Modeling Freeway Traffic Flow under off-Ramp Congestion

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Abstract: This paper studies the effects of queue formation in the bottlenecks at off-ramps on the capacity of the freeways. Six expressway exit-ramps throughout the city of Tehran, Iran were selected and their traffic flows were observed in thirty-minute intervals during which the queue formation and queue elimination occurred. Assuming that in the absence of the queue, the traffic flow is in its normal state, the changes in the volume of through vehicles has been modeled as an average estimator of the change in the expressway capacity.

The developed models prove that the changes in freeway capacity are due to queue formation at the off-ramp sections. However, the estimated figures are different from those obtained from the theory of freeway capacity. The conclusion is that lane blockage is only one of many factors that affect the freeway capacity while the queue forms. Since it is not possible to quantify all those factors individually, the resulting models are macroscopic estimates of the phenomenon.

Keywords: capacity drop, vehicles queue, exit-ramps, modeling.

1- INTRODUCTION

Due to the rapid development of cities, the transportation of goods and passengers has become an issue of concern. An important issue regarding the traffic management of a city street network is to alleviate congestion. A review of the studies in this field reveals that in spite of the obvious problems of offramp congestions, no comprehensive studies of its effects on expressway have been done in Iran.

Flow congestion in exit-ramps adversely affects the capacity of expressways at the bottlenecks section. Moreover, formation of long queues at the off-ramp section and the blockage of these sections affect other sections of the expressway, including the upstream of the bottleneck. Due to this congestion, even those vehicles that do not want to exit expressway experience long delays. This sometimes results in a total breakdown of the flow and blockage of the expressway.

2- LITERATURE REVIEW

Hall et. al studied the freeway capacity drop due to queue formation and pointed out inadequacies of the method presented by Highway Capacity Manual (HCM) to estimate the capacity of freeways[1]. They pointed out the alterations of the ideal capacity in transient state in which the traffic flow is unstable. They concluded that in transient state the output on the freeway downstream from the congested exit is a better estimator of the freeway capacity, because it shows more stable patterns.

In other studies, Banks dealt with dual capacity phenomenon caused by congestion in freeway and questioned the validity of shock wave theory in the aforementioned condition sections [2, 3]. Banks notes that the shock wave theory yields accurate results in case of a single wave; while in real congestion conditions the results are not reliable due to several shock waves resulting from stop and go. Moreover, the changes in time and spatial overheads raised questions regarding the validity of car-following theory in real congestion conditions. Studies have modified the shock wave and car-following theories so the results would be more compatible with observations [4, 5, and 6]. But Trieterer and Mayers noted that the condition in case of congestion is completely non-linear and thus, even the modified theories, due to their linear nature, will fail to yield an accurate estimation of the complicated congestion conditions [7].

Kerner also studied the changes in vehicle speeds in bottlenecks [8]. He observed the continuous changes in flow and speed of vehicles at bottleneck sections and indicated that the flow-density diagram fails to explain the conditions due to non-linear characteristics of transient flow, which always exit. He concluded that the application of kinematics' wave theory is not advisable for these conditions.

3- DATA COLLECTION

Preliminary observations of Tehran's street network indicated that although there are many off-ramp sites, only few sites experience congestions. Therefore, based on the consultations with the experts at Tehran Traffic and Transportation Organization, the following six sites were selected:

1.Modarres Expreesway, south bound, offramp to Sadr Expressway, east bound.

2.Modarres Expressway, south bound, offramp to Hemmat Expressway, east bound.

3.Modarres Expressway, south bound, offramp to Behesthi Ave. 4.Modarres Expressrway, south bound, offramp to Motahari Ave.

5.Kordestan Expressway, north bound, offramp to Tavanir Bridge.

6.Chamran Expressway, north bound, offramp to Hemmat Expressway, east bound.

All these off-ramps are located on 6-lane freeways with auxiliary deceleration lanes.

Each of the selected sites was filmed at Tehran Traffic Control Center for 30-minutes period. Table 1 presents the date and the time which each off-ramp traffic condition was recorded. The periods in which the sites were filmed were chosen in a way that queue formation was most likely to occur.

The information that was observed from the video films is the relative time and space of vehicles in queues at certain points of each bottleneck, volume counts in one-minute intervals, and time of queue formations and eliminations at each off-ramp site.

To extract the relative time and space of passing vehicles, different sections were selected along each off-ramp section and the time that each vehicle passed the selected sections was measured using a chronometer while the video player was playing back the film at half of the speed of the film so the real passing times would be half of the measured times. This provided more time to observe the traffic congestion. A sample of this information is provided in Table 2. The video films were played once again to count the number of passing vehicles separately and also to extract the state of the queue in each one-minute interval. Table 3 shows a sample of this information.

4- STUDY METHOD

The first step is to study the traffic flow in the

No.	Site	Week Day	Date	Beginning	End
1	Modarres freeway, south bound, off -ramp to Sadr freeway, east bound	Wednesday	10/8/2003	9:24:50	9:54:50
2	Modarres freew ay, south bound, off -ramp to Hemamt freeway, east bound	Monday	10/13/2003	7:48:00	8:18:00
3	Modarres freeway, south bound, off -ramp to Behesthi Av.	Wednesday	10/15/2003	9:26:05	9:56:05
4	Modarres freeway, south bound, off -ramp to Motahari Av.	Wednesday	10/15/2003	12:17:45	12:47:45
5	Kordestan freeway, north bound, off -ramp to Tavanir Bridge.	Tuesday	10/14/2003	8:11:30	8:41:30
6	Chamran freeway, north bound, off -ramp to Hemmat freeway, east bound	Monday	10/13/2004	9:07:00	9:37:00

Table (1) – Date and time of filming at different sites

Table (2) - Sample vehicle passing time and distance information

Vehicle #	Time to reach section 1		Time to reach section 2			Time to reach section 3			
	Min.	Sec.	Real	Min.	Sec.	Real	Min.	Sec.	Real
1	0	12	6.0	0	36	18.0	0	57	28.0
2	0	18	9.0	0	43	21.0	1	4	62.0
3	0	27	13.0	0	55	27.0	1	9	34.0
4	0	35	17.0	1	5	62.0	1	25	42.0
5	1	1	30.0	1	38	49.0	2	2	61.0

Table (3) – Vehicle behavior in queue, sample information

Beginning	End	Ve	hicle Count		Queue	Queue	Queue	Queue
		Passenger	Buses	Motor	in	in	in	in
		cars	trucks	bikes	storage lane	3^{RD}	2^{ND}	1 ⁸¹
						lane	lane	lane
7:48:00	7:49:00	86	2	4	~	-	-	-
7:49:00	7:50:00	87	2	3	~	-	-	-
7:50:00	7:51:00	98	2	-	-	-	-	-
7:51:00	7:52:00	84	1	1	✓	-	-	-
7:52:00	7:52:00	83	2	3	✓	-	-	-
7:53:00	7:54:00	83	1	4	~	-	-	-
7:54:00	7:55:00	74	1	6	\checkmark	\checkmark	-	-
7:55:00	7:56:00	82	_	3	\checkmark	_	-	-
7:56:00	7:57:00	75	2	5	\checkmark	~	-	-

freeway during the queue formation. To do time-space diagrams of vehicle so. movements inside queues at each off-ramp were plotted using the queue behavior information. As seen in Figures 1 to 6, each line represents a vehicle moving through the queue at the specified site. Thus, the slope of



Figure 1: Vehicles displacement, site 1.



Figure 3: Vehicles displacement, site 3.

100

80

40

20

0 0

100

Distance (m) 60 each line is the mean speed of the relevant vehicle between the two points. As there are many obvious changes in line slopes, the speed changes at all six sites observed are unstable.

It is concluded that the flow is in unstable



Figure 2: Vehicles displacement, site 2.



Figure 4: Vehicles displacement, site 4.



Figure 6: Vehicles displacement, site 6.

Figure 5: Vehicles displacement, site 5.

Time (s)

300

400

200

500

transient state and according to the studies reviewed in the previous section, shock wave theory, kinematics' wave theory and carfollowing theory may not be applicable.

5- MODELING

Regarding the inapplicability of queue formation theories, the next step to analyze the extracted information is to devise a model to explain the amount of decrease in expressway capacity in case of a queue at the exit-ramp. Before the model is illustrated, the HCM 94 method to specify freeway capacity in normal state is presented.

5-1- Freeway Flow

The HCM presents the following equation for the capacity of freeways [9]:

$$SF_{i} = c_{i} * (v/c)_{i} * N * f_{w} * f_{HV} * f_{p}$$
(1)

in which:

 SF_i : Flow rate in level of service *i*

 C_j : Ideal Capacity 2200 to 2300 passenger cars per hour per lane

 $(v/c)_i$: Volume Capacity Ration in level of service *i*

N: Number of freeway lanes

 f_{W} : Lane Width correction factor

 f_{HV} : Heavy Vehicles correction factor

 f_p : Drivers Unfamiliarity factor

When the queue of exiting vehicles backs up into the freeway, the changes in n and

consequently f_w both affect the freeway capacity. The change in freeway capacity causes changes in $(v/c)_i$ which affects the changes in the freeway level of service. Therefore, evaluation of the effect of each single variable is not possible. If f_{HV} and f_p are considered constant in the short periods of queue formation and elimination the flow rate can be explained as a function of all these variables. So:

$$SF_{i} = \left[c_{j} * (v/c)_{i} * N * f_{w} * f_{HV} * f_{p}\right] * \alpha_{q}$$
(2)

in which α_q is the overall impact factor on the flow rate downstream of the section at which the queue forms. The next step is to calculate α_q by presenting a model.

5-2- Model Development

Regarding all the conditions, the factors that affect, obtained from the models, and are divided into two groups of cumulative and reducing factors:

A) Cumulative Factors:

1-The change in direct flow due to congestion sighting in the off-ramp which leads to a decision to change the path [10]. 2-The drop in the level of service in the freeway due to congestion caused by capacity drop [1].

B) Reducing Factors:

1-Blockage of freeway lanes available to vehicles passing through.

2-Increasing delay for the vehicles upstream the specified section [11].

3-Instabilities in the speed of passing vehicles [12].

4-The interference between the vehicles passing through and the ones waiting in the queue at the off-ramp to exit [10].

It is assumed that all the factors mentioned are in effect when the queue forms. So, can be explained as a function of a variable that represents the state of the queue, named Q. Different states of the queue and relevant values of Q are shown in Table 4. The first lane is the lane closest to the median of the expressway.

As it is impossible to model the variable Q using the SPSS software, four dummy variables $Q_{st^{p}}$, Q_{L1} , Q_{L2} and Q_{L3} , should be used instead [4]. In such cases, n-1 dummy variables are needed to replace a variable with *n* states and the value of the last variable is clear if the other variables have certain values. Therefore, there is no need to use all the variables in a model, because they all make a set of linearly-dependant variables. The values of these dummy variables in each state of the queue are mentioned in Table 5.

Thus, the following model explains α_q :

Q	Queue state at the off -ramp
0	No queue
1	Queue in the storage lane
2	Queue in the thi rd lane
3	Queue in the second lane
4	Queue in the first lane

Table (4) - Numerical Values of Q

Table (5) - The values of dummy variables in different queue states

Q	Q _{ST}	Q_{L3}	Q_{L2}	Q_{L1}
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1

$$R_{SF} = \frac{SF_0 - SF_q}{SF_0} = b_0 Q_{st} + b_1 Q_{L1} + b_2 Q_{L2} + b_3 Q_{L3}$$
(3)

In which:

 $R_{sf} = \alpha_q$: Percentage of change in the flow rate when a queue forms.

 SF_o : Freeway flow rate when there is no queue.

 SF_q : Freeway flow rate when a queue forms.

 Q_{st} : The dummy variable representing the existence of queue in the storage lane.

 Q_{L1} : The dummy variable representing the existence of queue in the third lane.

 Q_{L2} : The dummy variable representing the existence of queue in the second lane.

 Q_{L3} : The dummy variable representing the existence of queue in the first lane.

bo,b1,b2,b3: The coefficients of the variables of the model.

To obtain the numerical value of α_q , the coefficients in equation 3 should be determined. These coefficients specify the numerical value of α_q in each certain state of queue, q.

The flow rate in one-minute periods is calculated using the collected information and applying the passenger car equivalent factor of 1.2 for buses and 0.1 for motorcycles. So:

$$SF = V_{p} + 1.2 * V_{b} + 0.1 * V_{m}$$
⁽⁴⁾

in which:

SF: Freeway flow rate in one-minute periods

 V_p : Passenger car count in one-minute periods

 V_b : Bus and Minibus count in one-minute periods.

 V_m : Motorcycle count in one-minute periods.

To calculate R_{sf} in each one-minute period, the nearest no-queue state (Q=0) is assumed as the null state (SF_o) and then R_{sf} is calculated according to equation 3.

To apply the queue state the values of the dummy variables Q_{st} , Q_{L1} , Q_{L2} and Q_{L3} are used, according to the average observed queue state in the specified one-minute period.

To obtain the coefficients of the model, SPSS software is used. Before the model is regressed, the correlation between the dependant variable and independent variables is examined. Following that, simple linear regression is used to obtain the numerical value of the coefficients of independent variables in model 3. The information of 5 sites is used to do the linear regression. The remaining information will later be used to verify the obtained model.

While the correlation matrixes for different sets of information to calibrate equation (3) are shown in Tables (6) to (20), the results of the linear regression for 5 sections are shown in Table (21). Ultimately, as the difference in the values of each coefficient from different sites is not significant, the arithmetic mean value of all the obtained coefficients will be taken as the desired coefficient in the final model. The mean value is calculated from all the available values at each site.

As seen in the tables above, the coefficient of queue impact in the storage lane is missing.

By paying attention to different stages of modeling, it is clear that in all but one case, there is no correlation between and . which means the capacity of the freeway is not influenced by the formation of queue in the auxiliary storage lane. In fact, storage lanes tend to eliminate the adverse effects of queue formation on the expressway. Thus, the related dummy variable, , is not present in any of the models. This however, is contrary to the reality. It is a commonly observed phenomenon that before the capacity of the storage lane is even near saturation, drivers enter/use the adjacent lane to move to the head of the queue, resulting in the closure of one or even more lanes. This is particularly true in an environment characterized by poor driver behavior and poor enforcement of traffic rules and regulations. The same is true of the queue formations on the other lanes.

The coefficient of the queue impact in the third lane is 0.252, which is the mean value of the four cases. The coefficient of the second lane is also the mean value of the two cases.

But the coefficient of the first lane is calculated in a different way. Considering the fact that when the queue extends to the first lane, all the other lanes are totally blocked, makes it clear that in this case there are no movements but in the first lane. This means that the calculated coefficient is relative to the second lane. So, the real coefficient for the first lane is:

$$b_3 = 0.332 + 0.423 = 0.755 \tag{5}$$

5-3- Model Verification

According to the study scheme, the information of the exit-ramp of Chamran expressway to Hemmat expressway is reserved for the verification of the model obtained from the other five sites. To verify the results, the scatter diagram of estimated vs. observed values of R_{sf} for the exit-ramp of Chamran expressway to Hemmat expressway is plotted, as shown in Figure 7. The equation of the regression line and the coefficient of regression are both shown on the diagram.

In ideal conditions, all the points would lie on the line x=y in such a diagram. If so, all the predicted values would be the same as the observed ones. The equation of the regression line here is:

$$y = 0.7496x - 0.0022 \tag{6}$$

As the coefficient of x is nearly 0.75 where it should be 1, and the constant is insignificant, the conclusion is that in comparison with the ideal conditions y=x the obtained model is of desirable accuracy to explain the observations. Hence, a 25% bias variation from site to site is acceptable.

7- Comparison with HCM 2000

The HCM 2000 Edition does not state a direct way of calculating the capacity of the freeway section. Instead, it provides a more detailed process of evaluating the level of service in basic freeway sections through calculation of density and speed. Combining the proposed formulas (7) and (8), the obtained result (Equation 9) will reflect a relationship between the hourly volume (V) on one hand and Speed (S), Density (D), Number of lanes (N) and other field factors on the other hand.

$$V = v_{p} * PHF * N * f_{HV} * f_{p}$$
(7)

Table (6) - Correlation Matrix - Modarres, South Bound - Sadr, East Bound

		RSF	Q_ST	Q_LANE	Q_LANE
RSF	Pearson Correlation	1.000	147	.544 **	.619**
	Sig. (2-tailed)		.437	.002	.000
	Ν	30	30	30	30
Q_ST	Pearson Correlation	147	1.000	395*	218
	Sig. (2-tailed)	.437		.031	.247
	Ν	30	30	30	30
Q_LANE1	Pearson Correlation	.544 **	395 *	1.000	201
	Sig. (2-tailed)	.002	.031		.287
	Ν	30	30	30	30
Q_LANE2	Pearson Correlation	.619**	218	201	1.000
	Sig. (2-tailed)	.000	.247	.287	
	Ν	30	30	30	30

Correlations

** Correlation is significant at the 0.01 level (2 -tailed).

*. Correlation is significant at the 0.05 level (2 -tailed).

Table (7) - Correlation Summary - Modarres, South Bound - Sadr, East Bound

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.921 ^a	.848	.836	7.013E-02

a. Predictors: (Constant), Q LANE2, Q LANE1

Table (8) - Correlation Results - Modarres, South Bound - Sadr, East Bound

Coefficients^a

Model		Unstand: Coeffi	ardized cients	Standardized Coefficients t		Sig.
		В	Std. Error	Beta		
1	(Constant)	6.861E-02	.016		4.265	.000
Q_LANE1		.268	.030	.696	9.074	.000
	Q_LANE2	.431	.044	.759	9.889	.000

		RSF	Q_ST	Q_LANE	Q_LANE	Q_LANE3
RSF	Pearson Correlation	1.000	.201	.785**	• . a	. ^a
	Sig. (2-tailed)		.288	.000		
	Ν	30	30	30	30	30
Q_ST	Pearson Correlation	.201	1.000	380*	. ^a	. ^a
	Sig. (2-tailed)	.288		.038		
	Ν	30	30	30	30	30
Q_LANE1	Pearson Correlation	.785**	380*	1.000	. a	. a
	Sig. (2-tailed)	.000	.038			
	Ν	30	30	30	30	30
Q_LANE2	Pearson Correlation	. ^a	. a	. ^a	. a	. a
	Sig. (2-tailed)					
	Ν	30	30	30	30	30
Q_LANE3	Pearson Correlation	. ^a	. ^a	. ^a	. a	. ^a
	Sig. (2-tailed)					
	Ν	30	30	30	30	30

Table (9) - Correlation Matrix - Modarres, South Bound - Hemmat, West Bound

Correlations

**. Correlation is significant at the 0.01 level (2 -tailed).
*. Correlation is significant at the 0.05 level (2 -tailed).

a. Cannot be computed because at least one of the variables is constant.

Table (10) - Correlation Summary - Modarres, South Bound - Hemmat, West Bound

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.785 ^a	.616	.602	7.718E-02

a. Predictors: (Constant), Q LANE1

Table (11) - Correlation Results - Modarres, South Bound - Hemmat, West Bound

Coefficients^a

Model		Unstandardized Coefficients		Standardi zed Coefficien ts	t	Sig.
		В	Std. Error	Beta		
1	(Constant)	6.676E-02	.016		4.238	.000
	Q_LANE1	.236	.035	.785	6.698	.000

Table (12) - Correlation Matrix - Modarres, South Bound - Beheshti

		RSF	Q_ST	Q_LANE1	Q_LANE	Q_LANE3
RSF	Pearson Correlation	1.000	.332	.766**	. ^a	. ^a
	Sig. (2-tailed)		.074	.000		
	Ν	30	30	30	30	30
Q_ST	Pearson Correlation	.332	1.000	291	. ^a	. a
	Sig. (2-tailed)	.074		.118		
	Ν	30	30	30	30	30
Q_LANE1	Pearson Correlation	.766**	291	1.000	. ^a	. a
	Sig. (2-tailed)	.000	.118			
	Ν	30	30	30	30	30
Q_LANE2	Pearson Correlation	. ^a	.a	. ^a	.a	.a
	Sig. (2-tailed)					
	Ν	30	30	30	30	30
Q_LANE3	Pearson Correlation	. ^a				
	Sig. (2-tailed)					
	Ν	30	30	30	30	30

Correlations

**. Correlation is significant at the 0.01 level (2 -tailed).

a. Cannot be computed because at least one of the variab les is constant.

Table (13) - Correlation Summary - Modarres, South Bound - Beheshti

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.766 ^a	.587	.572	6.013E-02

a. Predictors: (Constant), Q_LANE1

Table (14) - Correlation Results - Modarres, South Bound - Beheshti

Coefficients^a

	Model	Unstandardized Coefficients		Standardi zed Coefficien ts	t	Sig.
		В	Std. Error	Beta		
1	(Constant)	5.321E-02	.012		4.599	.000
	Q_LANE1	.231	.037	.766	6.302	.000

Table (15) - Correlation Matrix - Modarres, South Bound - Motahari

		RSF	Q_ST	Q_LANE1	Q_LANE2
RSF	Pearson Correlation	1.000	622 **	.496 **	.513 **
	Sig. (2-tailed)		.000	.005	.003
	Ν	31	31	31	31
Q_ST1	Pearson Correlation	622 **	1.000	812**	181
	Sig. (2-tailed)	.000		.000	.329
	Ν	31	31	31	31
Q_LANE1	Pearson Correlation	.496 **	812 **	1.000	309
	Sig. (2-tailed)	.005	.000		.091
	Ν	31	31	31	31
Q_LANE2	Pearson Correlation	.513 **	181	309	1.000
	Sig. (2-tailed)	.003	.329	.091	
	Ν	31	31	31	31

Correlations

**. Correlation is significant at the 0.01 level (2 -tailed).

Table (16) - Correlation Summary - Modarres, South Bound - Motahari

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.859 ^a	.738	.719	5.044E-02

a. Predictors: (Constant), Q_LANE2, Q_LANE1

Table (17) - Correlation Results - Modarres, South Bound - Motahari

Coefficients a,b

	Model	Unstan Coef B	dardized ficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	Q_LANE1	.272	.023	.827	11.946	.000
	Q_LANE2	.415	.068	.421	6.084	.000

a. Dependent Variable: RSF

b. Linear Regression through the Origin

		RSF	Q_ST1	Q_LANE1	Q_LANE2	Q_LANE3
RSF	Pearson Correlation	1.000			826**	.883**
	Sig. (2‡ailed)				000	.000
	N	30	30	30	30	30
Q_ST1	Pearson Correlation	а.	.a		.a	. 3
	Sig. (2‡ailed)					
	N	30	30	30	30	30
Q_LANE1	Pearson Correlation	а.	.ª	. ^a	.a	.a
	Sig. (2‡ailed)					
	N	30	30	30	30	30
Q_LANE2	Pearson Correlation	826**	.ª		1.000	935**
	Sig. (2‡ailed)	.000				.000
	N	30	30	30	30	30
Q_LANE3	Pearson Correlation	.883**	٩.	٩.	935**	1.000
	Sig. (2‡ailed)	.000			000.	
	N	30	30	30	30	30

Correlations

**. Correlation is significant at the0.01 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

Table (19) - Correlation Summary - Kordestan, North Bound - Tavanir

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.883 ^a	.780	.773	9.101E-02

a. Predictors: (Constant), Q_LANE3

Table (20) - Correlation Results - Kordestan, North Bound - Tavanir

Coefficients^a

	Model	Unstandardized Coefficients		Standardized Coefficients Beta	t	Sig.
1	(Constant)	1.975E-17	.023		.000	1.000
	Q_LANE3	.332	.033	.883	9.977	.000

$$D = \frac{v_p}{S} \tag{8}$$

$$V = D * S * PHF * N * f_{HV} * f_{p}$$
(9)

As could be concluded, any change in the number of lanes will have a direct effect on density, speed and hourly volume. As explained earlier, it is obvious that these variables are also interconnected and their individual effects can not be assessed. Alternatively, the approach explained in this study does not rely on the district relationship between the volume, density, etc. Although this relationship as explained in HCM 1994 edition (Equation 1) was chosen to clarify the existence of a factor such as α_q , a closer review of Equation 3 makes it clear that in order to calibrate α_q , a field approach was taken which was completely independent of the proposed HCM method of calculating the capacity of the basic free way section. The approach is completely based on field observations and



Figure 7: Scatter diagram of R_{sf}

Table (21) - The results of the regression at each site

Site	Storage Lane Coefficient	Third Lane Coefficient	Second Lane Coefficient	First Lane Coefficient	Coefficient of regression
	b_0	b_1	b_2	b_3	R^2
1		0.268	0.431		0.848
2		0.236			0.616
3		0.231			0.587
4		0.272	0.415		0.738
5					0.780
Mean Value		0.252	0.423	0.332*	

*To be corrected after the mean values are calculated

the calibration of the proposed model was done based on the changes observed on the field. Therefore, the results of this study will still be valid, regardless of any approach that would be proposed to calculate the capacity of basic free way sections.

6- CONCLUSION

The change in the speed of passing vehicles from upstream is a main indicator of the disturbance in the traffic flow. Regarding the time-space diagrams in Figures 1 to 6, the changes in vehicle speeds - which are the slope of the lines - are unpredictable and irregular. Thus, the disturbance in the traffic flow is for granted. Moreover, there are different factors affecting the expressway capacity and other flow characteristics. Quantifying the effect of each and every single factor takes a large-scale study and is not the purpose here. Instead, the macroscopic study was done.

Having made the model and obtaining the value of the coefficients, it is obvious that the results from different sites are not significantly different. This validates the hypothesis of the queue impact and its predictability as the base of this study.

In different stages of determining the model, no significant correlation is seen between the formations of queue in the storage lane and changes in the freeway capacity, which means the existence of queue in the storage lane is insignificant.

The mean value of the coefficient for the third lane is 0.252. The blockage of one lane of the freeway according to Equation 1, would cause a capacity drop of 0.333. The difference between these two values is related to other factors previously explained. The same applies to the coefficients of the first and the second lane. The mean value for the coefficients of the first and the second lane are 0.423 and 0.755 respectively, which

are comparable to theoretical values of 0.666 and 1.000 from Equation 1 for lane drops of 2 and 3 respectively. Similarly, these differences are caused by other factors rather than lane blockage.

In the process of model verification, the maximum difference between the observed values and predicted ones are only 30%, which is desirable regarding the changes in traffic flow states in different sites and their structural dissimilarities. So the resulting model seems to be a reliable one.

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