ARCHIVES OF TRANSPORT *ISSN (print):* *0866-9546*
Volume 43, Issue 3, 2017 ***e-ISSN (online):*** *2300-8830*
DOI: *10.5604/01.3001.0010.4226*

ANALYSIS OF THE INFLUENCE ON EXPRESSWAY SAFETY OF RAMPS

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Abstract: *As the very important parts of the expressway system, on and off ramps have a great effect on the operation effect of expressways. Once congestion occurs at on and off ramps, it will directly affect the safety of the expressway and vehicles. So this paper first analyzes the location design of on ramps, the length and the influences on the expressway running state of off ramp downstream traffic state, and establishes the expressway operation models based at on and off ramps. The expressway operation models include off ramp delay model, on ramp delay model, expressway delay model and side road delay model under the influence of the distance between on and off ramp and traffic volume. At the same time, the paper analyzes the connection between the traffic operation state and traffic safety, and establishes the expressway safety model based on congestion degree. Through simulation verification, the impact of on and off ramp on the security of the expressway is analyzed. In the simulation, safety rank division is simulated to verify and safety index of different safety ranks. Finally the paper concludes that the delay caused by traffic of the on and off ramps can decrease the safety of expressway.*

Key words: *expressway safety, on and off ramp, delay, accidents occurrence probability.*

1. Introduction

Due to on and off ramps on expressway, a large number of vehicles access and exit from expressway and the traffic on the outside lane slows to a crawl. Due to the relatively short distance between some ramps, traffic flows between the adjacent ramps will be frequent confluent, diverted and mixed. This is easy to cause conflictions and traffic safety problem (Karoń and Żochowska, 2015). Because there is no conflict point near the ramps, strict management and control measures are not taken generally. Therefore, conflictions of traffic volume near on and off ramps lead to congestions of expressway and side road (Handke, 2010).

Domestic and foreign scholars have done a lot of researches on on and off ramp setting. Leisch (1959) studied interchanges spacing of urban expressway. Al-Kaisy et al. (2002) analyzed the relationship between the ramp traffic flow, traffic capacity, main road traffic flow, length of deceleration lane and lane number in detail. Munoz and Daganzo (2002) described the traffic operation of the bottleneck section of the highway exit upstream in detail.

Jayakrishnan et al. (1995) simulated traffic flow of urban road, and proposed that there are many differences between urban road and highway, especially the mutual influences between multiple vehicle types in urban road. Kojima et al. (1995) selected an x-shaped-cross highway as the simulation object to study the mixed behavior of individual vehicle, and analyzed in which part of the weaving section mixed vehicles began to interweave. Research model consisted of three basic equations, which are simple forward movement, car following movement and braking movement.

In addition, Wang et al. (2015) presented Bayesian logistic regression models for single vehicle (SV) and multivehicle (MV) crashes on expressway ramps by using real-time microwave vehicle detection system data, real-time weather data, and ramp geometric information. Qu et al. (2014) aimed to assess the potential crash risks across different traffic lanes (shoulder lane, median lane, and middle lane) near to ramps (before on-ramps, between ramps, and after off-ramps). GAO and GUO (2006) took the common parallel ramp setting as the research object and put forward five ramp optimization design methods, which are changing location of the ramp, changing lane function of the intersection approach, setting left-turn in long distance, and changing lanes ahead on the side road, etc. Furthermore, Lee and Abdel-Aty (2006) proposed the method of predicting the temporal variation in crash risk on freeway ramps and at the intersections of ramps (the junction of ramps with crossroads). Bared et al. (1999) examined the impact of acceleration and deceleration lane lengths on traffic safety; Chen et al. (2009) evaluated the safety effects of the number and arrangement of lanes on freeway off-ramps; Liu et al. (2009) discussed three types of lane arrangements on freeway sections with closely spaced ramps and their safety effects; Pulugurtha and Bhatt (2010) analyzed the role of geometric characteristics and traffic on crashes in weaving sections.

Researches both at home and abroad showed that the existing researches are mainly about on and off ramps setting, but rarely involves the safety. This paper hopes to propose the relationship between on and off ramp and expressway safety based on the above research results.

2. Expressway running condition analysis on and off ramp

On and off ramp locations on expressway are closely related to urban network structure, and the matching way of off ramp and on ramp is also different. The paper mainly study two typical matching types of on and off ramp on expressway, that are on-off ramp group and off-on ramp group as shown in Figure 1.

The difference between two groups is that for on-off ramp group the distance between off ramp ahead and on ramp behind is fewer than the distance between the off ramp and other ramps, on the contrary, for out-on ramp group the distance between on ramp ahead and off ramp behind is fewer.

The short distance between on and off ramp will lead to congestion of expressway main road and side road, so the paper studies the two matching types. If the distance is long, on and off traffic flow on expressway will not interfere with each other, and the running condition of expressway main road and side road will not be affected. So the long distance condition is not the scope of this study.

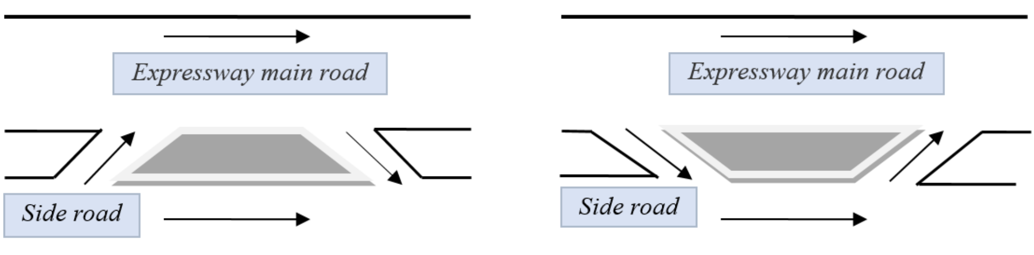
The definition of the distance size between on and off ramp has been reflected in the existing research results, so the paper does not study this problem anymore, but focuses on the influence of on and off ramps on traffic running state of expressway main road and side road.

2.1. On-off ramp group

As shown in Figure 1(a), once off ramp queuing occurs, and ascend to the expressway main road, it not only affects the normal traffic operation of expressway main road and produce corresponding delay, but also affects vehicles of on ramp entering the main road, and causes corresponding delay of side road. Based on the analysis, using critical gap theory and queuing theory, the expressway delay model and side road delay model can be established based on the queue length at on and off ramp.

Model principle is that vehicles enter off ramp based on critical gap theory, this maybe generate certain delay and queue.

According to queuing theory, input process of off ramp traffic is assumed as fixed-length distribution, that is $\lambda = q_c(veh/s)$, because of assumption of large traffic flow.



a）On-off ramp group　　　　b）Off-on ramp group

Fig. 1. on and off ramp on expressway

Queuing rule is first come first service, and service station is one lane. Service time distribution is assumed as exponential distribution, that is $\mu = E\left(q_f(t)\right) = \overline{q_f}(veh/s)$, because this paper argues that side road traffic volume is relatively large, critical gap is not uniform. Service intensity is that $\rho = \lambda/\mu$, and queuing model is *D/M/1*.
Then average queue length of off ramp is $L_{s=}\frac{\lambda}{\mu-\lambda}$, average queue vehicles number is $L_q = \rho L_s$
Delay of off ramp is

$$d = W_s + W_q = \frac{L_s}{\lambda} + \frac{L_q}{\lambda} = \frac{1+\rho}{\mu-\lambda} \quad (1)$$

where:
- μ is the average flow rate of the expressway exit ramp, which is the average service rate that side road traffic can serve for the main road traffic. The unit is veh/s.
- $\overline{q_f}$ is the average flow of expressway side road. The unit is veh/s.
- ρ is the service strength for queuing theory, which is the ratio of arrival rate and departure rate of off-ramp traffic flow into side road.
- L_s is the average number of queuing vehicles affected by side road traffic at the off ramp. The unit is *veh*.
- L_q is average number of queuing vehicles waiting for the off ramp. The unit is *veh*. d is the delays of traffic flow at the off ramp. The unit is s.
- W_s is customer stay time in queuing theory, which is the average travel time of all vehicles at the off ramp exiting from the main road. The unit is s.
- W_q is customer waiting time in queuing theory, which is the average waiting time of all vehicles at the off ramp exiting from the main road. The unit is s.

In addition, the maximum queue length of off ramp is also influenced by the signal control on side road. If there is signal control at the downstream intersection of off ramp, and the queue length may ascend to off ramp, forming time of the biggest queue length on off ramp is affected by the signal intersection, If the queue vehicles at downstream signal intersection do not ascend to off ramp, off ramp traffic will flow into side road with critical gap.

Therefore, service time of traffic flow out of off ramp under the influence of the side road signal control change into,

$$\mu = \overline{q_{ff}} = \frac{S\times 3600\times\frac{g}{c}}{3600} = S \times \frac{g}{c}(veh/s) \quad (2)$$

Therein,
- S is saturation traffic flow rate released in green time at the downstream signal control intersection.
- $\overline{q_{ff}}$ is average traffic of expressway side road affected by traffic signal on side road, the number of vehicles that can be discharged at each cycle at the downstream intersection of the side road is the section traffic volume at the off ramp. The unit is veh/s.
- g is green time at the downstream signal control intersection.
- C is signal cycle at the downstream signal control intersection.

Then average delay of off ramp is,

$$d_c = \frac{1+\rho}{\mu-\lambda} = \frac{\mu+\lambda}{\mu(\mu-\lambda)} = \begin{cases} \frac{q_c+\overline{q_f}}{\overline{q_f}(\overline{q_f}-q_c)} & q_c(C-g)\times 7+20 \le L_c \\ \frac{q_c+\overline{q_{ff}}}{\overline{q_{ff}}(\overline{q_{ff}}-q_c)} & q_c((C-g)\times 7+20 > L_c \end{cases} \quad (3)$$

Therein,
- L_c is the distance between the downstream signal control intersection and off ramp,
- q_c is traffic volume out of off ramp,

According to average queue length of off ramp, queue dissipation time can be calculated by $t_f = \frac{L_q}{\mu}$.
The delay calculation at expressway during the period of time is similar with that of the signal control intersection in one cycle, and the red time is d_c, that is the forming maximum queue length time of traffic flow out of off ramp, and green time is $\frac{q_k d_c}{(S-q_k)}$, that is the dissipation time of traffic flow out of off ramp.
According to steady state delay theory, $d_v = \frac{Sr^2}{2c(S-q)}$, the average delay at expressway is

$$d_k = d_c + \frac{Sr^2}{2c(S-q)} = d_c + \frac{Sd_c^2}{2(d_c+t_f)(S-q_k)} \quad (4)$$

Therein, q is the vehicle arrival rate of a certain section.

- q_k is average traffic volume at expressway. t_f is the dissipating time of the queue length on the exit ramp, and the unit is s. $t_f = \frac{q_k d_c}{(S-q_k)}$.
- r is virtual time of red light in a circle, and its value is d_c that is the average delay of the off ramp. The unit is s.
- g is virtual time of green light in a circle, and its value is the dissipating time of the queue length on the exit ramp.
- c is the virtual time of one cycle, is the sum of the virtual time of red light and green light. The unit is s.

If queue vehicles at expressway main road do not ascend to upstream on ramp, the traffic flow of on ramp can enter into expressway main road with critical gap, and then the delay of on ramp can be obtained by critical gap theory. Expressway section traffic volume is assumed as negative exponential distribution, and then probability of time headway greater than 6 seconds is $P(h \geq 6) = e^{\frac{-q_k \times 6}{3600}}$.
The number of space headway that expressway can provide to in-ramp in one hour $N = q_k \times e^{\frac{-q_k \times 6}{3600}}$.
Average waiting time of traffic flow on on ramp entering into expressway is $d_r{}' = \frac{3600}{N}$.
However, if queue length on expressway ascend to on ramp and it leads to on ramp traffic can't enter into the main road, average delay of traffic flow on on ramp entering into expressway includes the delay caused by queue dissipation time on off ramp is d_c, the delay on side road caused by traffic flow dissipation of expressway main road is d_k, and the delay caused by vehicles on on ramp entering into the main road is d_{r1}. And then $d_r = d_k + d_{r1}$.
Therein, d_{r1} is calculated by steady state theory, red time is d_k, green time is dissipation time of expressway queue length, that is $\frac{q_k \times (d_c + t_f)}{(S-q_k)}$, and then

$$d_{r1} = \frac{Sr^2}{2c(S-q)} = \frac{S{d_k}^2}{2\left(d_k + \frac{q_k \times (d_c + t_f)}{(S-q_k)}\right)(S-q_r)} \qquad (6)$$

Therein, q_r is the average traffic flow of the on ramp. The unit is veh/s.

On ramp delay is

$$d_r = \begin{cases} \frac{3600}{q_k \times e^{\frac{-q_k \times 6}{3600}}} + d_h \; q_k \times (d_c + t_f) \times 7 + 20 \leq L_s \\ d_k + d_{r1} \; q_k \times (d_c + t_f) \times 7 + 20 > L_s \end{cases} \qquad (7)$$

Therein,

- d_r is the average vehicle delays at the on ramp on the side road. The unit is veh/s.
- L_s is the distance between off ramp and on ramp on expressway.

The queue on on ramp will produce a certain delay to side road traffic of on ramp upstream. But considering that a part of side road traffic flow has been diverted into expressway main road at this time, the rest has existed queue because of signal control at the intersection downstream. Once queue vehicles on the on ramp dissipate, side road congestion will be relieved in a certain degree. Therefore, the delay of side road caused by expressway is considered that expressway behaves a lane to downstream intersection, the delay of expressway is computed , and delay of side road is mainly caused by the downstream intersection , is mutual independent by other lanes.
Therefore, under the first into then out condition, average delay of traffic flow is,

$$d_z = \frac{q_c d_c + q_k d_k + q_r d_r}{q_c + q_k + q_r} \qquad (8)$$

Therein, d_z is the average delays in all vehicles on expressways and side roads under the on-off ramp condition. The unit is s.

From the above model, it can be seen that expressway traffic operation state is closely related to signal circle at the downstream intersection, off ramp number, traffic volume of side road, traffic volume of expressway main road, distance between on and off ramp and traffic volume of on ramp. Among them, traffic volume parameters are a class of traffic parameters, parameter greatly affected by time is signal timing at the downstream intersection, parameter greatly affected by space is the distance between on and off ramp.

2.2. Off-on ramp group

From Figure 1(b), it can be seen that once on ramp queuing occurs, and ascend to the side road, it affects the normal operation of the side road traffic and produce corresponding queue and delay. At the same time, if the queue length of side road reaches off ramp, it will cause that vehicles of off ramp can not pull out of the expressway, and then the queue length of off ramp will be affected and expressway traffic will be disturbed.

Based on the analysis, using critical gap theory and queuing theory, the expressway delay model and side road delay model can be established based on the queue length of on and off ramp.

According to the delay model when traffic flow do not ascend to on ramp under the first into then out condition, the delay of on ramp under the first out then into condition can be calculated by

$$d_r = \frac{3600}{N} + d_h = \frac{3600}{q_k \times e^{\frac{-q_k \times 6}{3600}}} + d_h \tag{9}$$

Then queue length on on ramp is the number of vehicles entering into on ramp during the period of time between two adjacent critical gaps. The equation is $L_r = d_r \times \frac{3600}{N}$.

on time on on ramp is $t_r = \frac{q_r \times \frac{3600}{N}}{S}$.

Both queue length caused by vehicles of on ramp and queue dissipation time influence on traffic flow on side road and subsequent traffic greatly. During this time there is at least one lane traffic affected, and the influencing vehicles can pass this bottleneck after queue dissipation.

The paper assumes that the approach of off ramp is one lane, and only one lane on side road is disturbed, however, other lanes are not affected. Therefore, delay of the lane on side road can be calculated by the delay model of signal intersection. Red time is $r=d_r+t_r$, and green time is $g = \frac{q_f(d_r+t_r)}{S}$.

Average delay of the single lane on side road is

$$d_f = \frac{Sr^2}{2c(S-q)} = \frac{S(d_r+t_r)^2}{2\left(d_r+t_r+\frac{q_f(d_r+t_r)}{S}\right)(S-q_f)} \tag{10}$$

If queue length of side road is too long and queue traffic ascends to off ramp, traffic flow of off ramp entering into side road will be affected. Therefore, a certain delay can exist on off ramp and the delay is closely related to dissipation time on side road. If queue length on side road dissipates completely and there are critical gaps, traffic flow on on ramp can enter into side road.

Delay on off ramp is shown in equation 11.

Similarly, there is a certain delay on expressway main road because of traffic flow on off ramp. The delay model is closely linked with queue dissipation time of off ramp, and average delay on the right lane of expressway main road is,

$$d_k = d_c + \frac{Sd_c^2}{2(d_c+\frac{q_k d_c}{S})(S-q_k)} \tag{12}$$

Therefore, under the first out then into condition, average delay of traffic flow is,

$$d_z = \frac{q_c d_c + q_f d_f + q_k d_k + q_r d_r}{q_c+q_f+q_k+q_r} \tag{13}$$

From the above model, it can be seen that expressway traffic operation state is closely related to traffic volume of in ram, traffic volume of side road, traffic volume of expressway main road, and distance between on and off ramp. Among them, traffic volume parameters are a class of traffic parameters, there is no parameter affected by time, parameter greatly affected by space is the distance between on and off ramp.

3. Safety Analysis based on traffic operation state Expressway

According to the above research, we establish the relationship between the related traffic volume, the distance between on and off ramp and the total delay, and the total delay and the expressway safety are closely related.

Under the small traffic volume condition, vehicle speed is the key factor affecting road safety, however, under the large traffic volume condition, traffic volume and congestion degree are the important factors affecting road safety.

$$d_c = \begin{cases} d_r + t_r + \frac{q_f(d_r+t_r)}{S} + \frac{3600}{q_f \times e^{\frac{-q_f \times 6}{3600}}} + d_h \; q_f \times \left(d_r + t_r + \frac{q_f(d_r+t_r)}{S}\right) \times 7 + 20 > L_f \\ \frac{3600}{q_f \times e^{\frac{-q_f \times 6}{3600}}} + d_h q_f \times \left(d_r + t_r + \frac{q_f(d_r+t_r)}{S}\right) \times 7 + 20 \le L_f \end{cases} \tag{11}$$

When traffic volume is large, the probability of conflictions between vehicles becomes large. In the process of confluence and shunting, traffic accidents are easy to taken, such as cut rub, because of different driving technology, and road safety reduces sharply.

Compared with the urban road there is not signal intersection on expressway, but compared with the highway, the number of on and off ramp is far more than that of the highway. Hence as a relatively special type of road, the safety of expressway is mainly reflected under the large traffic volume. When the traffic volume is small, the safety of expressway is similar with that of highway, however, when the traffic volume is large, the safety of expressway is different from that of urban road because there is no signal intersection to ensure safety on expressway. Therefore, the paper mainly studies the effect of traffic congestion degree on expressway safety.

According to traffic control principle, when traffic flow ratio is less than 0.7 traffic is generally considered to be smooth, when traffic flow ratio is between 0.7 and 0.8, traffic flow begins to be in congested state, and when traffic flow ratio is more than 0.8, traffic flow is in saturation state and vehicles can not pass. It can be seen that with traffic volume increasing, road safety is changing to poorer, especially when traffic flow ratio is between 0.7 and 0.8, acceleration and deceleration behavior of a certain driver perhaps will lead to traffic accident and even the whole expressway network safety decreased.

Likewise, when on and off ramps delay increasing sharply expressway safety is reduced gradually, while when the delay is below the delay of smooth traffic flow expressway safety is relatively high. According to this principle, the paper established the model of on and off ramp delay and expressway safety.

The safety in this paper refers to probability of vehicles collision occurred. If collision probability is great the safety is poor, and if collision probability is small the safety is high. The paper argued that probability of vehicles collision occurred is mainly affected by delay and traffic flow ratio. Therefore, with delay and traffic flow ratio increasing collision probability is increasing. If traffic flow ratio is small and the congestion of on and off ramp is heavy, collision probability will be increasing, and if traffic flow ratio is great and the delay of on and off ramp is small, collision probability will be increasing too. Therefore, the safety model of accident occurrence probability based on the ramp is established. The principle is when a certain traffic flow delay occurs, the traffic flow is in congested and low speed, and it is similar to increasing some vehicles. That is to say, based on the original traffic flow, the delay is equivalent to increase some vehicles. Thus traffic volume is increased and safety is decreased. That is,

$$P(l) = \frac{q_k(1 + d_z/d_{max})}{C} = \begin{cases} \dfrac{q_k\left(1+\frac{q_c d_c + q_k d_k + q_r d_r}{\sum q \times d_{max}}\right)}{C} & l_{rc} \le l_{cmin} \\ \dfrac{q_k\left(1+\frac{q_c d_c + q_f d_f + q_k d_k + q_r d_r}{\sum q \times d_{max}}\right)}{C} & l_{cr} \le l_{rmin} \end{cases} \quad (14)$$

Therein,

- $P(l)$ is the accidents occurrence probability based on on and off ramp.
- d_z is the average delay produced by the weaving section , and the unit is s. Under the on-off ramp condition, d_z is $q_c d_c + q_k d_k + q_r d_r$, which is calculated by the delays and traffic volume of off ramp, expressway main road and on ramp. Under the off-on ramp condition, d_z is $q_c d_c + q_f d_f + q_k d_k + q_r d_r$, which is calculated by the delays and traffic volume of off ramp, expressway main road , on ramp and side road.
- $\sum q$ is the sum of all traffic flows delayed by weaving section, and the unit is *veh/h*. Under the on-off ramp condition, $\sum q$ is the total traffic flow of on-off ramp and expressway main road. Under the off-on ramp condition, $\sum q$ is the total traffic flow of on-off ramp, expressway main road and side road.
- d_{max} is the maximum delay caused by traffic flow in expressways under congestion condition, and the unit is *s*. The maximum delay value is proportional to congestion time. If the arrival traffic volume is increasing, congestion continues to deteriorate, and traffic delays continue to increase. If the arrival traffic flow is less than the departure flow, the traffic congestion begins to dissipate and the delays are decreasing gradually. Thus in order to reduce the effect of congestion time on the maximum delay, the maximum delay is calculated in the condition the queues begin to

dissipate when arrival traffic volume accumulated to the maximum leaving vehicle number. Do not considering increasing congestion as the number of arrival vehicles continues to increase in the condition of over saturation. In this assumption, it is possible to determine that the maximum delay of traffic flow is the cycle time of virtual cycle. Under the on-off ramp condition, the maximum delay $d_{max} = d_k + d_c + \frac{q_k(d_c+t_f)}{S-q_k}$. Under the off-on ramp condition, the maximum delay is $d_{max} = c = r + g = d_r + t_r + \frac{q_f(d_r+t_r)}{S}$.

- l_{rc} is the distance from the upstream on-ramp to the downstream off-ramp according to the traffic driving direction, and the unit is m.
- l_{cr} is the distance from the upstream off-ramp to the downstream on-ramp according to the traffic driving direction, and the unit is m.
- l_{cmin} is the minimum distance from the upstream on-ramp to the downstream off-ramp when the traffic flow at upstream on-ramp cannot affect the traffic flow at downstream off-ramp according to the traffic driving direction, the unit is *m*. $l_{rc} \leq l_{cmin}$ represents that the distance from the upstream on-ramp to the downstream off-ramp is less than the minimum distance and the traffic flow at on-ramp will affect the vehicles at off-ramp.
- l_{rmin} is the minimum distance from the upstream off-ramp to the downstream on-ramp when the traffic flow at upstream off-ramp cannot affect the traffic flow at downstream on-ramp according to the traffic driving direction, the unit is *m*. $l_{cr} \leq l_{rmin}$ represents that the distance from the upstream off-ramp to the downstream on-ramp is less than the minimum distance and the traffic flow at off-ramp will affect the vehicles at on-ramp. *C* is traffic capacity, and the unit is *veh/h*.

4. **Simulation verification**

As reflected factor of road traffic accident expressway safety random is obvious, simulation is not easy to achieve. Therefore, the paper assumed parameters on expressway, calculated different type of delay models at on and off ramp based on the above models, and the safety index on expressway of different types is obtained to judge whether the expressway situation assumed is consistent with the ultimate safety index, and then judge whether the model is feasible.

The paper assumed that on-off ramp group, traffic volume of single line on expressway main road is 900 *veh/h*, traffic volume of single line on side road is 600 *veh/h*, traffic volume of on ramp is 500 *veh/h*, traffic volume of off ramp is 400 *veh/h*, the distance between signal intersection of off ramp downstream and off ramp is over 300 meters and downstream signal intersection does not affect the traffic flow of the off ramp greatly. The distance between on and off ramp is only 100 meters, and the traffic flow is high. This paper would computer the safety of expressway in this condition to validate the accuracy of the new safety model.

Firstly delay on off ramp is calculated by

$$d_c = \frac{q_c + \overline{q_f}}{\overline{q_f}(\overline{q_f} - q_c)} = 30s \quad (15)$$

$$t_f = \frac{L_q}{\mu} = 30s \quad (16)$$

And delay on expressway is determined based on delay on off ramp, that is

$$d_k = d_c + \frac{Sd_c^2}{2(d_c+t_f)(S-q_k)} = 45s \quad (17)$$

$$d_{max} = d_k + \frac{q_k(d_c+t_f)}{S-q_k} = 99s \quad (18)$$

According to delay and dissipation time on off ramp, queue length on expressway is calculated by

$$q_k \times (d_c + t_f) \times 7 = 105s \quad (19)$$

That is more than 100 meters the distance between on and off ramp. It indicates that queue length on expressway ascends to the upstream on ramp, then

$$d_{r1} = \frac{S(d_k+d_c)^2}{2\left(d_k+d_c+\frac{q_k\times(d_c+t_f)}{(S-q_k)}\right)(S-q_r)} = 10.86s \quad (20)$$

$$d_r = d_k + d_{r1} = 55.86s \quad (21)$$

So the average delay of all traffic flow is,

$$d_z = \frac{q_c d_c + q_k d_k + q_r d_r}{q_c + q_k + q_r} = 44.68s \quad (22)$$

Finally, the accidents occurrence probability of expressway is calculated as 0.73.

$$P(l) = \frac{q_k(1+d_z/d_{max})}{C} = 0.73 \quad (23)$$

It can be seen that owing to the delays on the side road is not counted, the average delay of the whole traffic flow is not greatly increased. But supposed traffic flow ratio on expressway is 0.5 that is amount to the accidents occurrence probability of 50%, and at the on and off ramp, the accidents occurrence probability of expressway is 73%, which shows the degree of danger is increased by 46%, and the safety of expressway is decreased compared with the safety in the smooth flow condition.

5. Conclusions

As the very important parts of the expressway system, on and off ramps have a great effect on the operation effect of expressways. Once congestion occurs at on and off ramps, it will directly affect the safety of the expressway and vehicles. Therefore, this paper aims to analyze the influence on expressway safety in aspect of on and off ramps. Firstly, we analyzes the location design of on ramps, the length and the influences on the expressway running state of off ramp downstream traffic state. In addition, we establishes the expressway operation models to analyze delay of different matches of on and off ramps, which include off ramp, on ramp, expressway and side road delay model under the influence of the distance between on and off ramps and traffic volumes. Meanwhile, the connection between the traffic operation state and traffic safety is analyzed, and the expressway safety model based on congestion degree is established. Through simulation verification, the impact of on and off ramp on the security of the expressway is analyzed. Finally from the results it can be concluded that the delay caused by traffic of the on and off ramps can decrease the safety of expressway.

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