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The Effects of Fixed-Time Ramp Metering on Freeway Traffic Characteristics Using Microscopic Traffic Simulation

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Abstract

The effects of fixed-time ramp metering on the speed, density and flow of traffic in the influence area of freeway-ramp junctions were explored in this paper. The traffic parameters were obtained from the microscopic VerkehrIn Städten – SIMulations Model (VISSIM 5.40) stochastic simulator program. Four hundred models were built to obtain the traffic stream characteristics. Two fixed-time traffic signals for the ramp meters were assumed and applied for two different assumed geometric configurations of ramp-freeway junctions (Type I and Type II). Different traffic volume conditions were assumed for the ramps and the freeways to represent various traffic flow conditions on the downstream of the freeway. The ramp traffic volume was started from 200 vehicles per hour per lane (vphpl) to 1100 vphpl, with an increment of 100 vphpl; while, the traffic volume of the freeway was started from 400 vphpl to 2000 vphpl with an increment of 200 vphpl. Cameras and traffic detectors were installed at two sites of ramp-freeway junctions in the Kansas City metropolitan area to collect traffic data for the calibration process. The following traffic data were collected for the calibration process: the ramp traffic signal times, queue lengths on the ramp, traffic flow and composition of the ramp and freeway, speed of the vehicles at the upstream and downstream of the freeway. The relationship between the speed-flow-density of the vehicles within the ramp influence area with and without using ramp metering was obtained. The results of the study showed that ramp metering has different effects on the traffic flow characteristics based on the geometric configuration of the ramp-freeway junction and traffic flow conditions. Regarding the Type I junction, ramp metering could increase the average speed of the vehicles within the influence area when the flow was greater than 1000 vphpl; the Type II junction, however, did not show significant result. Based on these results, the study recommends that before implementing ramp metering on the ramp, a detailed study should be made of the geometric configuration of the ramp-freeway junction, and of the traffic flow conditions.

Keywords: Ramp meter, Microscopic Simulation, Speed, Flow, Density

1- Introduction

Ramp metering is deployed on freeway entrance ramps to regulate the flow of traffic entering the freeway in order to prevent or delay a decline in traffic performance (Piotrowicz and Robinson, 1995, pp.1). The first ramp metering, which was manually controlled in the field, was implemented in 1963 on Chicago's Eisenhower Expressway. In 1970, Minnesota DOT installed the first two fixed-time ramp meters on I-35E north of downtown St. Paul, Minnesota (Liu et al. 2007, pp.1). Nowadays, several sophisticated traffic responsive ramp metering algorithms are employed to cope with daily fluctuations and non-recurrent freeway conditions. Traffic responsive ramp metering algorithms are designed for variable metering rates based on freeway conditions. There are many ramp metering algorithms that have been deployed. Furthermore, the algorithms are divided into isolated and coordinated types (Zhang et al., 2001, pp.2). Some of the algorithms are working based on traffic characteristics of the freeway and/or the ramp. For example; Asservissement Linéaire d'Entrée Autoroutière (ALINEA) algorithm was proposed to maintain a desired level of occupancy (occupancy is the percent of time a traffic loop detector embedded in the road pavement is occupied by vehicles.) on the downstream mainline freeway (Papageorigou et al., 1997, pp. 58-64); in Zone algorithm, the mainline freeway corridor is divided into multiple zones based on the location of critical bottleneck and traffic volume in the corridor (chu et al., 2002, pp. 7-8); in Bottleneck algorithm, a system-level metering rate is calculated based on local conditions of occupancy levels of upstream of the given metered ramp and on system capacity constrains (Jacobsen et al., 1989, pp. 17-26); System-Wide Area Ramp Metering (SWARM), which is a centrally controlled system wide algorithm, was designed based on predicted densities at the system's bottleneck location (Paesani G. et al., 1997, pp. 1-7); seven detector inputs are used with Fuzzy Logic algorithm, which were downstream occupancy, downstream speed, upstream occupancy, occupancy at merge, speed at merge, queue occupancy, and advance queue occupancy (Tian et al. 2002, pp. 200-231). Most of the studies indicate that ramp metering by using either fixed-time or algorithms has beneficial effects on capacity of the freeway. This paper was conducted to know the effects of ramp metering on traffic characteristics of the freeway taking into consideration geometric configuration of the ramp-freeway junction and metering rates (signal timing).

2- Aim of the Study

This study focuses on the relationships of macroscopic traffic stream characteristics in the influence area of the freeway junctions with and without using ramp metering.

In this study, a microscopic traffic simulation program (VISSIM) was used to evaluate the effects of fixed-time ramp metering on the relationships of macroscopic traffic stream characteristics within the influence area of ramp-freeway junctions. The rest of this paper is organized as follows. Section 2 provides a literature review. Section 3 describes the methodological framework. Section 4 details how ramp metering affected the traffic characteristics within influenced areas of the selected geometric configurations of the junctions, followed by concluding remarks in section 5.

3- Literature Review

Several mathematical models have been built to figure out the fundamental relationships of macroscopic traffic stream characteristics (speed, flow, and density). The relationships derived between these parameters, however, are generally for free flow and congested flow conditions in links (not for interrupted flow such as at nodes).

Macroscopic stream models show the changes in traffic parameters with respect to each other; for example the change between speed and density. After observing traffic speed and density photographically, in 1934 Greenshield proposed the first simple single-regime model, which was based on the linear relationship between speed and density as shown in Figure 1 (Adolf, 1990, pp. 283-319) (Mathew, and Krishna, 2006, pp. 33-1 to 33-10). Greenshield observed a linear speed-density relationship from an aerial photographic study, and the equation for this relationship is:

$$u = uf - uf\,\frac{k}{kj} \ldots\ldots\ldots\ldots\ldots (1)$$

Where:

u is the mean speed at density k.

uf is the free flow speed

kj is the jam density

The parabolic in shape relation between flow and density can be derived by substituting equation (1) in following equation

$$q = k.u$$

As a result, equation 2 was obtained as shown below:

$$q = uf.\;k\; - \;uf\;\frac{k^2}{kj} \ldots\ldots\ldots\ldots\ldots (2)$$

The relation between flow and density in Greenshields model is shown in Figure 2.

The relation between flow and speed can be determined by substituting *k=q/u in* equation (1) as shown in Figure 3 and equation 3:

$$q = kj.\;u\; - \;\frac{kj}{uf}\,u^2 \ldots\ldots\ldots\ldots\ldots (3)$$

There is a disadvantage in Greenshiel's model, which is not easy to obtain jam density in the field (Mathew, and Krishna, 2006, pp. 33-1 to 33-10) (Garber and Hoel, 2015, pp 251-298).

In the field of traffic engineering, it is not easy to find the linear relationship between speed and density as in Greenshield's model. Greenberg therefore proposed the second single- regime model, which assumed a non-linear relationship between speed and density. Greenberg derived a model analytically, as shown in Figure 4 and equation 4:

$$u = u_{\circ}\, ln\frac{kj}{k} \text{.......(4)}$$

Since Greenberg's model was unable to predict speeds at low density, and since it was difficult to use it to estimate optimum speed, Underwood proposed the third single-regime model, which was an exponential model as shown in Figure 5. Underwood tried to overcome the drawbacks of Greenberg’s model. Underwood studied on Merritt Parkway in Connecticut and he advanced an exponential model as shown in Figure 5 and equation 5:

$$u = uf \,.\, e^{\frac{-k}{k_{\circ}}} \text{.......(5)}$$

Underwood's model had two drawbacks, however: first, it could not be used to predict speeds at high density, and second, it was once again difficult to use it to estimate optimum density (Adolf, 1990, pp. 283-319) (Mathew, and Krishna, 2006, pp. 33-1 to 33-10).

A group of researchers at Northwestern University therefore proposed a fourth model, based on the observation that most of the curves of speed-density relations are s-shaped. They derived an equation as shown below:

$$u = uf \,.\, e^{\frac{-1}{2}.(\frac{k}{k_{\circ}})^2} \text{.......(6)}$$

In their model, however, speed does not approach to zero when density approaches to jam density.
Based on Greenshield's model, the introduction of an additional parameter, n, was proposed by Drew in order to provide a more generalized modelling approach. The equation that Drew proposed is shown below:

$$u = uf \left[1 - \left(\frac{k}{kj}\right)^{n+\frac{1}{2}}\right] \text{.......(7)}$$

A family of models can be developed by varying the parameter n. Drew suggested -1, 0, +1 for n, and called these models linear, parabolic and exponential models respectively (Jun et.al 2009).
A new parameter N was also introduced in the so-called Pipes-Munjal Generalized Model in order to provide a more generalized modelling approach compared to the single-regime models (Yao et.al 2009, pp.670-676) as shown below.

$$u = uf \left[1 - \left(\frac{k}{kj}\right)^{N}\right] \text{.......(8)}$$

In 1961, Edie proposed the idea of multi-regime models. These models consist of separate equations to represent the speed-density relation at congested and uncongested traffic conditions. These models were proposed because human behaviours are different in such different situations. Although the multi-regime models are an improvement on the single-regime models, they have difficulty in determining the transition point between regimes (Yao et.al 2009, pp. 670-676).
Some studies used speed, density, and/or flow as indicators to know the effectiveness of ramp metering on freeway efficiency. According to many studies, fixed-time ramp metering can increase average mainline speed; however, they obtained different outcomes for the extent of this improvement. Piotrowicz and Robinson (1995) showed that ramp metering increased mainline speed by 16 to 62 percent; Meyer (1997) showed that average freeway speeds increased by 29 percent; Gaynor et al. (1997) indicated that a fixed-time ramp metering system increased the average speed by 9.4 percent; while, according to the study of Kesten et al. (2013), it increased the average speed by 53 percent. On the other hand, Poorjafari and Yue (2013) found that while fixed-time ramp metering systems could improve the freeway performance, especially in the peak-hours, it did not benefit the whole system. They therefore recommended a thorough site investigation before implementing ramp metering.
Almost all of the studies that have been done to understand the effects of ramp metering using algorithms indicate its positive effects on freeway efficiency. The study of Lipp et al. (1991) showed that after implementing the Helper ramp metering algorithm, the freeway speed increased by 58 percent. In Taylor et al.’s (1998) study, the Fuzzy ramp metering algorithm revealed a significant balance between mainline efficiency and ramp queues, especially when the demand exceeded the capacity.
This study was done to explore the effects of fixed-time ramp metering on the efficiency of freeways but at different traffic flows within the freeways and ramps.

4- Methodology

Two different geometric configurations of ramp-freeway junctions were selected in this study to explore the effectiveness of ramp metering on flow-speed-density relationships. The selected ramp-freeway junctions were named as Type I and Type II junctions, as shown in Figure 6. The difference between the two junctions lies in the number of lanes on the ramps and downstream on the freeway and the ramps. The Type I junction has five lanes in the downstream freeway, while the Type II junction has four lanes. The number of lanes in the ramp in the Type I junction is two, while it is one in the Type II junction. Two sites of ramp-freeway junctions were selected in the Kansas City metropolitan area to collect data for use in the VISSIM calibration processes. The selected junctions, which were similar to the Type I and Type II junction, were Metcalf Avenue, and Holmes Road connected to the I-435 freeway.

In order to calibrate the vehicle and driver behaviour parameters in the VISSIM model, the following traffic data were collected for the calibration process: the ramp traffic signal times, queue lengths on the ramp, traffic flow and composition of the ramp and freeway, speed of the vehicles at the upstream and downstream of the freeway. The Metcalf Avenue site connected to the I-435 freeway junction was chosen to collect the traffic data. Four video cameras were installed in the evening peak periods, as shown in Figure 7. Camera number 1 was used to collect traffic flow and composition in the upstream of the freeway at each lane; while camera number 2 was used to collect traffic flow, composition and lane proportions for both the right and left lanes of the ramp.

Camera number 3 was used to measure the queue length of vehicles that occurred on both the left and right lanes of the on-ramp. The queues were measured at the evening peak hour from the arterial street upstream of the ramp to the ramp meter's stop line. The average queue length of right and left lanes of the ramp was used as one of the traffic parameters in the calibration process.

Camera number 4 was used to record the metering rates (signal timing) for both the right and left ramp meters on the ramp. The Corridor Adaptive Ramp Metering Algorithm (CARMA) was used as a basis for operating the ramp metering rates. Based on the CARMA algorithm, the ramp meter's green and red times in the right and left lanes were working reciprocally. Also based on the algorithm, two seconds of all red signals existed in each cycle. In addition, the green and the red times were different for each cycle. The green-time periods were separated precisely for both the right and left lanes of the on-ramp.

Vehicle speed data could not be obtained from cameras; therefore, the Kansas City Scout's detectors were used to obtain the vehicle speed data.

Based on the collected signal data for the right and left lanes on the Metcalf Avenue on-ramp, signal timing was assumed for the calibration process.

A model was built and run five times for an hour with randomly selected seeds for both system and operational calibration parameters. The system parameter calibration was done by using the collected traffic and geometric data; while the operational parameter calibration was done by using the car following model of Widemann 1999. Headways, which were considered as the key parameters for the operational calibration, were obtained for the freeway upstream and downstream, as well as for the ramp and the auxiliary lanes, and the ramp influence area. The statistical t-test was used to test the field and calibrated traffic speed of the freeway vehicles and the queue length of the ramp vehicles.

Four hundred traffic volume scenarios were built for both geometric configurations of the ramp-freeway junctions. Each model was run three times for both cases of using ramp metering and without using ramp metering. A signal timing scenario of 12 seconds, which include 5 seconds red, 1 second all red, 5 seconds' green, and again 1 second all red (5R+1AR+5G+1AR), was assumed for the Type I junction; while a 6 seconds signal timing scenario of (4R+2G) was assumed for the Type II junction. The assumed traffic volume scenarios for the freeways and the ramps were selected to represent different cases of traffic flow, speed and density at the ramp influence areas. Table 1 shows the assumed traffic flow scenarios in which the traffic volumes of the freeway progressed from 200 to 2000 (vphpl), with an increment of 200 vphpl; while the traffic volumes of the ramp progressed from 200 to 1100 vphpl with an increment of 100 vphpl.

Based on the collected data, several other parameters were assumed in the models as shown below:

- The speed limit at the freeway was assumed to be 65 mph (105 km/hr); while the speed limit at the ramp was assumed as 45 mph (72 km/hr).
- The desired speed profile for the freeway upstream ranged from 55 mph (89 km/hr) to 80 mph (129 km/hr); while the desired speed profile for the ramp ranged from 42 mph (68 km/hr) to 48 mph (78 km/hr).
- Traffic composition for the freeways and the ramps included 97 percent passenger cars and 3 percent buses and trucks.
- The calibrated headways, which were 2.24, 4.29 and 1.1 seconds for the freeway upstream and downstream, the ramp and

auxiliary lanes, and the ramp influence area respectively, were used for all of the designed models.

- The car following model of Widemann 1999 and the free lane change option were chosen as driver behaviour parameters.
- Each simulated model was run three times with different seeds for one hour and five minutes. Only the outputs of the last hour were taken into account because the first five minutes of the models' running were required for vehicles to settle in the system so as to avoid any data bias. Platoons of the vehicles of the ramp were taken into account based on the calibrated queue lengths in the ramps.

To figure out the fundamental relationships of the macroscopic traffic stream characteristics in the ramp influence area, the VISSIM outputs of the average values of speed, flow, and density of the vehicles were taken for the assumed traffic volumes of the freeway and the ramp, and the assumed traffic signal of the ramp meters for the selected geometric design configurations. For all of the three traffic outputs, the average values of the mean of the parameters were taken in the influenced area. The mean values of the traffic parameters were taken for each 30 seconds of output.

5- Results of the Calibration Process

The average of the mean queue lengths for both right and left lanes of the Metcalf Avenue Ramp is shown in Figure 8. The mean value of the queue lengths was 31.7 m.

The total green-time period for the peak hour of the right lane's ramp meter on the ramp was 1,221.3 seconds, and the average value of the green-time period was 4.4 seconds, as shown in Figure (9).

The total green-time period for the peak hour of the left lane's ramp meter on the ramp was different from that for the right lane, 1,354.4 seconds; however, the average value of the green-time period was the same, i.e. 4.4 seconds, as shown in the Figure (10). This resulted in different cycle numbers for each of the lanes. As shown in Figures (9) and (10), the number of signal cycles in the right lane was 278, while in left lane it was 307 cycles.

The assumed signal timing for the calibration process was based on the collected signal data for the right and left lanes on the Metcalf Avenue on-ramp. Cycle timing lengths of 12 seconds were used for both lanes of the right and the left; however, four seconds was used for green-time period in the right lane and five seconds was used for green-time period in the left lane because the number of vehicles in the left lane was greater than the number of vehicles in the right lane. Table 2 shows the assumed signal timing for the ramp meters for the calibration process.

Table 3 shows the results of the calibration process that include a comparison between the field and calibrated speed and queue lengths. As shown in the table, all of the obtained p-values were greater than 0.05, indicating there was no significant difference between the field and calibrated speed and queue lengths at 5% significance level. The results of the calibrated headways for the freeway (upstream and downstream), and for the ramp and auxiliary lanes, and the ramp influence area, were 2.24, 4.29 and 1.1 seconds, respectively.

6- Results

The results show that ramp metering in the selected geometric junction configurations affected the speed-flow-density relationships within the influenced areas differently.

6-1- The Effects of Ramp Metering on Speed-Flow-Density within the Influenced Area of Type I Ramp-Freeway Junctions

Figure 11 shows the results of the effectiveness of ramp metering on the speed-density relationship within the ramp influence area of the Type I ramp-freeway junction. According to the figure, ramp metering could have positive effects by increasing the average speed of the vehicles within the ramp-freeway influence area. As indicated in the figure, the average speed of the vehicles was 48 mph (77 km/hr) when the average density reached 50 vphpl with no the ramp metering; while when ramp meters were in operation, the density never reached 30 vphpl; therefore the ramp metering could have positive effects by helping maintain a higher average speed of the vehicles in the influence area.

Figure 12 shows the results of the speed-flow relationships within the junction influence area when using ramp metering. When the flow reached 1000 vphpl, there was only an average of a 3 mph difference between the base case (no ramp metering) and using ramp metering; however, the ramp metering had a more positive effect when the flow reached 1500vphpl. This indicates that the more the traffic flow, the more effective the ramp metering is.

At the same time, ramp metering could increase the efficiency of the freeway by increasing the flow of vehicles that pass the influence area, especially when the average traffic density is equal to or greater than 25 vpmpl, as shown in Figure 13.

6-2- Effects of Ramp Metering on Freeway speed-flow-density within Type II Ramp-Freeway Junctions

The results of the effectiveness of ramp-metering on the speed-flow-density within the freeway influence area of type II junctions indicates that there is no significant difference between using ramp metering and base case. Figures 14, 15 and 16 show the relations between speed-density, speed-flow, and flow-density, respectively. The curves in the figures in respect to the use of ramp metering and the base case nearly coincide; therefore, it can be said that ramp metering does not offer great positive effects on the freeway influence area regarding the traffic parameters of speed, flow and density.

7- Conclusions

In conclusion, it was determined that ramp metering was able to increase the efficiency of the freeway given the geometric configuration of the Type I junction when the traffic flow was greater than 1000 vphpl or traffic density was greater than 25 vpmpl. Ramp metering was not able to increase the efficiency of the freeway when it was used with the Type II junction, because it obtained roughly the same results in respect to the traffic parameters of speed, flow, and density as without using ramp metering. This can be explained by the difference in the number of lanes in the two geometric configuration scenarios. In the Type I geometric configuration the number of auxiliary lanes is two and one of these lanes is carried along the freeway downstream for an effective distance in advance for the exit, while in the Type II geometric configuration there is only one auxiliary lane and this is not carried along the freeway, as illustrated in Figure 6. This more constricted lane structure may affect the performance of the ramp metering in terms of improving traffic flow within the ramp's influence area on the freeway.

The findings in respect to the effectiveness of ramp metering on speed-flow-density relations within a freeway ramp influence area show that ramp metering has different effects on the freeway efficiency based on the geometric configuration of the ramp-freeway junctions. For example, it increased speed of the vehicles within the influenced area when it was used for the Type I junction; however, it did not show any significant positive effects in the Type II junction. Furthermore, for the Type I ramp freeway junction, the results reveal that ramp metering could increase the speed of the vehicles within the influence area when the density was greater than 25 vpmpl or when the flow was greater than 1000 vphpl. Since the use of ramp metering is effective only when the traffic flow of the vehicles is greater than 1000 vphpl in the Type I geometric configuration, it is recommended to use metering only if the traffic density is greater than 25 vpmpl or when the traffic flow exceeds 1000 vphpl.

In addition, the results show that before deciding to install ramp metering, a detailed study should be conducted regarding the geometric configuration of the ramp-freeway junction, the traffic flow of the freeway and ramp, and the period of time that the ramp meters will be in operation in a day.

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تاثيرات استعمال الاشارة المرورية ذات الزمن الثابت على الخصائص المرورية لمنحدرات الطرق السريعة باستخدام المحاكاة المروية المصغرة

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المستخلص :

في هذه الدراسة تم بحث تاثيرات الاشارة المرورية ذات الزمن الثابت على السرعة والكثافة والحجم المروري في المنطقة المؤثرة لمنحدرات تقاطعات الطرق السريعة . تم الحصول على معطيات المرور من مصغر نموذج لبرنامج (VerkehrIn Städten – SIMulations Model VISSIM) تم اعداد (400) نموذج للحصول على خصائص سريان المرور. وتم افتراض اشارتين مرور ذات الزمن الثابت لمنحدر الطريق السريع وتطبيق ذلك على تشكيلين هندسيين مختلفين لمنحدر تقاطع الطريق السريع نوع 1 ونوع 2 .

تم افتراض احجام مرورية مختلفة للمنحدرات والطرق السريعة للتعبير عن احجام مرورية مختلفة في نهاية الطريق السريع. حيث ابتدأ حجم المرور للمنحدر من 200 مركبة لكل ساعة لكل ممر (مركبة / ساعة/ ممر) ولغاية 1100 (مركبة / ساعة/ ممر) بزيادة 100 (مركبة/ ساعة/ ممر) بينما ابتدأ حجم المرور للطريق السريع من 400 (مركبة/ ساعة/ ممر) ولغاية 2000 (مركبة / ساعة/ ممر) بزيادة 200 (مركبة / ساعة/ ممر) ، وتم استخدام الكاميرات وكاشفات المرور لجمع البيانات المرورية في مدينة كانساس - الولايات المتحدة الامريكية - لغرض عملية المعايرة .

تم الحصول على العلاقة بين السرعة والحجم والكثافة للمركبات في المنطقة المؤثرة للمنحدر مع او بدون استخدام الاشارة الضوئية في المنحدر .اظهرت نتائج الدراسة ان وضع الاشارة المرورية في المنحدر له تاثيرات مختلفة على خصائص حركة المرور بناء على التشكيل الهندسي لتقاطع الطريق السريع والمنحدر وعلى حجم المرور فيه .

بالنسبة لتقاطع نوع (1) فان وضع الاشارة الضوئية في المنحدر قد يزيد معدل سرعة المركبات في المنطقة المؤثرة عندما يكون حجم المرور اكثر من (1000) (مركبة / ساعة/ ممر) اما بالنسبة لتقاطع نوع 2 فلم تظهر لنا الدراسة اية نتائج مؤثرة . بناء على هذه النتائج فالدراسة تقترح وجوب اجراء دراسة مفصلة للتشكيل الهندسي لتقاطع الطريق والمنحدر ودراسة حجم المرور فيه قبل اقرار وضع الاشارة المرورية في المنحدر.

الكلمات المفتاحية : منحدرات الطرق ، المحاكاة المصغرة ، السرعة ، الكثافة ، سريان.

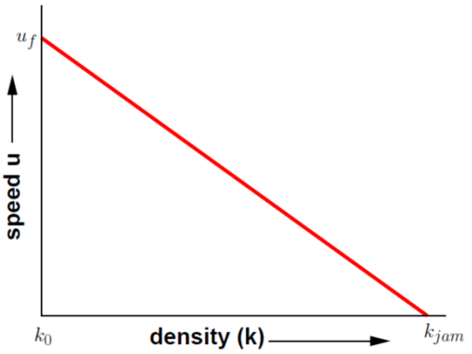


Figure (1): Relation between speed and density
(by Mathew and Krishna, 2006, pp. 33-1).

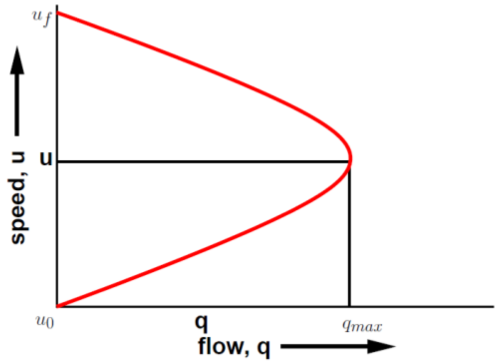


Figure (2): Relation between speed and flow
(by Mathew and Krishna, 2006, pp. 33-2).

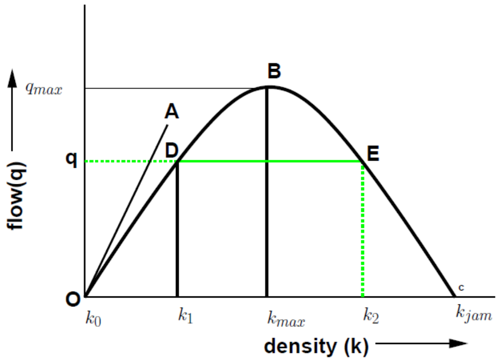


Figure (3): Relation between flow and density
(by Mathew and Krishna, 2006, pp. 33-2).

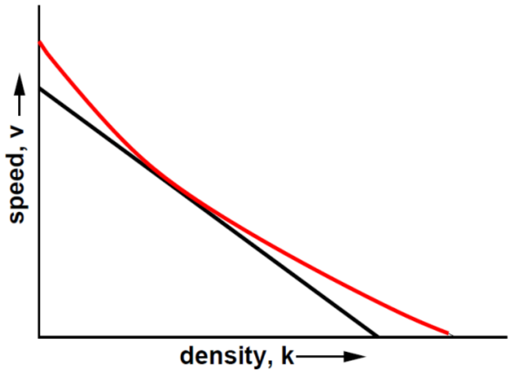


Figure (4): Greenberg's logarithmic model
(by Mathew and Krishna, 2006, pp. 33-5).

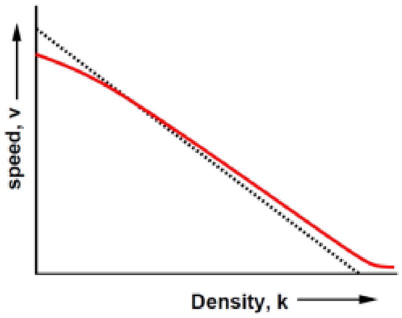
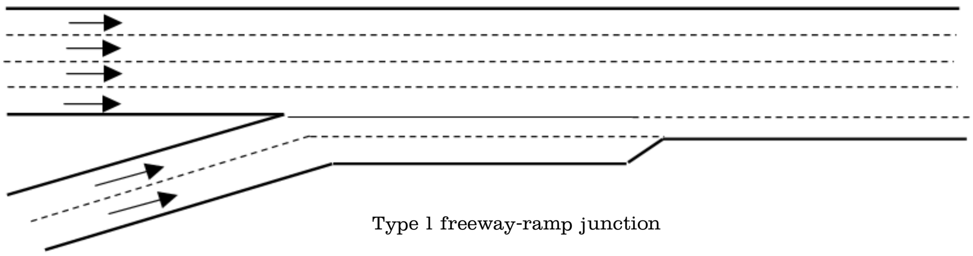
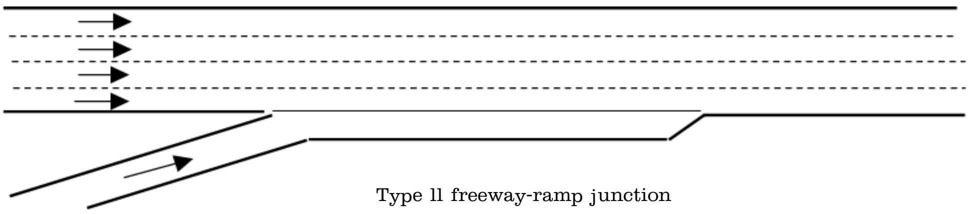


Figure (5): Underwood's exponential model
(by Mathew and Krishna, 2006, pp. 33-5)



Type I freeway-ramp junction



Type II freeway-ramp junction

Figure 6: The selected geometric configuration for on-ramps and freeways (by researchers)

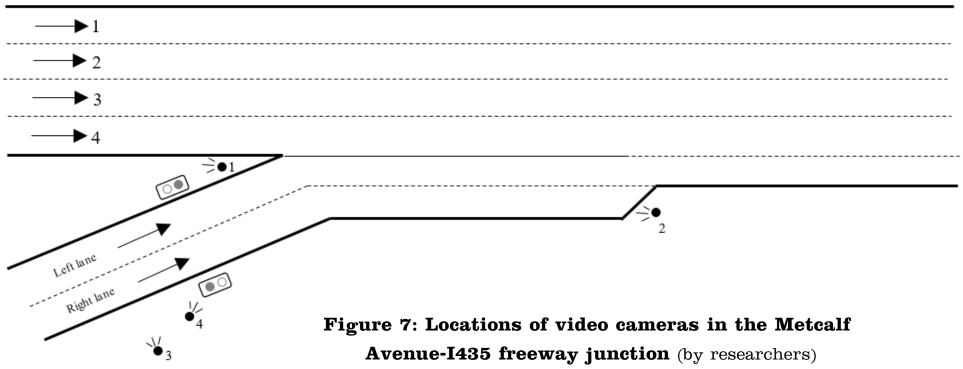


Figure 7: Locations of video cameras in the Metcalf Avenue-I435 freeway junction (by researchers)

Table 1: Traffic flow scenarios used in the study (by researchers)

		Freeway volume (vehicle per hour per lane)									
		200	400	600	800	1000	1200	1400	1600	1800	2000
Ramp Volume vehicles per hour per lane	200										
	300										
	400										
	500										
	600										
	700										
	800										
	900										
	1000										
	1100										

Table (2): Assumed design of signal timing periods for the calibration. (by researchers)

Lane	Design of signal timing periods	Cycle timing length
Right	4 s Green + 2 s All Red + 5 s Red + 1 s All Red	12 seconds
Left	4 s Red + 2 s All Red + 5 s Green + 1 s All Red	12 seconds

Table 3: Comparison between simulated and field data for calibration (by researchers)

			The ramp	The freeway	
	Run No.	**Seed No.**	**Average queue length, m**	**Upstream average speed, mph**	**Downstream average speed, mph**
VISSIM simulated	1	19	25.7	44.5	34.9
	2	47	35.5	44.9	31.4
	3	75	33.2	43.7	33.7
	4	103	44.2	45.2	33.8
	5	131	38.8	45.2	34.0
	Average simulated		35.5	44.7	33.6
	Standard deviation		6.85	0.60	1.32
	Field		31.7	44	35
	p-value		0.189	0.077	0.068

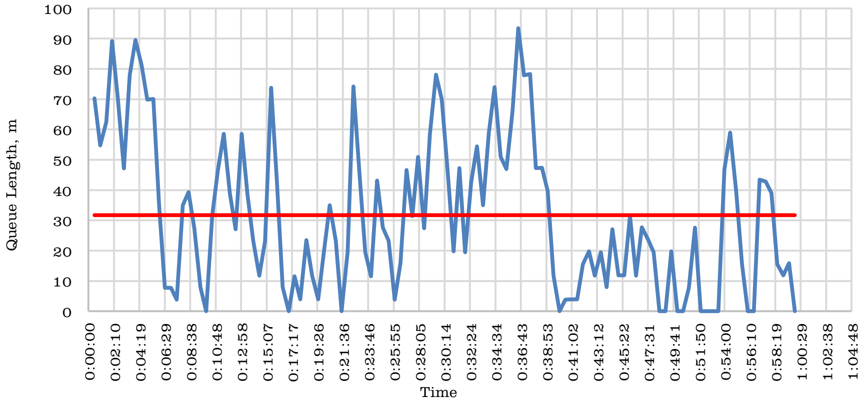


Figure 8: Average queue length (m) for both the right and left lanes on the Metcalf Avenue ramp (by researchers)

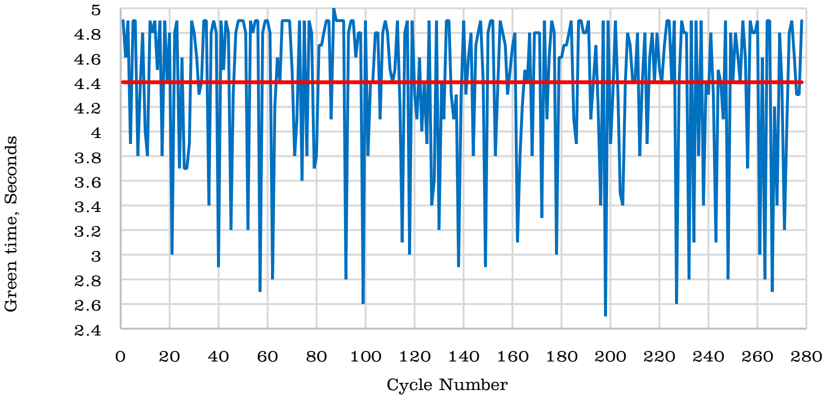


Figure 9: Peak hour green time for the right lane of the Metcalf Avenue ramp meter signal (by researchers)

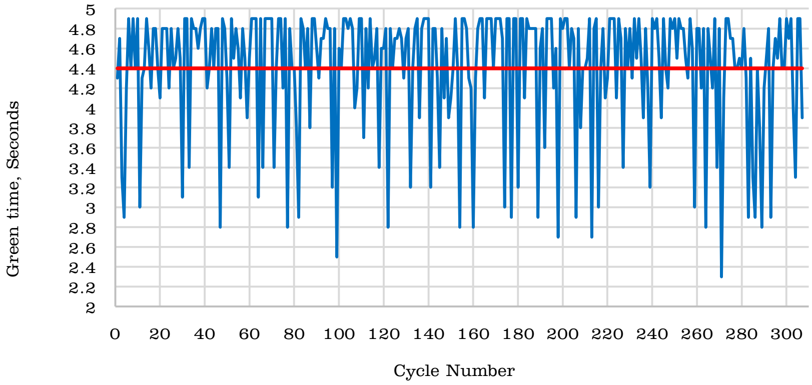


Figure 10: Peak hour green time for the left lane of the Metcalf Avenue ramp meter signal (by researchers)

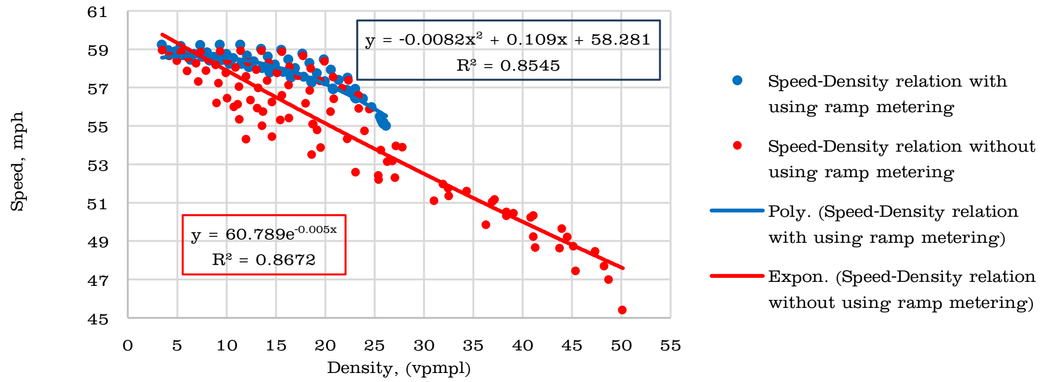


Figure 11: Speed-Density Relationship with and without Using Ramp Metering at Type I Junction (by researchers)

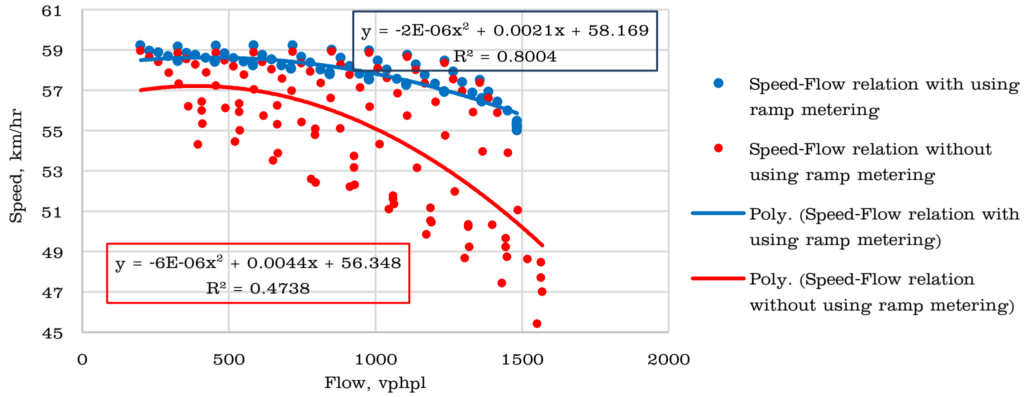


Figure 12: Speed-Flow Relationship with and without Using Ramp Metering in Type I Junction. (by researchers)

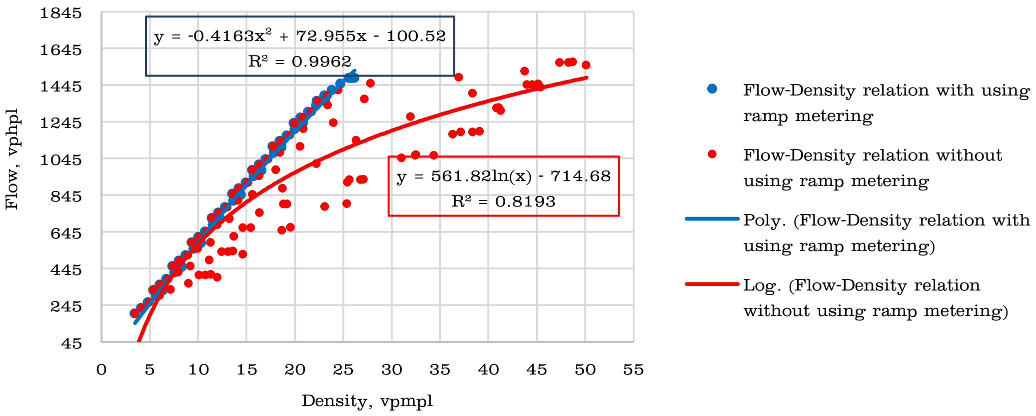


Figure 13: Flow-Density Relationship with and without using Ramp Metering at Type I Junction (by researchers)

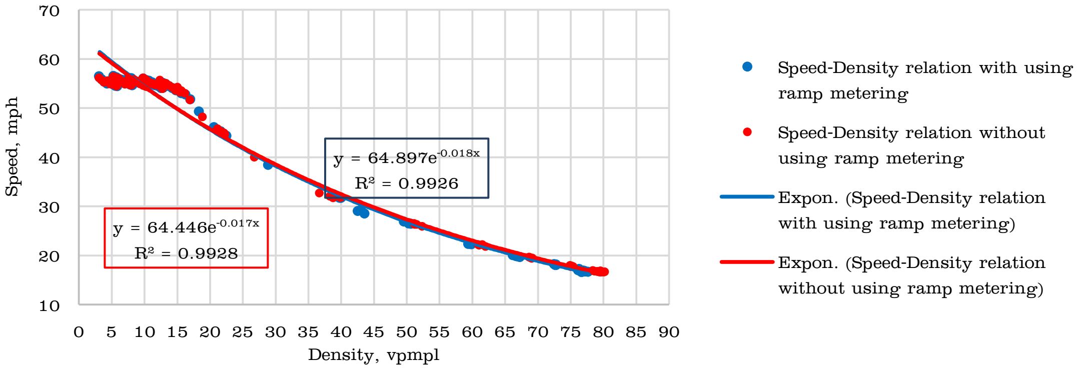


Figure 14: Speed-Density Relationship with and without using Ramp Metering at Type II Junction (by researchers)

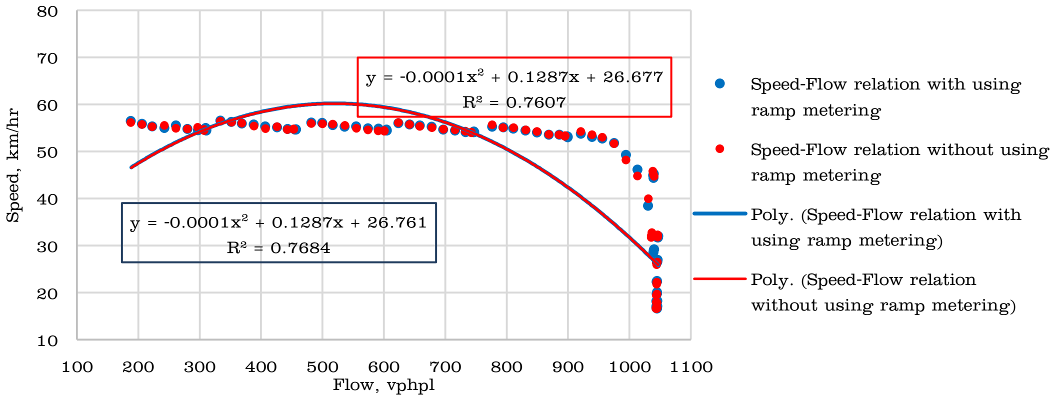


Figure 15: Speed-Flow Relationship with and without using Ramp Metering at a Type II Junction (by researchers)

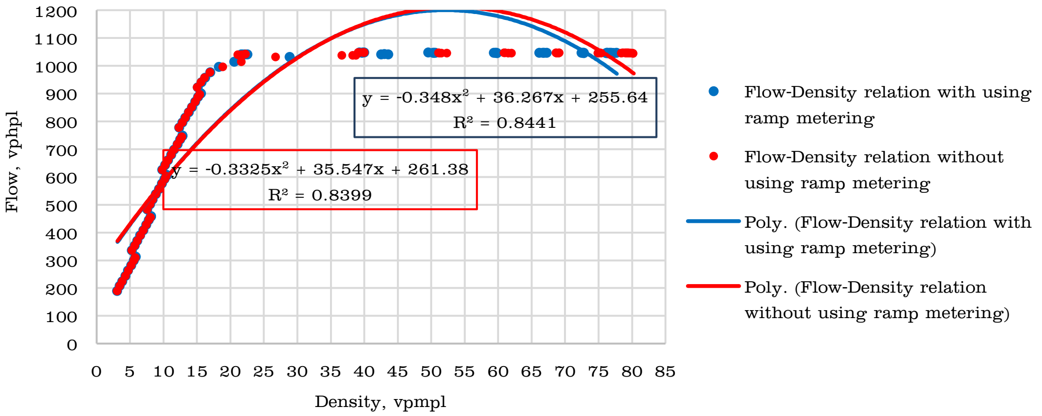


Figure 16: Flow-Density Relationship with and without using Ramp Metering at Type II Junction (by researchers)