AASCTF PENANG SMART MOBILITY MICRO-SIMULATION MODEL DEVELOPMENT

TRIAL AREA MODEL SCENARIO TESTING REPORT

OCTOBER 2022

ASEAN AUSTRALIA SMART CITIES TRUST FUND
Asian Development Bank

Australian Government
Department of Foreign Affairs and Trade

ADB

Project name	**Task Order No. 6 – Penang Smart Mobility Micro-Simulation Model Development**
Client name	**Asian Development Bank**
Type of report	**AASCTF Penang Smart Mobility Micro-Simulation Model Development – Trial Area Model Scenario Testing Report**
Date	**07/10/2022**
Company	**Ramboll**
Authored By	**Xu Yiheng & Ravindra Varma Datla**
Checked By	**Richard Sprosen**
Approved By	**Nick Fellows**

Adobe Stock

CONTENTS

TABLES

FIGURES

FIGURES

FIGURES

1 INTRODUCTION

Photo: Adobe Stock

1.1 BACKGROUND

Ramboll has been engaged through the ASEAN Australia Smart Cities Trust Fund (AASCTF) to conduct a Pilot Project for Penang. This Pilot Project intervention involves the development of a Transport Micro-Simulation Model of the historical center of Georgetown that can be used to assess future mobility interventions such as public transport, traffic improvements, pedestrianization and cycling improvements.

This pilot project will involve the development and calibration of the micro-simulation model using PTV Vissim software and testing of a limited set of potential future interventions for Georgetown, as well as training of Digital Penang / MBPP staff in the use of PTV Vissim. As the first batch of scenarios tested for the pilot area, this report includes four scenarios developed for the pilot area, covering traffic management measures on pedestrian / cyclist priority, public transport priority, traffic layout enhancement, and testing of traffic impact of new development.

This report presents the scenario testing results and comparison between results for scenarios considered. The use of this Vissim micro-simulation model will enable Penang to:

- provide the authority with an efficient tool to check and assess the implications of developer plans, and thus improve the implementation and enforcement of transportation policies;
- test and trial the implication of different transportation policies and designs (e.g., parking, e-buses, micro-mobility, car-free spaces, etc.);
- better communicate implications of transport policies and solutions to decision makers, developers and to the public; and
- knowledge-share with planners in Georgetown to provide the skills and tools to continue to enhance and improve smart mobility strategies moving forward.

1.2 ORGANIZATION OF THE SCENARIO TESTING REPORT

Following this introduction, the report is structured as follows:

- Chapter 2 provides detailed description of the four testing scenarios considered for the pilot area;
- Chapter 3 presents the information on study methodology adopted to develop micro-simulation models for all the scenarios;
- Chapter 4 summarizes the key model measurement results for assessment of all the scenarios;
- Chapter 5 provides a detailed comparison of model results between scenarios;
- Chapter 6 presents the next steps of this study.

2 SCENARIO DESCRIPTION

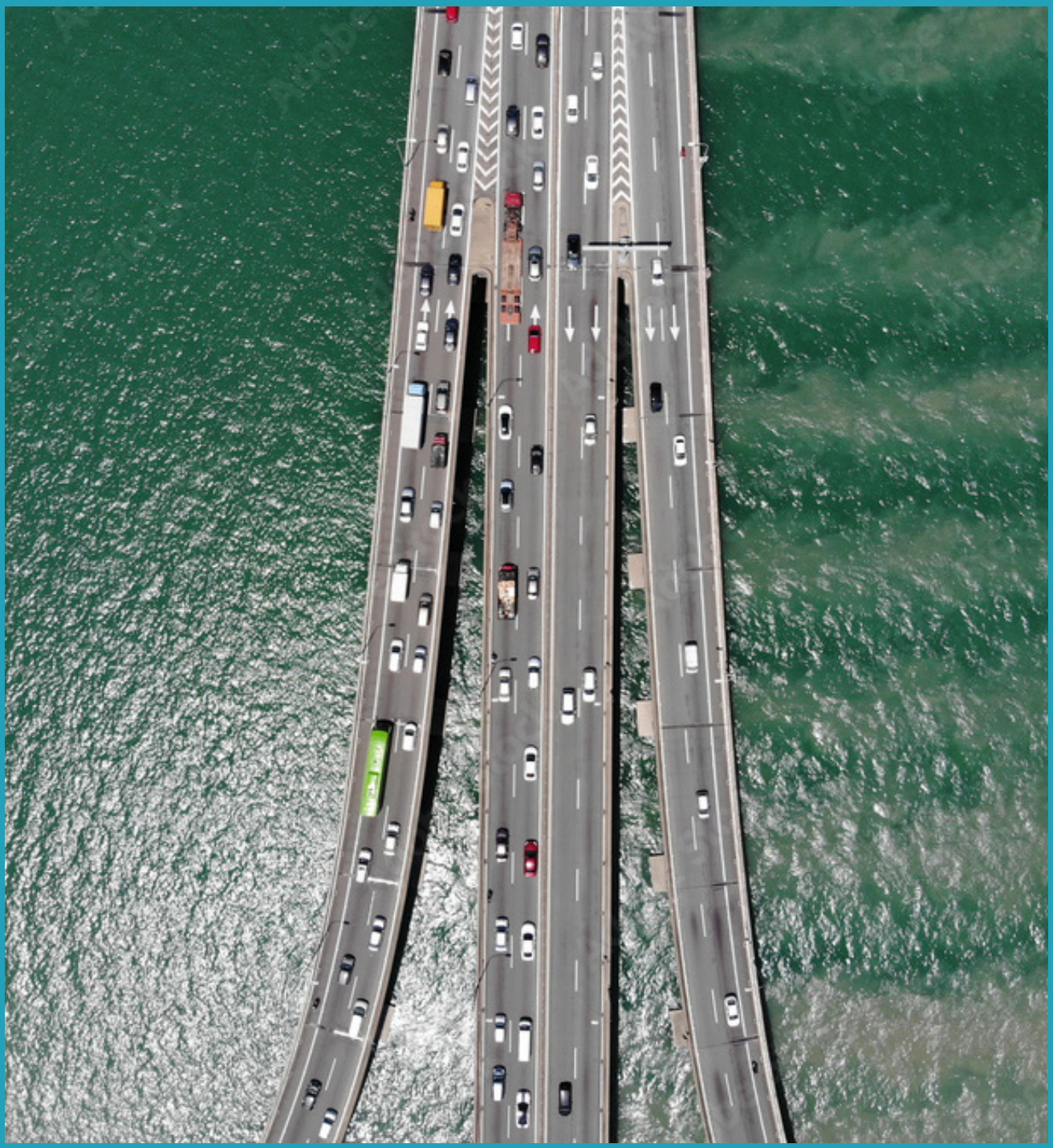


Photo: Adobe Stock

The following section outlines the development of intervention scenarios to be tested in the Stage 1 Pilot Area micro-simulation model development.

The working group (Ramboll, JA Consult, Digital Penang and MBPP) have held a number of meetings to discuss the intervention scenarios that will be tested in the Stage 1 Trial Micro-Simulation model. The basis for developing intervention options was the outcomes derived from the Penang Transport Masterplan 2030 (PTMP) and the Penang Green Transport Plan (PGTP), the latter gave a number of specific proposals for the Georgetown area which have broadly been adopted in the scenarios outlined below.

Four scenarios have been developed each with a different focus. The scenarios are tested in the calibrated pilot area micro-simulation model. Following completion of the Task Order/Pilot Project intervention, the models will be given to Digital Penang and MBPP who can then test further interventions in the future.

The intervention scenarios include:

- Scenario 1: Pedestrian and Cyclist Priority
  - Scenario proposed for this study focuses on providing priority pedestrian and cyclist corridors in the core area of Georgetown
- Scenario 2: Traffic Improvements
  - In this scenario, emphasis is given to understand the change in overall road network performance after adopting proposed road network improvements.
- Scenario 3: Public Transport Improvements
  - Main objective of this scenario is to understand the impact of implementation of dedicated public transport lanes on some sections of the study area on the road network performance.
- Scenario 4: Traffic Impact of New Development
  - Impact of additional traffic on road network due to new proposed developments is tested in this scenario.

Proposed detailed interventions in each scenario have been outlined below. Scenario development for Stage 2 will be conducted following the completion and presentation of Stage 1 in order to give stakeholders a clear understanding of the micro-simulation modelling strengths and capabilities.

2.1 SCENARIO 1: PEDESTRIAN AND CYCLIST PRIORITY

Scenario 1 proposed for this study focuses on providing priority pedestrian and cyclist corridors in the core area of Georgetown.

These facilities would mean pedestrians and cyclists will enjoy wider space when commuting through the city and be given priorities at key junctions. Overall, these measures are designed to improve the pedestrian experience and reduce the travel time needed through the city, resulting in a larger shift from traditional private car mode to walking and cycling.

Vissim simulation model is being used to test out the effectiveness on the priority scheme, as well as the impact on vehicular traffic when these schemes are implemented. The detailed traffic scheme changes are documented as in the figure and table below.

Figure 2-1: Scenario 1 Scheme

Individual traffic schemes proposed within this scenario are outlined, based on the location in the model area, in the table below.

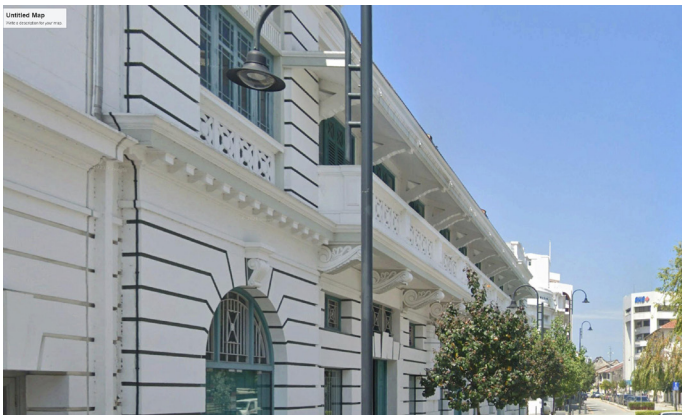
Table 2-1: Scenario 1 Scheme Details

Scenario 1		
Theme	**Road**	**Details (as discussed with Digital Penang)**
Pedestrian Priority	**Gat Lebuh China:** Pedestrian Walk 1 & 2	To expand the pedestrian walk with the following measurement: 1) Pedestrian walk total width: 5.5m with separation as follows: a) Walking path: 2.4m b) Small retail street: 2.1m c) Landscaping: 1m Proposed pedestrian priority facilities on Gat Lebuh China are shown in Figure 2-2 and Figure 2-3.
Pedestrian Priority	**Pengkalan Weld Street:** Pedestrian Walk 1 & 2	To expand the pedestrian walk with the following measurement: 1) Pedestrian walk total width: 4m with separation as follows: a) Walking path: 2.4m b) Landscaping: 1.5m Figure 2-4and Figure 2-5 below provides detailed information of pengkalan weld street in scenario-1.
Pedestrian Priority	**Pengkalan Weld Street:** Pedestrian Crossing 1	Propose to maintain the location with several upgrades as follows: i) Using Traffic Clamed Crossing with: - Actuated Signalling - Vertical speed control element set 5m to 10m from the cross. - Use pedestrian-activated warning lights, flashing beacons, or High Intensity Activated Crosswalks (HAWK) to increase motorists' awareness and improve pedestrian safety. 2) Ideally, pedestrian crossing is place at the inter-junction or at the mid-block. As existing crossing exist in the middle of Gat Lebuh Pasar, propose to close the road. Figure 3-2 provides pictorial information on vertical speed control and actuated signals.
Pedestrian Priority	**Pengkalan Weld Street:** Pedestrian Crossing 2	Pedestrian Cross location: 1) Shall place max 100m from Downing Street. If it takes a person more than 3 minutes to walk to a pedestrian crossing, he or she may decide to cross along a more direct, but unsafe or unprotected, route. 2) Install a pedestrian crossing where there is a significant pedestrian desire line. In this case pedestrian from Downing Street to Swettenham Pier. 3) A pedestrian crossing should be at least 3 m wide. 4) Using Traffic Clamed Crossing with: - Actuated Signalling - Vertical speed control element set 5m to 10m from the cross. - Use pedestrian-activated warning lights, flashing beacons, or High Intensity Activated Crosswalks (HAWK) to increase motorists' awareness and improve pedestrian safety. Figure 3-2 provides pictorial information on vertical speed control and actuated signals.

Pedestrian Priority	**Beach Street:** Pedestrian Walk 1 & 2	To expand the pedestrian walk with the following measurement: 1) Pedestrian walk total width: 3m with separation as follows: a) Walking path: 2.4m b) Street Light: 0.6m Proposed pedestrian priority facilities on beach street are shown in Figure 2-6 and Figure 2-7.
Pedestrian Priority	**Lebuh Victoria:** Pedestrian Walk 1 & 2	To expand the pedestrian walk with the following measurement: 1) Pedestrian walk total width: 3m with separation as follows: a) Walking path: 2.4m b) Street Light: 0.6m Figure 2-8 and Figure 2-9 below provides detailed information of Lebuh Victoria in scenario-1.
Pedestrian Priority	**Gat Lebuh Gereja:** Pedestrian Walk 1 & 2	To expand the pedestrian walk with the following measurement: 1) Pedestrian walk total width: 5.5m with separation as follows: a) Walking path: 2.4m b) Small retail street: 2.1m c) Landscaping: 1m Proposed pedestrian priority facilities on Gat Lebuh Gereja are shown in Figure 2-10 and Figure 2-11.
Pedestrian Priority	**Downing Street:** Pedestrian Walk 1 & 2	To expand the pedestrian walk with the following measurement: 1) Pedestrian walk total width: 5.5m with separation as follows: a) Walking path: 2.4m b) Landscaping: 1.5m Pedestrian priority facilities provided on Downing Street are Shown in Figure 2-12 and Figure 2-13.
Cyclist Priority	**Gat Lebuh China:** Bike Lane 1 & 2	Bike lane to be designed using Curbside Buffered Cycle Lane type, with the measurement as follows: 1) Lane width: 1.8m 2) Demarcation width: 1m Cycle path provided is shown in Figure 2-2 and Figure 2-3
Cyclist Priority	**Pengkalan Weld Street:** Bike Lane 1 & 2	Bike lane to be design using Protected Cycle Lane type, with the measurement as follows: 1) Lane width: 2m 2) Demarcation width: 1m Figure 2-4 and Figure 2-5 shows the cycle path provided on Pengkalan weld.

The following images shows the comparison of existing and proposed schemes in street view and section view, as per location.

Existing



Proposed

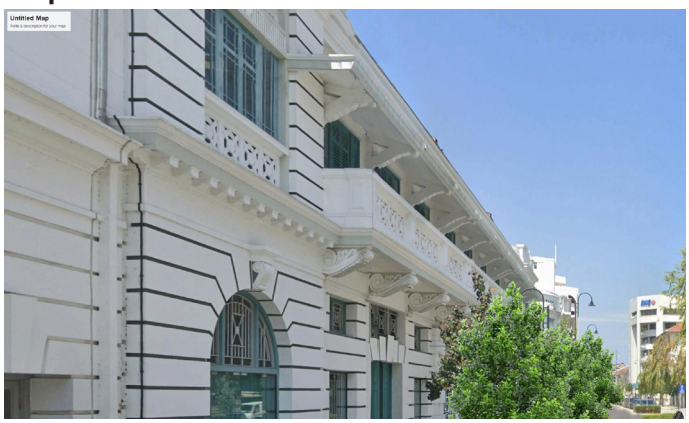
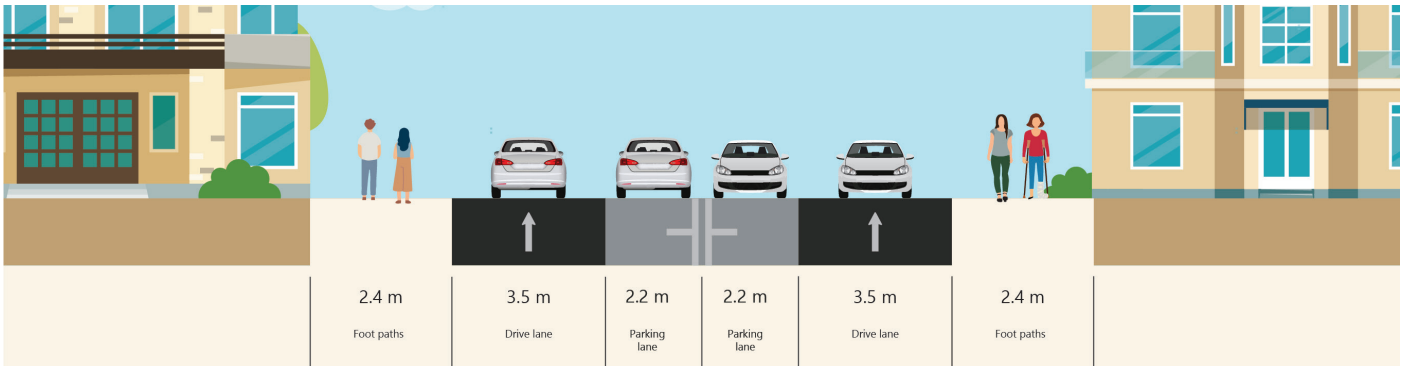


Figure 2-2 Scenario 1 Scheme Comparison Street View – Gat Lebuh China

Existing



Proposed

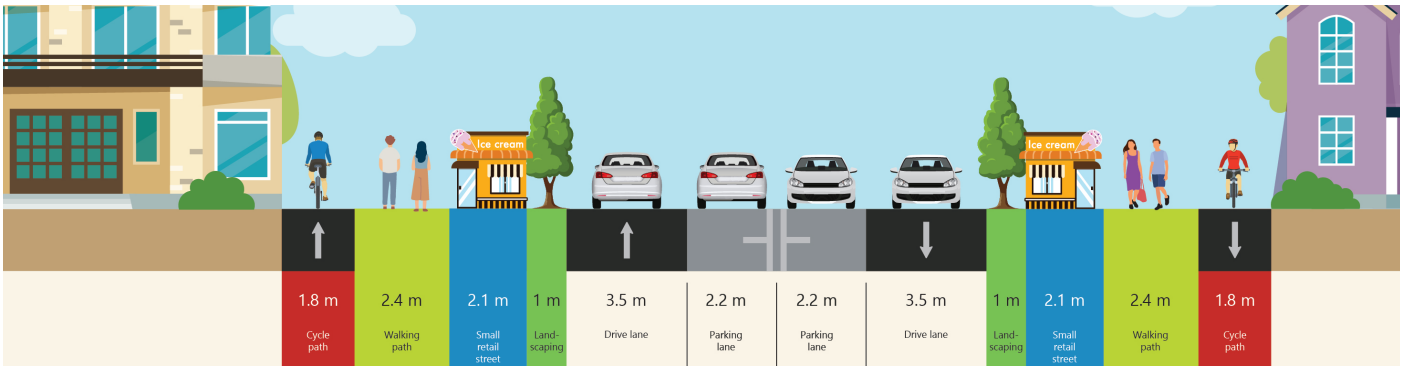


Figure 2-3 Scenario 1 Scheme Comparison Section View – Gat Lebuh China

Existing

Proposed

Figure 2-4 Scenario 1 Scheme Comparison Street View – Pengkalan Weld

Existing

Proposed

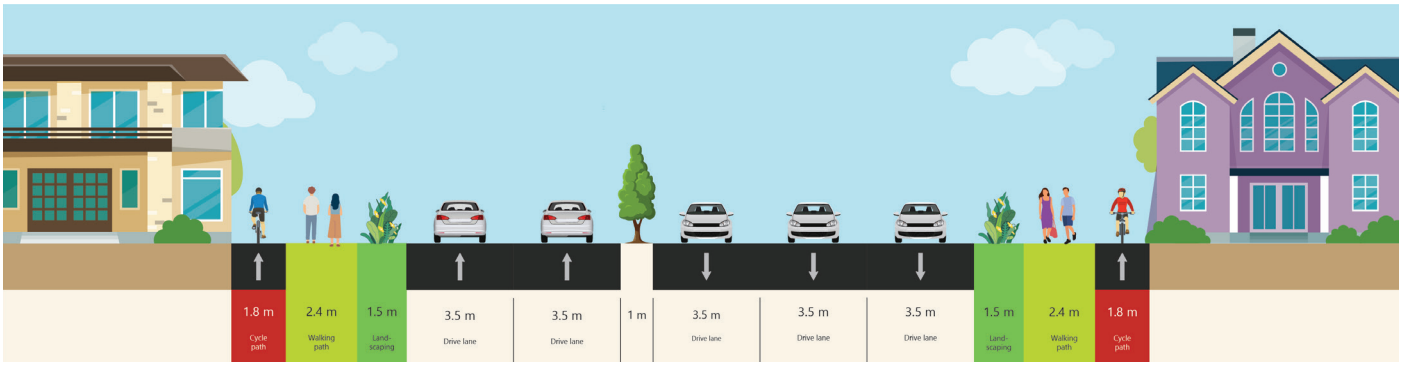


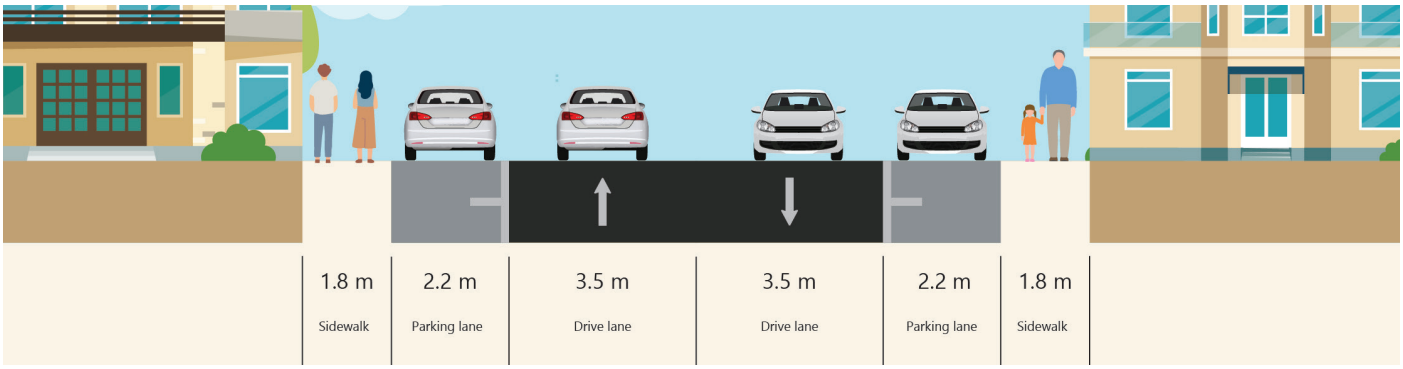
Figure 2-5 Scenario 1 Scheme Comparison Section View – Pengkalan Weld

Existing

Proposed

Figure 2-6 Scenario 1 Scheme Comparison Street View – Beach Street

Existing



Proposed

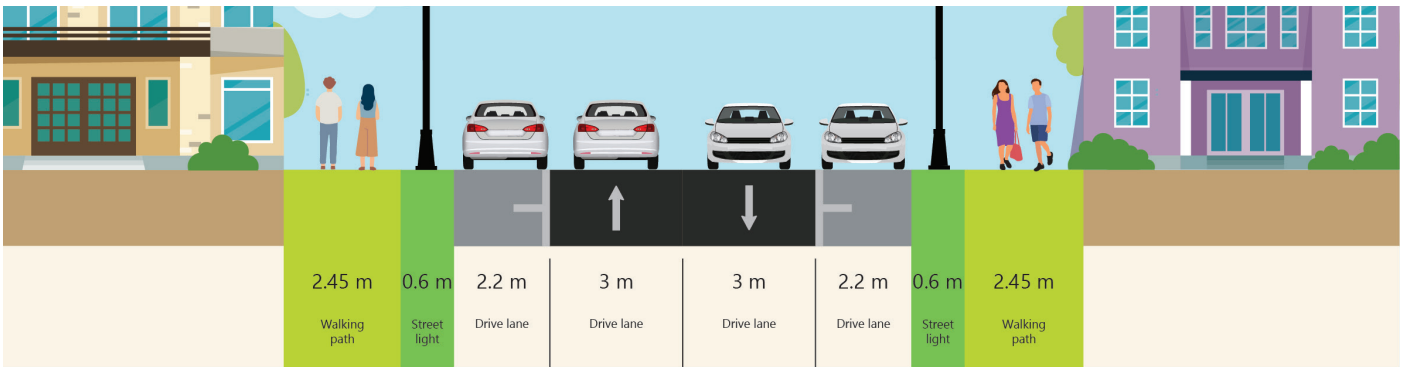


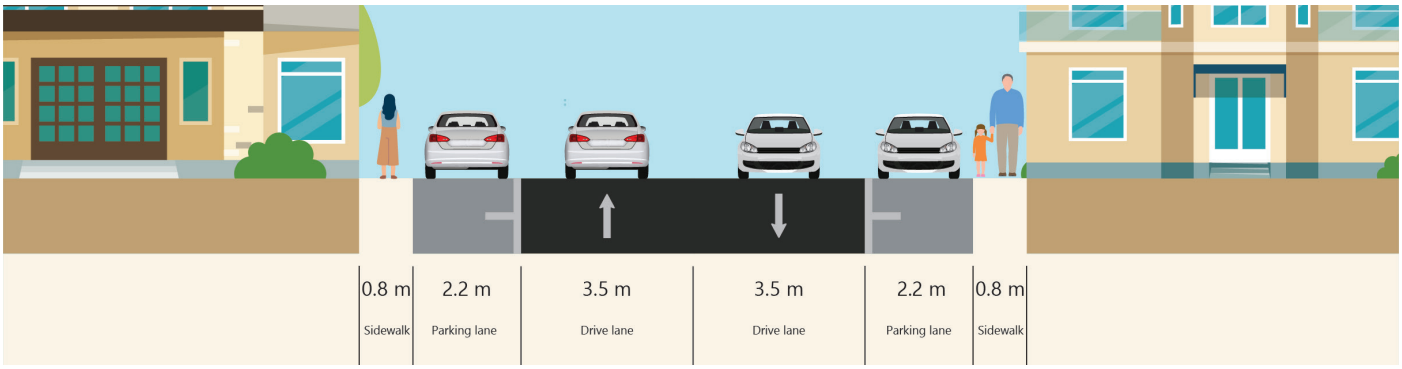
Figure 2-7 Scenario 1 Scheme Comparison Section View – Beach Street

Existing

Proposed

Figure 2-8 Scenario 1 Scheme Comparison Street View – Lebuh Victoria

Existing



Proposed

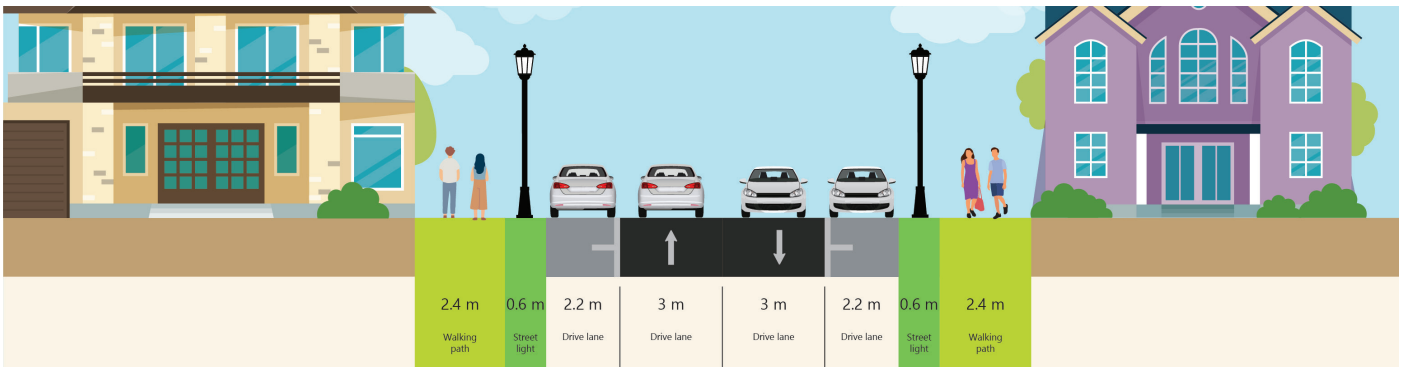


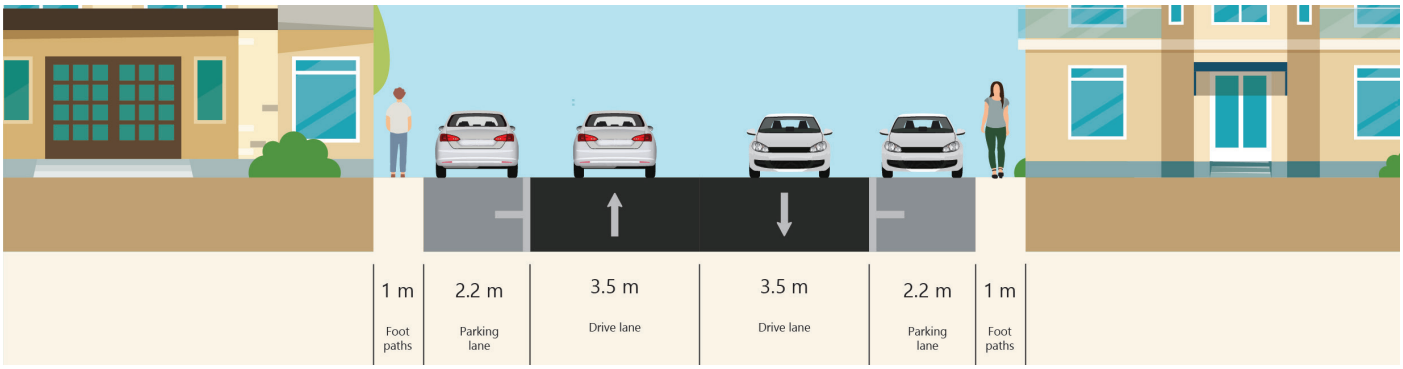
Figure 2-9 Scenario 1 Scheme Comparison Section View – Lebuh Victoria

Existing

Proposed

Figure 2-10 Scenario 1 Scheme Comparison Street View - Gat Lebuh Gereja

Existing



Proposed

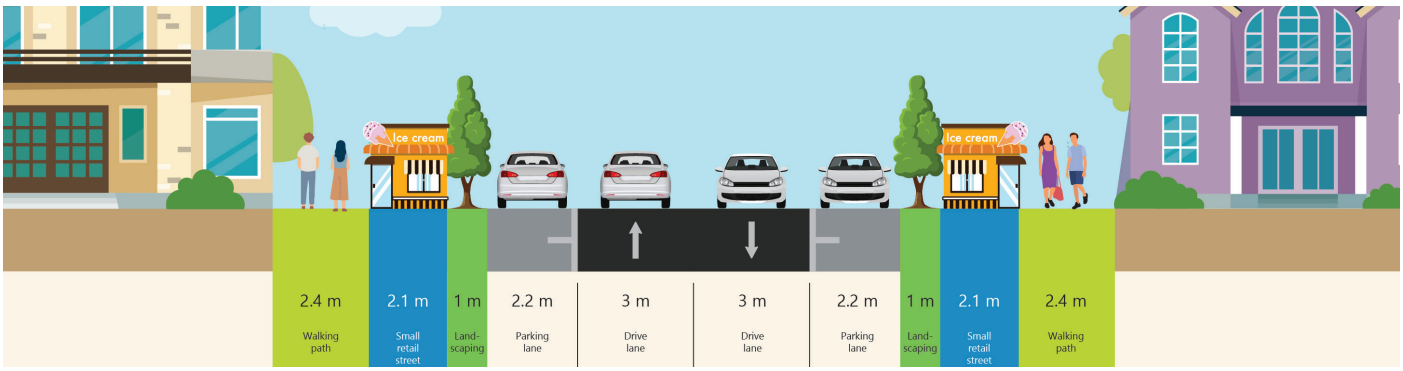


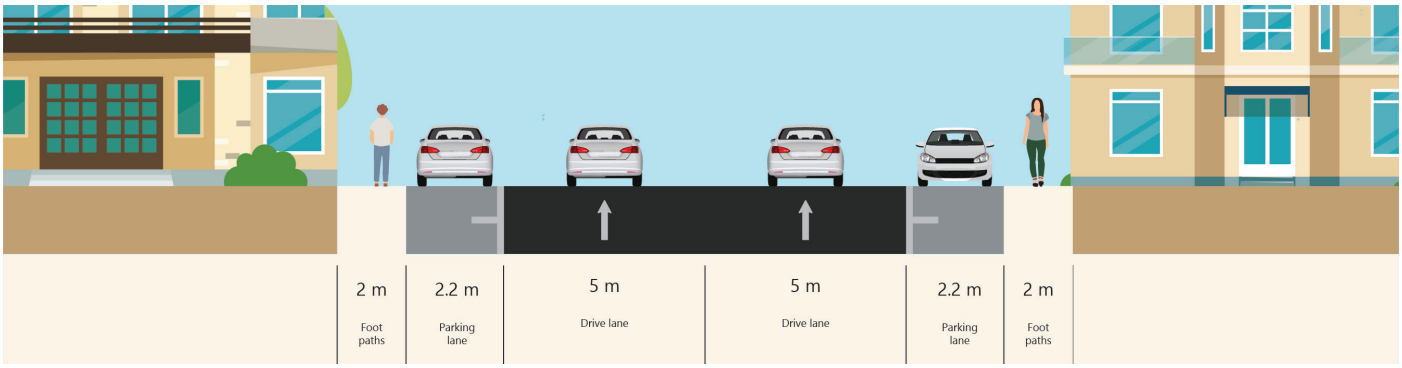
Figure 2-11 Scenario 1 Scheme Comparison Section View - Gat Lebuh Gereja

Existing

Proposed

Figure 2-12 Scenario 1 Scheme Comparison Street View – Downing Street

Existing



Proposed

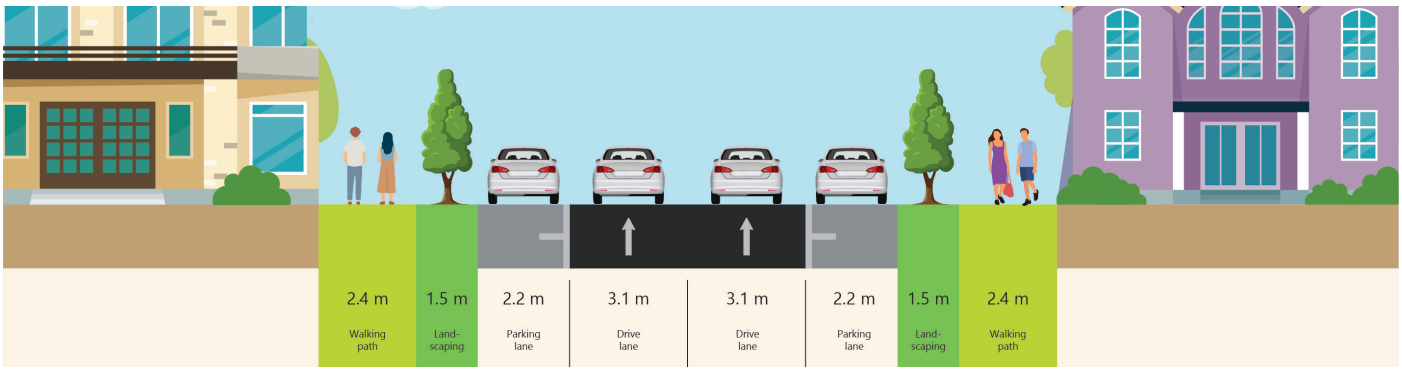


Figure 2-13 Scenario 1 Scheme Comparison Section View – Downing Street

2.2 SCENARIO 2: TRAFFIC IMPROVEMENT

The overall objective of this scenarios is to understand road network performance on implementation of some road network improvements. The improvements could include conversion of two-way road to one-way road, closure of road, and removal of parking.

These road network improvements are modelled in Vissim and its impact on road network performance is analysed from model measurements of the revised model. Testing of these types of scenarios in Vissim will help decision makers to understand road network performance prior to implementation of any improvements. The detailed traffic scheme changes are documented as in the figure and table below.

Figure 2-14: Scenario 2 Scheme

Table 2-2: Scenario 2 Scheme Details

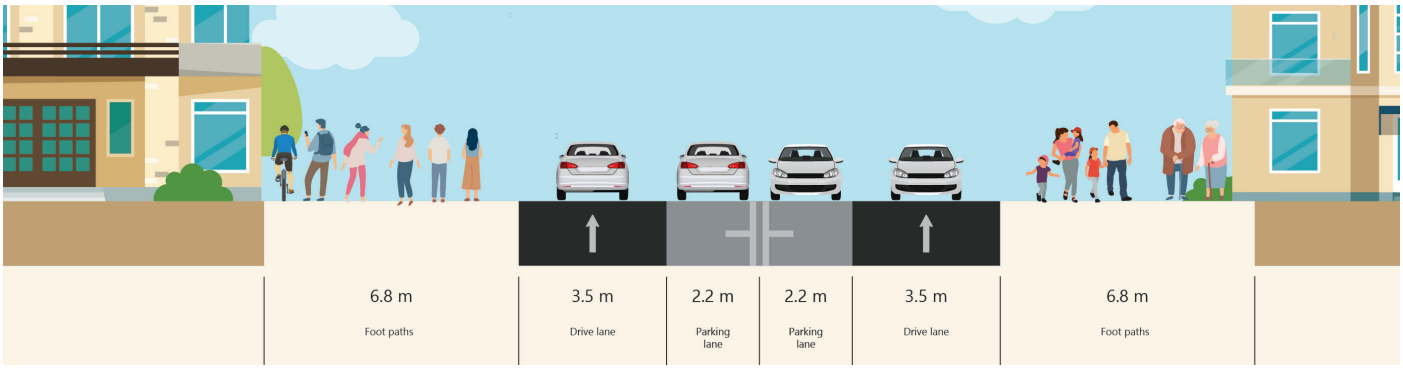
Scenario 2		
Theme	**Road**	**Details (as discussed with Digital Penang)**
Traffic Improvements	**Gat Lebuh China:** Remove Parking Spot	To remove all parking at Gat Lebuh China for giving away expansion of Pedestrian Walk with addition of space for commercial activities and landscaping. Traffic improvements proposed on Gat lebuh China in scenario-2 are shown in Figure 2-15 and Figure 2-16.
Traffic Improvements	**Beach Street:** One-Way Street	1) Introduction of 1-way street for beach street. Start from Gat Lebuh Chulia and end at Jubilee Clock Tower. 2) Widen sidewalks to provide accessibility and increased space for pedestrians and commercial activity. Alternate parking spaces with additional curb extensions, intermittent landscaping, and dedicated spaces for vendors. Pictorial representation of improvements on beach street are shown in Figure 2-6 and Figure 2-7.
Traffic Improvements	**Gat Lebuh Pasar:** Laneways	1) Increase the frontage area available for businesses in the city and create intimate environments by transforming laneways and alleys with active ground floor uses. 2) Maintain an accessible clear path of 3.5 m for emergency vehicle access. 3) Movable furniture can be placed in the emergency access path so long as they do not impede necessary but infrequent movements. Figure 2-19 and Figure 2-20 depicts the improvements proposed.
Traffic Improvements	**Gat Lebuh Pasar:** To close	The exit of Gat Lebuh Pasar is in the middle of a pedestrian crossing. as it is a safety issue, closing of this road is proposed. Another road beside the market can be replaced as an exit road. Figure 2-19 and Figure 2-20 depicts the improvements proposed.
Traffic Improvements	**Downing Street:** One-Way Street	1) Introduction of 1-way street for beach street. Start from Gat Lebuh Chulia and end at Jubilee Clock Tower. 2) Widen sidewalks to provide accessibility and increased space for pedestrians and commercial activity. Alternate parking spaces with additional curb extensions, intermittent landscaping, and dedicated spaces for vendors. Pictorial representation of improvements on Downing street are shown in Figure 2-21 and Figure 2-22.

Existing

Proposed

Figure 2-15 Scenario 2 Scheme Comparison Street View – Gat Lebuh China

Existing



Proposed

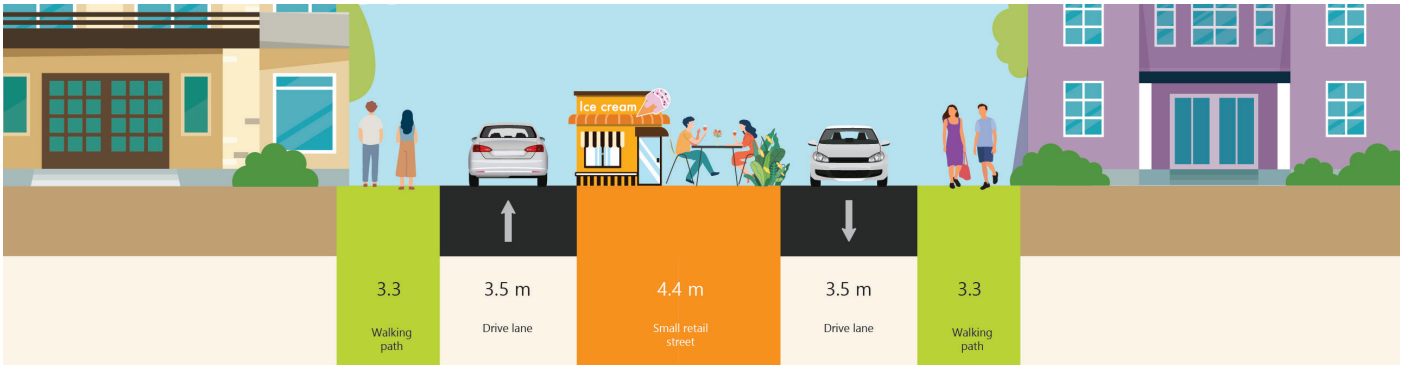


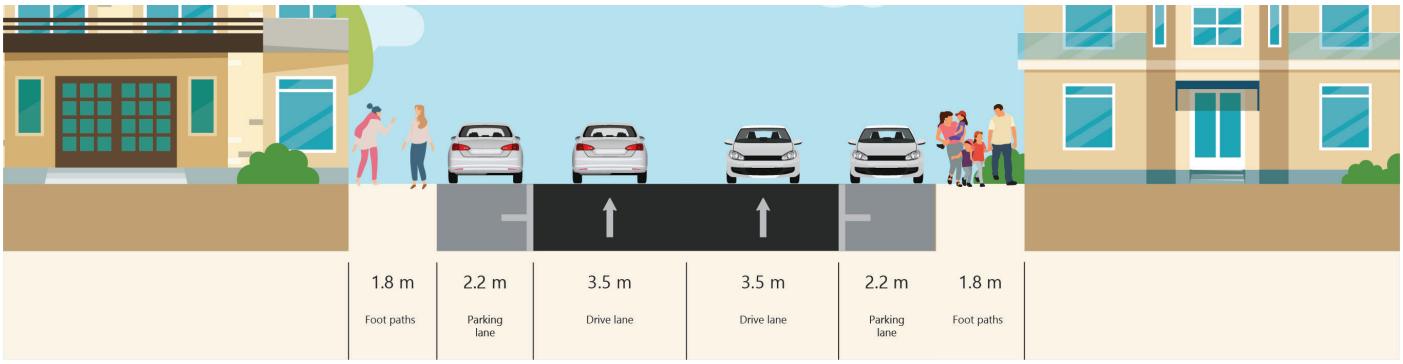
Figure 2-16 Scenario 2 Scheme Comparison Section View – Gat Lebuh China

Existing

Proposed

Figure 2-17 Scenario 2 Scheme Comparison Street View – Beach Street

Existing



Proposed

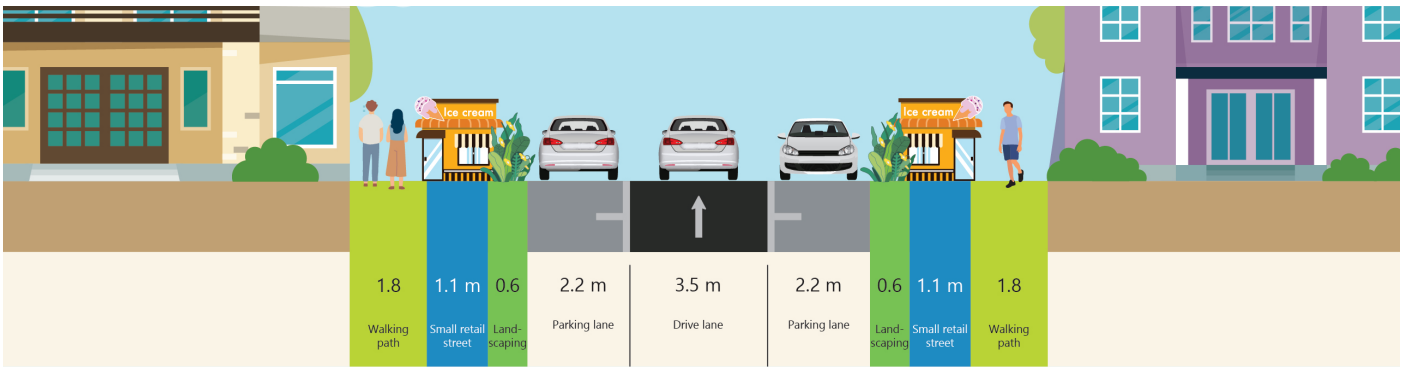


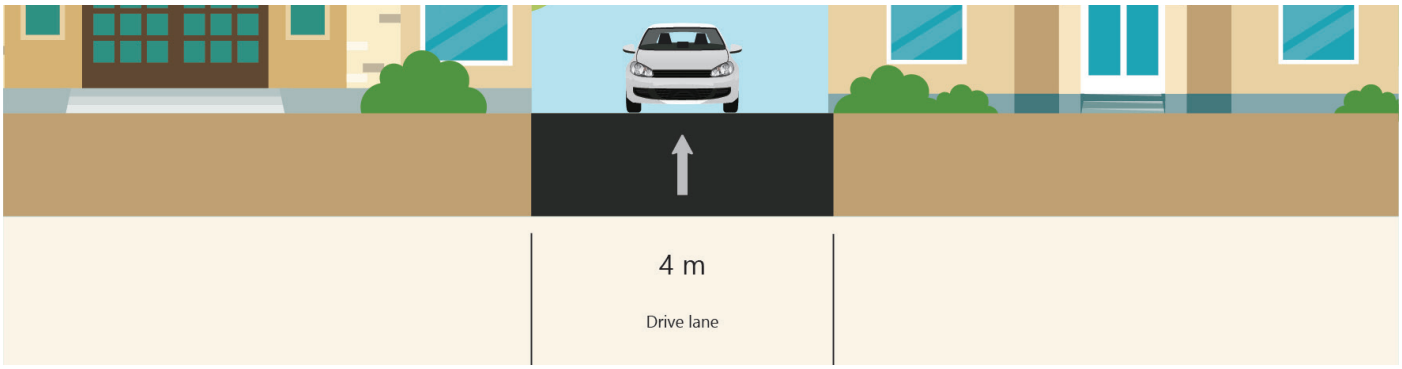
Figure 2-18 Scenario 2 Scheme Comparison Section View – Beach Street

Existing

Proposed

Figure 2-19 Scenario 2 Scheme Comparison Street View – Gat Lebuh Pasar

Existing



Proposed

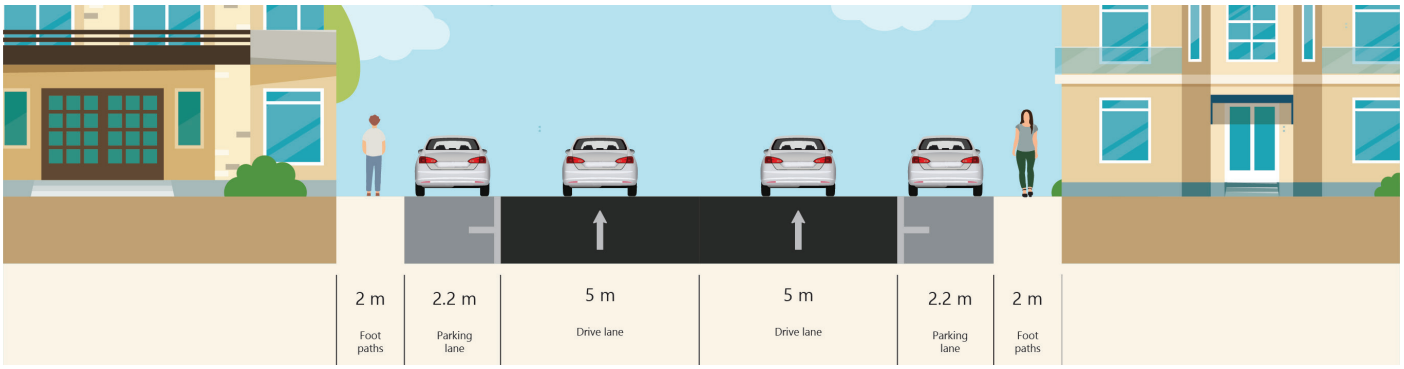
Figure 2-20 Scenario 2 Scheme Comparison Section View – Gat Lebuh Pasar

Existing

Proposed

Figure 2-21 Scenario 2 Scheme Comparison Street View – Downing Street

Existing



Proposed

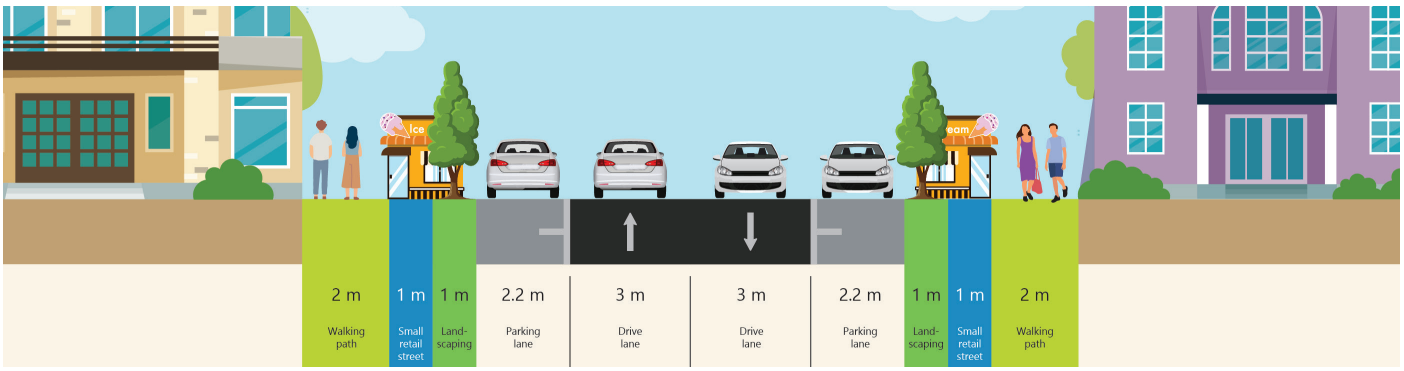


Figure 2-22 Scenario 2 Scheme Comparison Section View – Downing Street

2.3 SCENARIO 3: PUBLIC TRANSPORT PRIORITY

In this scenario, emphasis is given to providing provision on dedicated bus lanes for some sections of Pengkalan Weld which in turn offers fast, comfortable, and cost-effective urban transport system.

Vissim model is being used to test out the effectiveness on the bus priority scheme, as well as the impact on vehicular traffic when these schemes are implemented. The detailed traffic scheme changes are documented as in the figure and table below.

Individual traffic schemes proposed within this scenario are outlined, based on the location in the model area, in the table below.

Table 2-3 Scenario 3 Details

Scenario 3		
Theme	**Road**	**Details (as discussed with Digital Penang)**
Public Transport Improvements	**Gat Lebuh China:** Shared Street	Design principles: 1) Must prioritize vulnerable users, ensuring that clear paths are maintained. 2) Drainage channels and permeable materials should be provided in accordance with existing curb lines and slope. 3) Provide tactile warning strips at the entrance to all shared spaces. Warning strips should span the entire intersection crossing. 4) Maintain a clear path for delivery vehicles, and mark dedicated areas for vehicular movement with a change in paving pattern or type. 5) Pedestrian walk space to maintain at least 1.8m width 6) Install signage to educate the public on how to use a shared street in the early stages of conversion.
Public Transport Improvements	**Pengkalan Weld Street:** Bus Lane 1, 2 & 3	Design using offset transit lane. The standard width for road lane is 3.3m. Benefits: 1) Offset transit lanes reduce delays due to congestion. 2) Offset transit lanes raise the visibility of high-quality services, especially rapid service. Figure 2-24 and Figure 2-25 below shows the proposed public transport lane on pengklan weld road.
Public Transport Improvements	**Pengkalan Weld Street:** Bus Lane turn-in	Design using offset transit lane. The standard width for road lane is 3.3m. Benefits: 1) Offset transit lanes reduce delays due to congestion. 2) Offset transit lanes raise the visibility of high-quality services, especially rapid service.

Public Transport Improvements	**Lebuh Victoria:** Shared Street	Design principles: 1) Must prioritize vulnerable users, ensuring that clear paths are maintained. 2) Drainage channels and permeable materials should be provided in accordance with existing curb lines and slope. 3) Provide tactile warning strips at the entrance to all shared spaces. Warning strips should span the entire intersection crossing. 4) Maintain a clear path for delivery vehicles, and mark dedicated areas for vehicular movement with a change in paving pattern or type. 5) Pedestrian walk space to maintain at least 1.8m width 6) Install signage to educate the public on how to use a shared street in the early stages of conversion.
Public Transport Improvements	**Gat Lebuh Gereja:** Shared Street	Design principles: 1) Must prioritize vulnerable users, ensuring that clear paths are maintained. 2) Drainage channels and permeable materials should be provided in accordance with existing curb lines and slope. 3) Provide tactile warning strips at the entrance to all shared spaces. Warning strips should span the entire intersection crossing. 4) Maintain a clear path for delivery vehicles, and mark dedicated areas for vehicular movement with a change in paving pattern or type. 5) Pedestrian walk space to maintain atleast 1.8m width 6) Install signage to educate the public on how to use a shared street in the early stages of conversion.

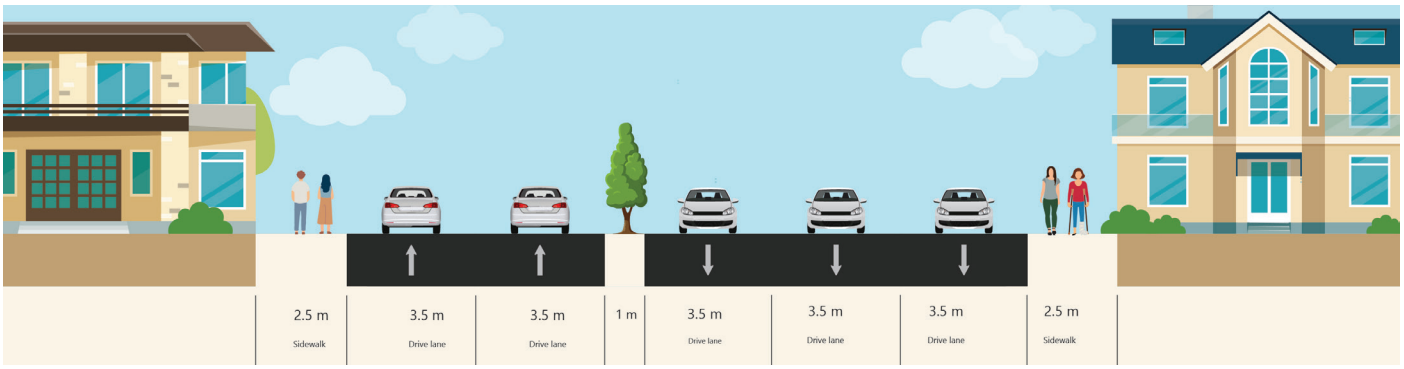
The following images shows the comparison of existing and proposed schemes in street view and section view, as per location.

Existing

Proposed

Figure 2-24 Scenario 3 Scheme Comparison Street View – Pengkalan Weld

Existing



Proposed

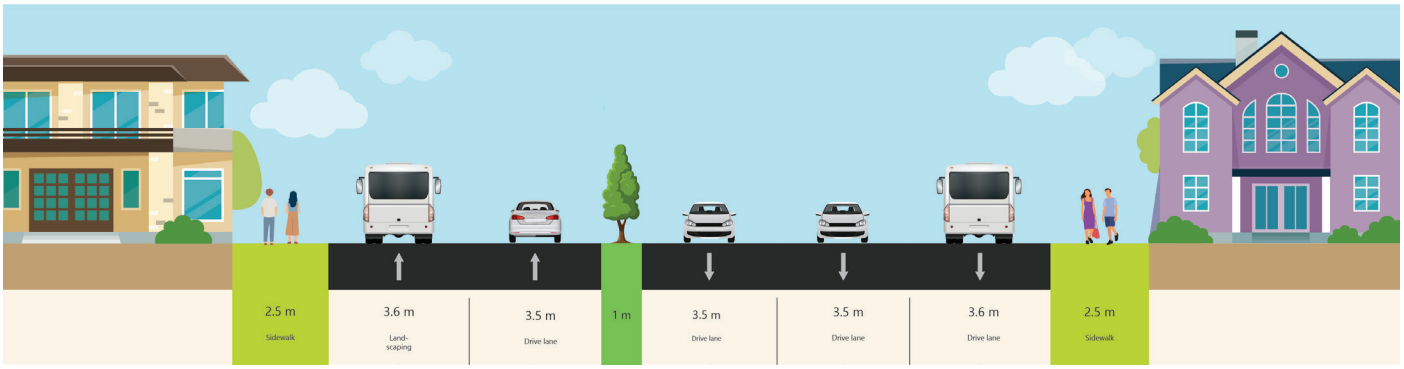


Figure 2-25 Scenario 3 Scheme Comparison Section View – Pengkalan Weld

2.4 SCENARIO 4: TRAFFIC IMPACT OF NEW DEVELOPMENT

Objective of this testing scenario is to analyses the impact of additional traffic generated by a newly proposed development on existing transport system.

This is in line with traffic impact assessment process to evaluate and approve the traffic impact of a new development within the city. This compares the new traffic demand with the traffic capacity of the network and will provide an insight into where traffic performance has changed, and where traffic improvement works might be required.

The detailed traffic scheme changes are documented as in the figure and table below.

Figure 2-26: Scenario 4 Interventions

Individual traffic schemes proposed within this scenario are outlined, based on the location in the model area, in the table below.

Table 2-4: Scenario 4 Details

Scenario 4		
Theme	**Road**	**Details (as discussed with Digital Penang)**
Traffic Impact of New Development	**Pengkalan Weld Street or Other Road with**	Digital Penang would like to study the new traffic demand and traffic impact of new on the study area. This will apply to one new development regardless of land use to be planned and constructed in the study area.
	New Development: Planning and Construction of New Development	On simulating and assessing the traffic impact, the following aspect will be included in the scenario: 1) Traffic impact of new demand brought by the new development on the road network 2) Traffic impact of construction road diversion and construction vehicle access 3) Traffic operations and management measures arising from post-implementation traffic issues 4) Traffic demand management recommendations and other traffic improvement recommendations

The following images shows the comparison of existing and proposed schemes in street view and section view, as per location.

3 STUDY METHODOLGY

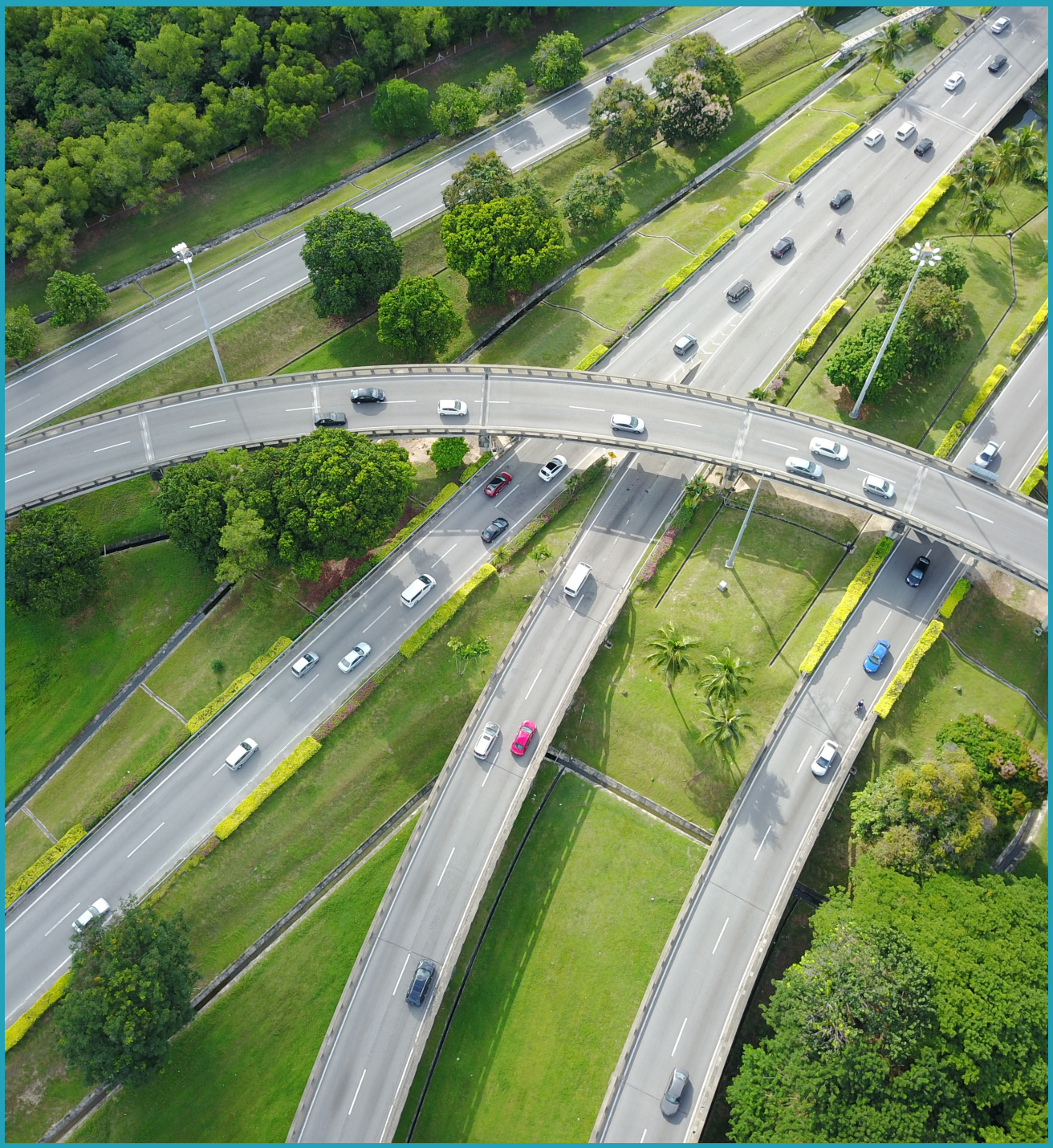


Photo: Adobe Stock

3.1 SCENARIO 1

Objective of this testing scenario is to analyses the impact of additional traffic generated by a newly proposed development on existing transport system.

Main objective of this scenario is to test the impact of provision of pedestrian and cyclist priority facilities along with traffic calming measures on overall network performance. Since there is no change in vehicular demand and distribution, the OD matrix and trip chain used in this scenario is same as that of base calibrated model.

As explained in Section 2.1, following additional features are coded in Scenario 1

- Walking paths on Gat Lebhu China, Pengkalan weld, Beach Street, Lebuh Victoria, Get Lebuh Gereja and Downing Street
- Small retail streets on Gat Lebhu China, Get Lebuh Gereja and Downing Street
- Landscaping on Gat Lebhu China, Pengkalan weld, Beach Street, Lebuh Victoria, Get Lebuh Gereja and Downing Street
- Actuated signals on Pengkalan weld
- Vertical speed control elements on Pengkalan weld
- Pedestrian crossings on Pengkalan weld

Below images depicts the Vissim model after inclusion of all the traffic measures for Scenario 1.

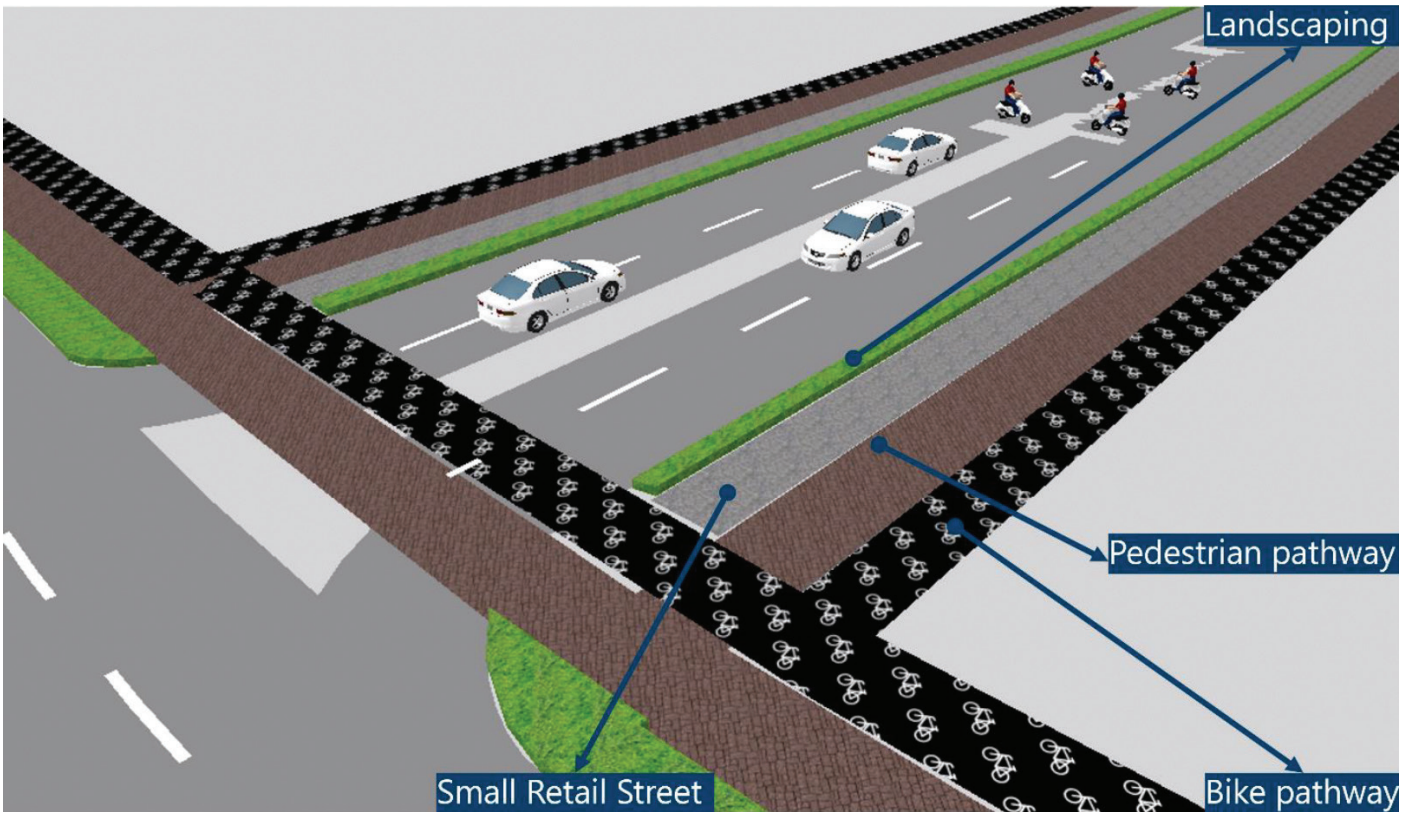


Figure 3-1 Scenario 1 - Gat Lebhu China

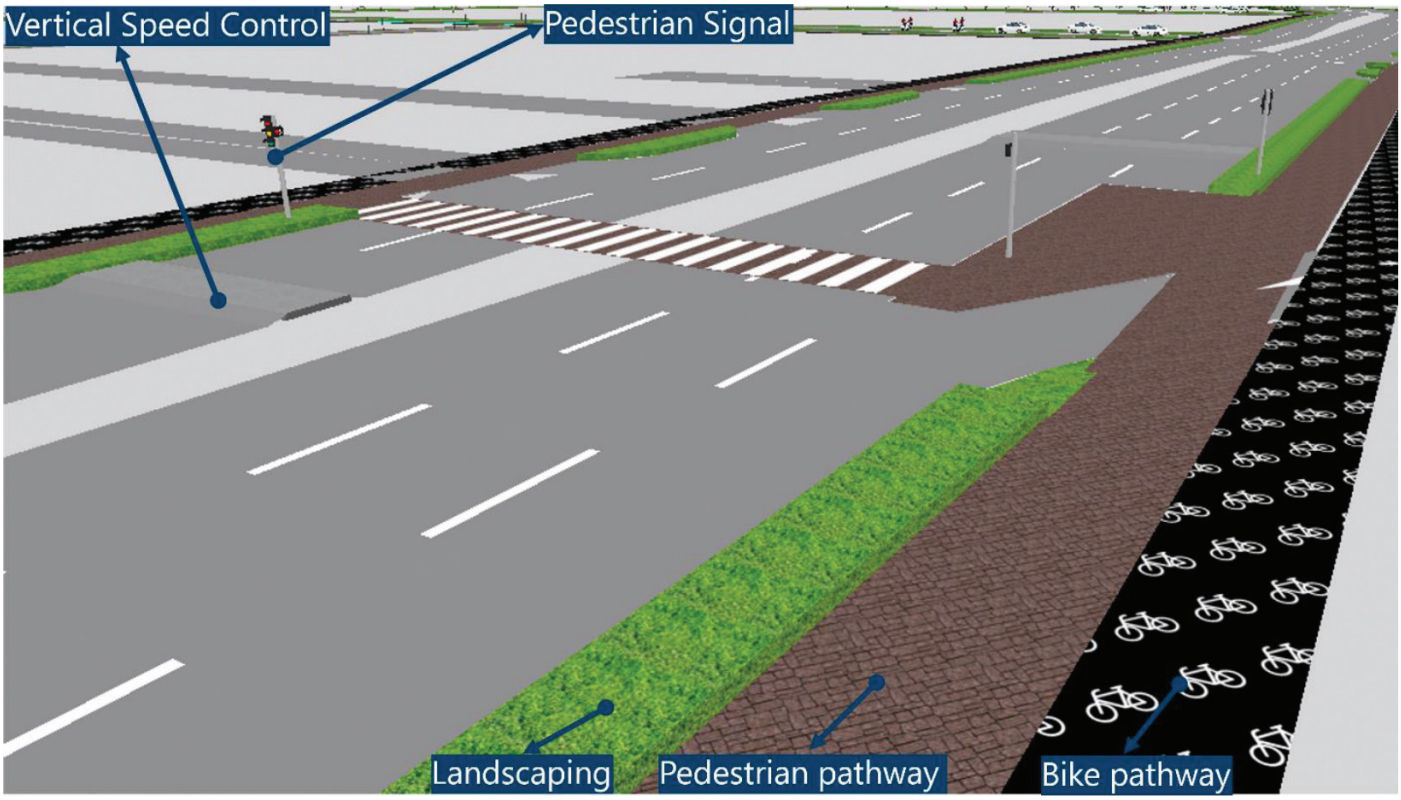


Figure 3-2 Scenario 1 - Pengkalan weld

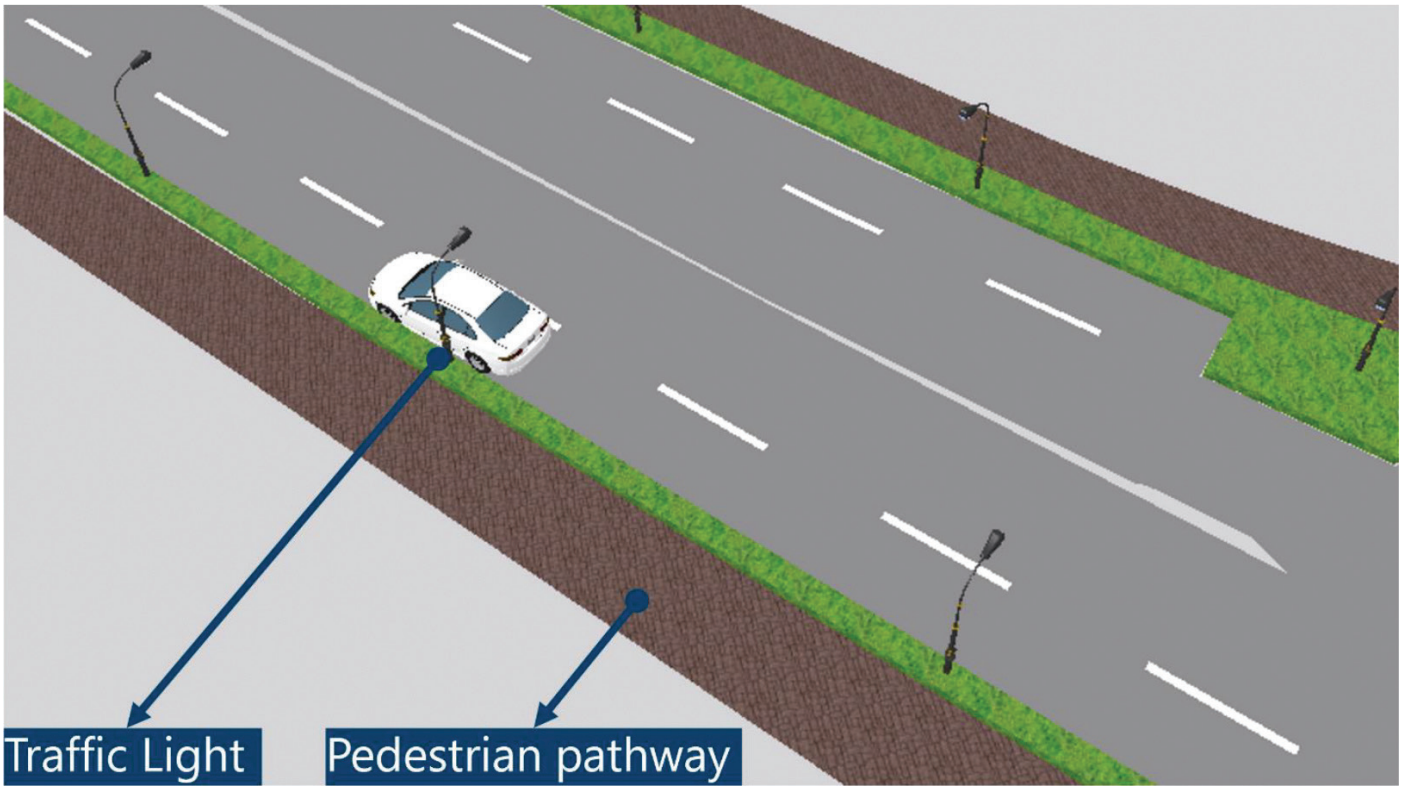


Figure 3-3 Scenario 1 - Beach Street

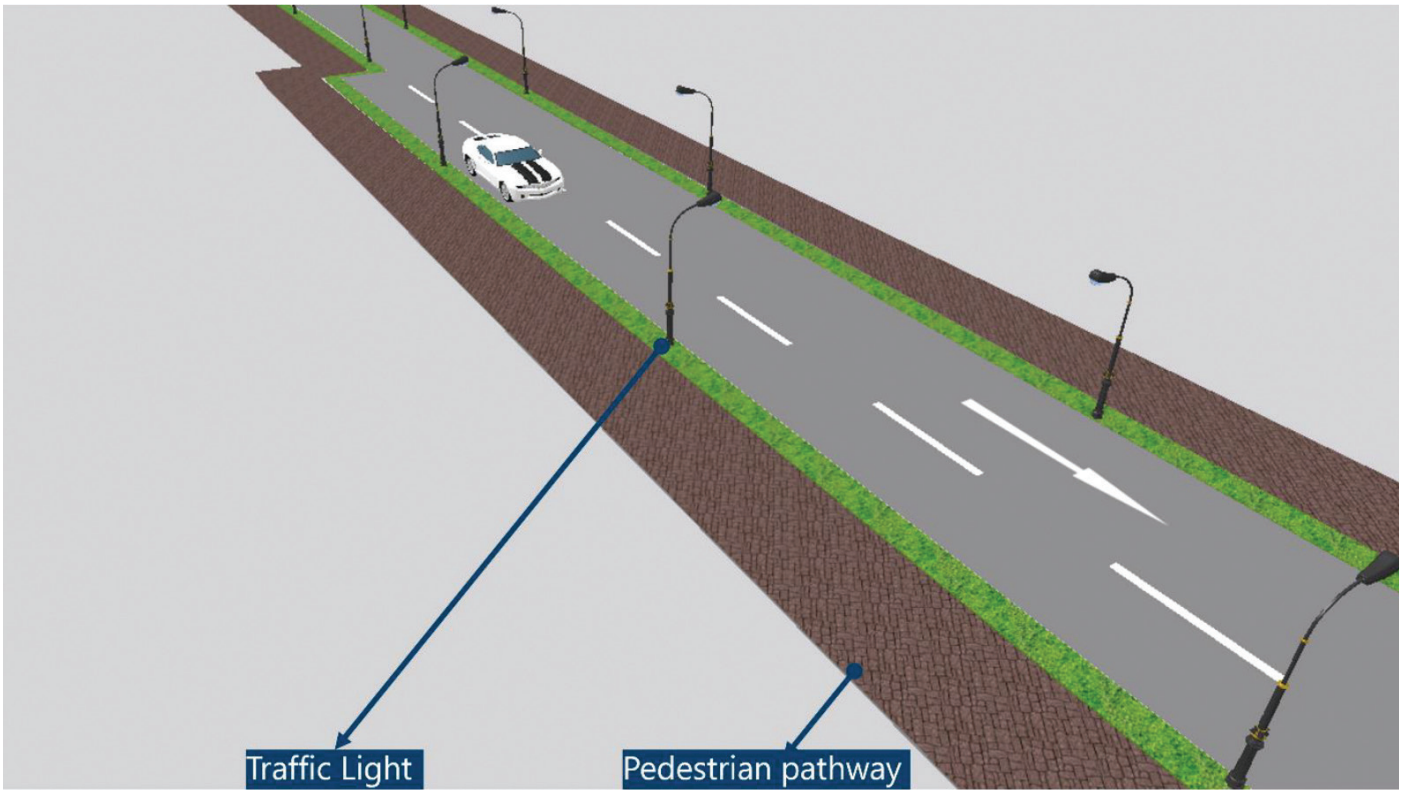


Figure 3-4 Scenario 1 – Lebuh Victoria

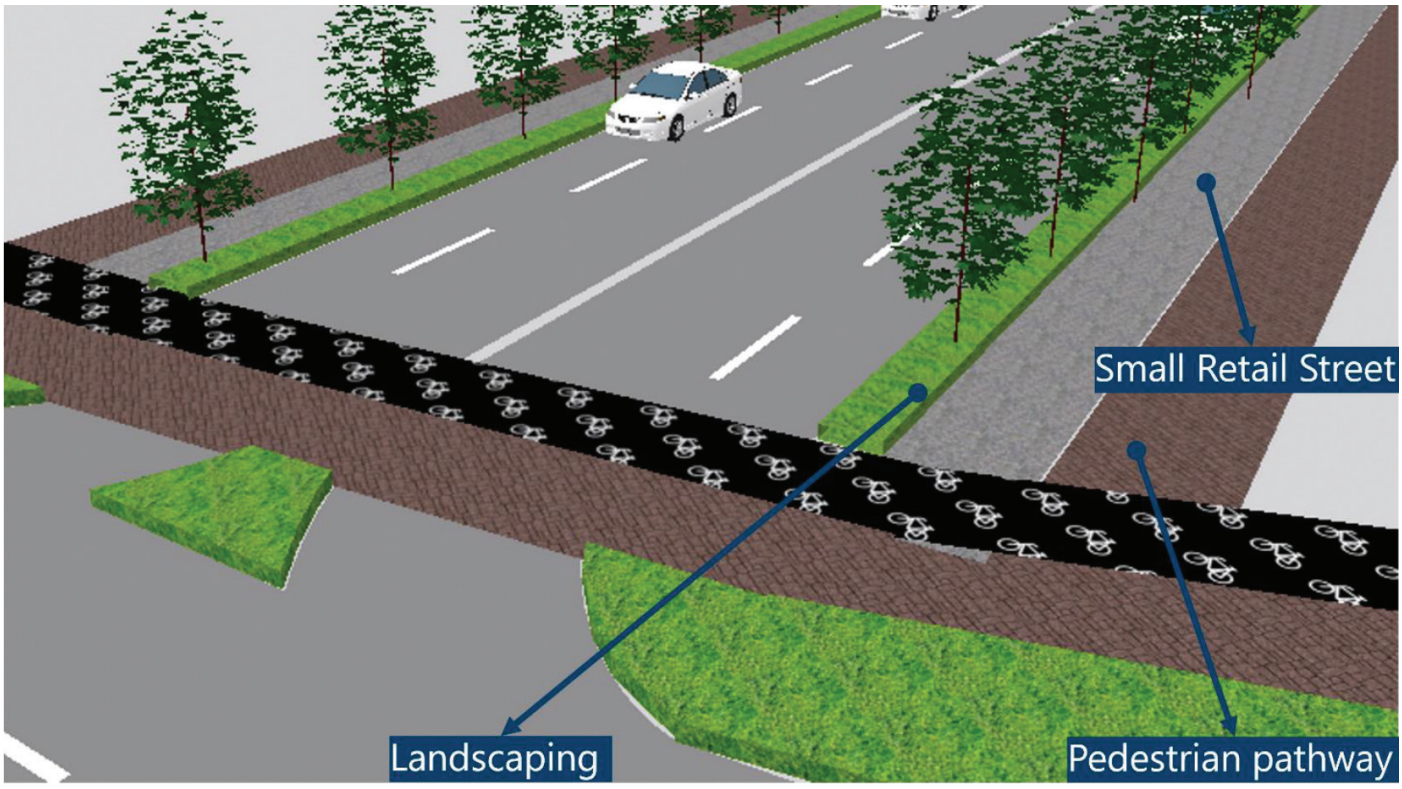


Figure 3-5 Scenario 1 – Gat Lebuh Gereja

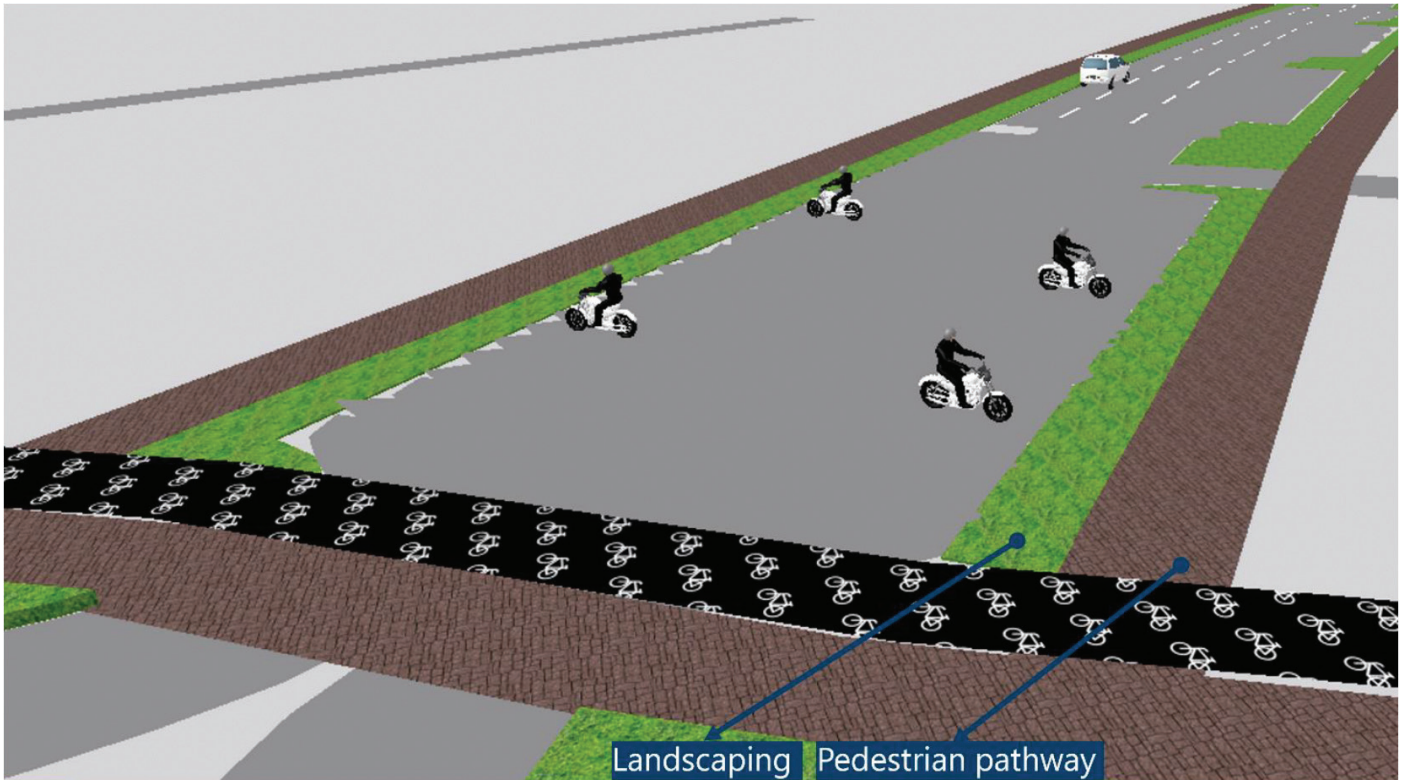


Figure 3-6 Scenario 1 – Downing Street

Because of change in road network there will be redistribution of trips and therefore there is need to develop different trip chain file for modelling parking in Vissim. Below image show the methodology adopted in Scenario 1 for Vissim model development.

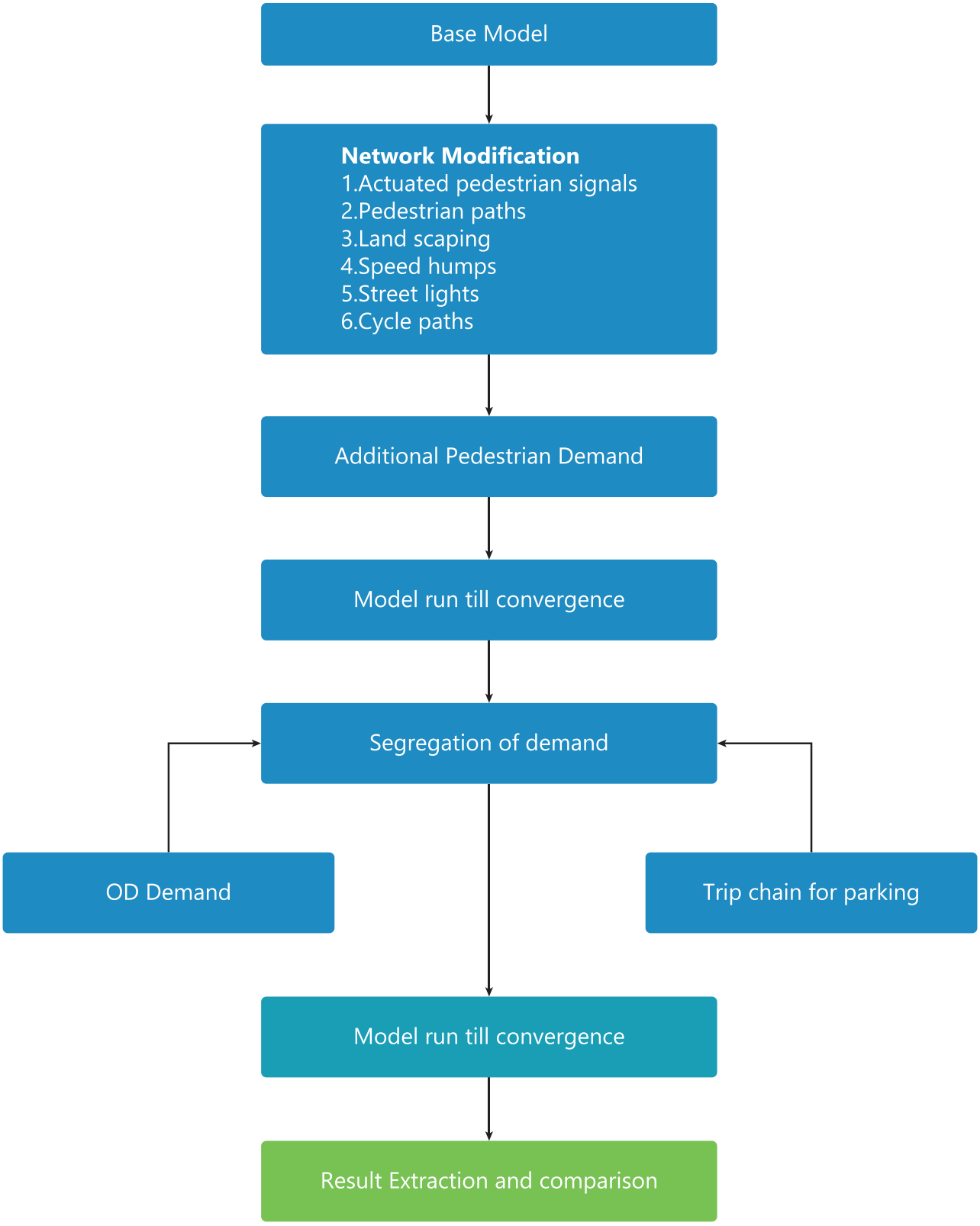


Figure 3-7 Scenario 1 – Methodology

3.2 SCENARIO 2

In this scenario, emphasis is given to understand the network performance after adopting road network improvements.

As explained in section 0, following major modifications to road network are carried out in Scenario 2

- Beach street conversion to one-way street
- Removal of parking lots on Gat lebuh china
- Closure of roads on Gat lebuh pasar

Below images depicts the Scenario 2 in Vissim after implementation of all the interventions.

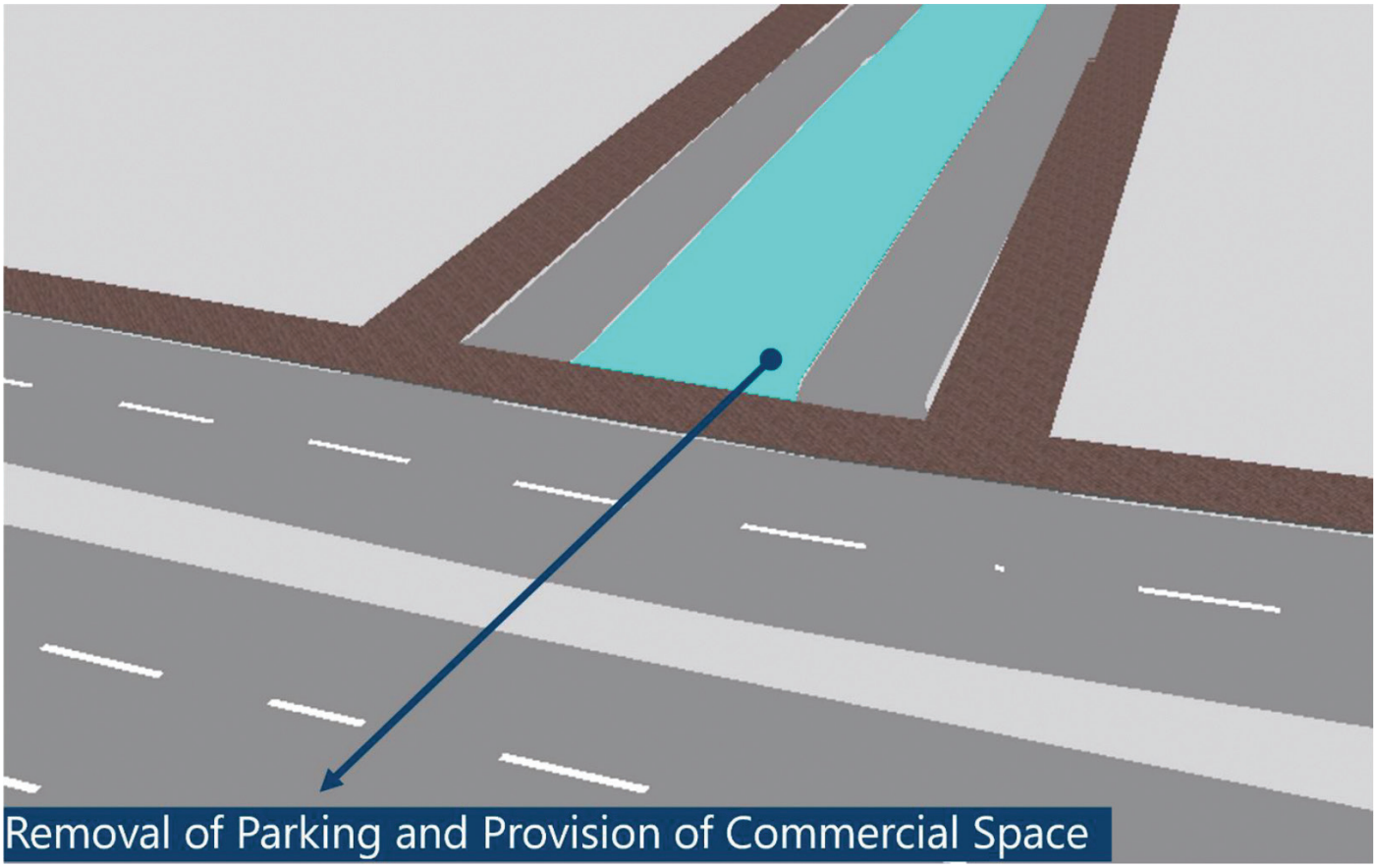


Figure 3-8 Scenario 2-Gat Lebuh China

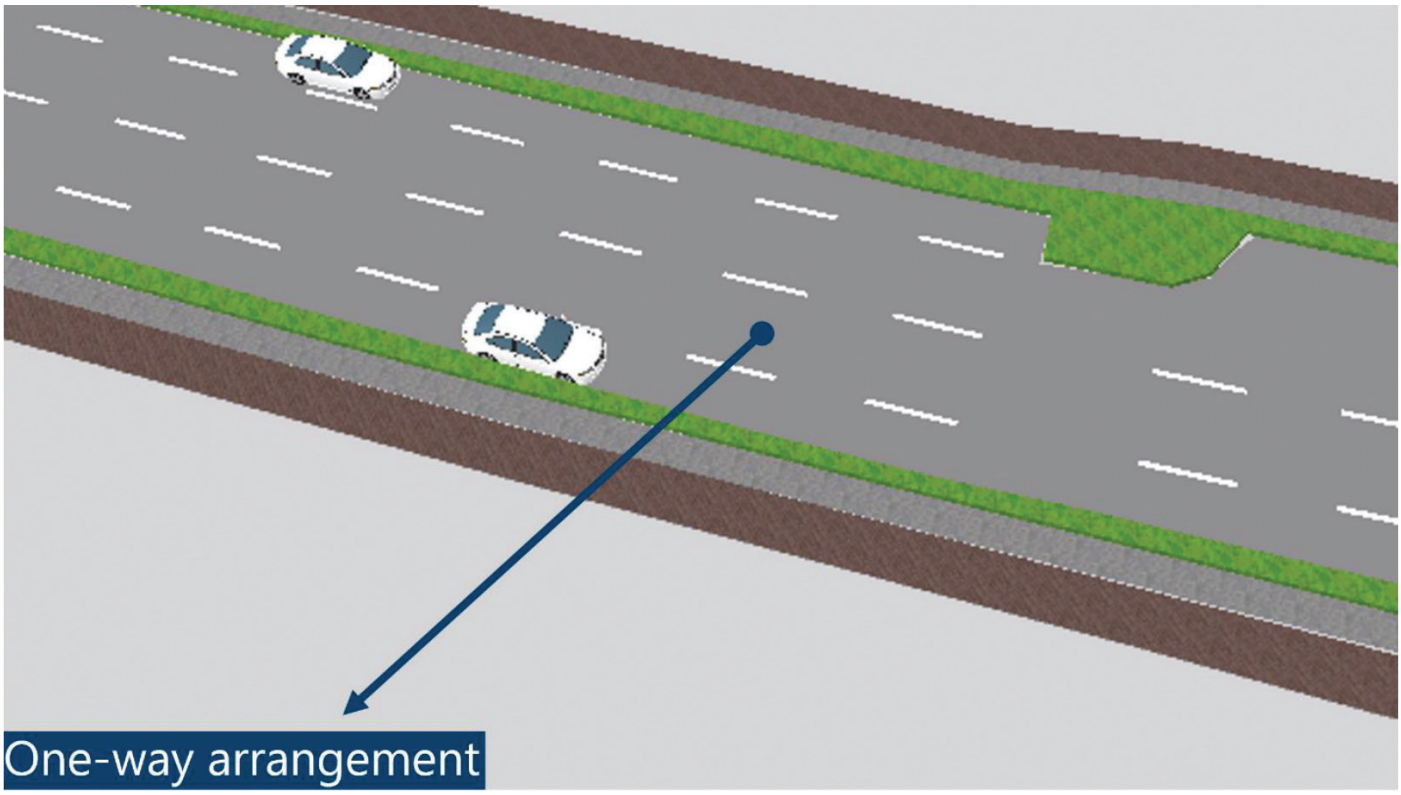


Figure 3-9 Scenario 2-Beach Street

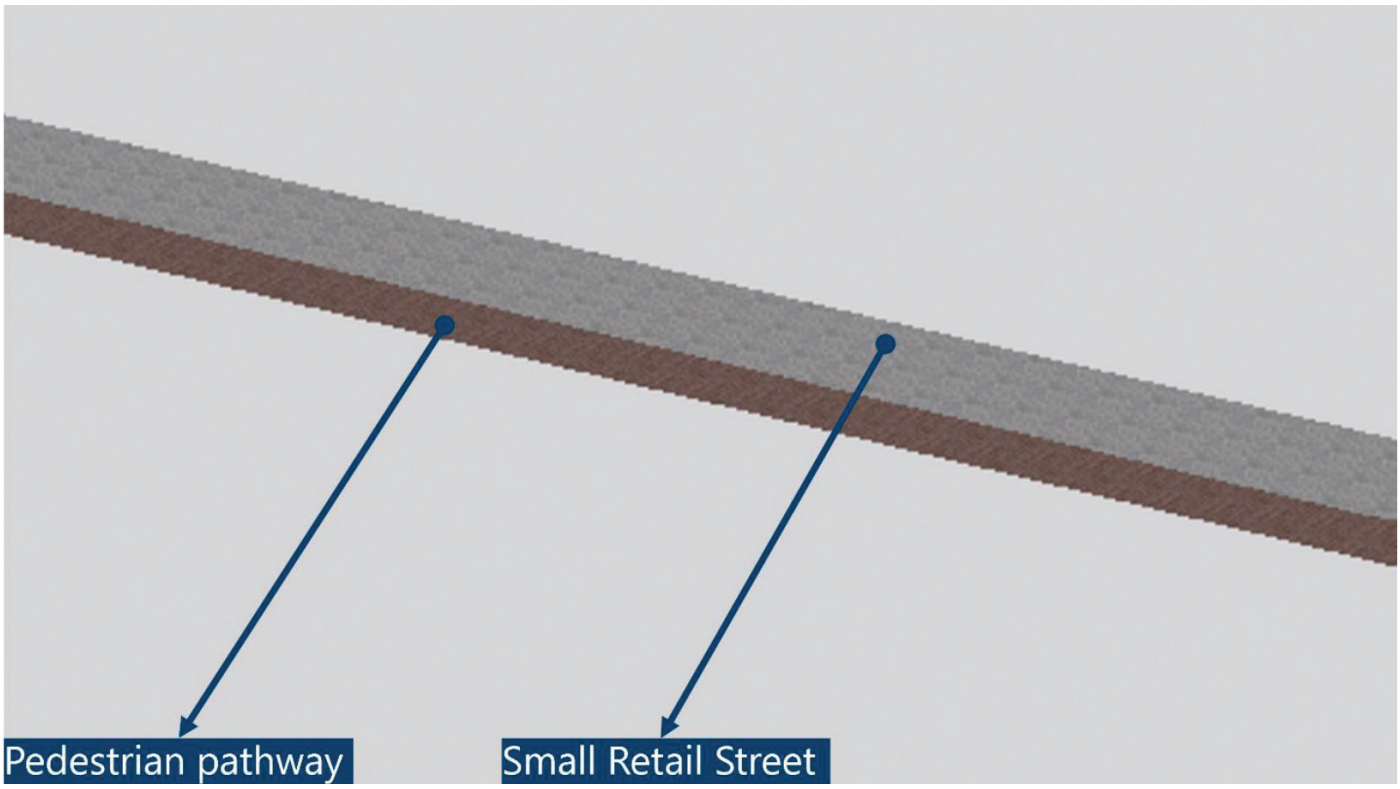


Figure 3-10 Scenario 2-Gat Lebuh Pasar

Figure 3-11 Scenario 2-Downing Street

Because of change in road network there will be redistribution of trips and therefore different OD matrix and trip chain file is derived by keeping the demand constant. Below image show the methodology adopted in Scenario 2 for Vissim model development.

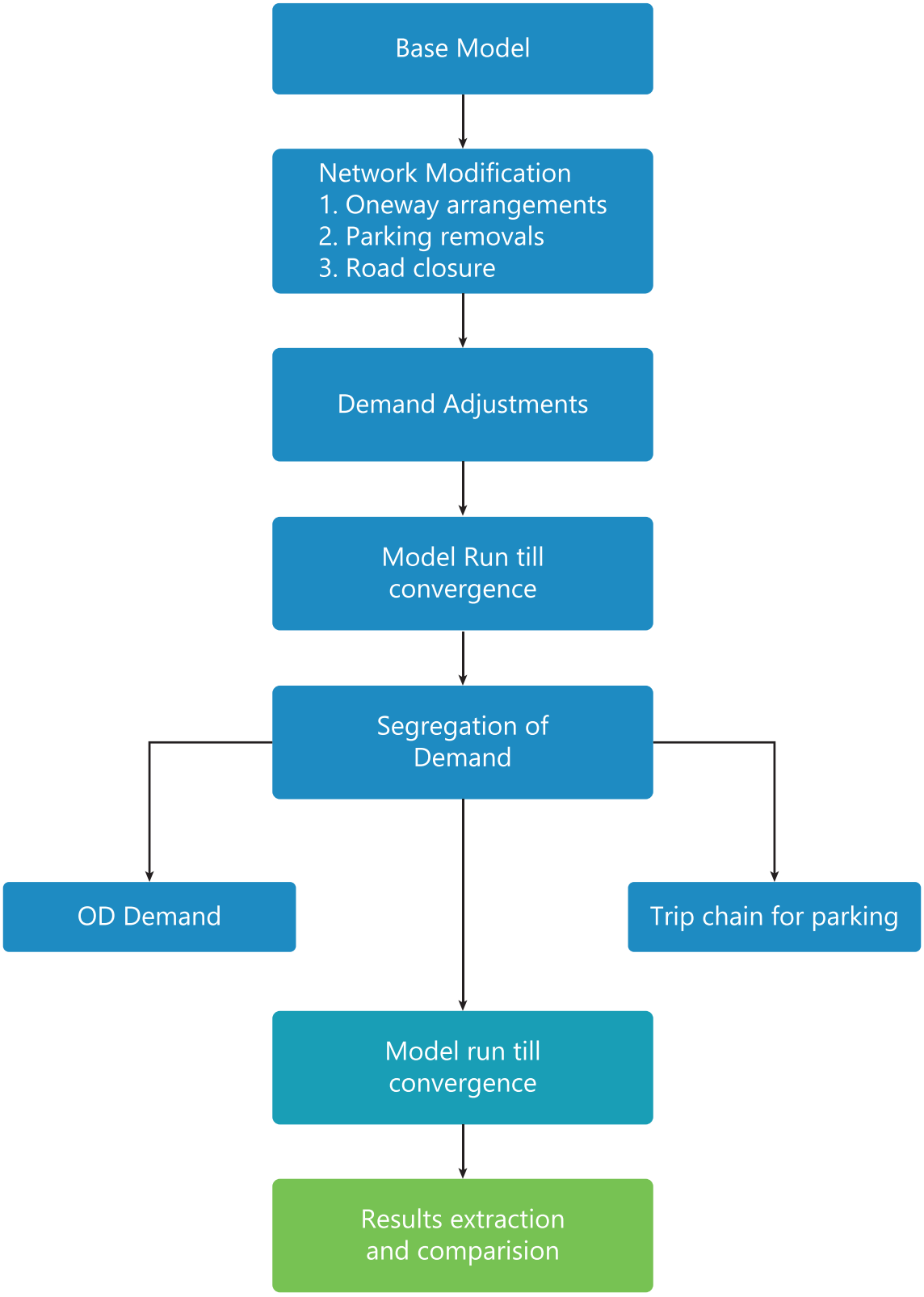


Figure 3-12 Scenario 2 – Methodology

3.3 SCENARIO 3

Main objective of this scenario is to understand the impact of implementation of dedicated public transport lanes on some sections of the study area on the road network performance.

As explained in section 2.3, following major modifications to road network are carried out in Scenario 3

- Dedicated Public transport lane at some sections of Pengakalan Weld as shown in below image

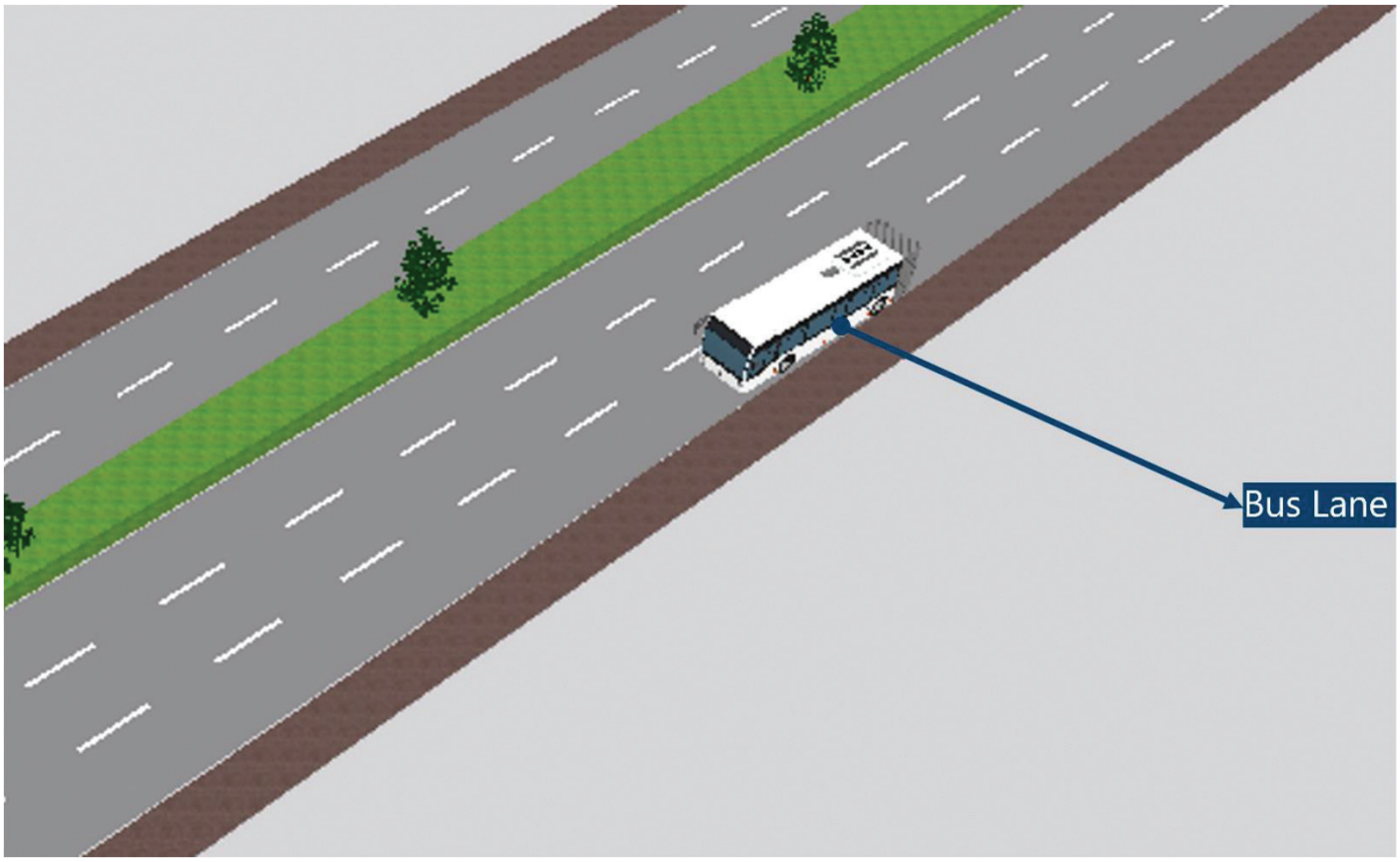


Figure 3-13 Scenario 3-Pengkalan Weld

Since there is no change in road network in terms of road closures/circulation, vehicular and parking demand will remain same as of base calibrated model. Below image show the methodology adopted for this scenario

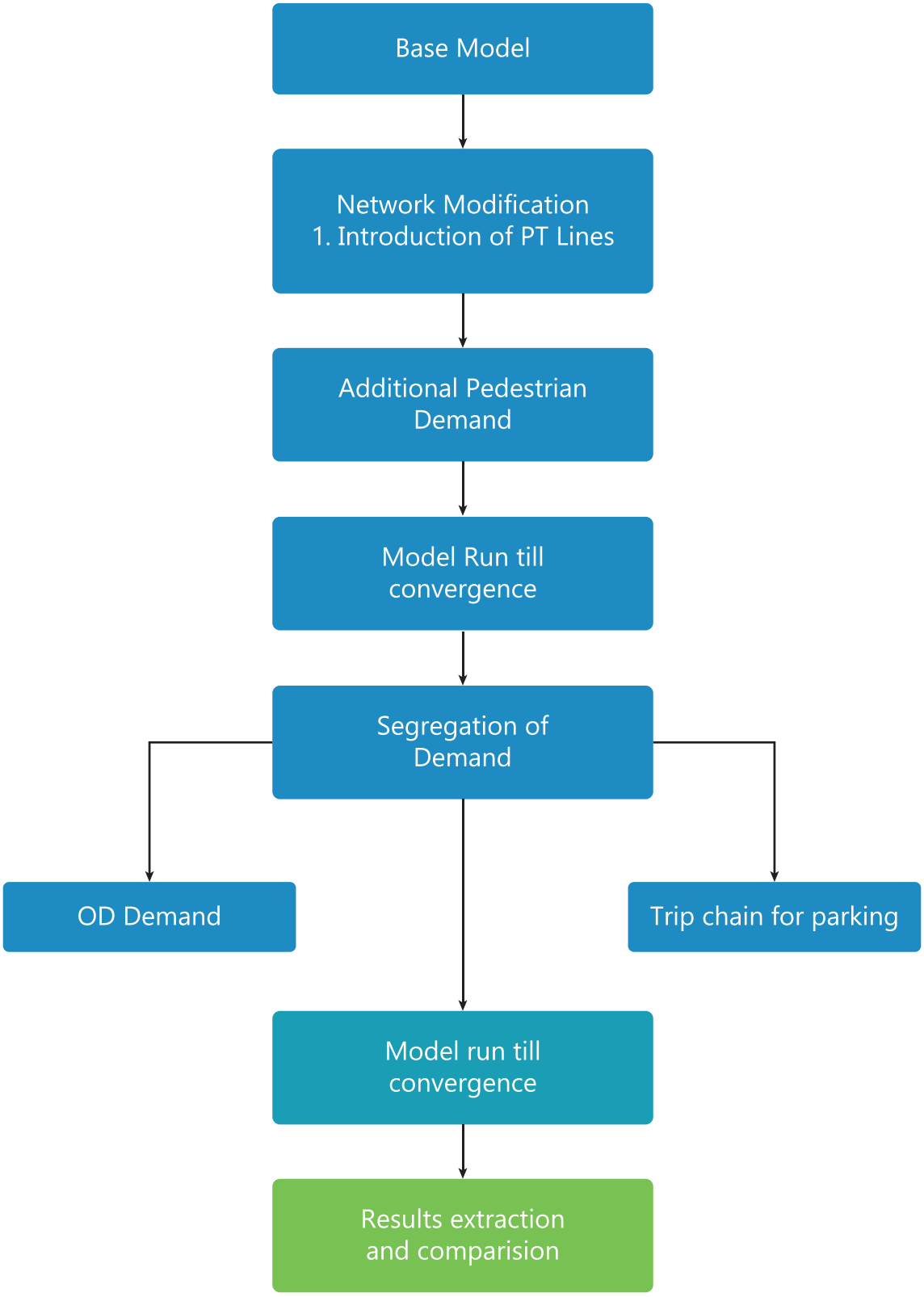


Figure 3-14 Scenario 3 – Methodology

3.4 SCENARIO 4

Impact of additional traffic on road network due to new proposed developments is tested in this scenario.

Digital Penang has provided land use details of the new development as shown in below table and location of the development is shown in Figure 3-15.

Table 3-1 Land use details of new development

Land use	Area (Sq.m)
Seafront F&B	2480
Showroom	975
E-Sports Arena	1551
Restaurants	464
Flight Simulator Training Center	4273
Remaining Area (Shops as assumed in progress meeting)	15213
Total Area	**24956**

Figure 3-15 Location of proposed new development

The number of trips generated by proposed development has been established with the use of trip generation rates that were obtained from the trip generation surveys conducted for the similar development during peak hours within Malaysia. Trip generation for the proposed new development using the trip rates is provided by JA Consult and details are as below.

Table 3-2 Trip generation of proposed development

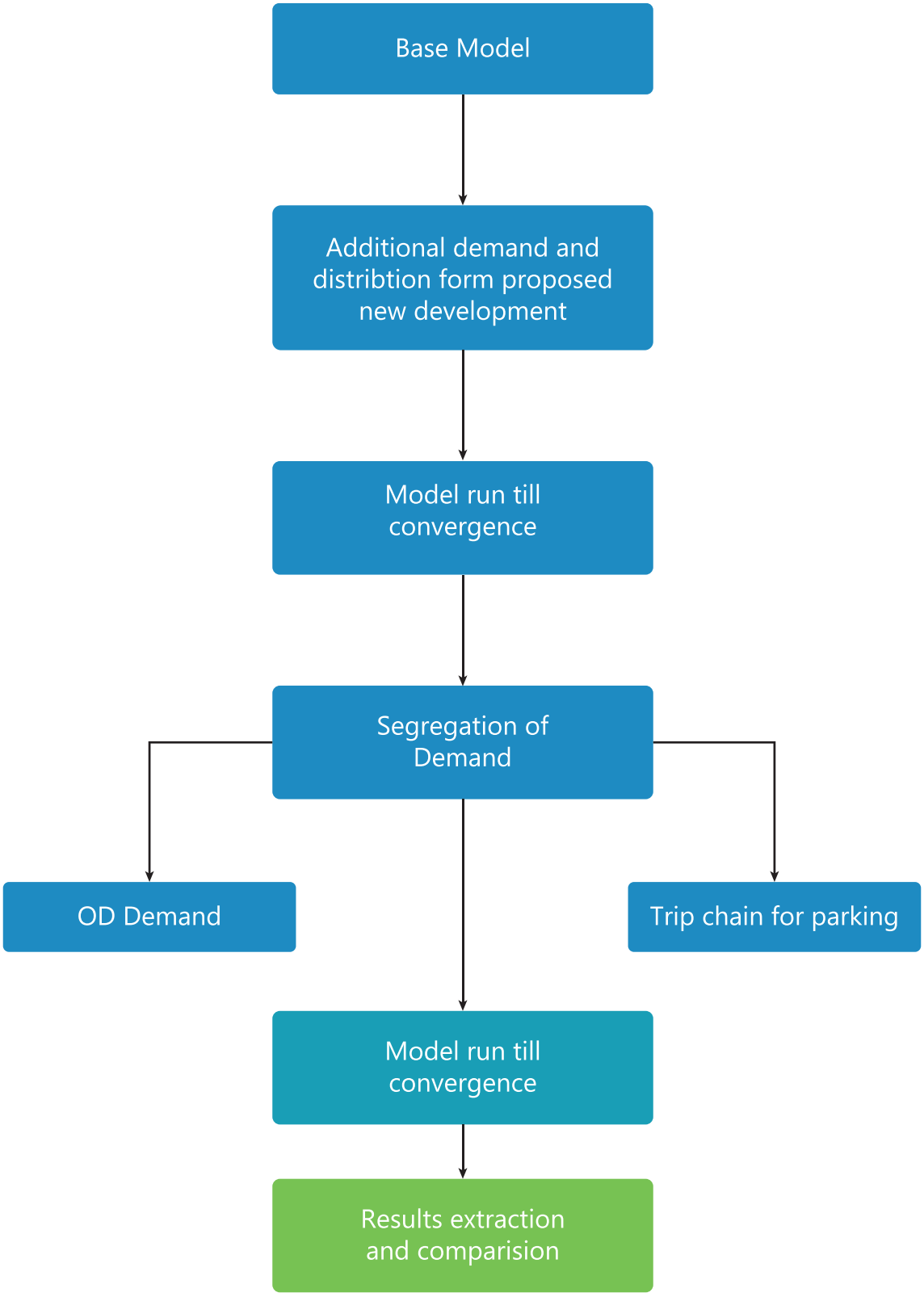
Land use	Area (Sq.m)	AM In	AM out	PM In	PM out
Seafront F&B	2480	22	9	10	20
Showroom & Remaining Area	16188	444	272	471	531
E-Sports Arena	1551	4	2	5	3
Restaurants	464	12	9	9	7
Flight Simulator	4273	40	9	7	36
Total Area	**24956**	**532**	**302**	**502**	**597**

Due to this additional demand, base calibrated demand matrix is adjusted to reflect this additional increase of the demand. Parking demand is assumed to remain unchanged as all the parking required for proposed development is assumed to be provided within the development.

Proposed development is assumed to be accessed from the Left in out as shown in figure below.

Figure 3-16 Proposed development access

Zone 4 in the base model is assumed to be proposed development zone in Scenario 4.



Methodology adopted to develop Vissim model for Scenario 4 is shown in figure below.

Figure 3-17 Scenario 4 – Methodology

4 MODEL ASSESSMENT

Photo: Adobe Stock

4.1 ASSESSMENT CRITERIA

With the base model fully calibrated through the steps mentioned above, the model is ready to be used as a base for testing the impacts of various traffic measures and proposals.

To show the implications of such impact, there are key measurements that can be taken from the model as assessment criteria. The criterion considered in this study for vehicular traffic are as follows:

- Delays (Level of Service)
- Density
- Speed
- Vehicle Travel Time
- Queue Lengths

Out of all the assessment criterion, delays / Level of Service is the most commonly used indicator of junction performance.

The criterion considered in this study for pedestrian traffic (as used in Scenario 1) are as follows:

- Pedestrian Travel Time

To study impact of traffic measures and proposals on pedestrians, pedestrian travel time measurement along Pengkalan weld road is considered as an assessment criterion.

4.1.1 Vehicular Measurement: Delay /Level of Service

Level of Service (LOS) criteria for delay as per HCM 2010 is shown in table below.

The Highway Capacity Manual (HCM) uses the concept of level of service (LOS) as a qualitative measure to describe operational conditions of vehicular traffic. The criterion for determining LOS at signalized and unsignalized intersections is delay per vehicle, in seconds per vehicle. Delay is the time loss of a traveller while crossing an intersection or while travelling on a road network.

Vehicular LOS analysis is based on a scale from A through F, with A representing the best and F representing the worst traveling conditions.

LOS	Controlled Intersections	Uncontrolled Intersections
A	0-10	0-10
B	11-25	11-15
C	21-35	16-25
D	36-55	26-35
E	56-80	36-50
F	**>80**	**>50**

Figure 3-18 LOS Criteria

4.1.2 Vehicular Measurement: Density

Traffic density is defined as the number of vehicles occupying a unit length of roadway. The easiest way to visualize traffic density is to consider an aerial photograph of a highway section and count of number of vehicles in 1 mile of a single lane. This will be the density per lane-mile. Traffic densities vary from 0 (no flow) to values representing stopped, bumper to bumper traffic. This upper limit, called jam density, depends on the traffic composition and the clear gaps between vehicles.

4.1.3 Vehicular Measurement: Speed

Speed id defined as distance covered by a vehicle in a specific time period. Average speed is defined as speed maintained by a vehicle over a given stretch of road while the vehicle is in motion.

4.1.4 Vehicular Measurement: Vehicle Travel Time

Average time taken for a vehicle to travel from one section to other section of the road is defined as vehicle travel time.

4.1.5 Vehicular Measurement: Queue Lengths

Queue length is defined as a length of vehicles waiting to move in the road network in which the flow rate is depreciated either by bottle necks or by priority/signalized junctions. Queue lengths for all the scenarios considered is shown in Appendix A of the report.

4.1.6 Pedestrian Measurement: Pedestrian Travel Time

Average time taken for a pedestrian to travel from one section to other section of the road is defined as pedestrian travel time.

4.2 BASE SCENARIO

Results obtained for Base Scenario in study area are presented in below sections.

4.2.1 Vehicular Measurement: Delay/Level of Service

The criterion for determining LOS at signalized and unsignalized intersections is delay per vehicle as explained in section 4.1.1. Below image shows the LOS for junctions in trial study area.

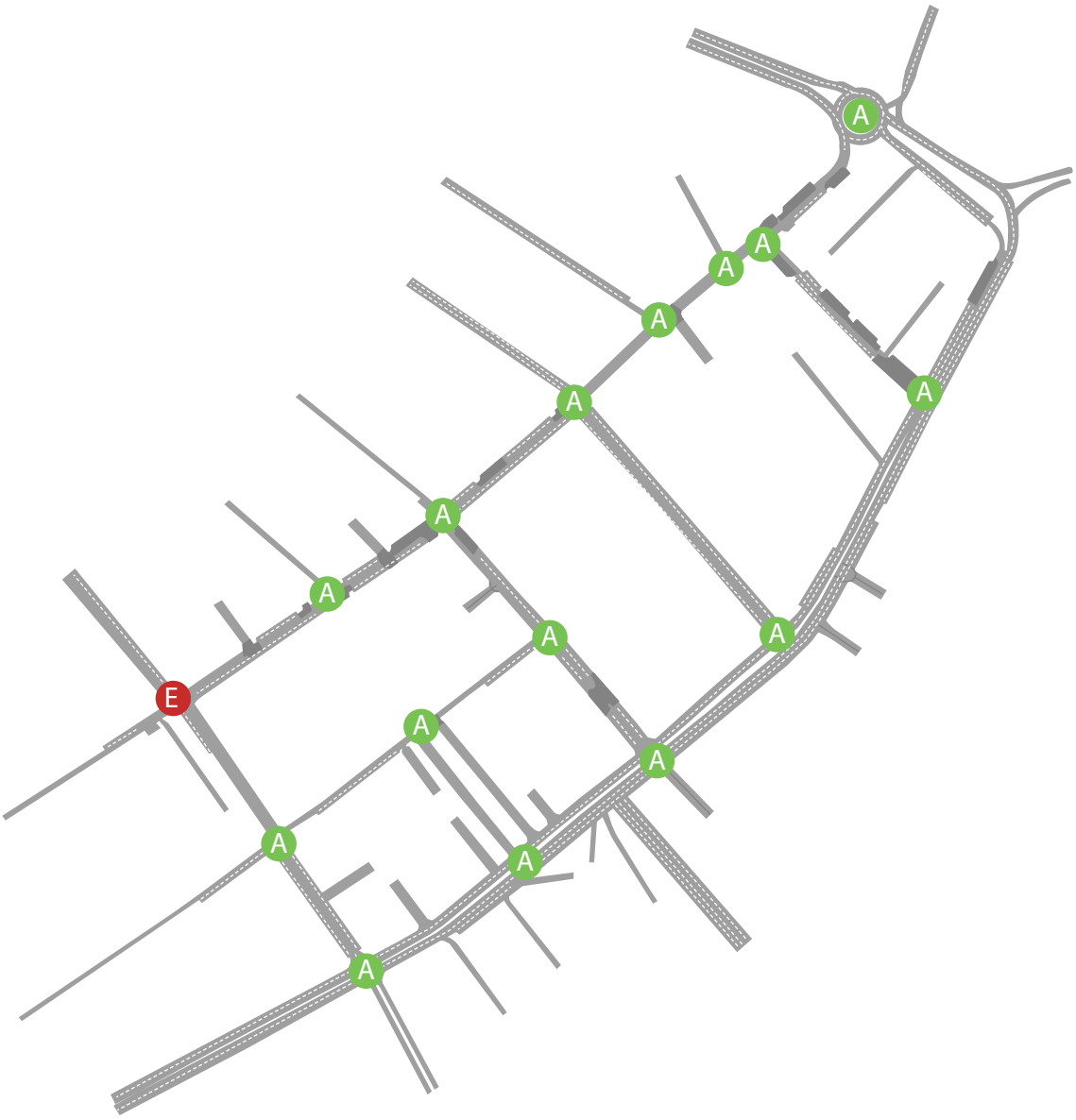


Figure 3-19 Level of Service-Scenario1 - AM and PM peak

All the junctions in Base scenario are performing with LOS A expect J23 which is performing at LOS E.

The diagram below presents the delay (in unit of seconds) experienced by vehicular traffic at each section of the road. In below image, sections with green indicates that delay is less and driving conditions are ideal and sections with yellow and lite orange indicates that congestions is noticeable and sections with red indicates that higher delay is experienced, and vehicles are moving slowly or stopping for reasonable amount of time. Irrespective of color in below image, higher the width of bar higher is the delay experienced by the vehicle.

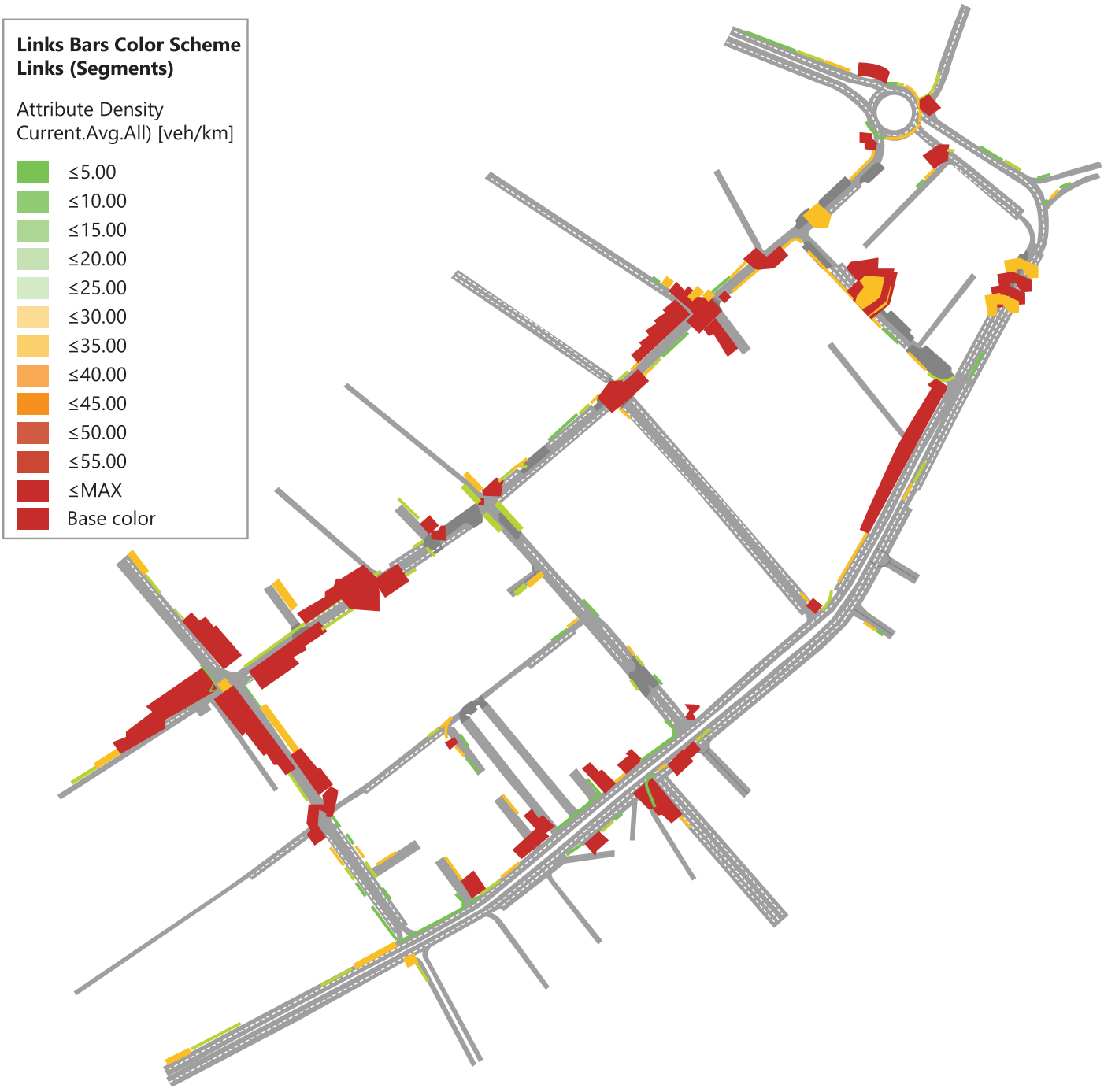


Figure 3-20 Delay-Base Scenario – AM peak

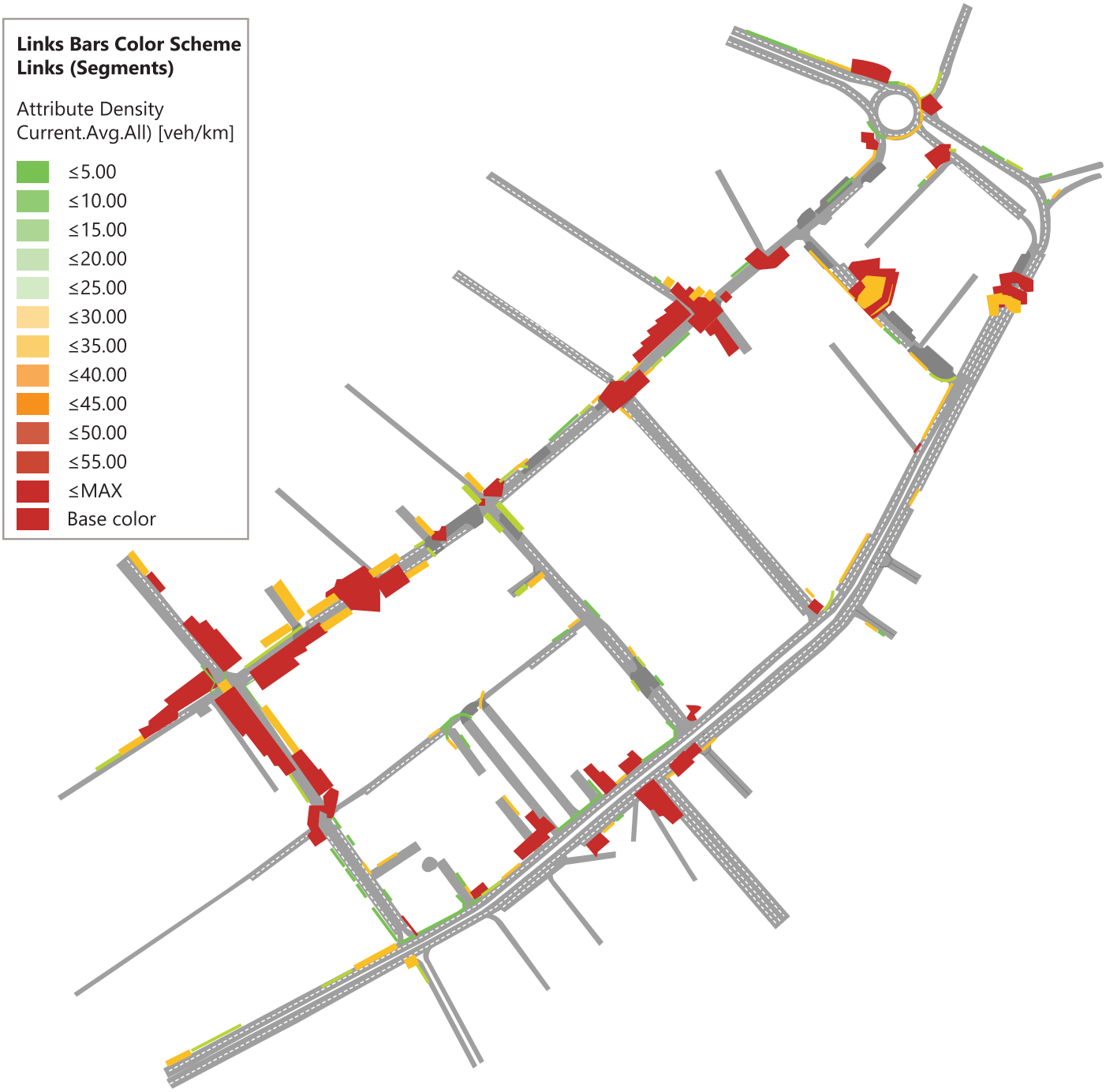


Figure 3-21 Delay-Base Scenario – PM peak

From above graphs it can be observed, dark red plots which indicates higher delay are majorly present on section near J23 in both the peaks.

4.2.2 Vehicular Measurement: Density

Density as explained in earlier sections is the number of vehicles occupying unit length of roadway. Green colour bar in below image indicates sections with low density and sections with yellow and orange indicates reasonable density and sections with red and pink indicates higher density, and it is generally experienced near to signalized sections. Width of the bar is proportional to the density experienced at those sections.

Figure 3-22 Density-Base Scenario – AM peak

Figure 3-23 Density-Base Scenario – PM peak

Higher density is usually observed near to priority/signalized junction or when there is a bottle necks in the road network. From above graphs it can be observed that higher densities are observed at sections near J3, J16 and J23.

4.2.3 Vehicular Measurement: Speed

Average speed on road network in scenario-1 is demonstrated in below images. Red color bar indicates sections on the road network with speed around 50 kmph and yellow bars indicates speed around 40 kmph.

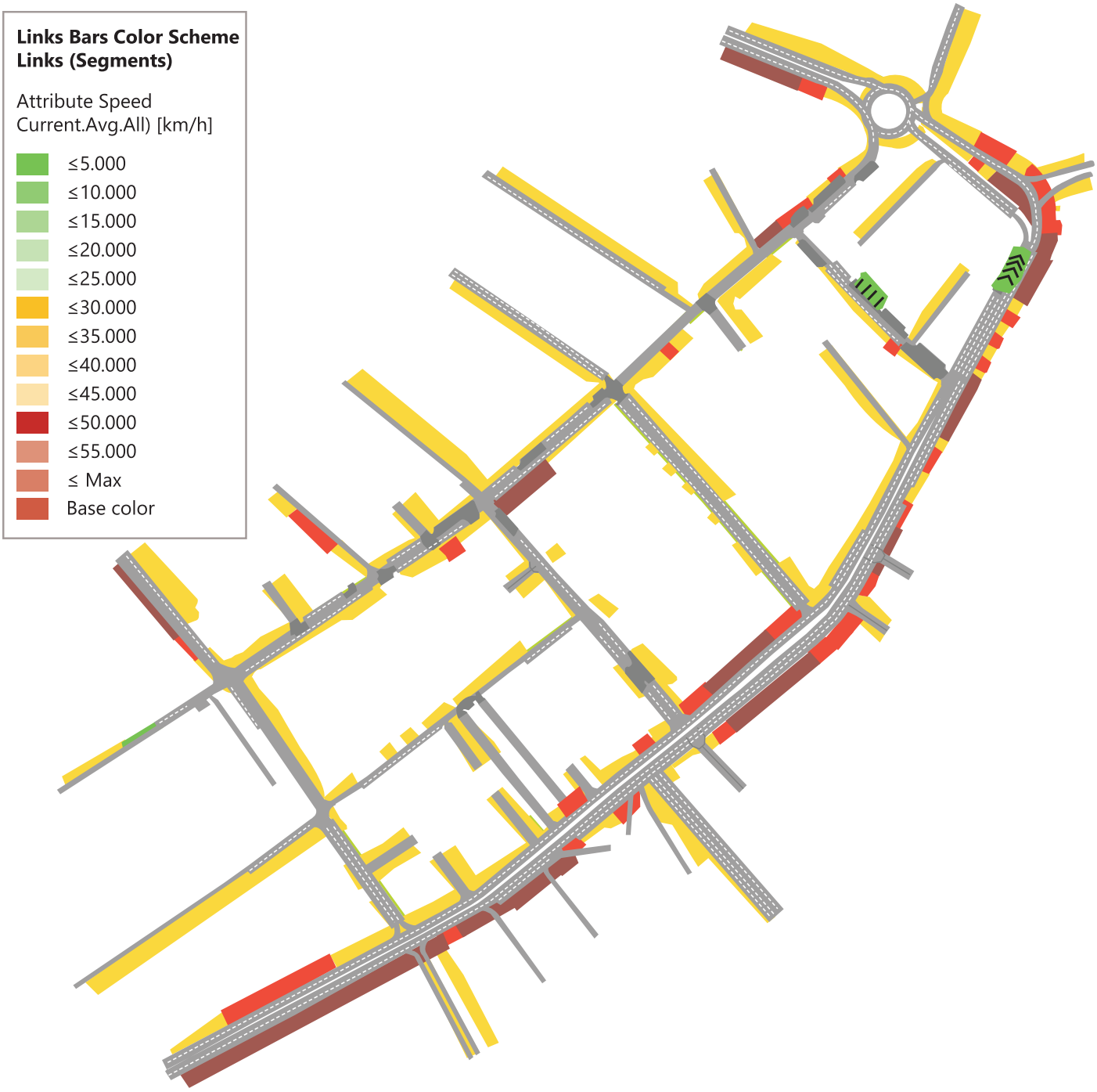


Figure 3-24 Speed- Base Scenario-AM Peak

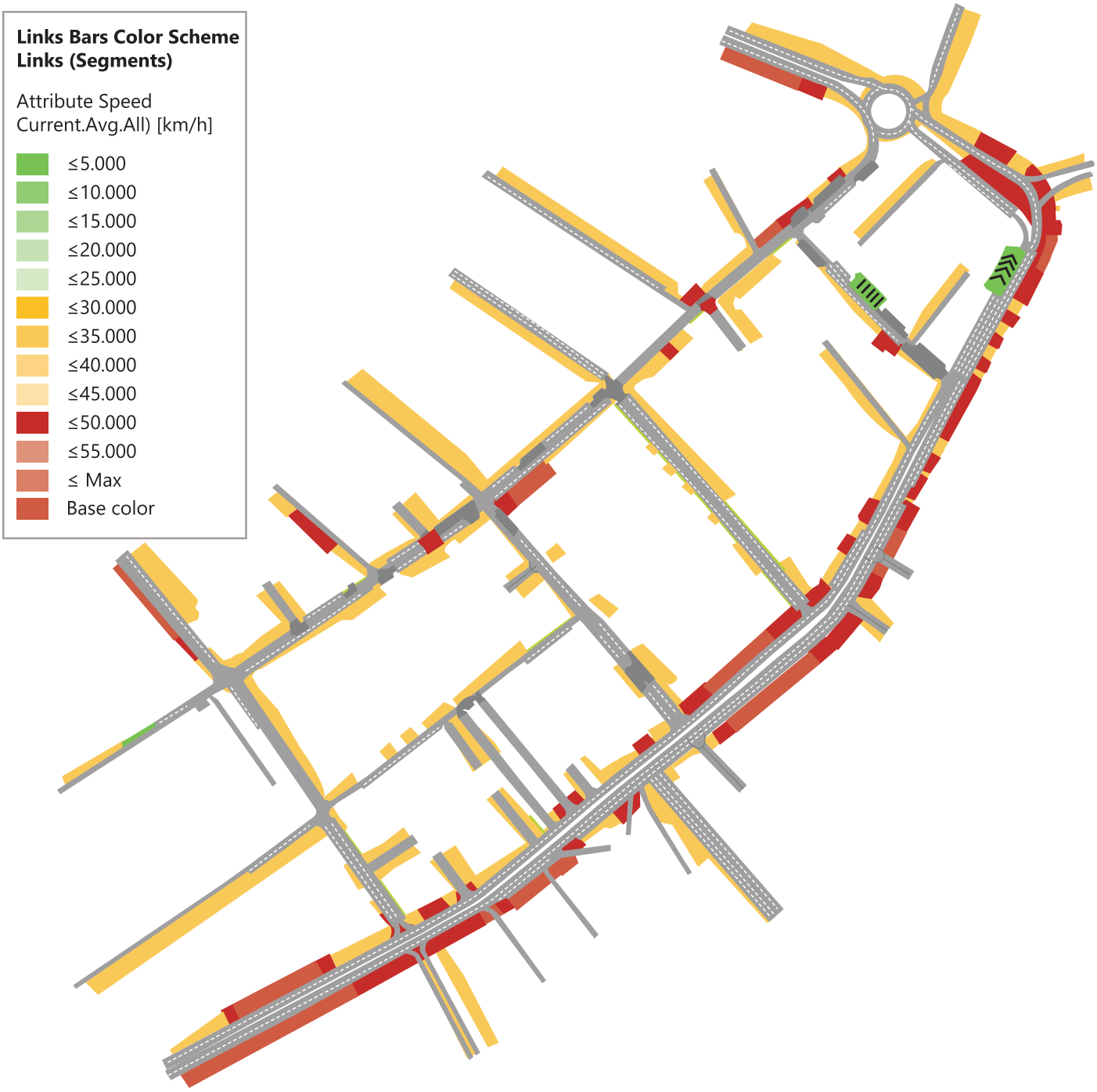


Figure 3-25 Speed- Base Scenario-PM Peak

From above graphs it can be observed that average speed on Pengkalan weld road is around 50 kmph and on other roads it is 40 kmph in AM peak.

4.3 SCENARIO 1

All the junctions in trail study area are unsignalized intersections expect Junction 23. Results obtained for scenario-1 in study area are shown in below sections of the report

4.3.1 Vehicular Measurement: Delay/Level of Service

The criterion for determining LOS at signalized and unsignalized intersections is delay per vehicle as explained in section 4.1.1. Below image shows the LOS for junctions in trial study area for scenario1.

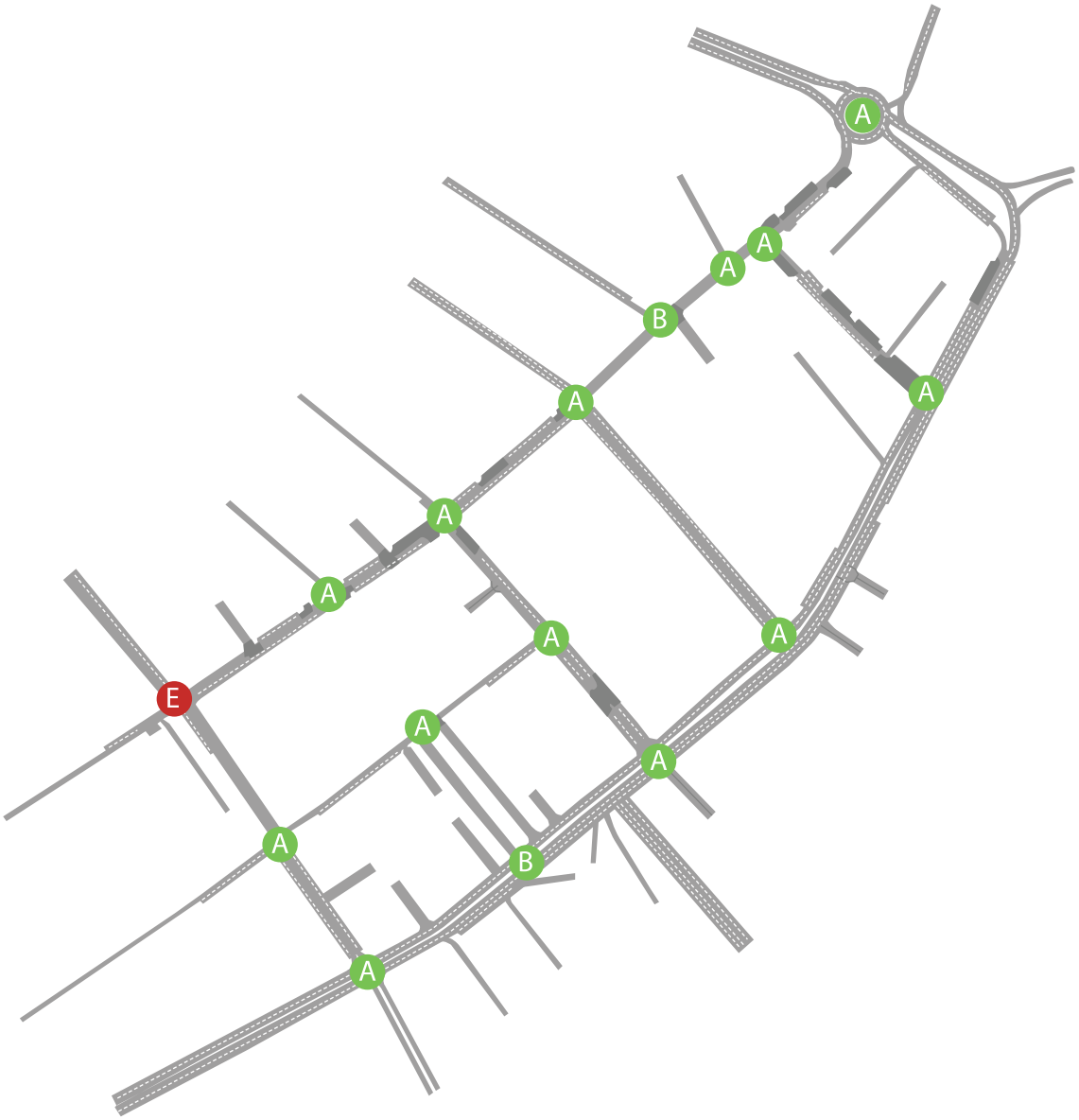


Figure 3-26 Level Of Service-Scenario1 - AM &PM peak

All the junctions in scenario-1 are performing with LOS A expect J4 and J23 which are performing at LOS B and LOS E respectively

The diagram below presents the delay (in unit of seconds) experienced by vehicular traffic at each section of the road. In below image, sections with green indicates that delay is less and driving conditions are ideal and sections with yellow and lite orange indicates that congestions is noticeable and sections with red indicates that higher delay is experienced, and vehicles are moving slowly or stopping for reasonable amount of time. Irrespective of color in below image, higher the width of bar higher is the delay experienced by the vehicle.

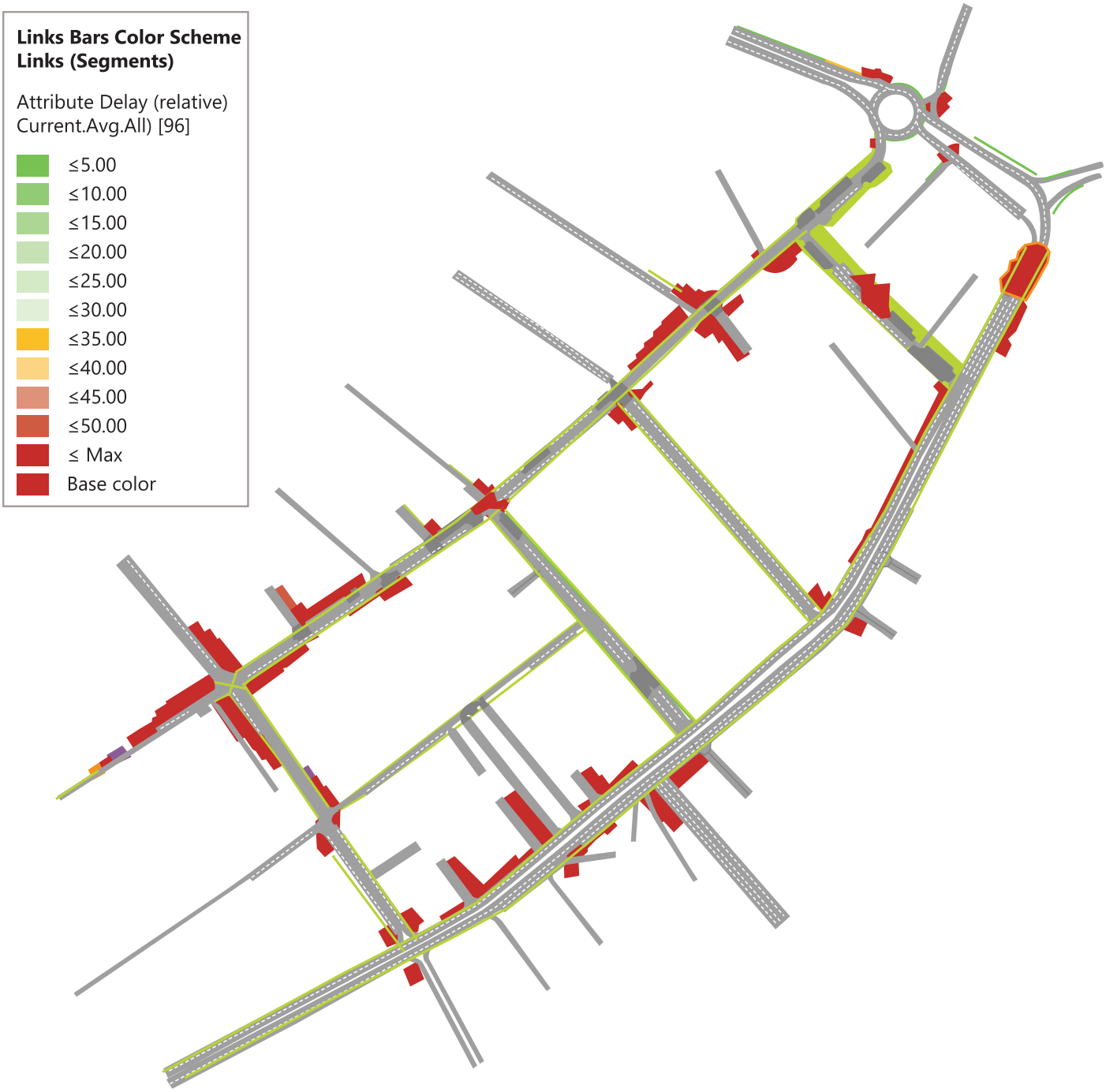


Figure 3-27 Delay-Scenario1 – AM peak

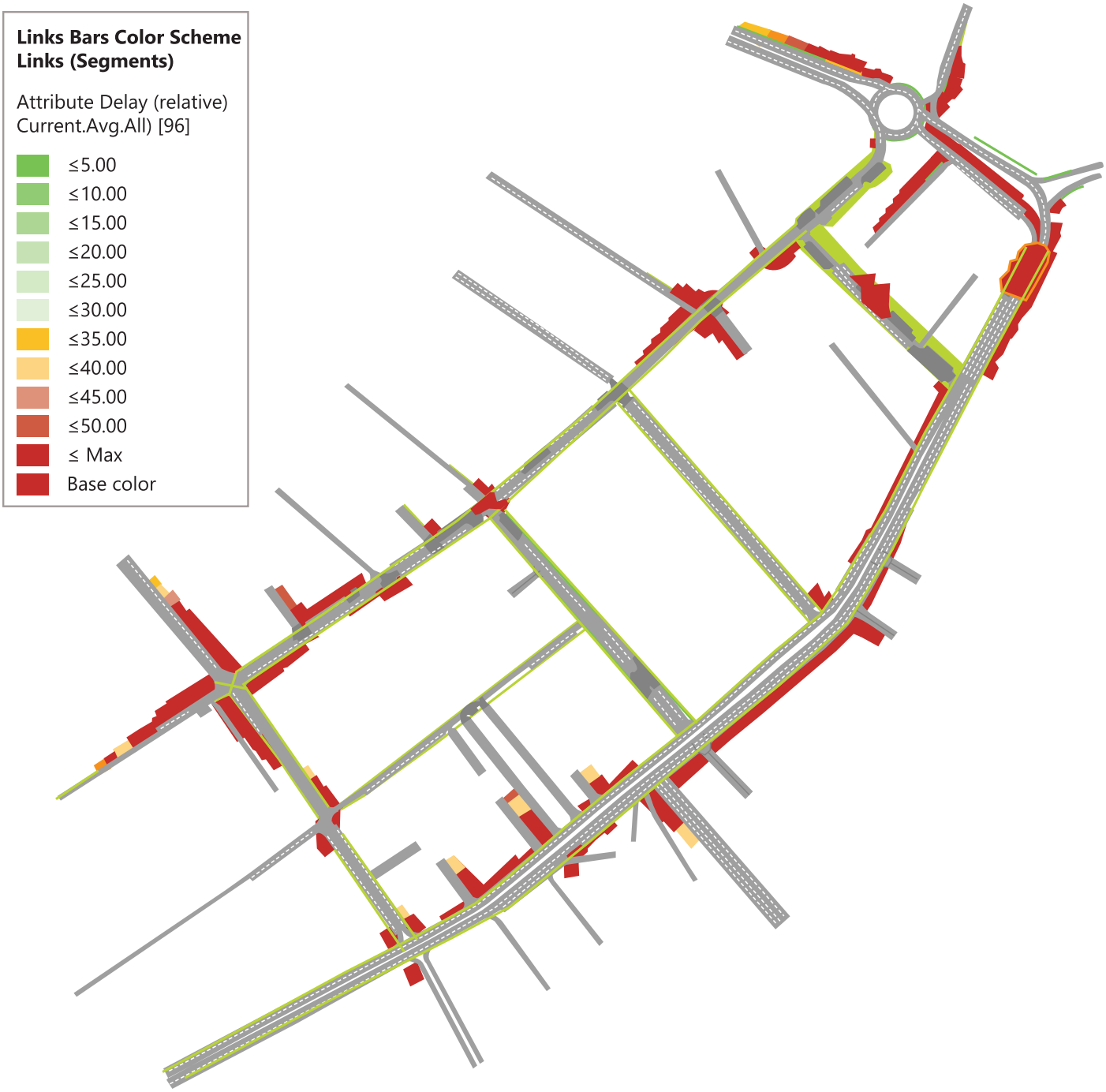


Figure 3-28 Delay-Scenario1 – PM peak

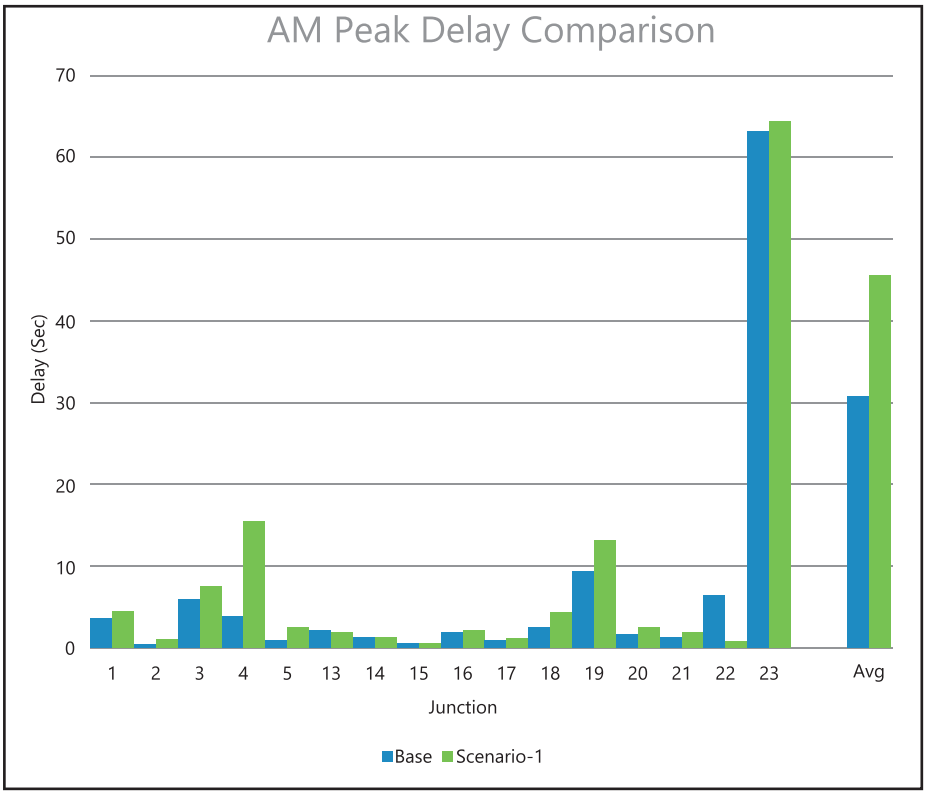


Figure 3-29 Scenario 1 - Delay Comparison -AM peak

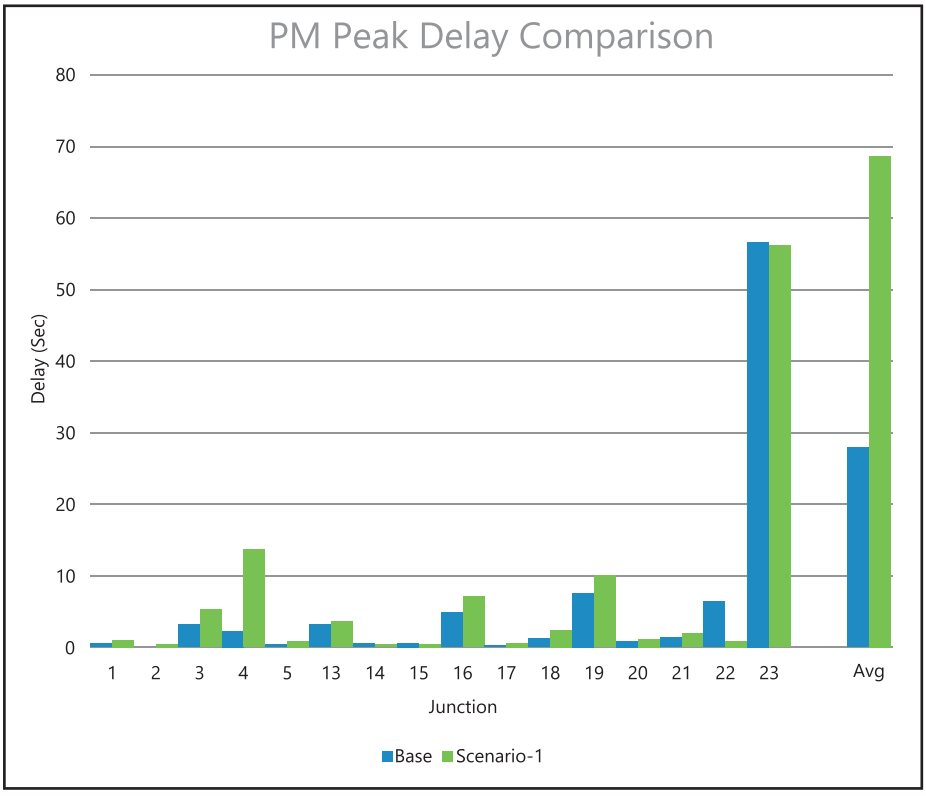


Figure 3-30 Scenario 1 - Delay Comparison -PM peak

From above graphs it can be inferred that all junctions are experiencing more or less same delay as in base scenario expect J4.

Delay is increased at J4 due to implementation of actuated pedestrian signal which gives priority for pedestrian movement and therefore results in increase of vehicular delay.

There is almost 48% and 145% increase in average delay on the road network in scenario-2 when compared with base scenario in AM and PM peak respectively.

4.3.2 Vehicular Measurement: Density

Density as explained in earlier sections is the number of vehicles occupying unit length of roadway. Green colour bar in below image indicates sections with low density and sections with yellow and orange indicates reasonable density and sections with red and pink indicates higher density, and it is generally experienced near to signalized sections. Width of the bar is proportional to the density experienced at those sections.

Figure 3-31 Density- Scenario 1-AM Peak

Figure 3-32 Density- Scenario 1-PM Peak

Due to implementation of actuated pedestrian signal along with vertical speed control elements at J1 and J4, density is relative higher at sections near J1 and J4 in both the peaks in scenario1.

4.3.3 Vehicular Measurement: Speed

Average speed on road network in scenario-1 is demonstrated in below images. Red color bar indicates sections on the road network with speed around 50 kmph and yellow bars indicates speed around 40 kmph.

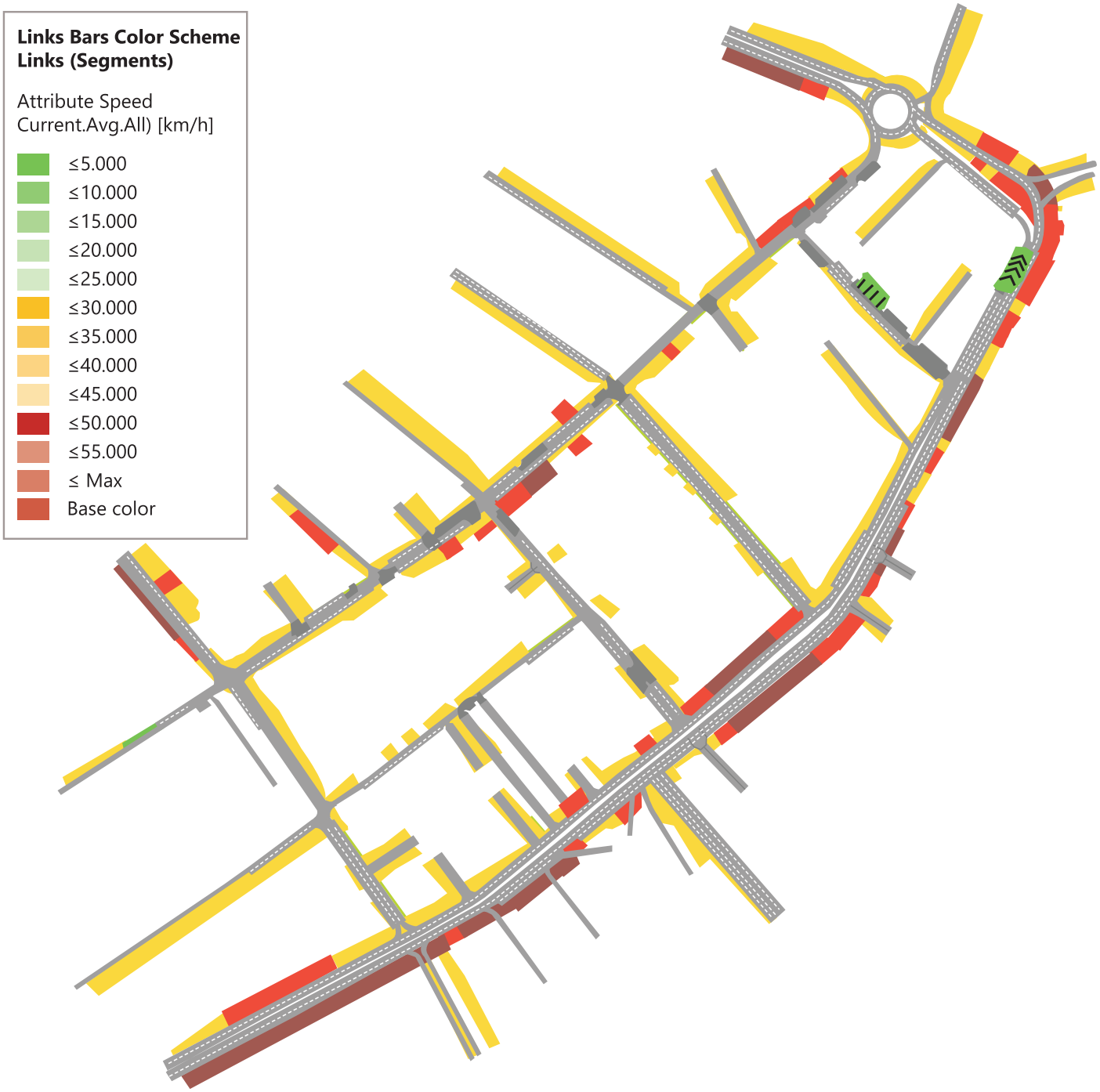


Figure 3-33 Speed- Scenario 1-AM Peak

Figure 3-34 Speed- Scenario 1-PM Peak

From above graphs it can be observed that average speed on Pengkalan road is around 50 kmph and on other roads it is 40 kmph in AM peak.

In PM peak, sections near to J1 and J4 of Pengkalan road, average road speed dropped to around 20 kmph. Observed reduction of speeds at those sections is due to introduction of vertical speed control and actuated pedestrian signals near J1 and J4.

4.3.3 Pedestrian Measurement: Travel Time

Time taken for pedestrian to travel from one end of Pengkalan weld road to other end in trail study area is measured as shown in figure below.

Figure 3-35 Pedestrian travel time sections

For better understanding the pedestrian performance in scenario-1 a comparison between base scenario and scenario-1 is done and is presented below.

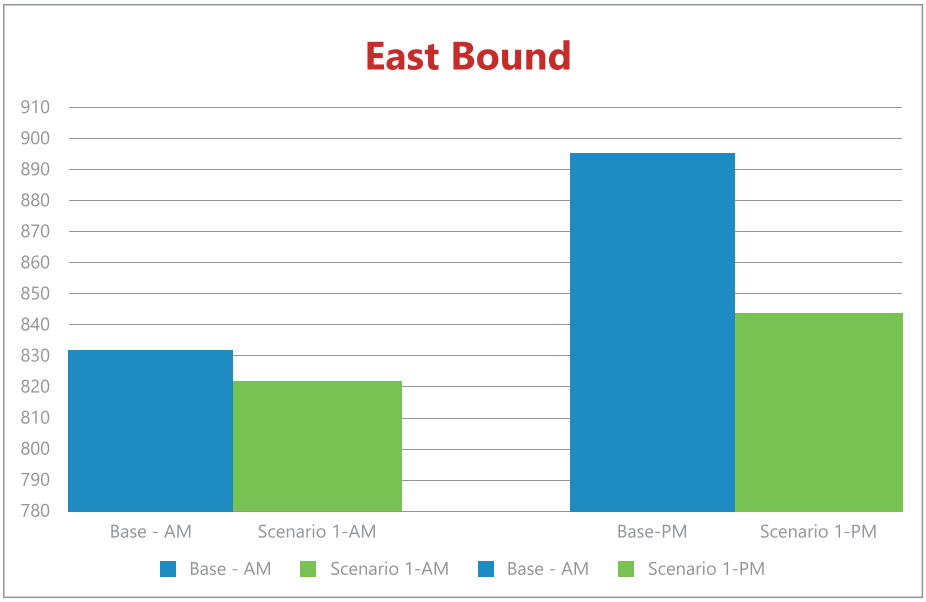


Figure 3-36 Pedestrian travel time-East Bound

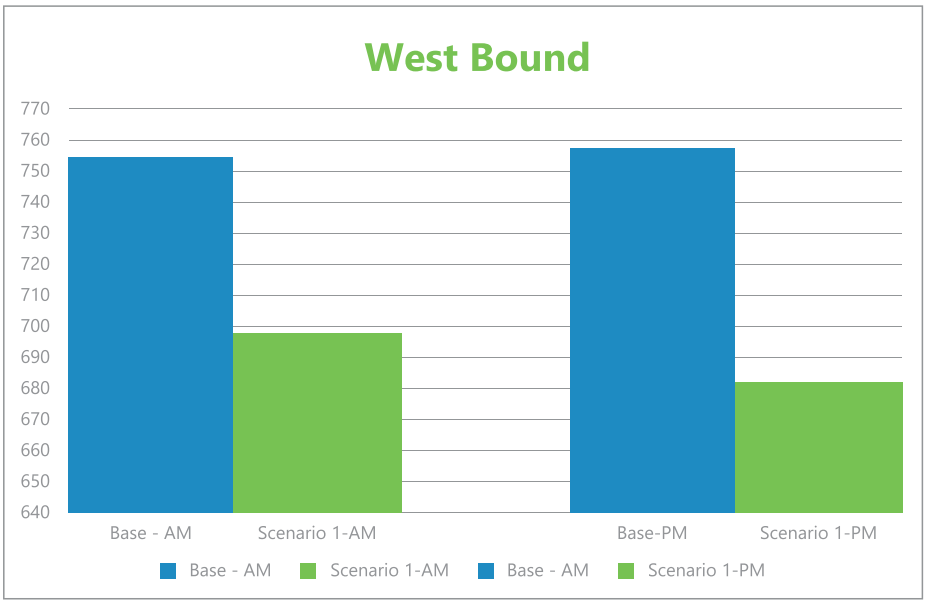


Figure 3-37 Pedestrian travel time-West Bound

There is certainly as decrease of pedestrian travel time in scenario-1 and following points can be inferred from above graphs:

- In east bound direction, pedestrian travel time in Scenario 1 is decreased by 1% and 6% respectively in AM and PM peak when compared with base scenario.
- Travel time is decreased by 8% and 11% in west bound direction when compared with bae scenario

4.4 SCENARIO 2

In this scenario, emphasis is given to understand the network performance after adopting road network improvements. Below sections provide the results of the assessment for Scenario 2.

4.4.1 Vehicular Measurement: Delay/Level of service

Based on LOS criteria for signalized and unsignalized intersections as explained in section 4.1.1, LOS for junctions is determined and presented in below images.

Figure 3-38 Level of Service-Scenario2 - AM peak

Figure 3-39 Level of Service-Scenario2 - PM peak

From the above images following observation can be done:

- All the junctions in scenario-2 are performing with LOS A expect J23 which is performing at LOS D in AM peak and
- In PM peak, J16 is operating at LOS B and J23 is operating at LOS D. Remaining junctions are operating with LOS A

In below image, sections with green indicates that delay is less and driving conditions are ideal and sections with yellow and lite orange indicates that congestions is noticeable and sections with red indicates that higher delay is experienced, and vehicles are moving slowly or stopping for reasonable amount of time. Irrespective of color in below image, higher the width of bar higher is the delay experienced by the vehicle.

Delay experienced on trial area road network in scenario-2 is displayed in below graphs.

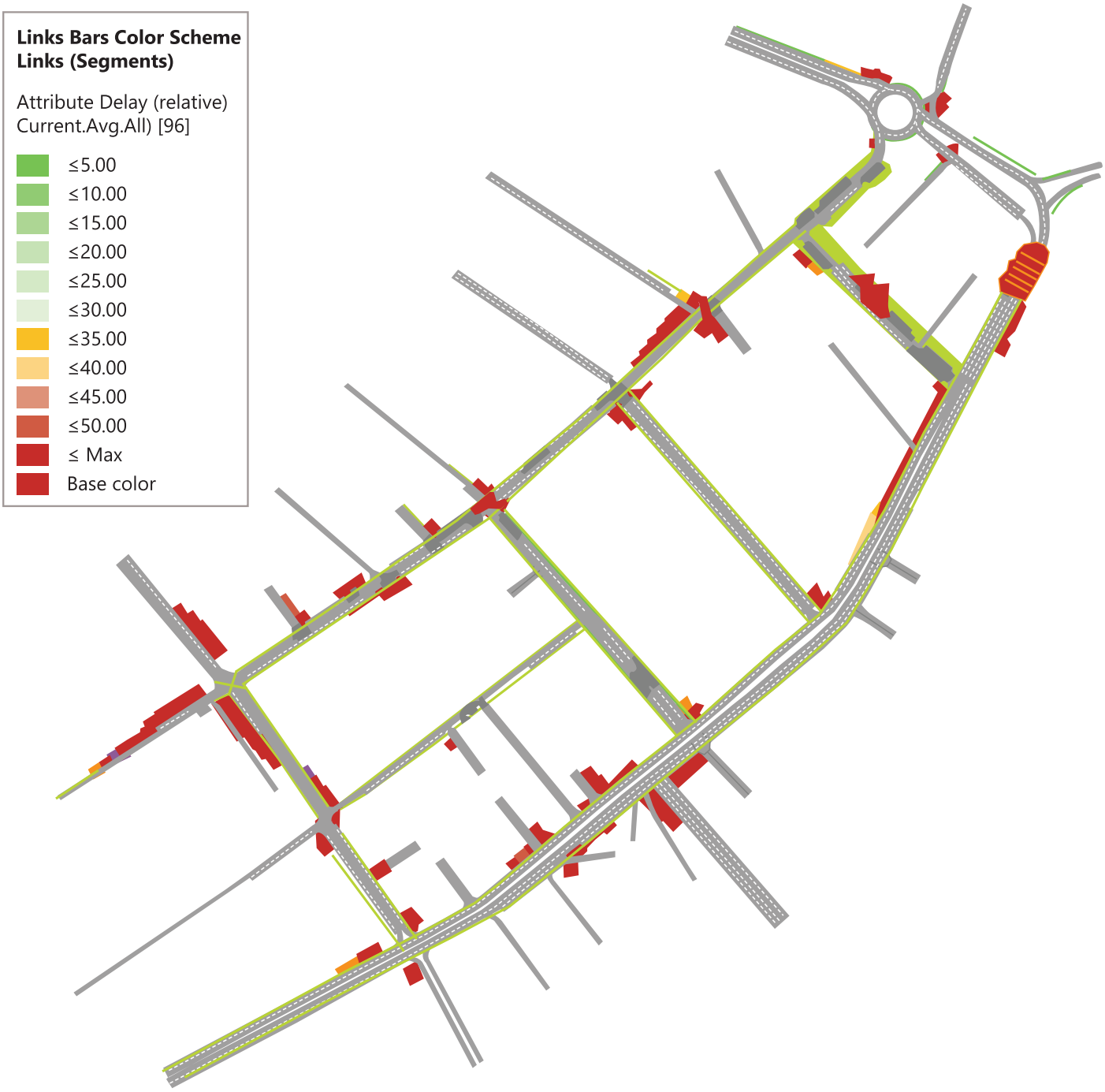


Figure 3-40 Delay-Scenario2 – AM peak

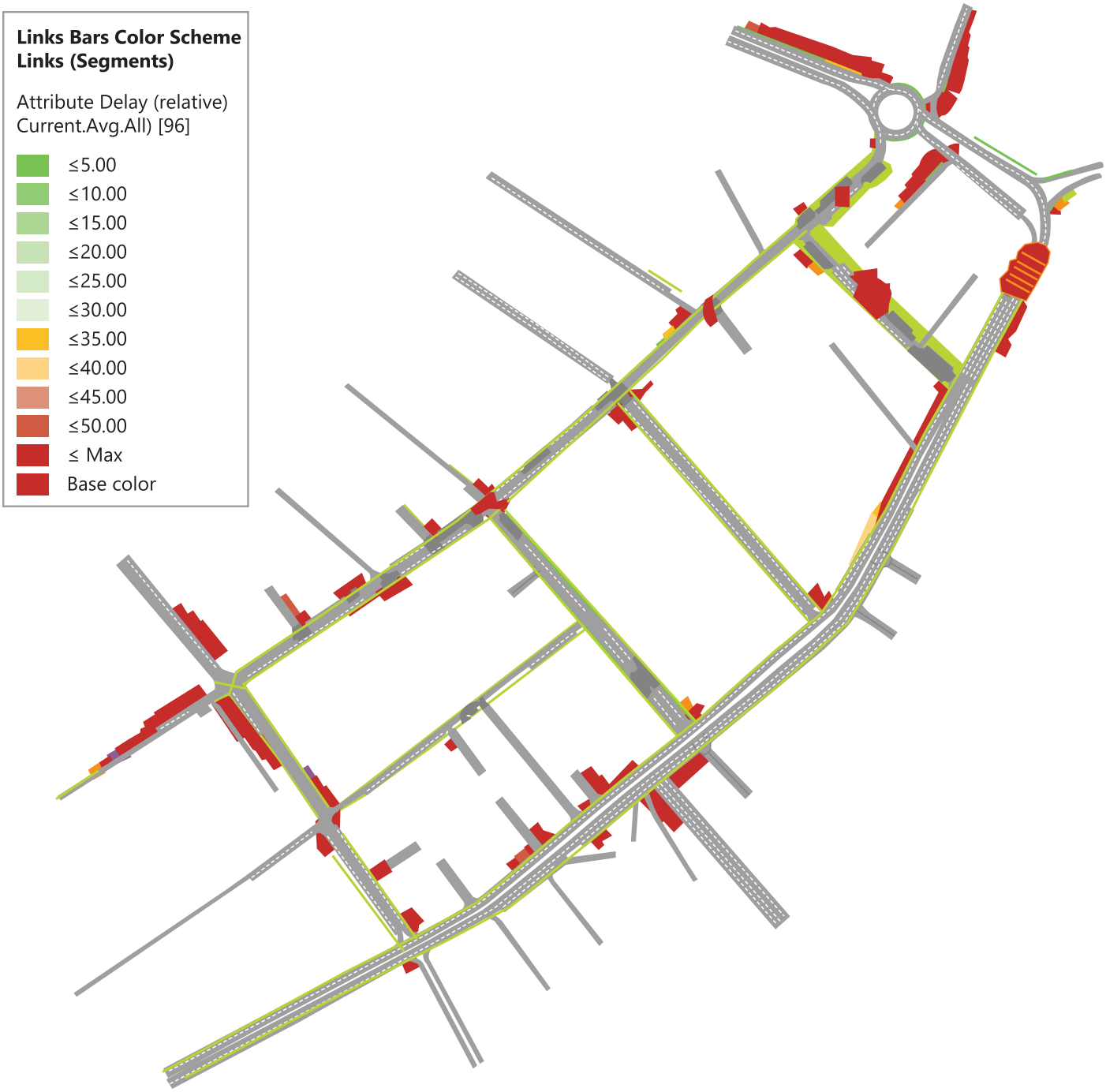


Figure 3-41 Delay-Scenario2 – PM peak

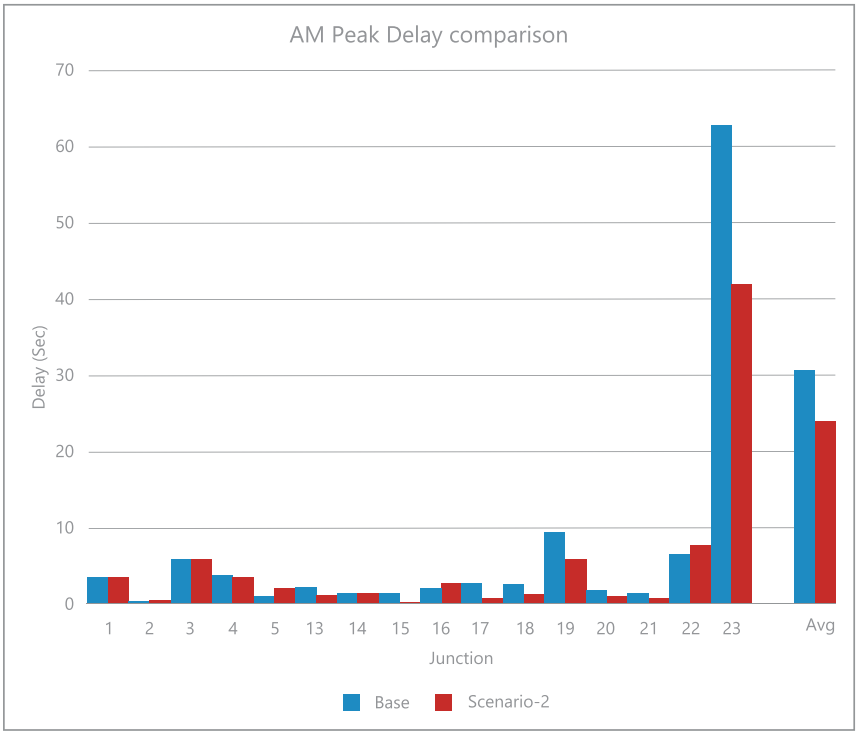


Figure 3-42 Scenario 2 - Delay Comparison -AM peak

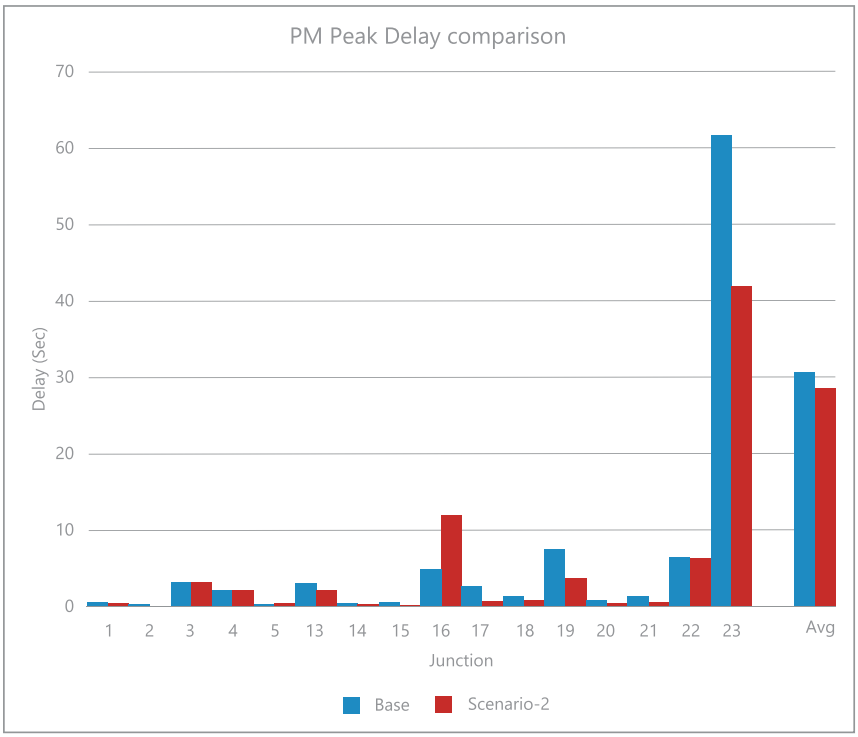


Figure 3-43 Scenario 2 - Delay Comparison -PM peak

Following observation can be made from above delay graphs and plots:

- For all the junctions expect J23, average delay is more or less same as of base scenario;
- Average Delay for J23 is reduced in scenario-2 due to provision of one-way arrangement on beach street which increases effective green time for all the movements and decreases the delay;
- Overall average delay is reduced in scenario2 by 22% and 6% in AM and PM peak respectively

4.4.2 Vehicular Measurement: Density

Density of the road network in scenario-2 is shown in below images. Green colour bar in below image indicates sections with low density and sections with yellow and orange indicates reasonable density and sections with red and pink indicates higher density, and it is generally experienced near to signalized sections. Width of the bar is proportional to the density experienced at those sections.

Figure 3-44 Density- Scenario 2-AM Peak

Figure 3-45 Density- Scenario 2-PM Peak

Density on pengkalan road west bound is increased due to introduction of one-way arrangement on beach street. Redistribution of trips is expected due to introduction of one-way arrangement, and it resulted in increase of traffic and therefore increase of density on pengkalan road.

4.4.2 Vehicular Measurement: Density

Average speed on road network in scenario-2 is demonstrated in below images. Red color bar indicates sections on the road network with speed around 50 kmph and yellow bars indicates speed around 40 kmph.

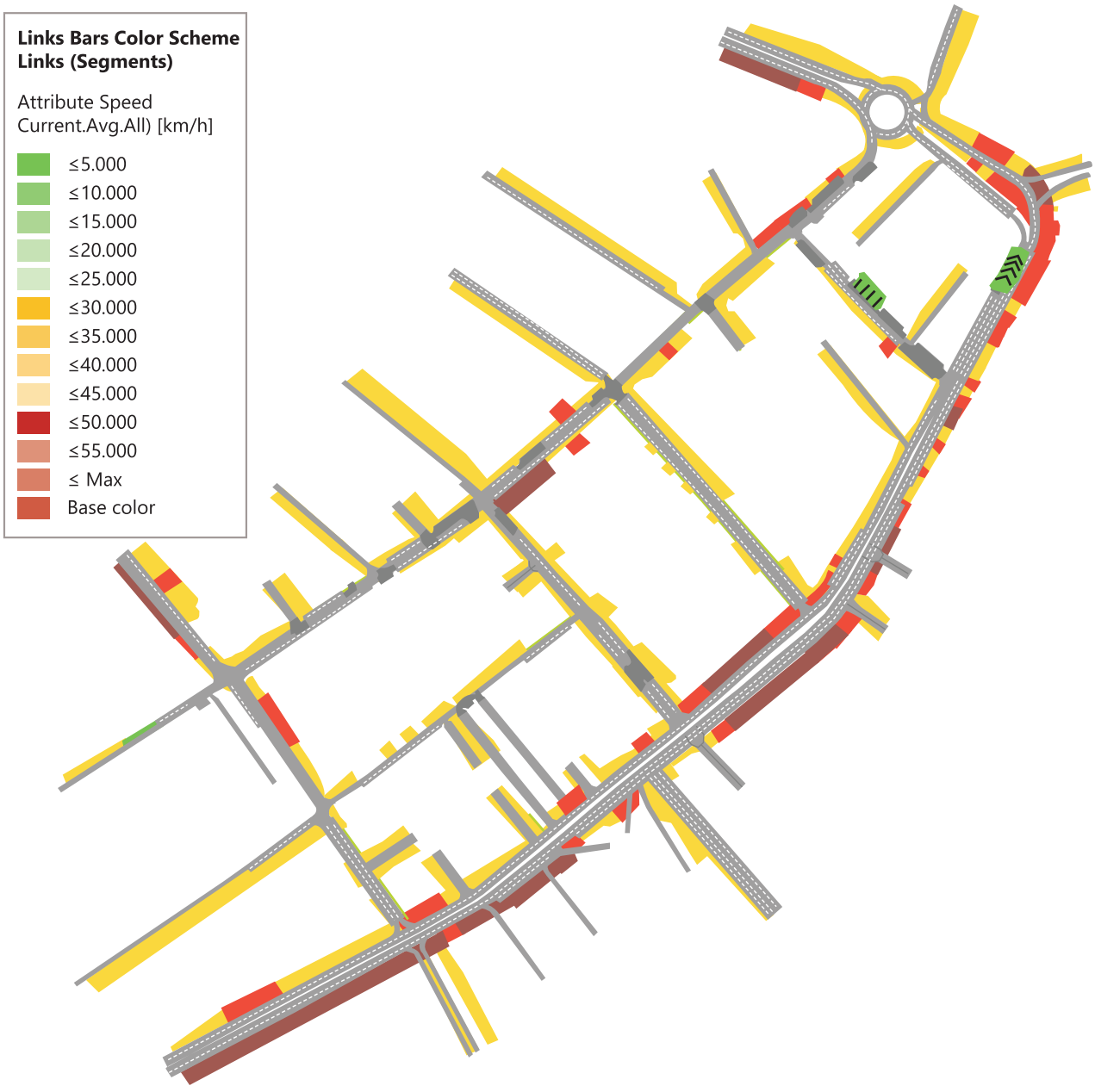


Figure 3-46 Speed- Scenario 2-AM Peak

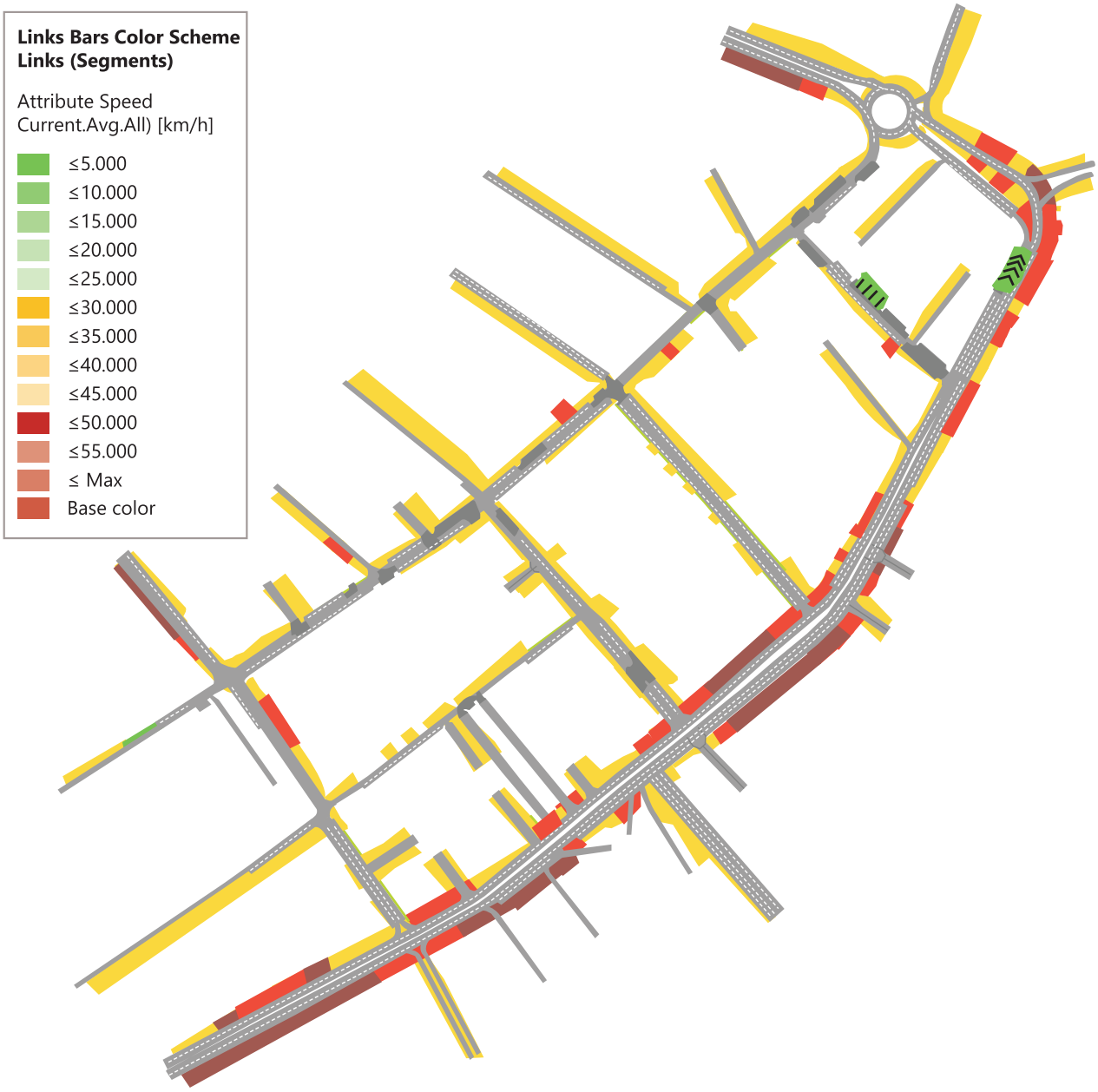


Figure 3-47 Speed- Scenario 2-PM Peak

From above graphs it can be observed that average speed on most sections of pengkalan road in both AM and PM peak is around 50kmph and on other roads it is around 40 kmph.

4.5 SCENARIO 3

In this scenario, as explained in in section Error! Reference source not found., PT lanes are added on some selected sections of the road and the impact is analyzed in below section of the report.

4.5.1 Vehicular Measurement: Delay/Level of service

LOS for all the junctions in trial study area for scenario3 are shown in below images.

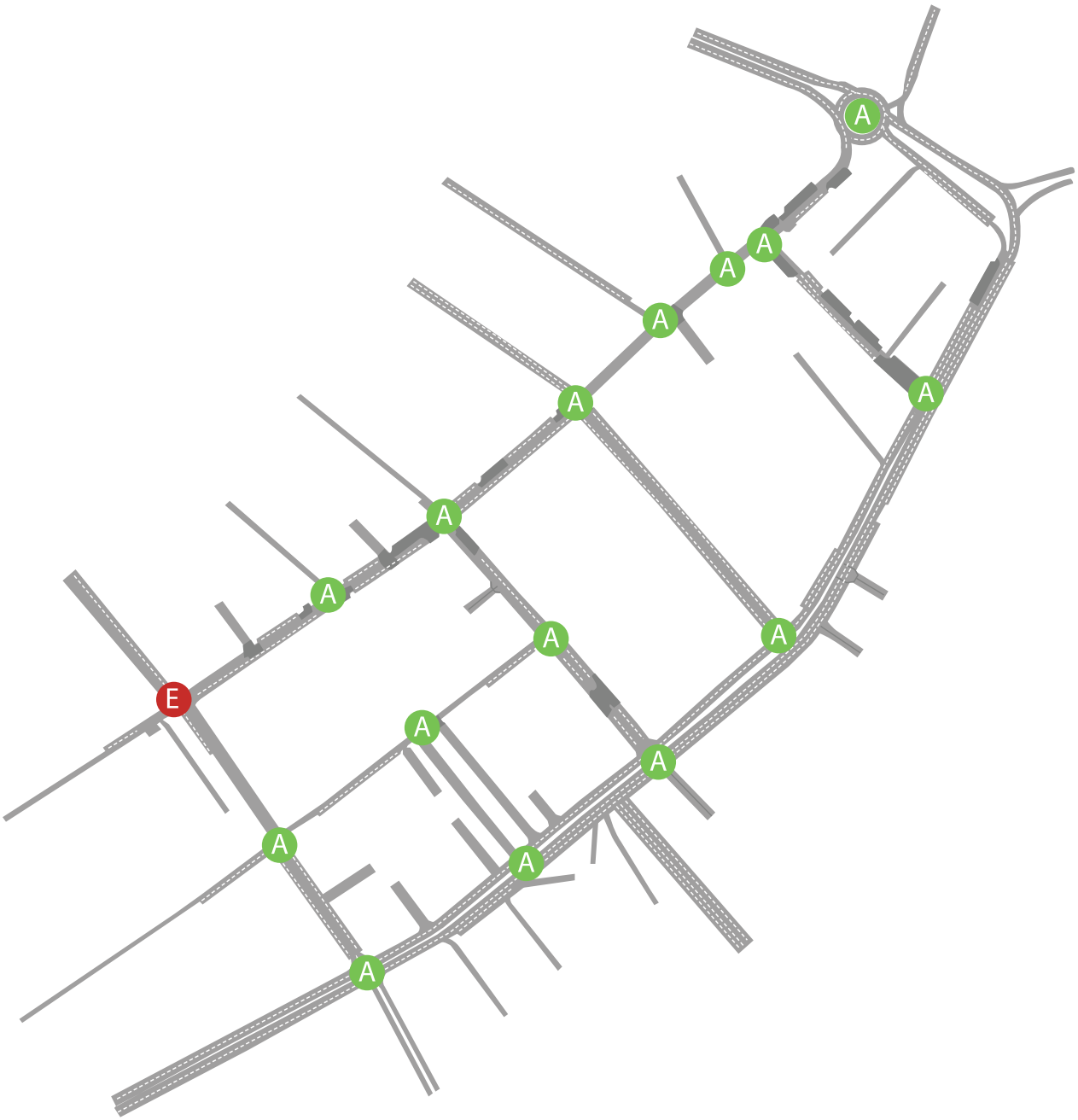


Figure 3-48 Level of Service-Scenario3 – AM & PM peak

All the junctions in scenario-3 in both the peaks are operating at LOS A expect J23 which is operating at LOS E.

Delay experienced on trial area road network in scenario-3 is displayed in below graphs.

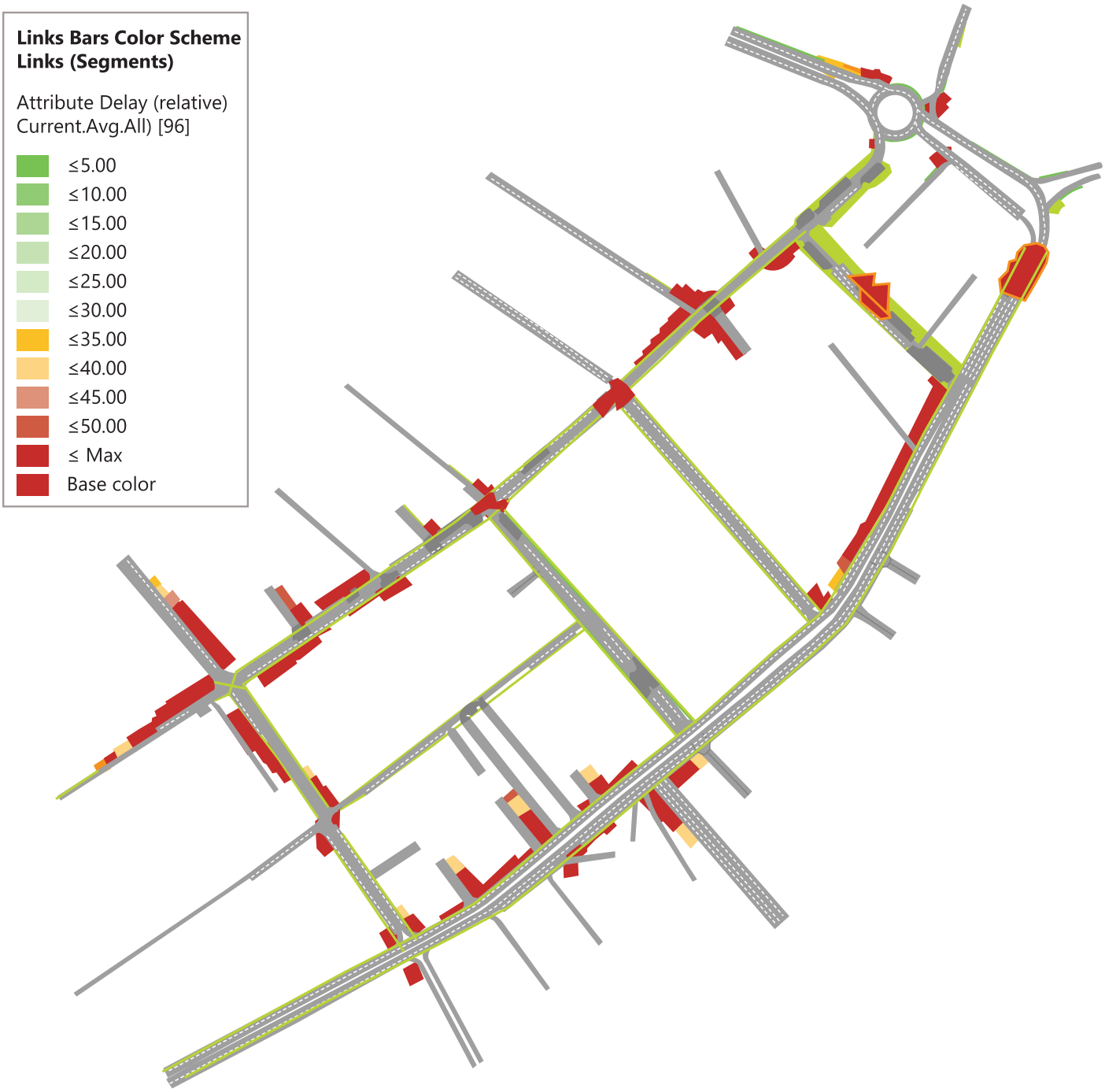


Figure 3-49 Delay-Scenario3 – AM peak

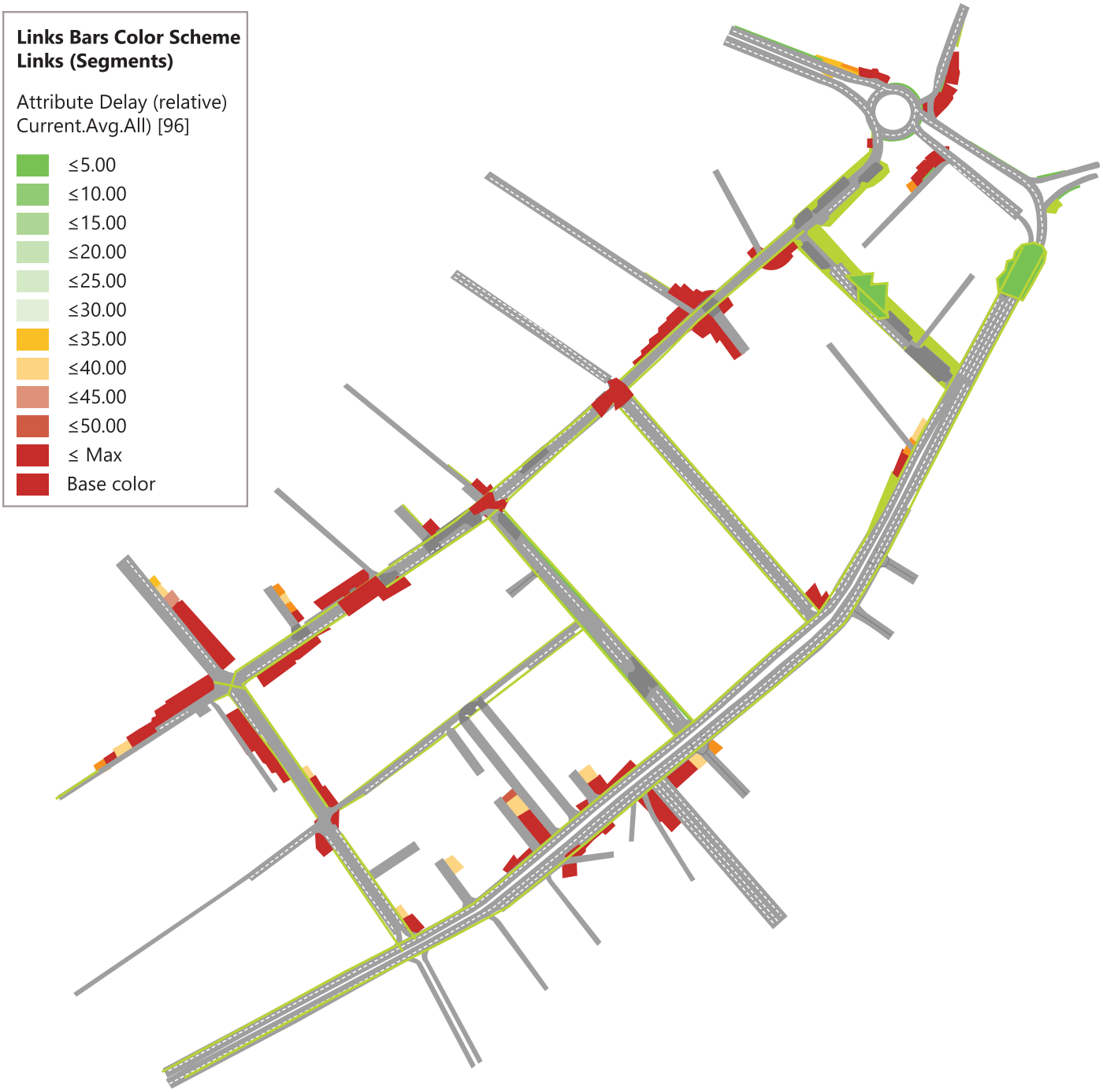


Figure 3-50 Delay-Scenario3 – PM peak

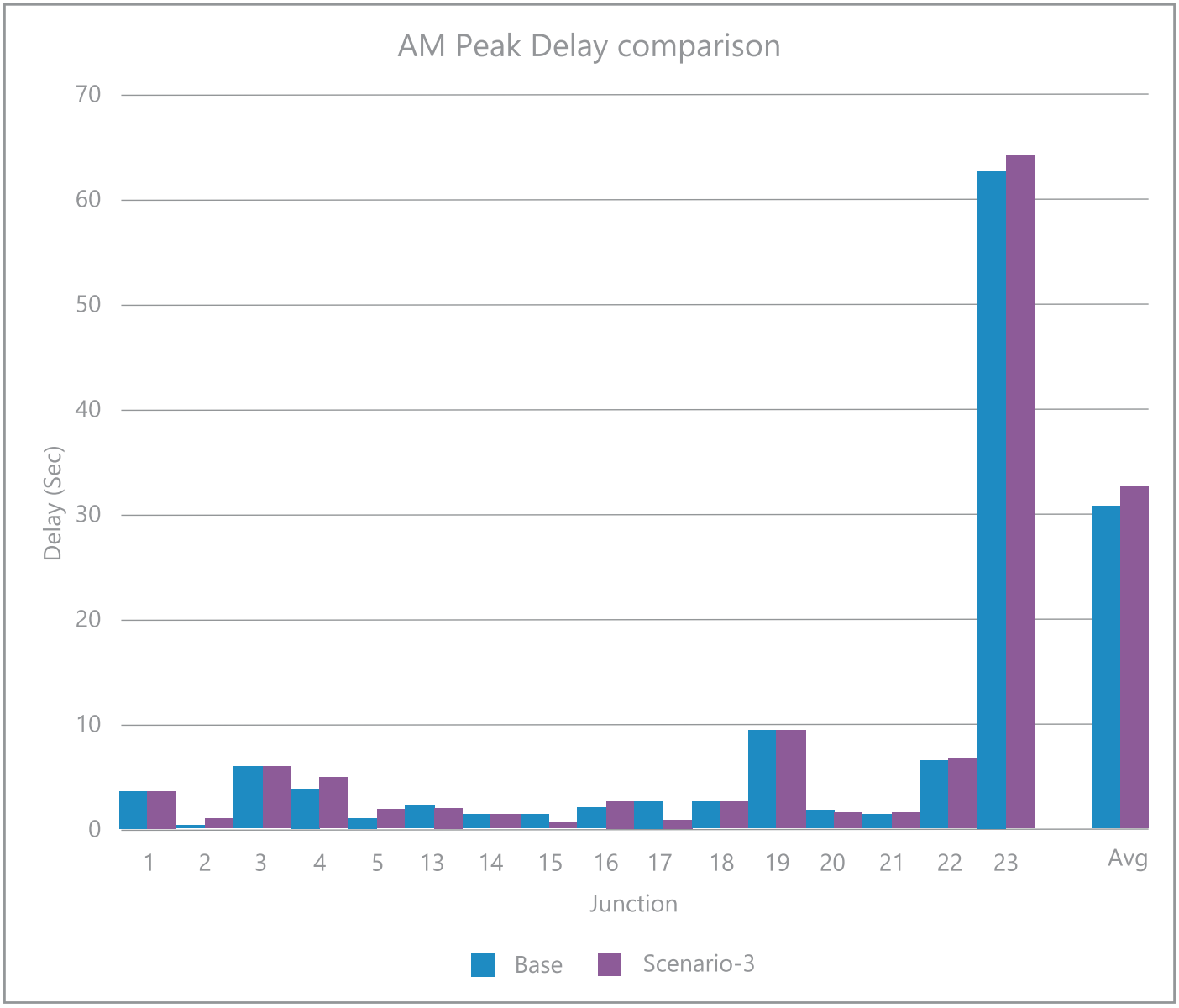


Figure 3-51 Scenario 3 - Delay Comparison -AM peak

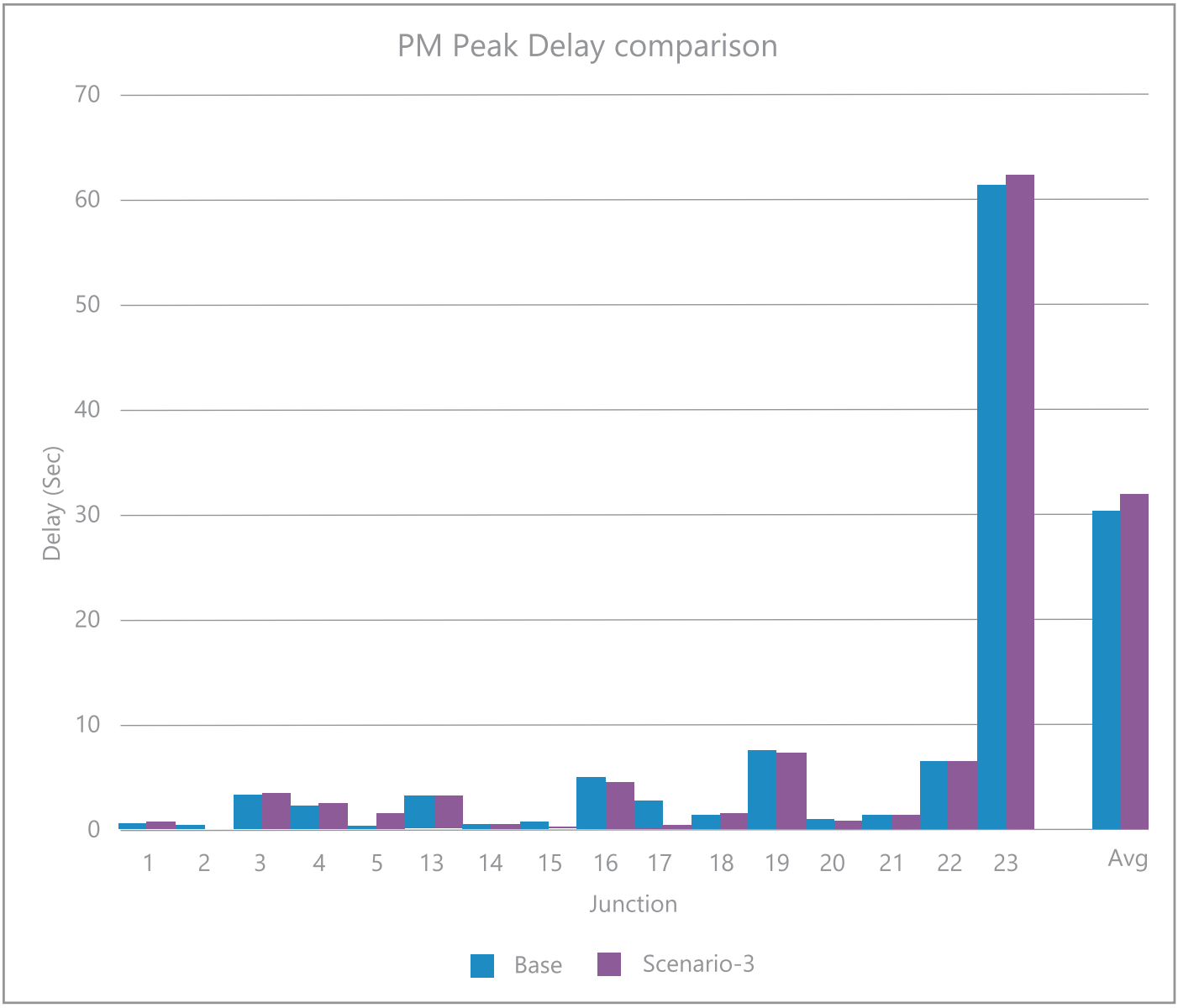


Figure 3-52 Scenario 3 - Delay Comparison -PM peak

Following observation can be made from above delay graphs and plots:

- For all the junctions in study area, average delay is more or less same as of base scenario and
- Overall average delay increase is minor in scenario3 which is 6% and 5% in AM and PM peak respectively

4.5.2 Vehicluar-Density

Density of the road network in scenario-3 is shown in below images

Figure 3-53 Density- Scenario 3-AM Peak

Figure 3-54 Density- Scenario 3-PM Peak

Minor increase in density is observed at sections where PT lane is introduced in both AM and PM peak. Due to introduction of PT lane, all the vehicles will be forced to travel on remaining lanes of the road, and it will decrease the capacity of the road and therefore increase the density.

4.5.3 Vehicular Measurement: Speed

Average speed on road network in scenario-3 is demonstrated in below images

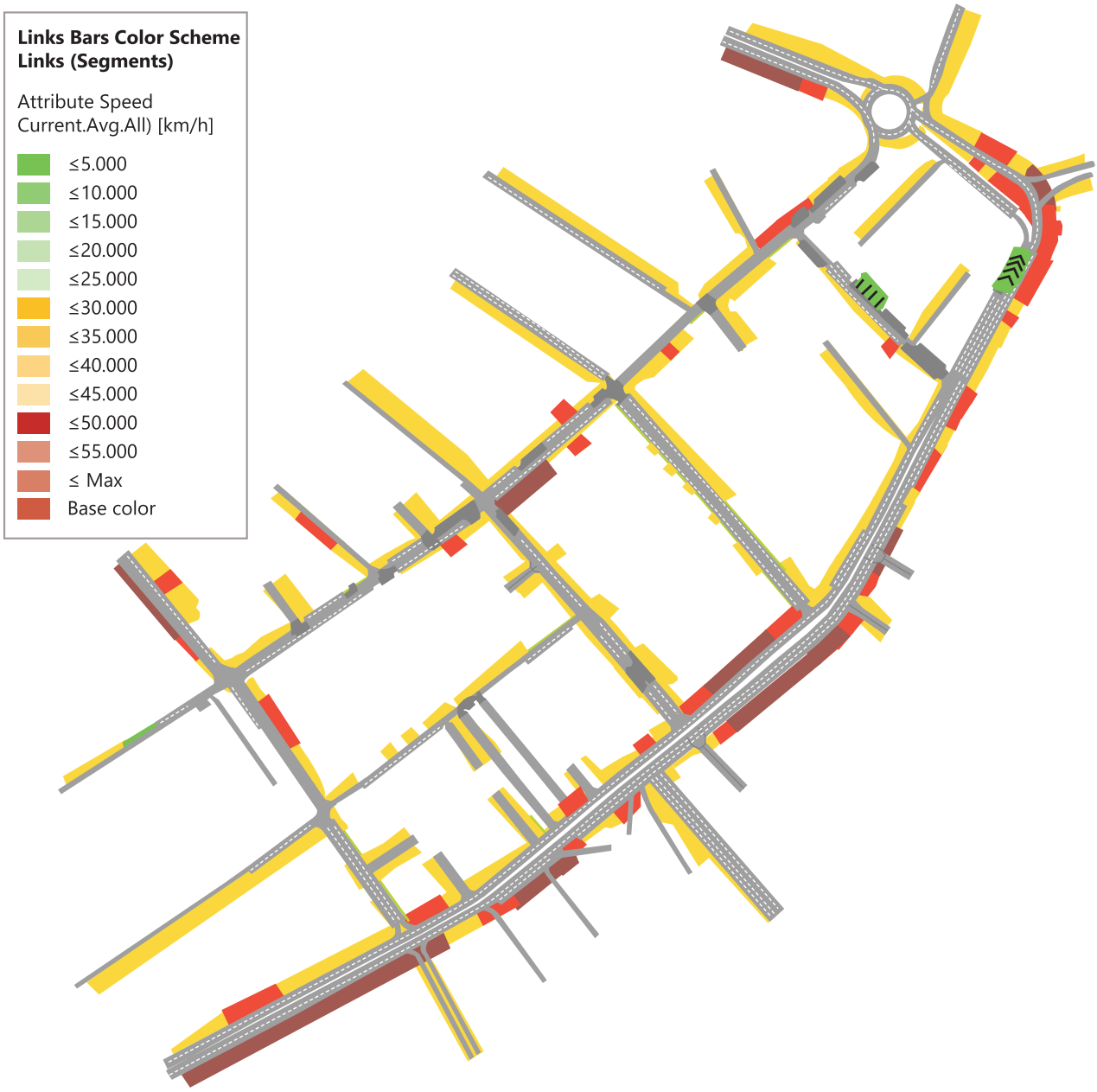


Figure 3-55 Speed- Scenario 3-AM Peak

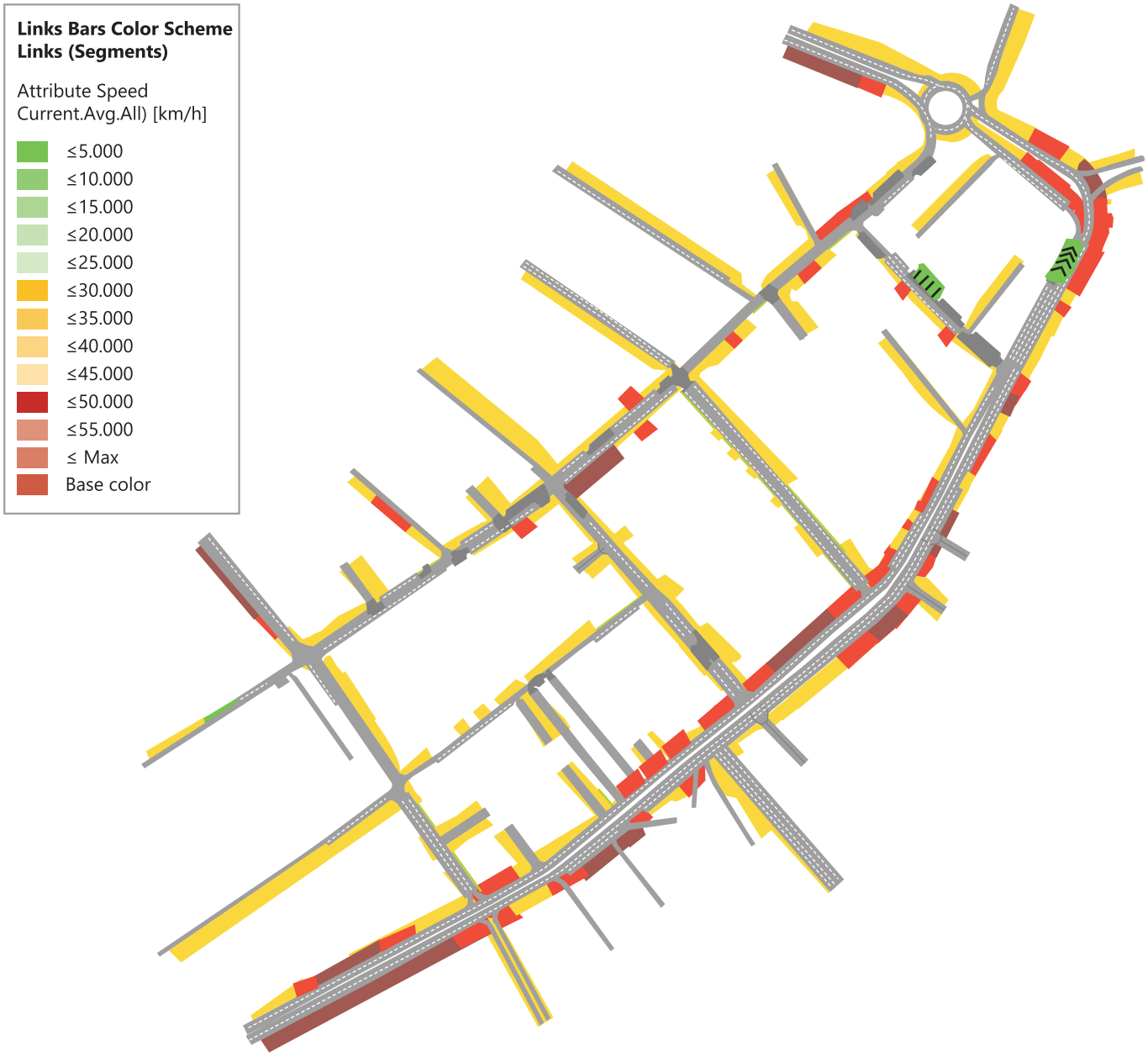


Figure 3-56 Speed- Scenario 3-PM Peak

From above graphs it can be observed that average speed on most sections of pengkalan road in both AM and PM peak is around 50kmph and on other roads it is 40 kmph.

4.6 SCENARIO 4

Results obtained for scenario-4 in study area are shown in below sections of the report

4.6.1 Vehicular Measurement: Delay/Level of service

LOS for all the junctions in trial study are for scenario4 are shown in below images.

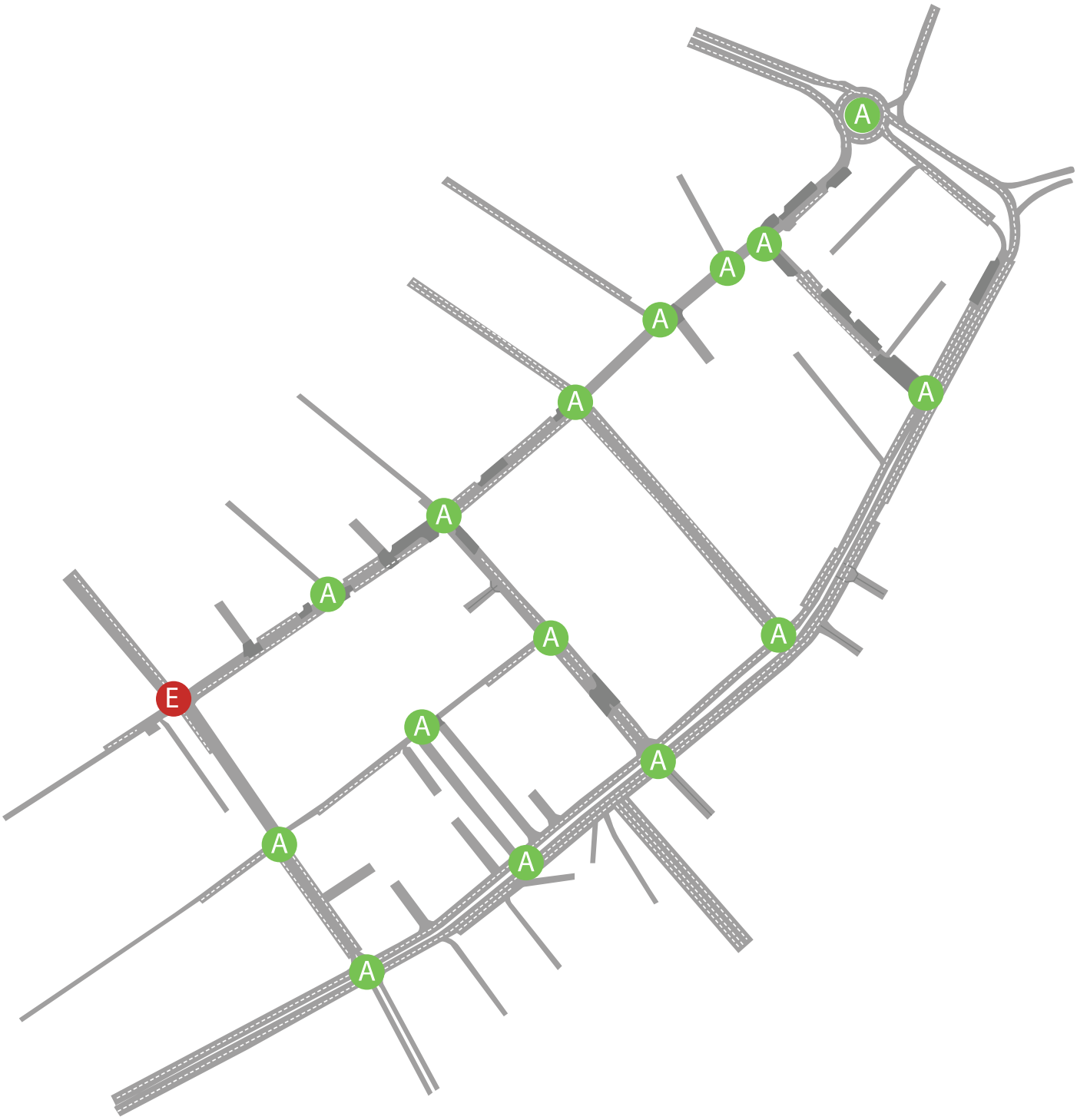


Figure 3-57 Level of Service-Scenario4 – AM Peak

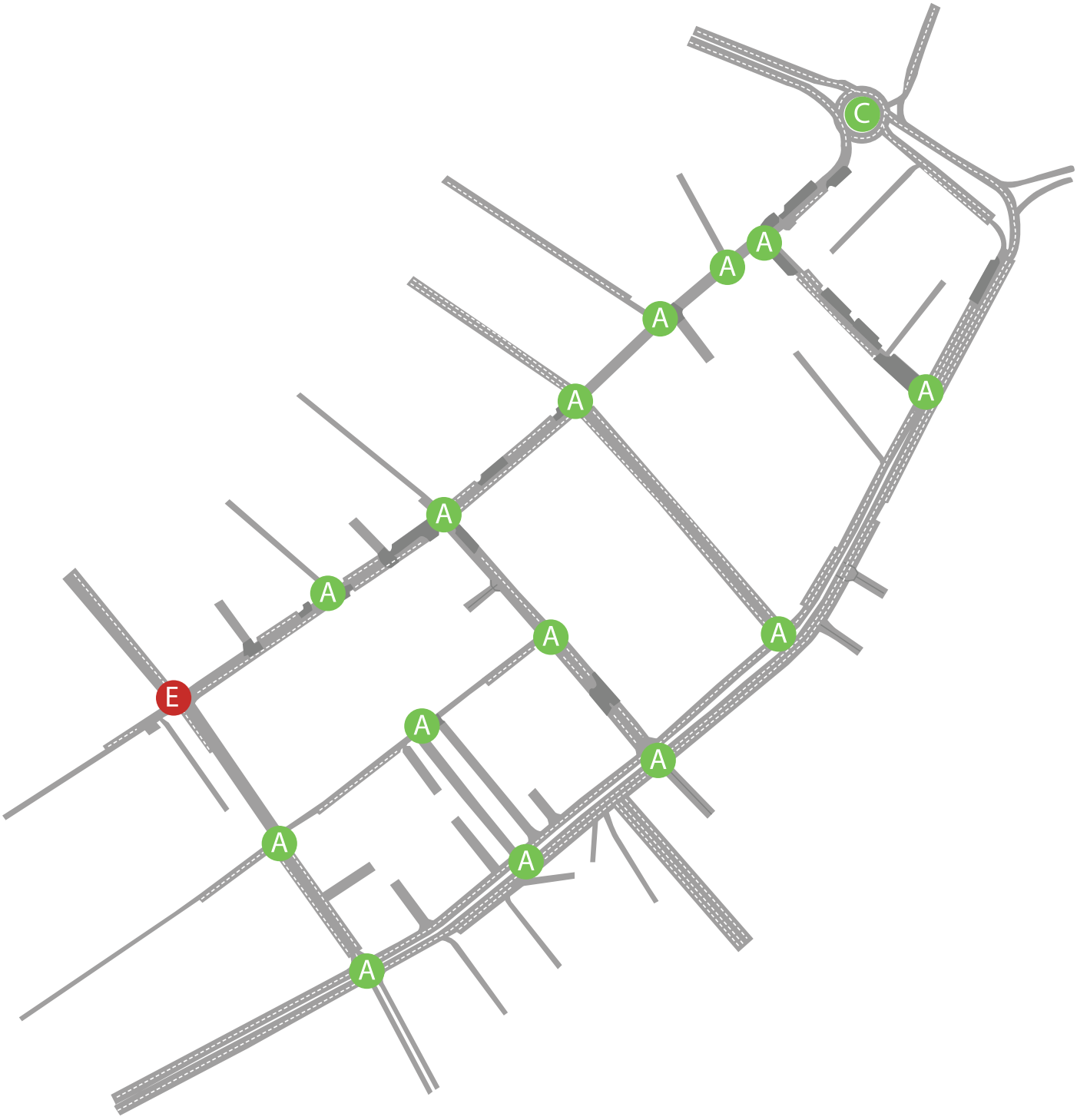


Figure 3-58 Level of Service-Scenario4 – PM Peak

Following observations can be done based on above images:

- In AM peak, all the junctions are operating with LOS A expect J23 which is operating at LOS E and
- J23 and J17 are operating at LOS E and LOS C respectively in PM peak and remaining junctions are performing with LOS A.

Delay experienced on trial area road network in scenario-4 is displayed in below graphs.

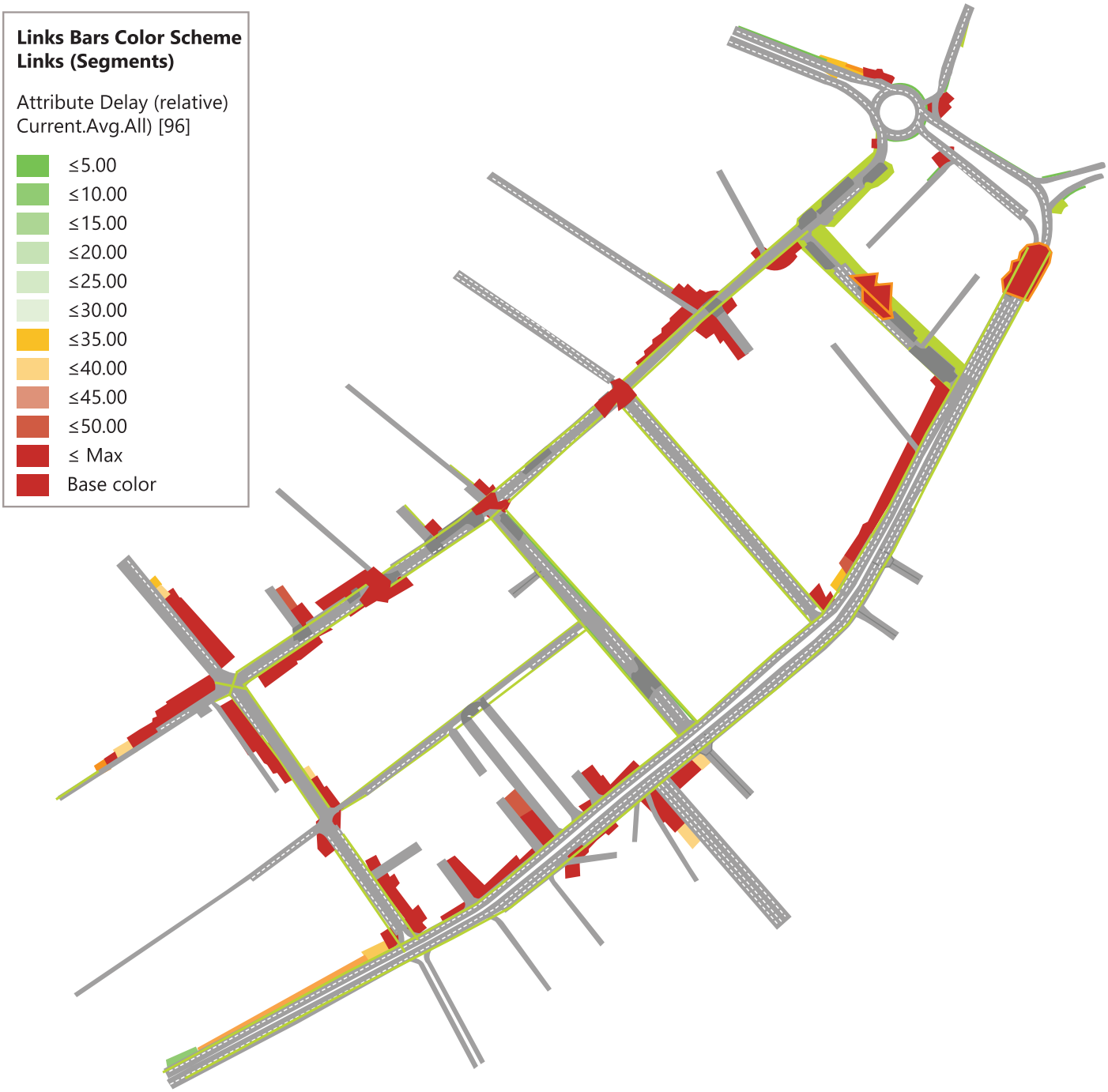


Figure 3-59 Delay-Scenario4 – AM peak

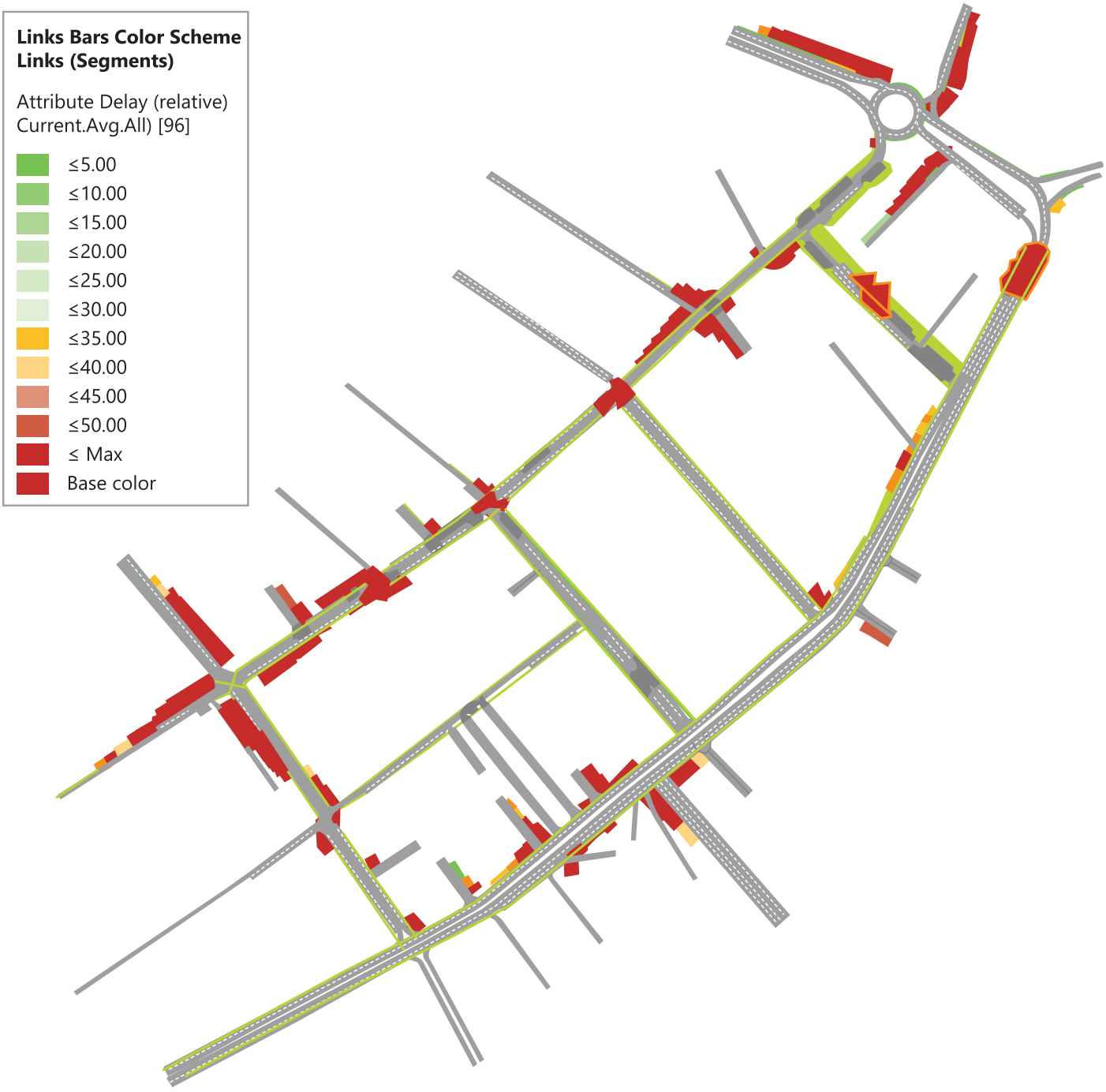


Figure 3-60 Delay-Scenario4 – PM peak

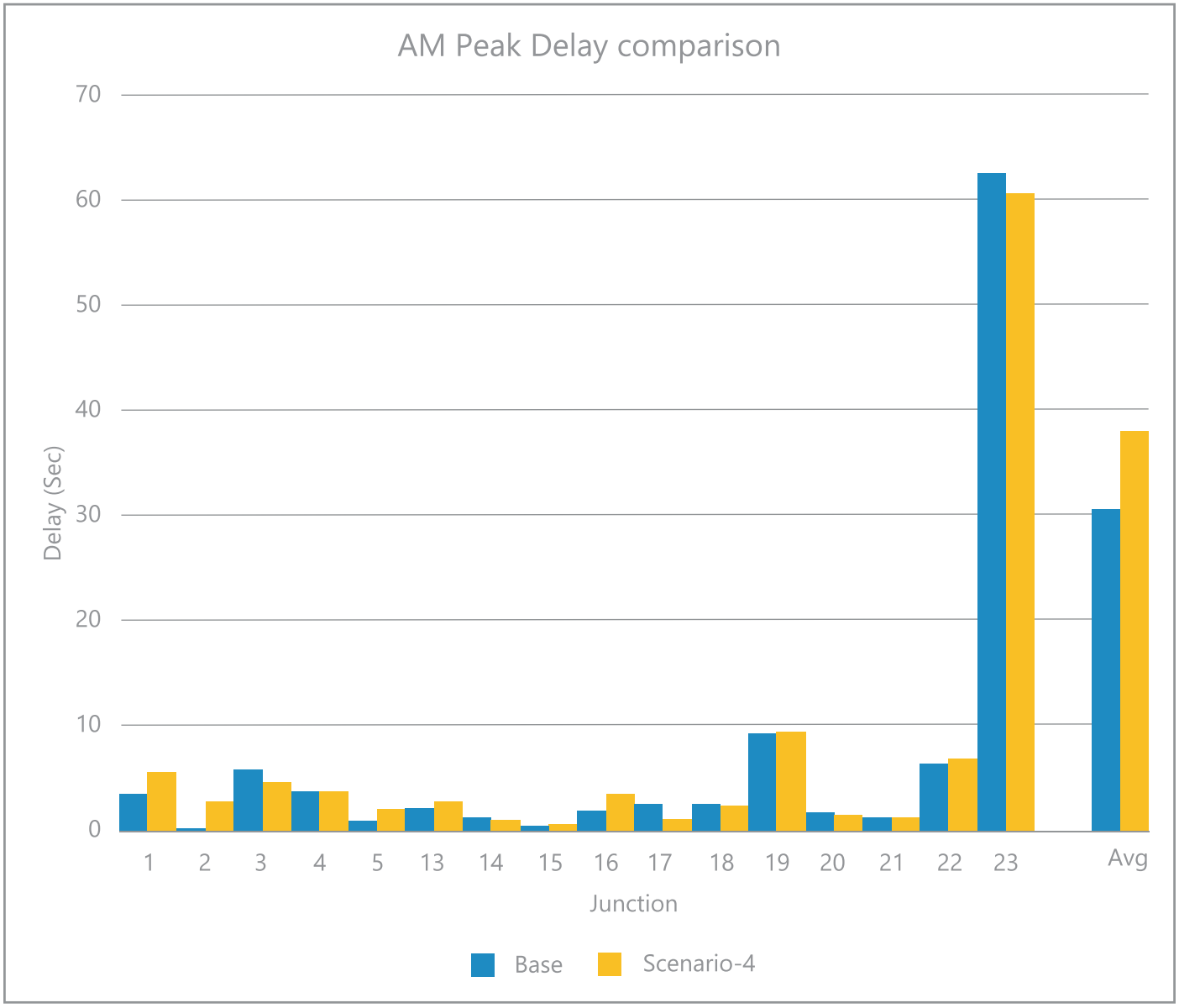


Figure 3-61 Scenario 4 - Delay Comparison -AM peak

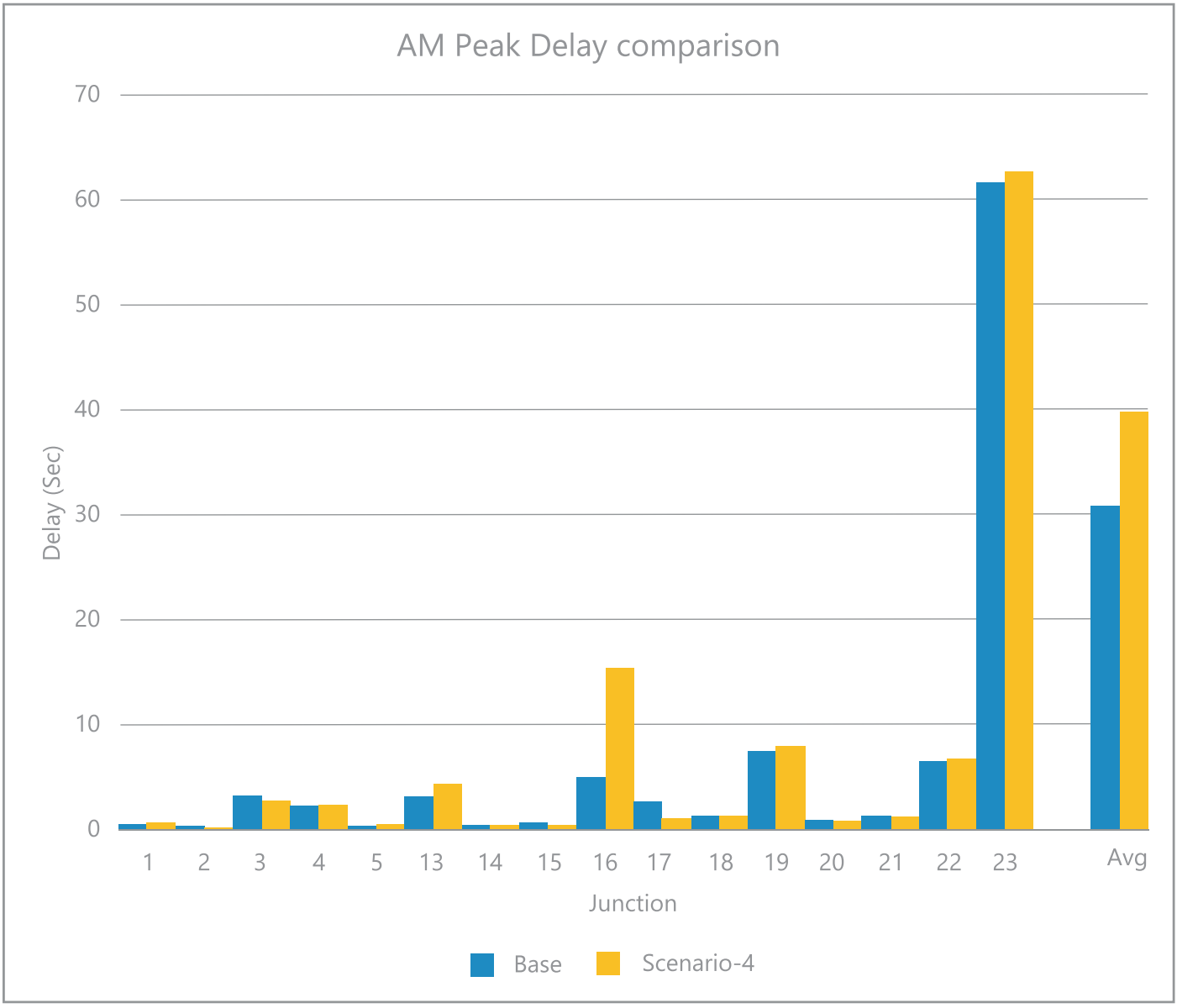


Figure 3-62 Scenario 4 - Delay Comparison -PM peak

Following observation can be made from above delay graphs and plots:

- For all the junctions in study area, average delay is more or less same as of base scenario expect J17 which is experiencing higher delay in PM peak and
- Overall average delay is increased in scenario4 by 24% and 33% in AM and PM peak respectively

4.6.2 Vehicular Measurement: Density

Density of the road network in scenario-4 is shown in below images

Figure 3-63 Density- Scenario 4-AM Peak

Figure 3-64 Density- Scenario 4-PM Peak

Minor increase in density is observed on pengkalan road due to trips generated by proposed new development which is adjacent to pengkalan road in both AM and PM peak.

4.6.2 Vehicular Measurement: Speed

Average speed on road network in scenario-4 is demonstrated in below images

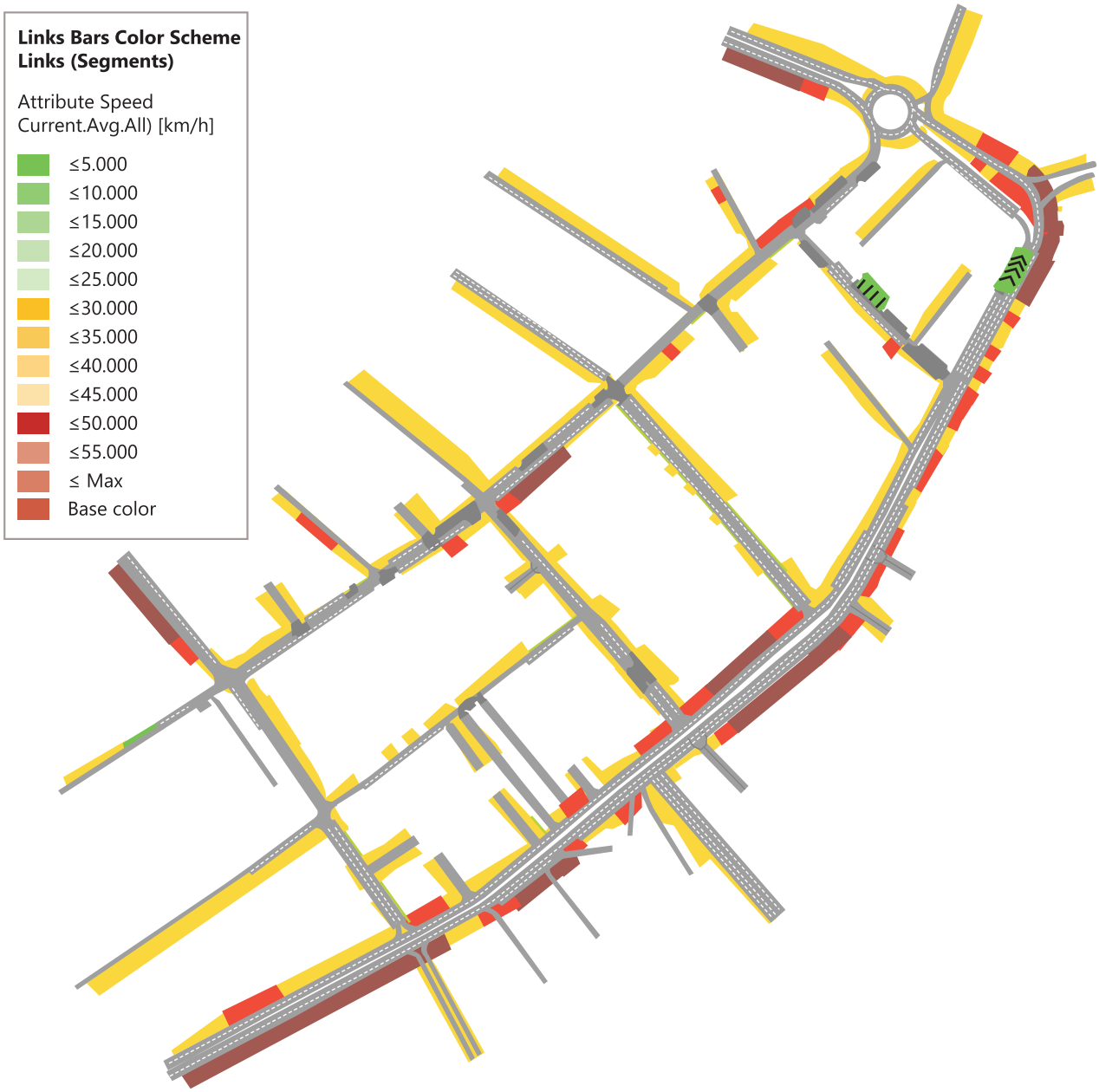


Figure 3-65 Speed- Scenario 4-AM Peak

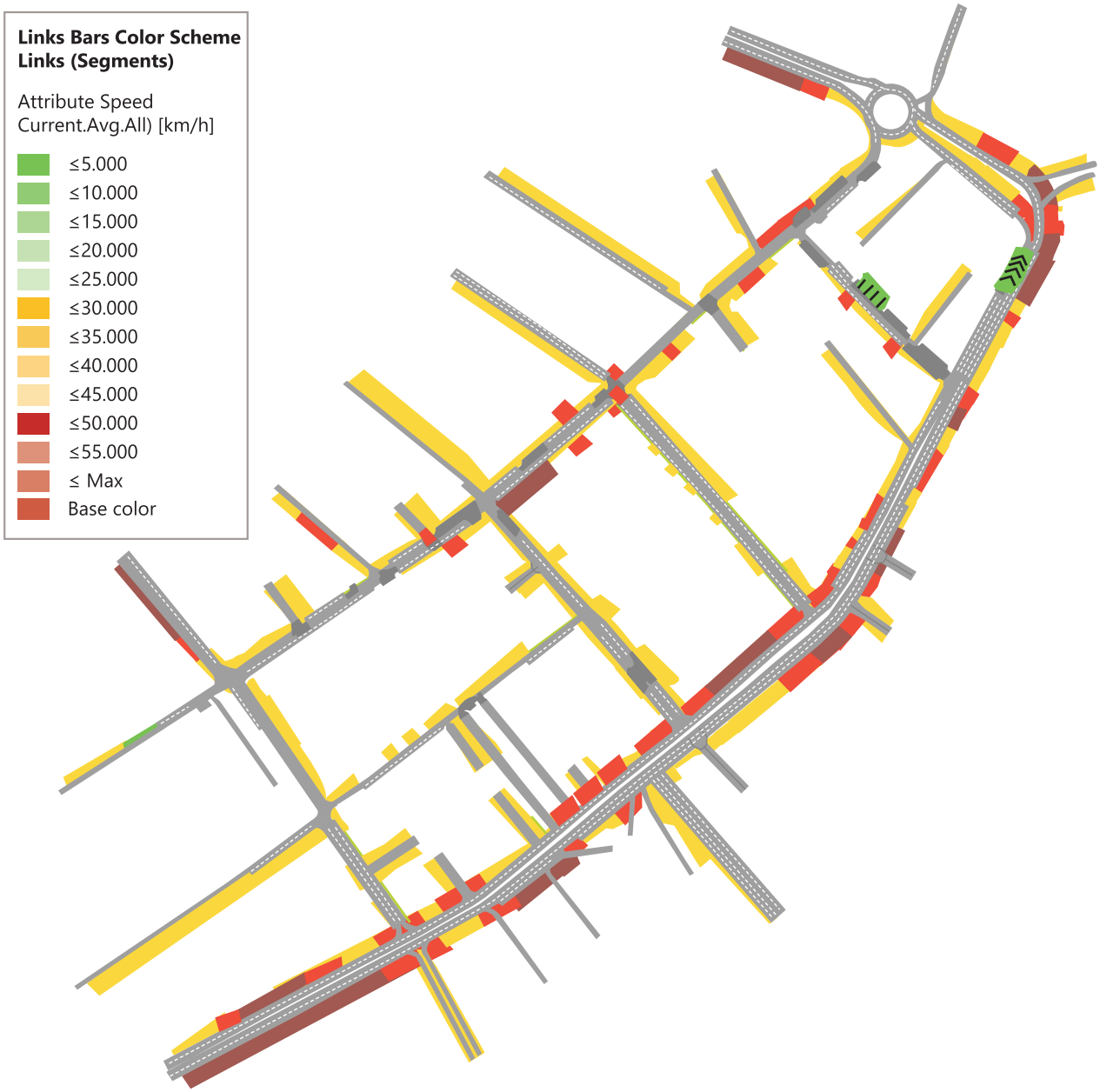


Figure 3-66 Speed- Scenario 4-PM Peak

From above graphs it can be observed that average speed on most sections of pengkalan road in both AM and PM peak is around 50kmph and on other roads it is 40 kmph.

5 COMPARISION AND FINDINGS

Photo: Adobe Stock

5.1 VEHICULAR MEASUREMENT: DELAY

Comparison of overall road network performance of the trial study area for all the scenarios considered in terms of delay is presented in figures below.

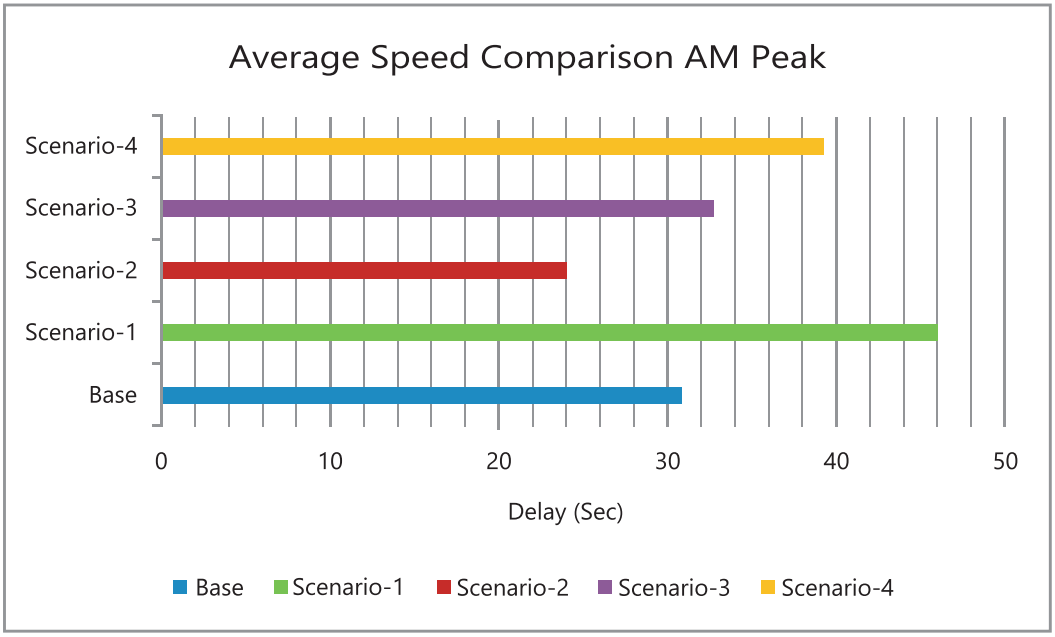


Figure 5-1 Average delay comparison – AM Peak

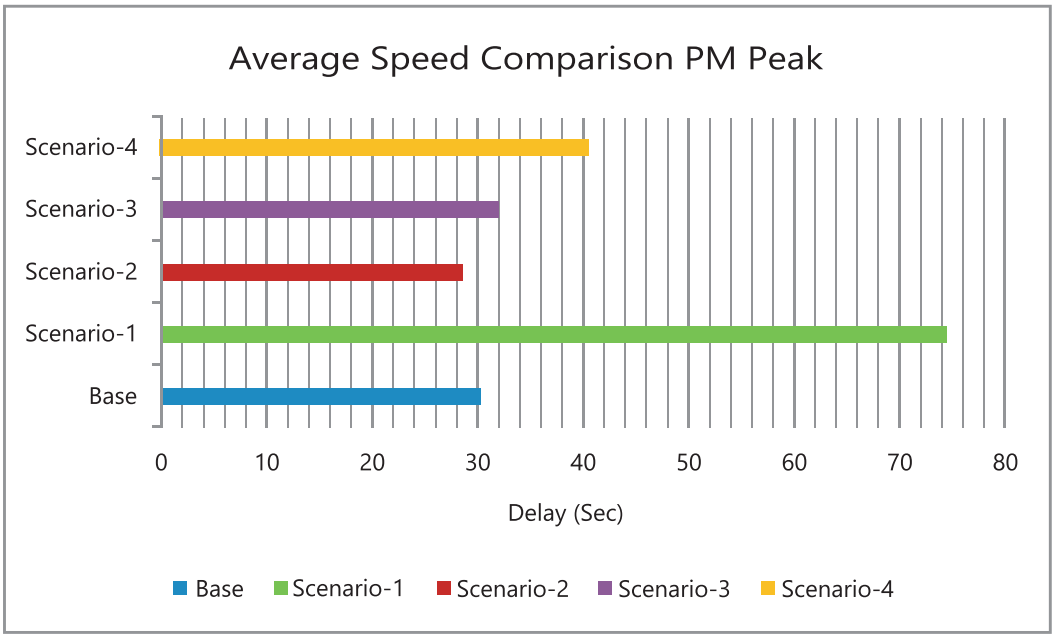


Figure 5-2 Average delay comparison – PM Peak

From above table, following points can be incurred when scenarios are compared with base scenario:

- Scenario 1: Due to introduction of pedestrian, cyclist priority facilities and traffic calming measures such as vertical speed humps in Scenario 1, overall average delay is increased from 31 sec to 46 sec which is around 48% increase in AM Peak. In PM peak overall average delay is increased from 30 sec to 74 sec in PM peak which is 143% increase
- Scenario 2: Road network improvements such as removal of parking, introduction one-way traffic at certain locations of trial study area is done in Scenario 2. Due to these improvements, interaction between vehicles is decreased and network is expected to perform better. Overall average delay is decreased from 31 sec to 24 which is around 22% decrease and in PM peak minor decrease of 6% is observed.
- Scenario 3: In Scenario 3, PT lane introduction is done at certain locations of Pengkalan Weld Road. Due to this improvement, capacity reduction of road is expected as there will be lane reduction. Overall average delay increase is minor, and it is around 6% and 5% increase in both AM and PM peak respectively
- Scenario 4: New development is proposed adjacent to Pengkalan Weld Road, which is expected to generate around 850 ,1100 trips in total in AM and PM peaks respectively. Estimated trip generation from the proposed development is relatively higher and is expected to deteriorate the overall network performance. Overall average delay is increased from 31 sec to 38 sec in AM peak which is around 24 % increase. In PM peak as well, average delay is increased by 32%

5.2 VEHICULAR MEASUREMENT: SPEED

Comparison of overall road network performance for all the scenarios in terms of speed is done and presented in below images

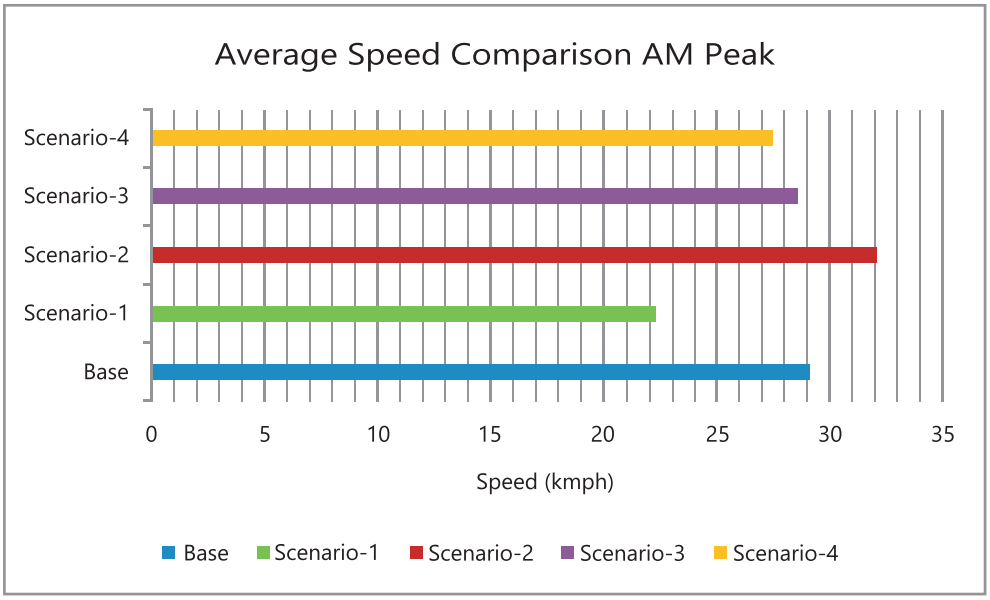


Figure 3-57 Level of Service-Scenario4 – AM Peak

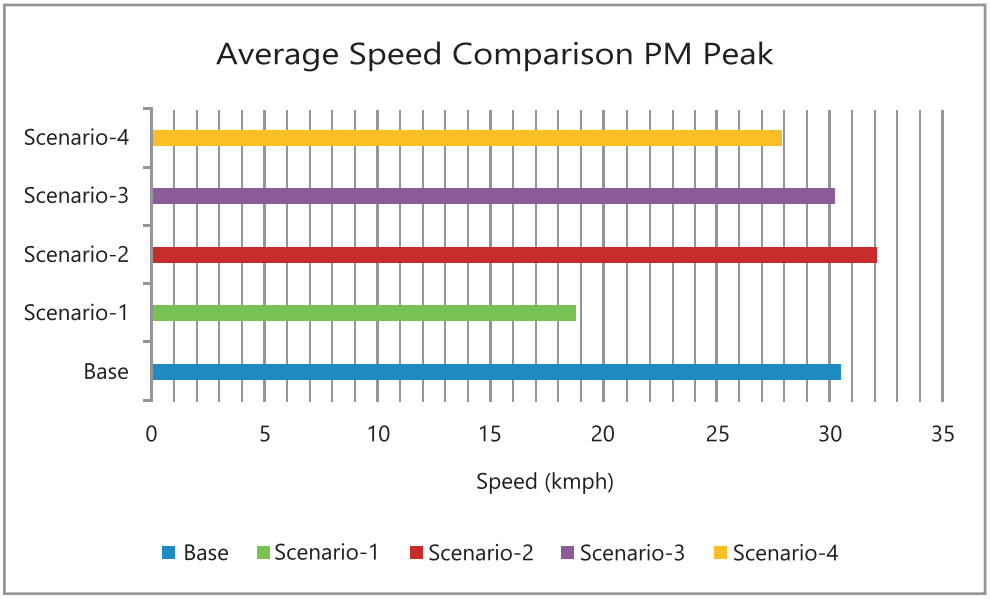


Figure 5-4 Average speed comparison – PM Peak

Following observation can be done from above speed images.

- Average speed of the network is around 30 kmph for all the scenarios expect Scenario 1
- In scenario-1, due to introduction of pedestrian, cyclist priority facilities and traffic calming measures, average speed is reduced to around 22% and 38% in AM and PM peak respectively when compared with Base scenario..

5.3 TRAVEL TIME

Certain sections of road are randomly selected, and travel time measurements are done to understand the impact of improvements carried out in all the scenarios

Below image shows the section considered for travel time measurements.

Figures below show the travel times on sections considered for all the scenarios:

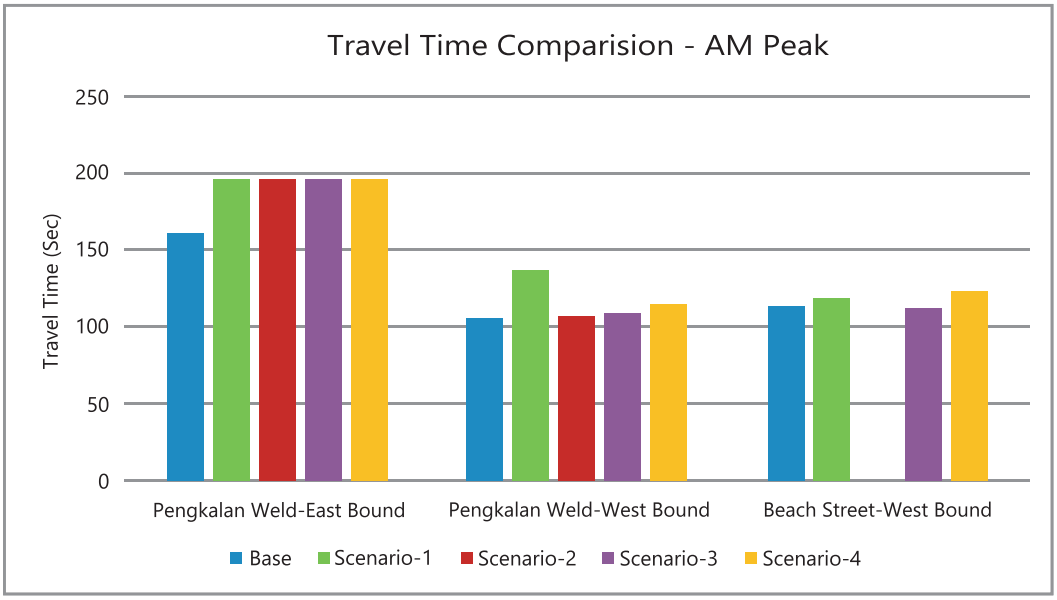


Figure 5-5 Travel Time – AM Peak

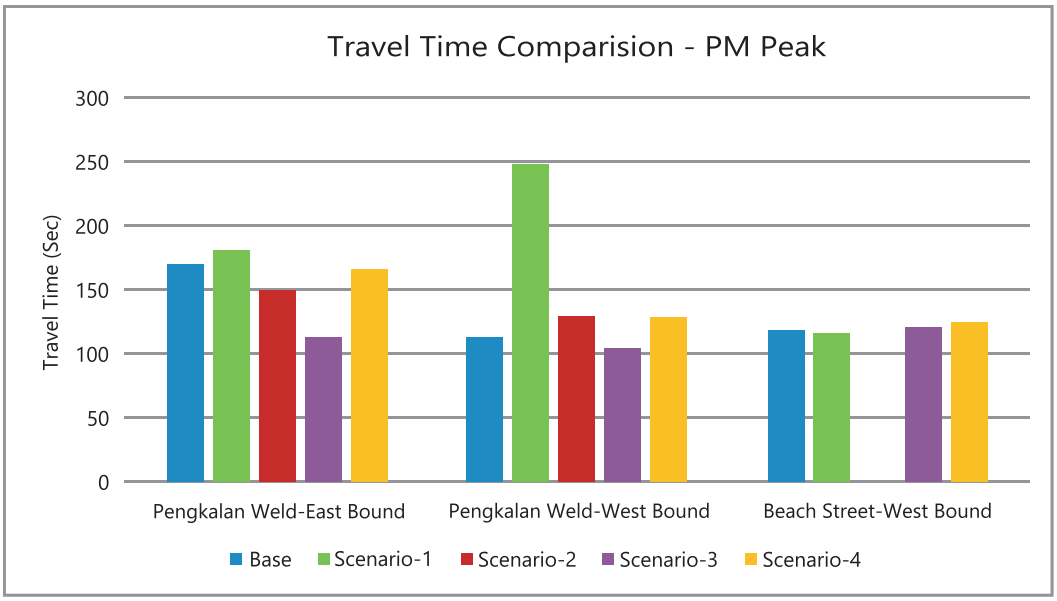


Figure 5-6 Travel Time – PM Peak

From above table, following points can be incurred:

- Pengkalan Weld East Bound: Travel time on Pengkalan Weld Road in east bound direction is higher in scenario-1 compared to all other scenarios. Travel time is 21% and 7% higher in AM and PM peak respectively when compared with base scenario.
- Pengkalan Weld West Bound: Travel time is 29% and 117% higher in AM and PM peak respectively in scenario-1 respectively when compared with base scenario for Pengkalan Weld Road in west bound direction.
- Beach street West Bound: Beach Street west bound is having more or less same travel times in all scenarios.

6 NEXT STEPS

Photo: Adobe Stock

6.1 NEXT MODEL STAGES

Upon the acceptance of the Stage 1 micro-simulation model report, Stage 2 will commence which will include simulation of a wider area of Georgetown encompassing the full UNESCO World Heritage area.

On completion of Stage 2, Ramboll will conduct a PTV accredited training courses on the use of Vissim software for MBPP and Digital Penang in order for the micro-simulation model to be used for ongoing testing of changes to transport within Georgetown beyond the conclusion of this Pilot Project.

6.2 NEXT DELIVERABLE STAGES

With the above model stages, the following deliverables will be produced and submitted as part of this project.

Deliverable	Contents
Model Inception and Trial Model Report (D1A)	Project inception, background information review, scenario development and simulation modelling methodology.
Survey Report (D1B)	Interim Technical Deliverable - Results of on-site surveys including traffic counts, parking and signal timing. Survey information is used as the input parameters into the model development to ensure the model is representative of real world conditions.
Stage 1 Base Model Calibration Report (D2A)	Interim Technical Deliverable – This report documents the model development and calibration and is a formal documentation of the models accuracy and reflectiveness of real world conditions.
Stage 1 Scenario Testing Report (D2B)	Stage 1 Final Deliverable – This report documents the simulation of the scenario testing and comparison of the base calibrated (real world) model to the future proposed interventions to evaluate their improvement.
Stage 2 Base Model Calibration Report (D3A)	Interim Technical Deliverable (Stage 2) – This report documents the model development and calibration and is a formal documentation of the models accuracy and reflectiveness of real world conditions for the larger Stage 2 area.
Stage 2 Scenario Testing Report (D3B)	Stage 2 Final Deliverable – This report documents the simulation of the scenario testing for Stage 2 and comparison of the base calibrated (real world) model to the future proposed interventions to evaluate their improvement.
Final Report (D4) and Project Evaluation (D5)	Compilation of Stage 1 and Stage 2 work above.

Table 6-1 Deliverable Stages

APPENDIX A

Photo: Adobe Stock

DELAY, LOS, AND QUEUE LENGTHS

BASE SCENARIO-AM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	0	299	0	A	17	J17-S-Left	2	470	1	A
	J1-E-Through	0	1070	0	A		J17-S-Right	2	1104	1	A
	J1-W-Left	34	1448	11	B		J17-W-Through	0	439	0	A
	Total		**2817**	**6**	**A**		**Total**		**2013**	**1**	**A**
2	J2-N-Left	0	78	3	A		J18-E-Right	2	206	4	A
	J2-W-Left	0	103	1	A		J18-E-Through	1	263	2	A
	J2-W-Through	0	1514	0	A		J18-W-Left	0	251	2	A
	Total		**1695**	**0**	**A**		J18-W-Through	0	438	2	A
3	J3-N-Left	0	45	5	A		**Total**		**1158**	**2**	**A**
	J3-W-Left	0	233	9	A		J19-E-Through	5	246	10	B
	J3-W-Through	0	1571	7	A		J19-N-Left	2	324	4	A
	Total		**1849**	**7**	**A**		J19-W-Through	7	481	12	B
4	J4-E-Through	4	912	11	B		**Total**		**1051**	**9**	**A**
	J4-N-Left	0	0	0	A		J20-E-Left	0	64	1	A
	J4-S-Left	0	40	0	A		J20-E-Right	1	56	5	A
	J4-W-Left	8	0	0	A		J20-E-Through	1	126	2	A
	J4-W-Through	8	1604	5	A		J20-S-Left	0	0	0	A
	Total		**2556**	**7**	**A**		J20-S-Right	0	28	7	A
5	J5-E-Left	0	53	0	A		J20-S-Through	0	74	4	A
	J5-E-Through	0	899	0	A		J20-W-Left	0	253	2	A
	J5-N-Left	0	88	4	A		J20-W-Right	0	14	2	A
	J5-S-Left	0	14	1	A		J20-W-Through	0	452	2	A
	J5-W-Left	1	525	2	A		**Total**		**1067**	**2**	**A**
	J5-W-Through	1	1543	2	A		J21-E-Left		0	0	A
	Total		**3122**	**1**	**A**		J21-E-Through	0	126	0	A
13	J13-N-Left	2	65	8	A		J21-N-left	0	213	1	A
	J13-N-Right	2	164	12	B		J21-N-Right	0	79	5	A
	J13-N-Through	2	124	9	A		J21-N-Through	0	18	3	A
	J13-S-Left	0	42	0	A		J21-S-Left	0	149	1	A
	J13-S-Right	1	175	2	A		J21-S-Right	0	205	3	A
	J13-S-Through	0	309	0	A		J21-S-U-Turn	0	0	0	A
	Total		**879**	**4**	**A**		J21-W-Right	0	10	2	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	311	2	A
	J14-W-Right	1	0	0	A		**Total**		**1111**	**2**	**A**
	Total		**224**	**2**	**A**		J22-E-Right	0	2	10	B
15	J15-N-Through	0	27	0	A		J22-E-Through	0	417	8	A

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	233	1	A		J22-W-Left	6	204	6	A
	J15-W-Left	0	203	1	A		J22-W-Through	6	264	6	A
	J15-W-Right	0	19	1	A		**Total**		**887**	**7**	**A**
	Total		**482**	**1**	**A**		J23-E-Left	15	174	58	E
	J16-E-Left1	0	36	1	A		J23-E-Right	15	61	61	E
	J16-E-Left2	0	12	5	A		J23-N-Left	14	148	57	E
	J16-E-Right	0	121	5	A		J23-N-Through	14	139	56	E
	J16-N-Through	1	457	4	A		J23-S-Right	19	63	49	D
16	J16-N-U-Turn	1	0	0	A	23	J23-S-Through	19	246	58	E
	J16-W-Left	0	965	1	A		J23-W-Left	31	122	80	E
	J16-W-Right1	0	227	2	A		J23-W-Right	31	44	105	F
	J16-W-Right2	0	352	2	A		J23-W-Through	31	200	84	F
	Total		**2559**	**2**	**A**		**Total**		**1197**	**66**	**E**

BASE SCENARIO-PM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J1-E-Right	1	240	0	A		J17-S-Left	0	186	1	A
1	J1-E-Through	1	2234	0	A	17	J17-S-Right	0	782	1	A
	J1-W-Left	3	804	4	A		J17-W-Through	0	612	0	A
	Total		**3278**	**1**	**A**		**Total**		**1580**	**0**	**A**
	J2-N-Left	0	61	1	A		J18-E-Right	0	3	1	A
2	J2-W-Left	0	72	0	A		J18-E-Through	0	183	0	A
	J2-W-Through	0	822	0	A	18	J18-W-Left	0	160	2	A
	Total		**955**	**0**	**A**		J18-W-Through	0	613	2	A
	J3-N-Left	0	49	4	A		**Total**		**959**	**2**	**A**
3	J3-W-Left	0	152	1	A		J19-E-Through	6	248	10	B
	J3-W-Through	0	845	5	A	19	J19-N-Left	1	329	4	A
	Total		**1046**	**4**	**A**		J19-W-Through	5	474	10	B

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
4	J4-E-Through	5	1956	6	A		**Total**		**1051**	**8**	**A**
	J4-N-Left	0	1	0	A	20	J20-E-Left	0	61	1	A
	J4-S-Left	0	20	0	A		J20-E-Right	0	20	4	A
	J4-W-Left	3	0	0	A		J20-E-Through	0	167	1	A
	J4-W-Through	3	920	5	A		J20-S-Left	0	32	1	A
	Total		**2897**	**6**	**A**		J20-S-Right	0	0	0	A
5	J5-E-Left	0	112	1	A		J20-S-Through	0	39	4	A
	J5-E-Through	0	1864	1	A		J20-W-Left	0	181	2	A
	J5-N-Left	0	149	1	A		J20-W-Right	0	0	0	A
	J5-S-Left	0	14	3	A		J20-W-Through	0	470	2	A
	J5-W-Left	0	345	1	A		**Total**		**970**	**2**	**A**
	J5-W-Through	0	714	0	A	21	J21-E-Left	0	0	0	A
	Total		**3198**	**1**	**A**		J21-E-Through	0	199	0	A
13	J13-N-Left	4	43	12	B		J21-N-left	0	186	1	A
	J13-N-Right	4	404	12	B		J21-N-Right	0	130	5	A
	J13-N-Through	4	187	19	C		J21-N-Through	0	32	3	A
	J13-S-Left	0	69	-1	A		J21-S-Left	0	148	1	A
	J13-S-Right	0	57	2	A		J21-S-Right	0	144	4	A
	J13-S-Through	0	219	0	A		J21-S-U-Turn	0	0	0	A
	Total		**979**	**9**	**A**		J21-W-Right	0	1	4	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	330	1	A
	J14-W-Right	0	1	0	A		**Total**		**1170**	**2**	**A**
	Total		**153**	**1**	**A**	22	J22-E-Right	1	12	3	A
15	J15-N-Through	0	32	0	A		J22-E-Through	1	547	9	A

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	152	1	A		J22-W-Left	4	256	5	A
	J15-W-Left	0	134	2	A		J22-W-Through	4	144	6	A
	J15-W-Right	0	18	0	A		**Total**		**959**	**7**	**A**
	Total		**336**	**1**	**A**	23	J23-E-Left	32	270	60	E
16	J16-E-Left1	3	215	3	A		J23-E-Right	32	144	60	E
	J16-E-Left2	4	85	13	A		J23-N-Left	25	199	61	E
	J16-E-Right	4	122	15	A		J23-N-Through	25	257	61	E
	J16-N-Through	9	645	9	A		J23-S-Right	13	29	70	E
	J16-N-U-Turn	9	109	9	A		J23-S-Through	13	193	57	E
	J16-W-Left	1	675	2	A		J23-W-Left	22	122	71	E
	J16-W-Right1	1	260	2	A		J23-W-Right	22	101	72	E
	J16-W-Right2	1	456	2	A		J23-W-Through	22	127	71	E
	Total		**3227**	**6**	**A**		**Total**		**1442**	**63**	**E**

SCENARIO 1-AM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	0	300	0	A	17	J17-S-Left	3	465	3	A
	J1-E-Through	0	1067	0	A		J17-S-Right	3	1085	1	A
	J1-W-Left	45	1434	9	A		J17-W-Through	0	437	0	A
	Total		**2801**	**4**	**A**		**Total**		**1987**	**1**	**A**
2	J2-N-Left	0	78	7	A	18	J18-E-Right	0	204	8	A
	J2-W-Left	0	106	2	A		J18-E-Through	0	262	3	A
	J2-W-Through	0	1500	1	A		J18-W-Left	45	249	4	A
	Total		**1748**	**1**	**A**		J18-W-Through	0	438	4	A
3	J3-N-Left	0	47	6	A		**Total**		**1153**	**4**	**A**
	J3-W-Left	1	231	10	B	19	J19-E-Through	0	247	12	B
	J3-W-Through	0	1559	7	A		J19-N-Left	0	324	8	A
	Total		**1837**	**8**	**A**		J19-W-Through	0	482	18	C
4	J4-E-Through	7	910	10	A		**Total**		**1053**	**13**	**B**
	J4-N-Left	0	0	0	A	20	J20-E-Left	1	64	4	A
	J4-S-Left	2	40	4	A		J20-E-Right	0	57	6	A
	J4-W-Left	47	0	0	A		J20-E-Through	7	126	2	A
	J4-W-Through	47	1580	20	C		J20-S-Left	0	0	0	A
	Total		**2648**	**15**	**C**		J20-S-Right	2	30	8	A
5	J5-E-Left	0	53	3	A		J20-S-Through	47	74	13	B
	J5-E-Through	0	899	0	A		J20-W-Left	47	247	1	A
	J5-N-Left	1	88	10	B		J20-W-Right	0	14	1	A
	J5-S-Left	0	14	3	A		J20-W-Through	0	452	1	A
	J5-W-Left	4	525	2	A		**Total**		**1078**	**3**	**A**
	J5-W-Through	4	1545	2	A	21	J21-E-Left	1	0	0	A
	Total		**3238**	**3**	**A**		J21-E-Through	0	126	0	A
13	J13-N-Left	2	65	4	A		J21-N-left	4	212	2	A
	J13-N-Right	2	164	6	A		J21-N-Right	4	79	5	A
	J13-N-Through	2	125	3	A		J21-N-Through	2	18	5	A
	J13-S-Left	0	42	0	A		J21-S-Left	2	149	2	A
	J13-S-Right	0	175	1	A		J21-S-Right	2	205	5	A
	J13-S-Through	0	308	0	A		J21-S-U-Turn	0	0	0	A
	Total		**879**	**2**	**A**		J21-W-Right	0	10	3	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	307	1	A
	J14-W-Right	1	0	0	A		**Total**		**1106**	**2**	**A**
	Total		**224**	**1**	**A**	22	J22-E-Right	0	3	15	B
15	J15-N-Through	0	28	1	A		J22-E-Through	1	412	9	A

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	231	0	A		J22-W-Left	0	202	8	A
	J15-W-Left	0	205	1	A		J22-W-Through	0	260	6	A
	J15-W-Right	0	19	0	A		**Total**		**307**	**1**	**A**
	Total		**483**	**1**	**A**	23	J23-E-Left	0	174	55	E
16	J16-E-Left1	0	28	1	A		J23-E-Right	0	61	66	E
	J16-E-Left2	1	20	6	A		J23-N-Left	0	148	56	E
	J16-E-Right	1	121	5	A		J23-N-Through	1	140	59	E
	J16-N-Through	2	439	4	A		J23-S-Right	1	63	46	D
	J16-N-U-Turn	2	0	0	A		J23-S-Through	2	245	56	E
	J16-W-Left	0	947	1	A		J23-W-Left	2	122	76	E
	J16-W-Right1	0	311	1	A		J23-W-Right	0	44	110	F
	J16-W-Right2	0	263	1	A		J23-W-Through	0	199	80	E
	Total		**2539**	**2**	**A**		**Total**		**1196**	**64**	**E**

SCENARIO 1-PM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	42	235	0	A	17	J17-S-Left	1	296	2	A
	J1-E-Through	42	2231	0	A		J17-S-Right	1	779	1	A
	J1-W-Left	7	918	4	A		J17-W-Through	0	612	0	A
	Total		**3384**	**1**	**A**		**Total**		**1687**	**1**	**A**
2	J2-N-Left	0	61	3	A	18	J18-E-Right	42	85	6	A
	J2-W-Left	0	130	2	A		J18-E-Through	42	211	2	A
	J2-W-Through	0	936	0	A		J18-W-Left	7	80	4	A
	Total		**1191**	**1**	**A**		J18-W-Through	0	613	3	A
3	J3-N-Left	1	133	5	A		**Total**		**989**	**3**	**A**
	J3-W-Left	0	108	6	B	19	J19-E-Through	0	248	12	B
	J3-W-Through	0	933	6	A		J19-N-Left	0	329	8	A
	Total		**1174**	**6**	**A**		J19-W-Through	1	362	13	B
4	J4-E-Through	164	1828	19	C		**Total**		**939**	**11**	**B**
	J4-N-Left	0	1	0	A	20	J20-E-Left	0	61	2	A
	J4-S-Left	1	20	3	A		J20-E-Right	0	20	3	A
	J4-W-Left	11	0	0	A		J20-E-Through	164	167	1	A
	J4-W-Through	11	954	10	C		J20-S-Left	0	85	3	A
	Total		**2920**	**15**	**B**		J20-S-Right	1	0	0	A
5	J5-E-Left	0	102	3	A		J20-S-Through	11	44	7	A
	J5-E-Through	0	1746	1	A		J20-W-Left	11	176	1	A
	J5-N-Left	1	190	3	B		J20-W-Right	0	0	0	A
	J5-S-Left	0	14	7	A		J20-W-Through	0	358	1	A
	J5-W-Left	0	342	1	A		**Total**		**923**	**1**	**A**
	J5-W-Through	0	717	0	A	21	J21-E-Left	1	0	0	A
	Total		**3225**	**1**	**A**		J21-E-Through	0	253	0	A
13	J13-N-Left	5	36	5	B		J21-N-left	0	160	2	A
	J13-N-Right	5	403	7	B		J21-N-Right	0	130	5	A
	J13-N-Through	5	228	6	C		J21-N-Through	5	58	4	A
	J13-S-Left	0	69	-1	A		J21-S-Left	5	98	2	A
	J13-S-Right	0	57	1	A		J21-S-Right	5	124	6	A
	J13-S-Through	0	216	0	A		J21-S-U-Turn	0	19	7	A
	Total		**1009**	**4**	**A**		J21-W-Right	0	36	4	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	260	1	A
	J14-W-Right	0	1	0	A		**Total**		**1138**	**2**	**A**
	Total		**147**	**1**	**A**	22	J22-E-Right	0	15	2	E
15	J15-N-Through	0	113	0	A		J22-E-Through	0	548	10	E

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	108	1	A		J22-W-Left	0	254	7	A
	J15-W-Left	0	127	1	A		J22-W-Through	0	109	8	A
	J15-W-Right	0	19	0	A		**Total**		**260**	**1**	**A**
	Total		**367**	**1**	**A**		J23-E-Left	0	269	61	E
	J16-E-Left1	7	211	7	A		J23-E-Right	0	145	57	E
	J16-E-Left2	7	91	19	C		J23-N-Left	7	165	61	E
	J16-E-Right	7	122	23	C		J23-N-Through	7	291	54	D
	J16-N-Through	13	396	15	C		J23-S-Right	7	26	66	E
16	J16-N-U-Turn	13	109	11	B	23	J23-S-Through	13	193	56	E
	J16-W-Left	1	678	1	A		J23-W-Left	13	122	70	E
	J16-W-Right1	1	410	2	A		J23-W-Right	1	101	70	E
	J16-W-Right2	1	305	8	A		J23-W-Through	1	127	68	E
	Total		**3229**	**8**	**A**		**Total**		**1439**	**61**	**E**

SCENARIO 2-AM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J1-E-Right	0	164	0	A		J16-N-Through	2	423	6	A
1	J1-E-Through	0	1391	0	A		J16-N-U-Turn	2	0	0	A
	J1-W-Left	12	1182	5	A		J16-W-Left	1	940	1	A
	Total		**2737**	**2**	**A**	16	J16-W-Right1	1	289	2	A
	J2-N-Left	0	32	2	A		J16-W-Right2	1	459	2	A
2	J2-W-Left	0	467	1	A		**Total**		**2716**	**3**	**A**
	J2-W-Through	0	1208	0	A		J17-S-Left	1	1178	1	A
	Total		**1707**	**1**	**A**		J17-S-Right	0	9	8	A
	J3-N-Left	0	100	4	A	17	J17-W-Through	0	510	0	A
3	J3-W-Left	0	223	5	A		**Total**		**1697**	**1**	**A**
	J3-W-Through	0	1575	6	A		J18-W-Left	0	483	1	A
	Total		**1898**	**6**	**A**	18	J18-W-Through	0	519	2	A
	J4-E-Through	5	1227	2	A		**Total**		**1002**	**1**	**A**
	J4-S-Left	0	40	0	A		J19-N-Left	0	322	2	A
4	J4-W-Through	8	1607	5	A	19	J19-W-Through	6	832	8	A
	Total		**2874**	**3**	**A**		**Total**		**1154**	**6**	**A**

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
5	J5-E-Left	0	49	0	A	20	J20-S-Right	1	381	2	A
	J5-E-Through	0	1218	0	A		J20-S-Through	1	82	3	A
	J5-N-Left	0	99	5	A		J20-W-Left	0	282	1	A
	J5-S-Left	0	14	3	A		J20-W-Right	0	34	0	A
	J5-W-Left	6	678	3	A		J20-W-Through	0	447	0	A
	J5-W-Through	6	1530	3	A		**Total**		**1246**	**1**	**A**
	Total		**3588**	**2**	**A**	21	J21-N-left	0	233	0	A
13	J13-N-Left	1	7	8	A		J21-N-Through	0	20	1	A
	J13-N-Right	1	83	8	A		J21-S-Right	0	189	2	A
	J13-N-Through	1	99	5	A		J21-S-U-Turn	0	9	1	A
	J13-S-Left	0	3	-1	A		J21-W-Right	0	0	0	A
	J13-S-Right	0	170	1	A		J21-W-Through	0	207	1	A
	J13-S-Through	0	507	0	A		**Total**		**807**	**1**	**A**
	Total		**869**	**1**	**A**	22	J22-W-Left	4	192	8	A
14	J14-S-Right	0	133	1	A		J22-W-Through	4	289	8	A
	Total		**133**	**1**	**A**		**Total**		**481**	**8**	**A**
15	J15-N-Through	0	30	0	A	23	J23-N-Left	11	147	46	D
	J15-S-Through	0	223	0	A		J23-N-Through	11	133	41	D
	J15-W-Left	0	62	1	A		J23-S-Right	23	222	38	D
	J15-W-Right	0	19	0	A		J23-S-Through	23	287	39	D
	Total		**385**	**0**	**A**		J23-W-Left	17	128	49	D
16	J16-E-Left1	0	33	0	A		J23-W-Right	17	56	35	C
	J16-E-Left2	0	16	5	A		J23-W-Through	17	249	45	D
	J16-E-Right	0	119	5	A		**Total**		**1222**	**42**	**D**

SCENARIO 2-PM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	2	80	0	A	16	J16-N-Through	37	570	24	C
	J1-E-Through	2	2804	0	A		J16-N-U-Turn	37	109	21	C
	J1-W-Left	4	1076	2	A		J16-W-Left	2	703	2	A
	Total		**3960**	**1**	**A**		J16-W-Right1	2	326	2	A
2	J2-N-Left	0	72	2	A		J16-W-Right2	2	769	3	A
	J2-W-Left	0	83	0	A		**Total**		**3670**	**13**	**B**
	J2-W-Through	0	1015	0	A	17	J17-S-Left	1	1072	1	A
	Total		**1170**	**0**	**A**		J17-S-Right	0	7	4	A
3	J3-N-Left	0	188	2	A		J17-W-Through	0	735	0	A
	J3-W-Left	0	107	2	A		**Total**		**1814**	**1**	**A**
	J3-W-Through	0	909	4	A	18	J18-W-Left	0	197	1	A
	Total		**1204**	**4**	**A**		J18-W-Through	0	743	1	A
4	J4-E-Through	6	2527	2	A		**Total**		**940**	**1**	**A**
	J4-S-Left	0	20	0	A	19	J19-N-Left	0	329	1	A
	J4-W-Through	3	940	4	A		J19-W-Through	4	581	6	A
	Total		**3487**	**3**	**A**		**Total**		**910**	**4**	**A**
5	J5-E-Left	0	115	1	A	20	J20-S-Right	0	16	1	A
	J5-E-Through	0	2432	1	A		J20-S-Through	0	66	2	A
	J5-N-Left	0	124	1	A		J20-W-Left	0	199	1	A
	J5-S-Left	0	14	6	A		J20-W-Right	0	72	0	A
	J5-W-Left	0	391	1	A		J20-W-Through	0	553	0	A
	J5-W-Through	0	716	1	A		**Total**		**924**	**1**	**A**
	Total		**3792**	**1**	**A**	21	J21-N-left	0	201	0	A
13	J13-N-Left	2	9	1	A		J21-N-Through	0	76	2	A
	J13-N-Right	2	175	8	A		J21-S-Right	0	147	2	A
	J13-N-Through	2	148	5	A		J21-S-U-Turn	0	3	3	A
	J13-S-Left	0	53	-1	A		J21-W-Right	0	14	0	A
	J13-S-Right	0	41	1	A		J21-W-Through	1	350	1	A
	J13-S-Through	0	297	-1	A		**Total**		**937**	**1**	**A**
	Total		**723**	**3**	**A**	22	J22-W-Left	3	265	7	A
14	J14-S-Right	0	129	1	A		J22-W-Through	3	233	7	A
	Total		**129**	**1**	**A**		**Total**		**500**	**7**	**A**
15	J15-N-Through	0	94	0	A	23	J23-N-Left	18	206	42	D

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	107	0	A		J23-N-Through	18	249	41	D
	J15-W-Left	0	32	0	A		J23-S-Right	10	66	33	C
	J15-W-Right	0	94	1	A		J23-S-Through	10	230	32	C
	Total		**327**	**A**	**A**		J23-W-Left	17	114	45	D
16	J16-E-Left1	16	289	17	C		J23-W-Right	17	82	50	D
	J16-E-Left2	16	50	54	F		J23-W-Through	17	225	48	D
	J16-E-Right	16	123	44	E		**Total**		**1172**	**42**	**D**

SCENARIO 3-AM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	0	299	0	A	17	J17-S-Left	1	497	1	A
	J1-E-Through	0	1072	0	A		J17-S-Right	1	1097	1	A
	J1-W-Left	44	1476	7	A		J17-W-Through	0	442	0	A
	Total		**2847**	**3**	**A**		**Total**		**2036**	**1**	**A**
2	J2-N-Left	0	79	2	A	18	J18-E-Right	2	205	4	A
	J2-W-Left	0	134	0	A		J18-E-Through	1	291	2	A
	J2-W-Through	0	1542	0	A		J18-W-Left	0	251	2	A
	Total		**1755**	**1**	**A**		J18-W-Through	0	443	2	A
3	J3-N-Left	0	70	3	A		**Total**		**1190**	**2**	**A**
	J3-W-Left	0	223	7	A	19	J19-E-Through	5	248	10	A
	J3-W-Through	0	1605	6	A		J19-N-Left	1	324	5	A
	Total		**1898**	**6**	**A**		J19-W-Through	7	453	13	A
4	J4-E-Through	0	40	0	A		**Total**		**1025**	**10**	**A**
	J4-N-Left	12	1629	6	A	20	J20-E-Left	0	64	2	A
	J4-S-Left	0	0	0	A		J20-E-Right	0	57	4	A
	J4-W-Left	4	916	3	A		J20-E-Through	0	127	1	A
	J4-W-Through	12	0	0	A		J20-S-Left	0	25	2	A
	Total		**2585**	**5**	**A**		J20-S-Right	0	32	5	A
5	J5-E-Left	0	99	5	A		J20-S-Through	0	75	5	A
	J5-E-Through	0	14	2	A		J20-W-Left	0	247	1	A
	J5-N-Left	1	53	3	A		J20-W-Right	0	14	1	A
	J5-S-Left	0	903	1	A		J20-W-Through	0	423	1	A
	J5-W-Left	3	517	2	A		**Total**		**1064**	**2**	**A**
	J5-W-Through	3	1553	2	A	21	J21-E-Left	0	0	0	A
	Total		**3139**	**2**	**A**		J21-E-Through	0	152	0	A
13	J13-N-Left	2	61	4	A		J21-N-left	0	212	1	A
	J13-N-Right	2	164	6	A		J21-N-Right	0	79	4	A
	J13-N-Through	2	135	4	A		J21-N-Through	0	18	3	A
	J13-S-Left	0	42	0	A		J21-S-Left	0	134	1	A
	J13-S-Right	0	175	1	A		J21-S-Right	0	182	3	A
	J13-S-Through	0	298	0	A		J21-S-U-Turn	0	0	0	A
	Total		**875**	**2**	**A**		J21-W-Right	0	10	2	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	301	1	A
	J14-W-Right	1	0	0	A		**Total**		**1088**	**1**	**A**
	Total		**220**	**1**	**A**	22	J22-E-Right	0	13	2	A
15	J15-N-Through	0	28	0	A		J22-E-Through	0	413	9	A

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	223	0	A		J22-W-Left	6	194	5	A
	J15-W-Left	0	178	1	A		J22-W-Through	6	256	6	A
	J15-W-Right	0	42	1	A		**Total**		**876**	**7**	**A**
	Total		**471**	**1**	**A**	23	J23-E-Left	14	174	58	E
16	J16-E-Left1	0	24	1	A		J23-E-Right	14	61	56	E
	J16-E-Left2	0	24	5	A		J23-N-Left	15	141	55	E
	J16-E-Right	0	121	5	A		J23-N-Through	15	147	58	E
	J16-N-Through	1	443	4	A		J23-S-Right	19	53	52	D
	J16-N-U-Turn	1	0	0	A		J23-S-Through	19	245	56	E
	J16-W-Left	0	956	1	A		J23-W-Left	31	122	77	E
	J16-W-Right1	0	338	2	A		J23-W-Right	31	44	95	F
	J16-W-Right2	0	238	2	A		J23-W-Through	31	199	82	F
	Total		**2548**	**2**	**A**		**Total**		**1186**	**64**	**E**

SCENARIO 3-PM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	1	240	0	A	17	J17-S-Left	0	183	1	A
	J1-E-Through	1	2235	0	A		J17-S-Right	0	780	1	A
	J1-W-Left	4	801	3	A		J17-W-Through	0	612	0	A
	Total		**3276**	**1**	A		**Total**		**1575**	**0**	**A**
2	J2-N-Left	0	61	1	A	18	J18-E-Right	0	3	0	A
	J2-W-Left	0	69	0	A		J18-E-Through	0	180	0	A
	J2-W-Through	0	819	0	A		J18-W-Left	0	160	2	A
	Total		**949**	**0**	**A**		J18-W-Through	0	613	2	A
3	J3-N-Left	0	49	2	A		**Total**		**956**	**1**	**A**
	J3-W-Left	0	156	1	A	19	J19-E-Through	6	248	10	A
	J3-W-Through	0	839	4	A		J19-N-Left	1	329	4	A
	Total		**1044**	**4**	**A**		J19-W-Through	5	476	10	B
4	J4-E-Through	0	20	0	A		**Total**		**1053**	**8**	**A**
	J4-N-Left	3	918	5	A	20	J20-E-Left	0	61	1	A
	J4-S-Left	0	1	0	A		J20-E-Right	0	20	7	A
	J4-W-Left	5	1955	2	A		J20-E-Through	0	167	1	A
	J4-W-Through	3	0	0	A		J20-S-Left	0	29	0	A
	Total		**2894**	**3**	**A**		J20-S-Right	0	0	0	A
5	J5-E-Left	0	146	2	A		J20-S-Through	0	39	6	A
	J5-E-Through	0	14	2	A		J20-W-Left	0	181	1	A
	J5-N-Left	5	111	5	A		J20-W-Right	0	0	0	A
	J5-S-Left	5	1863	2	A		J20-W-Through	0	472	1	A
	J5-W-Left	0	344	1	A		**Total**		**969**	**1**	**A**
	J5-W-Through	0	715	1	A	21	J21-E-Left	0	0	0	A
	Total		**3193**	**2**	**A**		J21-E-Through	0	196	0	A
13	J13-N-Left	4	43	5	A		J21-N-left	0	186	1	A
	J13-N-Right	4	403	6	A		J21-N-Right	0	130	6	A
	J13-N-Through	4	184	5	A		J21-N-Through	0	32	3	A
	J13-S-Left	0	69	-1	A		J21-S-Left	0	152	1	A
	J13-S-Right	0	57	2	A		J21-S-Right	0	144	4	A
	J13-S-Through	0	218	0	A		J21-S-U-Turn	0	0	0	A
	Total		**974**	**4**	**A**		J21-W-Right	0	1	5	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	333	1	A
	J14-W-Right	0	1	0	A		**Total**		**1174**	**2**	**A**
	Total		**153**	**1**	**A**	22	J22-E-Right	1	12	3	A
15	J15-N-Through	0	32	0	A		J22-E-Through	0	547	9	A

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	156	0	A		J22-W-Left	4	255	5	A
	J15-W-Left	0	134	1	A		J22-W-Through	4	147	6	A
	J15-W-Right	0	18	0	A		**Total**		**961**	**7**	**A**
	Total		**340**	**1**	**A**	23	J23-E-Left	29	270	59	E
16	J16-E-Left1	6	214	3	A		J23-E-Right	29	144	61	E
	J16-E-Left2	6	86	19	A		J23-N-Left	25	202	59	E
	J16-E-Right	6	122	16	A		J23-N-Through	25	254	56	E
	J16-N-Through	5	681	8	A		J23-S-Right	12	28	69	E
	J16-N-U-Turn	5	109	8	A		J23-S-Through	12	193	57	E
	J16-W-Left	1	673	2	A		J23-W-Left	22	122	70	E
	J16-W-Right1	1	238	2	A		J23-W-Right	22	101	69	E
	J16-W-Right2	1	479	2	A		J23-W-Through	22	127	69	E
	Total		**3224**	**5**	**A**		**Total**		**1441**	**61**	**E**

SCENARIO 3-PM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	1	240	0	A	17	J17-S-Left	0	183	1	A
	J1-E-Through	1	2235	0	A		J17-S-Right	0	780	1	A
	J1-W-Left	4	801	3	A		J17-W-Through	0	612	0	A
	Total		**3276**	**1**	A		**Total**		**1575**	**0**	**A**
2	J2-N-Left	0	61	1	A	18	J18-E-Right	0	3	0	A
	J2-W-Left	0	69	0	A		J18-E-Through	0	180	0	A
	J2-W-Through	0	819	0	A		J18-W-Left	0	160	2	A
	Total		**949**	**0**	**A**		J18-W-Through	0	613	2	A
3	J3-N-Left	0	49	2	A		**Total**		**956**	**1**	**A**
	J3-W-Left	0	156	1	A	19	J19-E-Through	6	248	10	A
	J3-W-Through	0	839	4	A		J19-N-Left	1	329	4	A
	Total		**1044**	**4**	**A**		J19-W-Through	5	476	10	B
4	J4-E-Through	0	20	0	A		**Total**		**1053**	**8**	**A**
	J4-N-Left	3	918	5	A	20	J20-E-Left	0	61	1	A
	J4-S-Left	0	1	0	A		J20-E-Right	0	20	7	A
	J4-W-Left	5	1955	2	A		J20-E-Through	0	167	1	A
	J4-W-Through	3	0	0	A		J20-S-Left	0	29	0	A
	Total		**2894**	**3**	**A**		J20-S-Right	0	0	0	A
5	J5-E-Left	0	146	2	A		J20-S-Through	0	39	6	A
	J5-E-Through	0	14	2	A		J20-W-Left	0	181	1	A
	J5-N-Left	5	111	5	A		J20-W-Right	0	0	0	A
	J5-S-Left	5	1863	2	A		J20-W-Through	0	472	1	A
	J5-W-Left	0	344	1	A		**Total**		**969**	**1**	**A**
	J5-W-Through	0	715	1	A	21	J21-E-Left	0	0	0	A
	Total		**3193**	**2**	**A**		J21-E-Through	0	196	0	A
13	J13-N-Left	4	43	5	A		J21-N-left	0	186	1	A
	J13-N-Right	4	403	6	A		J21-N-Right	0	130	6	A
	J13-N-Through	4	184	5	A		J21-N-Through	0	32	3	A
	J13-S-Left	0	69	-1	A		J21-S-Left	0	152	1	A
	J13-S-Right	0	57	2	A		J21-S-Right	0	144	4	A
	J13-S-Through	0	218	0	A		J21-S-U-Turn	0	0	0	A
	Total		**974**	**4**	**A**		J21-W-Right	0	1	5	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	333	1	A
	J14-W-Right	0	1	0	A		**Total**		**1174**	**2**	**A**
	Total		**153**	**1**	**A**	22	J22-E-Right	1	12	3	A
15	J15-N-Through	0	32	0	A		J22-E-Through	0	547	9	A

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	234	0	A		J22-W-Left	4	205	5	A
	J15-W-Left	0	195	2	A		J22-W-Through	4	264	6	A
	J15-W-Right	0	20	1	A		**Total**		**886**	**7**	**A**
	Total		**477**	**1**	**A**	23	J23-E-Left	31	173	59	E
16	J16-E-Left1	1	43	2	A		J23-E-Right	31	61	58	E
	J16-E-Left2	1	6	24	C		J23-N-Left	46	148	56	E
	J16-E-Right	1	121	9	A		J23-N-Through	46	307	54	D
	J16-N-Through	5	519	8	A		J23-S-Right	13	63	44	D
	J16-N-U-Turn	5	0	0	A		J23-S-Through	13	243	56	E
	J16-W-Left	0	942	1	A		J23-W-Left	21	124	73	E
	J16-W-Right1	0	436	2	A		J23-W-Right	21	44	85	F
	J16-W-Right2	0	439	2	A		J23-W-Through	21	199	76	E
	Total		**2958**	**4**	**A**		**Total**		**1362**	**61**	**E**

SCENARIO 4-PM PEAK

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
1	J1-E-Right	1	240	0	A	17	J17-S-Left	3	181	1	A
	J1-E-Through	1	2606	0	A		J17-S-Right	3	1101	2	A
	J1-W-Left	9	1123	3	A		J17-W-Through	0	611	0	A
	Total		**3969**	**1**	**A**		**Total**		**1893**	**1**	**A**
2	J2-N-Left	0	62	2	A	18	J18-E-Right	0	3	5	A
	J2-W-Left	0	40	0	A		J18-E-Through	0	177	0	A
	J2-W-Through	0	1141	0	A		J18-W-Left	0	160	2	A
	Total		**1243**	**0**	**A**		J18-W-Through	0	612	2	A
3	J3-N-Left	0	51	4	A		**Total**		**952**	**2**	**A**
	J3-W-Left	0	177	1	A	19	J19-E-Through	7	253	10	B
	J3-W-Through	0	1130	3	A		J19-N-Left	2	329	4	A
	Total		**1358**	**3**	**A**		J19-W-Through	6	481	11	B
4	J4-E-Through	6	2426	2	A		**Total**		**1063**	**9**	**A**
	J4-N-Left	0	1	3	A	20	J20-E-Left	0	62	0	A
	J4-S-Left	0	20	0	A		J20-E-Right	0	22	2	A
	J4-W-Left	5	0	0	A		J20-E-Through	0	169	0	A
	J4-W-Through	5	1228	4	A		J20-S-Left	0	1	0	A
	Total		**3675**	**3**	**A**		J20-S-Right	0	0	0	A
5	J5-E-Left	0	111	1	A		J20-S-Through	0	39	4	A
	J5-E-Through	0	2335	1	A		J20-W-Left	0	181	1	A
	J5-N-Left	2	305	2	A		J20-W-Right	0	0	0	A
	J5-S-Left	0	14	6	A		J20-W-Through	0	477	1	A
	J5-W-Left	0	334	1	A		**Total**		**951**	**1**	**A**
	J5-W-Through	0	869	0	A	21	J21-E-Left	0	0	0	A
	Total		**3968**	**1**	**A**		J21-E-Through	0	170	0	A
13	J13-N-Left	10	43	6	A		J21-N-left	0	186	1	A
	J13-N-Right	10	407	8	A		J21-N-Right	0	130	5	A
	J13-N-Through	10	343	6	A		J21-N-Through	0	32	3	A
	J13-S-Left	0	68	-1	A		J21-S-Left	0	174	1	A
	J13-S-Right	0	40	2	A		J21-S-Right	0	144	3	A
	J13-S-Through	0	225	0	A		J21-S-U-Turn	0	0	0	A
	Total		**1126**	**5**	**A**		J21-W-Right	0	1	0	A
14	J14-S-Right	0	0	0	A		J21-W-Through	0	338	1	A
	J14-W-Right	0	1	0	A		**Total**		**1175**	**1**	**A**
	Total		**153**	**1**	**A**	22	J22-E-Right	1	6	7	A
15	J15-N-Through	0	33	0	A		J22-E-Through	1	547	10	A

Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS	Junction	Movement	Avg Modelled Queue (m)	Volume	Delay	LOS
	J15-S-Through	0	177	0	A		J22-W-Left	6	265	5	A
	J15-W-Left	0	134	1	A		J22-W-Through	6	151	5	A
	J15-W-Right	0	18	1	A		**Total**		**969**	**8**	**A**
	Total		**362**	**1**	**A**		J23-E-Left	15	271	60	E
	J16-E-Left1	1	200	47	E		J23-E-Right	15	146	58	E
	J16-E-Left2	1	96	82	F		J23-N-Left	31	207	66	E
	J16-E-Right	1	120	86	F		J23-N-Through	31	415	61	E
	J16-N-Through	5	569	20	C		J23-S-Right	18	36	49	D
16	J16-N-U-Turn	5	107	22	C	23	J23-S-Through	18	193	61	E
	J16-W-Left	0	672	2	A		J23-W-Left	29	122	64	E
	J16-W-Right1	0	391	3	A		J23-W-Right	29	102	71	E
	J16-W-Right2	0	643	3	A		J23-W-Through	29	127	69	E
	Total		**3598**	**17**	**C**		**Total**		**1619**	**62**	**E**

APPENDIX B

Photo: Adobe Stock

NETWORK PERFORMANCE

AM peak-Network performance

Scenario	Delay (sec)	Avg Speed (kmph)
Base	31	29
Scenario 1	46	22
Scenario 2	24	32
Scenario 3	33	29
Scenario 4	38	27

PM peak-Network performance

Scenario	Delay (sec)	Avg Speed (kmph)
Base	30	30
Scenario 1	74	19
Scenario 2	28	32
Scenario 3	32	30
Scenario 4	40	27

ABOUT THE ASEAN AUSTRALIA SMART CITIES TRUST FUND

The ASEAN Australia Smart Cities Trust Fund (AASCTF) assists ASEAN cities in enhancing their planning systems, service delivery, and financial management by developing and testing appropriate digital urban solutions and systems. By working with cities, AASCTF facilitates their transformation to become more livable, resilient, and inclusive, while in the process identifying scalable best and next practices to be replicated across cities in Asia and the Pacific.

ASEAN AUSTRALIA SMART CITIES TRUST FUND
Asian Development Bank

Australian Government
Department of Foreign Affairs and Trade

ADB