OPERATIONAL ANALYSIS OF RAMPS ON EXISTING FREEWAY

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ABSTRACT

An operational analysis is an analytic evaluation of operation on an existing freeway ramps. In this case, all traffic and roadway conditions must be specified. The output of operational analysis is an estimate of the level of service for the ramp in question and of the approximate speed and density at which the traffic stream operations.

A ramp is length of roadway providing an exclusive connection between two highway facilities. On freeways, all entering and exiting maneuvers take place on ramps those are designed to facilitate smooth merging of on-ramp vehicles into the freeway traffic stream and smooth diverging of off-ramp vehicles from the freeway traffic stream onto the ramp.

The aim of this paper is the operational analysis of ramps on existing 6-lane freeway. This analysis involves the consideration of known freeway of Mohammed Al-Kasim freeway in Baghdad city. Given known geometric roadway conditions and projected traffic conditions, the operational analysis yields an estimate of the level of service and of the speed and density of the traffic stream. This paper has described the procedure for determining the level of service on Mohammed Al-Kasim freeway ramp sections as presented in the Highway Capacity Manual (HCM, 2000). Levels of service are determined for all ramps of the freeway using (HCS2000) software. Level of service of all

ramps are similar at AM and PM peak hour periods, because the data was collected under ordinary traffic conditions.

الخلاصة

أنّ تحليل الشغّل هو عملية تقييمُ تحليليُ على تعلياتِ طريق سريعٍ. في هذه الحالةِ، كُلّ شروط الطريقَ والمرورَ يجب أنْ يُحدّدا مسبقاً. إنّ ناتجَ التحليلِ الشغّالِ هو تخمينُ مستوى الخدمةِ للتعليةِ موضع السّؤال والسرعةِ والكثافةِ التقريبيةِ في أيّ عملياتِ جدولِ المرورَ.

أنّ تعلية الطريقِ السريع تُزوّدُ إتّصالَ خاصَّ بين وسيلتي طريق سريعِ. ويَحْدثُ كُلّ دُخُول وخُرُوج المناوراتِ على التعلياتِ التي تُصمّمُ لتَسهيل دَمْج ناعمِ للعرباتِ على التعليةَ إلى الطريق السريعِ ويَصْقلَ تَبَاعُد العرباتِ خارجِ التعليةَ مِنْ الطريق السريعِ.

إنّ هدفَ هذه الورقةِ هو تحليلُ الشغّلُ لتعلياتِ الطريقِ السريعِ المكون من ستة مسارات وبأتجاهين. يَتضمّنُ هذا التحليلِ إعتبارَ الطريق السريعِ لمحمد القاسم في مدينةِ بغداد. ان الغرض من اجراء تحليلَ الشغّلَ هو تخمينَ مستوى الخدمةِ والسرعةِ وكثافةِ المرورَ لتعليات هذا الطريق والذي تم تقسيمه الى اربعة مقاطع رئيسية كما قُدّمَ في دليلِ قدرةِ الطريق السريعَ (2000 ،HCM). ولقد تم ايجاد مستويات الخدمةِ لكُلّ التعليات بإستعمال البرنامج (HCS 2000) ,ولقد بين ناتج التحليل ان مستوى خدمةِ كُلّ التعليات مماثلة في فترات ساعة الذروةِ الصباح وفي المساء ، لأن البياناتَ جُمِعتْ تحت أوضاع مرورِ العاديةِ.

Keywords: Freeway, Operational Analysis, Traffic Engineering, Transportation Engineering.

1. INTRODUCTION

A ramp may consist of three geometric elements of interest (Garber and Hoel, 2002) and (Boyce, 2002):

1. **Ramp freeway junction:** is typically designed to permit high speed merging or diverging with minimum disruption to the adjacent freeway traffic.
2. **Ramp roadway:** geometric characteristics of ramp roadways vary from location to location. Ramps may vary in terms of number of lanes (usually one or two), design speed, grades, and horizontal curvature. The design of ramp roadways is seldom a source of operational difficulty unless a traffic incident causes disruption along their length.
3. **Ramp street junctions:** can permit uncontrolled merging and diverging movements, or they can take in the form of an at-grade intersection.

A ramp-freeway junction is an area of competing traffic demands for space.

There are two types of freeway ramps [Figure (1)] (AASHTO, 2001):

1. **On-ramp:** It is usually generated locally, although urban streets may bring some drivers to the ramp from more distance origins.
2. **Off –ramp:** The basic maneuver is diverge, that a single traffic stream separating into two streams.

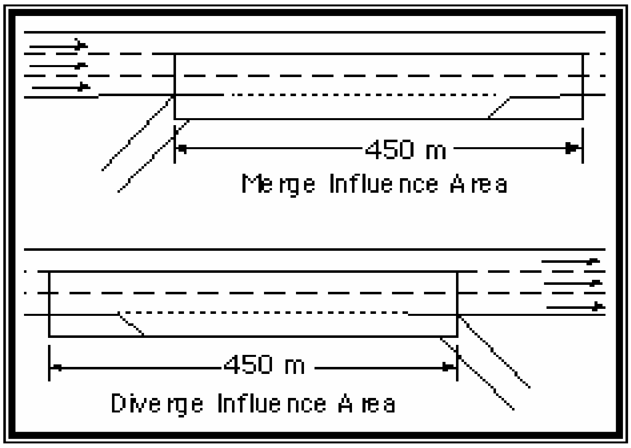

Figure (1): Types of Ramps.

2. LEVEL OF SERVICE

Level of services (LOS) qualitatively measures both the operating condition within a traffic system and how drivers and passenger perceive these conditions. Although speed is a major concern of drivers, freedom to maneuver within the traffic stream and the proximity to other vehicles are also important. (LOS) in merge and diverge influence areas are defined in terms of density for all cases of stable operation.

The LOS for basic freeway ramp is based on the reasonable range for speed-flow-density. Six level of service, designated A through F have been established.

The density used to define the various level of services (LOS) are as follow (HCM, 2000):-

1. **LOS A:** represents unrestricted operations. Density is low enough to permit smooth merging and diverging, with virtually no turbulence in the traffic stream.
2. **LOS B:** merging and diverging and diverging maneuvers become noticeable to through drivers, and minimal turbulence occurs. Merging drivers must adjust speeds to accomplish smooth transitions from the acceleration lane to the freeway.
3. **LOS C:** Speed within the influence area begins to decline as turbulence levels become noticeable. Both ramp and freeway vehicles begin to adjust their speeds to accomplish smooth transitions.
4. **LOS D:** Turbulence levels in the influence area become intrusive, and virtually all vehicles slow to accommodate merging and diverging. Some ramp queues may from at heavily used on-ramps, but freeway operation remains stable.
5. **LOS E:** Represents conditions approaching capacity. Speeds reduce significantly, and virtually all drivers feel turbulence. Flow levels

approach capacity, and small changes in demand or disruptions within the traffic Stream can cause both ramp and freeway queues to form.

6. **LOS F**: describes break down in the vehicular flow.

3. REQUIRED INPUT DATA AND ESTEMATED VALUES

Table (1) gives default values for input parameters in the absence of local data. The analyst should note that taking field measurements for use as inputs to an analysis is the most reliable means of generating parameters values. Only when this is not feasible should default values be considered.

3.1 Ramp Lanes

The analyst should assume single-lane ramps unless there is an indication of particularly heavy ramp demand. Ramp demands in excess of 1,500 veh/h generally warrant a second lane. A metered on-ramp may have two approach lanes to accommodate demand levels that could otherwise be accommodated by a single lane. One lane may be a high-occupancy vehicles (HOV) by pass lane (HCM, 2000).

Table (1): Required input data and default values.

Item	Default
Geometric Data	
Ramp Lanes	-------
Acceleration lane length	180 m
Deceleration lane length	42m
Ramp free-flow speed	55 km/h
Demand Data	
Demand volume	-------
PHF	0.88 rural, 0.92 urban
Percentage of heavy vehicles	10% rural, 5% urban
Driver population factor	1.0

3.2 Length of Acceleration / Deceleration Lane

The typical length of acceleration and deceleration lanes for ramps should be obtained from the design standards used by the highway-operating agency. The length of the acceleration or the deceleration lane is measured from the intersection of the edge of the travel way for the freeway and the ramp (point A) and the downstream intersection of the freeway and the ramp edges of the travel way (point B). These features are shown in Figures (2) and (3). In the absence of design information or field measurements, a default value of 42 m may be used for the length of the deceleration lane (HCM, 2000).

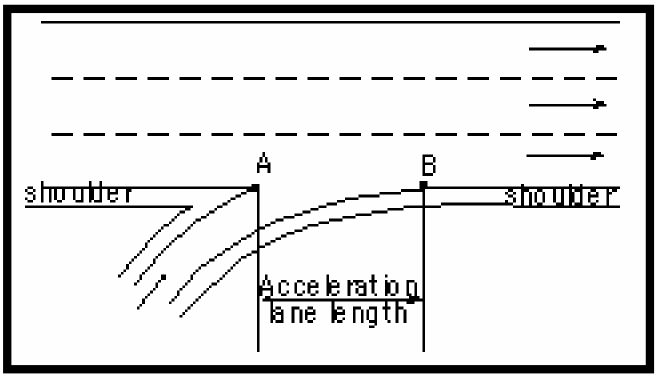

Figure (2): Acceleration Lane Length Diagram.

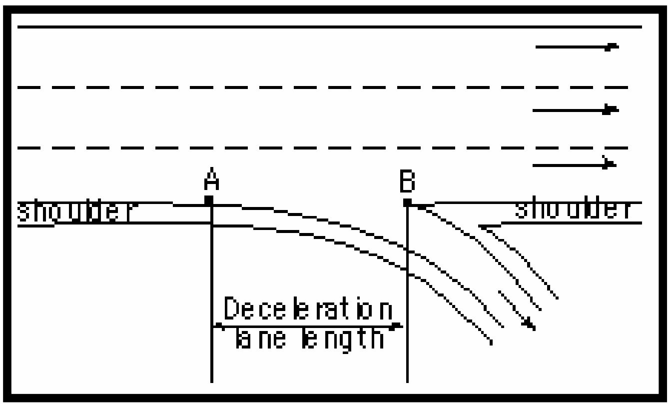

Figure (3): Deceleration Lane Length Diagram.

3.3 Ramp FFS

Ramp free-flow speeds usually range between 30 and 80 km/h depending on the grade, alignment, and control. In the absence of field-observed or locally developed values, 55 km/h may be assumed (HCM, 2000).

3.4 Length of Analysis Period

The planning, design, and analysis policies and the available resources of an agency will determine the selection of the analysis periods. The analyst may desire to evaluate the peak hours occurring during the morning commute, at midday, and during the evening commute on a typical weekday or during a peak hour on a weekend if the roadway segment carries a high volume of weekend recreational traffic. Within each hour analyzed, the highest 15-min volume is of primary interest. A peak-hour factor is applied to the hourly volume to convert it to a peak 15-min flow rate (Garber and Hoel, 2002).

3.5 Peak-Hour Factor (PHF)

In the absence of field measurements of PHF, approximations can be used. For congested conditions, 0.95 is a reasonable approximation. The PHF tends to be higher for operated conditions and lower for under saturated conditions. Default values of 0.92 for urban area and 0.88 for rural areas may be used in the absence of local data (Garber and Hoel, 2002).

3.6 Percentage of Heavy Vehicles

The percentage of heavy vehicles in rolling and mountainous terrain should be obtained from locally available data for similar facilities and demand conditions. If the proportion of recreational vehicles, trucks, and buses is not known, all the heavy vehicles can be considered to be trucks for the purpose of selecting passenger-car equivalents and computing the heavy-vehicle adjustment factor. Default values 5 percent heavy vehicles for urban areas and 10 percent heavy vehicles for rural areas may be used in the absence of local data (Garber and Hoel, 2002).

3.7 Driver Population Factor

Studies have noted that non-commuter driver populations do not display the same characteristics as regular commuters. Capacities have been observed to be as much as 10 to 15 percent lower than for commuter traffic traveling on the same segment, but FFS does not appear to be similarly affected (Garber and Hoel, 2002).

4. SERVICE VOLUME TABLE

Service volumes for ramp are difficult to describe because of the number of variables that affect the operations. Table (2) gives example volumes of a single lane on-ramp and off-ramp under a set of assumptions described in the footnote of the exhibit. Service volumes for LOS A through D are based on conditions producing the limiting densities for these LOS. Service volume for LOS E is based on the minimum of three limiting criteria: the capacity of the freeway, the maximum volume that can enter the ramp influence area, and the capacity of the ramp. In some cases, capacity constraints are more severe than density constraints. In such cases, some levels of service may not exist in practical terms for combinations of ramp and freeway volumes (HCM, 2000).

Table (2): Example service volumes for single-lane on-and off-ramps.

Mainline Number of Lane	Service Volumes (veh/h) for LOS				
	A	B	C	D	E
On-ramp					
2	N/A	290	1250	1760	1760
3	5	1660	1760	1760	1760
4	650	1760	1760	1760	1760
Off-ramp					
2	N/A	N/A	530	1360	1760
3	N/A	350	1340	1760	1760
4	N/A	830	1660	1760	1760

5. METHODOLOGY

Figure (4) illustrates input and basic computation order of the method for ramps and ramp junctions. The primary outputs of the method are LOS and capacity. As shown in Figure (4), the basic approach to modeling merges and diverge areas focuses on an influence area of 450 m including the acceleration or deceleration lane and lanes 1 and 2 of the freeway.

Although other freeway lanes may be affected by merging or diverging operations and the impact of congestion in the vicinity of a ramp can extend beyond the 450 m influence area, this defined area experiences most of the operational impact across all levels of service. Thus the operation of vehicles within the ramp influence area, as defined in Figure (5) is the focus of the computational procedures (HCM, 2000).

The Methodology has three major steps. First, flow-entering lanes 1 and 2 immediately upstream of the merge influence area (v_{12}) or at the beginning of the deceleration lane at diverge is determined.

Second, capacity values are determined and compared with existing or forecast demand flows to determine the likelihood of congestion. Several capacity values are determined:

- Maximum total flow approaching a major diverge area on the freeway (v_f),
- Maximum total flow departing from a merge or diverge area on the freeway (v_{fo}),
- Maximum total flow entering the ramp influence area (v_{R12} for merge areas and v_{12} for diverge areas), and
- Maximum flow on a ramp (v_R).

Finally the density of flow within the ramp influence area (D_R) and the level of service based on this variable are determined. For some situations, the average speed of vehicles within the influence area (S_R) may also be estimated.

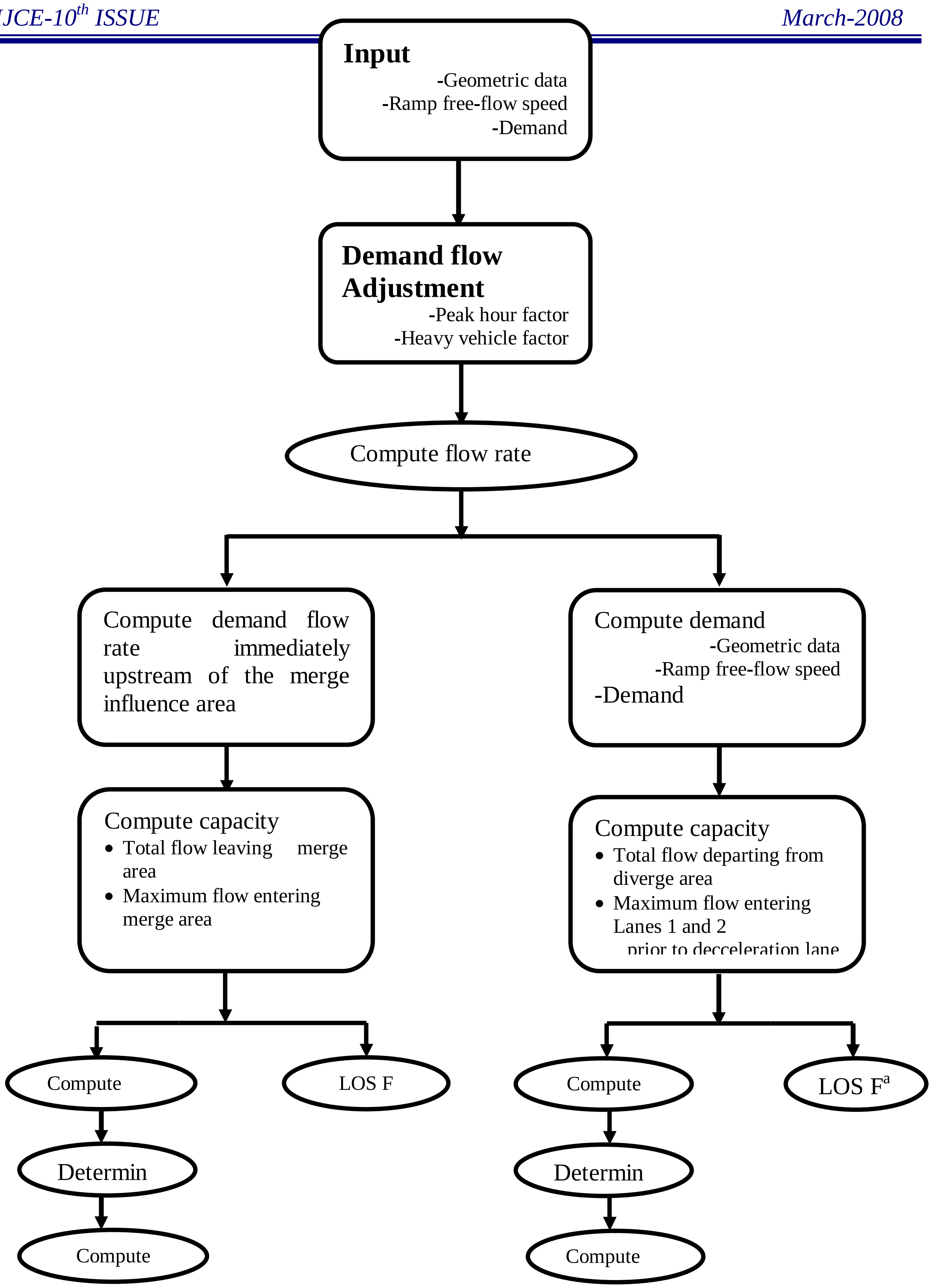

Figure (4): Ramps and Ramp Junctions' methodology.

Figure (5) shows the ramp influence areas and key variables and their relationship to each other. A critical geometric parameter influencing operations at merge or diverge areas is the length of acceleration lane (L_A) or deceleration lane (L_D). This length is measured from the point at which the left edge of the ramp lane or lanes and the right edge of the freeway lanes converges to the end of the taper segment connecting the ramp to the freeway. The point of convergence can be defined by painted markings or physical barriers or by some combination of the two. Note that both taper area and parallel ramps are measured in the same way.

All aspects of the model and LOS criteria are expressed in terms of equivalent maximum flow rates in passenger cars per hour (pc/h) under base conditions during the peak 15 min of the interested hour.

Therefore, before any of these procedures are applied, all relevant freeway and ramp flows must be converted to equivalent pc/h under base condition during the peak 15 min of the hour, using equation (1)(Garber and Hoel, 2002):

$$v_i = \frac{V_i}{PHF * f_{HV} * f_p} \quad \textbf{...(1)}$$

where:

v_i = flow rate for movement I under base conditions during peak 15 min of hour (pc/h).

V_i = hourly volume for movement I (veh/h),

PHF = peak-hour factor,

f_{HV} = adjacent factor for heavy vehicles, and

f_p = adjacent factor for driver population.

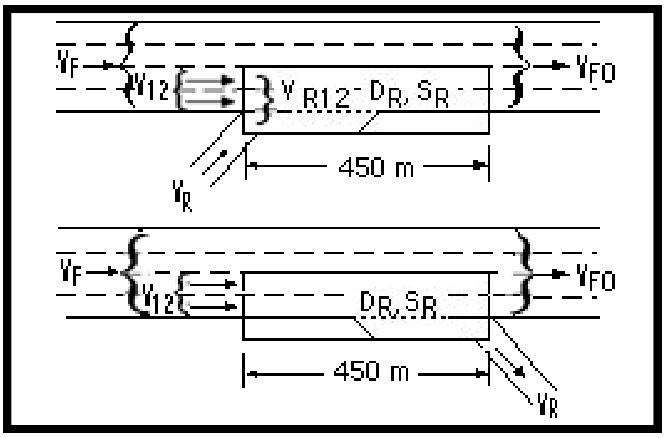

Figure (5): Critical ramp junction variables.

6. RAMP ROADWAYS

Because most operational problems occur at ramp terminals (either the ramp freeway terminal or the ramp-street terminal), little information exists regarding the operational characteristics of ramp roadways themselves. Ramp roadways differ from the freeway main line in that (O'Flaherty, 1988) and (Oglesby and Hicks, 1982):

- They are roadways of limited length and width (often just one lane);
- Free-flow speed is frequently lower than that of the roadways connected, particularly the freeway;
- On single-lane ramps, where passing is not possible, the adverse impact of trucks and other slow-moving vehicles is more pronounced than on multilane roadways; and
- At ramp-street junctions, queuing may develop on the ramp, particularly if the ramp-street junction is signalized.

Table (3) lists approximate criteria for the capacity of ramp roadways. It is unlikely that two-lane on-ramps can accommodate more than 2, 250 to 2,400 pc/h through the merge area itself. The two-lane configuration will achieve a merge with less turbulence and a higher LOS but will not increase the capacity of the merge, which is controlled by the capacity of the downstream freeway segment. For higher on-ramp flows, a two-lane on-ramp must be used in conjunction with a lane addition and major merge configuration.

Two-lane off-ramps can accommodate higher ramp flows through diverge area than can single-lane off-ramps. A major diverge configuration can also be considered, which may more effectively balance the per-lane flows on each departing leg.

Table (3): Approximate criteria for the capacity of ramp roadways.

Free-flow speed of ramp, S_{FR} (km/h)	**Capacity (pc/h)**	
	Single-Lane Ramps	Two-Lane ramps
<80	2200	4400
<65-80	2100	4100
<50-65	2000	3800
<30-50	1900	3500
<30	1800	3200

7. LOS

LOS in merge (and diverge) influence area is determined by density for all cases of operation, represented by LOS A through E. LOS exists when the total flow departing from the merge area (v) exceeds the capacity of the downstream freeway segment. No density will be predicted for such cases (Wright, et al, 1998).

LOS criteria for merge and diverge areas are listed in Table (4). The density values are shown for LOS A through E in Table (4) operation, with no breakdowns within the merge influence area (HCM, 2000).

Table (4): LOS criteria for merge and diverge areas.

LOS	Density (pc/km/h)
A	≤6
B	>6-12
C	>12-17
D	>17-22
E	>22
F	Demand exceeds capacity

8. MERGE INFLUENCE AREA

The subsections below describe the three primary steps in the model of analysis of merge areas. The model applies to single-lane, right-hand on-ramp merge areas (Garber and Hoel, 2002) and (HCM, 2000).

8.1 Predicting Flow Entering Lanes 1 and 2 (v_{12})

The principal influences on flow remaining in lanes 1 and 2 immediately upstream of the merge influence area are:

- Total freeway flow approaching merge area (v_f)(pc/h),
- Total ramp flow (vr) (pc/h),
- Total length of acceleration lane (L_A) (m), and
- Free-flow speed of ramp at point of merge area (S_{FR}) (km/h).

For six-lane freeways, however, sufficient data are available to take into account the effect of adjacent ramps on lane distribution at a subject ramp. When nearby ramps inject vehicles into or remove them from Lane 1, the lane distribution may be seriously altered. Important variables determining this impact include the total flow on the upstream (v_U) or down stream (v_D) ramp (or both), in pc/h and the distant from the subject ramp to the adjacent upstream (L_{up}) or downstream (L_{down}) ramp in meters. For ramps on six-lane freeways, therefore, an additional analysis step is necessary to determine whether adjacent ramp are close enough to affect lane distribution at the subject ramp.

Table (5) lists equations used for predicting v_{12} immediately upstream of the ramp influence area. These equations are apply to the six-lane freeway.

The variables used in Table (5) are defined as follows:

v_{12} = flow rate in lanes 1 and 2 of freeway immediately upstream of merge(pc/h),

v_f = freeway demand flow rate immediately upstream of merge (pc/h),

v_R = on-ramp demand flow rate (pc/h),

v_D = demand flow rate on adjacent downstream ramp (pc/h),

P_{FM}= proportion of approaching freeway flow in Lanes 1 and 2 immediately upstream of merge,

L_A = length of acceleration lane (m),

S_{FR} = free-flow speed of ramp (km/h),

L_{up} = distance to adjacent upstream ramp (m),and

L_{down} = distance to adjacent downstream ramp (m).

Table (5): Models for predicting v_{12} at on-ramps.

$\mathbf{v_{12} = v_F * P_{FM}}$	
For 4-lane freeway (2-lanes each direction)	P_{FM} =1.000
For 6-lane freeways (3 lanes each direction)	P_{FM}=0.5775+0.000092L_A (Equation 1) P_{FM}=0.7289-0.0000135(v_F+v_R)-

	$0.002048S_{FR}+0.0002L_A$ (Equation 2) $P_{FM}=0.5487+0.0801 \quad v_D/L_{down}$. (Equation 3)
For 8-lane freeways (4 lanes each direction)	$P_{FM}=0.2178-0.000125v_R+0.05887L_A/S_{FR}$

The general model specifies that v_{12} is a proportion of the approaching freeway flow, v_F. For six-lane freeways, the analysis is complicated by the fact that the effect of some types of adjacent ramps can be predicted. Table (6) lists the various sequences of ramps that may occur on six-lane freeways and the appropriate equation from Table (5) that should be applied in each case.

Equation (2) from Table (5) addresses cases with an adjacent upstream off-ramp. Adjacent on-ramps do not affect subject ramp behavior, and the analysis proceeds using equation 1. Where an adjacent upstream or downstream off-ramp (or both) exists, the decision to use equation 2 or 3 versus 1 is made by determining the equilibrium separation distance (L_{EQ}) between ramps. If the distance between ramps is greater than or equal to L_{EQ}, Equation 1 is always used. If the distance between ramps is less than $L_{EQ.}$ Equation 2 or 3 is used as appropriate.

L_{EQ} is that distance for which Equation 1 and 2 or 3, as appropriate, yield the same value of P_{FM}. Thus, where an adjacent upstream off-ramp exists, Equation 2 must be considered. If Equation 2 is set equal to Equation 1, L_{EQ}, is shown in Equation (2) (Garber and Hoel, 2002):

$$L_{EQ} = 0.0675(v_F+v_R) +0.46L_A +10.24S_{FR}-757 \qquad ...(2)$$

where:

L_{EQ} = equilibrium distance when Equation 1 is set equal to Equation 2 from Table (6).

Table (6): Selecting equations for P_{fm} for six-lane freeways.

Adjacent upstream ramp	Adjacent downstream ramp	Equation(s) used
None	None	Equation 1
None	On	Equation 1
None	Off	Equation 3 or 1
On	None	Equation 1
Off	None	Equation 2 or 1
On	On	Equation 1
On	Off	Equation 3 or 1
Off	On	Equation 2 or 1
Off	Off	Equation 3,2 or 1

8.2 Determining Capacity

The capacity of a merge area is determined primarily by the capacity of the downstream freeway segment. Thus, the total flow arriving on the upstream freeway and the on-ramp cannot exceed threw basic freeway capacity of the departing downstream freeway segment. There is no evidence that the turbulence of the merge area causes the downstream freeway capacity to be less than that of a basic freeway segment.

For an on-ramp, the flow entering the ramp influence area includes v_{12} and v_R. Thus, the total flow entering the ramp influence area is given according to equation (3).

$$v_{R12} = v_{12} + v_{R}. \quad ...(3)$$

Table (7) lists capacity flow rates for the total downstream freeway flow ($v = v_F + v_R$) and maximum desirable values for the total flow entering the ramp influence area (v_{R12}). Two conditions may occur for a given analysis. First, the total departing freeway flow (v) may exceed the capacity of the downstream freeway segment. Failure (LOS F) is expected, and queues will form upstream from the merge segment. When the downstream freeway capacity is exceeded, LOS F exists regardless of whether the flow rate entering the ramp influence area exceeds its capacity (HCM, 2000).

Table (7): Capacity values for merge areas.

Freeway Free-Flow Speed (km/h)	**Maximum Downstream Freeway Flow, v(pc/h)**				**Max Desirable Flow Entering Influence Area, v_{R12} (pc/h)**
	Number Of Lanes in One Direction				
	2	**3**	**4**	**>4**	
120	4800	7200	9600	2400/ln	4600
110	4700	7050	9400	2350/ln	4600
100	4600	6900	9200	2300/ln	4600
90	4500	6750	9000	2250/ln	4600

When the total downstream flow exceeds the basic freeway capacity of the downstream segment, LOS F exists. In such cases, no further computations are needed, and LOS F is assigned. For all other cases, including cases in which v_{R12} exceeds its stated limit, LOS is determined by estimating the density in the ramp influence area.

8.3 Determining LOS

LOS criteria for merge areas are based on density in the merge influence area as shown in Table (4) . Equation 4 is used to estimate the density in the merge influence area. Note that the equation for density applies only to under saturated flow conditions (Garber and Hoel, 2002):

$$D_R = 3.402 + 0.00458v_{12} - 0.01278L_A \quad ...(4)$$

where:

D_R = density of merge influence area (pc/km/ln),

V_R = on-ramp peak 15-min flow rate (pc/h),

v_{12} = flow rate entering ramp influence area (pc/h),and

L_A=length of acceleration lane (m).

9. DIVERGE INFLUENCE AREAS

Analysis procedures for diverge areas follow the same general approach as that for merges areas. The same three fundamental steps are followed: determine the approaching freeway flow in lanes 1 and 2 of the freeway (v_{12}), determine the capacity for the segment (v_F and v_{12}), and determine the density of flow within the ramp influence area (D_R). These procedures are then modified and applied to other diverge configurations and geometries (Garber and Hoel, 2002).

9.1Predicting Flow Entering Lanes 1 and 2 (v_{12})

Models for predicting freeway flow entering the diverge areas in lanes 1 and 2 of the freeway are shown in Table (8). The approach is similar to that for merge areas and is affected by the same variables. There are two major differences between merge-area analysis and diverge-area analysis. First, approaching flow in lanes 1 and 2 (v_{12}) is predicted for a point immediately upstream of the deceleration lane even if this point is upstream or downstream of the beginning of the ramp influence area. Second, at a diverge area, v_{12}

includes vr. Thus, the general model treats v_{12} as the sum of the off-ramp flow plus a proportion of the through freeway flow (HCM, 2000).

Table (8): Models for predicting v_{12} at off-ramps.

$V_{12} = v_R + (v_F - v_R)P_{FD}$	
For 4-lane freeways (2 lanes each direction)	PFD=1.00
For 6-lane freeways (3 lanes each direction)	PFD=0.760-0.000025vF-0.000046vR (Equation 5) PFD=0.717-0.000039vF+0.184vU/Lup (Equation 6) PFD=0.616-0.000021vF+0.038vD/Ldown(Equation 7)
For 8-lanes (4 lanes each direction)	PFD=0.436

The variables used in Table (8) are defined as follows:

v_{12} = flow rate in lanes 1 and 2 of freeway immediately Upstream of diverge (pc/h),

v_F = freeway demand flow rate immediately upstream of Diverge (pc/h),

v_R = off-ramp demand flow rate(pc/h),

v_U = demand flow rate on adjacent upstream ramp (pc/h),

v_D = demand flow rate on adjacent downstream ramp (pc/h),

P_{FD}= proportion of through freeway flow remaining in Lanes 1 and 2 immediately upstream of diverge,

L_{up} = distance to adjacent downstream ramp (m),

L_{down} = distance to adjacent downstream ramp (m).

For six-lane freeways, the analysis is complicated by the fact that the effect of some types of adjacent ramps can be accommodated. Table (9) shows the various sequences of ramps that may occur on six-lane freeways, and the appropriate equations from Table (9) that should be applied in each case.

Where an adjacent upstream on-ramp or downstream off-ramp exists, or where both exists, the decision to use Equation 6 or 7 versus 5 is made by determining the equilibrium separation distance (L_{EQ}) between ramps. If the distance between ramps is greater than or equal to L_{EQ}, Equation 5 is always used. If the distance between ramps is less than L_{EQ}, Equation 6 or 7 is used as appropriate (HCM, 2000).

Table (9): Selecting equations for p_{fd} for six-lane freeways.

Adjacent Upstream Ramp	Subject ramp	Adjacent downstream ramp	Equation(s) used
None	Off	None	Equation 5
None	Off	On	Equation 5
None	Off	Off	Equation 7 or 5
On	Off	None	Equation 6 or 5
Off	Off	None	Equation 5
On	Off	On	Equation 6 or 5
On	Off	Off	Equation 7,6,or 5
Off	Off	On	Equation 5
Off	Off	Off	Equation 7 or 5

9.2 Determining Capacity

The three limiting values that should be checked in a diverge area are the total flow that can depart from the diverge, the capacities of the departing freeway leg or legs or ramp, or both, and the maximum flow that can enter on Lanes 1 and 2 just prior to the deceleration lane.

In a diverge area, the total flow that can depart is generally limited by the capacity of freeway lanes approaching the diverge area. In all appropriate diverge designs, the number of lanes leaving diverge area is either equal to or one greater than the number entering. Table (10) lists the capacity values for flow (v_F) (HCM, 2000).

Table (10): Capacity values for diverge areas.

Freeway Free-Flow Speed(km/h)	Maximum upstream, v_{F1} or Downstream Freeway Flow, v(pc/h)				Max Flow Entering Influence Area,v_{12}(pc/h)
	Number Of Lanes in One Direction				
	2	3	4	>4	
120	4800	7200	9600	2400/ln	4400
110	4700	7050	9400	2350/ln	4400
100	4600	6900	9200	2300/ln	4400
90	4500	6750	9000	2250/ln	4400

9.2 Determining LOS

LOS criteria for diverge areas are based on density in diverge influence area. The numeric criteria are the same as those for merge areas, as in Table (4). Equation (5) is used to estimate density within diverge influence area (Garber and Hoel, 20002):

$$D_R=2.642 + 0.0053v_{12} – 0.0183lL_D \quad ...(5)$$

where:

D_R = density of diverge area (pc/km/h),

V_{12} = flow rate entering ramp influence area (pc/h),and

L_D = length of deceleration lane (m).

As was the cases for merge areas, the Equation predicting density in the segment (Equation 5) applies only to under saturated flow conditions. Density is not computed when capacity is exceeded. Thus, when demand flows exceed the capacity of the approaching freeway segment or either the departing freeway segment or segment or the ramp, LOS F is automatically applied. For all other cases, including those in which the maximum flow is entering the ramp influence area (v_{12}), the density is computed using Equation 5, and LOS is determined using the criteria of Table (4).

10. DETERMINING SPEED AT RAMP INFLUENCE AREAS

To address freeway and multi facility LOS, it is necessary to predict average speeds on long segment of a facility. Thus, it is useful to provide models for estimating average speeds within ramp influence areas and on lanes outside the influence area (Lanes 3 and 4, where they exists) within the length of the 450-m ramp influence area. From such estimates, a space means speed can be estimated for all vehicles traveling within the 450-m length of the ramp influence area on all lanes of the freeway (Garber and Hoel, 2002).

Table (11) provides Equations for estimating speeds. Note that speeds can be estimated only for flow cases. Capacity analysis for freeway facilities operating with over saturated flow conditions relies on deterministic queuing approaches. The Equations for average speed in outer lanes reflect average per-lane flow rates of up to 2,988 veh/h/ln for merge areas and 2,350 veh/h/ln for diverge areas. In the case of merge lanes, this flow rate is well above the accepted average across all lanes and that individual lanes will carry proportionally less or more flow.

Table (11): Average speeds in vicinity of freeway-ramp terminals.

	Average Speed in Ramp Influence Area (km/h)	Average Speed in outer Lanes of Ramp Influence Area (km/h)
Merge areas (On-ramps)	$S_R=S_{FF}-(S_{FF}-67)M_S$ $MS=0.321+0.0039e^{(vR12/1000)}-0.004(L_AS_{FR}/1000)$	$S_0=S_{FF}$. Where $v_{oA}<500$ pc/h $S_0=S_{FF}-0.0058(v_{oA}-500)$ Where $v_{oA}=500$ to 2300 pc/h $S_0=S_{FF}-10.52-0.01(v_{oA}-2300)$ Where $v_{oA}>2300$ pc/h
Diverge areas (Off-ramps)	$S_R=S_{FF}-(S_{FF}-67)D_S$ $D_S=0.883+0.00009v_R-o.oo8S_{FR}$	$S_0=1.06S_{FF}$ Where $v_{oA}<1000$ pc/h $S_o=1.06S_{FF}-0.0062(v_{OA}-1000)$ Where $v_{oA}\geq 1000$pc/h

In merge and diverge areas, through vehicles tend to left to avoid turbulence, resulting in cases where outer lanes are very heavily loaded compared with lanes within the ramp influence area (i.e., Lanes 1 and 2). Thus, even such high flow rates represent flow cases that have been observed in the field (HCM, 2000).

11. OPERATIONAL ANALYSIS OF APPLIED CASE

An older six-lane (Mohammed Al-Kasim) freeway with a 100 km/h design speed serves a directional peak hour volume of 2100 vph. Mohammed Al-Kasim is one of the freeways in Baghdad. It has a length of approximately 20 km. starting from Al-Wazereya in the north of Baghdad to the Rustumia in the south of Baghdad city. It’s parallel to the Army-Canal Highway.

Mohammed Al-Kasim Street is divided freeway with six lanes at a level terrain. The neighborhoods streets of Baghdad are connected with this freeway (in both north and south direction) by eight on-off ramps, starting from Bab Al-Mu`adham, Al-Nahdha, Al-Tahreer square, Andulus square, University of Technology, and Baghdad Al-Jadeedah [see Figure (6)].

It's clear from Figure (6) that the street was divided into four basic segments, and the required data was collected on these basic segments at AM peak hour (8:30 – 9:30 am) in the south direction as shown in Table (12). At PM peak hour (1:30 – 2:30 pm) in the north direction as shown in Table (13). The data was collected during the first week of January 2005.

The analysis approach for total freeway ramps evaluation is subject to Table (14). Levels of service are determined for the ramps of the four basic segments shown in figure (6) using HCS2000 software. The great segments could operate at level C. Level of service of all ramps are similar at AM and PM peak hour periods, because the data was collected under ordinary traffic conditions. The flexible pavement of some ramps of the freeway shows unsatisfactory performance due to the rutting. The occurrence of permanent deformation is one of the major problems affecting the performance of pavement structures. The trend toward heavier loading and high tire pressure as well as substantial increase in the number of load repetitions has significantly increased the importance of rutting phenomena.

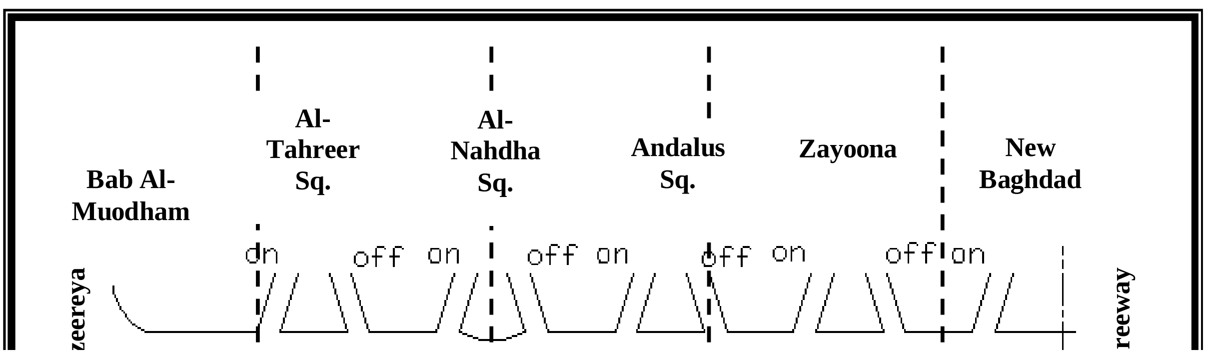

Figure (6): The sketch of Mohammed Al-Kasim Street.

Table (12): Data collected during the AM peak hour.

Segment	Type of ramp	Period	No. of Vehicles	
			Passenger	Trucks & Buses
A	Off	8:30-8:45	180	26
		8:45-9:00	182	25
		9:00-9:15	179	24
		9:15-9:30	185	26

	On	8:30-8:45	170	10
		8:45-9:00	167	17
		9:00-9:15	165	19
		9:15-9:30	172	19
B	Off	8:30-8:45	312	17
		8:45-9:00	292	21
		9:00-9:15	304	14
		9:15-9:30	319	16
	On	8:30-8:45	440	13
		8:45-9:00	428	15
		9:00-9:15	403	17
		9:15-9:30	414	16
C	Off	8:30-8:45	198	17
		8:45-9:00	192	22
		9:00-9:15	189	26
		9:15-9:30	191	19
	On	8:30-8:45	161	26
		8:45-9:00	159	18
		9:00-9:15	152	13
		9:15-9:30	158	21
D	Off	8:30-8:45	230	17
		8:45-9:00	229	19
		9:00-9:15	236	22
		9:15-9:30	241	13
	On	8:30-8:45	221	22
		8:45-9:00	219	19
		9:00-9:15	223	13
		9:15-9:30	229	8

Table (13): Data collected during the PM peak hour.

Segment	Type of ramp	Period	No. of Vehicles	
			Passenger	Trucks & Buses
A	On	8:30-8:45	303	17
		8:45-9:00	312	14
		9:00-9:15	309	13
		9:15-9:30	307	16
	Off	8:30-8:45	412	19
		8:45-9:00	398	21
		9:00-9:15	389	22
		9:15-9:30	403	17
B	On	8:30-8:45	356	18
		8:45-9:00	362	28
		9:00-9:15	371	17
		9:15-9:30	350	19
	Off	8:30-8:45	388	27
		8:45-9:00	377	31
		9:00-9:15	418	22

		9:15-9:30	419	31
C	On	8:30-8:45	159	18
		8:45-9:00	157	13
		9:00-9:15	163	12
		9:15-9:30	160	9
	Off	8:30-8:45	188	19
		8:45-9:00	179	21
		9:00-9:15	177	27
		9:15-9:30	179	14
D	On	8:30-8:45	130	14
		8:45-9:00	135	8
		9:00-9:15	127	19
		9:15-9:30	141	15
	Off	8:30-8:45	143	21
		8:45-9:00	149	29
		9:00-9:15	151	17
		9:15-9:30	152	15

Table (14): Results of the Operational Analysis of the Freeway Ramps.

Period	Segment	Type	Veh /h	T %	PHF	LOS	Density Pc/km/ln
AM	A	off	827	12	.98	A	1.7
		on	739	9	.97	B	6.7
	B	off	1295	5	.97	A	4.6
		on	1746	4	.96	C	13.1
	C	off	854	10	.99	A	3.3
		on	708	11	.95	B	6.8
	D	off	1007	7	.99	A	1.6
		on	954	6	.98	B	6.8
PM	A	on	1291	5	.99	B	9.8
		off	1681	5	.97	A	4.4
	B	on	1521	5	.98	B	11.6
		off	1713	6	.95	A	5.0
	C	on	691	8	.99	B	6.5
		off	804	10	.97	A	1.3
	D	on	589	10	.94	B	7.8
		off	677	12	.95	A	2.3

12. CONCLUSIONS

From the above operation analysis of Mohammed Al-Kasim ramps it can be conclude the following:

1. The major effective variables are the driver behavior and type of vehicles, which are considered non-uniform variables.
2. The randomly use of the street by the drivers cause the congestion in some parts specially the parts near the center of Baghdad.
3. The traffic flow does not reach the saturated state. It operates in a stable flow because the traffic volumes using this freeway are small. So, the breakdown state does not occur at the period of collecting the data of this project.
4. At PM peak hour, LOS is A at all off ramps. That means the number of vehicles diverge the freeway is constant at all segments and it is lower than the merging vehicles.

13. Nomenclature

D_R = density of diverge area (pc/km/h),

D_R = density of merge influence area (pc/km/ln),

f_{HV} = adjacent factor for heavy vehicles, and

f_p = adjacent factor for driver population.

L_A = length of acceleration lane (m),

L_A=length of acceleration lane (m).

L_D = length of deceleration lane (m).

L_{down} = distance to adjacent downstream ramp (m).

L_{up} = distance to adjacent upstream ramp (m),and

P_{FM}= proportion of approaching freeway flow in Lanes 1 and 2 immediately upstream of merge,

PHF = peak-hour factor,

S_{FR} = free-flow speed of ramp (km/h),

V_{12} = floe rate entering ramp influence area (pc/h),and

v_{12} = flow rate in lanes 1 and 2 of freeway immediately upstream of merge(pc/h),

v_{12} = flow rate entering ramp influence area (pc/h),and

v_D = demand flow rate on adjacent downstream ramp (pc/h),

v_f = freeway demand flow rate immediately upstream of merge (pc/h),

V_i = hourly volume for movement I (veh/h),

v_i = flow rate for movement I under base conditions during peak 15 min of hour (pc/h).

v_R = on-ramp demand flow rate (pc/h),

V_R = on-ramp peak 15-min flow rate (pc/h),

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