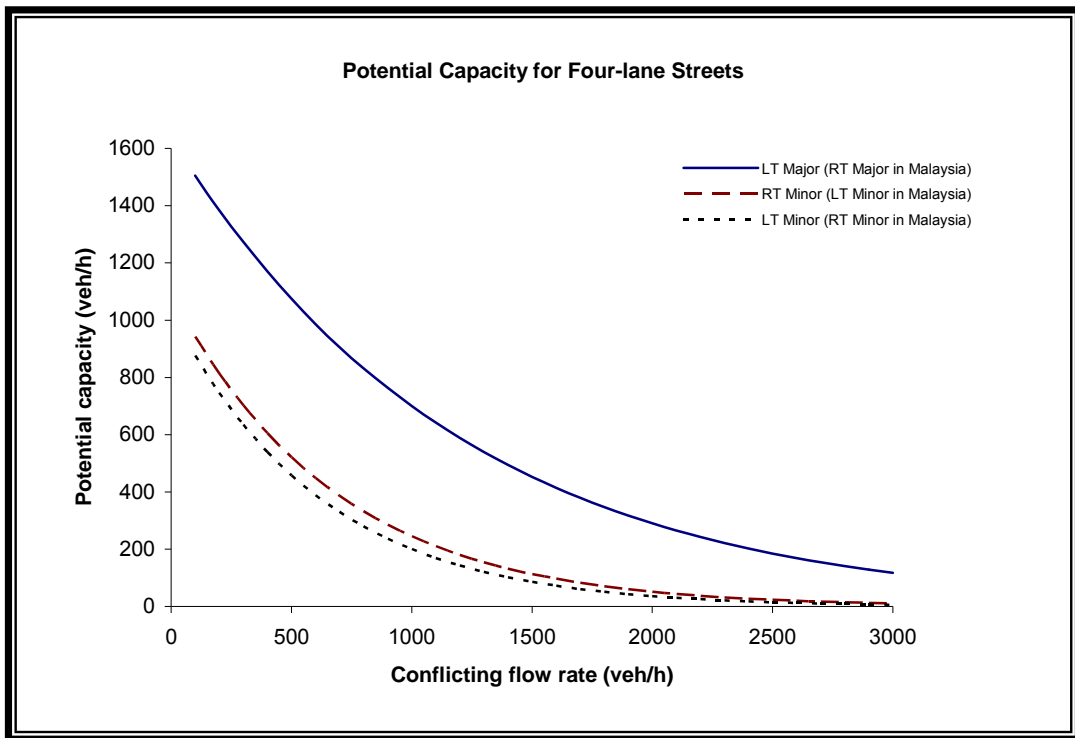


Figure 2.8: Potential capacity for four-lane streets of TWSC unsignalised intersection (TRB, 2000)

In order to calculate movement capacity, the potential capacity should be adjusted to take into consideration impedance effects, shared-lane operation, effects of upstream signals, two-stage gap acceptance process and flared minor-street approaches. There are 2 types of impedance effects; vehicles impedance and pedestrian impedance.

Vehicle impedance is associated to Rank 3 and Rank 4. It is assumed that any minor stream movements are not impeding the major traffic streams of Rank 1. Only the major-street through, right-turning (left-turning in Malaysia) traffic streams of Rank 1 are yielded by the minor traffic streams of Rank 2 and no other additional impedances from minor streams. Therefore, the movement capacity of Rank 2 is equal to its potential capacity. Rank 3 movements are impeded by higher rank movements. It also occurred to Rank 4 movements.

Minor-street vehicle streams must yield to pedestrian streams. Table 2.5 shows the relative hierarchy between pedestrian and vehicular streams use in this methodology.

Table 2.5: Relative pedestrian/vehicle hierarchy (TRB, 2000)

Vehicle Stream	Must Yield to Pedestrian Stream	Impedance Factor for Pedestrians, $P_{p,x}$
V_1	V_{16}	$P_{p,16}$
V_4	V_{15}	$P_{p,15}$
V_7	V_{15}, V_{13}	$(P_{p,15})(P_{p,13})$
V_8	V_{15}, V_{16}	$(P_{p,15})(P_{p,16})$
V_9	V_{15}, V_{14}	$(P_{p,15})(P_{p,14})$
V_{10}	V_{16}, V_{14}	$(P_{p,16})(P_{p,14})$
V_{11}	V_{15}, V_{16}	$(P_{p,15})(P_{p,16})$
V_{12}	V_{16}, V_{13}	$(P_{p,16})(P_{p,13})$

2.2.2.6 Estimating queue lengths

Estimation of queue length is an important consideration at unsignalised intersection (TRB, 2000). The mean queue length is computed as the product of the average delay per vehicle and the flow rate for the movement of interest. The expected total delay (vehicle-hours per hour) equals the expected number of vehicles in the average queue; that is, the total hourly delay and the average queue are numerically identical. For example, 4 vehicle-hours/hour of delay can be used interchangeably with an average queue length of four (vehicles) during the hour. Equation (2.7) is used to calculate the 95th-percentile queue.

$$Q_{95} = 900T \left[\frac{V_x}{C_{m,x}} - 1 + \sqrt{\left(\frac{V_x}{C_{m,x}} - 1 \right)^2 + \frac{\left(\frac{V_x}{C_{m,x}} \right) \left(\frac{3600}{C_{m,x}} \right)}{150T}} \right] \left(\frac{C_{m,x}}{3600} \right) \quad (2.7)$$

where,

Q_{95} = 95th-percentile queue (veh)

V_x = flow rate for movement x (veh/h)