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16. ABSTRACT

The primary objectives of this project have been to provide technical assistance on district freeway analysis projects, enhance the FREQ model based on guidance and suggestions from Caltrans staff members, and offer three freeway analysis workshops for Caltrans staff.

Technical assistance has been provided to staff members in eleven of the twelve districts. The technical assistance took the form of providing advice and guidance on general freeway analysis issues, identifying other simulation models that could be considered for freeway investigations, and offering detailed assistance on applications of the FREQ model. During 2007 there were at least twenty-one applications in California of the FREQ model conducted by Caltrans staff members, MPOs, and contracted consultants. Six of these FREQ model applications were presented at the project's October 30, 2007 workshop and four of these FREQ model applications were presented at the project's November 1, 2007 workshop.

Several levels of FREQ model enhancements were undertaken as part of this freeway analysis project. In response to two districts, special versions of the FREQ model were developed for their unique applications. In response to requests in several other districts, minor modifications were made to the standard FREQ model version. However primary attention was given to enhance the modeling of the interaction between on-ramp and off ramp operations with mainline freeway operations.

17. KEY WORDS

Computer simulation, HOV lanes, ramp metering, on-ramp analysis, off ramp analysis, model enhancements, freeway analysis techniques, freeway design, training, and education.

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FINAL REPORT

IMPROVE FREQ MACROSCOPIC FREEWAY ANALYSIS MODEL

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ABSTRACT

This document is the final report for the two-year ITS project "Improve FREQ Macroscopic Freeway Analysis Model". It has been supported by the California Department of Transportation. The primary objectives of this project have been to provide technical assistance to eleven of the twelve Caltrans district on freeway analysis projects, enhance the FREQ model based on guidance and suggestions from Caltrans staff members, and offer three freeway analysis workshops for Caltrans staff.

EXECUTIVE SUMMARY

This document is the final report for the two-year ITS project "Improve FREQ Macroscopic Freeway Analysis Model". It has been supported by the California Department of Transportation. The primary objectives of this project have been to provide technical assistance on district freeway analysis projects, enhance the FREQ model based on guidance and suggestions from Caltrans staff members, and offer three freeway analysis workshops for Caltrans staff.

Technical assistance has been provided to staff members in eleven of the twelve districts. The technical assistance took the form of providing advice and guidance on general freeway analysis issues, identifying other simulation models that could be considered for freeway investigations, and offering detailed assistance on applications of the FREQ model. During 2007 there were at least twenty-one applications in California of the FREQ model conducted by Caltrans staff members, MPOs, and contracted consultants. Six of these FREQ model applications were presented at the project's October 30, 2007 workshop and four of these FREQ model applications were presented at the project's November 1, 2007 workshop.

Several levels of FREQ model enhancements were undertaken as part of this freeway analysis project. In response to two districts, special versions of the FREQ model were developed for their unique applications. In response to requests in several other districts, minor modifications were made to the standard FREQ model version. However primary attention was given to enhance the modeling of the interaction between on-ramp and off-ramp operations with mainline freeway operations. Two versions including this interaction were developed and presented at the workshops in November 2007 and June 2008. Refinements in the ramp-freeway interaction module for off-ramp diverge analysis and on-ramp merge analysis are described in the following two portions of this final report. This is expected to be a continuing modeling activity.

Three training workshops were held for Caltrans staff members. The first two were held in the fall of 2007 and the third was held in June 2008. A one-day training workshop was held in Los Angeles on October 30, 2007 for the southern Caltrans districts. Twenty-seven (27) individuals attended this workshop from six districts. The second one-day training workshop was held in the Bay Area on November 1, 2007 for the northern Caltrans districts. Twenty-two (22) individuals attended this workshop from four districts and headquarters. The final workshop was a state-wide two-day advanced freeway analysis workshop that was held in the Bay Area on June 18-19, 2008. Twenty-two (22) individuals attended this workshop from seven districts and headquarters.

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REFINEMENTS IN THE
RAMP-FREEWAY INTERACTION MODULE FOR
OFF-RAMP DIVERGE ANALYSIS

The FAP project staff continues to refine and extend the ramp-freeway interaction module within the FREQ model. These refinements and extensions are continuing to evolve as project staff and model beta-testers gain experience and insights in applying the enhanced versions of the FREQ model. The refinements and extensions described in this document are being implemented in the next version of the model.

Some refinements in the ramp-freeway interaction module are underway based upon our own experiences and the feedback from Caltrans beta testers of the new version of the FREQ model (version 4.11). The intent of these refinements are to reduce user input data requirements without losing realism, make corrections, and developing a structure for handling a wide-variety of merge and diverge situations.

In the next version of the FREQ model (version 4.1x) the user input data requirements have been reduced and modified. The user will need to select only two parameters: the lower limb speed-v/c curve in the adjacent lane(s) when a queue is present and the upper limb speed-v/c curve in the other lanes when a queue is present in the adjacent lane(s). Two of the previous user-supplied parameters, predicted density and predicted flow in the adjacent lane(s) when a queue is present, will be calculated by the model.

A classification and methodology for analyzing a wide variety of off-ramp diverge situations are presented in *Illustration 1*. The development of a similar classification and methodology for analyzing a wide variety of on-ramp merge situations is currently underway.

While the next version of the FREQ model (version 4.1X) will contain enhancements to the earlier version 4.11, there still remains a number of limitations (including the current work underway on on-ramp merges):

- Freeway and ramp queuing due to on-ramp merge and off-ramp diverge problems are handled as isolated not interacting queuing processes,
- Unique freeway design features upstream and/or downstream of on-ramp merge and off-ramp diverge problems are not considered,
- These enhancements have only been incorporated into the FREQPE model and only for Day-1, and
- Fine tuning of freeway-ramp interaction parameters are expected.

A classification system and accompanying methodology for analyzing various off-ramp situations are presented in *Illustration 1*. The vertical columns identify the

planned off-ramp designs to be handled by the FREQ model and are labeled as *Type A* through *Type L*. The horizontal rows provide in a step-by-step manner the methodology for analyzing the particular off-ramp design.

As used in all FREQ models, the simulation begins in the first time slice in the first subsection. The analysis continues downstream until the last subsection is reached or an off-ramp diverge problem is encountered. When the analysis for the last subsection is completed, the simulation begins again in the next time slice in the first subsection. This process continues until the analysis for the last subsection in the last time slice is completed.

If an off-ramp diverge problem is encountered, the freeway-ramp interaction module is engaged. In the case of an off-ramp diverge problem, the simulation will predict the traffic demand that wishes to exit at the off-ramp based upon the origin-destination table within the model and the user has already entered the capacity of the off-ramp as part of the original model input. The traffic demand for the off-ramp is compared with the off-ramp capacity. If the traffic demand for the off-ramp is less than the off-ramp capacity, an off-ramp diverge problem does not occur and the simulation is continued in the next downstream subsection.

If the traffic demand for the off-ramp is greater than the off-ramp capacity, the freeway-ramp interaction module is engaged. The general steps taken in simulating off-ramp diverge problems are listed below. The specific details of each analytical step for each type of off-ramp design are presented in later portions of this document.

- The excess demand that can not be served by the off-ramp in this time slice is stored in upstream adjacent lane(s) as increased density based upon freeway geometrics and will later be transferred to the next time slice for further processing.
- The predicted flow in the upstream adjacent lane(s) is set by the model as a function of the off-ramp capacity which the user has previously entered in the original input data set. Thus the user will no longer have to enter the expected flows (as was done in version 4.11).
- The capacity of the affected upstream adjacent lane(s) is assumed to be 2000 vphpl.
- A volume-to-capacity ratio in the upstream adjacent lane(s) is calculated.
- The speed in the adjacent lane(s) is determined based upon the v/c ratio and the user-specified lower limb curve for the adjacent lane(s) with queues.
- The density in the upstream adjacent lane(s) is calculated as the ratio of lane flow to lane speed. Therefore the user will not need to input the expected density (as was done in version 4.11).
- The length of the upstream queue is determined based upon the excess demand that can not be served by the off-ramp, the off-ramp design, and the calculated lane density in the adjacent lane(s) in the affected upstream subsections.

- The capacity and demand in the other freeway lanes in each affected upstream subsection are adjusted considering the number of adjacent lane(s) handling the off-ramp diverge queue and the freeway demand to be served in the adjacent lane(s).

- The free-flow speed and hence the average speed in the other freeway mainline lane(s) are reduced because of the presence of congestion in the adjacent lane(s) caused by the ramp diverge problem. This reduction is based on the user-selected free-flow speeds in the other lanes.

The off-ramp diverge design geometrics and their associated analytical steps for simulation will be described for each of the twelve types of off-ramp designs in the following sections.

TYPE A

Type A off-ramp diverge design geometrics consist of a right-side single-lane off-ramp without a lane drop. When the traffic demand for the off-ramp exceeds the off-ramp capacity, queuing and congestion caused by the off-ramp diverge problem will occur in the upstream adjacent lane to the off-ramp and will extend into affected upstream subsection(s). The analytical steps described in the following paragraphs are summarized in the second column of *Illustration 1*. The values displayed are typical values.

1) The excess demand is calculated as the difference between the off-ramp demand determined from the model's origin-destination table and the off-ramp capacity entered previously by the user, and is stored in the adjacent lane to the off-ramp side of the freeway in affected upstream subsection(s) as increased lane density and later transferred to the next time slice for further processing. [See step A7) for calculation of the length of the upstream queue.]

2) The predicted flow in the adjacent lane for each affected upstream subsection will be set equal to the off-ramp capacity already entered by the user in the original freeway geometric data. The nominal off-ramp capacity is 1500 to 1600 vph.

3) The capacity of the adjacent lane for each affected upstream subsection is assumed to be 2000 vph.

4) The volume-to-capacity ratio in the adjacent lane for each affected upstream subsection is calculated as the ratio of the predicted flow to a assumed lane capacity of 2000 vph. This ratio would be expected to be on the order of -0.75 to -0.80. The negative sign indicates that the lower-limb of the selected speed to v/c ratio curve would be used and queuing is occurring.

5) A lower-limb speed to v/c ratio curve will be used to estimate the average speed in the adjacent lane for each affected upstream subsection. It is currently thought that the lower-limb curve with a speed of 30 mph at a v/c ratio of 1.00 is most appropriate. When this curve is used, the estimated average speed will be on the order of 12-15 mph. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph with a default value of 30 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower limb speed to v/c ratio curves.

6) Density in the adjacent lane for each affected upstream subsection is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in the upstream adjacent lane would be expected to be on the order of 105 to 125 vpm.

7) The length of the queuing in the adjacent lane in the affected upstream subsection(s) would be determined based upon the lane density calculated in the previous step A6) and the excess demand unserved at the off-ramp.

For example, if the calculated adjacent lane density is 120 vpm and the excess demand in terms of number of vehicles unserved at the off-ramp is 60 vehicles, the length of the queue would be 0.5 mile or 2640 feet.

8) The capacity of the other freeway lanes for each affected upstream subsection is reduced by 2000 vph. The demand for the other freeway lanes for all affected upstream subsections is reduced by the off-ramp demand.

9) The user would select what is considered a reasonable value within the range of 50 mph to the originally entered free-flow speed for the free-flow speed in the other lanes and it would be applied within the model to each affected upstream subsection. This reduction in free-flow speed is due to the presence of the queuing in the adjacent lanes. While the default value in the program is set for 50 mph, the user may consider using a higher free-flow speed for the other lanes.

TYPE B

Type B off-ramp diverge design geometrics consist of a right-side single-lane off-ramp with a single lane drop. When the traffic demand for the off-ramp exceeds the off-ramp capacity, queuing and congestion caused by the off-ramp diverge problem will occur in the adjacent lane to the off-ramp in affected upstream subsection(s). The analytical steps described in the following paragraphs are summarized in the third column of *Illustration 1*. The values displayed are typical values.

1) The excess demand is calculated as the difference between the off-ramp demand determined from the model's origin-destination table and the off-ramp capacity entered previously by the user, and is stored in the adjacent lane to the off-ramp side of the freeway in affected upstream subsection(s) as increased lane density and later transferred to the next time slice for further processing. [See step B7) for calculation of the length of the upstream queue.]

2) The flow in the adjacent lane in each affected upstream subsection will be set equal to the off-ramp capacity already entered by the user in the original freeway geometric input data. This capacity value is normally equal to about 1800 to 2000 vph.

3) The capacity of the adjacent lane in each affected upstream subsection is assumed to be 2000 vph.

4) A volume-to-capacity ratio is calculated for the adjacent lane for each affected upstream subsection(s) as the ratio of the predicted flow to a capacity of 2000 vph. This ratio would be expected to be on the order of -0.9 to -1.00. The negative sign indicates that the lower-limb of the selected speed to v/c ratio curve would be used and queuing is occurring.

5) A lower-limb speed to v/c ratio curve will be used to estimate the average speed in the adjacent lane for each affected upstream subsection. It is currently thought that the curve with a speed of 30 mph at a v/c ratio of -1.00 will be used. When this curve is used, the estimated average speed will be on the order of 20 to 30 mph. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph with a default value of 30 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower limb speed to v/c ratio curves.

6) Density in the adjacent lane in each affected upstream subsection is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in the upstream adjacent lane would be expected to be on the order of 70 to 90 vpm.

7) The length of the queuing in the adjacent lane in upstream subsection(s) would be determined based upon the lane density calculated in the previous step B6) and the excess demand unserved at the off-ramp. For example, if the calculated adjacent lane density is 80 vpm and the excess

demand in terms of number of vehicles unserved at the off-ramp is 60 vehicles, the length of the queue would be 0.75 mile or 3960 feet.

8) The capacity of the other freeway lanes for each affected upstream subsection is reduced by 2000 vph to account for the adjacent lane handling the off-ramp diverge problem. The demand in the other freeway lanes for each affected upstream subsection is reduced by the off-ramp demand.

9) The user would select what is considered a reasonable value within the range of 50 mph to the originally entered free-flow speed for the free-flow speed in the other lanes and it would be applied within the model to all affected upstream subsections. This reduction in free-flow speed is due to the presence of the queuing in the adjacent lanes. While the default value in the program is set for 50 mph, the user may consider using a higher free-flow speed for the other lanes.

TYPE C

Type C off-ramp diverge design geometrics consist of a right-side two-lane off-ramp with a single lane drop. When the traffic demand for the off-ramp exceeds the off-ramp capacity, queuing and congestion caused by the off-ramp diverge problem will occur in the two upstream adjacent lanes to the off-ramp side of the freeway in the affected upstream subsection(s). It will be assumed that the analysis procedures for the two lanes will be the same. The analytical steps described in the following paragraphs are summarized in the fourth column of *Illustration 1*. The values displayed are typical values.

1) The excess demand in each of the two adjacent lanes is calculated as one-half of the difference between the off-ramp demand determined from the model's origin-destination table and the off-ramp capacity originally entered by the user. This excess lane demand is stored equally in each of the two adjacent lanes in affected upstream subsection(s) as increased lane densities and later transferred to the next time slice for further processing. [See step C7) for calculation of the length of the upstream queue.]

2) The flow in each of these two adjacent lanes in each of the affected upstream subsections will be set equal to one-half of the off-ramp capacity already entered by the user in the original freeway geometric input data. The off-ramp capacity value for this ramp diverge geometric is normally equal to about 3000 vph and so one-half of this amount would be 1500 vph for the flow in each of the two lanes adjacent to the off-ramp side of the freeway.

3) The capacity of each of the two adjacent lanes in each of the affected upstream subsections is assumed to be 2000 vph.

4) A volume-to-capacity ratio is calculated for each of the two adjacent lanes in each of the affected upstream subsections as the ratio of the predicted lane flow to a lane capacity of 2000 vph. This ratio would be expected to be on the order of -0.75. The negative sign indicates that the lower-limb of the selected speed to v/c ratio curve would be used.

5) A lower-limb speed to v/c ratio curve will be used to estimate the average speed in the two adjacent lanes in each of the affected upstream subsection(s). While the default value in the program is 30 mph, it is currently thought that the curve with a speed of 40 mph at a v/c ratio of -1.00 might be more appropriate for this type of off-ramp configuration. When this curve is used, the estimated average speed will be on the order of 18 mph. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower limb speed to v/c ratio curves.

6) The density in each of two adjacent lanes in each of the upstream affected subsections is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in each of the adjacent two lanes in the affected

upstream subsections would be expected to be on the order of 80 to 85 vpm.

7) The length of the queuing in each of the adjacent lanes to the off-ramp in the affected upstream subsections would be determined based upon the lane density calculated in the previous step C6) and one-half of the the excess demand unserved at the off-ramp. The one-half is because there are two adjacent lanes for the storage of the excess demand. For example, if the calculated adjacent lane density is 83 vpmpl and the excess demand in terms of number of vehicles unserved at the off-ramp is 60 vehicles or 30 vehicles per adjacent lane, the length of the queue in each of the two adjacent lanes would be 0.36 mile or 1908 feet.

8) The capacity of the other freeway lanes for all affected upstream subsections is reduced by 4000 vph due to the two adjacent lanes handling the off-ramp diverge problem. The demand in the other freeway lanes for all affected upstream subsections is reduced by the off-ramp demand.

9) The user would select what is considered a reasonable value within the range of 50 mph to the originally entered free-flow speed for the free-flow speed in the other lanes and the model would apply it to all affected upstream subsections. This reduction in free-flow speed is due to the presence of the queuing in the adjacent lanes. It is suggested that the original default value of 50 mph be used for this type of ramp diverge situation.

TYPE D

Type D off-ramp diverge design geometrics consist of a right-side two-lane off-ramp with a two lanes dropped. Queuing and congestion caused by an off-ramp diverge problem will occur in the two upstream adjacent lanes to the off-ramp. These lanes would be analyzed in a manner somewhat similar to a *Type B* off-ramp diverge design procedure described earlier. The analytical steps described in the following paragraphs are summarized in the fifth column of *Illustration 1*. The values displayed are typical values.

1) The excess demand in each of the two lanes adjacent to the off-ramp side of the freeway is calculated as being one-half of the difference between the off-ramp demand as determined by the model's origin-destination table and the off-ramp capacity previously entered by the user. This excess demand is stored equally in each of the two adjacent lanes in the affected upstream subsections as increased lane density and later transferred to the next time slice for further processing. [See step D7) for calculation of the length of the upstream queue.]

2) The flow in each of the two adjacent lanes in the affected upstream subsections will be set equal to one-half of the off-ramp capacity that has already been entered by the user in the original freeway geometric input data. This capacity value is normally equal to about 3600 to 4000 vph which results in flows of 1800 to 2000 vph in each of the two adjacent lanes.

3) The lane capacity in each of the two adjacent lanes in the affected upstream subsections is assumed to be 2000 vphpl.

4) A volume-to-capacity ratio in the two adjacent lanes for the affected upstream subsections is calculated for each upstream affected subsection as the ratio of the predicted lane flow to the lane capacity of 2000 vph. This ratio would be expected to be on the order of 0.90 to -1.00 (the negative sign indicates that the lower-limb of the speed to v/c ratio curves would be used and queuing is occurring).

5) A lower-limb speed to v/c ratio curve will be used to estimate the average speed in the two adjacent lanes on the off-ramp side of the freeway in the affected upstream subsections. It is currently thought that the curve with a speed of 30 mph at a v/c ratio of -1.00 will be used. When this curve is used, the estimated average speed will be on the order of 20 to 30 mph. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph with a default value of 30 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower limb speed to v/c ratio curves.

6) Density in each of the two upstream adjacent lanes in the affected upstream subsections is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in each of the two upstream adjacent lanes would be expected to be on the order of 70 to 90 vpm.

7) The length of the queuing in each of the two adjacent upstream lanes would be determined based upon the lane density calculated in the previous step D6) and one-half of the excess demand unserved at the off-ramp. The one-half is because there are two adjacent lanes for the storage of the excess demand. For example, if the calculated adjacent lane density is 80 vpmpl and the excess demand in terms of number of vehicles unserved at the off-ramp is 60 vehicles or 30 vehicles per adjacent lane, the length of the queue in each of the two adjacent lanes would be 0.375 mile or 1980 feet.

8) The capacity of the other freeway lanes for all affected upstream subsections is reduced by 4000 vph due to the two adjacent lanes handling the off-ramp diverge problem. The demand in the other freeway lanes for all affected upstream subsections is reduced by the off-ramp demand.

9) The user would select what is considered a reasonable value within the range of 50 mph to the originally entered free-flow speed for the free-flow speed in the other lanes. This reduction in free-flow speed is due to the presence of the queuing in the adjacent lanes and is applied to all affected upstream subsections. A default free-flow speed of 50 mph is suggested for this type of off-ramp design.

TYPE E

Type E off-ramp diverge design geometrics consist of a right-side three-lane connector with two-lanes being dropped on the freeway. When the traffic demand for the off-ramp exceeds the off-ramp capacity, queuing and congestion caused by the off-ramp diverge problem will occur in the three upstream adjacent lanes to the off-ramp side of the freeway. It will be assumed that the analysis procedures for each of the three lanes will be the same. The procedure is somewhat similar to the *Type C* off-ramp configuration procedure. The analytical steps described in the following paragraphs are summarized in the sixth column of *Illustration 1*. The values displayed are typical values.

1) The excess demand in each of the three lanes is calculated as one-third of the difference between the off-ramp demand determined from the model's origin-destination table and the off-ramp capacity originally entered by the user. This excess lane demand is stored equally in each of the three adjacent lanes as increased lane densities in the affected upstream subsection(s) and later transferred to the next time slice for further processing. [See step E7) for calculation of the length of the upstream queue.]

2) The flow in each of these three adjacent lanes in the affected upstream subsections will be set equal to one-third of the off-ramp capacity already entered by the user in the original freeway geometric input data. The off-ramp capacity value for this ramp diverge geometric is normally equal to about 5000 vph and so one-third of this amount would be about 1700 vph for the flow in each of the three lanes adjacent to the off-ramp side of the freeway.

3) The capacity of each of the three lanes in the affected upstream subsection(s) is assumed to be 2000 vphpl.

4) A volume-to-capacity ratio is calculated for each of the three lanes in the affected upstream subsection(s) as the ratio of the predicted lane flow to a lane capacity of 2000 vph. This ratio would be expected to be on the order of -0.85 (the negative sign indicates that the lower-limb of the speed to v/c ratio curves would be used).

5) A lower-limb speed to v/c ratio curve will be used to estimate the average speed in the lanes closest to the off-ramp in the upstream subsection(s). While the default value in the program is 30 mph, it is currently thought that the curve with a speed of 40 mph at a v/c ratio of -1.00 might be more appropriate for this type of off-ramp configuration. When this curve is used, the estimated average speed will be on the order of 23 mph. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower limb speed to v/c ratio curves.

6) The density in each of three adjacent lanes in the upstream affected subsection(s) is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous

paragraphs, the density in each of the adjacent two lanes in the affected upstream subsections would be expected to be on the order of 75 to 80 vpmpl.

7) The length of the queuing in each of the three adjacent lanes to the off-ramp in the affected upstream subsections would be determined based upon the lane density calculated in the previous step E6) and one-third of the excess demand unserved at the off-ramp. The one-third is due to the fact that there are three lanes for the storage of excess demand. For example, if the calculated adjacent lane density is 80 vpmpl and the excess demand in terms of number of vehicles unserved at the off-ramp is 60 vehicles or 20 vehicles per adjacent lane, the length of the queue in each of the two adjacent lanes would be 0.25 mile or 1320 feet.

8) The capacity of the other freeway lanes for all affected upstream subsections is reduced by 6000 vph to account for the three adjacent lanes that handle the off-ramp diverge problem. The demand in the other freeway lanes for all affected upstream subsections is reduced by the off-ramp demand.

9) The user would select what is considered a reasonable value within the range of 50 mph to the originally entered free-flow speed for the free-flow speed of the other lanes due to the queuing in the adjacent lanes for all affected upstream subsections. This reduction in free-flow speed is due to the presence of the queuing in the adjacent lanes. It is suggested that the original default value of 50 mph be used for this type of ramp diverge situation.

TYPE F

Type F off-ramp diverge design geometrics consist of a right-side three-lane connector with three lanes being dropped. Queuing and congestion caused by an off-ramp diverge problem will occur in the three upstream adjacent lanes to the connector. These lanes would be analyzed in a manner somewhat similar to a *Type D* off-ramp diverge design procedure described earlier. The analytical steps described in the following paragraphs are summarized in the seventh column of *Illustration 1*. The values displayed are typical values.

1) The excess demand in each of the three lanes adjacent to the off-ramp side of the freeway is calculated as being one-third of the difference between the off-ramp demand as determined from the model's origin-destination table and the off-ramp capacity previously provided by the user. This excess lane demand is stored equally in each of the three adjacent lanes in the affected upstream subsections as increased lane density and later transferred to the next time slice. [See step F7) for calculation of the length of the upstream queue.]

2) The flow in each of the three adjacent lanes in the affected upstream subsections will be set equal to one-third of the off-ramp capacity that has already been entered by the user in the original freeway geometric input data. This capacity value is normally equal to about 5400 to 6000 vph which results in flows of 1800 to 2000 vph in each of the three adjacent lanes.

3) The lane capacity in each of the three adjacent lanes in the affected upstream subsection(s) is assumed to be 2000 vph.

4) A volume-to-capacity ratio is calculated for the three adjacent lanes in each upstream affected subsection as the ratio of the predicted flow to a capacity of 2000 vph. This ratio would be expected to be on the order of 0.90 to -1.00 (the negative sign indicates that the lower-limb of the speed to v/c ratio curves would be used and queuing is occurring).

5) A lower-limb speed to v/c ratio curve will be used to estimate the average speed in the three adjacent lanes on the off-ramp side of the freeway in the affected upstream subsections. It is currently thought that the curve with a speed of 30 mph at a v/c ratio of -1.00 will be used. When this curve is used, the estimated average speed will be on the order of 20 to 30 mph. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph with a default value of 30 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower limb speed to v/c ratio curves.

6) Density in each of the three upstream adjacent lanes in the affected upstream subsections is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in each of the three upstream adjacent lanes would be expected to be on the order of 70 to 90 vpmpl.

7) The length of the queuing in each of the three adjacent upstream lanes would be determined based upon the lane density calculated in the

previous step F6) and one-third of the excess demand unserved at the off-ramp. The one-third is due to the fact that there are three lanes for the storage of excess demand. For example, if the calculated adjacent lane density is 80 vpmpl and the excess demand in terms of number of vehicles unserved at the off-ramp is 60 vehicles or 20 vehicles per adjacent lane, the length of the queue in each of the two adjacent lanes would be 0.25 mile or 1320 feet.

8) The capacity of the other freeway lanes for all affected upstream subsections is reduced by 6000 vph to account for the adjacent lanes handling the off-ramp diverge problem. The demand in the other freeway lanes for all affected upstream subsections is reduced by the off-ramp demand.

9) The user would select what is considered a reasonable value within the range of 50 mph to the originally entered free-flow speed for the free-flow speeds in the other lanes for all affected upstream subsections. This reduction in free-flow speed is due to the presence of the queuing in the adjacent lanes. A default free-flow speed of 50 mph is suggested for this type of off-ramp design.

TYPE G

Type G off-ramp diverge design geometrics consist of a left-side single-lane off-ramp without a lane drop. When the traffic demand for the off-ramp exceeds the off-ramp capacity, queuing and congestion caused by the off-ramp diverge problem will occur in the upstream adjacent lane to the off-ramp. The analytical steps are summarized in the eighth column of *Illustration 1*.

Little information is available about the effects of left-side off-ramp diverge problems on upstream freeway subsections. There is a general consensus that left-side ramp diverge problems have a greater adverse effect on upstream freeway subsections than right-side off-ramps. For purposes of the next version of the FREQ model, it will be assumed that the analytical process will be the same as for the corresponding right-side off-ramp design. However the user will have the flexibility in selecting the off-ramp capacity, the lower limb speed-v/c ratio lower-limb curve, and the reduction in free-flow speed for the other lanes.

TYPE H

Type H off-ramp diverge design geometrics consist of a left-side single-lane off-ramp with a single lane drop. When the traffic demand for the off-ramp exceeds the off-ramp capacity, queuing and congestion caused by the off-ramp diverge problem will occur in the upstream adjacent lane to the off-ramp. The analytical steps are summarized in the ninth column of *Illustration 1*.

Little information is available about the effects of left-side off-ramp diverge problems on upstream freeway subsections. There is a general consensus that left-side ramp diverge problems have a greater adverse effect on upstream freeway subsections than right-side off-ramps. For purposes of the next version of the FREQ model, it will be assumed that the analytical process will be the same as for the corresponding right-side off-ramp design. However the user will have the flexibility in selecting the off-ramp capacity, the lower limb speed-v/c ratio lower-limb curve, and the reduction in free-flow speed for the other lanes.

TYPE I

Type I off-ramp diverge design geometrics consist of a left-side two-lane off-ramp with a single lane drop. When the traffic demand for the off-ramp exceeds the off-ramp capacity, queuing and congestion caused by the off-ramp diverge problem will occur in the two upstream adjacent lanes to the off-ramp. The analytical steps are summarized in the tenth column of *Illustration* 1.

Little information is available about the effects of left-side off-ramp diverge problems on upstream freeway subsections. There is a general consensus that left-side ramp diverge problems have a greater adverse effect on upstream freeway subsections than right-side off-ramps. For purposes of the next version of the FREQ model, it will be assumed that the analytical process will be the same as for the corresponding right-side off-ramp design. However the user will have the flexibility in selecting the off-ramp capacity, the lower limb speed-v/c ratio lower-limb curve, and the reduction in free-flow speed for the other lanes.

TYPE J

Type J off-ramp diverge design geometrics consist of a left-side two-lane off-ramp with a two lanes dropped. Queuing and congestion caused by anoff-ramp diverge problem will occur in the two upstream adjacent lanes to the off-ramp. The analytical steps are summarized in the eleventh column of *Illustration 1*.

Little information is available about the effects of left-side off-ramp diverge problems on *f* freeway subsections. There is a general consensus that left-side ramp diverge problems have a greater adverse effect on upstream freeway subsections than right-side off-ramps. For purposes of the next version of the FREQ model, it will be assumed that the analytical process will be the same as for the corresponding right-side off-ramp design. However the user will have the flexibility in selecting the off-ramp capacity, the lower limb speed-v/c ratio lower-limb curve, and the reduction in free-flow speed for the other lanes.

Type K

Type K off-ramp diverge design geometrics consist of a left-side three-lane connector with two-lanes being dropped on the freeway. Queuing and congestion caused by the off-ramp diverge problem will occur in the three upstream adjacent lanes to the off-ramp. The analytical steps are summarized in the twelfth column of *Illustration 1*.

Little information is available about the effects of left-side off-ramp diverge problems on upstream freeway subsections. There is a general consensus that left-side ramp diverge problems have a greater adverse effect on upstream freeway subsections than right-side off-ramps. For purposes of the next version of the FREQ model, it will be assumed that the analytical process will be the same as for the corresponding right-side off-ramp design. However the user will have the flexibility in selecting the off-ramp capacity, the lower limb speed-v/c ratio lower-limb curve, and the reduction in free-flow speed for the other lanes.

Type L

Type L off-ramp diverge design geometrics consist of a left-side three-lane connector with three lanes being dropped. Queuing and congestion caused by an off-ramp diverge problem will occur in the three upstream adjacent lanes to the connector. The analytical steps are summarized in the thirteenth column of *Illustration 1*.

Little information is available about the effects of left-side off-ramp diverge problems on upstream freeway subsections. There is a general consensus that left-side ramp diverge problems have a greater adverse effect on upstream freeway subsections than right-side off-ramps. For purposes of the next version of the FREQ model, it will be assumed that the analytical process will be the same as for the corresponding right-side off-ramp design. However the user will have the flexibility in selecting the off-ramp capacity, the lower limb speed-v/c ratio lower-limb curve, and the reduction in free-flow speed for the other lanes.

ILLUSTRATION 1   OFF-RAMP STEPS OF ANALYSIS BY TYPE OF OFF-RAMP DESIGN (Revised)

OFF-RAMP STEPS OF ANALYSIS BY TYPE OF OFF-RAMP DESIGN	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E	TYPE F	TYPE G **	TYPE H **	TYPE I **	TYPE J **	TYPE K **	TYPE L **
ADJACENT LANE POSITION Right (RS) or Left (LS) side	RS	RS	RS	RS	RS	RS	LS	LS	LS	LS	LS	LS
UPSTREAM FREEWAY LANES (N)	N	N	N	N	N	N	N	N	N	N	N	N
NUMBER OF OFF-RAMP LANE(S) (1, 2, 3)	1	1	2	2	3	3	1	1	2	2	3	3
DOWNSTREAM FREEWAY LANES (N, N-1, N-2, N-3)	N	N-1	N-1	N-2	N-2	N-3	N	N-1	N-1	N-2	N-2	N-3
UPSTREAM LANES AFFECTED (1, 2, 3)	1	1	2	2	3	3	1	1	2	2	3	3
1) STORING EXCESS DEMAND ADJACENT LANE(S)	*	*	*	*	*	*	*	*	*	*	*	*
2) PREDICTED LANE FLOW (vphpl) ADJACENT LANE(S)	1500 to 1600	1800 to 2000	1500	1800 to 2000	1700	1800 to 2000	1500 to 1600	1800 to 2000	1500	1800 to 2000	1700	1800 to 2000
3) PREDICTED LANE CAPACITY ADJACENT LANE(S)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
4) CALCULATING V/C RATIO ADJACENT LANE(S)	-0.75 to -0.80	-0.9 to -1.0	-0.75	-0.9 to -1.0	-0.85	-0.9 to -1.0	-0.75 to -0.80	-0.9 to -1.0	-0.75	-0.9 to -1.0	-0.85	-0.9 to -1.0
5) LOWER-LIMB CURVE AND AVERAGE SPEED IN ADJACENT LANE	30 / 12 to 15	30 / 20 to 30	40 / 18	30 / 20 to 30	40 / 23	30 / 20 to 30	30 / 12 to 15	30 / 20 to 30	40 / 18	30 / 20 to 30	40 / 23	30 / 20 to 30
6) ESTIMATED LANE DENSITY ADJACENT LANE(S)	105 to 125	70 to 90	80 to 85	70 to 90	75 to 80	70 to 90	105 to 125	70 to 90	80 to 85	70 to 90	75 to 80	70 to 90
7) CALCULATING QUEUE LENGTH ADJACENT LANE(S)	*	*	*	*	*	*	*	*	*	*	*	*
8) CAPACITY & DEMAND ADJUSTMENT OTHER FREEWAY LANES	-2000 ***	-2000 ***	-4000 ***	-4000 ***	-6000 ***	-6000 ***	-2000 ***	-2000 ***	-4000 ***	-4000 ***	-6000 ***	-6000 ***
9) FREE-FLOW SPEED ADJUSTMENT OTHER FREEWAY LANES	60	60	50	50	50	50	50	50	50	50	50	50

* See Text for Queue Length Calculation
**See Text for Left-Side Ramp Adjustments
*** Deduct Adjacent Lane(s) Demand

SOME REFINEMENTS IN THE RAMP-FREEWAY INTERACTION MODULE FOR *ON-RAMP* MERGE ANALYSIS

This document accompanies the earlier one dealing with refinements to the off-ramp diverge analysis (fap09-18.doc). This document deals with refinements to the on-ramp merge analysis. The refinements and extensions described in this document are planned for implementation in the next version of the model.

These refinements resulted from comments from Caltrans beta testers of the new version of the FREQ model (version 4.11) and further research by the project staff. The intent of these refinements are to reduce user input requirements without losing realism, make corrections and add clarity to the supporting documentation, and develop a structure for handling a wide-variety of on-ramp merge situations.

In the next version of the FREQ model (version 4.1x) the user input data requirements have been reduced and modified. The user will need to select only two parameters: the lower limb speed-v/c curve in the adjacent lane(s) when a queue is present and the upper limb speed-v/c curve in the other lane(s) when a queue is present in the adjacent lane(s). Two of the previous user-supplied parameters, predicted density and predicted flow in the adjacent lane(s) when a queue is present, will be calculated by the model.

A classification and methodology for analyzing a wide-variety of on-ramp merge situations is presented in Illustration 1. This classification and methodology is similar and compatible with the earlier one for off-ramp situations.

While the next version of the FREQ model (version 4.1X) will contain enhancements to the earlier version 4.11, there still remain a number of limitations:

- Freeway and ramp queuing due to on-ramp merge problems are handled as isolated not interacting queuing processes,
- Unique freeway design features upstream and downstream of the on-ramp merge problem are not considered,
- These enhancements have only been incorporated into the FREQPE model and only for Day -1, and
- Fine tuning of ramp-freeway interaction parameters is expected.

A classification system and accompanying methodology for analyzing various on-ramp situations are presented in Illustration 1. The vertical columns identify the planned on-ramp designs to be handled by the FREQ model and are labeled as Type A through Type L. The horizontal rows provide in a step-by-step manner the methodology for analyzing the particular on-ramp design.

As employed in all FREQ models, the simulation begins in the first time slice in the first subsection. The analysis continues downstream until the last subsection is reached or an on-ramp merge problem is encountered. The ramp-freeway interaction module simulates the effects of the on-ramp merge problem. The analysis continues in the same manner to downstream subsections. When the analysis for the last subsection is completed, the simulation begins again in the next time slice in the first subsection. This process continues until the analysis for the last subsection in the last time slice is completed.

The on-ramp merge design geometrics and their associated analytical steps for simulation within the ramp-freeway interaction module are described for each of the twelve types of on-ramp designs in the following sections.

TYPE A

Type A on-ramp merge design geometrics consist of a right-side single-lane on-ramp without a freeway lane being added. The analytical steps undertaken to simulate the effects of on-ramp merge problems are described below as three series of analytical steps.

- The first series of steps are undertaken to determine whether there is an on-ramp merge problem, and if so, whether it affects the upstream adjacent freeway lane, the on-ramp, or both. This series of steps is referred to as the preliminary series of steps.

- The second series of steps are undertaken to analyze the upstream adjacent freeway lane and the other freeway lanes in the event the on-ramp merge problem affects upstream freeway operations. This series of steps is referred to as the freeway series of steps.

- The third and final series of steps are undertaken to re-simulate the on-ramp performance in the event the on-ramp proper capacity constraint and/or the on-ramp merge problem affects the on-ramp operations. This series of steps is referred to as the on-ramp series of steps.

1) PRELIMINARY SERIES OF STEPS

The following preliminary series of steps are initially undertaken as described in the following paragraphs.

a) The traffic demand in the adjacent freeway lane just upstream of the on-ramp is calculated based upon the model's origin-destination table and the freeway lane distribution algorithm.

b) The traffic demand on the on-ramp proper is calculated based upon the model's origin-destination table. The traffic demand from the on-ramp that reaches the on-ramp merge area is limited by the capacity on the on-ramp proper previously entered by the user. The revised default value for the on-ramp proper capacity has now been increased to 2000 vphpl since merge analysis procedures have now been addressed for all types of on-ramps.

c) The user has previously entered the capacity of the merge lane that serves both freeway and on-ramp traffic. The default value is 2400 vph.

d) The sum of the demands in the adjacent freeway lane just upstream of the on-ramp and the demand from the on-ramp that reaches the on-ramp merge area is compared with the user-specified merge lane capacity.

e) If the sum of the demands is less than the user-specified merge lane capacity, there is no on-ramp merge problem and the ramp-freeway interaction module is not further engaged.

f) If the sum of the two demands is greater than the user-specified merge lane capacity, there will be queuing either in the adjacent lane just upstream of the on-ramp, on the on-ramp, or in both.

g) To determine where the queuing will take place, additional analysis is required. The first step is to assign one-half of the available user-specified merge lane capacity for the traffic in the adjacent freeway lane just

upstream of the on-ramp and the other one-half of the specified merge lane capacity for the traffic that reaches the on-ramp merge area from the on-ramp lane. Assuming the default merge lane capacity of 2400 vph, one-half of the merge lane capacity would be 1200 vph.

h) If either the freeway or ramp lane demand is less than one-half the user-specified merge lane capacity, the on-ramp merge does not have an adverse effect on that particular lane. Under this condition, the freeway or ramp lane flow will be equal to its lane demand. The excess unused capacity is re-assigned to the other lane.

i) The other lane will have a queue and the excess demand will be equal to the difference between the lane's demand entering the on-ramp merge area and the sum of the original assigned one-half of the merge lane capacity plus the re-assigned excess capacity from the other lane. The lane flow will be equal to one-half of the merge lane capacity plus the re-assigned excess capacity from the other lane.

j) If both the freeway and ramp lane demands are greater than one-half the user-specified merge lane capacity, there will be a queue in each of the lanes and there is no excess capacity to be re-assigned to the other lane.

k) The excess demand in each of the two lanes is calculated as the difference between the calculated lane demand and one-half of the merge lane capacity and the flow in the each of the two lanes is equal to one-half the merge lane capacity.

2) FREEWAY SERIES OF STEPS

The following freeway series of steps are undertaken as described in the following paragraphs.

a) If there is excess demand in the upstream adjacent freeway lane due to the on-ramp merge problem, the following steps are undertaken to simulate the effect of the excess demand on upstream freeway subsection(s) performance in both the adjacent lane as well as in the other freeway lanes. After simulation of this time slice, the excess demand is transferred to the next time slice for further processing.

b) The capacity of the upstream adjacent freeway lane is assumed to be 2000 vph and thus the maximum flow in the upstream adjacent freeway lane would be 2000 vph.

c) As stated earlier, the minimum flow in the upstream adjacent freeway lane is set equal to one-half of the on-ramp merge capacity. Assuming the default merge lane capacity of 2400 vph, the minimum flow would be 1200 vph.

d) The volume-to-capacity ratio is computed and would vary between -0.60 and -1.00 depending upon the quantity of traffic entering from the on-ramp. The negative sign indicates that the lower-limb of the user-selected speed to v/c ratio curve would be used when queuing is occurring.

e) The lower-limb speed to v/c ratio curve will be used to estimate the average speed in the adjacent lane for each affected upstream subsection. It is

currently thought that the lower-limb curve with a speed of 30 mph at a v/c ratio of -1.00 is most appropriate.

f)   When this curve is used, the calculated average speed will be on the order of 8 to 30 mph depending upon the v/c ratio. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph with a default value of 30 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower-limb speed to v/c ratio curves.

g)   Density in the upstream adjacent freeway lane for each affected upstream subsection is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in the upstream adjacent freeway lane would be expected to be on the order of 67 vpmpl to 150 vpmpl.

h)   The length of the queuing in the adjacent freeway lane in the affected upstream subsection(s) would be calculated as the ratio of the excess demand to the calculated lane density. For example, if the excess demand is 50 vehicles and the calculated adjacent freeway lane density is 100 vpmpl, the length of the queue would extend 0.5 miles or 2640 feet upstream of the on-ramp in the adjacent freeway lane.

i)   The capacity of the other freeway lanes for each affected upstream subsection is reduced by 2000 vph. The demand for the other freeway lanes for all affected upstream subsection(s) is reduced by the assigned demand in the adjacent freeway lane.

j)   The occurrence of the queuing in the upstream adjacent freeway lane will cause a reduction in average speeds in the other freeway lanes. This is accomplished in the simulation by the user selecting a reduced free-flow speed and the model selecting the accompanying speed to v/c ratio upper-limb curve to estimate the average speed in the other freeway lanes. While the default free-flow speed value in the program is set for 50 mph, the user can select any free-flow speed between 50 mph and the previously entered free-flow speed for the other freeway lanes when there is no queuing in the adjacent freeway lane.

3) ON-RAMP SERIES OF STEPS

The following on-ramp series of steps are undertaken as described in the following paragraphs. One series of steps considers the capacity on the on-ramp proper and the other considers the capacity of the merge lane.

a) The first step is to compare the on-ramp demand with the user-specified capacity on the ramp lane proper.

- The default on-ramp proper capacity has been increased from 1500 to 2000 vph because merge analysis has now been extended to all appropriate types of on-ramp merge situations.

- If the on-ramp demand is less than the on-ramp proper capacity, there is no queue at the entrance to the on-ramp and all of the on-ramp demand can reach the freeway on-ramp merge point.

- If the demand is greater than the capacity, there is a queue at the entrance to the on-ramp and the demand that can reach the freeway on-ramp merge point is limited to the on-ramp capacity.

- Any excess demand at the entrance to the on-ramp is re-assigned to the next time slice.

b) The second step is to compare the on-ramp demand that can reach the freeway ramp merge point with the allocated capacity for the ramp lane at the freeway ramp merge point.

- The allocated capacity for the ramp lane at the freeway ramp merge point depends on whether there is excess capacity in the upstream freeway lane.

- If there is no excess capacity available in the upstream adjacent freeway lane, the capacity for the ramp lane at the freeway ramp merge point would be equal to one-half of the user-specified freeway ramp merge capacity.

- If there is excess capacity available in the upstream freeway lane, the capacity for the ramp lane at the freeway ramp merge point would be equal to one-half of the user-specified freeway ramp merge capacity plus the transferred excess capacity from the adjacent freeway lane.

- Any excess demand at the freeway on-ramp merge is transferred to the next time slice.

c) Queuing and associated delays may occur at the entrance to the on-ramp and/or on the on-ramp entering the freeway ramp merge. These analyses are current handled within the FREQ model using queuing analysis techniques.

TYPE B

Type B on-ramp design geometrics consist of a right-side single-lane on-ramp with a single freeway lane being added. Essentially the freeway traffic in the upstream adjacent freeway lane does not merge with the single-lane on-ramp traffic and each traffic stream has its own lane at the on-ramp merge location. The default capacity value for the on-ramp proper is 2000 vph.

While merging does not actually occur, there will likely be more lane changing downstream of the on-ramp due to some on-ramp traffic wishing to move into the left-lanes of the freeway as they become freeway through traffic and some upstream adjacent lane traffic wishing to move to the downstream far right-side added lane for exiting at downstream right-side off-ramp(s). Depending primarily on the distance to downstream off-ramp(s) and the downstream off-ramp demand(s), the capacity of the downstream subsection(s) may be reduced due to these lane-changing or weaving movements.

The user should either engage the weaving analysis in the model which automatically may reduce the downstream subsection(s) capacity to account for the weaving effect and/or manually reduce the downstream subsection capacity based upon other means.

TYPE C

Type C on-ramp merge design geometrics consist of a right-side two-lane on-ramp with a single freeway lane being added. The analytical steps undertaken to simulate the effects of this type of on-ramp design is similar to the one described above as Type A and consist of the following three series of analytical steps.

- The first series of steps are undertaken to determine whether there is an on-ramp merge problem, and if so, whether it affects the upstream adjacent freeway lane, the on-ramp, or both. This series of steps is referred to as the preliminary series of steps.

- The second series of steps are undertaken to analyze the upstream adjacent freeway lane and the other freeway lanes in the event the on-ramp merge problem affects upstream freeway operations. This series of steps is referred to as the freeway series of steps.

- The third and final series of steps are undertaken to re-simulate the on-ramp in the event the on-ramp merge problem affects the on-ramp operations. This series of steps is referred to as the on-ramp series of steps.

1) PRELIMINARY SERIES OF STEPS

The preliminary series of steps are similar with those for the Type A on-ramp except as noted below.

a) The traffic demand in the adjacent freeway lane just upstream of the on-ramp is calculated based upon the model's origin-destination table and the freeway lane distribution algorithm.

b) The traffic demand on the on-ramp proper is calculated based upon the model's origin-destination table. The traffic demand from the on-ramp proper that reaches the on-ramp merge area is limited by the capacity on the on-ramp proper previously entered by the user. The revised default value for the on-ramp proper capacity has now been increased to 2000 vphpl since merge analysis procedures had now been addressed for all types of on-ramps. The traffic demand that can reach the on-ramp merge area from the ramp lane adjacent to the freeway (the left-most lane of the on-ramp) is assumed to be forty percent (40%) of the total two-lane on-ramp demand that can reach the freeway ramp merge point.

c) The user has previously entered the capacity of the merge lane that serves both freeway and on-ramp traffic. The default value is 2400 vph.

d) The sum of the demands in the adjacent freeway lane just upstream of the on-ramp and the demand from the on-ramp that reaches the on-ramp area in the ramp lane adjacent to the freeway is compared with the user-specified merge lane capacity.

e) If the sum of the demands is less than the user-specified merge lane capacity, there is no on-ramp merge problem and the ramp-freeway interaction module is not further engaged.

f) It the sum of the two demands is greater than the user-specified merge lane capacity, there will be queuing either in the adjacent freeway lane just

upstream of the on-ramp, on the on-ramp lane adjacent to the freeway, or in both.

g) To determine where the queuing will take place, additional analysis is required. The first step is to assign one-half of the available user-specified merge lane capacity for the traffic in the adjacent freeway lane just upstream of the on-ramp and the other one-half of the specified merge lane capacity for the traffic that reaches the on-ramp merge area from the on-ramp in the ramp lane adjacent to the freeway. Assuming the default merge lane capacity of 2400 vph, one-half of the merge lane capacity would be 1200 vph.

h) If either the demand in the adjacent freeway lane or the on-ramp lane adjacent to the freeway is less than one-half the user-specified merge lane capacity, the on-ramp merge does not have an adverse effect on that particular lane. Under this condition, the freeway or ramp lane flow will be equal to the lane demand. The excess unused capacity is re-assigned to the other lane.

i) The other lane will have a queue and the excess demand will be equal to the difference between the lane's demand entering the on-ramp merge area and the sum of the original assigned one-half of the merge lane capacity plus the re-assigned excess capacity from the other lane. The lane flow will be equal to one-half of the merge lane capacity plus the re-assigned excess capacity from the other lane.

j) If the demand in both the freeway lane adjacent to the on-ramp and the on-ramp lane adjacent to the freeway are greater than one-half the user-specified merge lane capacity, there will be a queue in each of the lanes and there is no excess capacity to be re-assigned to the other lane.

k) The excess demand in each of the two lanes is calculated as the difference between the calculated lane demand and one-half of the merge lane capacity and the flow in each of the two lanes is equal to one-half the merge lane capacity.

2) FREEWAY SERIES OF STEPS

The following freeway series of steps are undertaken as described in the following paragraphs.

a) If there is excess demand in the upstream adjacent freeway lane due to the on-ramp merge problem, the following steps are undertaken to simulate the effect of the excess demand on upstream freeway subsection(s) performance in both the adjacent lane as well as in the other freeway lanes. After simulation of this time slice, the excess demand is transferred to the next time slice for further processing.

b) The capacity of the upstream adjacent freeway lane is assumed to be 2000 vph and thus the maximum flow in the upstream adjacent freeway lane would be 2000 vph.

c) As stated earlier, the minimum flow in the upstream adjacent freeway lane is set equal to one-half of the on-ramp merge capacity. Assuming the

default merge lane capacity of 2400 vph, the minimum flow would be 1200 vph.

d) The volume-to-capacity ratio is computed and would vary between -0.60 and -1.00 depending upon the quantity of traffic entering from the on-ramp. The negative sign indicates that the lower-limb of the user-selected speed to v/c ratio curve would be used when queuing is occurring.

e) The lower-limb speed to v/c ratio curve will be used to estimate the average speed in the adjacent lane for each affected upstream subsection. It is currently thought that the lower-limb curve with a speed of 30 mph at a v/c ratio of -1.00 is most appropriate.

f) When this curve is used, the calculated average speed will be on the order of 8 to 30 mph depending upon the v/c ratio. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph with a default value of 30 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower-limb speed to v/c ratio curves.

g) Density in the upstream adjacent freeway lane for each affected upstream subsection is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in the upstream adjacent freeway lane would be expected to be on the order of 67 vpmpl to 150 vpmpl.

h) The length of the queuing in the adjacent freeway lane in the affected upstream subsection(s) would be calculated as the ratio of the excess demand to the calculated lane density. For example, if the excess demand is 50 vehicles and the calculated adjacent freeway lane density is 100 vpmpl, the length of the queue would extend 0.5 miles or 2640 feet upstream of the on-ramp in the adjacent freeway lane.

i) The capacity of the other freeway lanes for each affected upstream subsection is reduced by 2000 vph. The demand for the other freeway lanes for all affected upstream subsection(s) is reduced by the assigned demand in the adjacent freeway lane.

j) The occurrence of the queuing in the upstream adjacent freeway lane will cause a reduction in average speeds in the other freeway lanes. This is accomplished in the simulation by the user selecting a reduced free-flow speed and the model selecting the accompanying speed to v/c ratio upper-limb curve to estimate the average speed in the other freeway lanes. While the default free-flow speed value in the program is set for 50 mph, the user can select any free-flow speed between 50 mph and the previously entered free-flow speed for the other freeway lanes when there is no queuing in the adjacent freeway lane.

3) ON-RAMP SERIES OF STEPS

The following on-ramp series of steps are undertaken as described in the following paragraphs. One series of steps considers the capacity on the on-ramp proper and the other considers the capacity of the merge lane.

a) The first step is to compare the on-ramp demand with the user-specified capacity on the ramp lane proper.

- The default on-ramp proper capacity has been increased from 3000 to 4000 vph because merge analysis has now been extended to all appropriate types of on-ramp merge situations.
- If the on-ramp demand is less than the on-ramp proper capacity, there is no queue at the entrance to the on-ramp and all of the on-ramp demand can reach the freeway on-ramp merge point.
- If the demand is greater than the capacity, there is a queue at the entrance to the on-ramp and the demand that can reach the freeway on-ramp merge point is limited to the on-ramp capacity.
- Any excess demand at the entrance to the on-ramp is transferred to the next time slice.

b) The second step is to compare the on-ramp demand that can reach the freeway ramp merge in the ramp lane adjacent to the freeway with the allocated capacity for that ramp lane at the freeway ramp merge point.

- The on-ramp demand assigned to the ramp lane adjacent to the freeway is forty percent (40%) of the total on-ramp demand that can reach the freeway ramp merge point.
- The allocated capacity for the ramp lane adjacent to the freeway at the freeway ramp merge point depends on whether there is excess capacity in the upstream adjacent freeway lane.
- If there is no excess capacity available in the upstream adjacent freeway lane, the capacity for the ramp lane adjacent to the freeway at the freeway ramp merge point would be equal to one-half of the user-specified freeway ramp merge capacity.
- If there is excess capacity available in the upstream freeway lane, the capacity for the ramp lane adjacent to the freeway at the freeway ramp merge would be equal to one-half of the user-specified freeway ramp merge capacity plus the re-assigned excess capacity from the adjacent freeway lane.
- Any excess demand at the freeway on-ramp merge is transferred to the next time slice.

c) Queuing and associated delays may occur at the entrance to the on-ramp and/or on the on-ramp adjacent to the freeway at the freeway ramp merge. These analyses will be handled within the FREQ model using queuing analysis techniques.

TYPE D

Type D on-ramp design geometrics consist of a two-lane right-side on-ramp with two freeway lanes being added. Essentially the freeway traffic in the upstream adjacent freeway lane does not merge with the two-lane on-ramp traffic and each traffic stream has its own lane(s) at the on-ramp merge. The default capacity value for the two-lane on-ramp proper is 4000 vph.

While merging does not actually occur, there will likely be more lane changing downstream of the on-ramp due to some on-ramp traffic wishing to move into the left-lanes of the freeway as they become freeway through traffic and some upstream adjacent lane traffic wishing to move to the downstream far right-side lane(s) for exiting at downstream right-side off-ramp(s). Depending primarily on the distance to downstream off-ramp(s) and the downstream off-ramp demand(s), the capacity of the downstream subsection(s) may be reduced due to this lane-changing or weaving movements.

The user should either engage the weaving analysis in the model which automatically may reduce the downstream subsection(s) capacity to account for this weaving effect and/or manually reduce the downstream subsection capacity based upon other means.

Type E

Type E on-ramp merge design geometrics consist of a right-side three-lane connector with two added freeway lanes at the merge point. The analytical steps undertaken to simulate the effects of this type of on-ramp design is similar to the one described above as Type C and consist of the following three series of analytical steps.

- The first series of steps are undertaken to determine whether there is an on-ramp merge problem, and if so, whether it affects the upstream adjacent freeway lane, the on-ramp, or both. This series of steps is referred to as the preliminary series of steps.

- The second series of steps are undertaken to analyze the upstream adjacent freeway lane and the other freeway lanes in the event the on-ramp merge problem affects upstream freeway operations. This series of steps is referred to as the freeway series of steps.

- The third and final series of steps are undertaken to re-simulate the on-ramp performance in the event the on-ramp proper capacity constraint and/or the on-ramp merge problem affects the on-ramp operations. This series of steps is referred to as the on-ramp series of steps.

1) PRELIMINARY SERIES OF STEPS

The preliminary series of steps are similar with those for the Type C on-ramp except as noted below.

a) The traffic demand in the adjacent freeway lane just upstream of the on-ramp is calculated based upon the model's origin-destination table and the freeway lane distribution algorithm.

b) The traffic demand on the on-ramp proper is calculated based upon the model's origin-destination table. The traffic demand from the on-ramp proper that reaches the on-ramp merge area is limited by the capacity on the on-ramp proper previously entered by the user. The revised default value for the on-ramp proper capacity has now been increased to 2000 vphpl since merge analysis procedures had now been addressed for all types of on-ramps. The traffic demand that can reach the on-ramp merge area from the ramp lane adjacent to the freeway (the left-most lane of the on-ramp) is assumed to be twenty-five percent (25%) of the total three-lane on-ramp demand that can reach the freeway ramp merge point.

c) The user has previously entered the capacity of the merge lane that serves both freeway and on-ramp traffic. The default value is 2400 vph.

d) The sum of the demands in the adjacent freeway lane just upstream of the on-ramp and the demand from the on-ramp that reaches the on-ramp area in the ramp lane adjacent to the freeway is compared with the user-specified merge lane capacity.

e) If the sum of the demands is less than the user-specified merge lane capacity, there is no on-ramp merge problem and the ramp-freeway interaction module is not further engaged.

f) If the sum of the two demands is greater than the user-specified merge lane capacity, there will be queuing either in the adjacent freeway lane just upstream of the on-ramp, on the on-ramp lane adjacent to the freeway, or in both.

g) To determine where the queuing will take place, additional analysis is required. The first step is to assign one-half of the available user-specified merge lane capacity for the traffic in the adjacent freeway lane just upstream of the on-ramp and the other one-half of the specified merge lane capacity for the traffic that reaches the on-ramp merge area from the on-ramp in the ramp lane adjacent to the freeway. Assuming the default merge lane capacity of 2400 vph, one-half of the merge lane capacity would be 1200 vph.

h) If either the demand in the adjacent freeway lane or the on-ramp lane adjacent to the freeway is less than one-half the user-specified merge lane capacity, the on-ramp merge does not have an adverse effect on that particular lane. Under this condition, the freeway or ramp lane flow will be equal to the lane demand. The excess unused capacity is re-assigned to the other lane.

i) The other lane will have a queue and the excess demand will be equal to the difference between the lane's demand entering the on-ramp merge area and the sum of the original assigned one-half of the merge lane capacity plus the re-assigned excess capacity from the other lane. The lane flow will be equal to one-half of the merge lane capacity plus the re-assigned excess capacity from the other lane.

j) If the demand in both the freeway lane adjacent to the on-ramp and the on-ramp lane adjacent to the freeway are greater than one-half the user-specified merge lane capacity, there will be a queue in each of the lanes and there is no excess capacity to be re-assigned to the other lane.

k) The excess demand in each of the two lanes is calculated as the difference between the calculated lane demand and one-half of the merge lane capacity and the flow in each of the two lanes is equal to one-half the merge lane capacity.

2) FREEWAY SERIES OF STEPS

The following freeway series of steps are undertaken as described in the following paragraphs.

a) If there is excess demand in the upstream adjacent freeway lane due to the on-ramp merge problem, the following steps are undertaken to simulate the effect of the excess demand on upstream freeway subsection(s) performance in both the adjacent lane as well as in the other freeway lanes. After simulation of this time slice, the excess demand is transferred to the next time slice for further processing.

b) The capacity of the upstream adjacent freeway lane is assumed to be 2000 vph and thus the maximum flow in the upstream adjacent freeway lane would be 2000 vph.

c) As stated earlier, the minimum flow in the upstream adjacent freeway lane is set equal to one-half of the on-ramp merge capacity. Assuming the default merge lane capacity of 2400 vph, the minimum flow would be 1200 vph.

d) The volume-to-capacity ratio is computed and would vary between -0.60 and -1.00 depending upon the quantity of traffic entering from the on-ramp. The negative sign indicates that the lower-limb of the user-selected speed to v/c ratio curve would be used when queuing is occurring.

e) The lower-limb speed to v/c ratio curve will be used to estimate the average speed in the adjacent lane for each affected upstream subsection. It is currently thought that the lower-limb curve with a speed of 30 mph at a v/c ratio of -1.00 is most appropriate.

f) When this curve is used, the calculated average speed will be on the order of 8 to 30 mph depending upon the v/c ratio. To provide flexibility, the user will be able to select the lower-limb curve within the range of 20 to 40 mph with a default value of 30 mph. Refer to the Freeway Analysis Manual on page 1-9 for FREQ model's available upper-limb and lower-limb speed to v/c ratio curves.

g) Density in the upstream adjacent freeway lane for each affected upstream subsection is determined as the ratio of the lane flow divided by the lane speed. Given the expected values for flow and speed in the previous paragraphs, the density in the upstream adjacent freeway lane would be expected to be on the order of 67 vpmpl to 150 vpmpl.

h) The length of the queuing in the adjacent freeway lane in the affected upstream subsection(s) would be calculated as the ratio of the excess demand to the calculated lane density. For example, if the excess demand is 50 vehicles and the calculated adjacent freeway lane density is 100 vpm, the length of the queue would extend 0.5 miles or 2640 feet upstream of the on-ramp in the adjacent freeway lane.

i) The capacity of the other freeway lanes for each affected upstream subsection is reduced by 2000 vph. The demand for the other freeway lanes for all affected upstream subsection(s) is reduced by the assigned demand in the adjacent freeway lane.

j) The occurrence of the queuing in the upstream adjacent freeway lane will cause a reduction in average speeds in the other freeway lanes. This is accomplished in the simulation by the user selecting a reduced free-flow speed and the model selecting the accompanying speed to v/c ratio upper-limb curve to estimate the average speed in the other freeway lanes. While the default free-flow speed value in the program is set for 50 mph, the user can select any free-flow speed between 50 mph and the previously entered free-flow speed for the other freeway lanes when there is no queuing in the adjacent freeway lane.

3) On-Ramp Series of Steps

The following on-ramp series of steps are undertaken as described in the following paragraphs. One series of steps considers the capacity on the on-ramp proper and the other considers the capacity of the merge lane.

a) The first step is to compare the on-ramp demand with the user-specified capacity on the ramp lane proper.

- The default on-ramp proper capacity has been increased from 5000 to 6000 vph because merge analysis has now been extended to all appropriate types of on-ramp merge situations.
- If the on-ramp demand is less than the on-ramp proper capacity, there is no queue at the entrance to the on-ramp and all of the on-ramp demand can reach the freeway on-ramp merge point.
- If the demand is greater than the capacity, there is a queue at the entrance to the on-ramp and the demand that can reach the freeway on-ramp merge point is limited to the on-ramp capacity.
- Any excess demand at the entrance to the on-ramp is transferred to the next time slice.

b) The second step is to compare the on-ramp demand that can reach the freeway ramp merge point in the ramp lane adjacent to the freeway with the allocated capacity for that ramp lane at the freeway ramp merge point.

- The on-ramp demand assigned to the ramp lane adjacent to the freeway is twenty-five percent (25%) of the total on-ramp demand that can reach the freeway ramp merge point.
- The allocated capacity for the ramp lane at the freeway ramp merge point depends on whether there is excess capacity in the upstream freeway lane.
- If there is no excess capacity available in the upstream adjacent freeway lane, the capacity for the ramp lane adjacent to the freeway at the freeway ramp merge point would be equal to one-half of the user-specified freeway ramp merge capacity.
- If there is excess capacity available in the upstream freeway lane, the capacity for the ramp lane adjacent to the freeway at the freeway ramp merge would be equal to one-half of the user-specified freeway ramp merge capacity plus the re-assigned excess capacity from the adjacent freeway lane.
- Any excess demand at the freeway on-ramp merge is transferred to the next time slice.

c) Queuing and associated delays may occur at the entrance to the on-ramp and/or on the on-ramp adjacent to the freeway at the freeway ramp merge. These analyses will be handled within the FREQ model using queuing analysis techniques.

TYPE F

Type F on-ramp design geometrics consist of a three-lane right-side connector with three freeway lanes being added. Essentially the freeway traffic in the upstream adjacent freeway lane does not merge with the three-lane on-ramp traffic and each traffic stream has its own lane(s) at the on-ramp merge. The default capacity for the three-lane on-ramp proper is 6000 vph.

While merging does not actually occur there will likely be more lane changing downstream of the on-ramp due to some connector traffic wishing to move into the left-lanes of the freeway as they become mainline freeway traffic users and some upstream adjacent lane traffic wishing to move to the downstream far right-side lane(s) for exiting at downstream right-side off-ramp(s). Depending primarily on the distance to downstream off-ramp(s) and the downstream off-ramp demand(s), the capacity of the downstream subsection(s) may be reduced due to this lane-changing or weaving movements.

The user should either engage the weaving analysis in the model which automatically may reduce the subsection capacity to account for this effect of weaving and/or manually reduce the downstream subsection capacity based upon other means.

TYPE G

Type G on-ramp merge design geometrics consist of a left-side single-lane on-ramp without a freeway lane being added. The procedures for analysis this type of on-ramp merge are similar to the procedures described earlier for the Type A right-side on-ramp merge design geometrics with the following exceptions.

- The user may consider selecting a slightly lower on-ramp merge capacity because the on-ramp is on the left-side of the freeway.

- The user may also consider selecting a lower free-flow speed for the other lanes when congestion occurs in the freeway lane adjacent to the on-ramp.

- The most important difference is estimating the proportion of freeway traffic in the freeway lane just upstream of the left-side on-ramp merge. Until research becomes available it will be assumed that under medium to heavy freeway traffic conditions, the freeway lane adjacent to the left-side on-ramp will carry 1/N proportion of the total freeway traffic where N is the number of freeway lanes

TYPE H

Type H on-ramp design geometrics consist of a left-side single-lane on-ramp with a single freeway lane being added. Essentially the freeway traffic in the upstream adjacent freeway lane does not merge with the single-lane on-ramp traffic and each traffic stream has its own lane at the on-ramp location.

The procedures for analysis this type of on-ramp merge are similar to the procedures described earlier for the Type B right-side on-ramp merge design geometrics with the following exceptions.

- The user may consider selecting a slightly lower on-ramp merge capacity because the on-ramp is on the left-side of the freeway.

- The user may also consider selecting a lower free-flow speed for the other lanes when congestion occurs in the freeway lane adjacent to the left-side on-ramp.

- While merging does not actually occur there will likely be more lane changing downstream of the on-ramp due to some on-ramp traffic wishing to move into the other freeway lanes or exit on some nearby downstream right-side off-ramp(s). Depending primarily on the distance to downstream off-ramp(s) and the downstream off-ramp demand(s), the capacity of the downstream subsection(s) may be reduced due to these lane-changing or weaving movements. The user should either engage the weaving analysis in the model which automatically reduces the capacity and/or manually reduce the downstream subsection capacity based upon other means.

TYPE I

Type I on-ramp design geometrics consist of a two-lane left-side on-ramp with a single freeway lane added at the merge point. The procedures for analysis this type of on-ramp merge are similar to the procedures described earlier for the Type C right-side on-ramp merge design geometrics with the following exceptions.

- The user may consider selecting a slightly lower on-ramp merge capacity because the on-ramp is on the left-side of the freeway.

- The user may also consider selecting a lower free-flow speed for the other lanes when congestion occurs in the freeway lane adjacent to the on-ramp.

- The most important difference is estimating the proportion of freeway traffic in the adjacent freeway lane just upstream of the left-side on-ramp merge. Until research becomes available it will be assumed that under medium to heavy freeway traffic conditions, the freeway lane adjacent to the left-side on-ramp will carry 1/N proportion of the total freeway traffic where N is the number of freeway lanes.

TYPE J

Type J on-ramp design geometrics consist of a two-lane left-side on-ramp with two freeway lanes being added. Essentially the freeway traffic in the upstream adjacent freeway lane does not merge with the two-lane on-ramp traffic and each traffic stream has its own lane(s) at the on-ramp location.

The procedures for analysis this type of on-ramp merge are similar to the procedures described earlier for the Type D right-side on-ramp merge design geometrics with the following exceptions.

- The user may consider selecting a slightly lower on-ramp merge capacity because the on-ramp is on the left-side of the freeway.

- The user may also consider selecting a lower free-flow speed for the other lanes when congestion occurs in the freeway lane adjacent to the left-side on-ramp.

- While merging does not actually occur there will likely be more lane changing downstream of the on-ramp due to some on-ramp traffic wishing to move into the other freeway lanes or exit on some nearby downstream right-side off-ramp(s). Depending primarily on the distance to downstream off-ramp(s) and the downstream off-ramp demand(s), the capacity of the downstream subsection(s) may be reduced due to these lane-changing or weaving movements. The user should either engage the weaving analysis in the model which automatically reduces the capacity and/or manually reduce the downstream subsection capacity based upon other means.

TYPE K

Type K on-ramp design geometrics consist of a three-lane left-side connector with two freeway lanes being added at the merge point. The procedures for analysis this type of on-ramp merge are similar to the procedures described earlier for the Type E right-side on-ramp merge design geometrics with the following exceptions.

- The user may consider selecting a slightly lower on-ramp merge capacity because the on-ramp is on the left-side of the freeway.

- The user may also consider selecting a lower free-flow speed for the other lanes when congestion occurs in the freeway lane adjacent to the on-ramp.

- The most important difference is estimating the proportion of freeway traffic in the adjacent freeway lane just upstream of the left-side on-ramp merge. Until research becomes available it will be assumed that under medium to heavy freeway traffic conditions, the freeway lane adjacent to the left-side on-ramp will carry 1/N proportion of the total freeway traffic where N is the number of freeway lanes.

TYPE L

Type F on-ramp design geometrics consist of a three-lane left-side connector with three freeway lanes being added. Essentially the freeway traffic in the upstream adjacent freeway lane does not merge with the three-lane on-ramp traffic and each traffic stream has its own lane(s) at the on-ramp location.

The procedures for analysis this type of on-ramp merge are similar to the procedures described earlier for the Type F right-side on-ramp merge design geometrics with the following exceptions.

- The user may consider selecting a slightly lower on-ramp merge capacity because the on-ramp is on the left-side of the freeway.

- The user may also consider selecting a lower free-flow speed for the other lanes when congestion occurs in the freeway lane adjacent to the left-side on-ramp.

- While merging does not actually occur there will likely be more lane changing downstream of the on-ramp due to some on-ramp traffic wishing to move into the other freeway lanes or exit on some nearby downstream right-side off-ramp(s). Depending primarily on the distance to downstream off-ramp(s) and the downstream off-ramp demand(s), the capacity of the downstream subsection(s) may be reduced due to these lane-changing or weaving movements. The user should either engage the weaving analysis in the model which automatically reduces the capacity and/or manually reduce the downstream subsection capacity based upon other means.

ON-RAMP STEPS OF ANALYSIS BY TYPE OF ON-RAMP DESIGN

FILE=ON-RAMP MERGE ANALYSIS2

ON-RAMP STEPS OF ANALYSIS BY TYPE OF ON-RAMP DESIGN	TYPE A	TYPE B	TYPE C	TYPE D	TYPE E	TYPE F	TYPE G	TYPE H	TYPE I	TYPE J	TYPE K	TYPE L
ADJACENT LANE POSITION Right (RS) or Left (LS) side	RS	RS	RS	RS	RS	RS	LS	LS	LS	LS	LS	LS
UPSTREAM FREEWAY LANES (N)	N	N	N	N	N	N	N	N	N	N	N	N
NUMBER OF ON-RAMP LANE(S) (1, 2, 3)	1	1	2	2	3	3	1	1	2	2	3	3
DOWNSTREAM FREEWAY LANES (N, N+1, N+2, N+3)	N	N+1	N+1	N+2	N+2	N+3	N	N+1	N+1	N+2	N+2	N+3
RAMP INVESTIGATIONS On-Ramp Merge Analysis	YES	NA	YES	NA	YES	NA	YES	NA	YES	NA	YES	NA
On-Ramp Proper	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEFAULT CAPACITIES On-Ramp Proper	2000	2000	4000	4000	6000	6000	2000	2000	4000	4000	6000	6000
Merge Lane Capacity	2400	NA	2400	NA	2400	NA	2400	NA	2400	NA	2400	NA
DEFAULT SPEED VS V/C CURVE Other Freeway Lanes	50	NA	50	NA	50	NA	50	NA	50	NA	50	NA
Adjacent Lane	30	NA	30	NA	30	NA	30	NA	30	NA	30	NA
ADJACENT ON-RAMP LANE DEMAND Percent of Total On-Ramp Demand	100%	NA	40%	NA	25%	NA	100%	NA	40%	NA	25%	NA

NA There is no ramp merging since the ramp traffic enters the freeway on its exclusive lane(s). Special attention is needed for downstream freeway lane changing and weaving.