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Controlling Congestion in Al-Seeb Highway Using Ramp Metering (Case Study)

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Abstract

This paper represents a case study of traffic congestion within a section on Al Seeb Street highway due to the on-ramp merging of vehicles that causes a bottleneck in the mainline road. It studies the efficiency of installing ramp metering within a ramp within the selected study zone. This is done by simulating the collected data using Vissim software by drawing three one-hour-long scenarios; the first scenario reflects the data collected for 30 minutes duration and is used as a base scenario to draw the other two scenarios, which are reflected as factored-up scenarios to create a situation observed in the early morning in the study zone at 6:00-7:00 in which slowing down of speeds exist, and breakdown is raised in working days. The two factoring-up scenarios were as follows: one without ramp metering and the other without ramp metering. Each scenario was calibrated and run five times with random seeds, and then the average was considered. The simulation examines the ability of RM to smooth traffic in mainline and reduce queuing on on-ramp roads within the selected study zone by comparing the performance of the network for the scenarios and comparing them in terms of the overall delays, number of stops and the average speeds for the vehicles within the mainline. The results showed a good performance reflected by the scenario with ramp metering with a reduction of the overall delay, a decrease in stops number and an increase of the average speed were achieved. For the base scenario, a visualization (video extracted from Vissim software) was extracted, showing no need to install RM with an associated table showing a number of stops equal to zero with an average speed of 102.74 km/h and a total delay of 6045 seconds. For the second scenario with no RM, a visualization was extracted showing a slowing down of speeds for vehicles within the mainline while vehicles merging from the on-ramp and need to be controlled with a table showing a number of stops equal to 16 and an average speed equal to 58 km/h and a total delay of 916,874 seconds. For the third scenario with RM, a visualization was extracted showing good control of the second scenario with a table showing the number of stops equal to 6, an average speed equal to 61 km/h and a total delay equal to 484,466 seconds. Ten literatures in regard to this study have been reviewed. The data collected are quantitative, which are collected using an indirect manual counting method and then the data is used to feed the software for simulation.

Keywords

On-Ramp Merge, Ramp-Metering, Vissim Simulation

1. Introduction

Congestion is a serious problem that troubles everyday life in almost all modern societies. It is known to hurt life quality and the environment due to its impact on time loss from origin to destination and the associated consequences, including disturbing the flow, accidents, fuel consumption, and impacting driver's behaviour. One of the significant measures of congestion is the on-ramp merging. Merging of vehicles from the on-ramp pushes the vehicles within the mainline upstream to slow down to avoid accidents or to allow them for safe merging. Also, those cars have to find a gap to merge within the mainline stream, so a stop is considered, and subsequently, queuing takes place. However, in some areas with low traffic volume, there is no issue related to merging. Still, on some roads with relatively high volumes, merging becomes an absolute problem, leading to bottlenecks. In the case of high traffic volume, a classic solution can be implemented to control the congestion raised due to merging, which is adding a new lane for merging. However, this is not possible in all situations as sometimes there is no area to extend the road further. In this case, installing an inelegant transport system (ramp metering) could be the solution.

1.1. Aim of Study

To determine the efficiency of installing a smart solution, specifically, ramp metering within a case study zone in Al-Seeb mainline street to tackle congestion raised due to on-ramp merging.

1.2. Research Objectives

- To calculate real-time traffic volume on the main road (upstream and downstream).
- To calculate real-time traffic volume on On-ramp roads.
- To analyze the collected data and assess the need for traffic control.
- To simulate the data using VISSIM software.
- To compare the network performance before and after installing ramp metering within the study zone.
- To develop recommendations and build upon the simulation outputs regarding the smart solution.

1.3. Scope

The study will cover a distance extending about 2.5 km of a section on Al Seeb Street, as illustrated in Figure 1. The section consists of a mainline with three lanes in each way (dual street) and an on-ramp road with one lane such that only one way is considered for this study W-E, including the on-ramp road.

1.4. Problem Statement

It is experienced that Al Seeb Highway is highly congested in peak hours, specifically from 6:00 am to 8:00 am during working days within the study zone. The timeline was selected due to the massive volume of vehicles as employees head towards their offices. This congestion is due to several parameters playing roles simultaneously: ramp merging, population growth, dense employees in Al Seeb and Muscat overall, and the tendency to own private cars while heading towards the workplace. But mainly, on-ramp roads make a real bottleneck at the selected study zone as the merging of vehicles forces the cars in the mainline to slow down and even stop to allow safe merging.

Therefore, finding a smart solution for traffic volume at that study zone becomes necessary as adopting a classic solution, *i.e.*, adding a new lane, is not applicable in all cases and may harm the environment, *i.e.* dust and noise.

1.5. Significance of the Study

The study gives a Simulation using VISSIM software for a smart alternative solution, particularly RM for ramp roads, to tackle the traffic volume problem raised due to vehicles merging. Reflecting actual data collected within the study zone may help avoid the need for expanding the road by constructing a new lane so that no road destruction or air pollution associated with drilling, excavation and

Figure 1. On-ramp section location in AL-Seeb Highway. (Source: Google Maps)

construction is encountered. This study will show the efficiency of installing ramp metering within the study zone in terms of delay and speed. It will be the first study for ramp metering in Oman using VISSIM software, as RM is a new concept in Oman.

2. Literature Review

This chapter discusses the relevant literature on controlling traffic volume in mainline due to on-ramp merging to better understand the different controlling strategies for managing traffic congestion due to on-ramp roads either by a theoretically based approach or by simulation using programs.

[1] conducted a study on a mainline road with an on-ramp section in the USA to tackle the problem of congestion that occurred downstream of the Ramp. They proposed installing a responsive ramp metering with a certain non-linear policy design that provides the system with an anticipation capability. A vector-based reinforcement learning technique was used to assess the proposal's viability so that the ramp metering could regulate the distant downstream congestion via self-computational action and assignment. It is a fully coded process done with the help of MATLAB. The idea was built by considering three points within the mainline, say A, B, and C in the downstream with distinct distances with respect to the Ramp to locate the detectors as shown in **Figure 2**. The variables to be considered to identify equations used in the reinforcement learning were:

1) The number of lanes before and after the lane drop.

2) Traffic densities of the three specified points within the mainline.

3) Traffic demand on the Ramp requires identifying queue length and arrival flow rate at the Ramp.

This technique required the assignment of the outputs to the proper action value done by approximation, which is for this study done by ANN, which is a non-linear mapping. The findings of this computational process were plotted by MATLAB, which showed that the traffic volume under the studied area was successfully controlled [1].

[2] conducted a study in which adaptive ramp metering was used with a developed algorithmic process to optimize the functionality of the ramp metering aimed at controlling the traffic congestion results due to ramp flow. The algorithm enables the system to estimate the probability of jam formation within

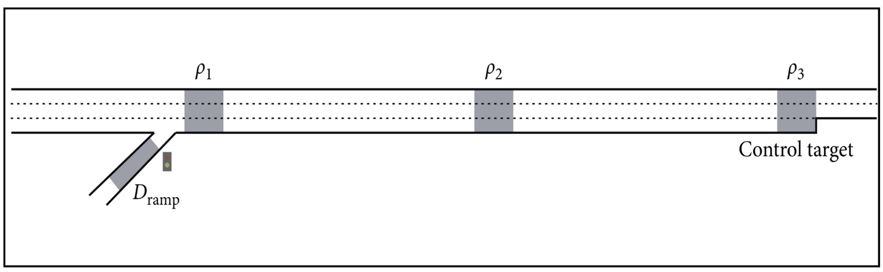

Figure 2. Reinforcement learning technique used four variables [1].

the mainline. The algorithm was represented in this study as a matrix form, which in turn reflected in MATLAB as bar charts. The idea of the study build based on a video analysis of a mainline road consisting of 3 lanes with an on-ramp road such that lane 1 is the nearest to the Ramp. The analysis showed the behavior of mainline users occupying lane 1 when the flow on the ramp lane was made 15% - 25% of the flow on the mainline, which caused noticeable turbulence for lane one from 50 to 300 m in the upstream direction. Furthermore, when the percentage of flow on-ramp increased to more than 26% of the flow on the mainline, turbulence was noticed within the behavior of users in lanes 2 and 3 of the mainline, so suggested a relationship between traffic flow on the Ramp and overall traffic control on mainline represented by an algorithmic process. The study showed that one vehicle to be merged per cycle, where one cycle represents 4 - 4.5 seconds, shows better overall flow control [2].

[3] Conducted a study in China, particularly on Changi freeway, using macro traffic flow theory to regulate the congested traffic flow due to on-ramp by developing an algorithm-based controller, which is based on traditional PID control but with an optimized version by connected with PSO to function as one unit called PSO-PID controller. The study is interpreted under a macroscopic view in which one direction is considered for the traffic flow, and the vehicles are treated as overall mass regardless of the individual vehicle features. Detection devices collect the data, and the idea is that PID is a classical closed loop widely used worldwide. Still, it has a limitation in that the errors accumulate and need complicated calculations, which require a long time to converge and hence many iterations accordingly, so the traffic control is slower. The new optimized version connected the PSO adaptor based on a certain algorithm that enabled the ramp metering to take immediate effect per error. By this, the metering function will take less time to converge and less iteration. Thus, better and faster control of traffic will be accordingly. With the help of MATLAB, a simulation was done, which was reflected as graphs. The results showed that the traffic congestion in the mainline due to the Ramp is effectively controlled [3].

[4] conducted a study on a freeway section in Orlando in the USA, consisting of multiple on-ramp roads. This study aims to reduce the crash risk raised due to congestion formed by on-ramp merging. ALINEA algorithm was used for modelling the case study and introduced as a feedback method for real-time such that the ramp metering adapted to receive prompt feedback from the downstream section within the mainline so that the downstream section will be regulated to be fully utilized but without disturbance and accordingly a significant reduction in the risk of crashes on the mainline. This is done by mathematically modelling the mainline considering the peak period and then simulating by PARAMICS micro-simulation to assess the whole scenario under the ALINEA control law equation, which is represented as a function depends on the occupancy of the mainline road at a particular time and critical current occupancy within downstream. The data used for this study were archived data collected by

a loop detector. The study findings showed that the ALINEA model was effective and regulates the congestion such that installing ramp metering in multiple successive on-ramps will remarkably reduce the congestion as well as the crash risk by adapting shorter signal cycles while in single ramp metering, similar results will be achieved with longer signal cycles [4].

[5] conducted a study on a mainline in Australia consisting of an on-ramp road. This study aims to implement an on-ramp queue controlling strategy to avoid spillover of vehicles within the Ramp in the adjacent surface roads. ALINEA algorithm was used for modelling the case study incorporated with speed recovery technique such that three detectors will be located within the ramp road: one at the mouth of the Ramp, second in the middle of the Ramp, and third at the end as shown in **Figure 3**. The ALINEA algorithm will be used to regulate the queueing in the Ramp by calculating the number of vehicles in the queue at a current time interval also for forecasting the arrival of a new vehicle in the next time interval, which acts as a prediction aspect. This strategy only works when there is a large queueing size, utilizing predetermined activation and deactivation factors. The system works when the number of vehicles within the queue exceeds a certain number so that the metering works to allow the maximum merge to the mainline. Unfortunately, this merge will create a disturbance to the main line; here, the concept of mainline speed recovery is taking place. Once a disturbance on the mainline is recognized, the metering switches on its classic function and regulates the merging in the mainline, trying to recover the situation. A micro-simulator AIMSUN is used to assess the function of the cooperated strategy. The findings showed that the queue management strategy incorporated with the speed recovery technique could achieve an excellent balance between mainline stability and on-ramp management [5].

All traffic volume studies need to undergo a collection data phase to enable the conductor to understand the actual situation of a particular roadway volume to analyze and give a better view based on actual data and consequently help the decision-making process and draw realistic plans. Data collection for traffic volume studies could be either by manual ways or automatic ways. The selection is always based on several factors, including the availability of tools, cost, affordability, volume level, surveyors, and the chosen day (weather and events on the

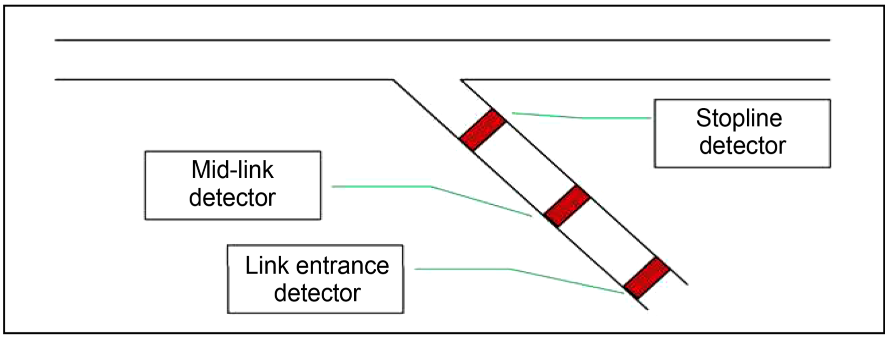

Figure 3. Detectors' locations on a ramp [5].

road). This chapter discusses five literature reviews relevant to traffic volume studies to understand the different data collection methods better.

[6] conducted a classified traffic volume study in which traffic volume and type of vehicle are considered for a road section extending from Baily Road to Kakrail Circle as a study zone in Bangladesh. The study's purpose was to identify the demand within the study zone. The study involved data collection for that section in two directions (E to W & W to E) in which direct manual count is considered. The collection duration was fifteen minutes, from 11:00 am till 11:15 am, which is considered a short count for continuous days such that the first two days were weekend days and the other two days were work days. The weather was sunny for all four days. In this surveying, four enumerators were used. Before the team started collecting the needed data, they went to study the zone a day before, divided the zone into five sections equally and identified the spots that would be used as reference points during data collection on the operation days. The team used tally sheets, pens and stopwatches during operation days. The study concludes that most traffic streams within the studied zone were light vehicles as a composite result. This is because the study zone is near a residential area where the residents are of high income, so they prefer owning cars instead of using public transportation. Also, the buses there are very old and crowded, leaving most passengers seatless. The study findings indicate a necessity to enhance and expand the bus fleet to ensure passengers can access available seating. This enhancement aims to improve the overall experience for passengers, potentially encouraging the public to use public transportation instead of private vehicles [6].

[7] conducted a traffic volume study in Pantapath to Russel Square in Bangladesh in order to determine the demand in the study zone in which one way is considered only from E to W for data collection. The survey method is direct manual count, in which the data is collected within one day only, and the selected timing was 25 minutes; the weather was humid and hot. The timing was divided into 5 minutes gab, and the data was collected with vehicle type consideration, including bus, CNG, car, motorcycle, NMV and one column for jeep/microbus/ambulance. The result of the composition of the traffic stream shows the following percentages, as represented in **Figure 4**:

Cars (62%), CNG (10%), bus (8%), NMV (5%), Motorcycle (1%), jeep/microbus/ambulance (11%), utility (3%) [7].

[8] conducted a traffic survey in India. The survey was 15 min long at the Sanat Nagar/Rawalpora intersection during the peak hour from 9 am to 10 am. The team used direct manual count to collect data such that two surveyors were recording at every leg of the intersection, so the total number of surveyors was eight. The purpose of the study is to figure out the intersection approach delay within the mentioned intersection at each leg and the traffic flow as well. The names of the intersection legs are Hyderpora, Barzulla, Nowgam & Rawalpora. The sheets were prepared at a prior time before the operation day in which vehicles were classified as fast vehicles, which included cars, tempos, auto rickshaws,

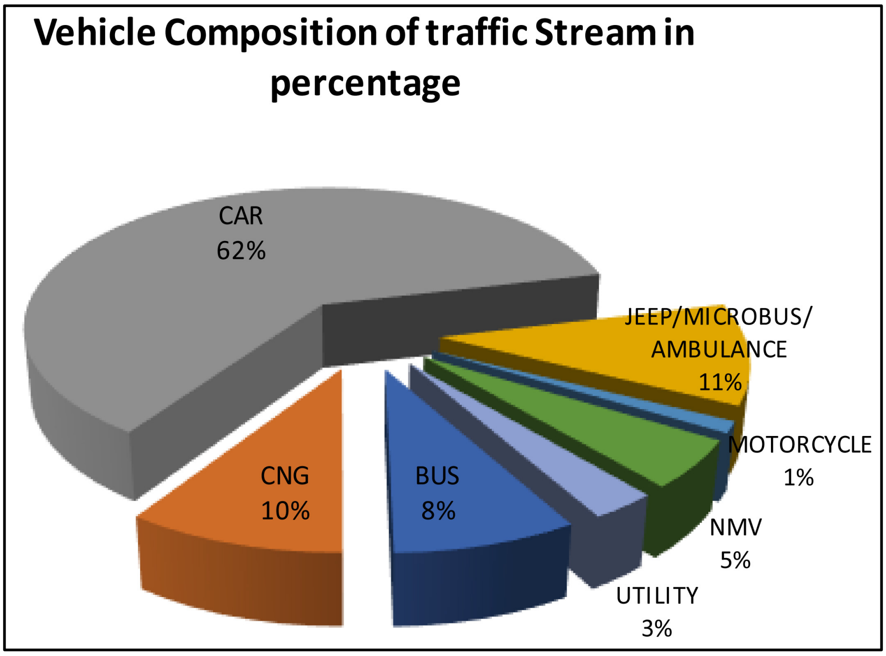

Figure 4. Traffic stream composition [7].

tractors, pickups & vans as one group and motorcycles & scooters as one group and agricultural tractor light commercial vehicle as a group and trucks & buses as one group and tractor-trailer, truck trailer units as one group. The other class was slow vehicles, including cycles, cycle rickshaws, hand carts, horse-drawn and bullock carts individually. After the recording, the data is tabulated to determine the intersection peak hour design. The study concluded that the direct manual method comes in third ranking in accuracy after the photographic method and the combination of the manual and automatic methods [8].

[9] conducted a study titled "Use of Hi-resolution Data for Evaluating the Accuracy of traffic volume counts collected by microwave sensors" to assess the accuracy level of data provided by microwave sensors. The study underwent a data collection phase in which both matrix sensors with firmware and direct manual count were used. The manual count was conducted within an intersection using JAMAR counters such that each leg of the intersection had been surveyed for a one-hour duration with 5 min intervals then the data was downloaded using Petra software.

Regarding the matrix sensor method, which uses a traffic server, the data collected by the traffic controller (signal) such that the controller records all events within the intersection and then inserts them as data into the server in matrix form, providing information on the signal identification number, time of event deducted, the leg and the lane then data need to be processed to be in final statistical form to facilitate the comparison between the two methods. The study concluded that the sensor method data are almost similar to data produced by manual count, but it is time and effort-consuming. Furthermore, it meets the needs of traffic engineers, especially for the turning volume counts with multiple lanes, as the level of accuracy is acceptable [9].

[10] conducted a traffic study entitled "The Application of the Shortest Path and Maximum Flow with Bottleneck in Traffic Flow of Kota Kinabalu". This study aims to identify the maximum flow, the shortest pathway and the path where the bottleneck occurs to tackle the congestion and for improvement. The study zone section extends from Bandaraya Mosque to Kampung Air in Kota Kinabalu, in which manual traffic count with video recordings was used for traffic volume data collection where a tripod stand was used to hold the camera to take video shots in the evening time during peak hours from 5 pm to 6 pm within the study zone. Afterwards, the video records were reviewed then manual counting was done to get the actual traffic volume via video clips. The data were sorted in terms of vehicle types, light/heavy. The study concluded that the shortest pathway in the study zone was selected as s - $V1$ - $V5$ - $V7$ - t such that about 5.74 km from Bandaraya Mosque to reach Kampung Air in Kota Kinabalu. The maximum flow routes were s - $V1$ - $V5$ - $V7$ - t, second s - $V2$ - $V3$ - $V6$ - $V9$ - t, third s - $V2$ - $V3$ - $V6$ - $V9$ - $V10$ - t, the total flow of the three routes is 2598 vehicles/hr, the bottleneck ways were found in Jalan Laiman Diki and Jalan Coastal [10].

Chapter Summary

Ramp metering is one of the smart solutions and an intelligent transport system used to regulate the congestion due to entrance via on-ramp roads. It is also a cost-effective tool compared with the construction of new lanes in terms of material provision, construction cost and maintenance cost as well. However, different algorithmic models and simulation software have been used to control each case study's nature, as explained above, such that the first study used A vector-based reinforcement learning technique and simulated it by MATLAB. A second study used a matrix form algorithm and simulated by MATLAB. The third study used the PSO-PID controller model and simulated by MATLAB. The fourth study used the ALINEA algorithm and simulated by PARAMICS micro-simulation. The fifth study used a queue management strategy incorporated with a speed recovery technique which required ALINEA algorithm in activated case only and simulated by AIMSUN. Moreover, any traffic volume studies must undergo a data collection phase; therefore, the last five studies represent the data collection methods used for different volume studies. This study case intended to use VISSIM software to assess the ramp metering functionality within a section of Al Seeb Highway using actual data collected using indirect manual counting.

3. Methodology

3.1. Study Methodology

The implementation of this study requires a variety of activities illustrated in the following scheme (**Figure 5**):

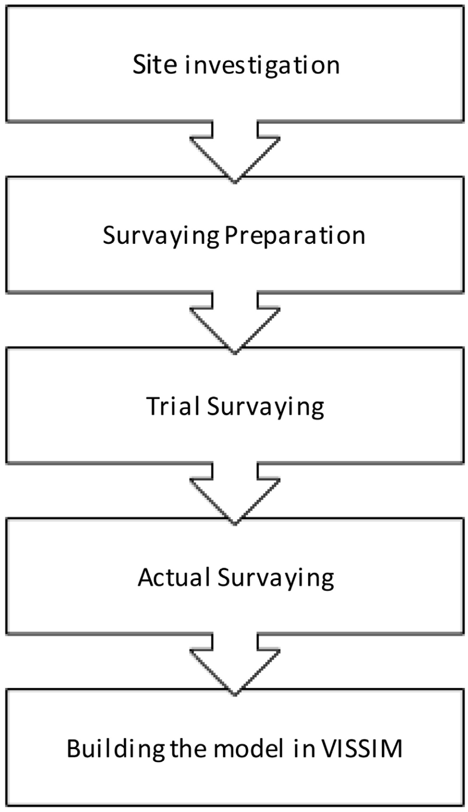

Figure 5. Schematic drawing for the activities.

3.1.1. Site Investigation

Several site visits have been conducted to determine the suitability of locations for the study. This involves assessing the feasibility of implementing ramp metering in two scenarios: Case 1, represented in **Figure 6**, involves a direct connection between the ramp road and the mainline, which represents an ideal situation for ramp metering implementation due to the presence of a merging zone. In Case 2, as shown in **Figure 7**, the ramp road has gained an additional lane, making it unnecessary to install ramp metering as the addition of the lane achieves similar results to ramp metering.

The two cases are illustrated as the following.

The selected study zone consists of a mainline of 3 lanes with a ramp road immediately merging to the mainline (no additional lane added for merging vehicles) such that the upstream and downstream motorways have the same number of lanes. In addition, the study zone has a weaving length of 230 m and a merging tapper of 25 m long.

During the site investigation, the surveyor could identify the volume of the traffic and accordingly specify the perfect available method for counting as the available counting methods for this study were direct manual counting method and indirect manual counting method.

- The direct manual count method entails personnel or surveyors being physically present at the study location. They utilize hand sheets, tally sheets, stopwatches, and basic manual counters to record vehicle data. This involves

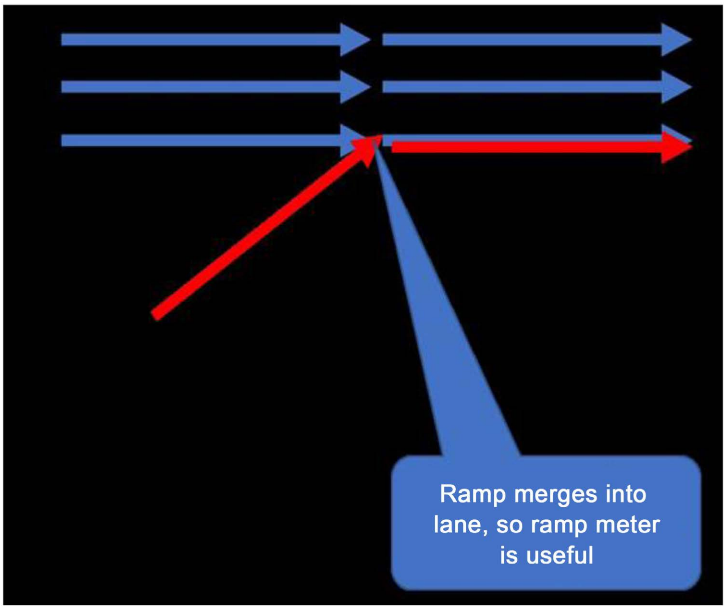

Figure 6. Case 1 ramp merges into lane.

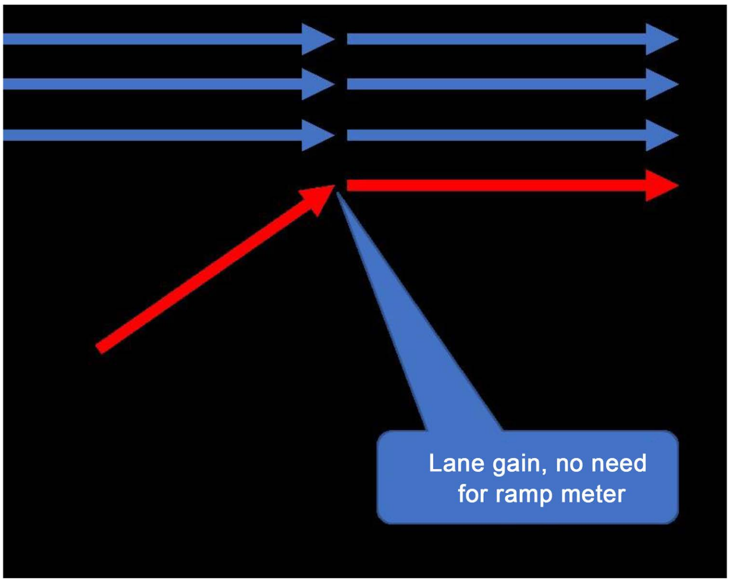

Figure 7. Case 2 extra lane gain

members stationed at predetermined locations for specified periods, observing and tallying vehicles passing by, taking into account vehicle types (light: car, minibus, etc. or heavy: bus, truck, etc.). This method has some limitations. Firstly, it is suitable only for locations with relatively low traffic volumes, such as roads during off-peak hours. This allows surveyors to realistically track and record vehicles, considering the limitations of human speed when simultaneously recording data and moving along the site. Second, it is sensitive to weather conditions and external events and cannot be conducted in bad weather. Third, not suitable for long-period tracking (maximum 30 min). However, it has the advantage that the surveyor can use the data immediately after collection.

- The indirect manual count involves using a camera to record a video of the actual flow of the vehicles on a particular road within a specific duration of time, either with the help of the surveyor or with the help of a camera stand. This method is applicable where there is a vast volume of traffic and multiple road lanes. This method enables the surveyor to get a chance to verify by repeating the video record several times later. Accurate data can be achieved by this method; however, it still needs effort and time after receiving the video from the owner to get the data in terms of counting the vehicles via the video with repetition for verification and then putting the data in tabulated form for analysis.

As the investigator classified the volume as high volume; hence, the indirect manual count method is used for this study.

3.1.2. Surveying Preparation

The preparation includes the provision of Personal Protective Tools in terms of a helmet and reflection jacket, provision of a camera, stand, and stopwatch.

3.1.3. Trial Surveying

A day before the actual surveying, a trial surveying was conducted to identify the proper location for recording video clips and to specify the timing. This was essential to avoid periods of traffic breakdowns, which could skew the accuracy of vehicle counts. Consequently, 7:00 am was selected as the optimal time, ensuring a steady traffic flow for accurate recording.

3.1.4. Actual Surveying

30-minute video recordings were conducted at the three spots that were considered for this study. The recordings were then processed using the InShot application to reduce the clips' speed and enable manual counting via the clips.

3.1.5. Building the Model in VISSIM

Data extracted from manual counting was used to feed VISSIM software. This study required two scenarios to be drawn such that the first scenario reflects the current traffic situation within the selected study zone while the second scenario reflects the traffic situation after the installation of RM.

3.2. Method Used for This Study

The surveyor selected the indirect manual counting method.

Reasons for selecting the indirect manual counting method.

- The automatic counting methods are not available.
- The direct manual count is not applicable as the volume was huge.

Challenges the surveyor faced while collecting data.

- The surveyor faced difficulty recording a video at the downstream spot as it was illegal to stop there. However, this was overcome by getting permission from a policeman just for 30 min.

3.3. Data Collection

Weather condition: A sunny and clear sky.

Location: The data was collected from Al Seeb Street in one direction. The exact location is illustrated in Figure 8 below.

3.3.1. Characteristics of Al Seeb Street

- Road type: duel road
- Road class arterial
- No. of lane each way = three lanes
- lane width = 3.65 m
- Shoulder width = 2.2 m
- Median width = 3 m
- Slop = 1.5%

3.3.2. Date & Time

The survey was on Thursday, 27th of October 2022. The recording was in the morning on a working day started recording at 7:29 am when the breakdown disappeared, and the flow began to move freely. The recording commenced at 7:30, coinciding with the peak hours of traffic in Muscat, Oman, which typically span from 6:00 am to 9:00 am. Within this timeframe, there is a high potential for traffic congestion, which is desirable for the study. However, excessive congestion leading to vehicle breakdowns disrupts traffic flow and does not accurately reflect the intended recording conditions. Therefore, the recording was initiated at 7:30 to avoid such breakdowns, which had previously occurred at the study location. This timing ensures the recording captures a consistent flow of vehicles at a certain speed, facilitating the accurate estimation of car volume passing through the designated spot.

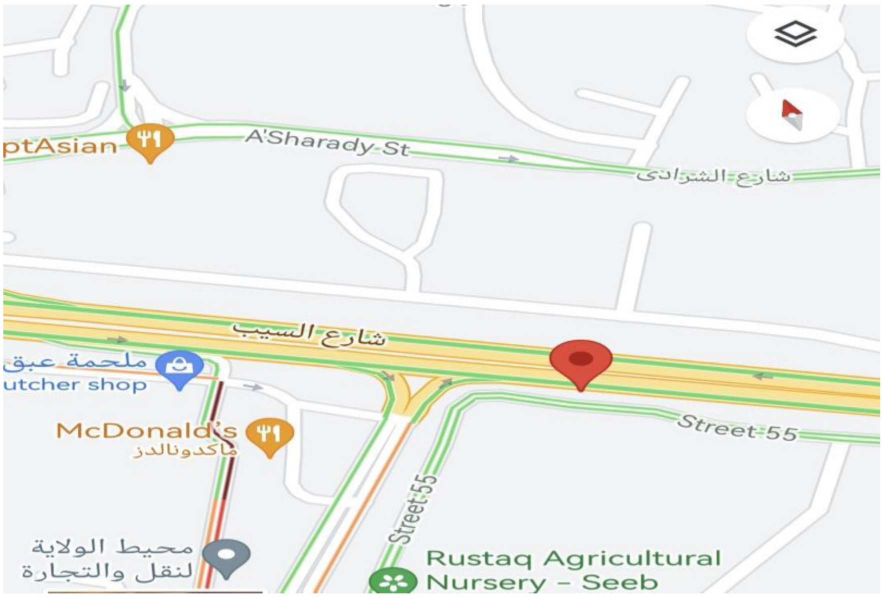

Figure 8. The study zone (google map).

3.3.3. Procedure of Manual Count Done for This Study

- The videos have undergone some adjustments using the InShot app that makes adjustments as desired so that to have an accurate count:
  - The video had been cut into mini videos, each of 5-time intervals.
  - Then, the running speed of each mini-video was slowed down to 50%.
  - Then, counting was taken place by classifying the light (cars/pickup/jeep/minibuses) as one group and heavy vehicles (bus/truck) as one group.
  - The data are tabulated.

3.3.4. The Collected Data at Upstream, Table 1

Surveyor's name: Zahra said Khalfan Al Habsi

Date: October 27, 2022 (Thursday, working day)

Time: 07:29 (peak hour)

Street name: Al Seeb highway street

Type of street: highway/arterial (main line)

Number of lanes: 3

Location: A (upstream)

Total duration: 30 min

3.3.5. The Collected Data at the Ramp Nose, Table 2

Surveyor's name: Zahra said Khalfan Al Habsi

Date: October 27, 2022 (Thursday, working day)

Time: 07:29 (peak hour)

Street name: Al Seeb Highway Street

Type of street: ramp road

Number of lanes: 1 lane

Location: B (at the nose of the Ramp)

Total duration: 30 min

3.3.6. The Collected Data Downstream, Table 3

Surveyor's name: Zahra said Khalfan Al Habsi

Table 1. Traffic data for 30 minutes upstream of the study zone.

Time interval (min)	Light vehicles	Heavy vehicles	Total
	Cars/jeep/pickup/minibus	Bus/truck	
00:00-00:05	178	3	181
00:05-00:10	177	1	178
00:10-00:15	220	5	225
00:15-00:20	225	5	230
00:20-00:25	218	4	222
00:25-00:30	200	8	208
total	1218	26	1244

Table 2. Traffic data for 30 minutes within the Ramp at the study zone.

Time interval (min)	Light vehicles	Heavy vehicles	Total
	Cars/jeep/pickup/minibus	Bus/truck	
00:00-00:05	46	0	46
00:05-00:10	43	0	43
00:10-00:15	37	1	38
00:15-00:20	50	1	51
00:20-00:25	47	0	47
00:25-00:30	52	2	54
total	275	4	279

Table 3. Traffic data for 30 min within downstream at the study zone.

Time interval (min)	Light vehicles	Heavy vehicles	Total
	Cars/jeep/pickup/minibus	Bus/truck	
00:00-00:05	241	9	250
00:05-00:10	272	8	280
00:10-00:15	259	13	272
00:15-00:20	265	7	272
00:20-00:25	227	10	237
00:25-00:30	252	7	259
total	1516	54	1570

Date: October 27, 2022 (Thursday, working day)
Time: 8:00 (peak hour)
Street name: Al Seeb Highway Street
Type of street: highway/arterial (main line)
Number of lanes: 3
Location: C (Downstream)
Total duration: 30 min

3.4. Data Analysis

3.4.1. Chart Representation of Data

The following pie charts reflect the data collected in three locations in percentages representing the type of vehicles. This study considers light vehicles as cars/jeeps/pick up/mini buses while heavy vehicles as buses/trucks. Figure 9 represents the types of vehicles at the Ramp; Figure 10 shows the data upstream, while Figure 11 shows the data downstream of the Ramp. Figure 12 illustrates the composition of all three streams.

3.4.2. Calculations of PHF and LOS

It is evident from the charts that the downstream is the convergent spot of two

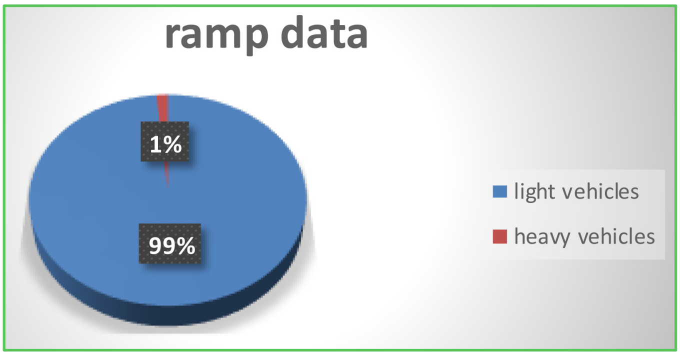

Figure 9. Pie chart showing the percentage of types of vehicles flow within Ramp.

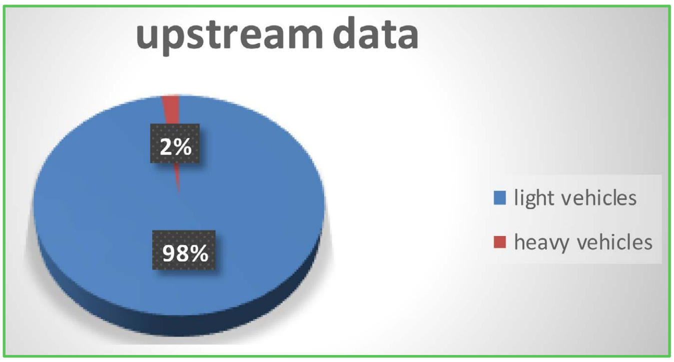

Figure 10. Pie chart showing the percentage of types of vehicles flow within upstream.

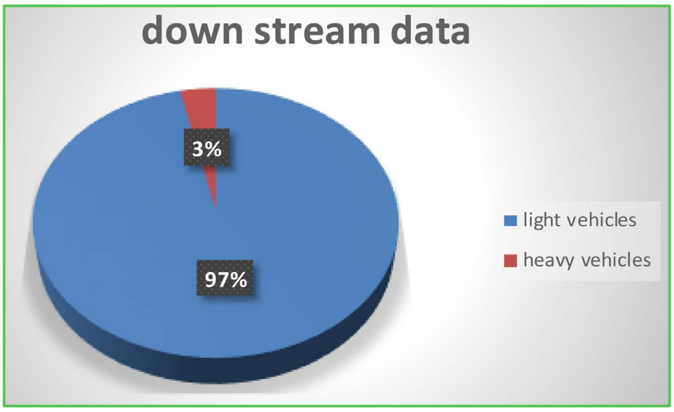

Figure 11. Pie chart showing the percentage of types of vehicles flow downstream.

streams, which need to be controlled to avoid a breakdown of the flow.

So,

- Service flow rate for downstream spot = no. of vehicles in downstream in 30 minute = 1570 × 2 = 3140 vehicle/hr
- Daily volume = Service flow rate × 24 = 3140 × 24 = 75,360 vehicles per day.
- Weekly working days volume = Daily volume × 5 = 376,800 vehicle/working days

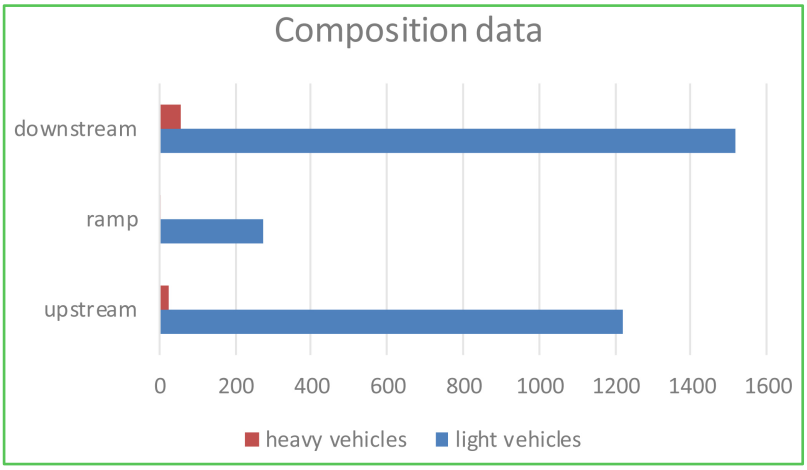

Figure 12. Bar chart showing a composition of the three streams.

PHF:

Since the downstream spot represents the converged stream of vehicles coming from the upstream spot and vehicles coming from the Ramp and also representing a road intersection, PHF is calculated downstream. The PHF was then used to identify the LOS of that street. To calculate PHF needed one-hour data, but the available data for the downstream spot is data corresponding to half an hour, so factor it by 2 (assuming the flow is identical to the first 30-minute flow in the worse case):

$$1570 \times 2 = 3140 \text{ vehicles/hour.}$$

From Table 3 related to the downstream, a 15-minute time interval volume is required; hence, with incorporation with the aforementioned assumption concluded that:

Traffic volume for first 15 minutes = 250 + 280 + 272 = 802

Traffic volume for the second 15 minutes= 272 + 237 + 259 = 768

Traffic volume for third 15 minutes = 250 + 280 + 272 = 802 (assumed)

Traffic volume for fourth 15 minutes = 272 + 237 + 259 (assumed)

PHF = (hourly volume/4 × volume count at highest 15-min) [11].

So,

PHF15 = hourly traffic volume/(4 × V15(max))

Where, V15(max) = 802 vehicle/15 min

Hence,

PHF15 = 3140/(4 × 802) = 0.97

LOS:

As the PHF15 value comes close to one, it means LOS is worse in terms of capacity (the road is mostly fully occupied by vehicles). Referred to the LOS Table 4.

From Table 4, it is clear that the LOS for the downstream spot is (F), which means the traffic volume is high and needs to be controlled. LOS F is characterized by a breakdown in flow, queues from behind, and demand > capacity.

Table 4. Level of service LOS [11].

Peak Hour Factor Value	LOS
0.7 or less	A
0.8 or less	B
0.85 or less	C
0.90 or less	D
0.95 or less	E
>1 or less	F

3.5. Simulation

- Background about a simulation of the transportation system in general:

It is an application of computer-based software to give a visual illustration of future scenarios as well as present through feeding the software with available transportation data such that based on the data, the scenario will be drawn with the least errors such that it helps the planning process and decision-making process. For this study, VISSIM software will be considered for simulation.

- Ramp metering system: it is a traffic-responsive system which is connected to sensors so that the sensors give a signal to the ramp metering to allow vehicle merge without causing speed to slow down for vehicles occupying the main line road and reduce huge queuing in on-ramp road as well.
- Background about VISSIM software: it is a microscopic simulator in which the time and behavior of drivers and features of vehicles are considered and modelling both urban traffic and public transit operations under several constraints such as traffic composition, lane configuration, transit stops, and traffic signals. [12]
- Significance of VISSIM simulation in the study:

The findings from the manual count will feed VISUM software for simulation purposes to see if the installation of the ramp-metering system will smooth the flow or not, then recommendations to be built based on the result of the simulation.

3.5.1. Scenarios Considered in This Simulation

As the traffic data was collected when the flow was moving (While a breakdown exists, no scene of collecting data), the observer waited till the flow started moving. The impact was that the on-ramp input reduced significantly), the matter that makes the collected data were not reflecting the actual situation when the speed of the vehicle started to slow down due to the on-ramp merging of vehicles and a breakdown formed as a result then a factoring up step was necessary to the vehicle inputs for both in mainline and on-ramp road to demonstrate a situation similar to the real in early peak hour within the study zone from 6:00-7:00 which is characterized with high volume and the vehicles have to slow down their speeds due to on-ramp merge. This was done by observing the study zone from 6:00 - 7:00. Based on observation, the vehicles within the mainline had been factored up by 2.67, and the vehicles within the on-ramp road had been factored up by 1.2. then, two factoring-up scenarios were built.

The original count scenario was necessary even if it reflects normal flow with no issue and represents no need for installing a ramp. As the results in the next chapter will show zero stops in the Ramp, it was necessary to reflect the data collected and to build the base model. The three scenarios considered in this study are as following:

1) Original count Scenario for no ramp meter reflecting 1 hour for the study zone.

2) Factored-up flows scenario for no Ramp Meter reflecting 1-hour run for the study zone.

3) Factored-up flows With Ramp Meter reflecting a 1-hour run for the study zone after installing the ramp meter.

Here below the screen shoots representing steps for modeling:

Background Step, Figure 13: The map background enables the simulator to draw the model exactly as it is in reality, in terms of shape, exits, on-ramps, and directions. The link's width is drawn as it appears in the map scale. This gives it a high degree of accuracy as software.

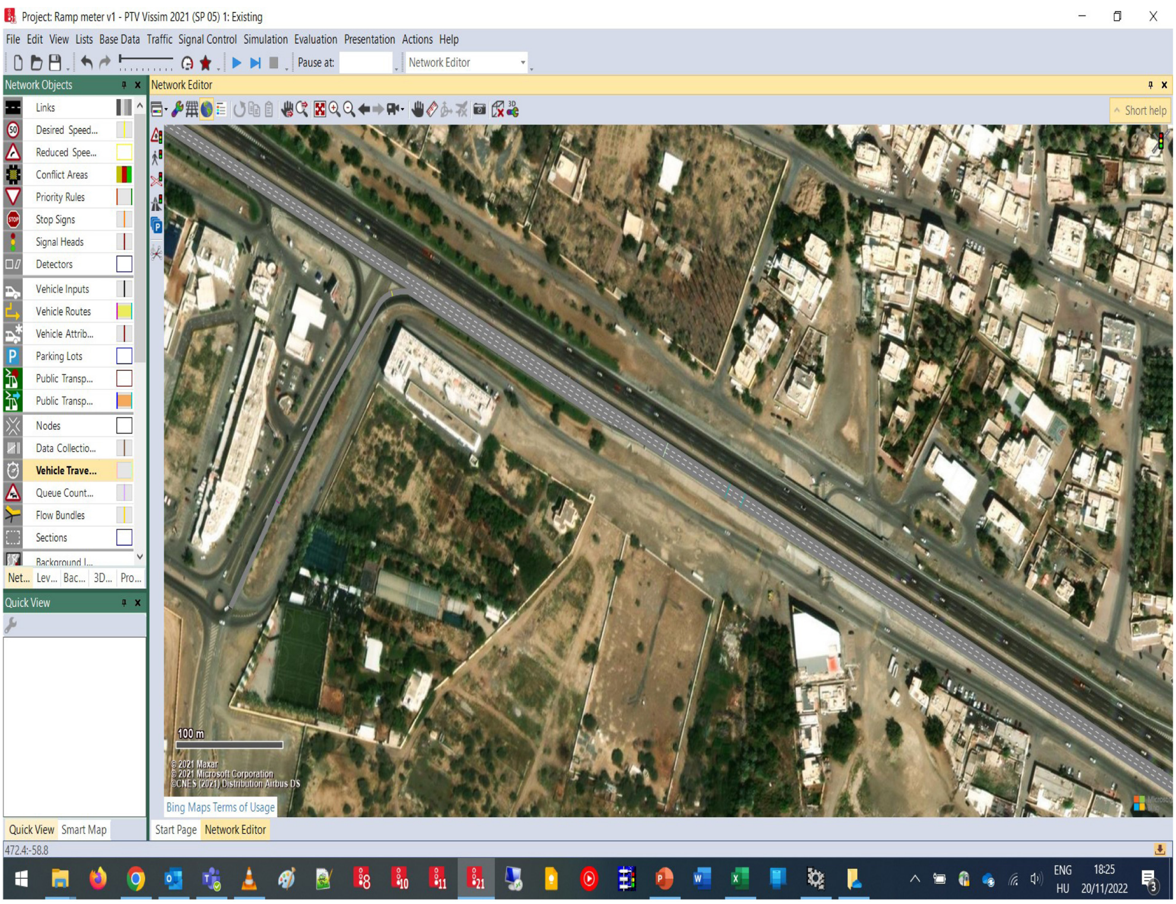

Figure 13. Map background. (Source: vissim 2022 extract)

Layout Step, Figure 14: The map background is removed after finishing the drawing. Just the model layout is kept with adding JT marks which indicate the considered distance for the journey time measurement for delay extraction for this model, which is about 2.5 km length within the mainline, and the purpose is to reflect the behavior of vehicles within the JT marks in terms of time delay and speed as well. This step is necessary for simplifying as it is impossible to simulate the whole street.

Vehicle Input Step (Figure 15 & Figure 16): entering vehicles input both in mainline and in Ramp such that for the original count scenario, the original upstream data is multiplied by two and original data collected from Ramp multiplied by two as the model is for one 1hour, and the collected data duration was for 30 min only that's why multiplied by 2. For the factored-up scenario with no ramp, the data for input entered for simulating the original count scenario were factored up by 2.67 for upstream and by 1.2 for Ramp (after factoring up decimal numbers, the correct numbers were considered only).

Vehicle Routing Step, Figure 17: Vehicle routing is necessary to assign vehicles to certain decisions while moving as many types of vehicle routing are provided in vissim software. The most common ones are either static routing or partial routing; for this study, static routing was chosen for all scenarios. Vehicle routing identifies the vehicle's decision to select the path/lane while entering the network. For static, the vehicles start from the farthest point in the model and in

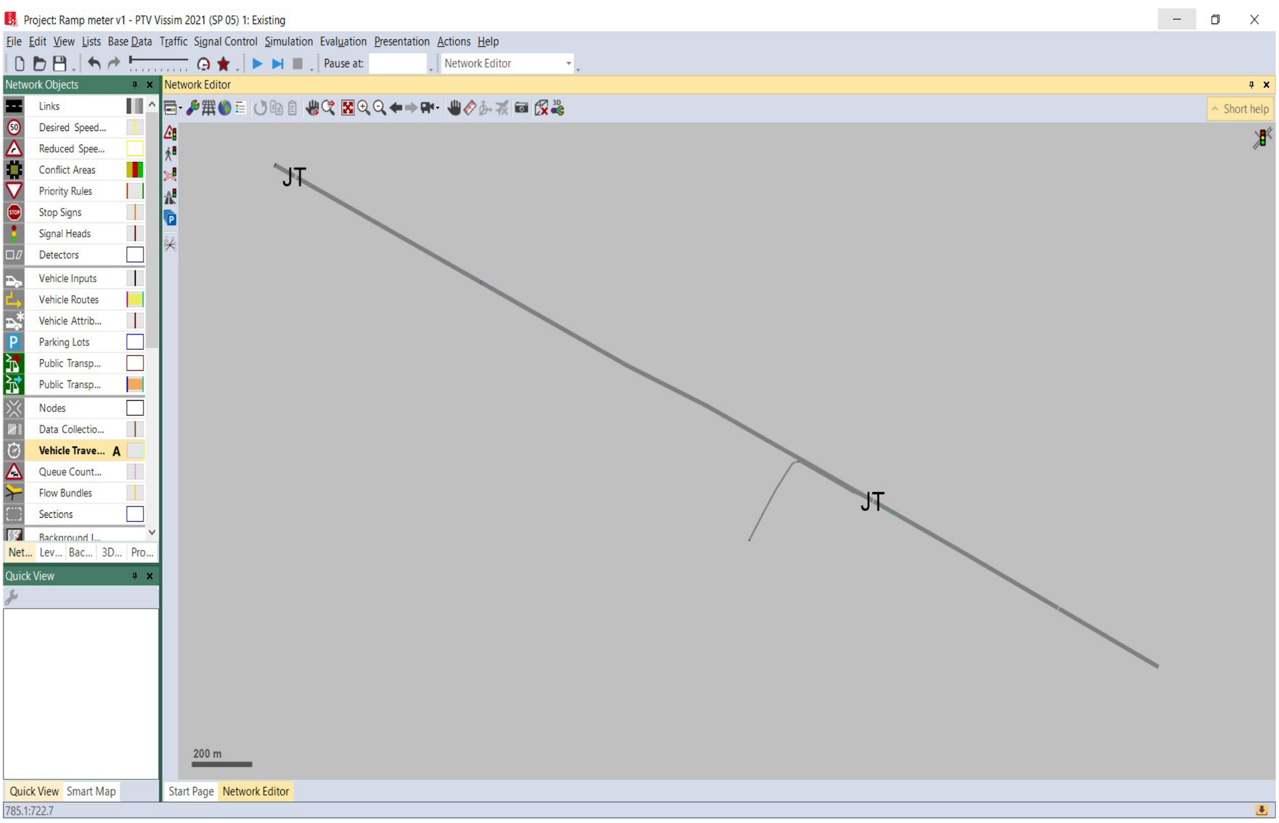

Figure 14. Model layout. (Source: vissim 2022 extract)

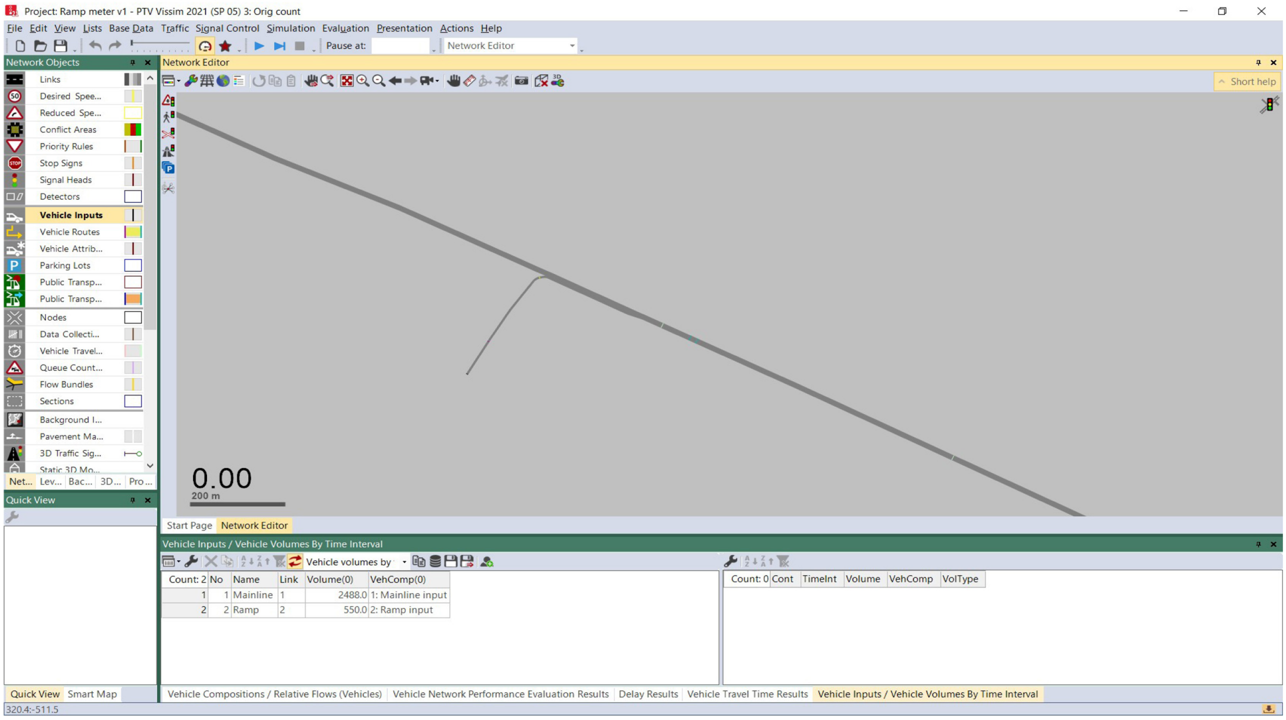

Figure 15. Vehicle inputs for original count scenario. (Source: vissim 2022 extract)

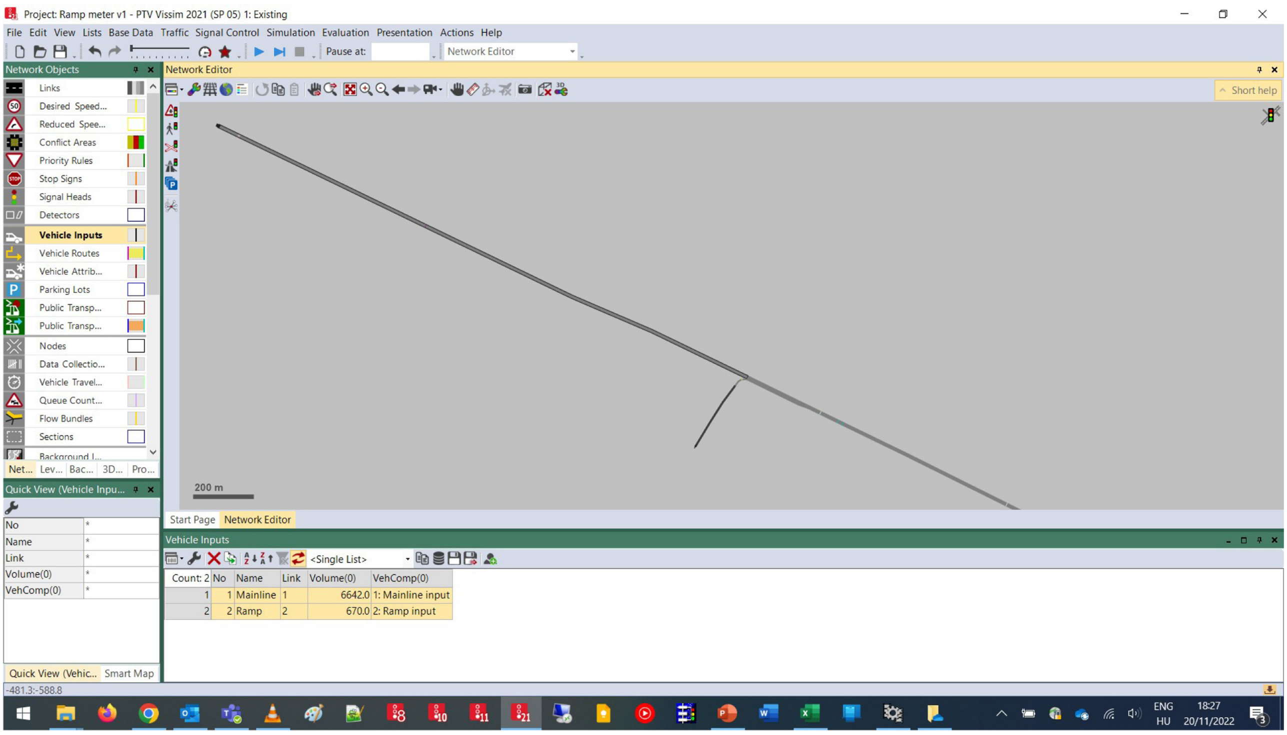

Figure 16. Vehicle inputs for factored-up scenario for no ramp. (Source: vissim 2022 extract)

a continuous link. In this study, the vehicles in the mainline upstream were assigned to have only one decision as left lane while meeting a car merging from the Ramp, while the vehicles coming from the Ramp have two decisions, either merging directly or stopping.

RM Step, Figure 18: This step was applicable just for the factored-up scenario with ramp metering in which the detectors were allocated downstream and on the Ramp; also, the ramp metering was located within 20 m with respect to the ramp nose.

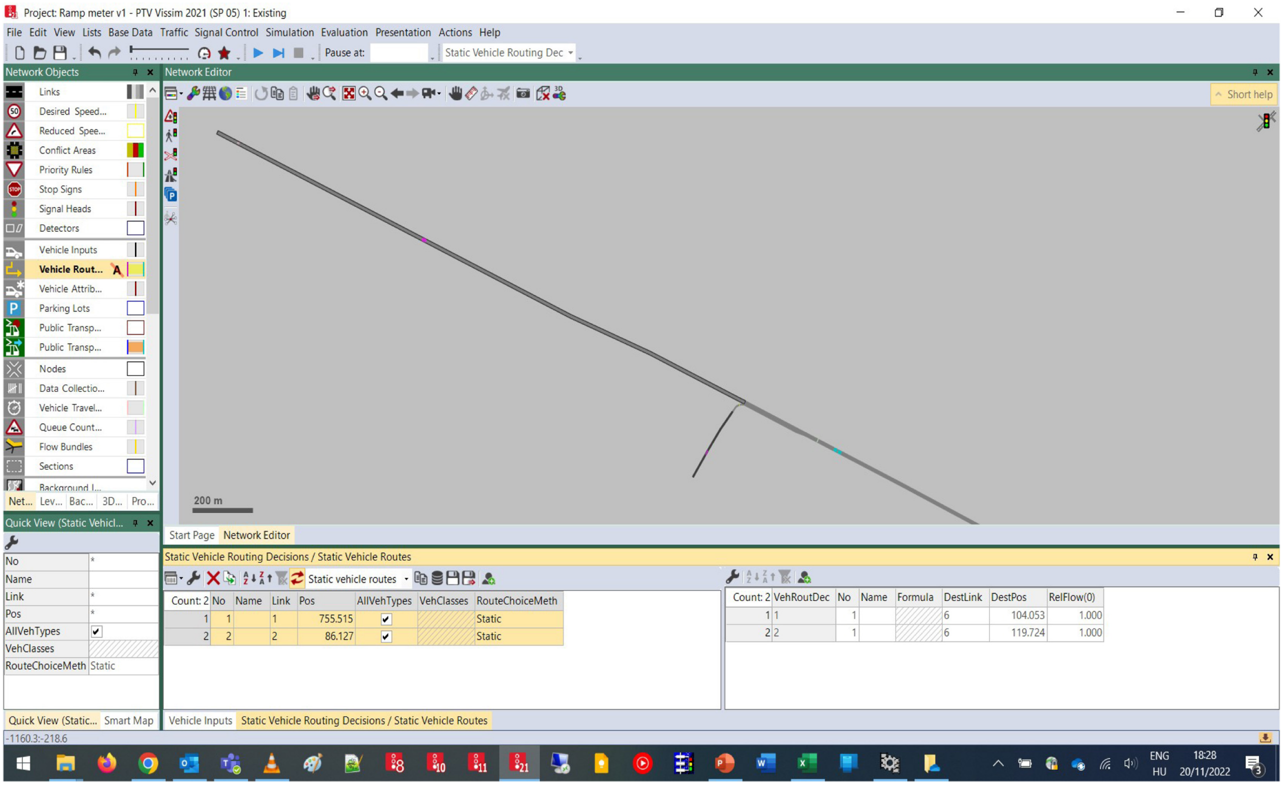

Figure 17. Vehicle routes for factored-up scenario for no ramp. (Source: vissim 2022 extract)

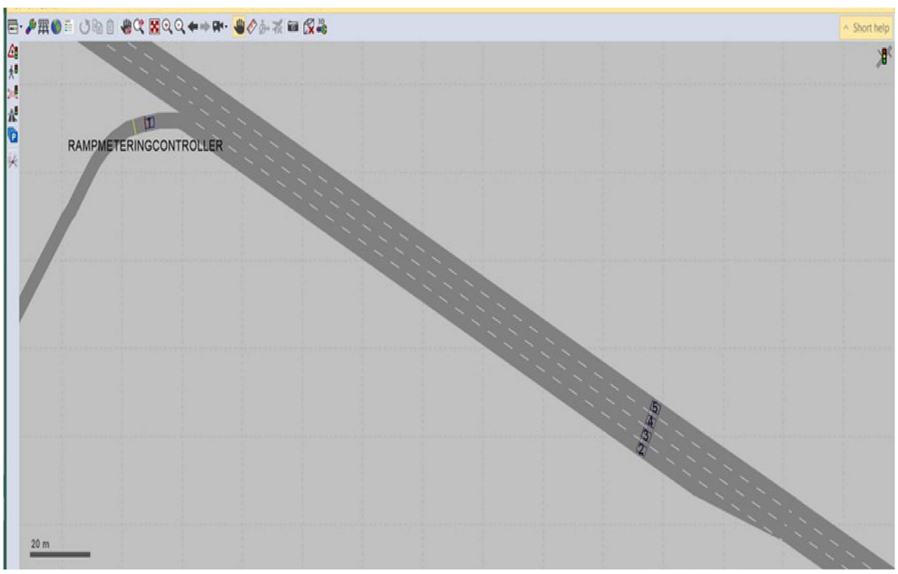

Figure 18. The position of ramp metering and detectors for the factored-up scenario with ramp metering. (Source: Vissim 2022 extract)

3.5.2. Calibration

Calibration is the number of iterations used to run the model before and after installing the RM for accuracy purposes. In this study, scenarios were run five times, each using different seeds, and then the average was taken for all five. This is done by using random seeds for each scenario per run, and consequently, parameters like speed, driving behavior, delay and travel time vary accordingly.

The seeds are shown in Figures 19-22.

4. Results and Discussions

4.1. Results for the Original Count Scenario

Discussion Related to the Original Count Scenario

Table 5 shows that the flow has no issue while vehicles merge from the on-ramp

Table 5. Results reflecting the original count scenario. (Source: Vissim 2022 extract)

Peak Hour Factor Value	Original Counts
Average network per vehicle (sec)	1.93
Delay along motorway (sec)	1.24
Journey time along the motorway (sec)	72.29
(A) Total delay (s) of vehicles in the network and exited vehicles (sec)	5929.96
(B) Total delay (s) of vehicles could not enter the network (sec)	114.58
Sum of all delays (A + B) (sec)	6045
Number of stops	0
Average speed (km/h)	102.74

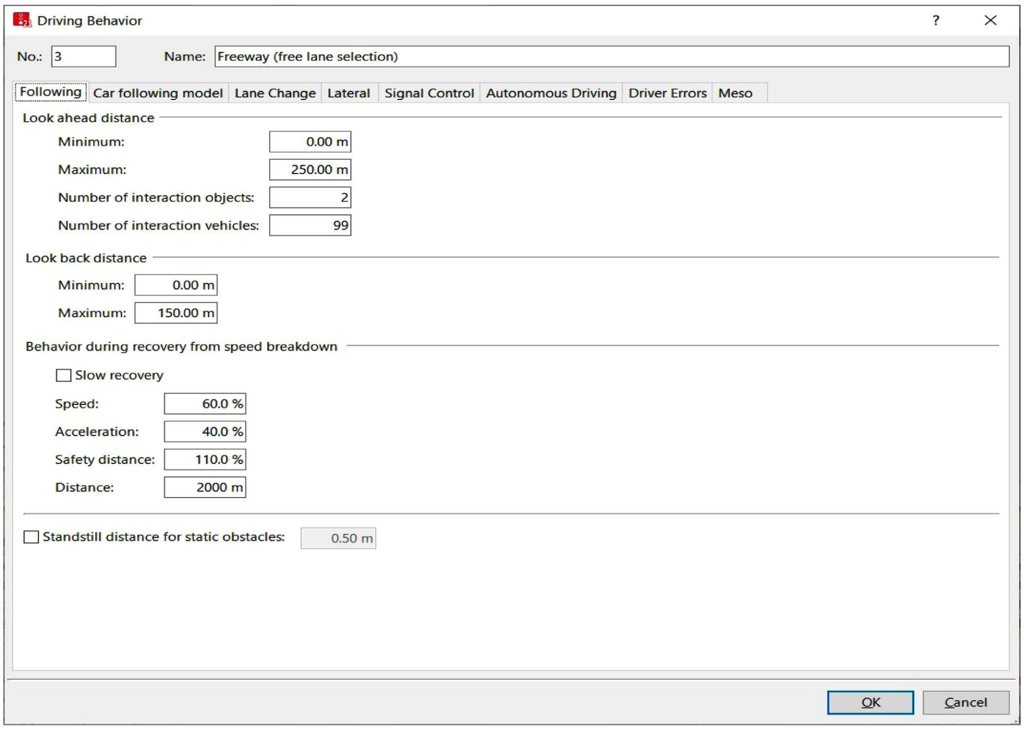

Figure 19. Driving behavior/following calibration (vissim 2022 extract).

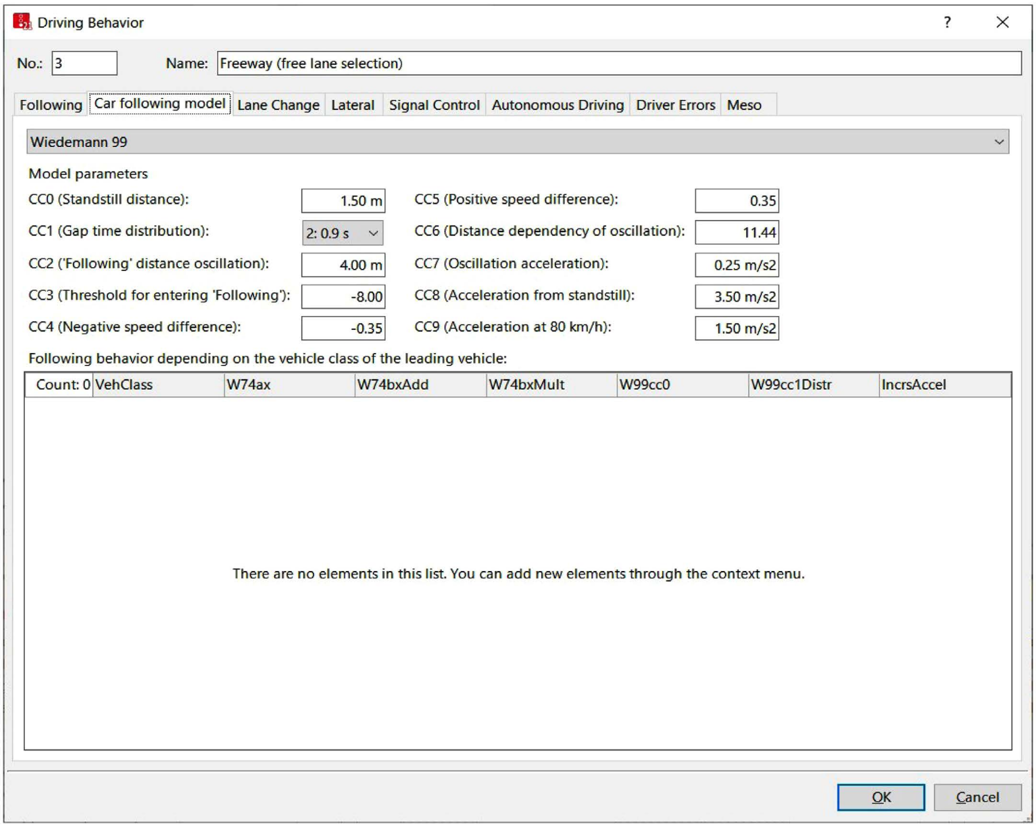

Figure 20. Driving behavior/car following model calibration (vissim 2022 extract).

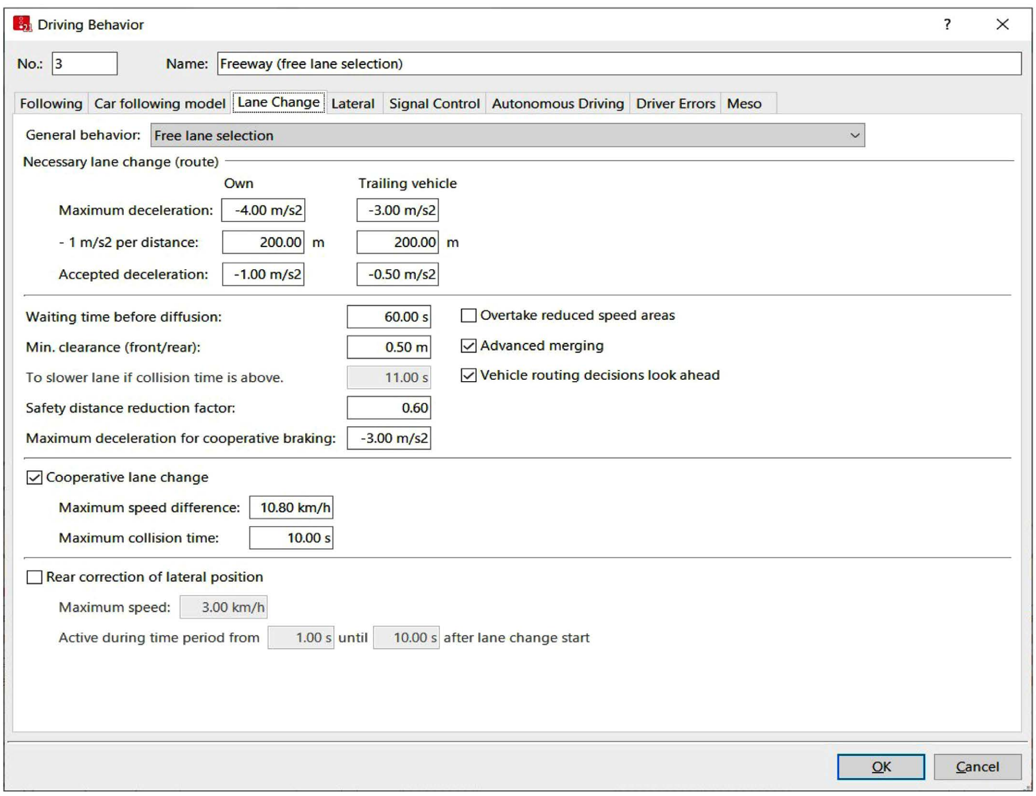

Figure 21. Driving behavior/lane change calibration (vissim 2022 extract).

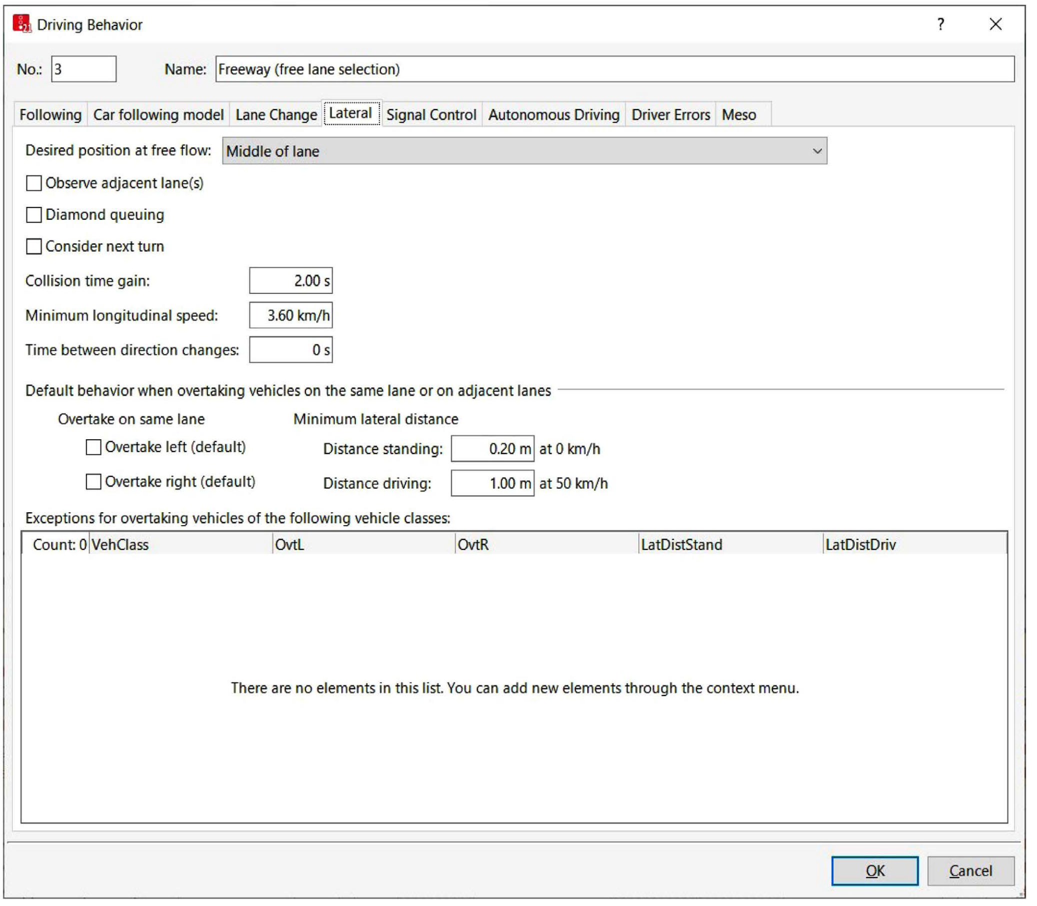

Figure 22. Driving behavior/lateral calibration (vissim 2022 extract).

road as there are no stop counts and the average speed is high, indicating the free flow of vehicles with no congestion and the delay is reasonable. Installing an RM in situations reflecting similar readings as in Table 5 is unnecessary.

4.2. Results for the Factored-Up Scenarios with RM and with No RM

Table 6 Results reflect two scenarios with a Ramp and with no Ramp. (Source: Vissim 2022 extract).

Discussion for Factored-Up Scenarios

From Table 6 below, we can evaluate the function of the ramp metering by comparing the overall delays with and without ramp metering and the average speed. The table shows good results once ramp metering is considered, so the second scenario gives a good difference in journey time and speed. By installing ramp metering, the overall time journey is reduced from 140 seconds to 121 seconds, and the speed of vehicles increases from 58 km/h to 61 km/h. Furthermore, the number of stops coinciding with no RM scenario is 16, which is reduced to 6 while RM is considered. In addition, the overall delays show a remarkable reduction from 916,874 seconds to 484,466 seconds. In reference to the

Table 6. Results reflect two scenarios with a Ramp and with no Ramp. (Source: Vissim 2022 extract)

Peak Hour Factor Value	No ramp meter	With Ramp meter	Diff (1-(with Ramp/No Ramp)
Average network per vehicle (sec)	36	26	28%
Delay along motorway (sec)	34	16	53%
Journey time along the motorway (sec)	140	121	14%
(A) Total delay (s) of vehicles in the network and exited vehicles (sec)	248,481	189,065	24%
(B) Total delay (s) of vehicles could not enter the network (sec)	668,393	295,402	56%
Sum of all delays (A + B) (sec)	916,874	484,466	47%
Number of stops	16	6	63%
Average speed (km/h)	58	61	−5%

study conducted by [13] titled "Evaluation of the Applicability of the Ramp Metering to a Freeway Using Microsimulation: A Case Study in Riyadh, Saudi Arabia" shows results aligned with this study in terms of getting better performance/control after installing RM.

5. Conclusion

Merging is one of the main factors that caused traffic congestion within the mainline in the selected study zone. This report studied the effectiveness of installing RM within the Ramp. For this, a base scenario (original count reflection) and two additional main scenarios were drawn, simulated and compared using VISSIM to assess the network's performance with and without RM. The simulation results, considering ramp metering as a smart solution for a similar situation to this study case, showed positive results in terms of delay reduction and overall performance of the network, reflecting the effectiveness of installing RM.

6. Recommendations

6.1. Recommendation Based on Outputs

Need to adopt simulation software, *i.e.* VISSIM software, in governmental transportation Omani institutions to give a chance to check the functionality of smart solutions before taking decisions in terms of tables with different parameters and visualizations before and after. Currently, none of the transportation governmental entities in Oman host such software. However, the Ministry of Transportation has a similar software (VISUM), although it is not activated yet. It differs from VISIM and has no feature to examine ITS systems, whereas VISSIM has multiple futures to examine ITS systems.

6.2. Recommendation for Future Work

- A short count was considered for this study (only 30 minutes). It is recommended to extend the duration for data collection to be not less than one hour.
- Due to resource constraints normal video recording was taken for this study, but for more realistic data better to consider CCTV/Video with processing and classifying system. Recommended to use CCTV/Video with processing and classifying system if available.
- Lack of surveyors as this study relayed only one surveyor. Recommended to ensure a team of expert surveyors of not less than four members.
- To receive approval from traffic police ahead of time before counting is started to avoid any inconvenience.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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List of Abbreviation

VISSIM: Verkehr- In Städten – SIMulation, Microsimulation Traffic Software
RM: Ramp Metering
ANN: Artificial Neural Network
MATLAB: Matrix Laboratory
PSO: Particle Swarm Optimization
PID: Proportional Integral Derivative
PARAMICS: Three-Dimensional Traffic Modelling Software
ALINEA: Algorithmic Model
AIMSUN: Traffic Modelling Software.
PHF: Peak Hour Factor
LOS: Level of Service