2020 Edition

Traffic Report

Kigali Master Plan 2050

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Executive Summary

Six corridors and 31 intersections were assessed during the AM and PM peak periods within the City of Kigali. The aim of the assessment was to reduce the congestion along these corridors as part of the (quick wins) status quo solutions, which forms part of the 2018 masterplan review. The corridors and intersections are shown in the figure below:

This section of the master plan review includes the assessment of the functionality of the intersections in terms of the level of service (LOS), V/C ratio and queue lengths for the status quo and for a horizon year of 5 years. The transportation masterplan section further assesses the transportation network of the entire city from between 2018 and 2050.

The input data was obtained through manual counts of the intersections and corridors, as well as through video (traffic flow) assessments.

The data collection process for the traffic counts was done using local enumerators, trained by the consultant engineers, to conduct the traffic counts at the intersections and along the corridors in the city. The counts were done on normal weekdays. Normal weekdays are those that have no major trip alteration behaviour influencing factors. These are essentially Tuesdays, Wednesdays and Thursdays, where no public holidays, school holidays, events and or external factors are occurring.

The traffic counts were conducted to determine the peak hour movements for the AM and PM peaks to be used to assess the intersection capacities. The video assessments were done by recording the routes using a SmartyCam recording device in a moving vehicle, to assess the infrastructure, lanes, road reserve, NMT presence, etc.

The traffic counts were concluded at 18:00 as the visibility for the enumerators and the reliability of the counts would decrease substantially after dark. Therefore, to accommodate for the very late increased peak of between 18:30 and 19:30, the counts were adjusted.

The adjustment increased the total PM traffic trips by approximately 3894 trips along the corridors within the network. This significant alteration caused a large increase in the PM congestion and ultimately the level of service of the intersections. The status quo traffic used for the PM peak capacity analysis was the adjusted traffic counts.

Hereafter, each corridor and major road was classified in accordance to the Rwandan road classification standards. The results indicated that the lowest classified road along the six corridors was a collector. Hence, the proposed solutions allowed for surfacing of roads, duelling of the carriageways, conversions to traffic signals and roundabouts.

The data obtained from the City of Kigali (CoK) regarding the proposed BRT routes resulted in six of the roads within the corridors to be upgraded to BRT routes. This included the lower order collectors previously identified. However, due to the period analysed (which is the immediate future before the BRT will be constructed), the BRT influences were not considered for this study.

The car growth forecast for the City of Kigali, according to the BRT report, grows from 32% of mode split in 2017 to 52% in 2050 with the BRT (60% without BRT). This results in a 1.5% car growth per annum for 30 years. The expected traffic growth is estimated to grow at 2.20% per year up until 2050. Hence, the traffic growth is estimated to grow at between 1.5% and 2.2% per year. However, the 5-year assessment estimated a more aggressive design factor than the 1.5-2.2% growth, yet, due to the phasing of the masterplan and the economic factors, it used a lower growth rate than the population growth estimate.

The growth rate used of 3% compounded for a 5-year horizon was selected, which is an average growth estimate. This growth rate equates to 16% increase in traffic on the corridors analysed or an applied factor of 1.16. Consequently, the 3% growth allows for a 7 to 10 year horizon year in relation to the estimated traffic growth rate as per the transportation macro-model, which over a 5-year period amount to between 1.11 and 1.07 applied growth factors.

The results of the intersection analysis indicated that only 6 and 7 of the 31 intersections assessed are functioning with an acceptable LOS, V/C ratio and queue lengths in the AM and PM peaks respectively. Of the 25 failing intersections, 3 intersections function acceptably with regards to the V/C and LOS assessment in the AM peak and PM peaks.

However, these intersections are functioning unacceptably in terms of the queue length calculations. Of the 31 intersections assessed, 22 are currently failing in terms of the LOS assessments in the AM peak, while 23 are failing in the PM peak.

Hereafter, the intersections were optimised. The optimisation was done initially using the status quo balanced traffic counts. The results of the proposed solutions indicated that all 31 of the assessed intersections' congestion issues were resolved with the proposed solutions.

It was determined that 27 of the 31 intersections required geometric upgrades to resolve the congestion concerns. All queue lengths and V/C ratio issues were resolved with the proposed solutions, either with the SIDRA software, or with the VISSIM software. The proposed solutions resulted in 16 traffic signals, 12 roundabouts and 3 priority-controlled intersections.

The proposed solutions was then subjected to the future traffic demands and re-assessed. The results of the future analysis indicated that only 4 of the 31 intersections fail. However, 2 of the 4 failing intersections are resolved in the network analysis. The remaining 27 intersections are all functioning with acceptable delays, queue lengths and V/C ratios, with the applied future growth. This essentially results in 27 of the 31 intersections having an excess of 1.16 times the current capacity available for future traffic expansion. The majority of the corridors' intersections are functioning with an average LOS B for all the movements. This is a substantial improvement from the Status Quo functioning of a LOS E.

The following two tables show a summary of what was required at each intersection, for AM and PM peak, and the resultant level of service and max queue distance for the base year:

AM PEAK					
NUMBER	PROPOSED UPGRADES			STATUS	DESCRIPTION
	TYPE	MAX QUEUE	LOS	ACCEPTABLE/ FAIL	
1	Circle	3,1	A	Acceptable	No Change
2	Signal	27,9	B	Acceptable	Signal and Geometric Upgrade
3	Signal	35,6	C	Acceptable	Geometric and Phasing Upgrade
4	Signal	25,4	C	Acceptable	Signal and Geometric Upgrade
5	Circle	14,6	B	Acceptable	Geometric Upgrade
6	Signal	45	C	Acceptable	Signal and Geometric Upgrade
7	Circle	2,9	A	Acceptable	Geometric Upgrade
8	Circle	0,4	A	Acceptable	No Change
9	Circle	N/A	No conflict	Acceptable	No Change
10	Unsolvable in SIDRA (Solved in Vissim as Grade Separation)				Flyover left turn Northern Approach
11	Signal	21	D	Acceptable	Signal and Geometric Upgrade
12	Signal	14	B	Acceptable	Signal and Geometric Upgrade
13	Circle	5,8	A	Acceptable	Geometric Upgrade
14	Signal	16,6	A	Acceptable	Vissim Resolved as priority with left lane
15	Signal	31,7	B	Acceptable	Signal and Geometric Upgrade
16.1	Signal	29	B	Acceptable	Signal and Geometric Upgrade
16.2	Signal	21,6	B	Acceptable	Signal and Geometric Upgrade
17	Signal	12,9	C	Acceptable	Signal and Geometric Upgrade
18	Signal	20,4	C	Acceptable	Signal and Geometric Upgrade
19	Circle	6,3	A	Acceptable	Circle and Geometric Upgraded
20	Circle	20,9	A	Acceptable	Circle and Geometric Upgraded
21	Signal	44,1	C	Acceptable	Signal and Geometric Upgrade
22	Circle	12,8	B	Acceptable	Circle and Geometric Upgraded
23	Circle	14,7	B	Acceptable	Geometric Upgrade
24	Priority	4	D (East)	Acceptable	No Change
25	Circle	17,8	A	Acceptable	Circle and Geometric Upgraded
26	Priority	2,4	B (East)	Acceptable	No Change
27	Signal	21,1	B	Acceptable	Signal and Geometric Upgrade
28	Priority	1,9	C (South)	Acceptable	South East Left Turn Lane
29	Signal	27	C	Acceptable	Signal and Geometric Upgrade
30	Signal	11,1	B	Acceptable	Signal and Geometric Upgrade
	16 Signals **12 Circles** **3 priority**			**31 Acceptable**	**All intersections are resolved to have an acceptable LOS and queue length for the type of intersection**

	PM PEAK				
NUMBER	PROPOSED UPGRADES			STATUS	DESCRIPTION
	TYPE	MAX QUEUE	LOS	ACCEPTABLE/ FAIL	
1	Circle	2,4	A	Acceptable	No Change

NUMBER	PM PEAK				
	PROPOSED UPGRADES			STATUS	DESCRIPTION
	TYPE	MAX QUEUE	LOS	ACCEPTABLE/ FAIL	
2	Signal	23,3	C	Acceptable	Signal and Geometric Upgrade
3	Signal	30,7	C	Acceptable	Geometric and Phasing Upgrade
4	Signal	27,9	C	Acceptable	Signal and Geometric Upgrade
5	Circle	11	B	Acceptable	Geometric Upgrade
6	Signal	24,9	C	Acceptable	Signal and Geometric Upgrade
7	Circle	3	A	Acceptable	Geometric Upgrade
8	Circle	0,5	A	Acceptable	No Change
9	Circle	N/A	No conflict	Acceptable	No Change
10	Unsolvable in SIDRA (Solved in Vissim as Grade Separation)				Flyover left turn Northern Approach
11	Signal	16	C	Acceptable	Signal and Geometric Upgrade
12	Signal	19,7	C	Acceptable	Signal and Geometric Upgrade
13	Circle	3,2	A	Acceptable	Geometric Upgrade
14	Signal	8,3	A	Acceptable	Vissim Resolved as priority with left lane
15	Signal	31,4	B	Acceptable	Signal and Geometric Upgrade
16.1	Signal	22,2	B	Acceptable	Signal and Geometric Upgrade
16.2	Signal	31,3	C	Acceptable	Signal and Geometric Upgrade
17	Signal	20,8	C	Acceptable	Signal and Geometric Upgrade
18	Signal	27,1	B	Acceptable	Signal and Geometric Upgrade
19	Circle	5,5	A	Acceptable	Circle and Geometric Upgraded
20	Circle	25,6	B	Acceptable	Circle and Geometric Upgraded
21	Signal	38,8	C	Acceptable	Signal and Geometric Upgrade
22	Circle	7,9	A	Acceptable	Circle and Geometric Upgraded
23	Circle	6,8	B	Acceptable	Geometric Upgrade
24	Priority	11,3	F (East)	Fail	Vissim resolved the intersection
25	Circle	19,6	A	Acceptable	Circle and Geometric Upgraded
26	Priority	1,8	B (East)	Acceptable	No Change
27	Signal	19,9	B	Acceptable	Signal and Geometric Upgrade
28	Priority	3,7	B (East)	Acceptable	South East Left Turn Lane
29	Signal	17,5	B	Acceptable	Signal and Geometric Upgrade
30	Signal	14,8	B	Acceptable	Signal and Geometric Upgrade
	16 Signals **12 Circles** **3 priority**			**31 Acceptable**	**All intersections are resolved to have an acceptable LOS and queue length for the type of intersection**

Following the intersection analysis, the proposed solutions were assessed through the entire network. To analyse the network as a whole, micro-simulation was used. For the network analysis, the counts had to be balanced, to ensure approximately the same volumes of vehicles leaving one intersection, will arrive at the next, adjacent intersection. This is required to ensure the accuracy of the input to the network. The driver behaviour was adjusted in an attempt to replicate the driver characteristics of Rwanda. This was done by adjusting the front and rear gap acceptance, safety distance and additional stop distances to be more representative of Kigali. (It represents more aggressive driver behaviour than the European experience.)

The following image is a screenshot of the Vissim model, indicating the extent:

As a result, the model was repeatedly calibrated until it represented the status quo as reasonably as possible. The calibrated status quo models forms the base models and was used to assess the future scenarios, using the altered driver behaviour. The results of the status quo (base year) indicated that when analysing specific delays per intersection type, the average delay of turning movements at unsignalised intersections is 48.2 seconds, which is an unacceptable LOS E. The situation is similar for signalised intersections, with an average delay of 60.4 seconds for the turning movements, which is again a level of service E. Therefore, the status quo traffic is functioning with an unacceptable LOS E in the AM peak

When assessing the PM peak, for unsignalised intersections, the average delay is 32.4 seconds, which results in a level of service D. This is slightly better than the morning peak period, which has a level of service E for unsignalised intersections. However, for signalised intersections, the average delay is 88.5 seconds, which yields a level of service F. This is worse than the morning peak period. It is thus obvious that for both main peak periods, there is currently a significant delay in the City of Kigali.

The following table indicates the breakdown of the level of service for turning movements of the base year, using status quo geometry, for the AM peak and PM peak respectively.

AM PEAK – STATUS QUO GEOMETRY – BASE YEAR							
TOTAL	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**	**% FAILURE**
247	98	22	19	16	12	80	37%
PM PEAK – STATUS QUO GEOMETRY – BASE YEAR							
TOTAL	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**	**% FAILURE**
247	101	24	30	15	20	57	31%

However, when the model is assessed with the proposed solutions implemented, during the AM peak, there is a 0% failure rate, thus the levels of congestion are within acceptable ranges. The average delay of turning movements at unsignalised intersections is an acceptable 7.4 seconds, which yields a level of service A. For signalised intersections, the delay is 23.7 seconds, which is a favourable level of service C throughout the city.

Similarly, for the PM peak, there is 0% failure rate. With the unsignalised intersections functioning with an average delay of 11.3 seconds. This means the level of service will improve from a current D, to a B. For the signalised intersections, this average delay will be 22.6 seconds, or level of service C. This is a significant improvement from LOS F and once implemented will provide immediate traffic congestion relief.

The following table indicates the breakdown of the level of service for turning movements of the base year, using proposed geometry, for the AM peak and PM peak respectively.

AM PEAK – PROPOSED GEOMETRY – BASE YEAR							
TOTAL	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**	**% FAILURE**
247	113	42	55	37	0	0	0%
PM PEAK – PROPOSED GEOMETRY – BASE YEAR							
TOTAL	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**	**% FAILURE**
247	121	36	53	37	0	0	0%

It is clear then that the proposed solutions do improve congestion throughout the city substantially for the status quo traffic. These solutions were then assessed with the applied future growth. The results indicated that the average delay for unsignalised intersections for the PM peak is 12.1 seconds, or level of service B. For signalised intersections, this value is 24.9 seconds, or level of service C. Thus, the network as a whole will still function very well in the horizon year. The average delay for the AM peak for unsignalised intersections will be 10.6 seconds, level of service B. For signalised intersections, this average delay will increase to 26.1 seconds, which is a level of service C.

The following table indicates the breakdown of the level of service for turning movements of the horizon year, using the proposed upgraded geometry, for the AM peak and PM peak respectively.

AM PEAK – PROPOSED GEOMETRY – HORIZON YEAR							
TOTAL	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**	**% FAILURE**
247	113	32	55	40	6	2	3%
PM PEAK – PROPOSED GEOMETRY – HORIZON YEAR							
TOTAL	**LOS A**	**LOS B**	**LOS C**	**LOS D**	**LOS E**	**LOS F**	**% FAILURE**
247	107	45	51	37	3	4	3%

Therefore, it is evident that the network as a whole is still functioning very well, with the exception of one or two turning movement throughout the model. During this stage, intersections 14 and 10 were at an acceptable level of service that could not be resolved using SIDRA.

Yet, the most problematic result for the future assessment is the failure of intersection 5. This is the intersection between KN 5 Road, KG 1 Avenue and KG 11 Avenue. The current layout is that of a two-lane roundabout.

To achieve the favourable level of service shown in the second scenario, slip lanes are added to each approach, which removes the right-turning vehicles from the roundabout, and subsequently increases capacity. Is evident that this solution is not future proof. Due to the high volumes, a signalised intersection will not be sufficient.

One alternative is grade separation, which will prove difficult due to the location of the intersection. There is a large density of buildings around this intersection, with accesses. Thus, grade separating this intersection will cause just as much problems as it solves.

The only plausible solution would thus be providing alternate arterial routes in the city, to alleviate the congestion on KN 5 Road. This is being developed for in the future road network in the city transportation model.

Therefore, based on the network and intersection analysis, the identified 31 intersections currently have 25 intersections that are failing with the status quo traffic. Yet with the proposed solutions, the overall network delays will reduce from a LOS E to a LOS B for the future scenarios.

To achieve these significant improvements to the mobility within the city, the 31 intersections will require significant geometric upgrades, signalisation and conversions to roundabouts. However, the results of the proposed improvements will give additional capacity to the road network in excess of 1.16 times the current capacity. **It is therefore recommended that the proposed solutions and upgrades be moved to the detailed design and implementation phase.**

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1. Introduction

1.1. Background

The City of Kigali (CoK) has been developing rapidly over the past decade and as such has embarked on various citywide planning projects. The resolution for the initiative is to ensure that the city does not develop without the proper strategies in place. As part of the strategy, the city regularly updates the existing city masterplan.

In 2018, Surbana Jurong (SJ) was appointed to update the CoK Masterplan. SMEC South Africa was appointed through SJ to develop the transportation plan for the Update of the Kigali City Master Plan. The transportation plan task was sub-divided into the citywide macro model for the assessment of the future transportation scenarios for 2050, and the micro-simulation (quick wins) assessment of six selected corridors, as discussed and agreed to with the CoK.

Figure 1-1: Locality Map of the micro-simulation routes and intersections

The aim of the Macro-model is to develop a road hierarchy network, including the proposed public transport network, to accommodate the social-economic growth predicted until 2050. The micro-simulation models or traffic models were developed to resolve existing congestion within the city on these six selected routes, which are considered of strategic importance to the city.

The focus of this report is on the micro-simulation and assessment of the identified routes and associated intersections. The purpose is to relieve congestion and propose solutions to the existing traffic congestion along these corridors, and test these solutions for a forecasted 5 years. (Some of these corridors will be developed as BRT routes in the future, but until this happens, they can be upgraded at limited cost to a significantly higher road capacity, as will be shown.)

1.2. Goals & Objectives

The goals and objectives of the Traffic models are to resolve congestion cause by the existing infrastructure and traffic parameters within the city and to ensure that these alterations are suitable for a horizon year of 2022. (It implies that in 2022, that years' traffic will still experience an acceptable level- of- service.)

The scope of works is as follows:

- *Assess the status quo of the existing selected road network and Intersections.*
- *Develop and apply the design growth factor to the arterials based on the macro model predictions.*
- *Develop and simulate solutions to resolve traffic congestion along the corridors.*
- *Compile a report on the findings and proposed solutions.*

1.3. Study Area

During the inception phase of the project, the study area, which includes the routes and intersections of the micro-simulation model, was presented and agreed to by the CoK. Refer to **Annexure A** for the inception report. The routes include the following corridors:

- *Corridor 1: KG 11 Ave and KG 17 Ave.*
- *Corridor 2: KN5 road from the Airport.*
- *Corridor 3 + Link: KN 5 (Circle) and KG 7 to KN 8.*
- *Corridor 4A-B: KN3 and KK8 and KK15.*
- *Corridor 5: KN 7 road to KN 8 Interchange.*

Figure 1-2: Routes and Intersections to be analysed.

Figure 1-3: Corridor 1

Corridor 1 spans intersections 18 to 22 and is located around the stadium in Kigali, along KG 11 Ave and KG 17 Ave.

Figure 1-4: Corridor 2

Corridor 2 is located next to the airport and spans intersections 1 to 5. Corridor 2 is along the KN5 road.

Figure 1-5: Corridor 3+Link

Corridor 3 and Link spans intersections 5 to 14 and is situation along roads KN5, KG7 and KN8. The route passes the ICC, US Embassy, Police Head Quarters, Ministry of Agriculture and Animal Resources and the President's office.

Figure 1-6: Corridor 4

Corridor 4 is located along roads KN3, KK8 and KK15. This route spans intersections 23-30.

Figure 1-7: Corridor 5

Corridor 5 is located along roads KN7 to the KN8 interchange. The route spans intersections 15-17. The route starts at the Nyabugogo Taxi Park.

The intersections assessed are all located along the corridors and were selected and agreed to with the CoK. These are shown in Table 1-1 below and Figures 1-2 - 1-7 above.

Table 1-1: Micro-simulation intersections

MICRO-SIMULATION INTERSECTIONS			
NUMBER	CORRIDOR	INTERSECTION	CONTROL
1	2	KK103 St/ KK 5 Ave	Circle
2	2	KN5/KK3	Priority
3	2	KN5/ KG109	Signal
4	2	KN3/KN5	Priority
5	2	KN 5/ KG1	Circle
6	3	KG 9/ KN5	Signal
7	3	KN 5/KG501	Circle
8	3	ICC/KG644	Circle
9	3	ICC	Circle
10	Link	KG7 /KG501	Circle
11	Link	KG694/ KG 7	Priority
12	Link	KG 7/KG 550	Priority
13	Link	KN 8/ KG 3	Circle
14	Link	KN8/ KG704	Priority
15	5	KN 8/ KK14	Priority
16.1	5	KN7/ KN8	Priority
16.2	5	KN7 Interchange	Priority
17	5	KN 7/ Kigali Gatuna Rd	Stop
18	1	KG11/ KG113	Stop
19	1	KG11 / KG13	Priority
20	1	KG11/ KG17	Priority
21	1	KG2/ KG11	Priority
22	1	KG17/ KG16	Priority
23	4	KN3/ KG 1	Circle
24	4	KK19/ KK15	Priority
25	4	KK35/ KK15	Priority
26	4	KK21/ KK15	Priority
27	4	KK8/ KK15	Priority
28	4	KK 34/ KK8	Priority
29	4	KN3/ KK8	Priority
30	4	KN3/ KK 500	Priority

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2. Data Collection

The data collection phase for this study was conducted in two sections, namely: Traffic Counts and SmartyCAM Recordings.

2.1. Traffic Counts

The data collection process for the traffic counts was done using local enumerators, trained by the consultant engineers, to conduct the traffic counts at the intersections and along the corridors throughout the city. The counts were done on normal weekdays. Normal weekdays are those that do not have major trip alteration behaviour influencing factors. These are essentially Tuesdays, Wednesdays and Thursdays, where no public holidays, school holidays, events and, or external factors are occurring.

The traffic counts were conducted to determine the peak hour traffic movements for the morning (AM) and afternoon (PM) peaks to be used to assess the intersection capacities. The counts were not done to determine the AADT (average annual daily traffic) as there is no need for a pavement calculation at this phase of the study. As a result, there was no need to conduct a 7-day traffic count. The counts were used for planning purposes and not detailed design purposes.

2.1.1. Intersection Counts

The intersection counts were done from 6:00 -18:00 on 17-19 July as per the inception report. The reason for conducting traffic counts manually from between 06:00 am to 18:00pm was based on visibility in the city of Kigali as well and accepted peak periods internationally. Sun Rise is at 6:04am and sunset in July 2018 was at 18:05 pm (Figure 2-1). From previous experience, it is known that traffic counts done in the dark are not accurate and are unsafe for the enumerators doing the traffic counts. However, it was noted that due to the spatial planning of the various parts of the city, and due to congestion, the peak periods differ somewhat.

Select month and year: July 2018 Show

Date	Sun				Twilight					
					Civil		Nautical		Astronomical	
	Sunrise	Sunset	Solar Noon	Day Length	Begin	End	Begin	End	Begin	End
Sunday, July 1	6:03 AM	6:04 PM	12:03 PM	12h 0m 42s	5:40 AM	6:26 PM	5:14 AM	6:52 PM	4:48 AM	7:18 PM
Monday, July 2	6:03 AM	6:04 PM	12:03 PM	12h 0m 44s	5:41 AM	6:26 PM	5:15 AM	6:52 PM	4:48 AM	7:18 PM
Tuesday, July 3	6:03 AM	6:04 PM	12:04 PM	12h 0m 45s	5:41 AM	6:26 PM	5:15 AM	6:52 PM	4:49 AM	7:19 PM
Wednesday, July 4	6:03 AM	6:04 PM	12:04 PM	12h 0m 46s	5:41 AM	6:27 PM	5:15 AM	6:53 PM	4:49 AM	7:19 PM
Thursday, July 5	6:04 AM	6:04 PM	12:04 PM	12h 0m 48s	5:41 AM	6:27 PM	5:15 AM	6:53 PM	4:49 AM	7:19 PM
Friday, July 6	6:04 AM	6:05 PM	12:04 PM	12h 0m 49s	5:41 AM	6:27 PM	5:15 AM	6:53 PM	4:49 AM	7:19 PM
Saturday, July 7	6:04 AM	6:05 PM	12:04 PM	12h 0m 52s	5:42 AM	6:27 PM	5:16 AM	6:53 PM	4:49 AM	7:19 PM
Sunday, July 8	6:04 AM	6:05 PM	12:04 PM	12h 0m 53s	5:42 AM	6:27 PM	5:16 AM	6:53 PM	4:50 AM	7:19 PM
Monday, July 9	6:04 AM	6:05 PM	12:05 PM	12h 0m 55s	5:42 AM	6:27 PM	5:16 AM	6:53 PM	4:50 AM	7:19 PM
Tuesday, July 10	6:04 AM	6:05 PM	12:05 PM	12h 0m 57s	5:42 AM	6:27 PM	5:16 AM	6:53 PM	4:50 AM	7:19 PM
Wednesday, July 11	6:04 AM	6:05 PM	12:05 PM	12h 0m 59s	5:42 AM	6:28 PM	5:16 AM	6:53 PM	4:50 AM	7:19 PM
Thursday, July 12	6:04 AM	6:05 PM	12:05 PM	12h 1m 1s	5:42 AM	6:28 PM	5:16 AM	6:54 PM	4:50 AM	7:20 PM
Friday, July 13	6:05 AM	6:06 PM	12:05 PM	12h 1m 4s	5:42 AM	6:28 PM	5:17 AM	6:54 PM	4:51 AM	7:20 PM
Saturday, July 14	6:05 AM	6:06 PM	12:05 PM	12h 1m 6s	5:42 AM	6:28 PM	5:17 AM	6:54 PM	4:51 AM	7:20 PM
Sunday, July 15	6:05 AM	6:06 PM	12:05 PM	12h 1m 8s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:51 AM	7:20 PM
Monday, July 16	6:05 AM	6:06 PM	12:05 PM	12h 1m 11s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:51 AM	7:20 PM
Tuesday, July 17	6:05 AM	6:06 PM	12:05 PM	12h 1m 14s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:51 AM	7:20 PM
Wednesday, July 18	6:05 AM	6:06 PM	12:06 PM	12h 1m 17s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:51 AM	7:20 PM
Thursday, July 19	6:05 AM	6:06 PM	12:06 PM	12h 1m 20s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:52 AM	7:20 PM
Friday, July 20	6:05 AM	6:06 PM	12:06 PM	12h 1m 23s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:52 AM	7:20 PM
Saturday, July 21	6:05 AM	6:06 PM	12:06 PM	12h 1m 25s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:52 AM	7:20 PM
Sunday, July 22	6:05 AM	6:06 PM	12:06 PM	12h 1m 29s	5:43 AM	6:28 PM	5:17 AM	6:54 PM	4:52 AM	7:20 PM
Monday, July 23	6:05 AM	6:07 PM	12:06 PM	12h 1m 33s	5:43 AM	6:28 PM	5:18 AM	6:54 PM	4:52 AM	7:20 PM
Tuesday, July 24	6:05 AM	6:07 PM	12:06 PM	12h 1m 35s	5:43 AM	6:29 PM	5:18 AM	6:54 PM	4:52 AM	7:20 PM
Wednesday, July 25	6:05 AM	6:07 PM	12:06 PM	12h 1m 39s	5:43 AM	6:29 PM	5:18 AM	6:54 PM	4:52 AM	7:19 PM
Thursday, July 26	6:05 AM	6:07 PM	12:06 PM	12h 1m 42s	5:43 AM	6:29 PM	5:18 AM	6:54 PM	4:52 AM	7:19 PM
Friday, July 27	6:05 AM	6:07 PM	12:06 PM	12h 1m 47s	5:43 AM	6:29 PM	5:18 AM	6:54 PM	4:52 AM	7:19 PM
Saturday, July 28	6:05 AM	6:07 PM	12:06 PM	12h 1m 50s	5:43 AM	6:28 PM	5:18 AM	6:54 PM	4:52 AM	7:19 PM
Sunday, July 29	6:05 AM	6:07 PM	12:06 PM	12h 1m 53s	5:43 AM	6:28 PM	5:18 AM	6:54 PM	4:52 AM	7:19 PM
Monday, July 30	6:05 AM	6:07 PM	12:06 PM	12h 1m 58s	5:43 AM	6:28 PM	5:18 AM	6:54 PM	4:52 AM	7:19 PM
Tuesday, July 31	6:05 AM	6:07 PM	12:06 PM	12h 2m 1s	5:43 AM	6:28 PM	5:18 AM	6:54 PM	4:52 AM	7:19 PM

Figure 2-1: Sunrise and sunset for Kigali - July 2018

The conditions on the day was sunny and pleasant. There were no reports of unusual traffic behaviour. There were no interruptions from police regarding the authorisation to conduct the counts. The traffic counts were counted as classified counts:

- *LV Light Vehicles*
- *HV Heavy vehicles*
- *Busses*
- *Motorcycles*

The motorcycle volume passenger car unit (PCU) was assigned at 0.25 for the analysis in SIDRA. The PCU values range from between 0.5, for unsaturated conditions, to 0.20 in saturated (intersections) conditions on studies ranging from the U.S. HCM 1997 (Highway Capacity Manual) and the Malaysia research done in 2006. The extensive range can be attributed to a number of factors, such as congestion, driver behaviour, allowable queuing methods, and traffic composition. In addition, during the study, 22nd ARRB Conference – Research into Practice, Canberra Australia, 2006, it was noted that:

"A high percentage of motorcycles in the traffic stream will reduce the saturation flows in pcu/hr significantly. When the percentage of motorcycles in the traffic flow exceeds 50%, the percentage reduction in saturation flows in pcu/hr is more than 50%. This is mainly due to the influence of the motorcycle pce value, which is less than 1.0. The percentage of reduction in saturation flows in pcu/hr is the largest for the Indonesian HCM (1996), followed closely by MHCM (2006) and then the Arahan Teknik (Jalan) 13/87 and lastly the U.S. HCM (2000). This is actually in accordance with the motorcycle pce values in which the pce value for motorcycles adopted by the Indonesian HCM

(1996) is the smallest which is only 0.2, followed by MHCM (2006) which is 0.22 and then the Arahan Teknik (Jalan) 13/87 which is 0.33, whereas in the U.S. HCM (2000), motorcycles were not taken into consideration in the estimation of saturation flows.", Figures 2-2 – 2-4."

The differences can further be attributed to the driver behaviour, traffic composition and variances between the researched areas. The observed driver behaviour in Kigali is more accommodating and aggressive than in accordance with the USA cities, and more in align with the Indonesian and Malaysian countries.

Furthermore, the observed queuing of motorcycles at intersections in Kigali is done along the shoulders, between vehicles and bunching (Figure 2-3). In addition, the vehicle composition obtained from the traffic counts indicates a high percentage of motorcycles, between 40 and 60% of mixed traffic are motorcycles with an average of 51% throughout all the traffic counts conducted in the city (Figure 2-2).

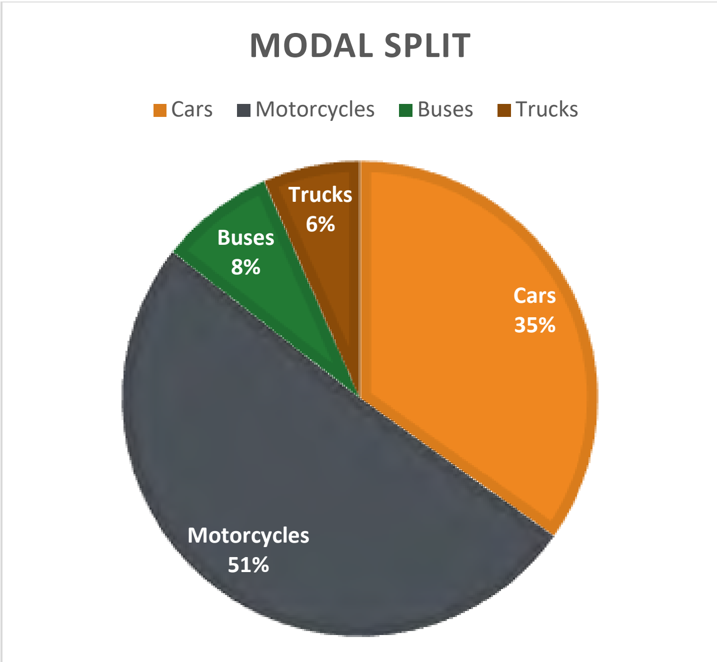

Figure 2-2: Average modal split in the City of Kigali

Consequently, the modal split further identifies with the Malaysia and Indonesian assessment. Therefore, based on the driver behaviour, experience in Africa, the modal split, the research done on the 22nd ARRB Conference – Research into Practice, Canberra Australia, 2006, and the high congestion in the CoK, the PCU factor for motorcycles in Kigali was used as 0.25 for the capacity calculations at the intersections for the Standalone (SIDRA) assessments. (PCE= PCU where PCE is passenger car equivalent and PCU is known as the passenger car unit, depending on which source is quoted.)

Table 2-1: Pce values for signalised intersections according to Arahan Teknik (Jalan) 13/87 as compared to Webster values

Vehicle categories	*Arahan Teknik (Jalan) 13/87*	Webster (1966)
Passenger cars	1.00	1.00
Motorcycles	0.33	0.33
Medium/ light lorries	1.75	1.75
Heavy lorries	2.25	1.75
Buses	2.25	2.25

Table 2-2: Proposed pce values for signalised intersections in Malaysia (MHCM, 2006), Webster

Vehicle categories	Pce values
Passenger cars	1.00
Motorcycles	0.22

Table 2-3: Pce values adopted by the Indonesian HCM (1996)

Movement types	Vehicle categories	Pce values
Protected movements	Light vehicles	1.00
	Heavy vehicles	1.30
	Motorcycles	0.20
Opposed movements	Light vehicles	1.00
	Heavy vehicles	1.30
	Motorcycles	0.40

Figure 2-3: Recorded Motor Cycles Queuing in Kigali and during free flow

The heavy vehicles PCU used is an average of 1.65 for the assessments of the intersections in SIDRA. This value is considered acceptable for heavy to medium goods vehicles (Figure 2-4).

Figure 2-4: Recorded Heavy Vehicles in Kigali

The actual volumes as per the traffic counts for each vehicle classification was used in the network (PTV Vissim) micro-simulation analysis. In the software, the vehicles are modelled as per the individual vehicle, with unique characteristics, and not based on PCU factors. The results of the AM and PM traffic counts (three hours) for all 31 intersections are shown in Figure 2-5 to Figure 2-35 to below. The raw data for the traffic counts can be found in **Annexure B.**

AM Peak

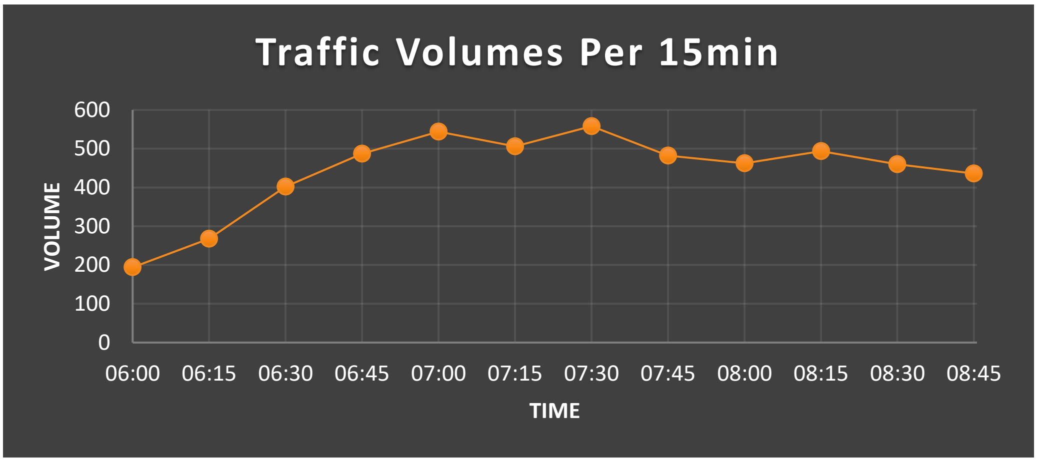

Figure 2-5: Intersection 1 AM peak

The peak period for intersection 1 occurred between 06:45 and 07:45. The highest volume occurs at 07:30.

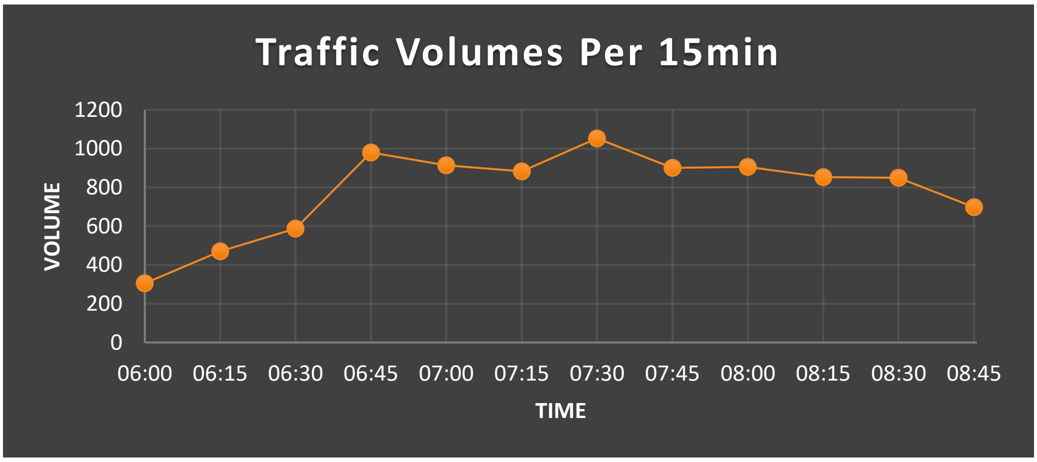

Figure 2-6: Intersection 2 AM peak

The peak period for intersection 2 occurred between 06:45 and 07:45. The highest volume occurs at 07:30.

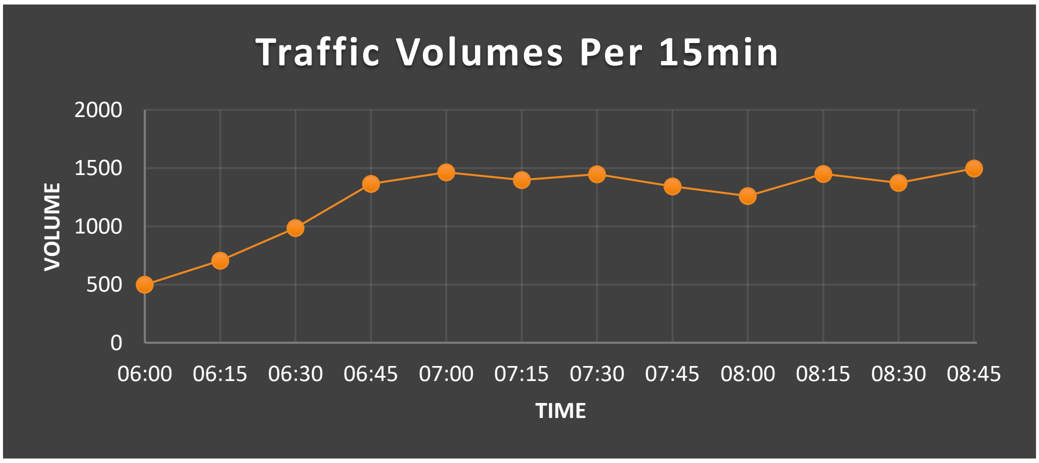

Figure 2-7: Intersection 3 AM peak

The peak period for intersection 3 occurred between 06:45 and 07:45. The highest volume occurs at 08:15.

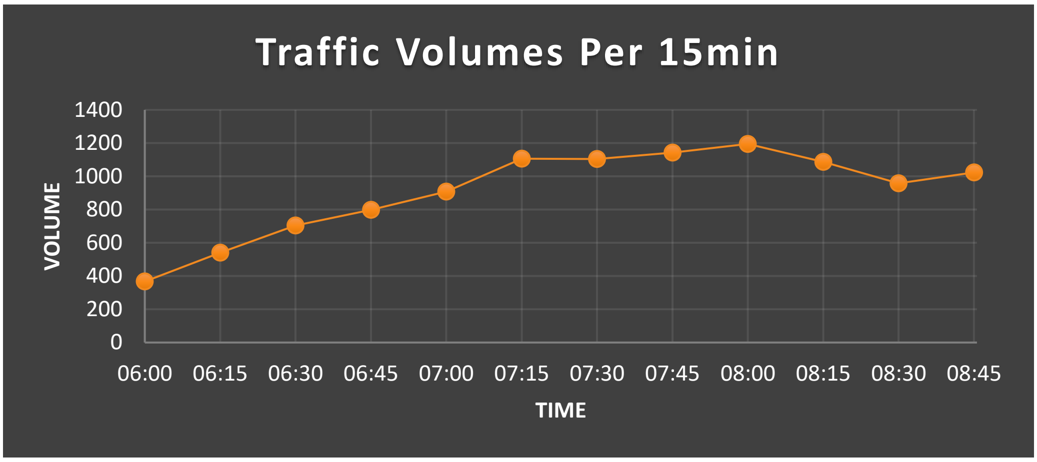

Figure 2-8: Intersection 4 AM peak

The peak period for intersection 4 occurred between 07:15 and 08:15. The highest volume occurs at 08:00.

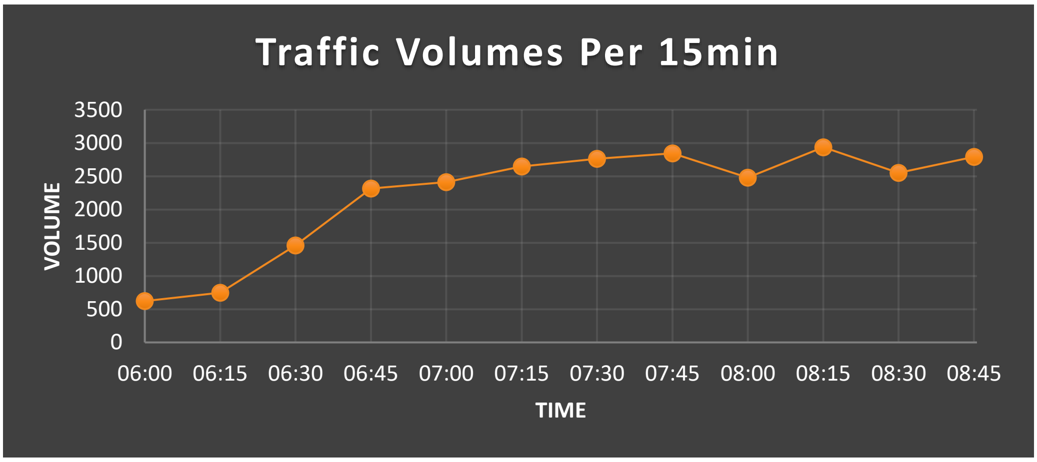

Figure 2-9: Intersection 5 AM peak

The peak period for intersection 5 occurred between 07:30 and 08:30. The highest volume occurs at 08:15.

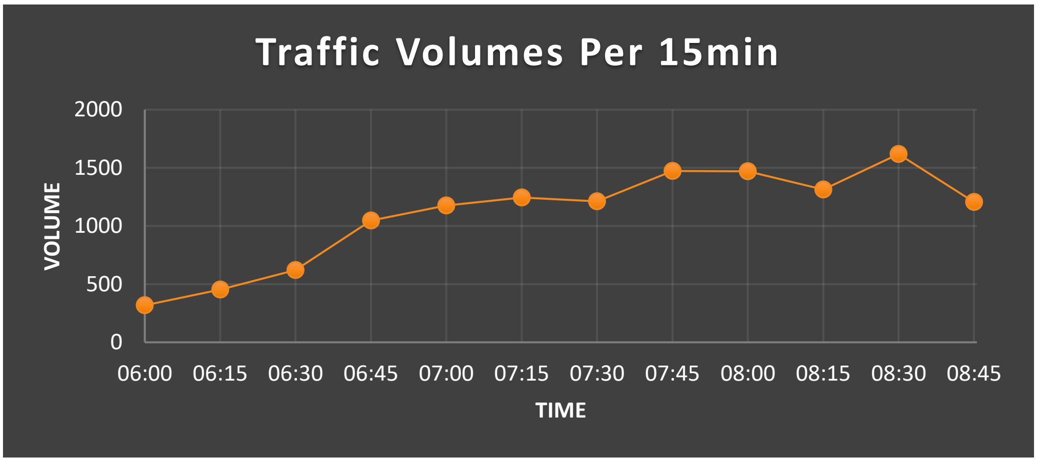

Figure 2-10: Intersection 6 AM peak

The peak period for intersection 6 occurred between 07:45 and 08:45. The highest volume occurs at 08:30.

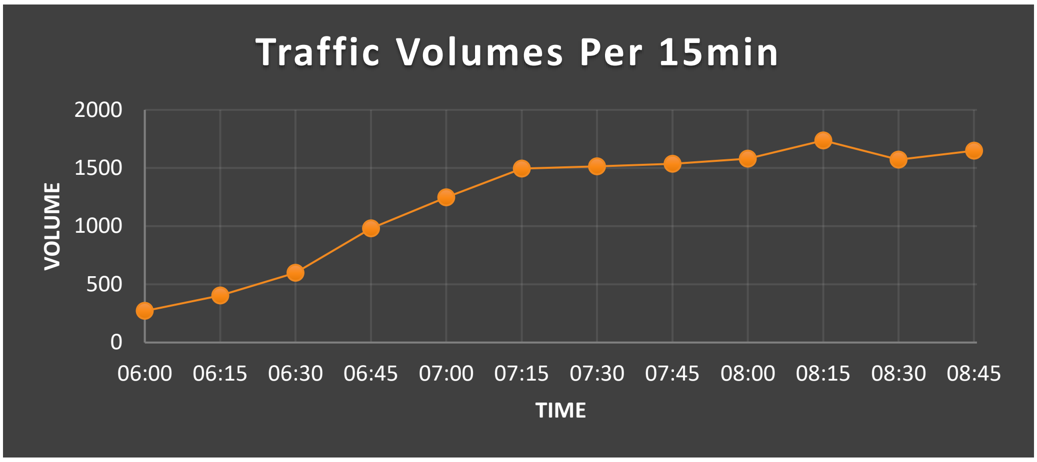

Figure 2-11: Intersection 7 AM peak

The peak period for intersection 7 occurred between 08:00 and 09:00. The highest volume occurs at 08:15.

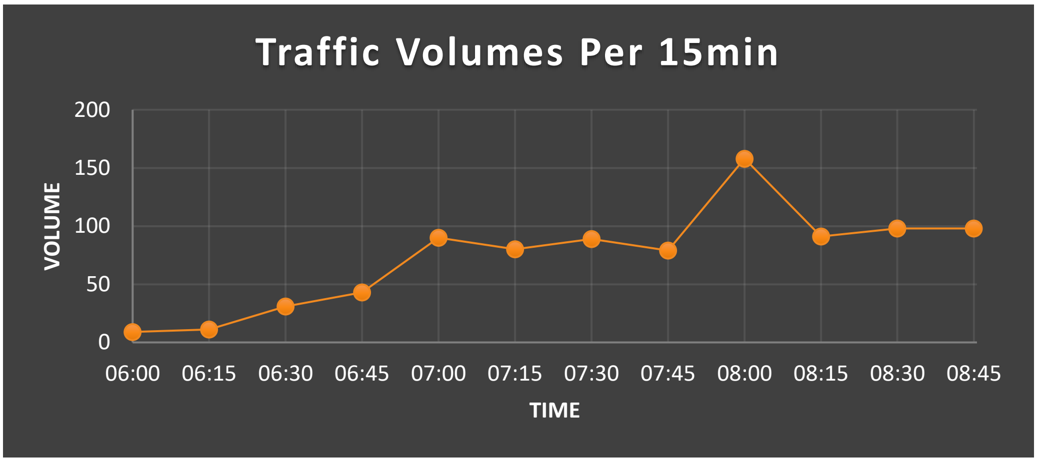

Figure 2-12: Intersection 8 AM peak

The peak period for intersection 8 occurred between 08:00 and 09:00. The highest volume occurs at 08:00.

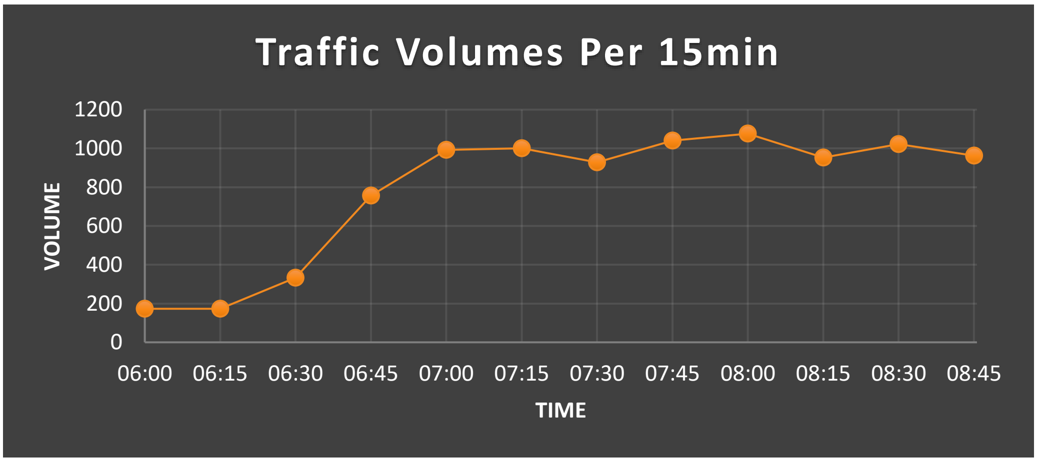

Figure 2-13: Intersection 9 AM peak

The peak period for intersection 9 occurred between 07:45 and 08:45. The highest volume occurs at 08:00.

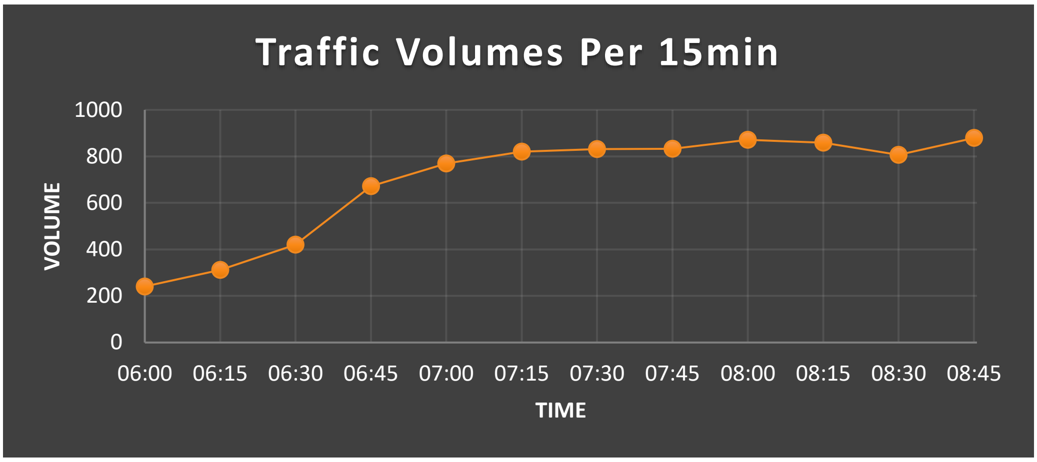

Figure 2-14: Intersection 10 AM peak

The peak period for intersection 10 occurred between 08:00 and 09:00. The highest volume occurs at 08:00.

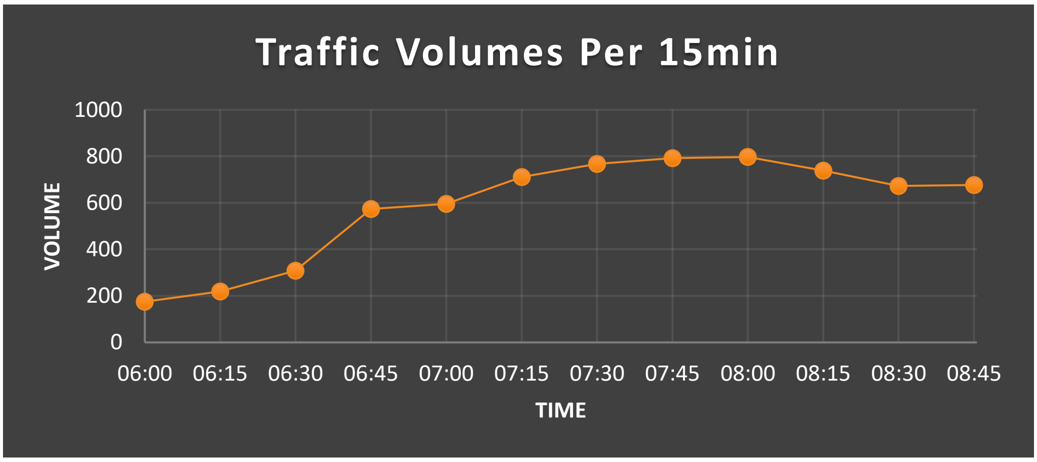

Figure 2-15: Intersection 11 AM peak

The peak period for intersection 11 occurred between 07:30 and 08:30. The highest volume occurs at 08:00.

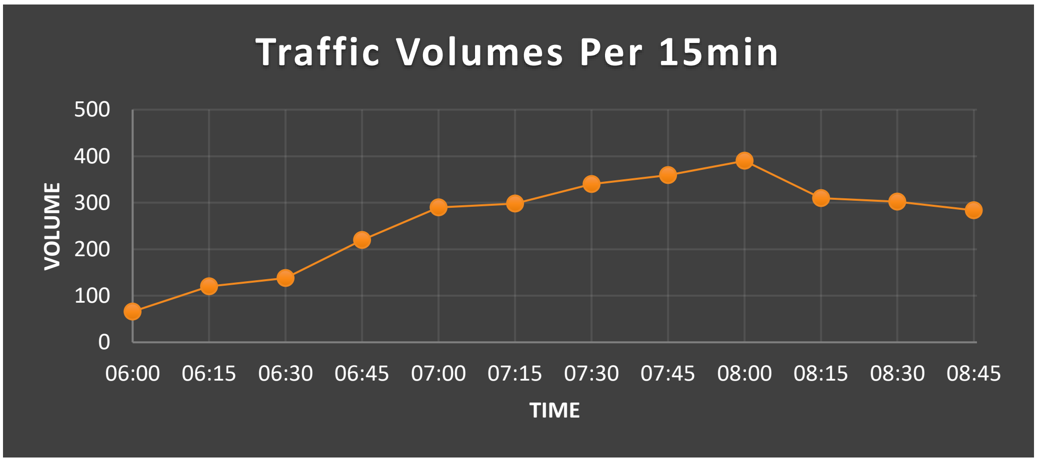

Figure 2-16: Intersection 12 AM peak

The peak period for intersection 12 occurred between 07:30 and 08:30. The highest volume occurs at 08:00.

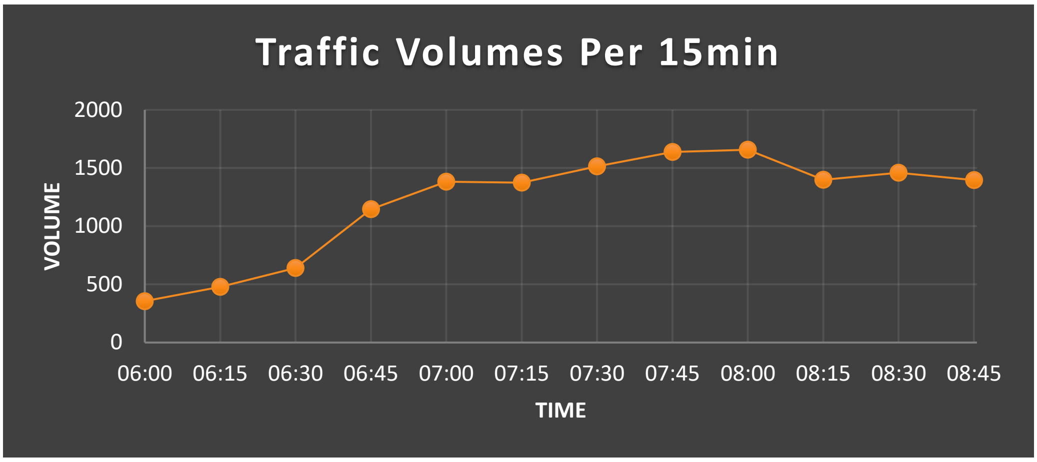

Figure 2-17: Intersection 13 AM peak

The peak period for intersection 13 occurred between 07:30 and 08:30. The highest volume occurs at 08:00.

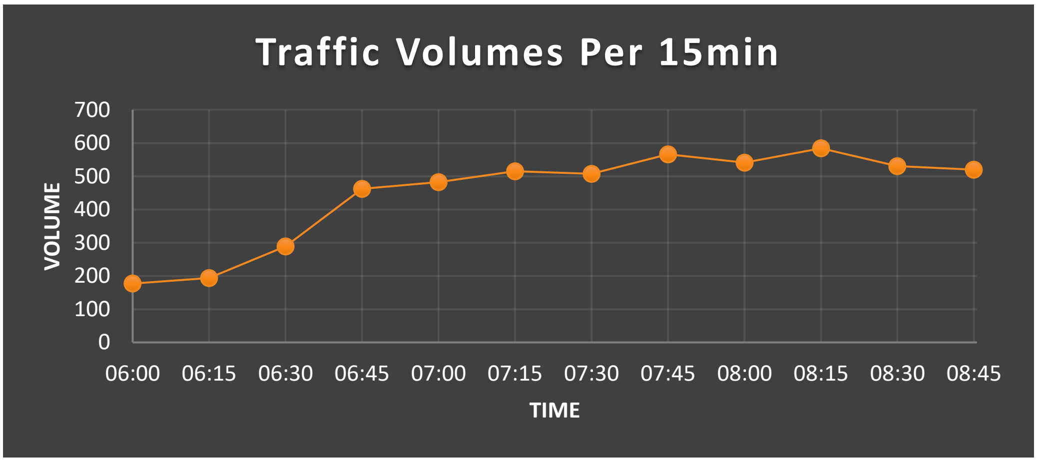

Figure 2-18: Intersection 14 AM peak

The peak period for intersection 14 occurred between 07:45 and 08:45. The highest volume occurs at 08:15.

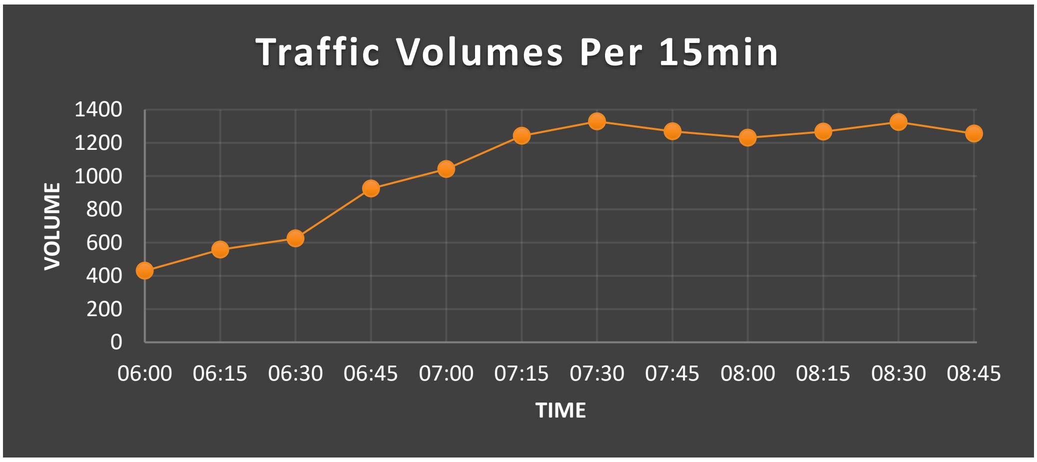

Figure 2-19: Intersection 15 AM peak

The peak period for intersection 15 occurred between 07:30 and 08:30. The highest volume occurs at 07:30.

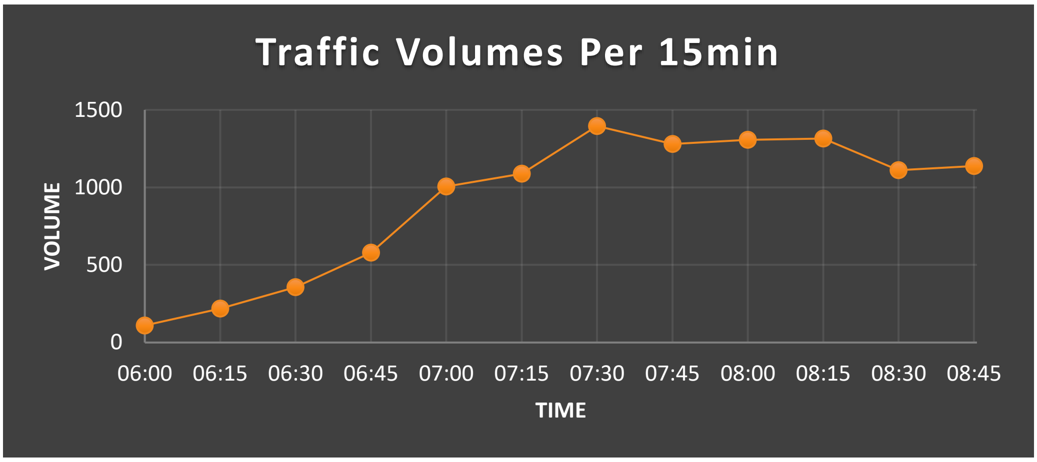

Figure 2-20: Intersection 16-1 AM peak

The peak period for intersection 16-1 occurred between 07:30 and 08:30. The highest volume occurs at 07:30.

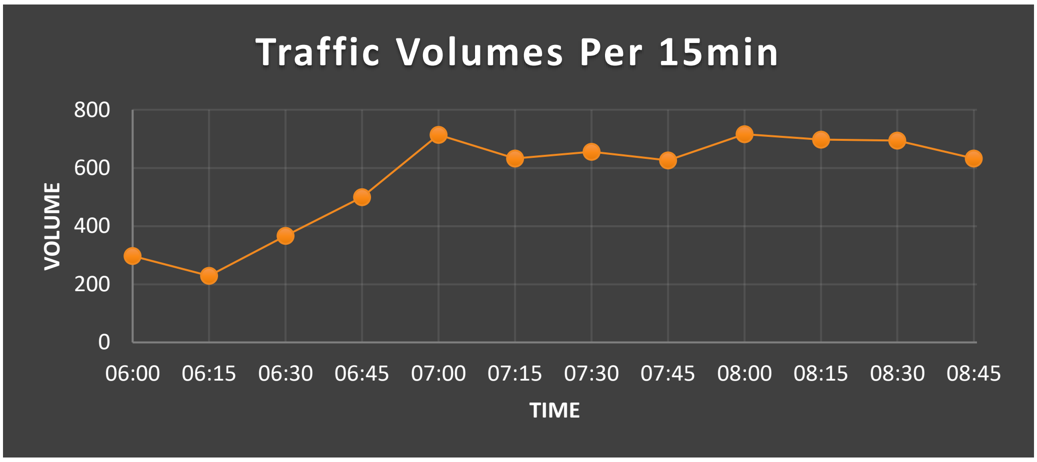

Figure 2-21: Intersection 16-2 AM peak

The peak period for intersection 16-2 occurred between 08:00 and 09:00. The highest volume occurs at 07:00.

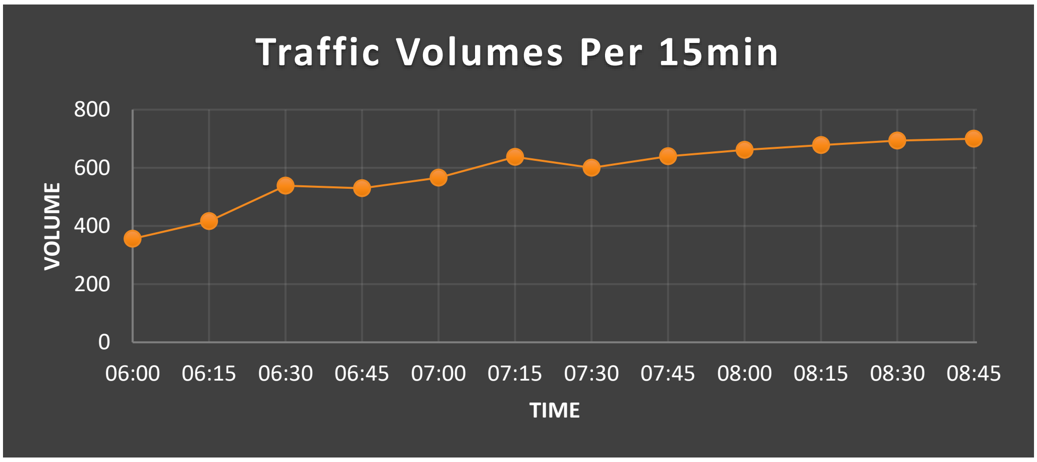

Figure 2-22: Intersection 17 AM peak

The peak period for intersection 17 occurred between 08:00 and 09:00. The highest volume occurs at 07:15.

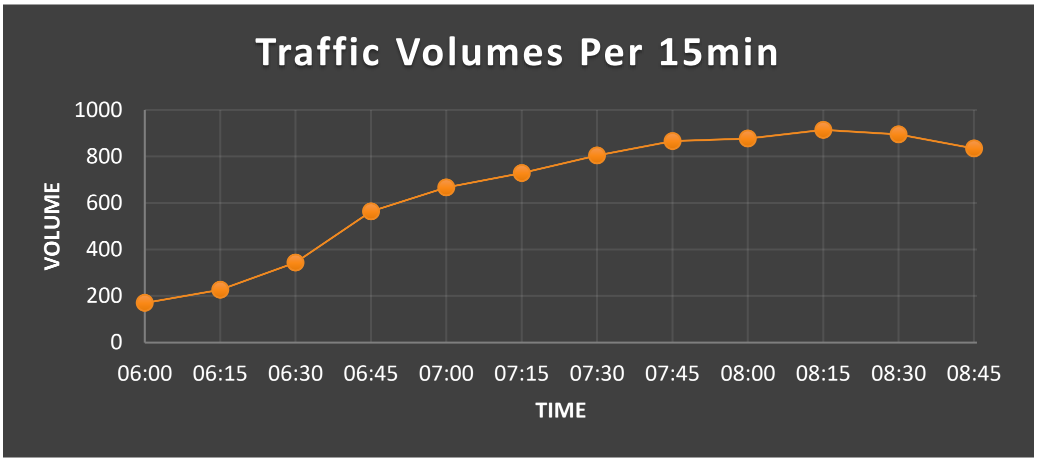

Figure 2-23: Intersection 18 AM peak

The peak period for intersection 18 occurred between 07:45 and 08:45. The highest volume occurs at 08:15.

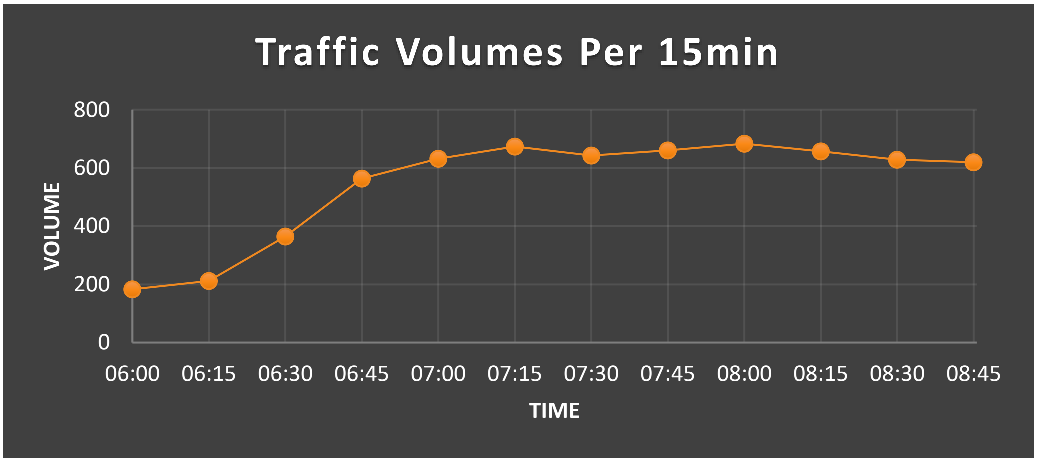

Figure 2-24: Intersection 19 AM peak

The peak period for intersection 19 occurred between 06:45 and 07:45. The highest volume occurs at 08:00.

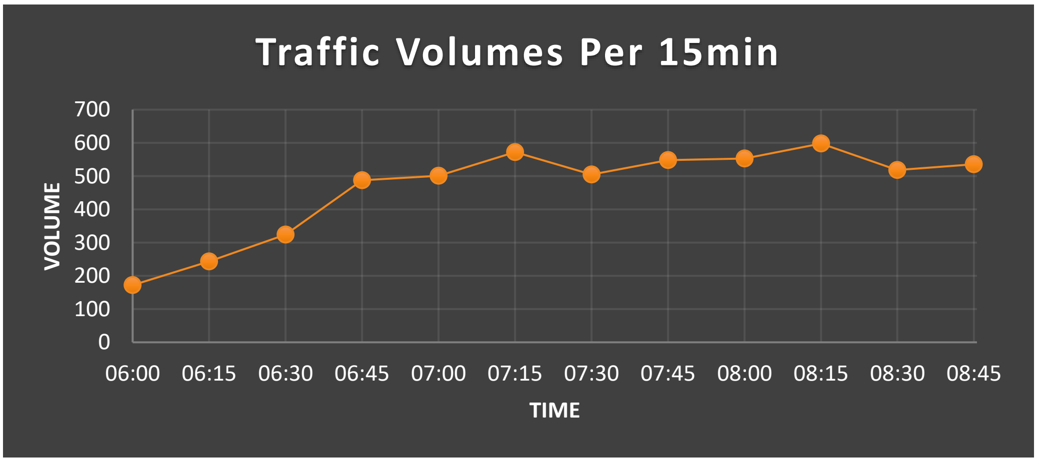

Figure 2-25: Intersection 20 AM peak

The peak period for intersection 20 occurred between 07:45 and 08:45. The highest volume occurs at 08:15.

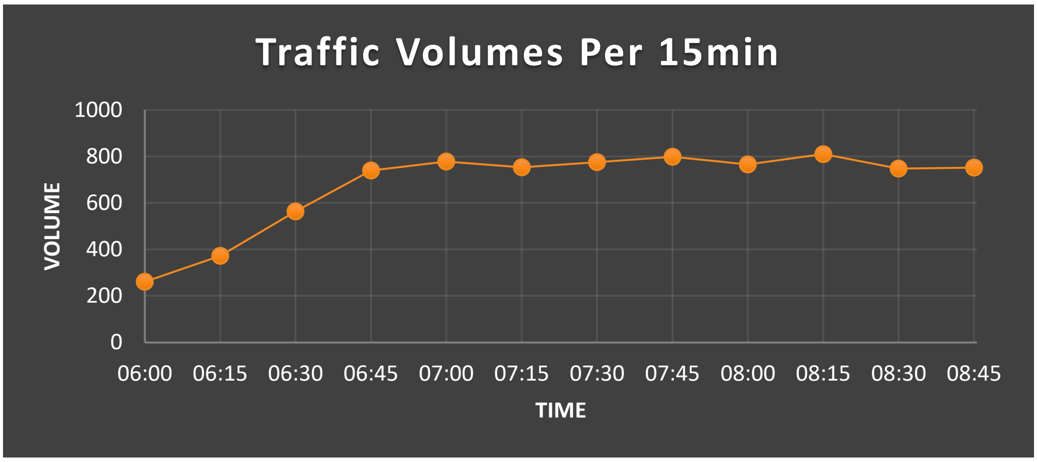

Figure 2-26: Intersection 21 AM peak

The peak period for intersection 21 occurred between 07:30 and 08:30. The highest volume occurs at 08:15.

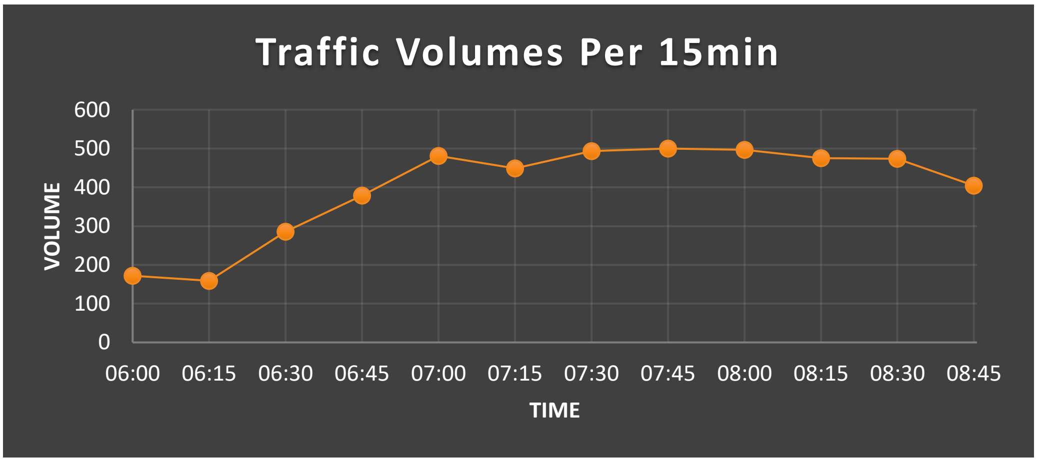

Figure 2-27: Intersection 22 AM peak

The peak period for intersection 22 occurred between 07:30 and 08:30. The highest volume occurs at 07:45.

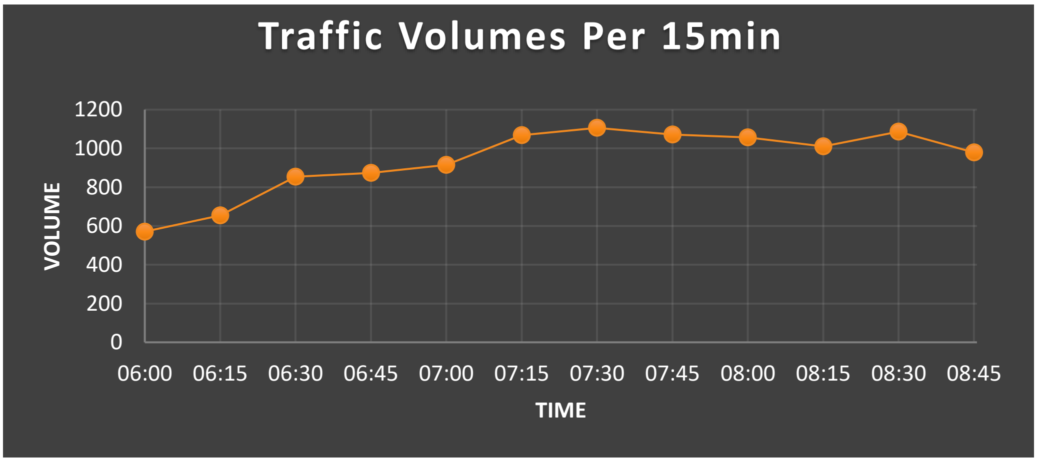

Figure 2-28: Intersection 23 AM peak

The peak period for intersection 23 occurred between 07:15 and 08:15. The highest volume occurs at 07:45.

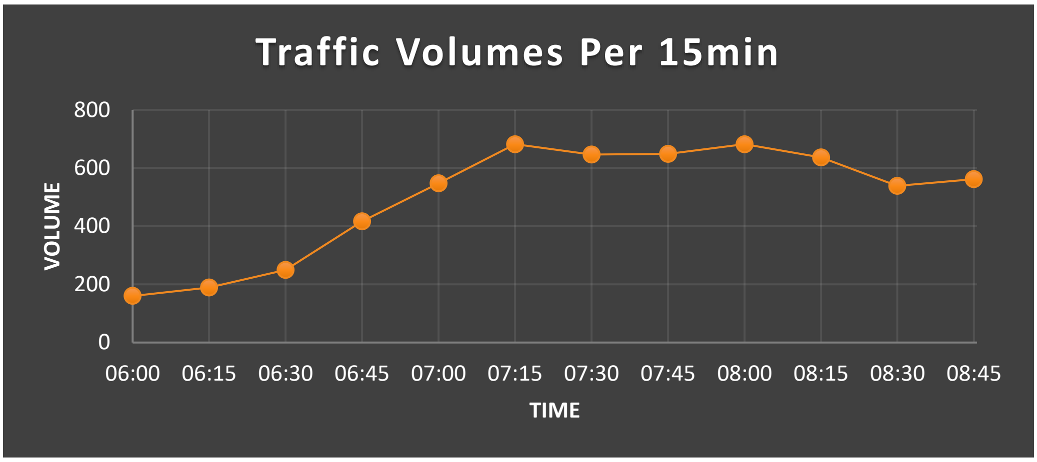

Figure 2-29: Intersection 24 AM peak

The peak period for intersection 24 occurred between 07:15 and 08:15. The highest volume occurs at 07:15.

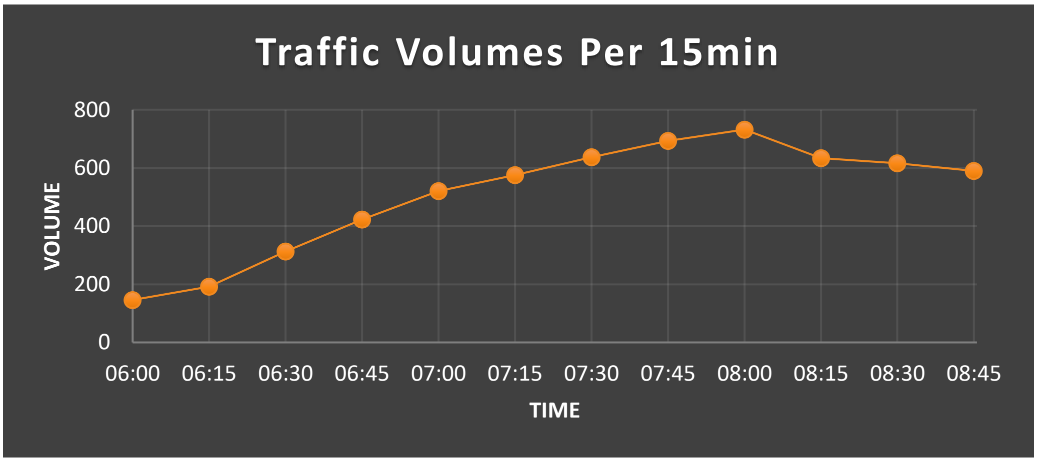

Figure 2-30: Intersection 25 AM peak

The peak period for intersection 25 occurred between 07:30 and 08:30. The highest volume occurs at 08:00.

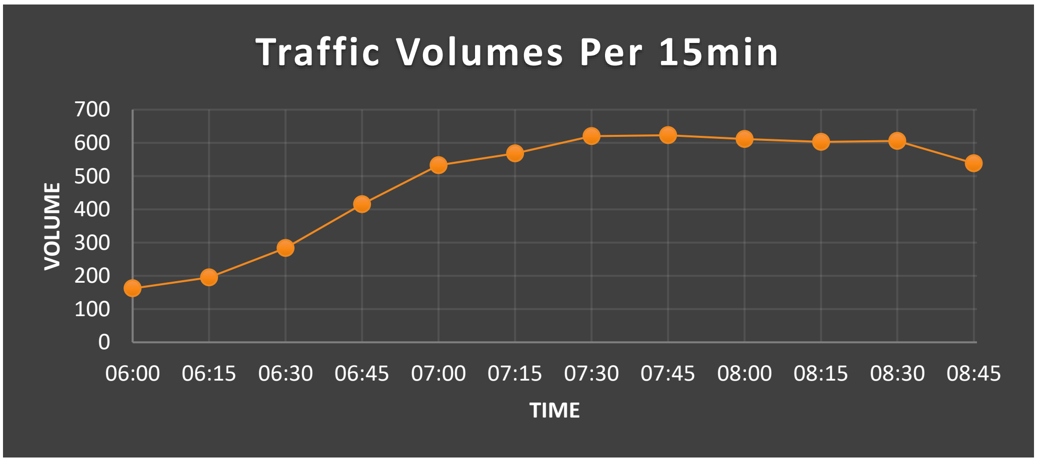

Figure 2-31: Intersection 26 AM peak

The peak period for intersection 26 occurred between 07:30 and 08:30. The highest volume occurs at 07:45.

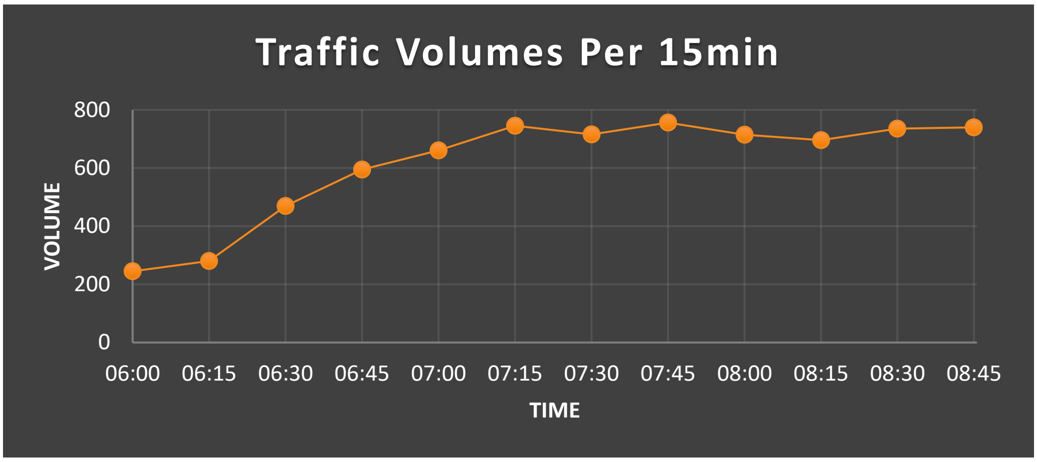

Figure 2-32: Intersection 27 AM peak

The peak period for intersection 27 occurred between 07:15 and 08:15. The highest volume occurs at 07:45.

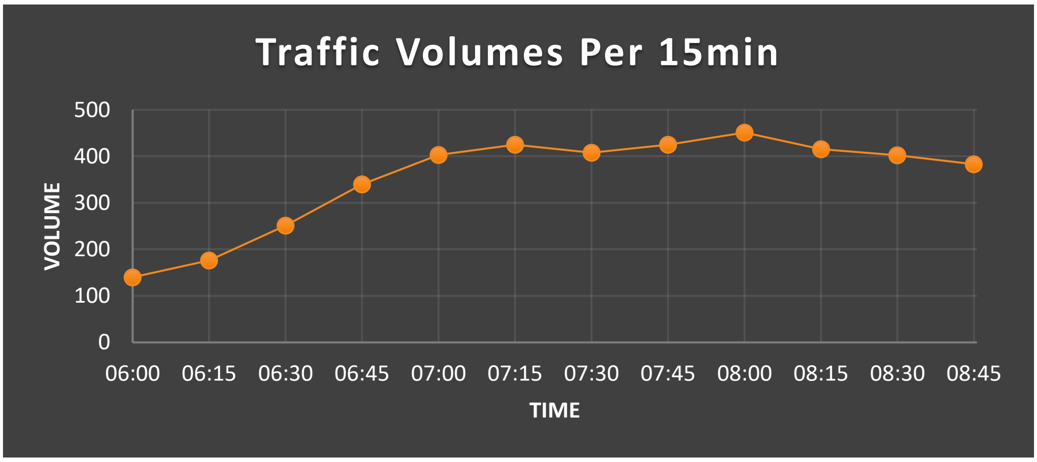

Figure 2-33:Intersection 28 AM peak

The peak period for intersection 28 occurred between 07:15 and 08:15. The highest volume occurs at 08:00.

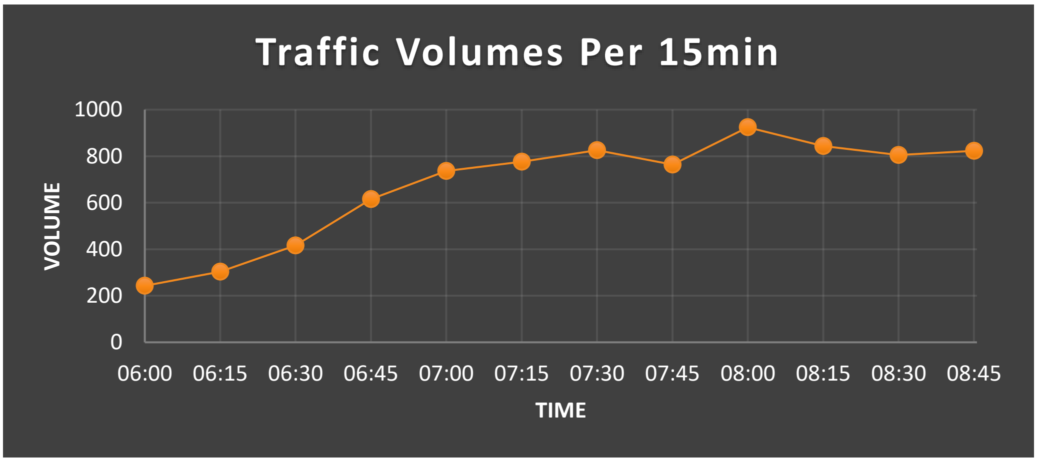

Figure 2-34: Intersection 29 AM peak

The peak period for intersection 29 occurred between 08:00 and 09:00. The highest volume occurs at 08:00.

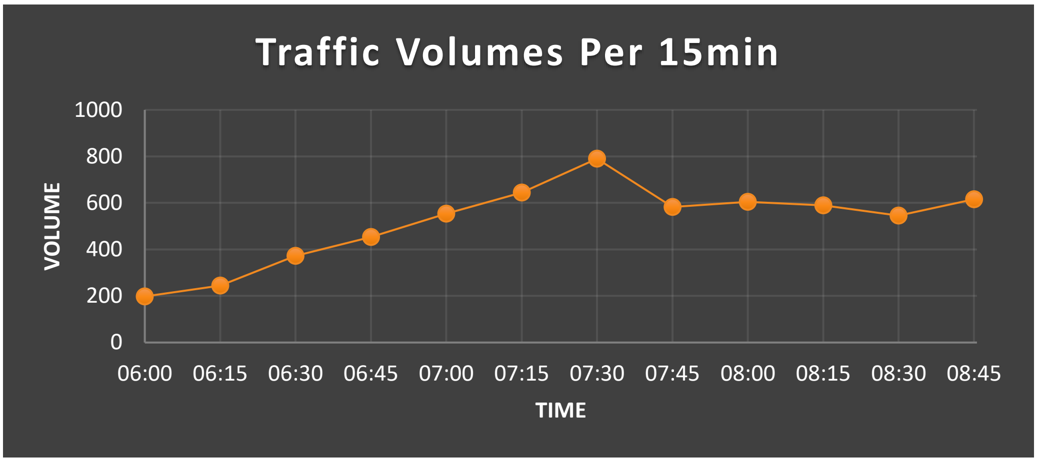

Figure 2-35: Intersection 30 AM peak

The peak period for intersection 30 occurred between 07:15 and 08:15. The highest volume occurs at 07:30. The most frequent traffic peak occurs between 07:30 and 08:30 in the AM period based on the assessment of all 30 intersection traffic counts.

PM Peak

The PM traffic counts peak 15 min periods are shown below in Figure 2-36 to Figure 2-66. The results of the traffic counts were plotted for the 15 min periods to obtain the peak PM period.

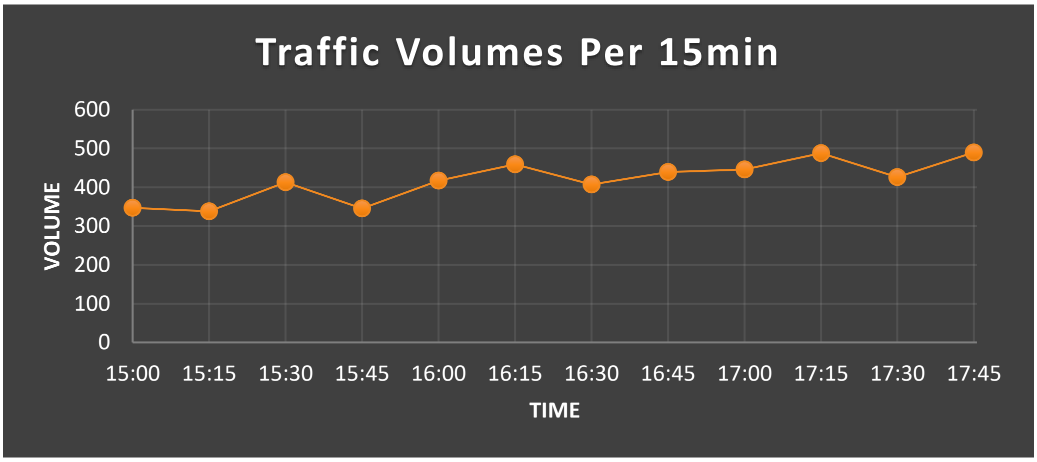

Figure 2-36: Intersection 1 PM peak

The period for intersection 1 occurred between 17:00 and 18:00. The highest volume occurs at 17:15.

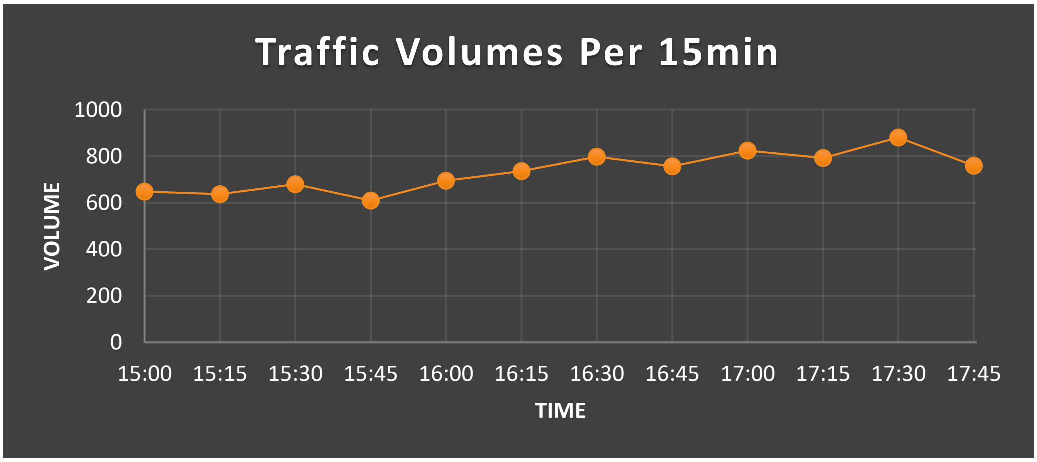

Figure 2-37: Intersection 2 PM peak

The peak period for intersection 2 occurred between 17:00 and 18:00. The highest volume occurs at 17:30.

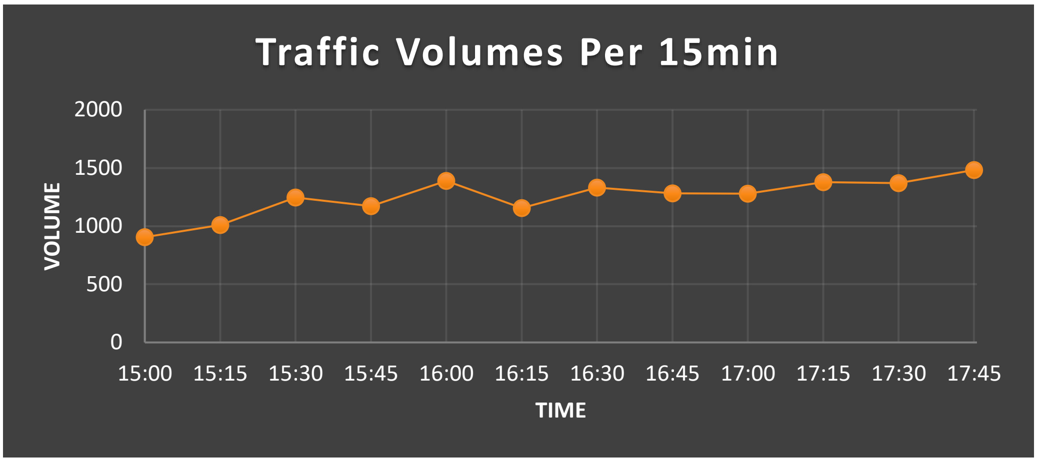

Figure 2-38: Intersection 3 PM peak

The peak period for intersection 3 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

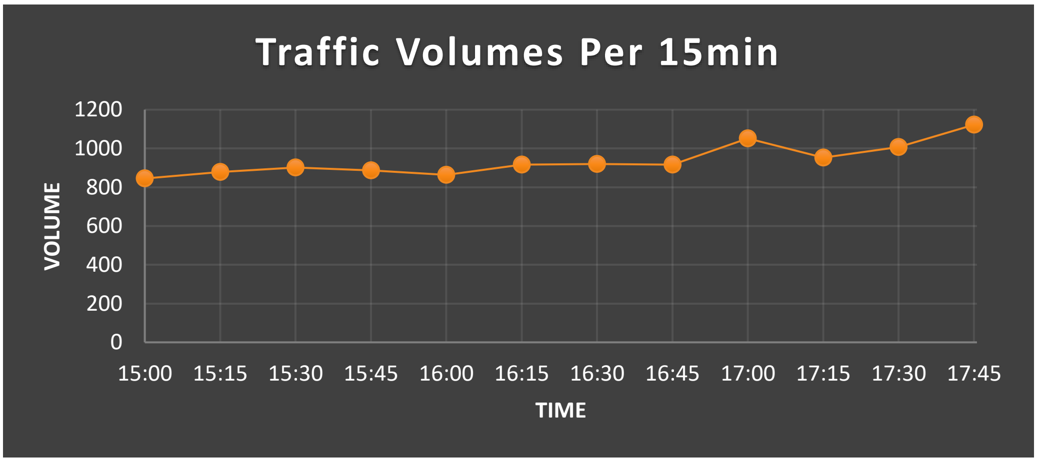

Figure 2-39: Intersection 4 PM peak

The peak period for intersection 4 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

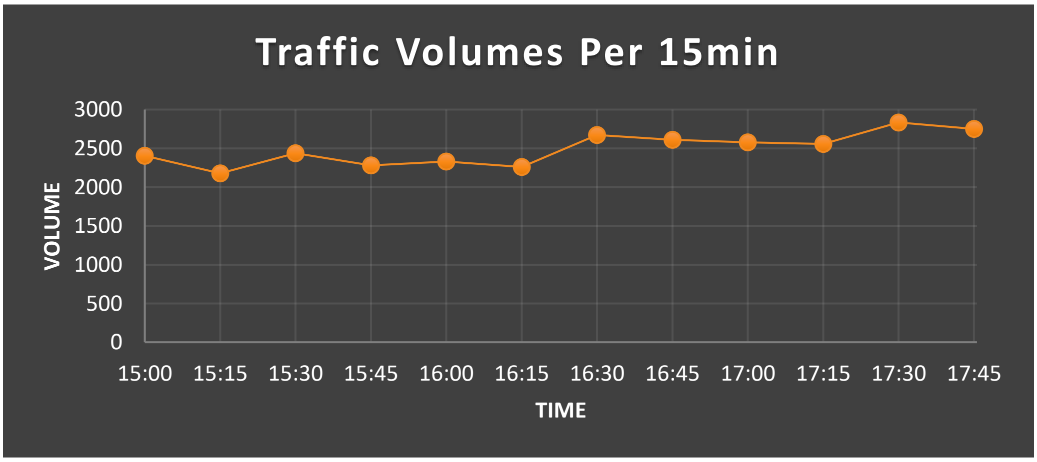

Figure 2-40: Intersection 5 PM peak

The peak period for intersection 5 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

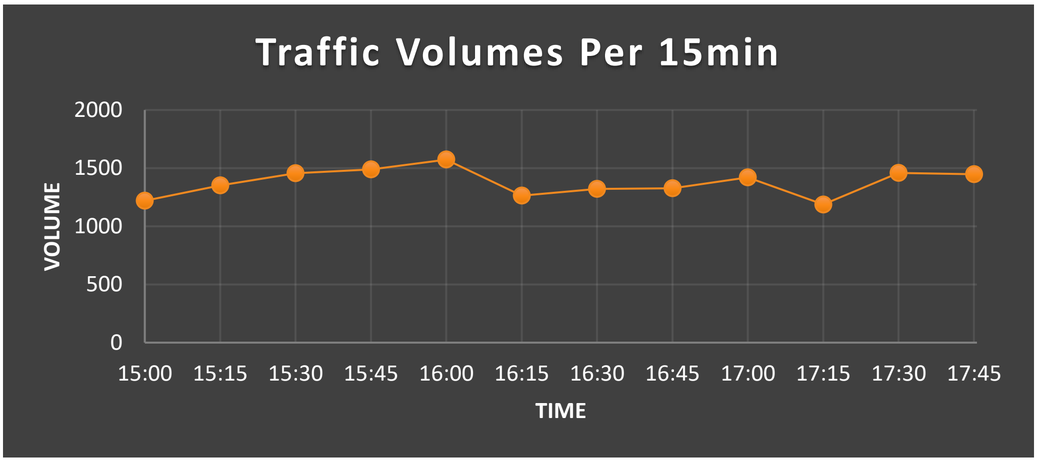

Figure 2-41: Intersection 6 PM peak

The peak period for intersection 6 occurred between 15:15 and 16:15. The highest volume occurs at 16:00.

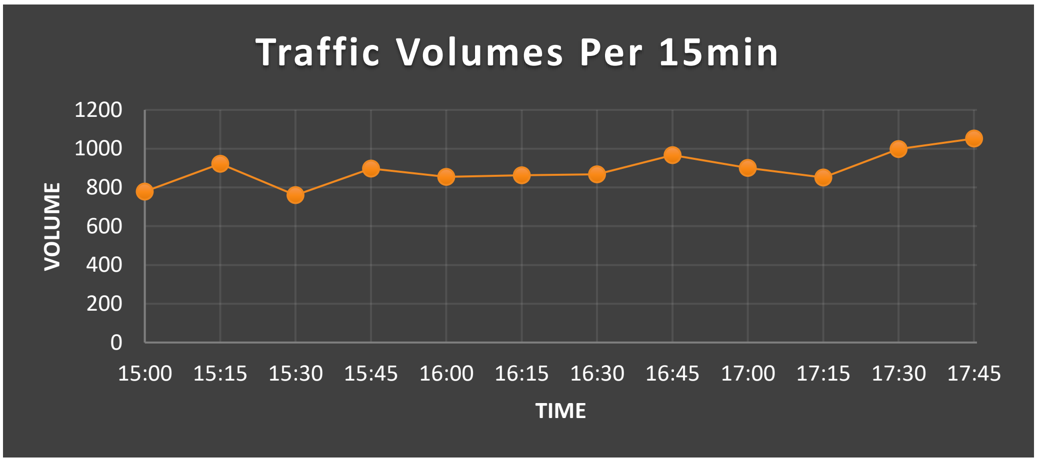

Figure 2-42: Intersection 7 PM peak

The peak period for intersection 7 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

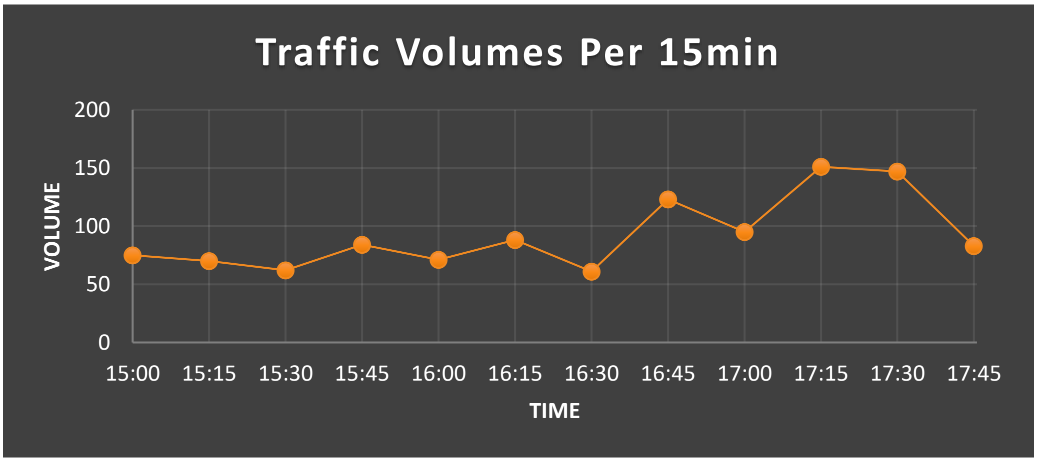

Figure 2-43: Intersection 8 PM peak

The peak period for intersection 8 occurred between 16:45 and 17:45. The highest volume occurs at17:15.

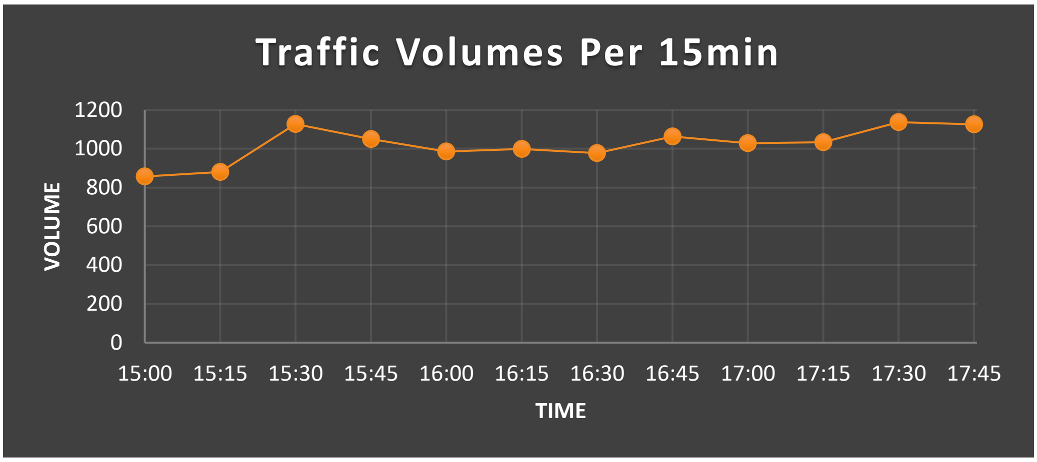

Figure 2-44: Intersection 9 PM peak

The peak period for intersection 9 occurred between 17:00 and 18:00. The highest volume occurs at 17:30.

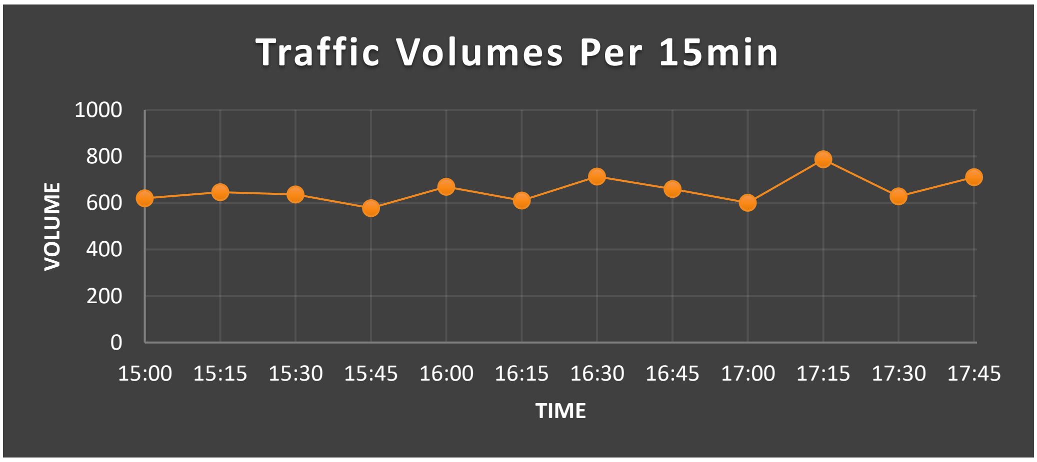

Figure 2-45: Intersection 10 PM peak

The peak period for intersection 10 occurred between 16:30 and 17:30. The highest volume occurs at 17:15.

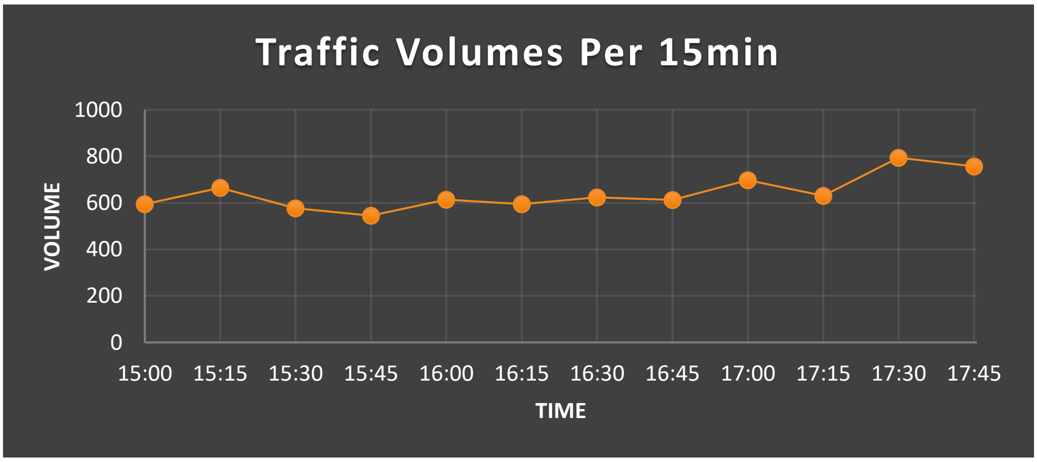

Figure 2-46: Intersection 11 PM peak

The peak period for intersection 11 occurred between 17:00 and 18:00. The highest volume occurs at 17:30.

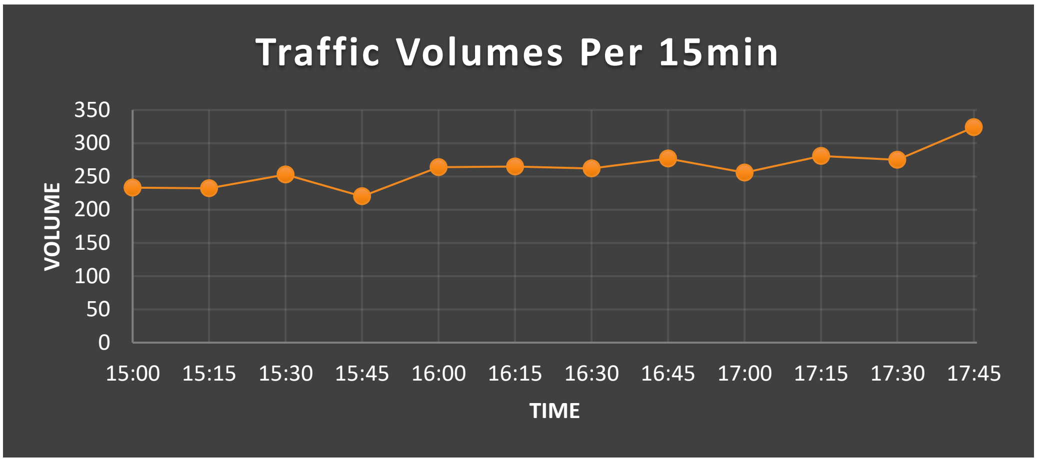

Figure 2-47: Intersection 12 PM peak

The peak period for intersection 12 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

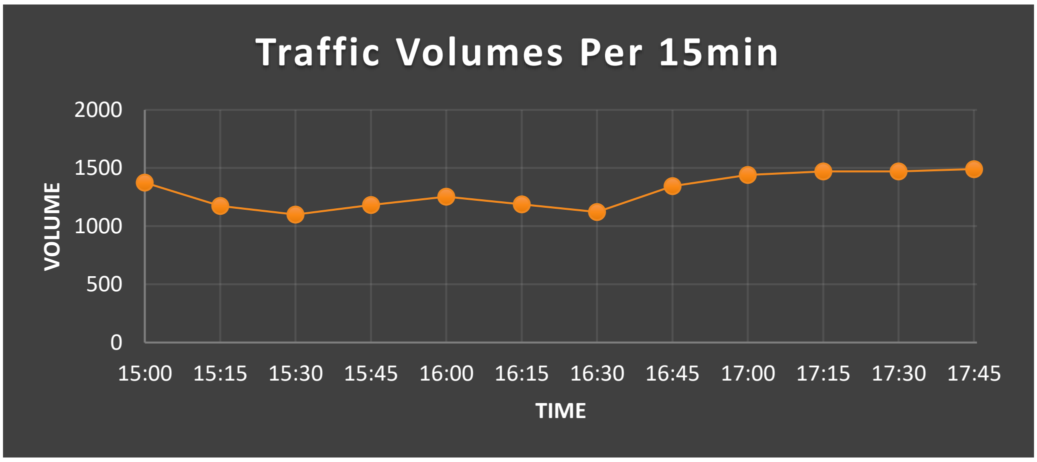

Figure 2-48: Intersection 13 PM peak

The peak period for intersection 13 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

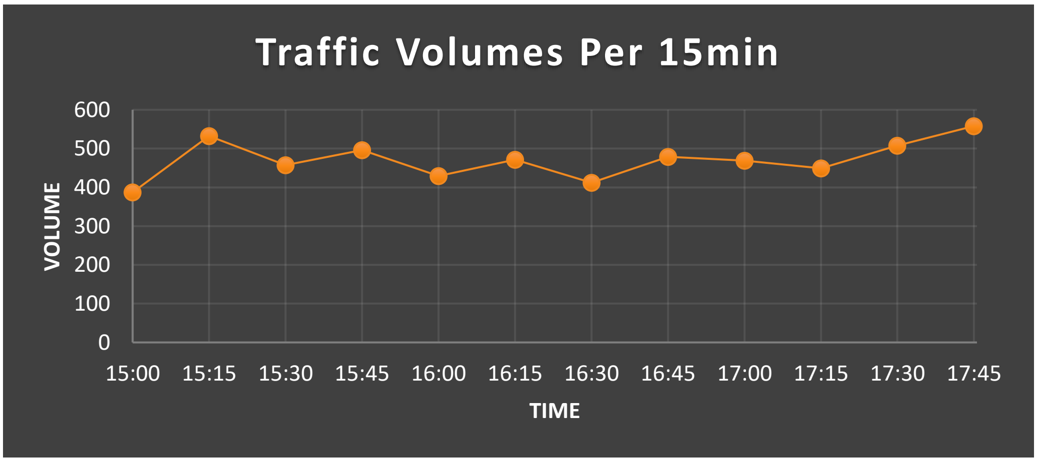

Figure 2-49: Intersection 14 PM peak

The peak period for intersection 14 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

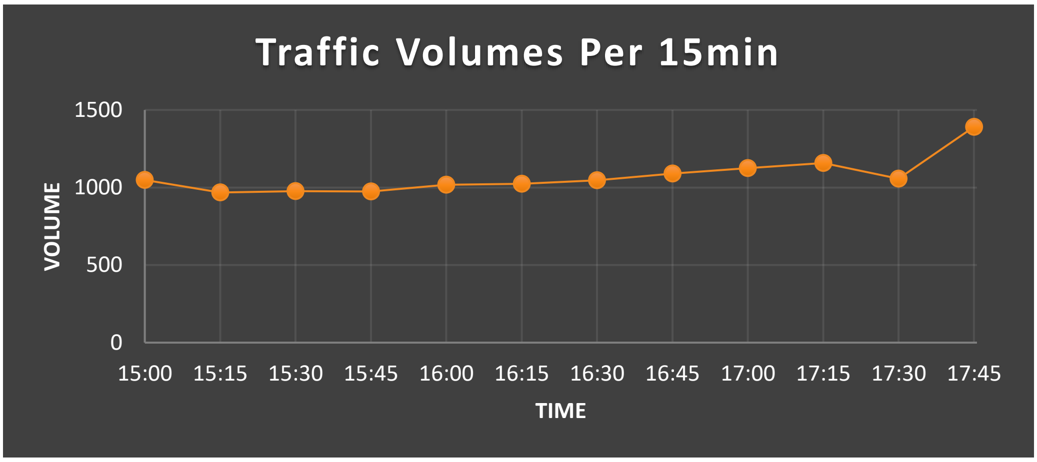

Figure 2-50: Intersection 15 PM peak

The peak period for intersection 15 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

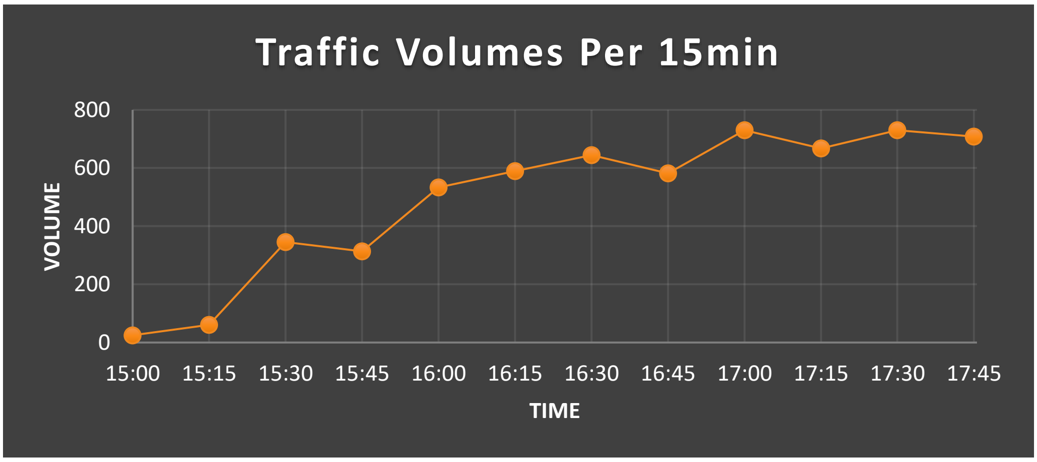

Figure 2-51: Intersection 16-1 PM peak

The peak period for intersection 16-1 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

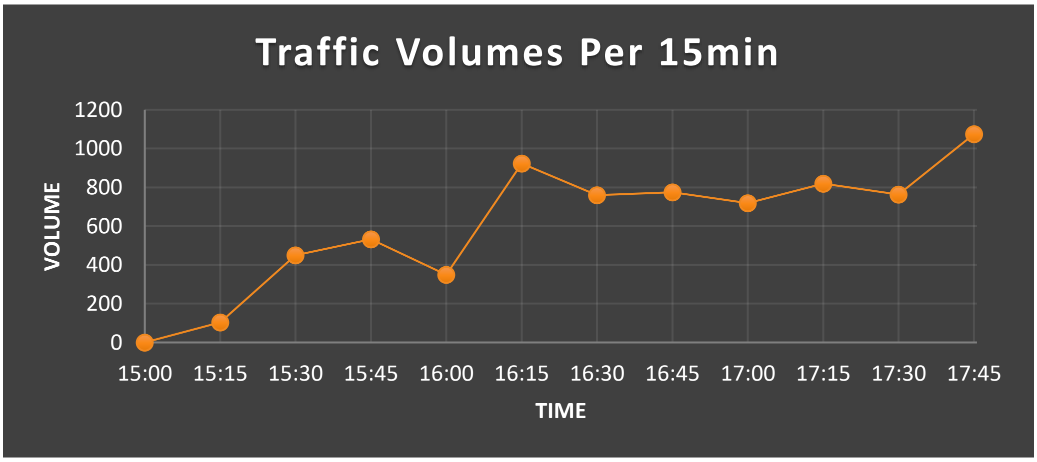

Figure 2-52: Intersection 16-2 PM peak

The peak period for intersection 16-2 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

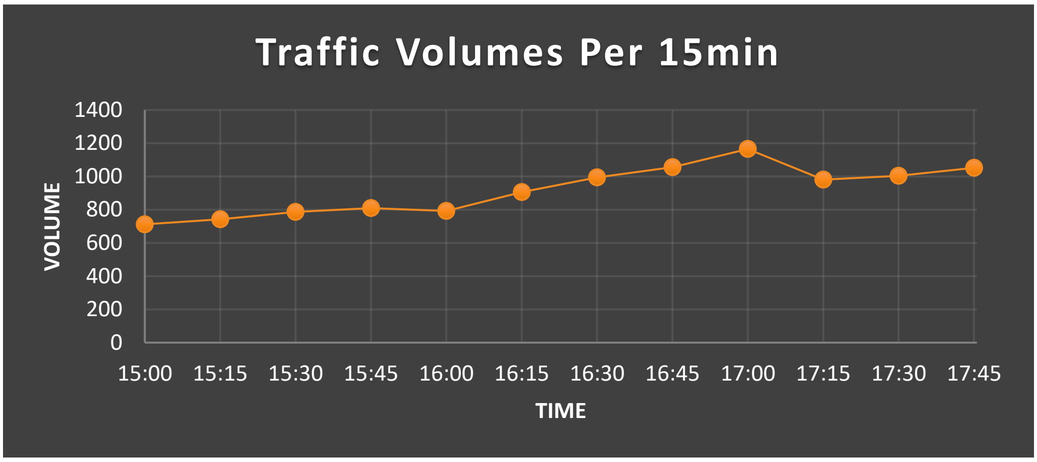

Figure 2-53: Intersection 17 PM peak

The peak period for intersection 17 occurred between 16:45 and 17:45. The highest volume occurs at 17:00.

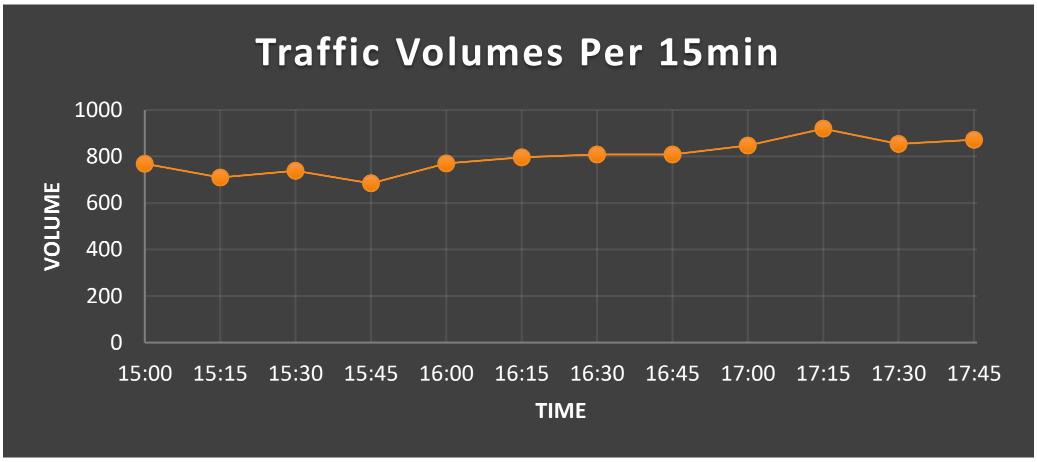

Figure 2-54: Intersection 18 PM peak

The peak period for intersection 18 occurred between 17:00 and 18:00. The highest volume occurs at 17:15.

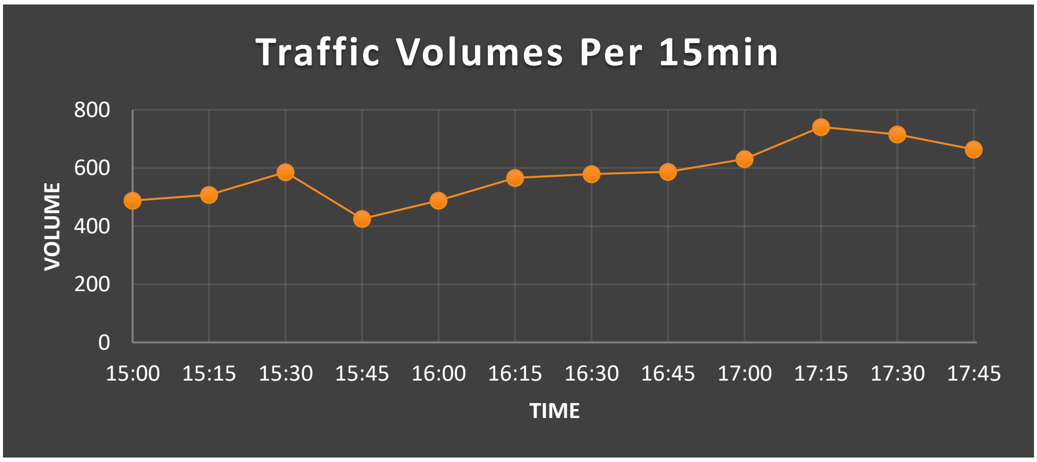

Figure 2-55: Intersection 19 PM peak

The peak period for intersection 19 occurred between 17:00 and 18:00. The highest volume occurs at 17:15.

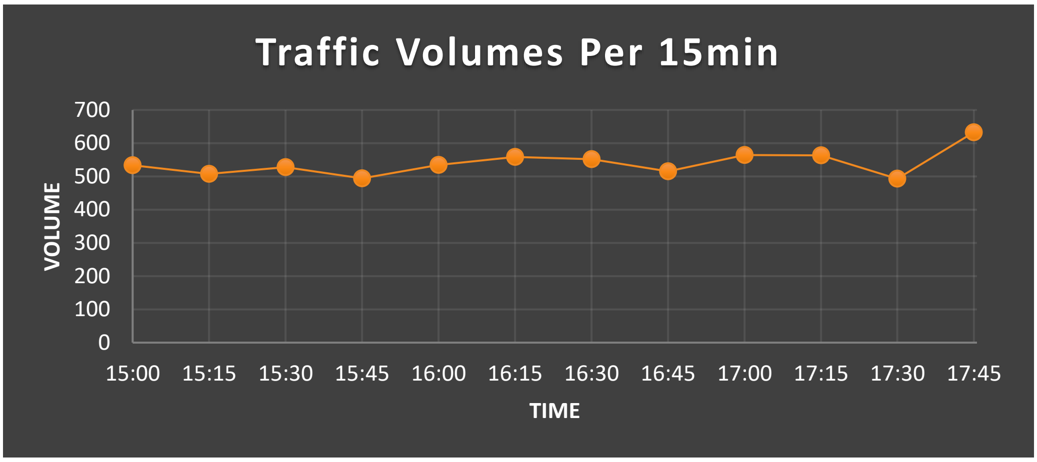

Figure 2-56: Intersection 20 PM peak

The peak period for intersection 20 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

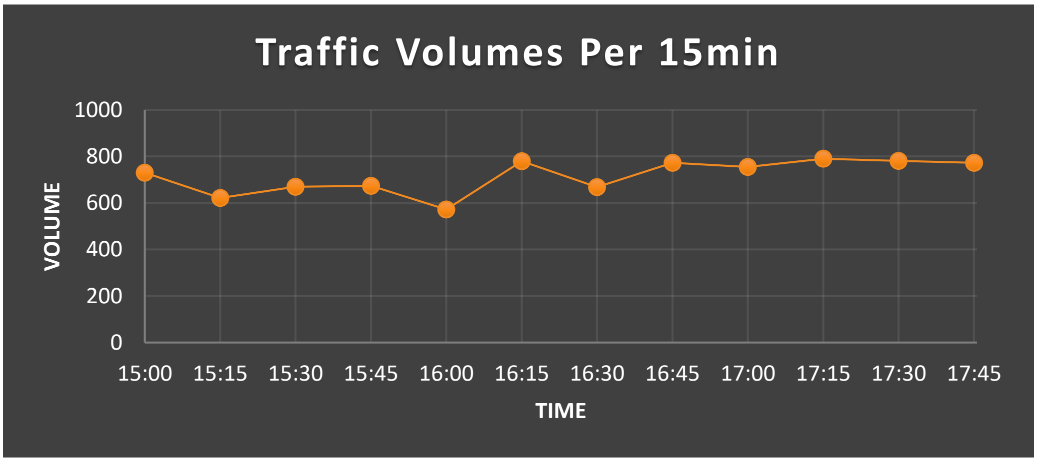

Figure 2-57: Intersection 21 PM peak

The peak period for intersection 21 occurred between 16:45 and 17:45. The highest volume occurs at 17:15.

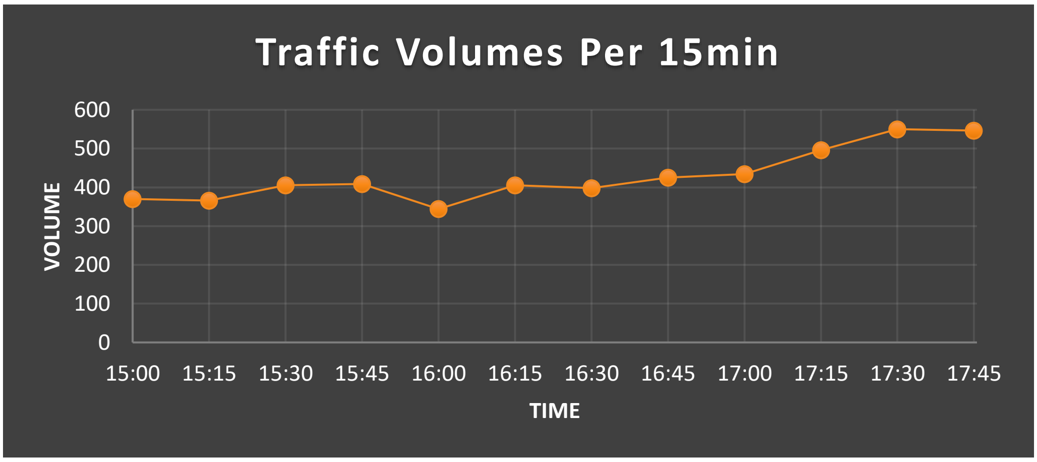

Figure 2-58: Intersection 22 PM peak

The peak period for intersection 22 occurred between 17:00 and 18:00. The highest volume occurs at 17:30.

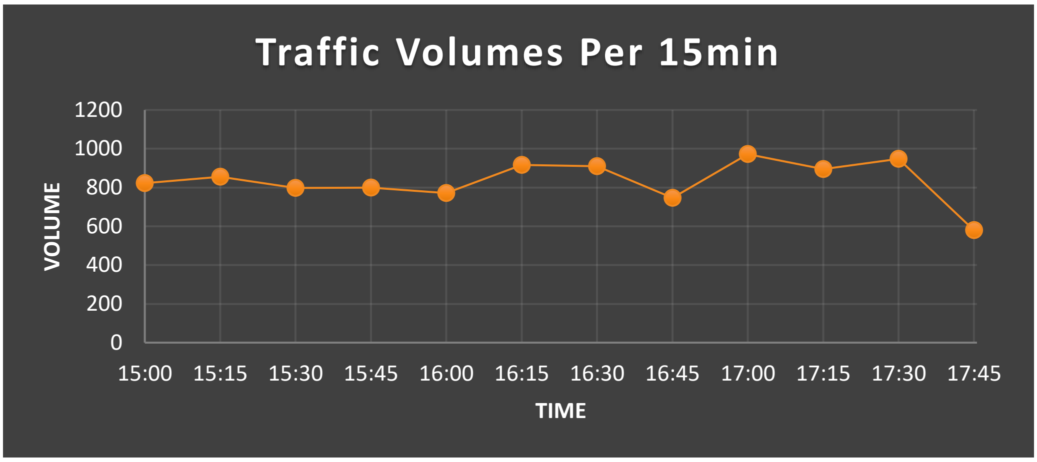

Figure 2-59: Intersection 23 PM peak

The peak period for intersection 23 occurred between 16:45 and 17:45. The highest volume occurs at 17:00.

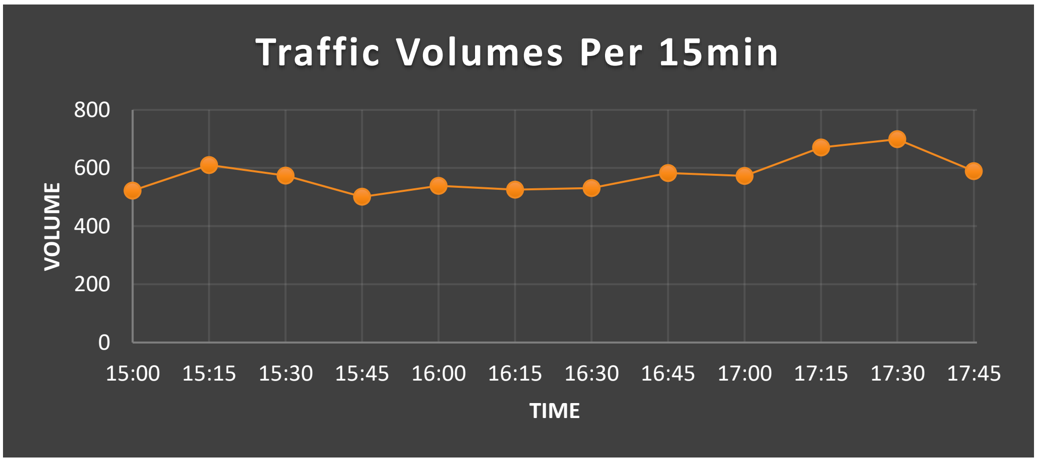

Figure 2-60: Intersection 24 PM peak

The peak period for intersection 24 occurred between 17:00 and 18:00. The highest volume occurs at 17:30.

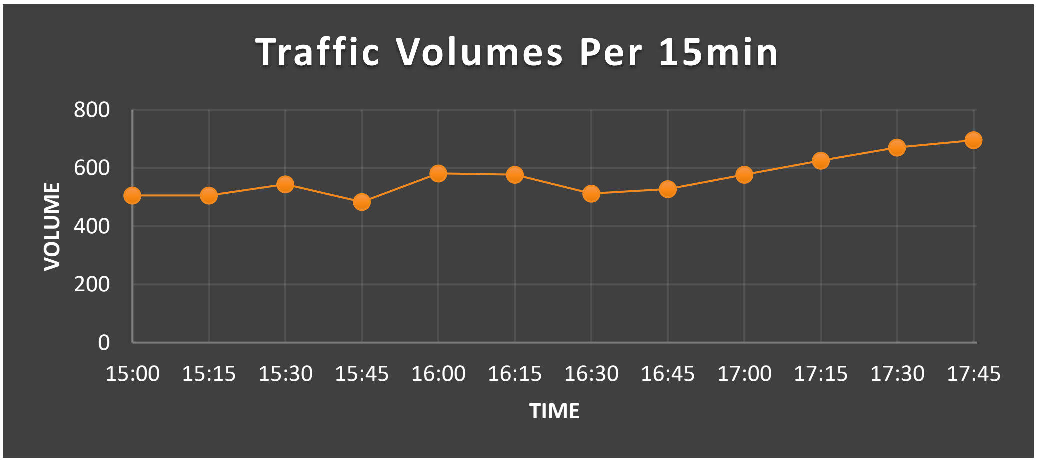

Figure 2-61: Intersection 25 PM peak

The peak period for intersection 25 occurred between 17:00 and 18:00. The highest volume occurs at 18:00.

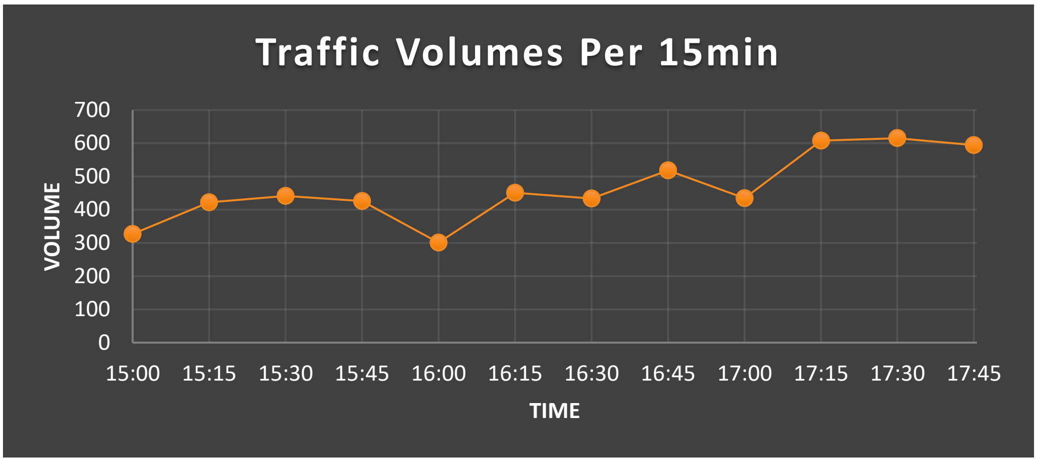

Figure 2-62: Intersection 26 PM peak

The peak period for intersection 26 occurred between 17:00 and 18:00. The highest volume occurs at 17:15.

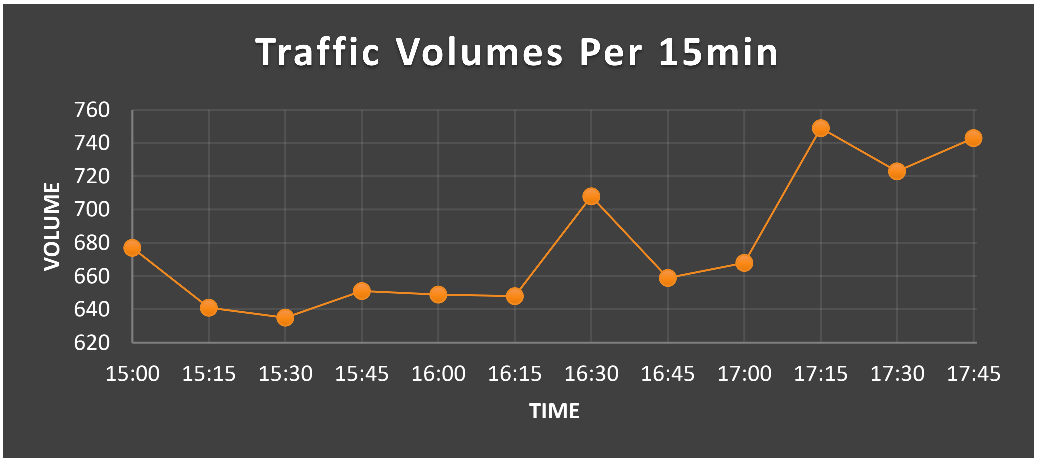

Figure 2-63: Intersection 27 PM peak

The peak period for intersection 27 occurred between 17:00 and 18:00. The highest volume occurs at 17:15.

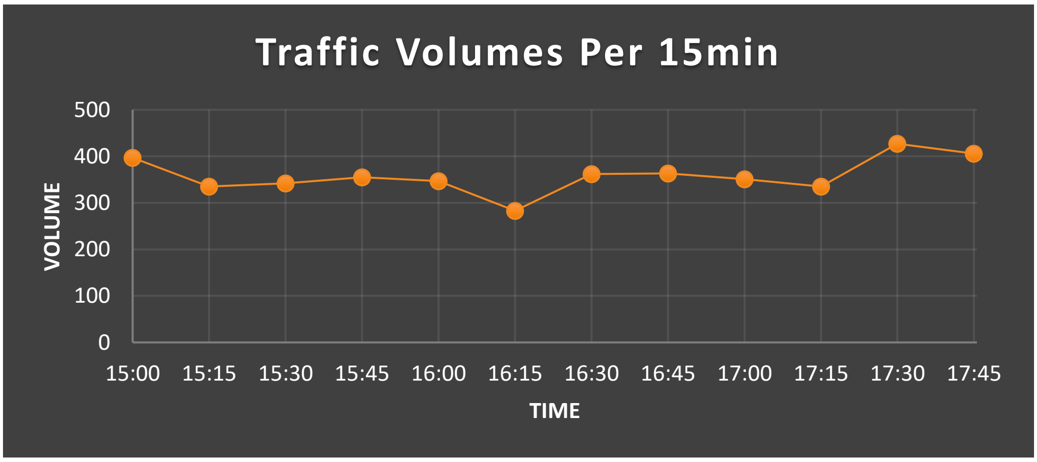

Figure 2-64:Intersection 28 PM peak

The peak period for intersection 28 occurred between 17:00 and 18:00. The highest volume occurs at 17:30.

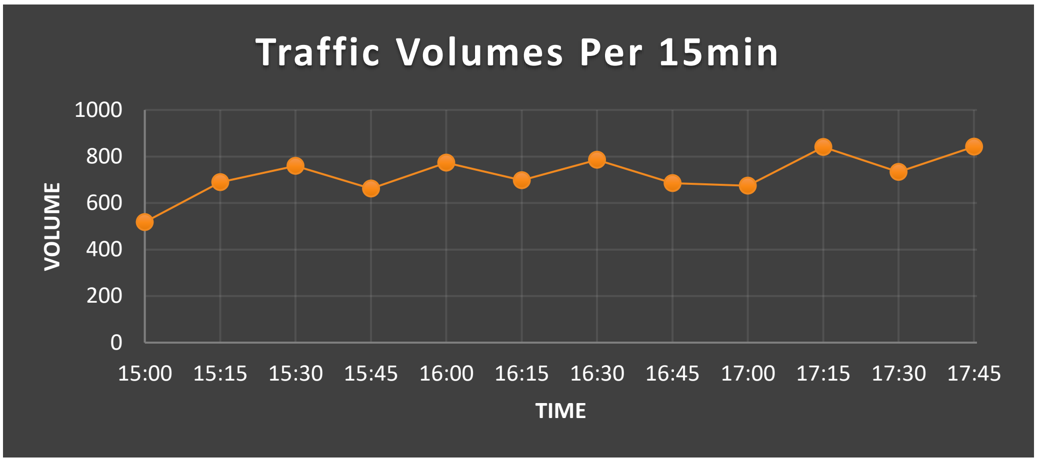

Figure 2-65: Intersection 29 PM peak

The peak period for intersection 29 occurred between 17:00 and 18:00. The highest volume occurs at 17:15.

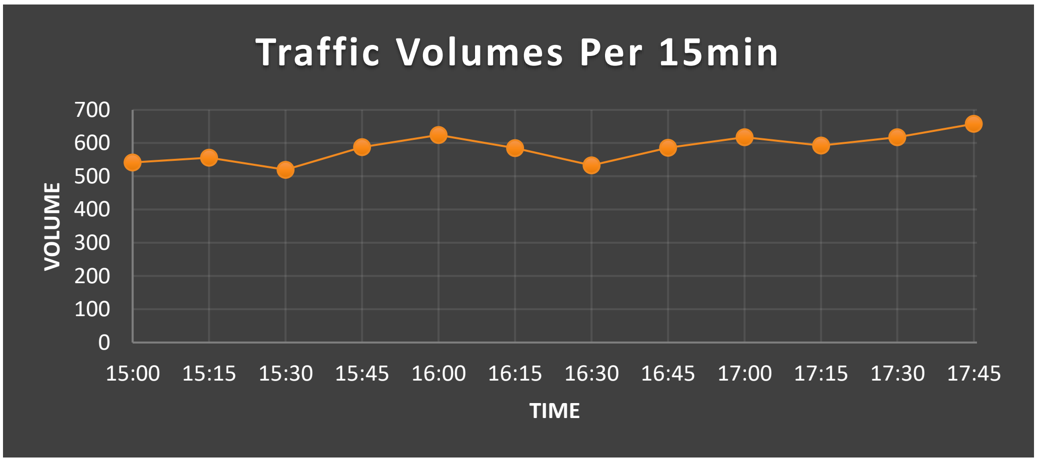

Figure 2-66: Intersection 30 AM peak

The peak period for intersection 30 occurred between 17:00 and 18:00. The highest volume occurs at 18:00. The PM peak was calculated between 17:00-18:00. Moreover, it was noted that during this period, the majority of the intersections had the 15min peak between 17:45 and 18:00 with the trend in the traffic seemingly increasing past 18:00. The traffic counts were concluded at 18:00, as the visibility for the enumerators and the reliability of the counts would decrease substantially after dark. Therefore, to accommodate for the increased peak of between 18:30 and 19:30, the counts were adjusted.

The PM peak counts were compared to the total volume at each intersection of the AM peak. Moreover, the PM counts' 15min peak was multiplied by the 4 (Transportation and Engineering Planning, 2005) to account for the Peak Hour.

This was then set against the AM peak period. The result gave a total difference across the 31 intersections corridors of approximately 5%. Consequently, the PM peak traffic counts were increased by 5% along the corridors to account for the shifted peak period outside of the counting times. This adjustment increased the total PM traffic trips by approximately 3894 trips along the corridors within the network. This significant alteration caused a large increase in the PM congestion and ultimately the level of service of the intersections. The Status Quo traffic used for the PM peak in both the SIDRA and Vissim models are the adjusted traffic counts.

Corridor Counts

The corridor counts were done for also to be used in the Macro-model. The counts were done to develop an AM peak macro-simulation model in PTV Visum. The counts were conducted on normal weekdays from 17-19 July 2018 on a sunny day. The counts were captured manually using local enumerators from Kigali. The enumerators were trained by the consultant team.

The enumerators comprised of final year civil engineering students from the University of Rwanda. Only the AM peak macro-model was developed as per the inception meeting. Hence, the counts were done from 06:00 – 09:00. Thirty Link Counts were completed throughout the city. The results of the link counts were used to determine the trip distribution parameters, modal split and peak period to the various attraction areas within the city. For the purpose of the micro-simulation model, the link counts were used to validate the AM peak calculated times (Table 2-4). The locations of the counts are shown in Figure 2-67.

Figure 2-67: Cordon Counts Locality Map

The peak period was calculated at 07:30 to 08h30 for the AM peak. This result indicates a small variation between the intersection counts and the link counts. However, the locations of the link counts and the intersection counts and congestion plays a role in the variation of the peak periods. As a result, the AM peak of between 07:30-08:30 is acceptable.

Table 2-4 Peak period, Link Counts

LOCATION	PEAK HOUR VOLUME (BOTH DIRECTIONS)	TIME INTERVAL (PEAK STARTS)
1	134	07:45:00
2	292	06:30:00
3	1080	06:45:00
4	966	08:00:00
5	184	07:30:00
6	1360	07:00:00
7	1360	07:00:00
8	359	06:45:00
9	3756	07:30:00
10	2162	07:30:00
11	2488	07:15:00
12	3659	07:15:00
13	791	06:45:00
14	933	07:15:00
15	3227	07:45:00
16	2856	08:00:00
17	472	07:45:00
18	232	06:30:00
19	1999	07:30:00
20	2447	08:00:00
21	1342	07:15:00
22	1941	07:15:00
23	1753	07:15:00
24	1984	08:00:00
25	338	06:45:00
26	1074	06:45:00
27	773	07:30:00
28	1105	07:15:00
29	558	07:00:00
30	3688	08:00:00
	Average	**07:18:30**

2.1.2. SmartyCAM Recordings

SmartyCAM recordings were done from 17-19 July 2018. The recordings are of the six corridors. The recordings were filmed during the PM period to assist with the visuals of the driver behaviour and existing road infrastructure along the corridors. The recordings can be found in **Annexure C.** (It assisted with the calibration of the Vissim Model.)

Figure 2-68: SmartyCAM recordings

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3. Methodology

The objectives of the analysis of the identified routes and intersections were achieved by the completion of the following key tasks:

- Classified traffic counts at all 31 intersections;
- SIDRA analysis of the isolated intersections;
- Assessment of the intersections based on capacity;
- Development of a model in PTV Vissim, that is adjusted to the Kigali driving behaviour to determine the network effect;
- Development of solutions in SIDRA to optimise the intersections;
- Testing of the optimised solutions in PTV Vissim, to assess the network effect of the solutions;
- Proposal of solutions to solve the congestion with a 5-year horizon forecast, using the macro-simulation model predictions regarding traffic growth; and
- Drafting of a report of the findings and proposed solutions.

3.1. Road Classification

For the purposes of assessing and developing solutions to the congestion within the city, along the corridors assessed in this project, it is necessary to classify and note the functionality of the road to determine the primary purpose of the route. This will aid not only in proposing solutions to existing issues, but to further enhance the primary purpose of the route.

The Rwandan government has published Official Gazette No. 04 of 23/01/2012 to establish the law governing the roads in Rwanda. The Official gazette states that public road network shall comprise of the following classifications:

- **National roads**: National roads shall be those comprising the following categories:
  - International roads that link Rwanda with neighbouring countries;
  - Roads that link Districts or that link a District and the CoK;
  - Roads that link areas of tourist significance and facilities of national or international importance, such as ports and airports.
- Districts and City of Kigali roads and that of other urban areas – Class 1
  - Class 1 shall be roads linking different Sectors' headquarters within the same District, or those roads that are used within the same Sector.
- Districts and City of Kigali roads and that of other urban areas - Class 2
  - Class 2 shall be arterial roads that connect Districts roads to rural community centres that are inhabited as an agglomeration.
- Specific roads
  - Specific roads shall be those specifically constructed to connect national roads or District roads to Kigali City and other urban areas to the centres for private sectors activities, such as agricultural production, natural resources processing or to tourist sites.

Table 3-1: National Road Classes

ROAD CLASS	DEFINITION	LANE WIDTH (M)	ROAD WIDTH (M)	TOTAL ROAD RESERVE (M)
National Roads	International roads that link Rwanda with neighbouring countries; Roads that link Districts or that link a District and the CoK;	3.52 m	-	44 m

ROAD CLASS	DEFINITION	LANE WIDTH (M)	ROAD WIDTH (M)	TOTAL ROAD RESERVE (M)
	Roads that link areas of tourist significance and facilities of national or international importance such as ports and airports			
Districts and CoK roads and that of other urban areas - Class 1 Roads	Roads linking different sector headquarters within the same District, or those roads that are used within the same sector.	3.52 m	-	44 m
Districts and CoK roads and that of other urban areas - Class 2 Roads	Arterial roads that connect Districts roads to rural community centres that are inhabited as an agglomeration.	-	6.03 m	24 m
Specific Roads	Roads specifically constructed to connect national roads or District roads to Kigali City and other urban areas to the centres for private sector's activities such agricultural production, natural resources processing or to tourist sites.	-	-	-

Rwanda has further developed an urban planning manual called the Urban Planning Code (UPC). This manual characterises design principles and guidelines for all urban areas within the country. In this manual, there is a section on the classification and geometric requirements of the road and transport networks within the country. Chapter 3: Inner-Urban Transport and Traffic Management contains the definitions and regulatory specifications of the classification of the types of roads in the country. The document refers to there being four classifications of roads, namely:

- Primary Distributor
- Secondary Distributor
- Local Distributor
- Access Road

The definitions of these roads are shown in the extract below:

Primary distributor roads shall be used in planning to form the primary network within an urban area and distribute traffic between central and nodal business districts.

Secondary distributor roads shall be used in planning to distribute the traffic between different neighborhood areas and land use zones of an urban or human settlement area and link to the primary access network.

Local distributor roads shall be used in planning to distribute the traffic within different neighborhood areas and land use zones and link to the secondary access network. There may be major and minor local distributor roads depending on the volume of traffic generated within the area, and on the types of vehicles allowed.

Access roads shall be used in planning to link individual plots, buildings and open spaces to a local distributor road. Access roads in housing areas and shopping centers are termed streets and are further classified into primary and secondary streets. They may be cul-de-sacs or loops.

Figure 3-1: Extract from Inner-Urban Transport and Traffic Management

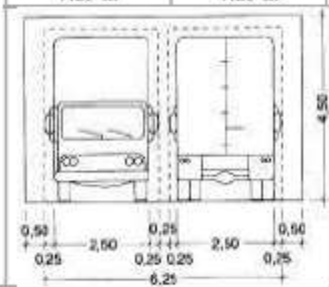
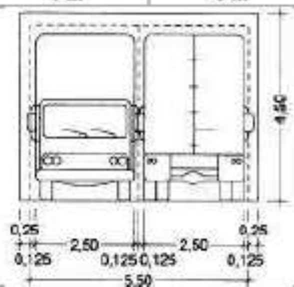
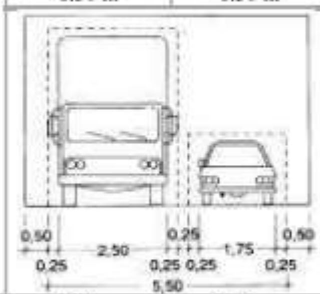
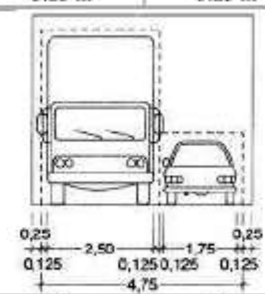
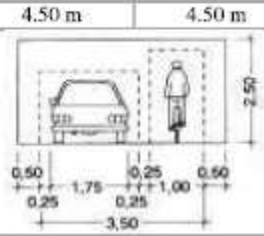
These four types of roads have very different geometric design and land requirements. The major factors affecting the parameters are:

- Carriageway
- Pedestrian pathway
- Cycle track

- Two-wheel vehicle drive
- Drainage
- On street parking
- Row of trees
- Hard Shoulder
- Verge, with or without planting reserve and marginal strip
- Central reserve and traffic island
- Service road

These items are then specified in terms of the minimum design requirements for the four different intra-urban roads as shown in Table 3-2 in the UPC below.

Table 3-2: Minimum Design Requirements for Intra-urban roads

Road characteristics	Intra-Urban Road categories			
	Primary Distributor Road	Secondary Distributor Road	Local distributor road	Access Road
Passage space at general speed				
Drive lane for all vehicles	4 m	4 m	3.25 m	3.25 m
Drive lane for vehicles excluding trucks and buses	3.25 m	3.25 m	2.50 m	2.50 m
Two drive lanes for all vehicles passing each other	7.25 m	7.25 m	6 m	6 m
				
Two drive lanes for all vehicles, with trucks passing motor vehicles	6.50 m	6.50 m	5.25 m	5.25 m
				
Two drive lanes for all cars and jeeps passing each other	5.75 m	5.75 m	4.50 m	4.50 m
Two drive lanes for motor vehicles (cars and jeeps) and bicycle			4.50 m	4.50 m
				
Additional design requirements				
Number of lanes	2-4	2	1-2	1-2
Pavement	Paved	Paved	Paved/Unpaved	Paved/Unpaved
Pedestrian traffic	Separated sidewalk	Separated sidewalk	Separated sidewalk	Yes
Two-wheel traffic	Separated cycle lane	Separated cycle lane		
On-street parking	Designated areas	Yes	Yes	Yes

Yet, for the City of Kigali, there has been further developments regarding the classification of the road network due to the proposed new BRT roads, upgraded national routes and the advancement of the city. This was captured in the 2013 Master Plan and was gazetted in the 03/12/2015 Special Official Gazette.

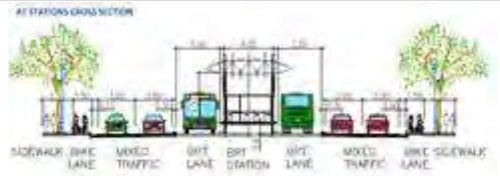
The gazette also stipulates road dimensions such as the minimum lane width, minimum carriageway width and road reserve. The Rwandan government has published a Special Official Gazette of 03/12/2015 to establish the law governing the road reserves in Rwanda. The road reserve includes embankments, edge areas, bollards, road lighting facilities, storm water, drainage facilities, grassy strips, central median strips, hard and soft shoulders, fills, walls, stairs, bridges, tunnels, technological and artistic works, road signs and other elements related to road. The information contained in this gazette and in the 2013 master plan is thus far more detailed than the UPC and as such will be used to classify the road network affected in this project.

This is shown in the following table (Source: Transportation Master Plan for the City of Kigali, Rwanda (2013)). In addition to the gazetted road classifications, there is a description of the proposed BRT cross-sections. This is shown in Table 3-3 and Table 3-4. Due to the significant improvements to the road classifications done for the City of Kigali and the proposed BRT routes etc., that gazetted road classification for Kigali was used to determine the road classification of the road network analysed.

Table 3-3: Kigali Road Types

TYPES	HIGH CAPACITY URBAN ROADS	MAJOR ARTERIAL ROADS			MINOR ARTERIAL ROADS			COLLECTOR ROADS	
	TRUNK ROADS		LINK ROADS	CBD THOROUGHFARE		BUS ROUTES	COMMERCIAL STREETS	RESIDENTIAL STREETS	RURAL ROAD
Description									
DESIGN SPEEDS & GEOMETRY									
Maximum Speed Limit	90 – 120 km/h	75 – 90km/h	75 – 90 km/h	40 – 75 km/h	40 – 75 km/h	30 – 60 km/h	30 – 40 km/h	30 – 40 km/h	75 – 90 km/h
GEOMETRY DESIGN TO INTERNATIONAL STANDARDS									
STREET DIMENSIONS									
Desirable Road Reserve Width	37 – 44 m	34 – 37 m	34 – 37 m	28 – 37 m	22 – 27 m	27 m	27 m	18 – 22 m	18 – 22 m
Typical number of lanes per direction	2 – 5 lanes	2 – 4 lanes	2 – 3 lanes	2 – 3 lanes	1 – 2 lanes	1 – 2 lanes	1 – 2 lanes	1 – 2 lanes	1 – 2 lanes
Minimum Carriageway Width	3.5 m per lane	3.5 m per lane	3.5 m per lane	3.5 m per lane	3.5 m per lane	3.5 m per lane	3.5 m per lane	3 m per lane	4 m per lane
Median Width	4 m	1 – 4 m	0.6 – 4 m	0.6 m	0.6 m	0.6 m	0.6 – 2 m	-	-
Hard Shoulder	3 m	-	-	-	-	-	-	-	-
Easement / Verge	2.5 – 6 m	2.5 – 6 m	-	-	-	-	-	-	2 – 3.5 m
Footway	-	-	1.5 m min	1.5 m min	1.5 m min	2 m min	2 m min	1.5 m min	-
Cycleway	-	-	1.5 m min	1.5 m min	1.5 m min	1.5 m min, or omit	1.5 m min, or omit	1.5 m min	-
Planting Strip	-	-	2 m	2 m	2 m	2 m	2 m	2 m	-
Vehicular Crossovers	No	No	No	No	No	Yes	Yes	Yes	Yes
Traffic Calming	No	No	No	No	No	Yes	Yes	Yes	-
On-street Car Parking	No	No	No	No	No	No	Short-term	Yes	-
PUBLIC TRANSPORT									
Bus Access	Not Recommended	Not Recommended	Yes	Yes	Yes	Yes	Maybe	Maybe	Yes
Bus Stations			-	Maybe	Maybe	Yes	Maybe	Maybe	Yes
OTHER INFORMATION									
Statutory Services	In Verge	In Verge	In Planting Strip	In Planting Strip	In Planting Strip	In Planting Strip	In Planting Strip	In Planting Strip	In Verge
Lighting Required	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Table 3-4: BRT Cross-sections

BRT INFRASTRUCTURE TYPE	AT STATION CROSS SECTIONS	DESIGN SPEEDS		INFRASTRUCTURE			
		MAXIMUM SPEED LIMIT	DESIRABLE ROAD RESERVE WIDTH	MINIMUM CARRIAGEWAY WIDTH	VEHICULAR CROSSOVERS	TRAFFIC CALMING	ON-STREET CAR PARKING
Type I Station		40 – 75 km/h	34 – 40 m	3.5 m per lane	No	No	No
Type II Station		40 – 75 km/h	34 – 40 m	3.5 m per lane	No	No	No
Type III Station		40 – 75 km/h	34 – 40 m	3.5 m per lane	No	No	No
Type IV Station		40 – 75 km/h	34 – 40 m	3.5 m per lane	No	No	No
Type V Station		40 – 75 km/h	34 – 40 m	3.5 m per lane	No	No	No
Section Between BRT Stations		40 – 75 km/h	34 – 40 m	3.5 m per lane	No	No	No

3.2. Capacity Criteria

The capacity criteria were assessed in accordance with the HCM 2010 (Highway Capacity Manual), SARTSM (South African Road Traffic Signs Manual) queue length warrants for priority and uncontrolled intersections, TRH 26 (Technical Recommendations for Highways) and the Transportation and Engineering Planning SI Edition 2005 manual. The capacity assessments were based on the following criteria:

- Level of Service (LOS)
- Queue Length
- Volume/Capacity (V/C) Ratios

It must be noted that the proposed improvements and assessments were done purely based on improving capacity and minimising delays in the most effective manner.

3.2.1. Level of Service

The results of the traffic analysis will be based on a Level of Service (LOS) measurement, which uses measured delay experienced by a vehicle at the intersection and compares it to a scale of values defining the LOS. The Level of Service (LOS) is based on the Table 3-5 below, which has been taken from the HCM 2010 manual.

The type of intersection affects the allowable delay in each LOS bracket resulting in different values for a traffic signal and non-signalized intersection. An acceptable LOS is on an intersection where a LOS D and above (A, B and C) is achieved. An unacceptable LOS is represented by an E and an F.

Table 3-5: Level of Service

Level of Service	Control Delay per vehicle in seconds	
	Traffic Signal	Traffic Circle
A	0 - 10sec	0 - 10sec
B	> 10 - 20 sec	> 10 - 15 sec
C	> 20 - 35 sec	> 15 - 25 sec
D	> 35 - 55 sec	> 25 - 35 sec
E	> 55 - 80 sec	> 35 - 50 sec
F	> 80 sec	> 50 sec

3.2.2. Queue Distance

The intersections are further assessed based on the individual queue lengths calculated for each movement. The queue lengths are then assessed based on the warrants and recommendations shown in Figure 3-2.

When uncontrolled or priority-controlled intersections' queue lengths exceed the warrants below, improvements such as geometric or traffic signals are required. The warrants are as per the TMH 16 TIA Vol2 and in accordance with SARTSM:

6.2.3. The SARTSM queue length warrant requires that ANY of the following three queue length warrants are met:

a) WARRANT 1: The average length of ANY individual queue equals or exceeds four (4) over any one hour of a normal day.

b) WARRANT 2: The SUM of the average lengths of all queues equals or exceeds six (6) over any one hour of a normal day.

c) WARRANT 3: The SUM of the average lengths of all queues equals or exceeds four (4) over each of any eight hours of a normal day (the hours do not have to be consecutive, but they may not overlap).

Note that a normal day can be any day of the week, including Saturdays or Sundays.

6.2.4. In terms of the requirements of this manual, Queue Length Warrant 1 may be reduced from 4 to 2 when the intersection does not comply with the capacity and level-of-service requirements of Chapter 3 of this manual. This reduction is, however, only allowed on Class 2 and 3 roads and where the intersection fully complies with the intersection spacing/separation requirements of this manual.

6.2.5 It is also a requirement of this manual that traffic signals should not be installed on any of the following classes of roads, even if the SARTSM warrants are met:

a) All rural classes of roads.

b) Urban Class 4b and 5b roads that serve single dwelling residential developments (except at intersections with higher classes of roads).

6.2.6. According to SARTSM, traffic signals may also not be installed on roads with a speed limit higher than 80 km/h.

Figure 3-2: Chapter 6.2.3-6.2.6 of the TMH 16 TIA Vol2

3.2.3. V/C Ratio

The Volume/Capacity (V/C) ratio is used in the evaluation of the various movements of the intersections. The capacity condition for an intersection is defined by a composite volume/capacity ratio for the critical lane groups for the intersection. The capacity for the entire intersection is not explicitly defined. The level of service is based on the average stopped delay per vehicle, for the traffic movements in the intersection. This is due to delay being accepted as the best measure of quality of service to users. Table 3-6 below indicates the evaluation criteria for the V/C movement ratios.

Table 3-6: V/C Ratio Criteria

Table 1. Intersection Status Criteria for Planning*

Critical v/c Ratio X_{cm}	Capacity Condition
$X_{cm} \leq 0.85$	Under capacity
$0.85 < X_{cm} \leq 0.95$	Near capacity
$0.95 < X_{cm} \leq 1.00$	At capacity
Xcm > 1.00	Over capacity

* Based on Table 9-14, 1994 HCM

The V/C ratios can be aligned to determine the LOS of each movement, as shown in Table 3-7. However, the V/C ratio is used in the calculation of the LOS delays experienced by each movement.

Table 3-7: ICU LOS Thresholds, Traffic Analysis Toolbox Volume VI

Table 13. ICU LOS Thresholds

LOS	Maximum ICU
A	55%
B	64%
C	73%
D	82%
E	91%
F	100%

The V/C calculations varies substantially based on the control of the intersection. This is detailed in the HCM. The V/C ratios are calculated in the SIDRA analysis and are displayed in the movement summaries of each intersection. These ratios are used to calculate the LOS.

3.3. SIDRA Intersection Software

The SIDRA INTERSECTION software is for use as an aid for design and evaluation of individual intersections and networks of intersections. It can be used to analyse signalised intersections (fixed-time / pre-timed and actuated), signalised and un-signalised (Figure 3-3 to 3-8) pedestrian crossings, roundabouts (un-signalised), roundabouts with metering signals, fully-signalised roundabouts, two-way stop sign and give-way / yield sign control, all-way stop sign control, single point interchanges (signalised), freeway diamond interchanges (signalised, roundabout, sign control), diverging diamond interchanges. It can also be used for uninterrupted traffic flow conditions and merge analysis.

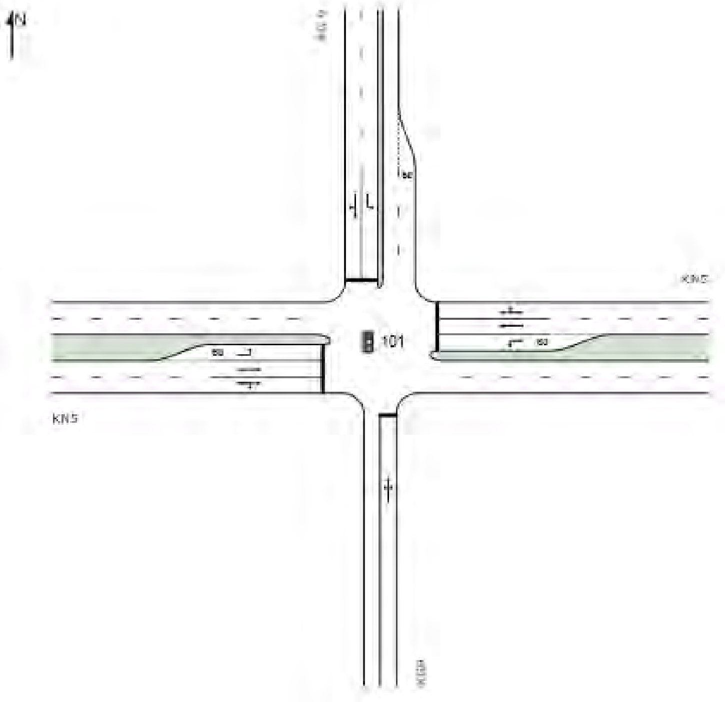


Figure 3-3: Typical SIDRA Intersection Layout

SIDRA INTERSECTION allows modelling of separate Movement Classes (Light Vehicles, Heavy Vehicles, Buses, Bicycles, Large Trucks, Light Rail / Trams and two User Classes) with different vehicle characteristics. These movements can be allocated to different lanes, lane segments and signal phases, for example for modelling bus priority lanes at signals.

Signal timing calculations for single intersections and network timings, including signal offsets for signal coordination are carried out. A unique method is used to determine signal timings for a number of intersections, operating under a single signal controller (common control groups) (Figure 3-4).

PHASE TIMING SUMMARY

Phase	A	B	C
Phase Change Time (sec)	0	35	83
Green Time (sec)	28	41	20
Phase Time (sec)	35	48	27
Phase Split	32%	44%	25%

See the Phase Information section in the Detailed Output report for more detailed information including input values of Yellow Time and All-Red Time, and information on any adjustments to Intergreen Time, Phase Time and Green Time values in cases of Pedestrian Actuation, Phase Actuation and Phase Frequency values (user-specified or implied) less than 100%.

OUTPUT PHASE SEQUENCE

Figure 3-4: SIDRA Signal Settings Dialog

SIDRA INTERSECTION is an advanced micro-analytical traffic evaluation tool that employs lane-by-lane and vehicle path (drive-cycle) models coupled with an iterative approximation method to provide estimates of capacity and performance statistics (delay, queue length, stop rate, etc). All input and output data and modelling are based on Origin-Destination movements. This improves handling of movements at intersections with diagonal legs and U turns.

The SIDRA NETWORK model determines the backward spread of congestion, as queues on downstream lanes block upstream lanes (queue spillback), and applies capacity constraint to oversaturated upstream lanes, thus limiting the flows entering downstream lanes. These two elements are highly interactive with opposing effects. A network-wide iterative process is used to find a solution that balances these opposing effects.

Unlike traditional network models that use aggregate models of "links" or "lane groups", SIDRA INTERSECTION uses a lane-based model to create second-by-second platoon arrival and departure patterns for signalised Sites (at-grade intersections, interchanges, pedestrian crossings) to calculate signal coordination effects as a function of signal offsets for internal approaches in network analysis.

The model takes into account midblock lane changes, that apply to signal platoon patterns. This is particularly important in evaluating closely spaced (paired) intersections with high demand flows, where vehicles have limited opportunities for lane changes between intersections. These lane-based modelling requirements are important in emulating the forward movements of platoons for estimating performance measures (delay, back of queue, stop rate) at an individual lane level.

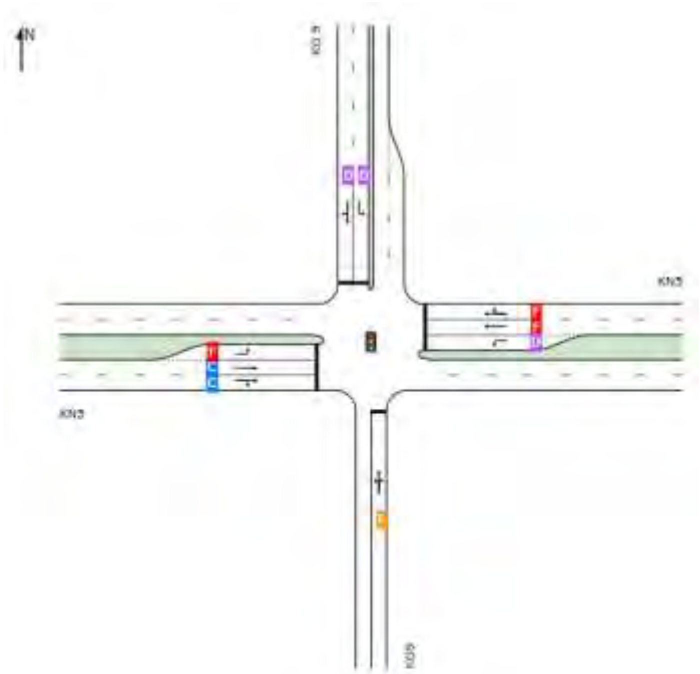


Figure 3-5: SIDRA Typical LOS Output

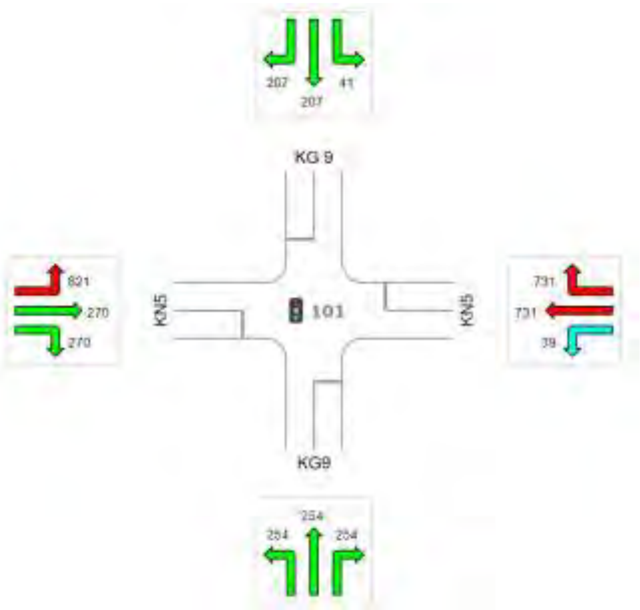


Figure 3-6: SIDRA Typical Queue Distance Output

SIDRA INTERSECTION provides various facilities for calibration of its traffic models for local conditions. The US HCM software setups (Customary and Metric units) of SIDRA INTERSECTION is based on the calibration of model parameters against the Highway Capacity Manual.

In the USA, SIDRA INTERSECTION is recognised by the US Highway Capacity Manual, TRB Roundabout Guide (NCHRP Report 672) and various local roundabout guides. SIDRA INTERSECTION is the most widely used software tool in the USA for roundabout capacity and performance analysis. In Australia and New Zealand, SIDRA INTERSECTION is endorsed by AUSTROADS and various local guidelines (the Association of Australian State, Territory and Federal Road and Transport Authorities).

Since its first release in 1984, the use of SIDRA INTERSECTION has grown steadily over the years to make it a best-selling software package. In February 2017, the latest versions of the software were in use by about 1930 organisations with about 8200 licences in 84 countries. The countries where SIDRA INTERSECTION was used most extensively were (with the approximate number of organisations shown) USA (650), Australia (440), Europe (190), New Zealand (70), South Africa (120), Canada (100), Malaysia & Singapore (110), Arabian Peninsula (90) and Latin America (60).

SIDRA was used in this project as the standalone assessment based tool, to analysis the capacity and level of service on the 31 intersections. The programme was used to calculate the V/C ratio, LOS and Queue lengths of each movement at each intersection for the status quo, improved solutions and forecasted traffic scenarios.

Table 3-8: Typical Analytical Movement Summary

Movement Performance - Vehicles												
Mov ID	Turn	Demand Flows Total veh/h	HV %	Deg. Satn v/c	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	Distance m	Prop. Queued	Effective Stop Rate	Aver. No. Cycles	Average Speed km/h
East: KN5												
5	T1	1173	10.8	0.242	0.6	LOS A	1.1	8.8	0.10	0.03	0.10	59.1
6	R2	50	16.0	0.242	10.8	LOS B	1.1	8.8	0.24	0.06	0.25	56.4
Approach		1223	11.1	0.242	1.0	NA	1.1	8.8	0.10	0.03	0.11	59.0
North: KK 3 Rd												
7	L2	51	11.8	9.993	16268.4	LOS F	1259.8	9789.2	1.00	18.55	50.97	0.2
9	R2	1047	12.9	9.993	16204.3	LOS F	1259.8	9789.2	1.00	18.55	50.97	0.2
Approach		1098	12.8	9.993	16207.3	LOS F	1259.8	9789.2	1.00	18.55	50.97	0.2
West: KN 5												
10	L2	648	11.7	0.962	31.6	LOS D	15.8	121.4	0.98	2.43	6.08	38.4
11	T1	692	9.5	0.158	1.1	LOS A	0.9	6.4	0.19	0.00	0.19	58.9
Approach		1340	10.6	0.962	15.9	NA	15.8	121.4	0.57	1.17	3.04	46.8
All Vehicles		3661	11.4	9.993	4867.0	NA	1259.8	9789.2	0.54	6.00	16.44	0.7

3.4. PTV Vissim Micro-Simulation Software

The Vissim micro-simulation software package visually simulates the various traffic, which allow the user to analyse traffic scenarios more accurately, but its specific application is in the field of road network capacity simulation.

The software developer PTV Vision describes Vissim as:

"Vissim is a microscopic, time step and behaviour based simulation model developed to model urban traffic and public transport operations... " (PTV, 2018)

Vissim has been used to simulate the existing and proposed usage of the network. The program uses stochastic models controlled by routing decisions to determine the flow of traffic throughout the network. Existing traffic counts were used on each critical intersection so that the model can accurately predict the real life scenario, which can then be used for further investigation to optimise routes and accommodate future developments, with increases in traffic.

3.4.1. Methodology

The data gathered through traffic counts and flow distributions were all used to build the micro simulation model. The accuracy of this information is vital as it determines the accuracy of the status quo model. A scaled aerial photograph is used to map out the network and illustrate the roads, determining the number of lanes and turning sequences.

Each intersection/interchange was modelled with trial and error using the Vissim model. This includes the flow rates of vehicles from each link in each direction (otherwise referred to as routing decisions), types of intersection (i.e. 4-way stops, yield, slip lanes and traffic lights) and traffic light timings.

Traffic inputs are used to generate vehicles on the outskirts of the model. As this traffic moves through the network it is divided up into the network on a percentage basis, which has been calculated from the routing decisions. The vehicles are each modelled individually and “observe” other vehicles on the road, they also see other vehicles approaching an intersection and react according to the type of intersection placed on its route.

Through simulating the intersections and traffic lights, as they are in reality, the model causes vehicles to queue and wait their turn, resulting in traffic congestion at intersections with limited capacity, thus simulating the real occurrence.

3.4.2. Vissim Modelling

The Vissim model has a number of parameters, that have to be set for the type of driving behaviour that the vehicles will use, while travelling through the network. Other inputs are:

- the ratio of cars, trucks, buses and taxis;
- speed limits, that the vehicles have to abide by;
- sight distance as to how far the driver looks ahead and behind his vehicle;
- acceleration and deceleration profiles;
- routing movements;
- traffic light configurations;
- what is done by a vehicle when it approaches an amber traffic light;
- right of way movements;
- driver behaviour profiles for each vehicle type;
- temporary lack of attention time;
- vehicle types and classes;
- lane position and orientation;
- traffic signal setting and phases;
- stop lines and yield lines; and
- data collection points (otherwise referred to as nodes).

Some of these elements are explained in more detail later. There are also additions to the network that have no effect on the actual simulation of the network and are only for cosmetic purposes, some of these include:

- Road markings (i.e. lane lines, turning arrows, stop lines, etc.).
- Colour and type of cars represented in the network.
- 3D elements (i.e. buildings, traffic signal lights, trees, grass, etc.).

A number of the most important inputs, are described in further detail below.

3.4.3. Speed and acceleration distribution

Each vehicle that is used in the network has a speed distribution allocated to it. This provides a ‘band’ over which the vehicles speed will oscillate to more accurately represent the human error that is present, while people are driving. For example, cars that are travelling in the 60 km/h zone will have a band of 30km/h (i.e. a minimum of 50km/h and a maximum 80km/h). While the model is running the speed of such a car, it will be anywhere within that band of 30km/h. A similar principle is used when a car is accelerating to its desired speed.

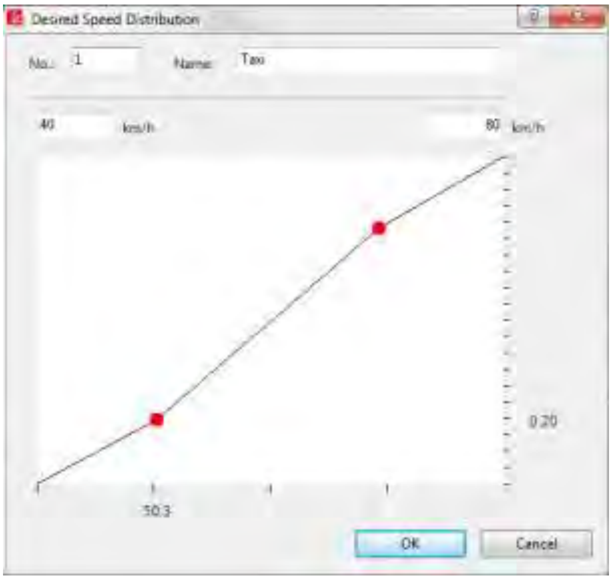


Figure 3-7: Speed distribution profile

3.4.4. Reduction in speed areas

While the vehicles travel through the network, they are allocated a desired speed, which they try to maintain without causing a collision. The vehicle however does not know to slow down when approaching a non-obstructed corner and thus would be cornering at around 60km/h.

For this reason, reduction speed bands are put in place so that the vehicle knows what at which speed it would be able to corner. These reduced speed areas are defined for all the vehicle classes, as cars are substantially faster around corners than busses and trucks.

The vehicle will register that there is a reduced speed area ahead and decelerate so that when it crosses the band it will be travelling at the desired speed. Once it has completed the predefined area, the vehicle will accelerate to its desired speed once again. The reduced speeds for the model are shown in Table 2-2 below:

Table 3-9: Reduction in Speeds

VEHICLE TYPE	CORNERS (KM/H)	CIRCLES (KM/H)
Cars	25 (max 30)	30 (max 35)
Taxis	25 (max 30)	30 (max 35)
Buses	15 (max 20)	20 (max 25)
Trucks	15 (max 20)	20 (max 25)

The reduced speed areas are calculated based on an equation, which defines the radius of the corner that the vehicle will have to take. An average radius is determined for the majority of the corners in the network and averaged, to obtain a relatively accurate broad value to be applied to all intersections.

$$V = 17.34R^{0.26057}$$

V = Velocity ($m.s^{-1}$)

R = Radius (m)

3.4.5. Routing

Routing is used as a way of distributing the cars proportionally through the network. The accuracy of this information is very important as it is the base on which the model functions.

The traffic counts done on each intersection are used here to distribute the cars evenly between the movements. The program uses a Poisson distribution to allocate the cars through each movement. This allows an even distribution of cars in each movement through the predefined period.

Below is a visual example of how a routing decision works. In the figure, the red line at the start of the yellow indicates the start of the routing decision. Once the car crosses the line it is told which direction it will be going in. It will continue in the direction allocated to it, until it crosses the green line at the end of the yellow band. The vehicle thus has to make the appropriate decisions within that area as to which lane it has to be in to make the prescribed movement.

Figure 3-8: Example of a routing decision

On sections of road where there are multiple roads entering a main stream of traffic, the routes are combined to allow the cars to make their lane selection prior to the intersection to help prevent vehicles from trying to change lanes at the last minute.

3.4.6. Traffic signals

Traffic signals are programmed in an add-on program called VISSIG and are all modelled as fixed time traffic lights for the status quo model.

Figure 2-6 indicates the program used to set the traffic light timings. Each signal group represents an alternate approach of a turning movement. Where the green bands overlap, it indicates movements are green simultaneously.

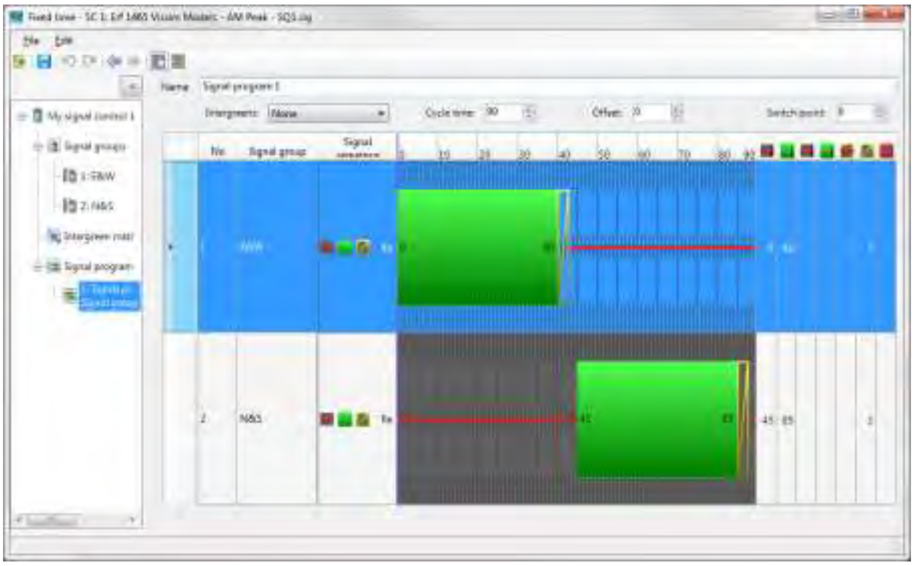


Figure 3-9: Visual example of typical traffic light offsets

3.4.7. Right of way movements

When modelling an intersection, the lanes that clash have to be given a movement that has priority over other movements. The diagram in Figure 2-7 shows how movements that clash are represented; the green lines are given right of way over the red movement. When a vehicle approaches such a movement, it will assess the vehicle on the opposing movements and determine how fast the vehicle is moving and whether it has enough time to cross without causing a collision.

A four-way stop is modelled using a sequence of priority movements put in place to allow each approach its desired movement. In order to obtain an equal distribution amongst the approaches, the movement to the right of each approach has right of way. This creates a circular effect on the intersection, which works quite well in simulating a realistic four-way stop.

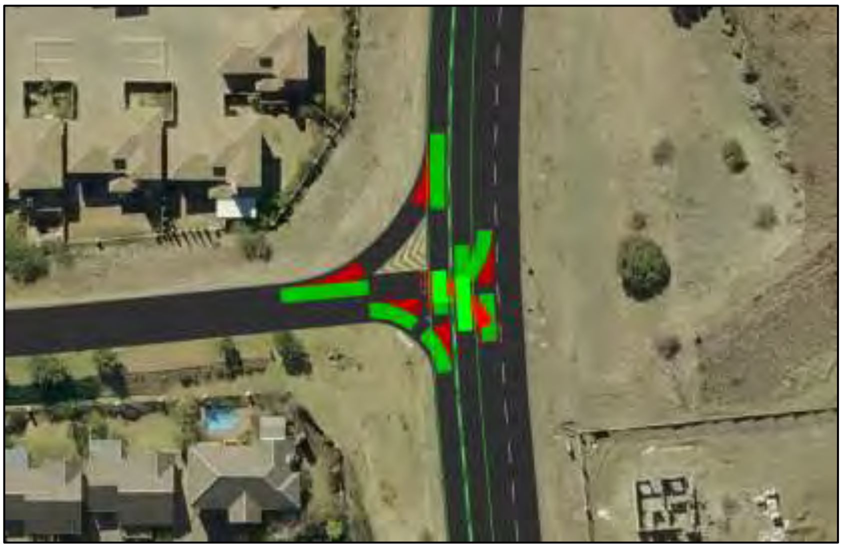


Figure 3-10: Right of way movements

3.5. Future Assessment

The traffic growth factors are determined through the master plan's traffic growth expectations for 2050 and then calculated annually. This is then extrapolated for a 5-year forecast. In addition, the traffic growth is measured against the parameters for developing cities. The growth is then applied to the existing corridors and the intersections are re-assessed using both SIDRA and Vissim as specified above.

4

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4. Traffic Growth

The car growth forecast for the City of Kigali, according to the BRT report, growths from 32% of mode split in 2017 to 52% in 2050 (with the BRT, 60% without BRT). This results in a 1.5% car growth per year for 30 years. Moreover, the expected traffic growth is estimated to grow at 2.20% per year until 2050. Hence, the traffic growth is estimated to grow at between 1.5% - 2.2% per annum.

Table 4-1: Estimated City Traffic Growth_ Transportation Model

Macro Model City Wide	2018	2050
Number of Peak Hour Moto	47162	111180
Number of Peak Hour Car	41235	97420
Sum of Car and Moto	**88397**	**208600**
Growth Rate		2,36
Rate per year		**2,20%**

However, in accordance with the masterplan it is estimated that the population will growth in Kigali by between 4-6% per year. The population growth rate is estimated for above average to fast growing cities. However, the traffic growth rate estimation over the next 30 years is estimated to be for a low growth rate city (Table 3-10). This can be attributed to the economic conditions, urbanisation of rural communities, designing of walkable/ green cities and improved and reliable public transport.

Table 4-2: Table 1.1 Typical Growth Rates, TRH 17

Table 1.1: Typical Traffic Growth Rates

Development Area	Growth rate
Low growth areas	0 - 3%
Average growth areas	3 - 4%
Above average growth areas	4 - 6%
Fast growing areas	6 - 8%
Exceptionally high growth areas	> 8%

Source: City Council of Pretoria (1998)

However, the purpose of this study is to assess the traffic implications over the next 5 years (Quick wins). As such, the implementation of a full BRT public transport network and the design of a green city as per the 2050 Masterplan may not be achieved to its full potential over the next 5 years. Yet, it must be noted that the BRT network is planned to be located on multiple roads along the corridors assessed in this study.

Therefore, the 5-year assessment estimated a more aggressive design factor than the 1.5-2.2% growth yet, due to the phasing of the masterplan and the economic factors, it used a lower growth rate than the population growth estimate.

The growth rate used was 3% compounded for a 5-year horizon was selected, which is an average growth estimate. This growth rate equates to 16% increase in traffic on the corridors or an applied factor of 1.16. Consequently, the 3% growth allows for a 7 to 10-year horizon year in relation to the estimated traffic growth rate as per the transportation macro-model, which over a 5-year period amounts to between 1.11 and 1.07 applied growth factors.

This results in the proposed 3% estimated growth rate being more conservative than the transportation model, yet will allow for adequate phasing time for the proposed future BRT network, other transport related networks and funding, to design and implement the proposed solutions. Moreover, in accordance to the Road Access Policy, November 1996, this growth rate of 3% per annum is considered an industry standard for urban zones.

5

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5. Intersection Analysis (SIDRA)

5.1. Road Classification

The roads along the corridors in question were classified in accordance with the road classification criteria of the CoK. The corridors are existing and have previously been classified. Therefore, the existing classification of the corridors were compared to the existing road conditions. However, none of the smaller side roads were classified. The routes that were classified contained the following major roads:

- Corridor 1: KG 11 Ave and KG 17 Ave
- Corridor 2: KN5
- Corridor 3: KN5, KG 7 and KN 8
- Corridor 4: KN3, KK8 and KK15
- Corridor 5: KN 7

Along the corridors the roads were assessed as per Table 5-1 below. It was observed that the road reserve differs substantially along the course of each road and as such, an average was calculated for each road. The majority of the roads' existing classifications were correct. However, the sections of the roads in Corridor 5 were observed to be functioning, due to infrastructure, as minor arterials rather that major arterials. Similarly, for corridor 4, roads KK8 and KK15 infrastructure, is that of a collector or minor arterial rather than that of a Major arterial. Yet the volume of traffic along these roads in high. Furthermore, it was noted that the future plans for the BRT, falls on several roads within the network. These are:

- KG 11
- KN 3
- KN 5
- KK 15
- KN 8
- KN 7

As a result, these roads will be upgraded in the future to a BRT road classification and associated infrastructure will be implemented. This will result in roads KG 11, KK 15, KN 8 and KN 7 all requiring major increases to the road reserve and major improvements to the existing road infrastructure. Nevertheless, this report is regarding the current improvements that can be implemented to reduce congestion along these routes and as such, the existing road classifications will be used to design the proposed infrastructure.

Table 5-1: Corridor Classification

CORRIDOR	ROADS	EXISTING CLASSIFICATION	ROAD RESERVE AVERAGE	MEDIAN AVERAGE	LANE NUMBER	SHOULDER	FOOT PATH	CYCLE WAY	PLANTING STRIP	TRAFFIC CALMING	ON STREET PARKING	LIGHTING	DESIGN CLASSIFICATION
Corridor 1	KG11	Minor/Major Arterial	**20**	-	2	Kerbed	Yes	Yes	Yes	Yes	No	Yes	Minor Arterial
	KG17	Collector	**20**	-	2	Kerbed	Yes	Yes	Yes	No	No	Yes	Collector
Corridor 2	KN5	Major Arterial	**30**	**7**	4	Kerbed	Yes	Combined	No	No	No	Yes	Major Arterial
Corridor 3 + Link	KN5	Major Arterial	**36**	**6**	4	Kerbed	Yes	Combined	No	No	No	Yes	Major Arterial
	KG501	Major Arterial	**33**	**5**	4	Kerbed	Yes	Yes	Yes	No	No	Yes	Major Arterial
	KG7	Major Arterial	**29**	**6**	4	Kerbed	Yes	Combined	Yes	No	No	Yes	Major Arterial
	KN8	Major Arterial	**24**	-	2	Kerbed	Yes	No	No	No	No	Yes	Minor/ Major Arterial
Corridor 4A-B	KN3	Major Arterial	**28**	**2**	4	Kerbed	Yes	Combined	Occasionally	No	No	Yes	Major Arterial
	KK15	Major Arterial	**20**	-	2	Surfaced Shoulder/ Kerbed	Yes	No	No	No	No	Yes	Minor Arterial/ Collector
	KK8	Major Arterial	**16**	-	2	Surfaced Shoulder	Shoulder	Combined on Shoulder	No	Yes	No	Yes	Collector
Corridor 5	KN8	Major Arterial	**24**	-	2	Kerbed	Yes	No	No	No	No	Yes	Minor/ Major Arterial
	KN7	Major Arterial	**17**	-	2	Kerbed	Yes	No	No	No	No	Yes	Minor Arterial

5.2. Status Quo Analysis

The SIDRA analysis was done for the status quo to determine the current functionality of the intersections as standalone intersections. The analysis was done to determine the existing intersection capacity without outside influence from the adjacent intersections. This purpose of the standalone assessment is to optimise the intersections based on capacity, and to identify intersections that are failing due to individual capacity constraints and not due to the failures of the adjacent intersections. The analysis was done to determine the existing movements' V/C ratios, LOS and queue lengths. The intersections were assessed using the status quo road infrastructure and traffic counts.

The vehicle classifications were segregated into three classes, namely: Light vehicles, Heavy Vehicles and Motorcycles as shown below in Figure 5-1 for the analysis in SIDRA.

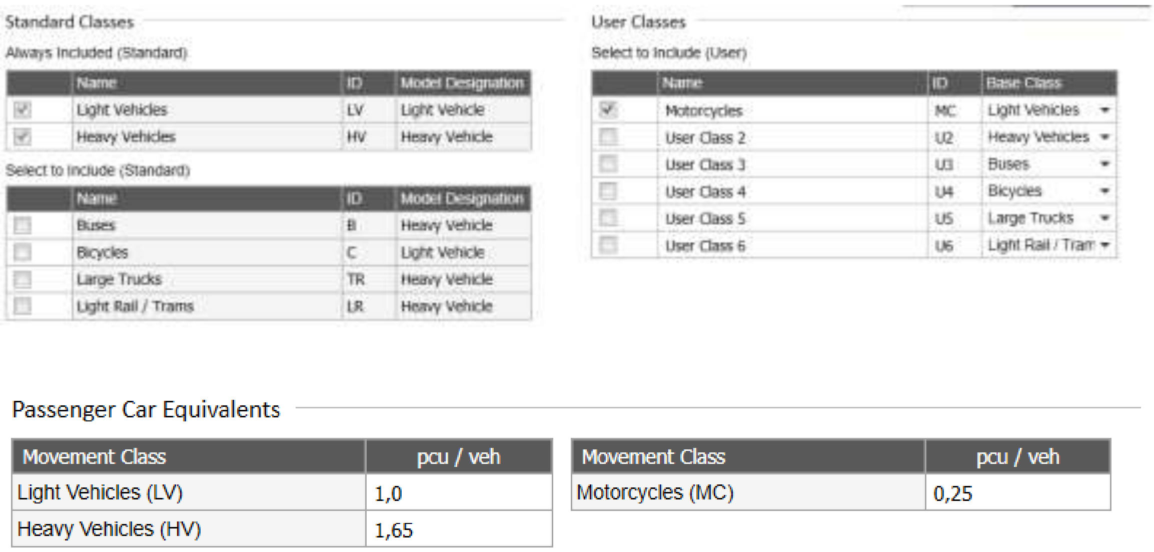


Figure 5-1: Vehicle Classification in SIDRA

The results of the intersection analysis for the status quo are shown in Table 5-2. Of the 31 intersections assessed, eight are roundabouts, two are signals and 21 are priority-controlled intersections.

Only six (AM) and seven (PM) of the 31 intersections assessed are functioning with an acceptable LOS, V/C ratio and queue lengths. Of the 25 failing intersections, intersections 13, 24 and 28 function acceptably in terms of the V/C ratio and LOS assessment in the AM peak and PM peaks.

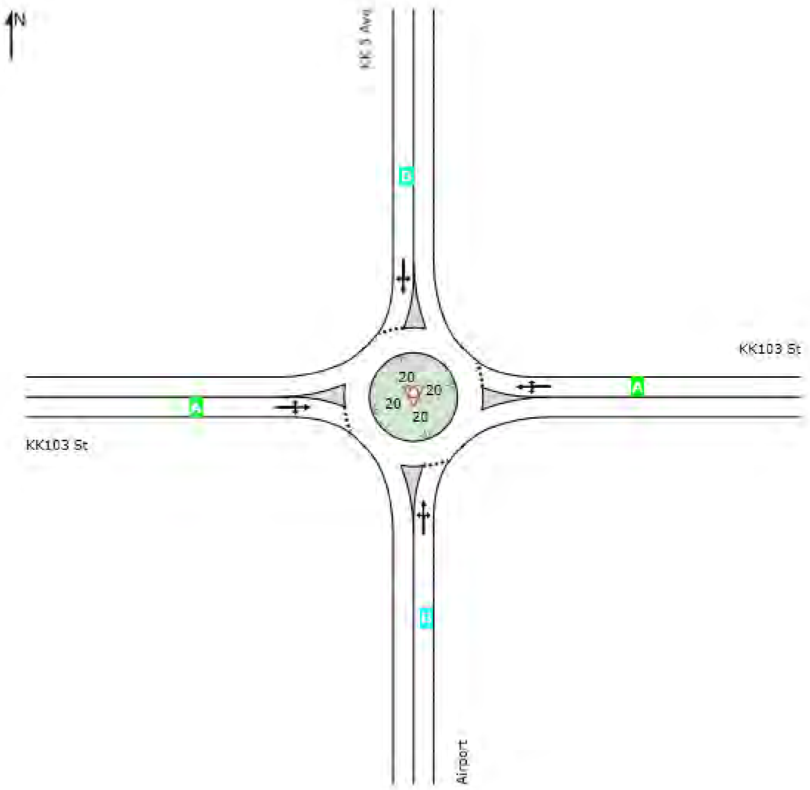
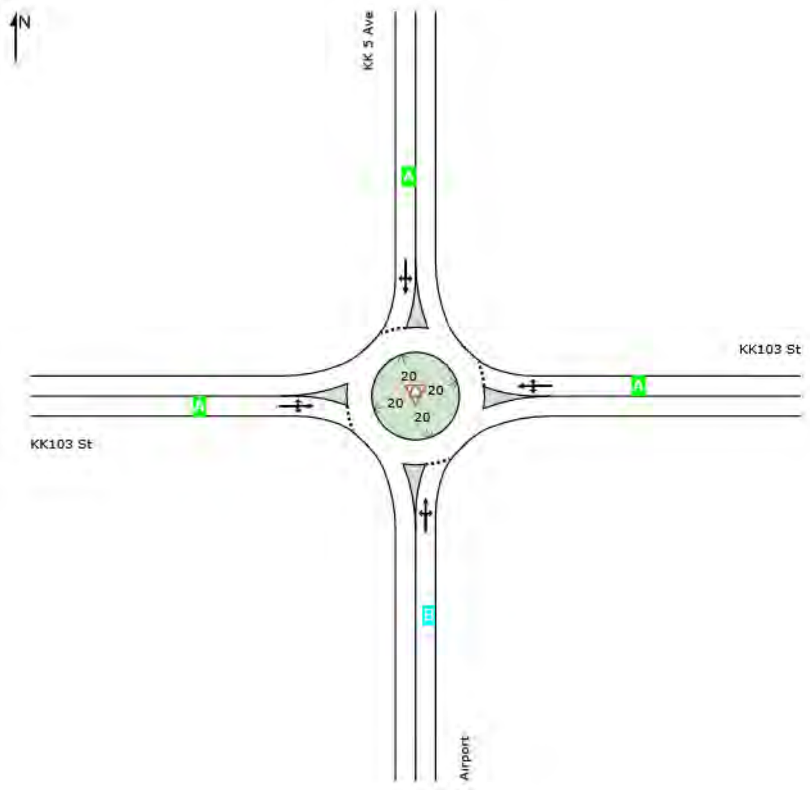
However, these intersections are functioning unacceptably in terms of the queue length calculations. Of the 31 intersections assessed, 22 are currently failing in terms of the LOS assessments in the AM peak, while 23 are failing in the PM peak. These values are shown in detail in the movement summaries, which can be found in **Annexure D.**

Table 5-2: SIDRA AM Peak Status Quo Results

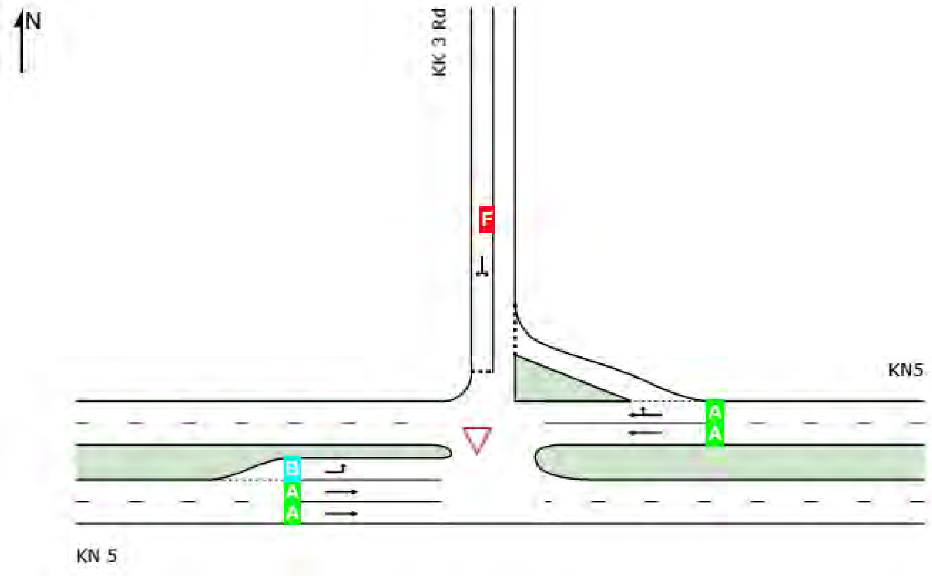
AM PEAK					
INTERSECTION	DESCRIPTION	STATUS QUO			STATUS
		TYPE	MAX QUEUE (VEHICLES)	LOS	ACCEPTABLE/ FAIL
1	KK103 St/ KK5 Ave	Circle	3,1	A	Acceptable
2	KN5/KK3	Priority	1259,8	F (North)	Fail
3	KN5/ KG109	Signal	310,4	F	Fail
4	KN3/KN5	Priority	1254,1	F (South)	Fail
5	KN5/ KG1	Circle	1055,2	F	Fail
6	KG9/ KN5	Signal	115,3	F	Fail
7	KN5/KG501	Circle	573,3	F	Fail
8	ICC/KG644	Circle	0,4	A	Acceptable
9	ICC	Circle	N/A	No conflict	Acceptable
10	KG7 /KG501	Circle	595,6	F	Fail
11	KG694/ KG7	Priority	1123,9	F (North and South)	Fail
12	KG7/KG550	Priority	383,6	F (North and South)	Fail
13	KN8/ KG3	Circle	77,4	D (North E)	Fail
14	KN8/ KG704	Priority	21	D (East)	Fail on Queue
15	KN8/ KK14	Priority	1550,5	F (North and South)	Fail
16.1	KN7/ KN8	Priority	1436,3	F (North and East)	Fail
16.2	KN7 Interchange	Priority	508,1	F (North)	Fail
17	KN7/ Kigali Gatuna Rd	Stop	67,5	F (All)	Fail
18	KG11/ KG113	Stop	919,5	F (All)	Fail
19	KG11 / KG13	Priority	213,6	F (South)	Fail
20	KG11/ KG17	Priority	10,9	F (North and South)	Fail
21	KG2/ KG11	Priority	904,2	F (North and South)	Fail
22	KG17/ KG16	Priority	241,1	F (North)	Fail
23	KN3/ KG 1	Circle	250,4	F (South)	Fail
24	KK19/ KK15	Priority	4	D (East)	Acceptable
25	KK35/ KK15	Priority	258,3	F (East and West)	Fail
26	KK21/ KK15	Priority	2,4	B (East)	Acceptable
27	KK8/ KK15	Priority	824,2	F (South and West)	Fail
28	KK34/ KK8	Priority	6,3	B (East)	Fail
29	KN3/ KK8	Priority	1090,3	F (North turning and East)	Fail
30	KN3/ KK500	Priority	204	F (South)	Fail
Conclusion	**31 Intersections**	**8 Circles**			**25 Fail**
		2 Signals			**6 Acceptable**
		21 Priority			

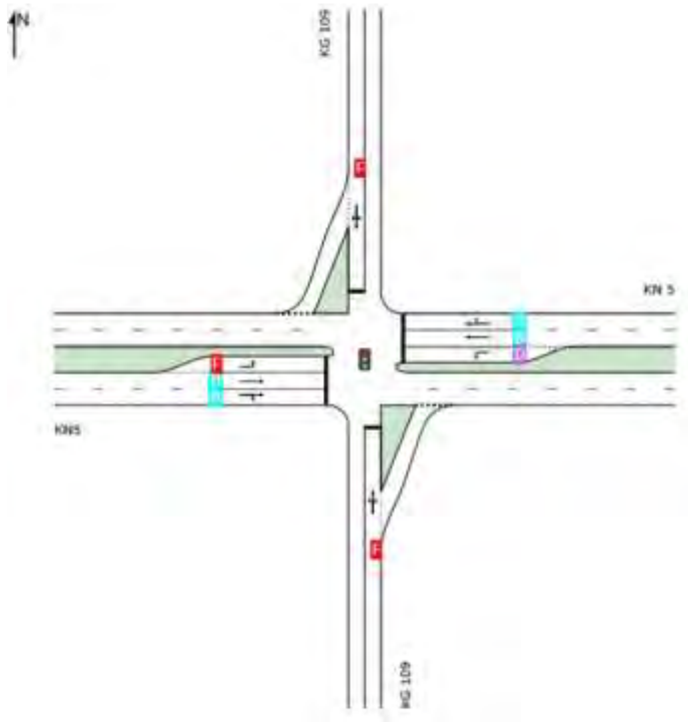
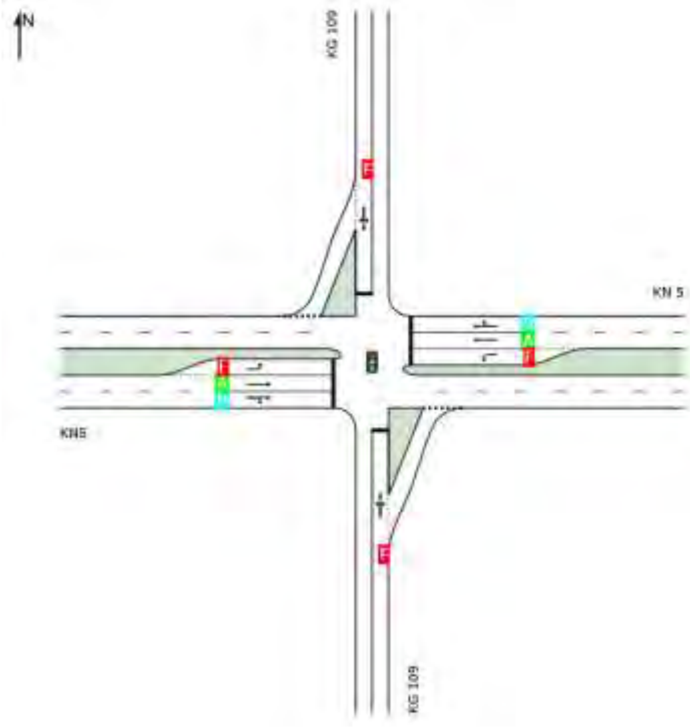
Table 5-3: SIDRA PM Peak Status Quo Results

PM PEAK					
INTERSECTION	DESCRIPTION	STATUS QUO			STATUS
		TYPE	MAX QUE (VEHICLES)	LOS	ACCEPTABLE/ FAIL
1	KK103 St/ KK5 Ave	Circle	2,4	A	Acceptable
2	KN5/KK3	Priority	500	F (North)	Fail
3	KN5/ KG109	Signal	241	F	Fail
4	KN3/KN5	Priority	2089	F (South and East)	Fail
5	KN5/ KG1	Circle	392	F	Fail
6	KG9/ KN5	Signal	347,6	F	Fail
7	KN5/KG501	Circle	281	F	Fail
8	ICC/KG644	Circle	0,5	A	Acceptable
9	ICC	Circle	N/A	No conflict	Acceptable
10	KG7 /KG501	Circle	8,3	A	Acceptable
11	KG694/ KG7	Priority	732	F (North and South)	Fail
12	KG7/KG550	Priority	445	F (North and South)	Fail
13	KN8/ KG3	Circle	20,5	B	Acceptable
14	KN8/ KG704	Priority	8,3	D (West)	Fail on Queue
15	KN8/ KK14	Priority	1652	F (North and South)	Fail
16.1	KN7/ KN8	Priority	1595	F (North and East)	Fail
16.2	KN7 Interchange	Priority	1075	F (North)	Fail
17	KN7/ Kigali Gatuna Rd	Stop	485	F (All)	Fail
18	KG11/ KG113	Stop	864,8	F (All)	Fail
19	KG11 / KG13	Priority	134	F (South)	Fail
20	KG11/ KG17	Priority	57,9	F (North and South)	Fail
21	KG2/ KG11	Priority	708	F (North and South)	Fail
22	KG17/ KG16	Priority	96,9	F (North)	Fail
23	KN3/ KG1	Circle	57,9	F on South East/ Overall C	Fail
24	KK19/ KK15	Priority	11,3	F (East)	Fail
25	KK35/ KK15	Priority	330	F (East and West)	Fail
26	KK21/ KK15	Priority	1,8	B (East)	Acceptable
27	KK8/ KK15	Priority	874	F (South and West)	Fail
28	KK34/ KK8	Priority	3,7	B (East)	Acceptable
29	KN3/ KK8	Priority	512	F (North turning and East)	Fail
30	KN3/ KK500	Priority	241	F (South)	Fail
Conclusion	**31 Intersections**	**8 Circles**			**24 Fail**
		2 Signals			**7 Acceptable**
		21 Priority			

AM Peak: Intersection 1	PM Peak: Intersection 1
	

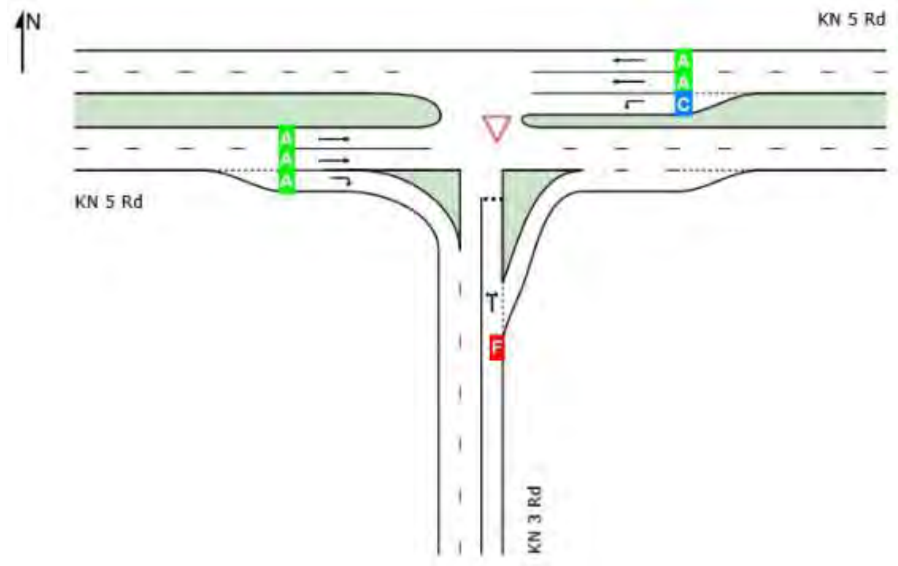
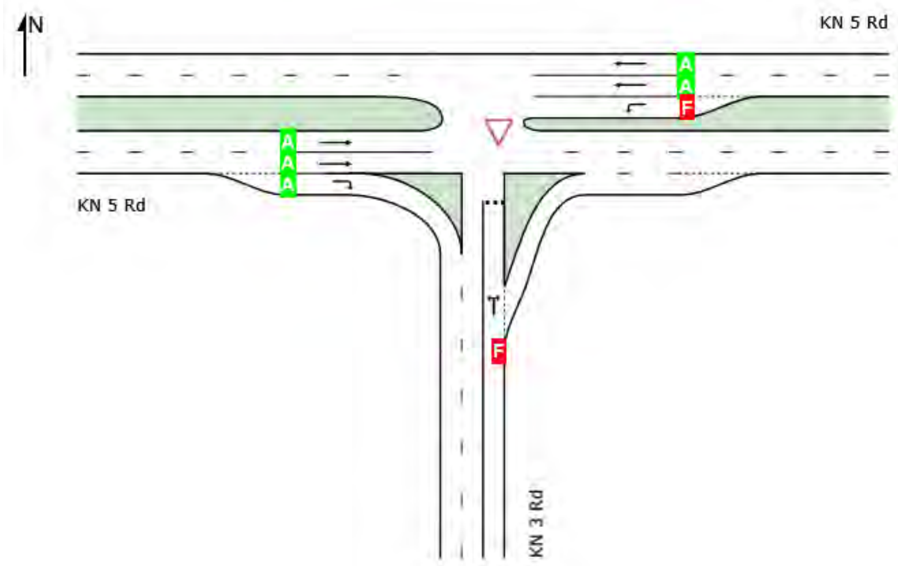
Notes:
The AM and PM peak functions acceptably regarding the LOS, queue lengths and V/C ratios.

AM Peak: Intersection 2	PM Peak: Intersection 2
	
Notes:	
The AM and PM peak fails on the northern approach. Moreover, the western approach left turn queue length was calculated at 15.8 vehicles during the AM peak.	

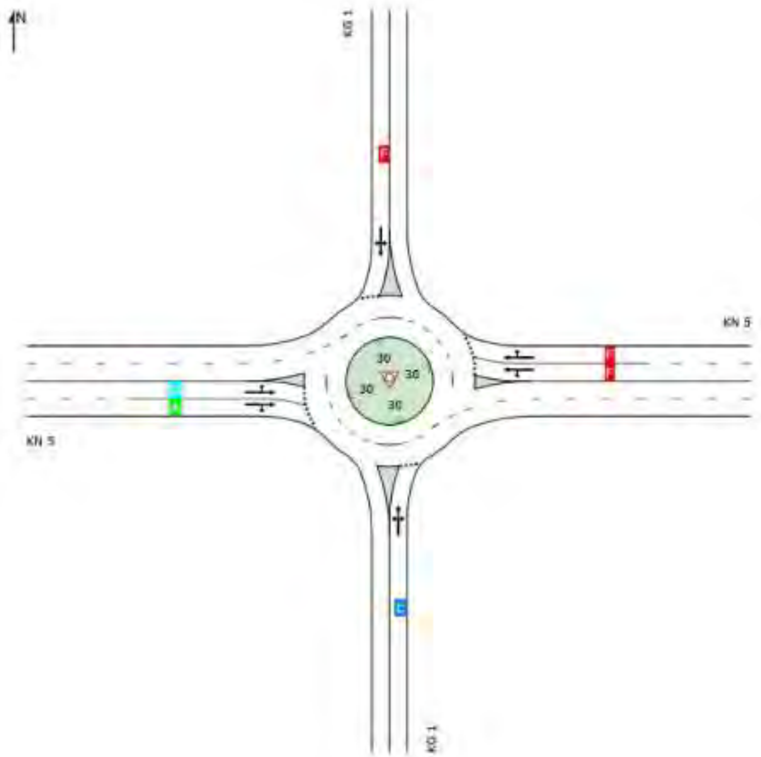
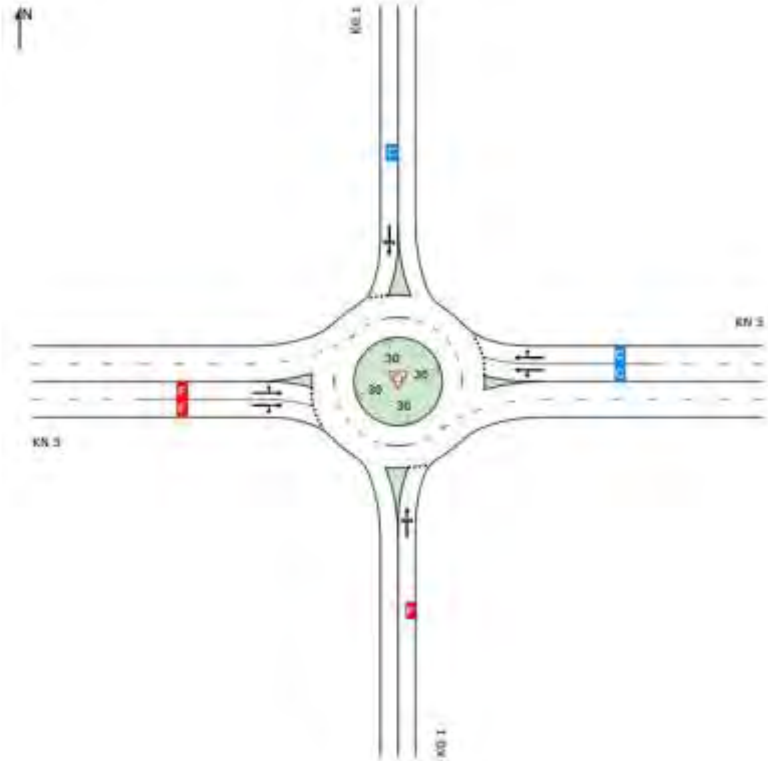
AM Peak: Intersection 3	PM Peak: Intersection 3
	

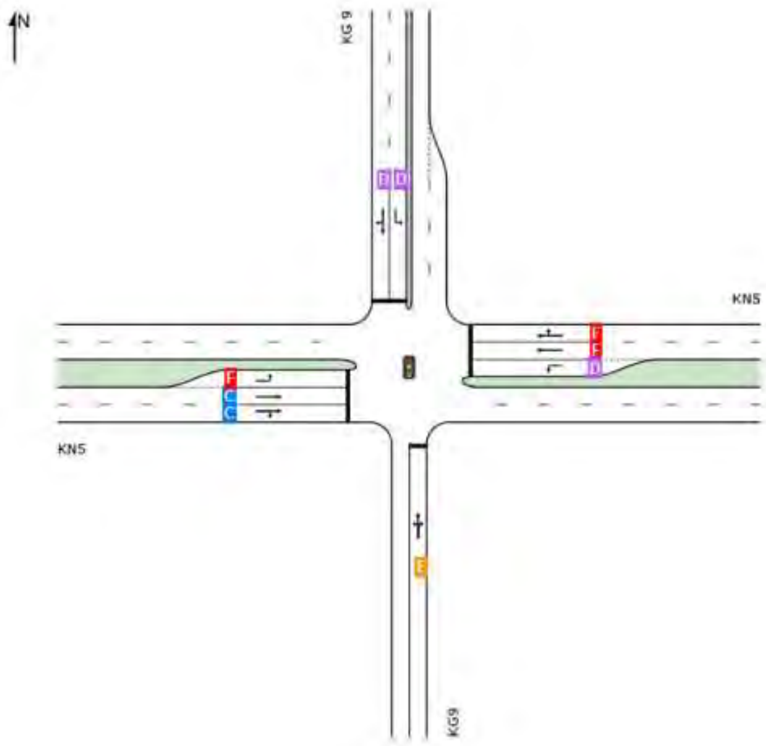
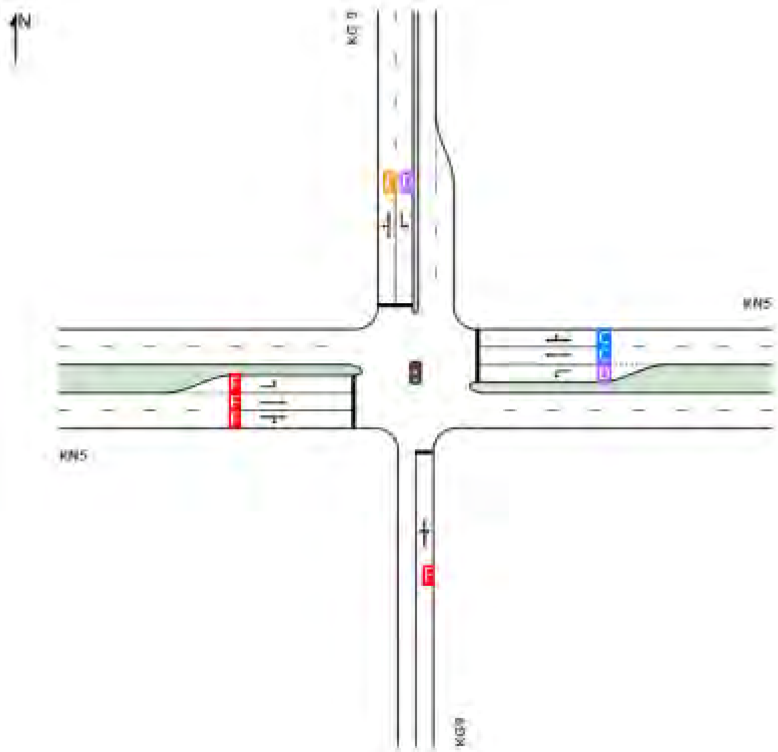
Notes:

During the AM peak, the signal lights were flashing. This occurrence was observed on multiple days. The AM and PM peak fails with an unacceptable LOS F. Movements from the western, northern, eastern and southern approaches are failing.

AM Peak: Intersection 4	PM Peak: Intersection 4
	

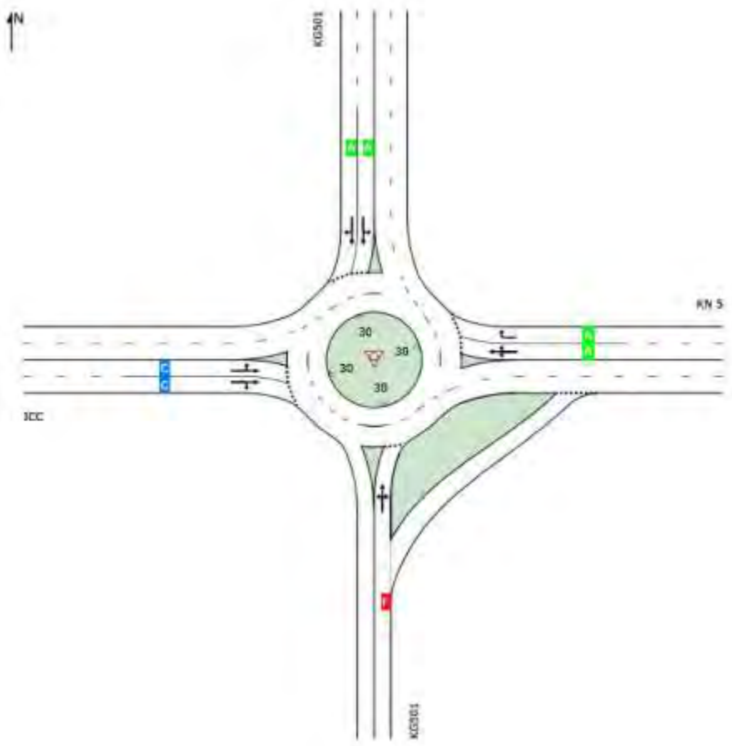
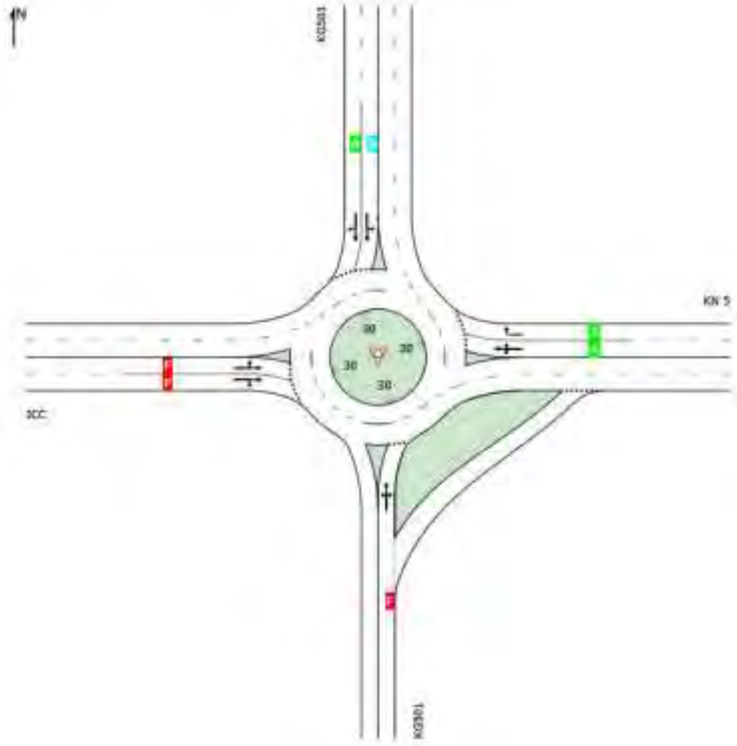
Notes:
The AM peak fails due to the unacceptable LOS F for the southern approach. Additionally, during the AM peak, the eastern approach left turn fails with an unacceptable queue length of 8 vehicles. The PM peak fails with both the southern and eastern left turn approaches functioning with an unacceptable LOS F.

<table>
<tr><th>AM Peak: Intersection 5</th><th>PM Peak: Intersection 5</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th colspan="2">Notes:</th></tr>
<tr><td colspan="2">The AM peak fails with unacceptable delays on the northern and eastern approaches while the PM peak fails with unacceptable delays on the western and southern approaches.</td></tr>
</table>

AM Peak: Intersection 6	PM Peak: Intersection 6
	

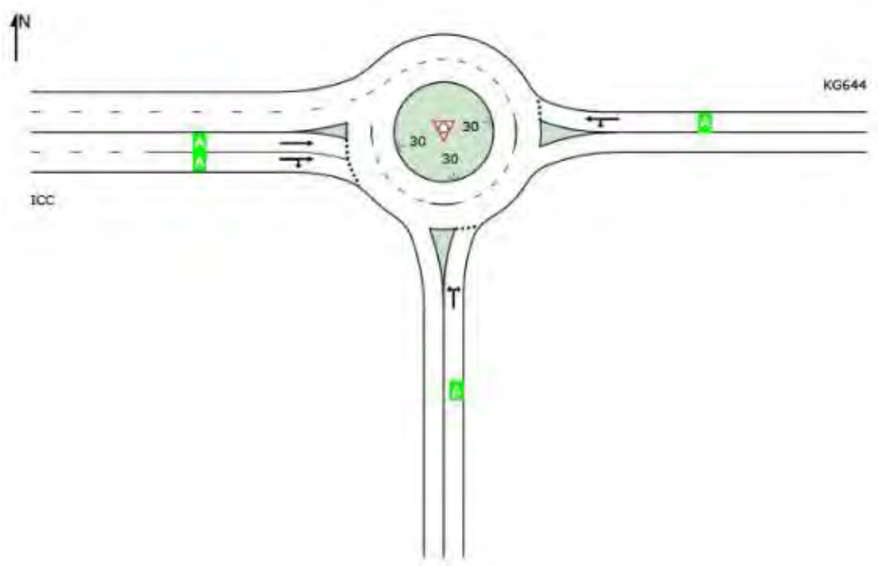
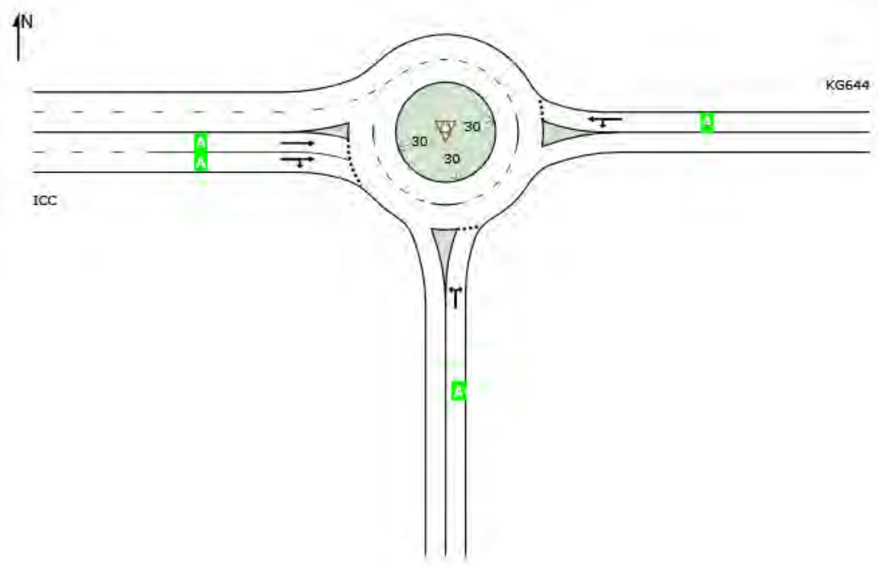
Notes:

The AM peak fails with an overall unacceptable LOS F. The western approach left turn movement, eastern approach through movements and the southern approach all fail during the AM peak. During the PM peak, the western and southern approaches fail with an unacceptable LOS F. Moreover, the northern approach through and right turn movement fails with an unacceptable LOS E. The overall intersection LOS for both the AM and PM peak is an F with a PM V/C ratio of 2.4.

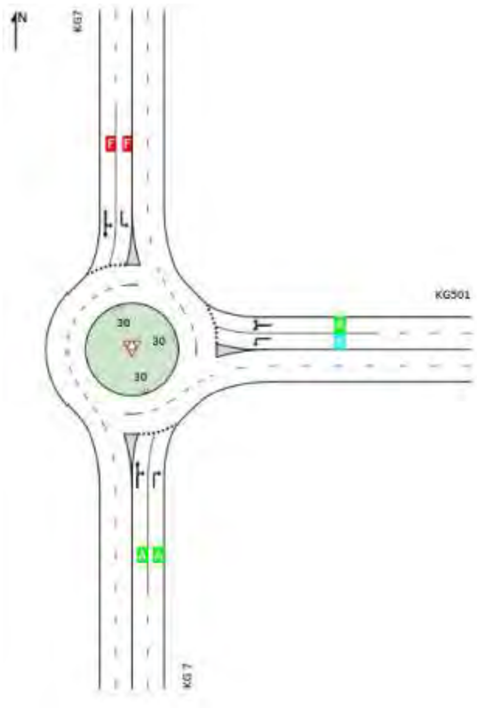
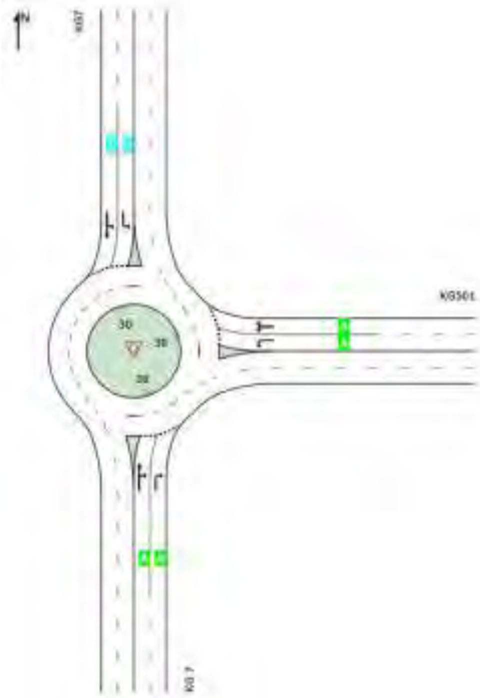
AM Peak: Intersection 7	PM Peak: Intersection 7
	

Notes:

The AM fails with an unacceptable LOS F on the southern approach. The PM fails with LOS F on the southern and western approaches. The western approach is a very low volume movement, as this road is closed and only used by ICC traffic.

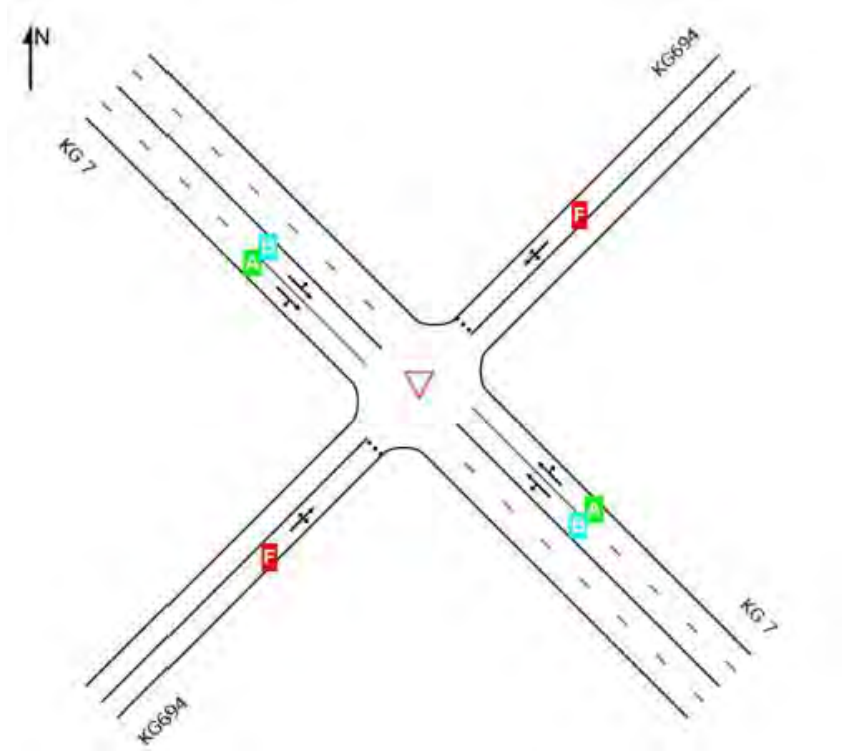
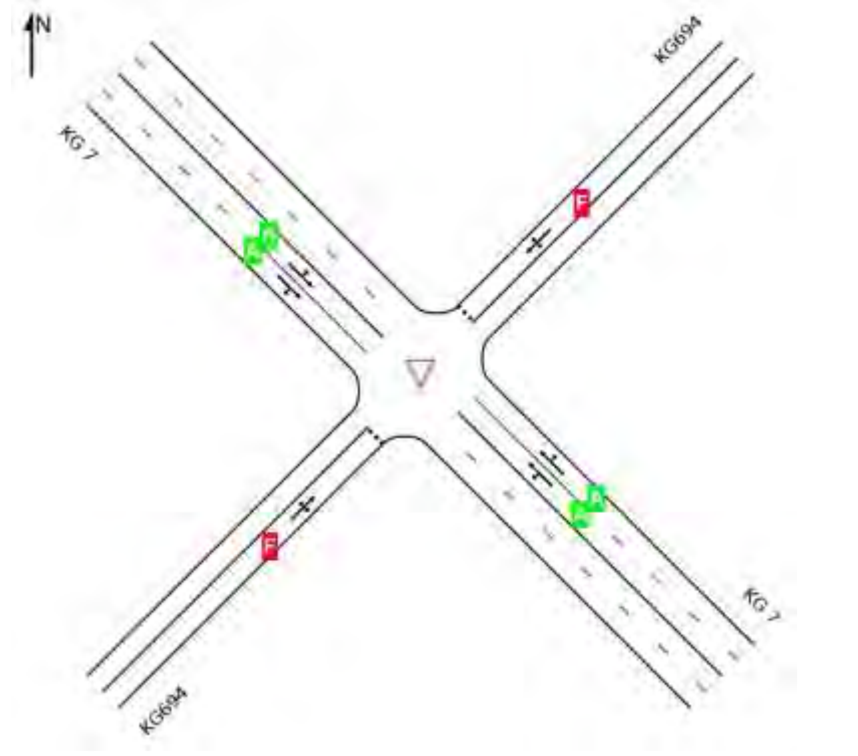
AM Peak: Intersection 8	PM Peak: Intersection 8
	

Notes:
The AM and PM peak functions acceptably.

AM Peak: Intersection 10	PM Peak: Intersection 10
	

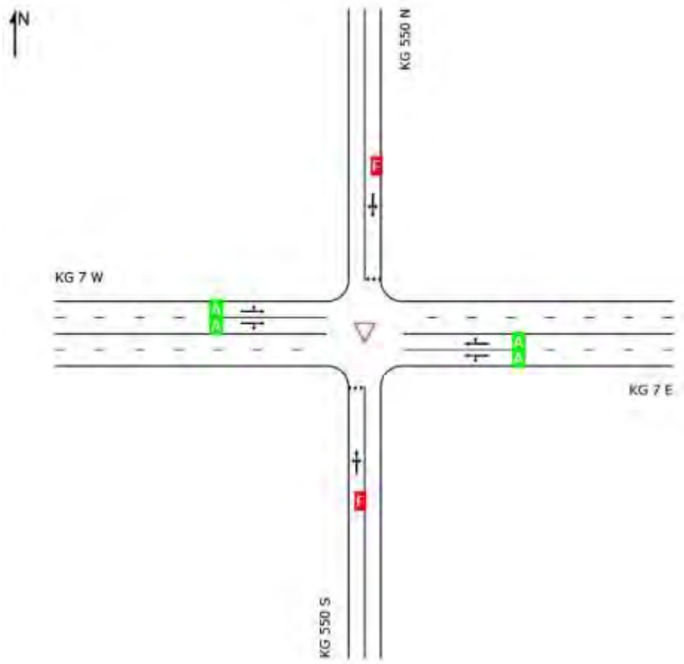
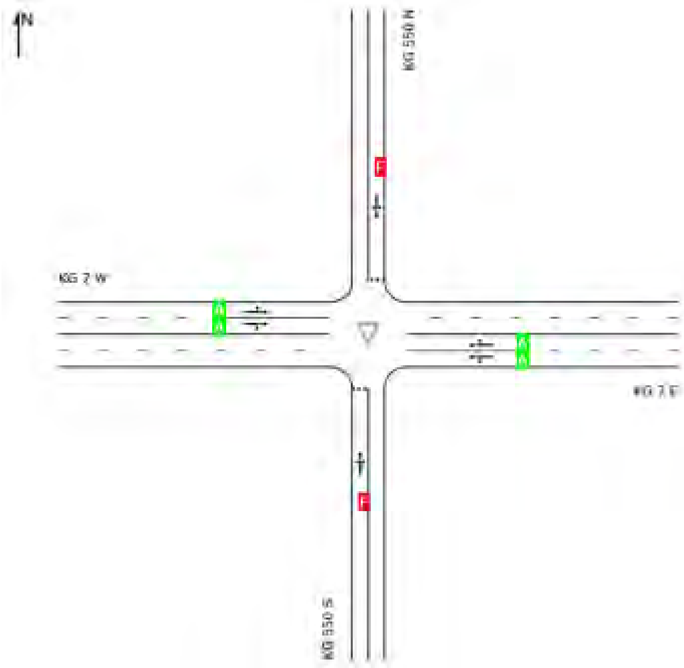
Notes:

The AM peak fails with an unacceptable LOS F on the northern approach. This is due to the major movements being a left turn from the eastern approach and a left turn from the northern approach conflicting with each other. The AM peak overall LOS is an unacceptable LOS F with a V/C ratio of 2.9. This intersection functions acceptably in the PM peak.

AM Peak: Intersection 11	PM Peak: Intersection 11
	

Notes:

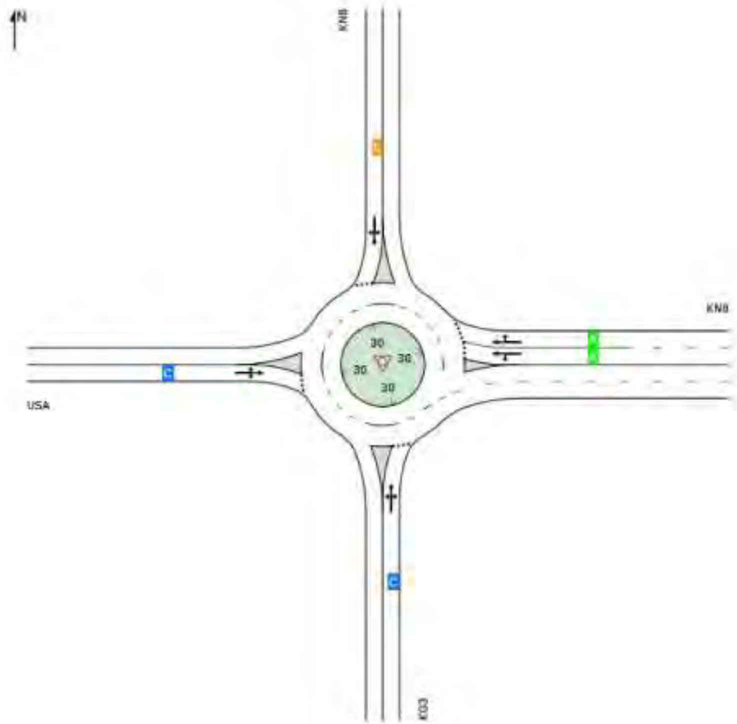
The AM and PM peak fails with unacceptable delays and queue lengths for the south-western and north-eastern approaches. The overall V/C ratios are 50.8 and 23.2 in the AM and PM peak respectively.

AM Peak: Intersection 12	PM Peak: Intersection 12
	

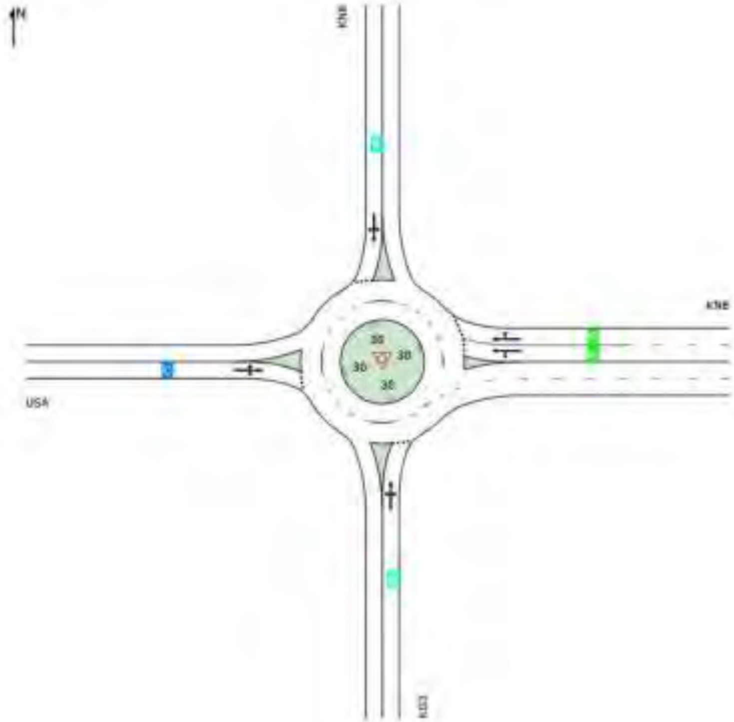
Notes:

The AM and PM peak fails with unacceptable delays and queue lengths for the southern and northern approaches. Moreover, the V/C ratios for the AM and PM peaks are 9 and 14 respectively.

AM Peak: Intersection 13

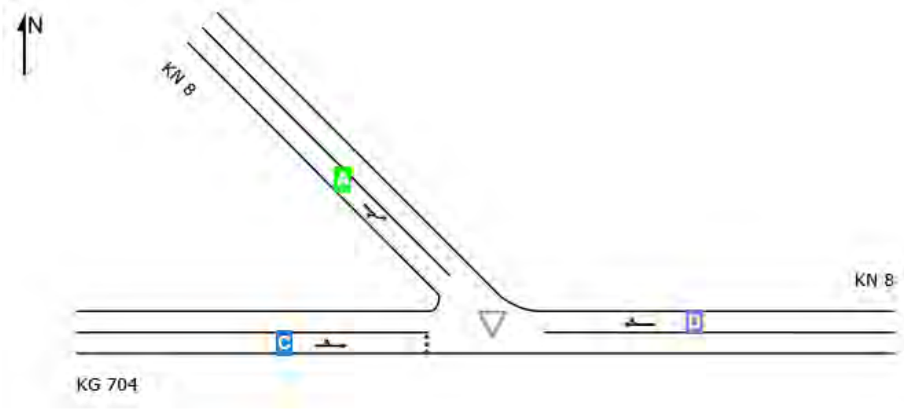
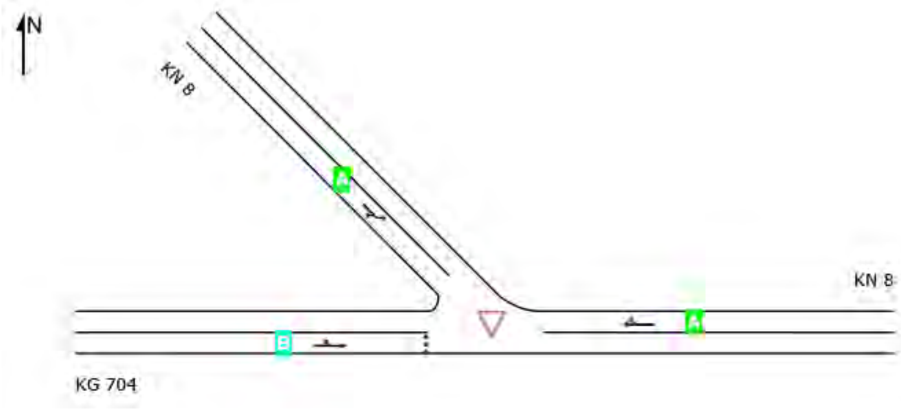


PM Peak: Intersection 13



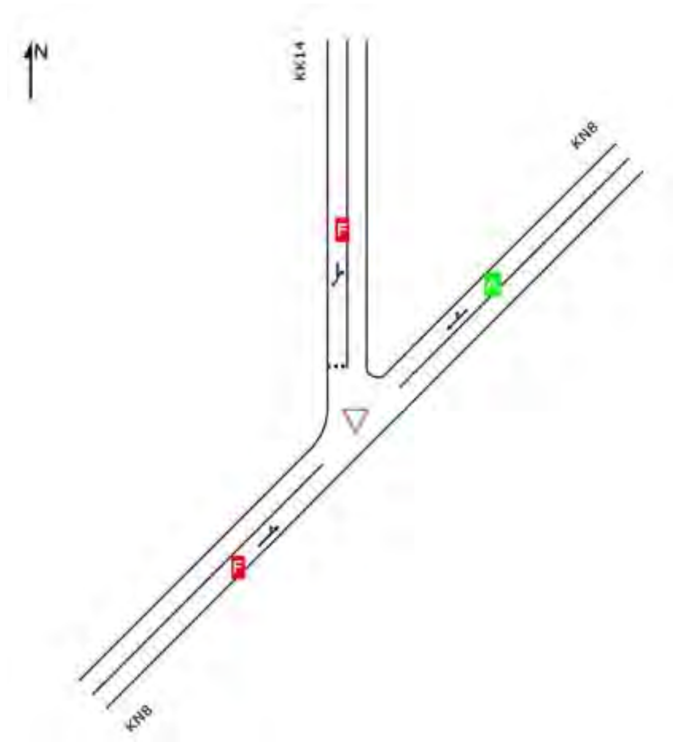
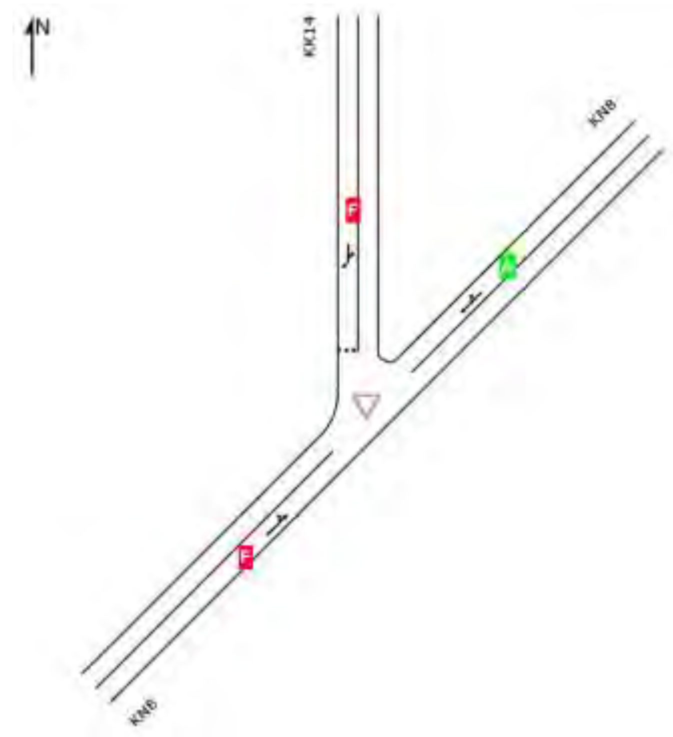
Notes:

The AM peak Fails with an unacceptable LOS E from the northern approach. The PM peak is acceptable.

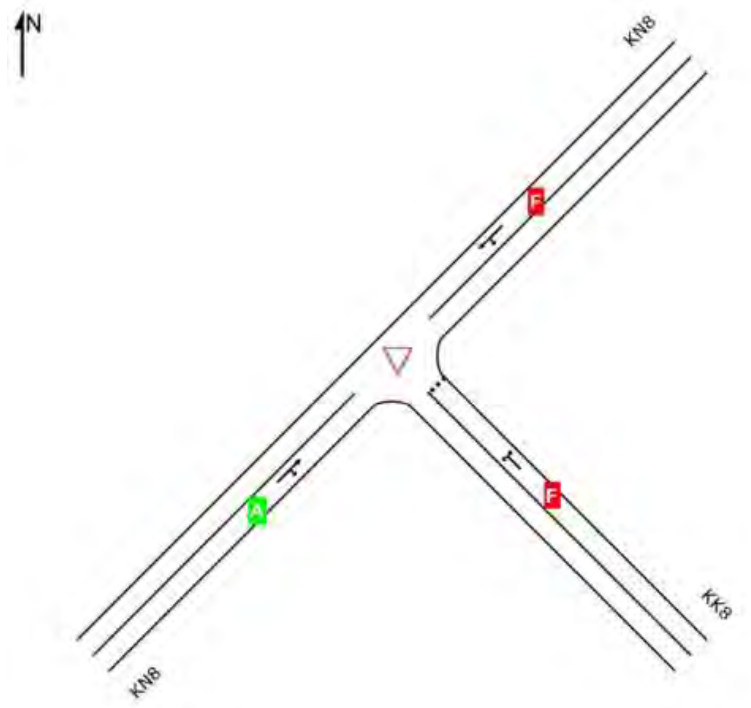
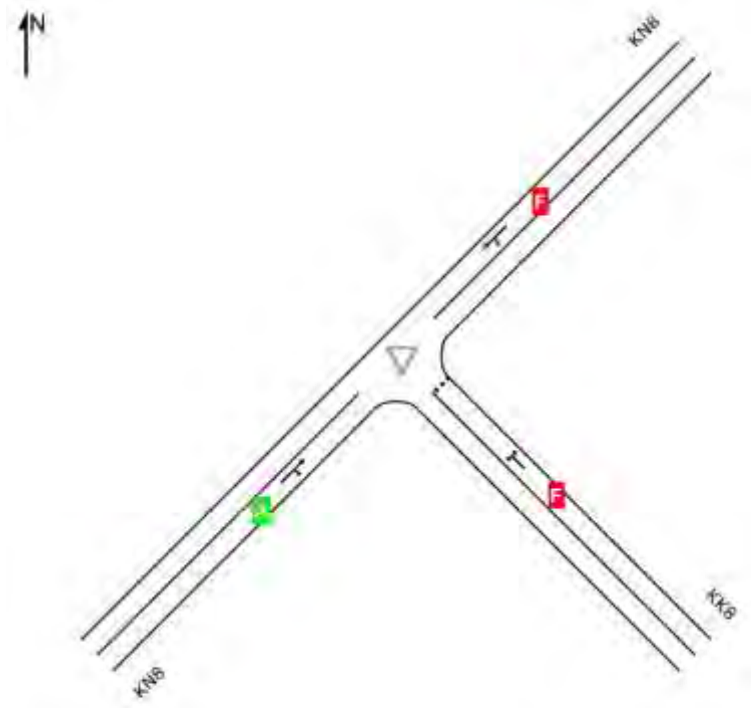
AM Peak: Intersection 14	PM Peak: Intersection 14
	

Notes:

The intersection functions with acceptable delays during both the AM and PM peak. However, the queue length on the eastern approach during the AM peak is 21.1 vehicles. Similarly, during the PM peak the queue lengths on the north-western approach is 8.3 vehicles.

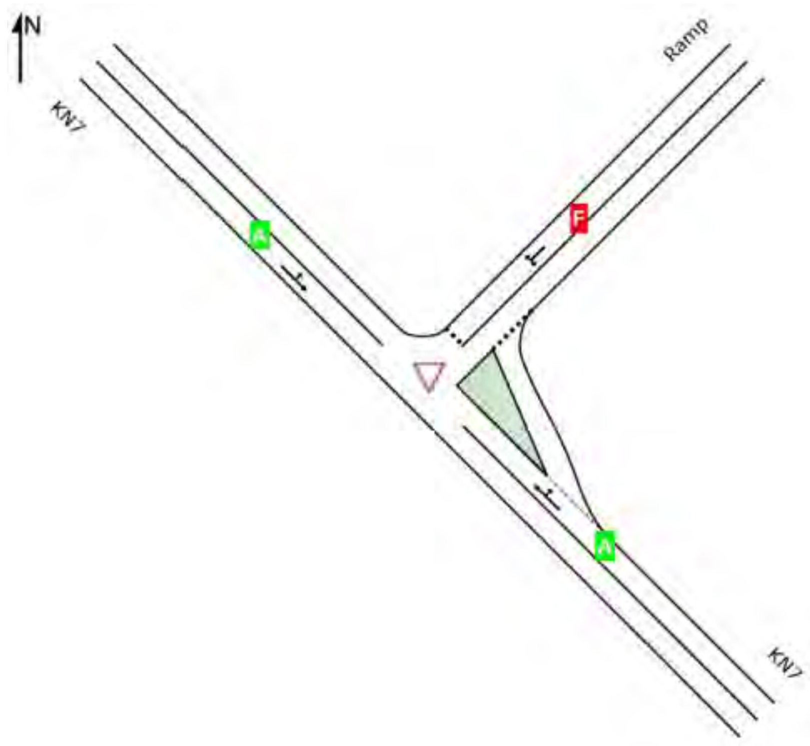
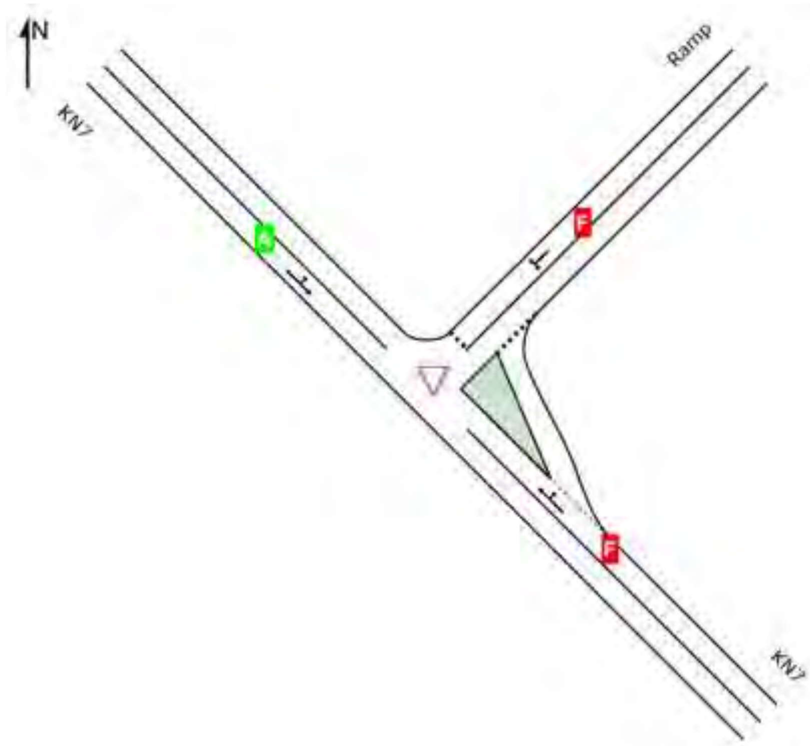
AM Peak: Intersection 15	PM Peak: Intersection 15
	

Notes:
The AM and PM peak fails on both the northern and south-western approaches with unacceptable delays, V/C ratios and queue lengths.

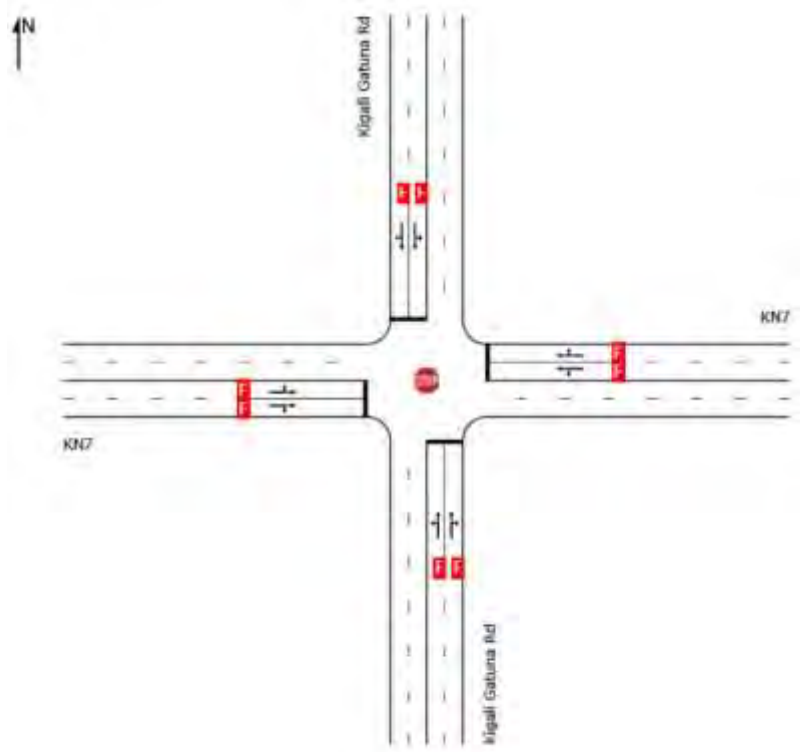
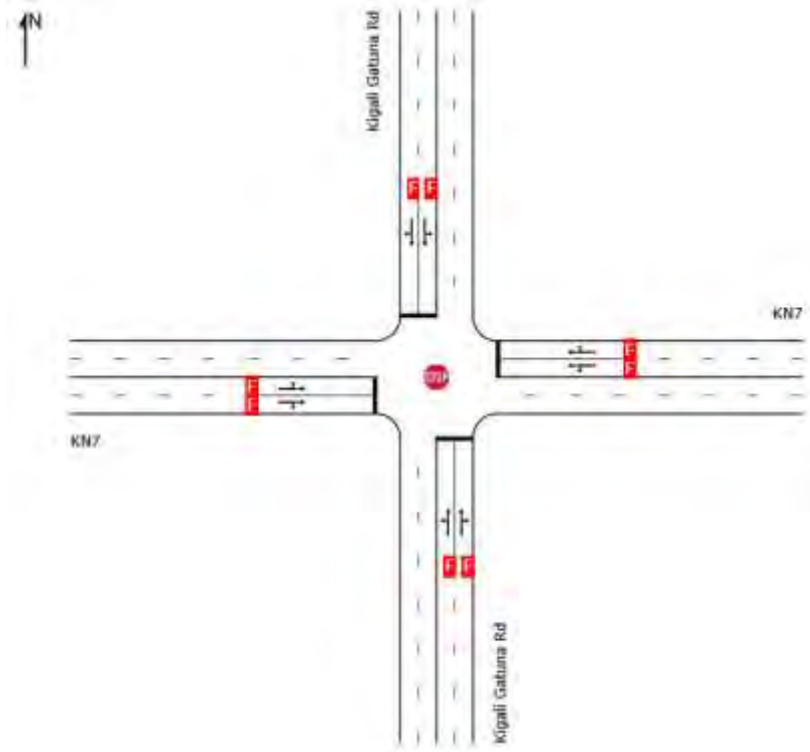
AM Peak: Intersection 16-1	PM Peak: Intersection 16-1
	

Notes:

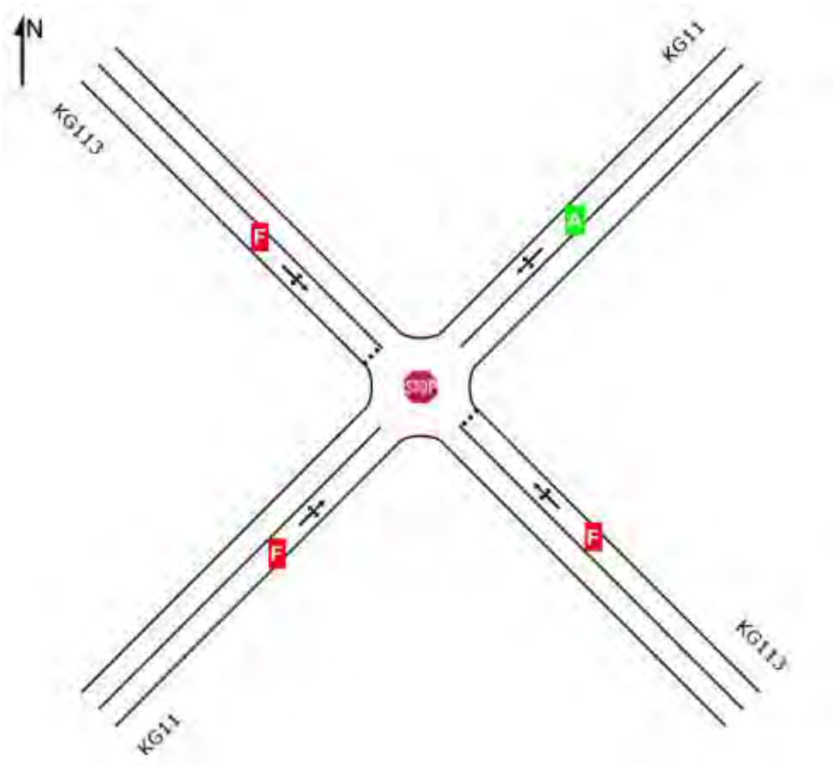
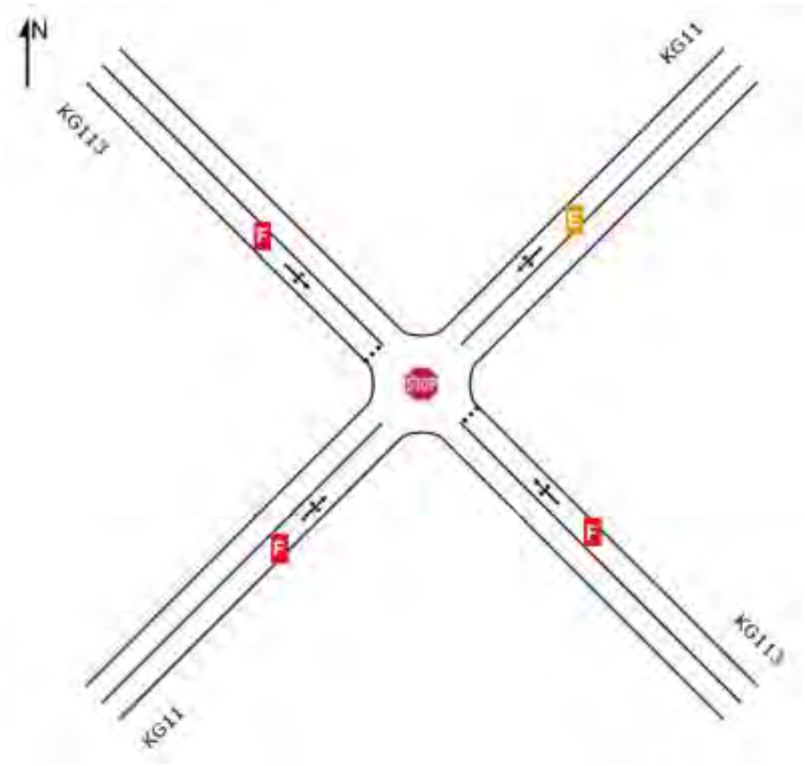
The intersection fails with unacceptable delays, V/C ratios and queue lengths on both the south-eastern and north-eastern approaches. The V/C ratios exceed 40 in the AM peak and 13 in the PM peak.

AM Peak: Intersection 16-2	PM Peak: Intersection 16-2
	

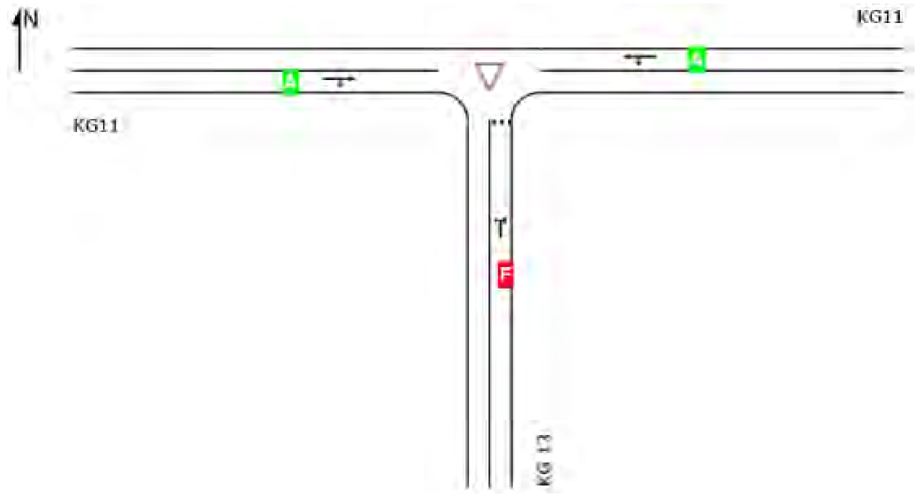
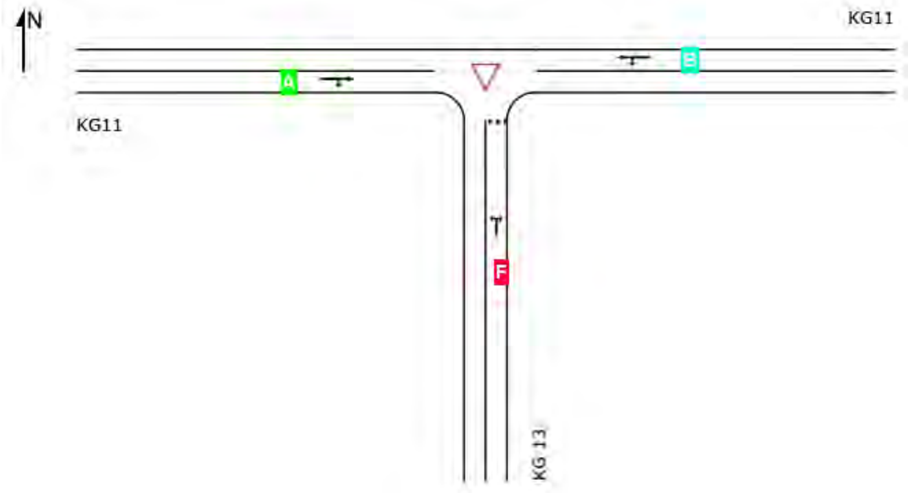
Notes:
The AM peak fails with unacceptable delays on the north eastern approach. The PM peak fails with unacceptable delays, queue lengths and V/C ratios on the south-eastern and north-eastern approaches.

AM Peak: Intersection 17	PM Peak: Intersection 17
	

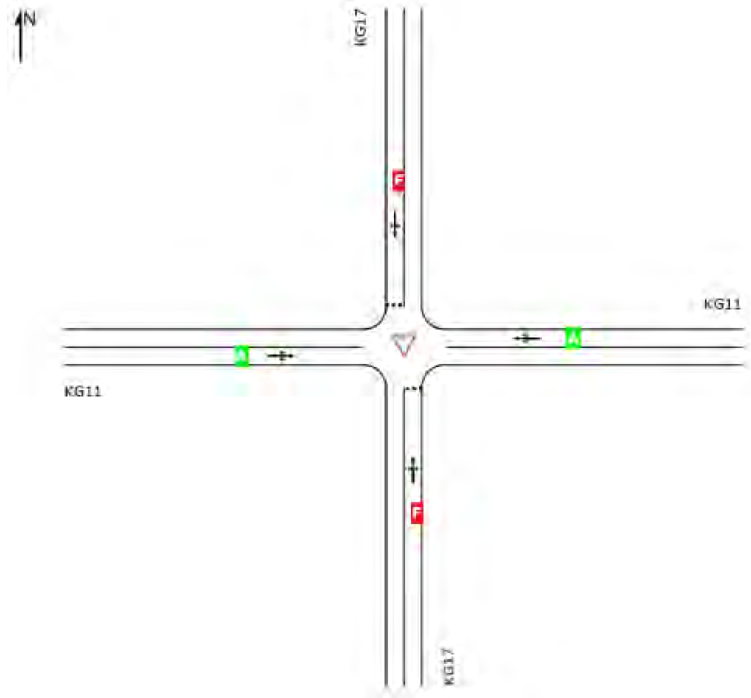
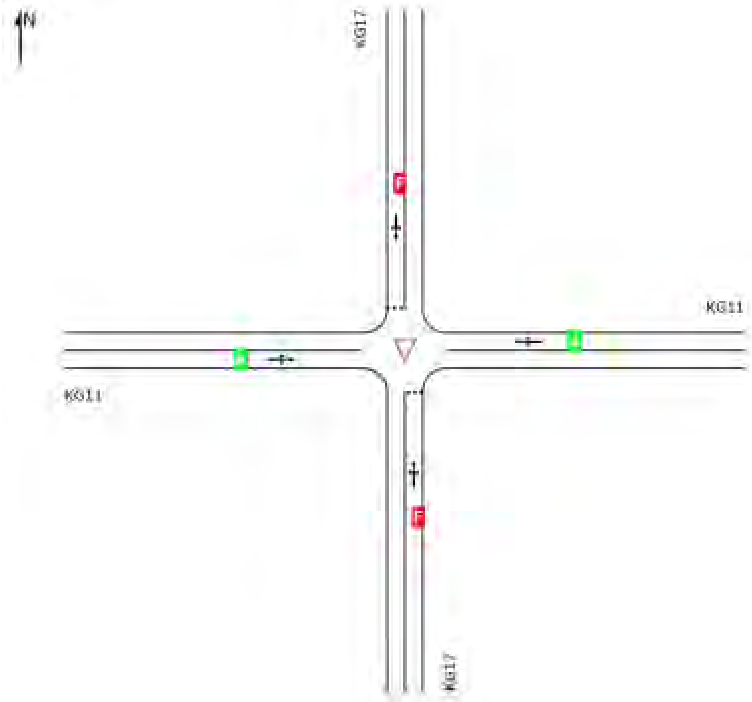
Notes:
Intersection 17 is a signalised intersection. However, the signals are not operational and as a result, the intersection is functioning as a 4-way stop. This results in all four legs of the intersection failing with unacceptable delays, V/C ratios and queue lengths during both the AM and PM peaks.

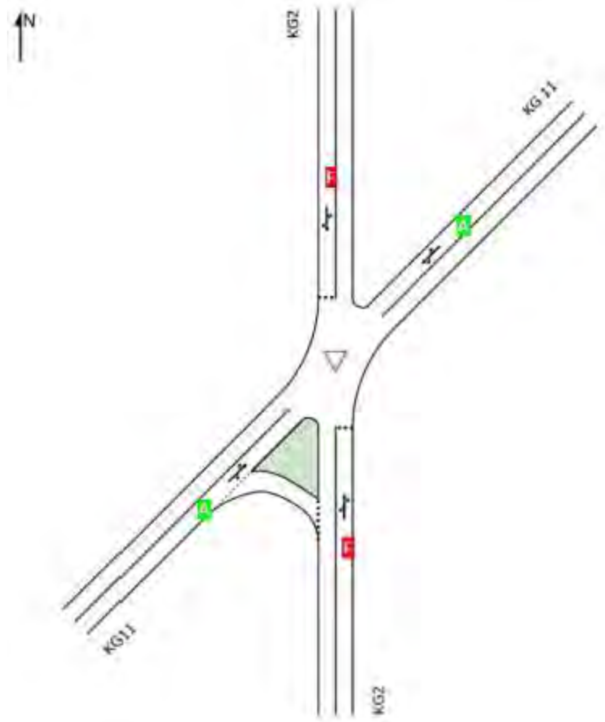
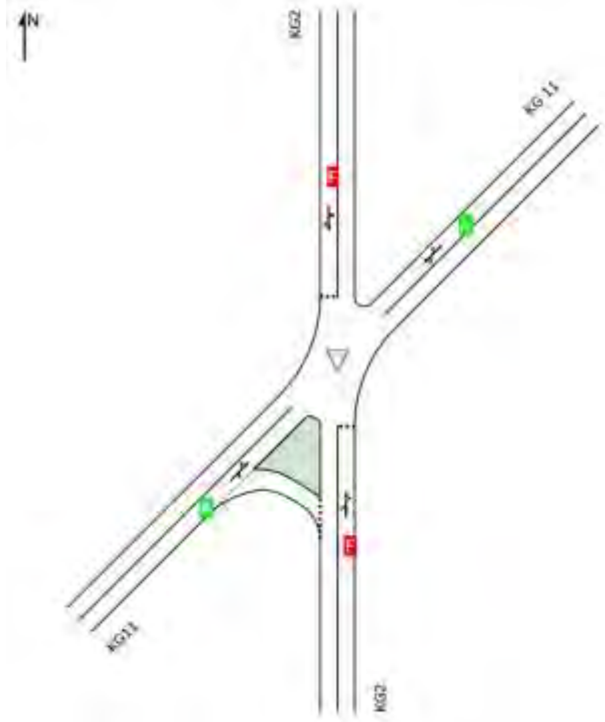
AM Peak: Intersection 18	PM Peak: Intersection 18
	

Notes:
Intersection 18 fails along 3 approaches during the AM peak and on all four approaches during the PM peak with unacceptable delays of LOS F and E, as well as with unacceptable queue lengths and V/C ratios. The south-eastern approach is the most adversely affected with a V/C ratio of 25 during the AM peak and 37 in the PM peak.

AM Peak: Intersection 19	PM Peak: Intersection 19
	

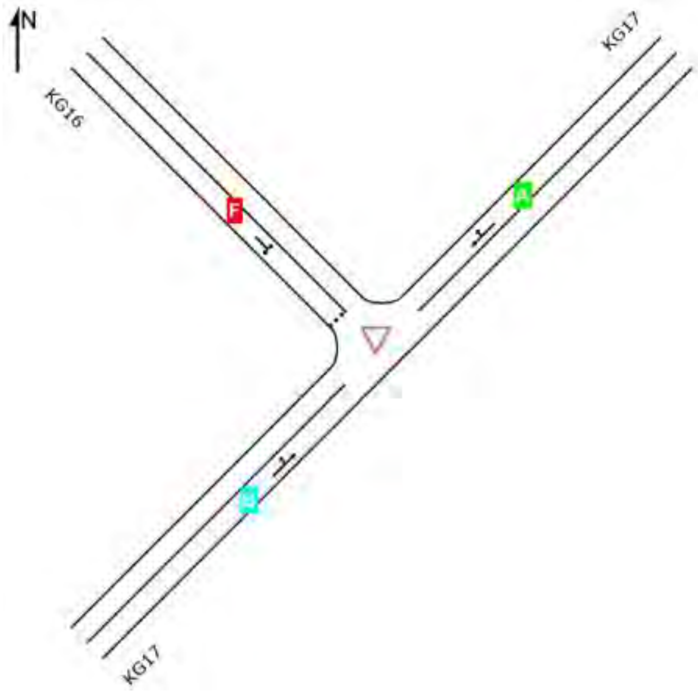
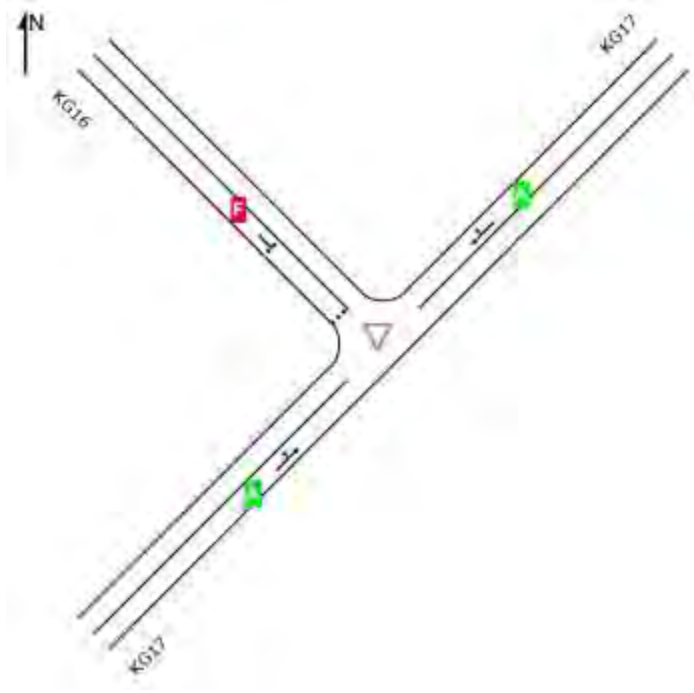
Notes:
The AM and PM peak fails with an unacceptable LOS F for intersection 19, as a result of the southern approach.

AM Peak: Intersection 20	PM Peak: Intersection 20
	
Notes:	
The AM and PM peak functions with an unacceptable LOS F and large queue lengths on both the southern and northern approaches.	

AM Peak: Intersection 21	PM Peak: Intersection 21
	

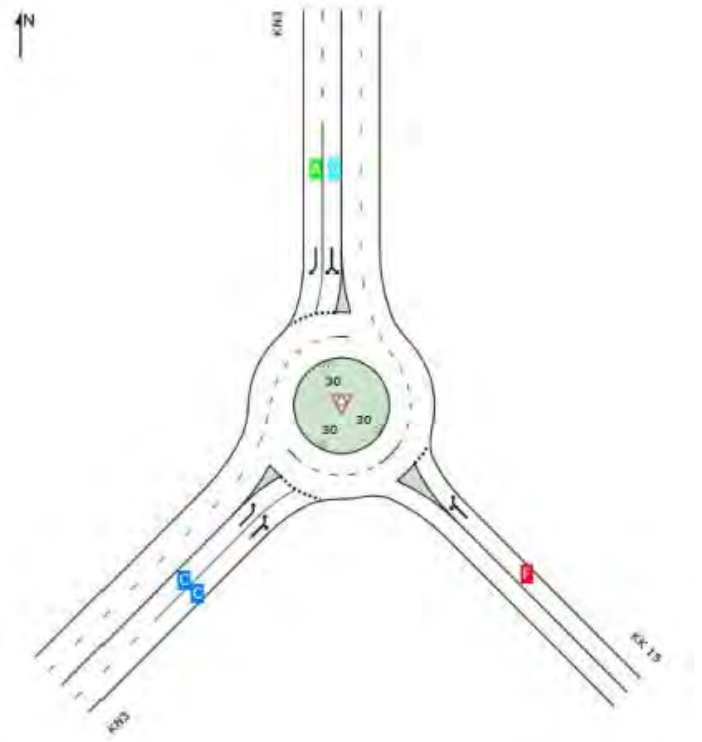
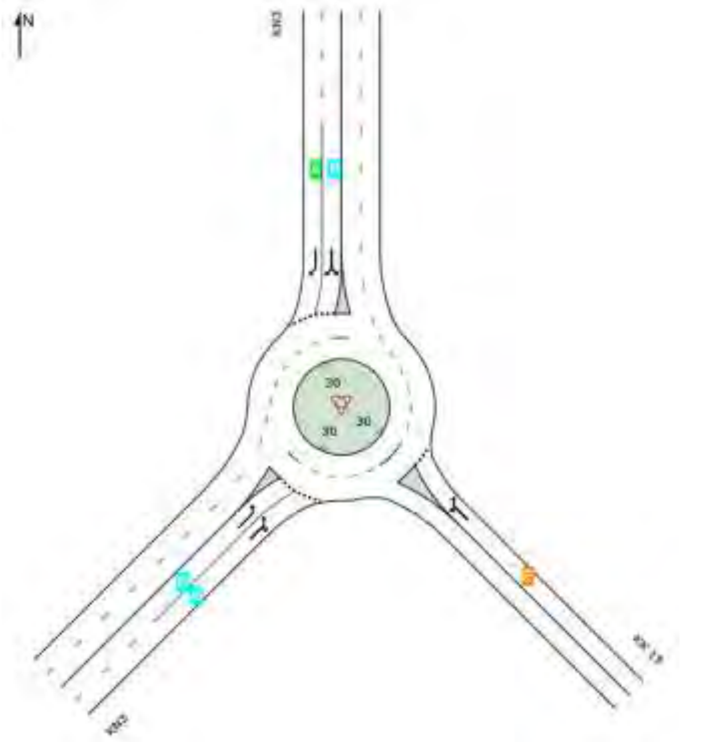
Notes:

Intersection 21 fails with an unacceptable LOS F and large queue lengths on both the northern and southern approaches during the AM peak and PM peak. Moreover, the V/C ratios for both the AM and PM peak exceed 7.

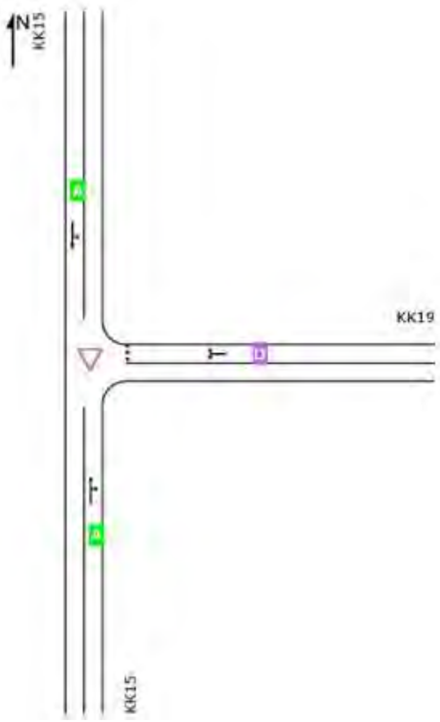
AM Peak: Intersection 22	PM Peak: Intersection 22
	

Notes:

The AM and PM peak fails with an unacceptable LOS F and excessive queue lengths on the north-western approach.

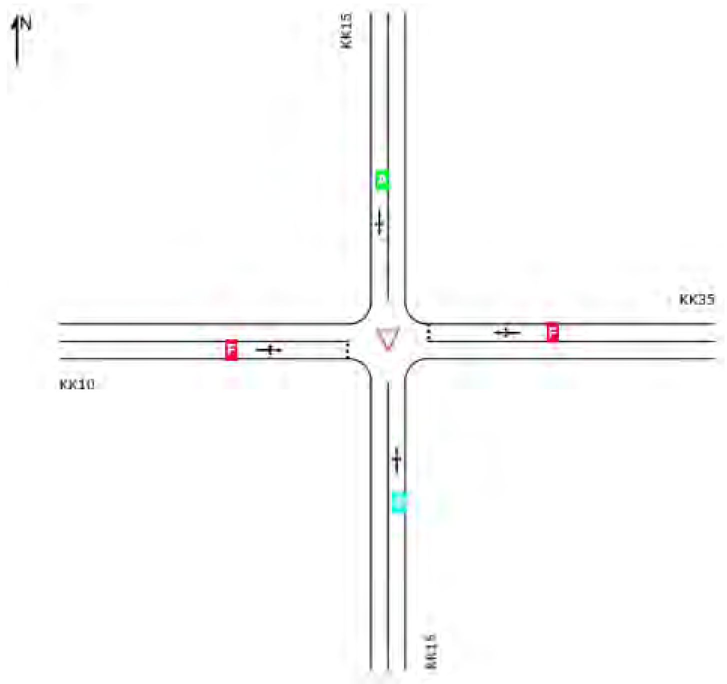
AM Peak: Intersection 23	PM Peak: Intersection 23
	

Notes:
Intersection 23 fails with an unacceptable delay on the south-eastern approach during the AM peak and PM peak. However, the overall functionality of the intersection is acceptable. It must be noted that the intersection was under construction during the traffic counting period.

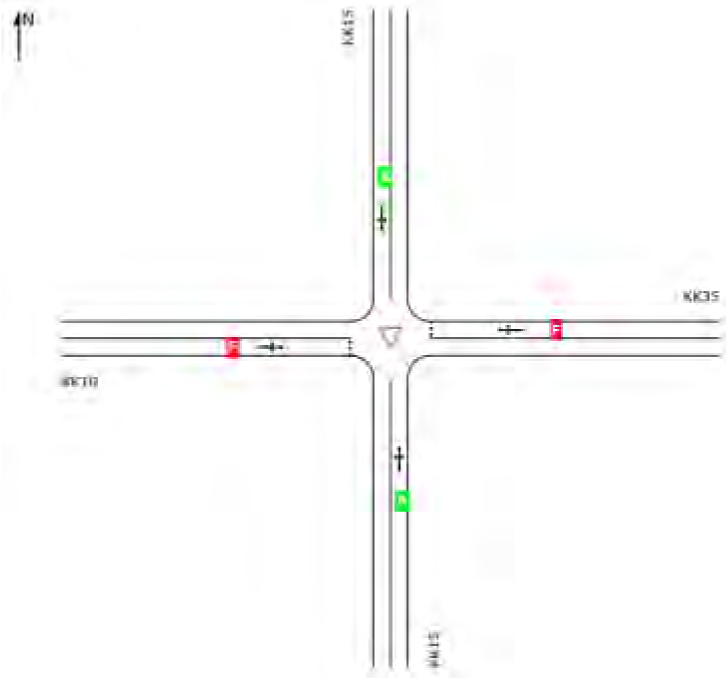
AM Peak: Intersection 24	PM Peak: Intersection 24
	

Notes:
The AM peak functions acceptably with regards to LOS and V/C ratios. However, it must be noted that the eastern approach queue length is at 4 vehicles. The PM peak functions acceptably.

AM Peak: Intersection 25



PM Peak: Intersection 25

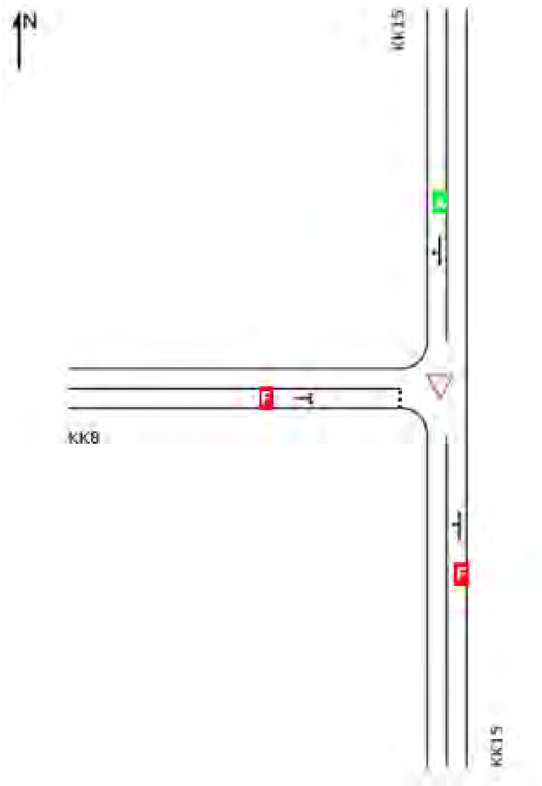
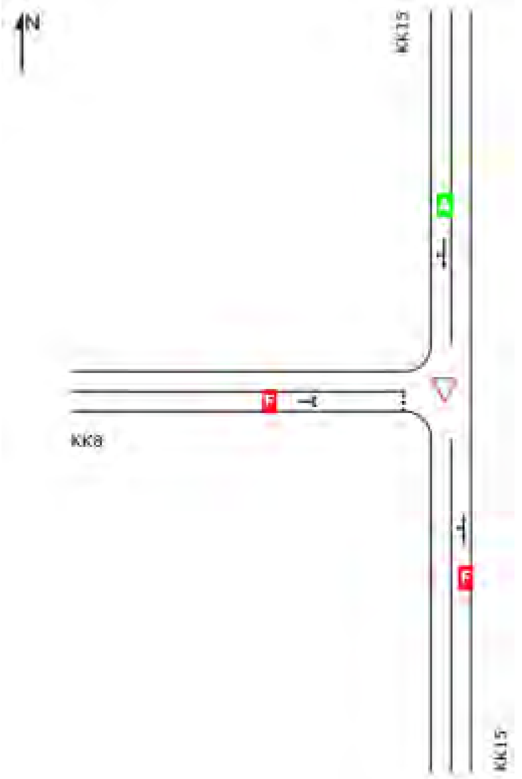


Notes:

Intersection 25 fails with unacceptable delays and queue lengths on the eastern and western approaches for both peak hours.

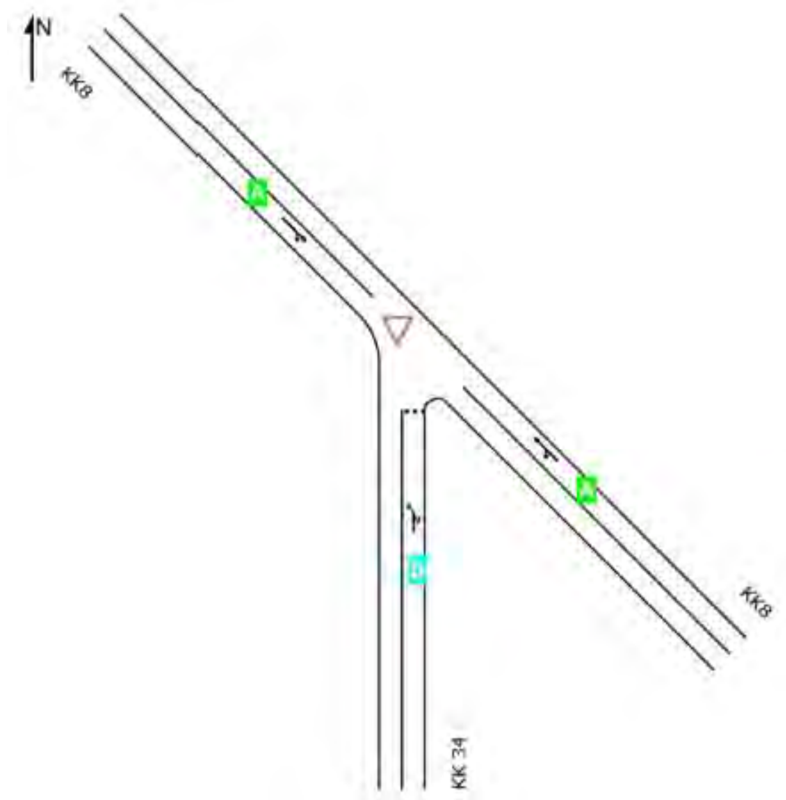
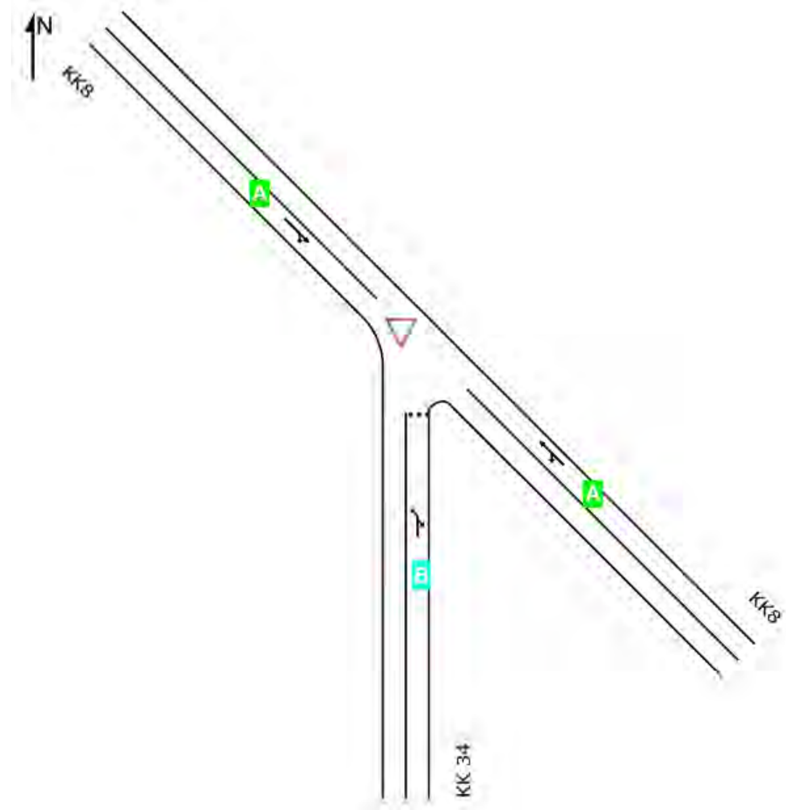
AM Peak: Intersection 26	PM Peak: Intersection 26
	

Notes:
The AM and PM peak functions acceptably.

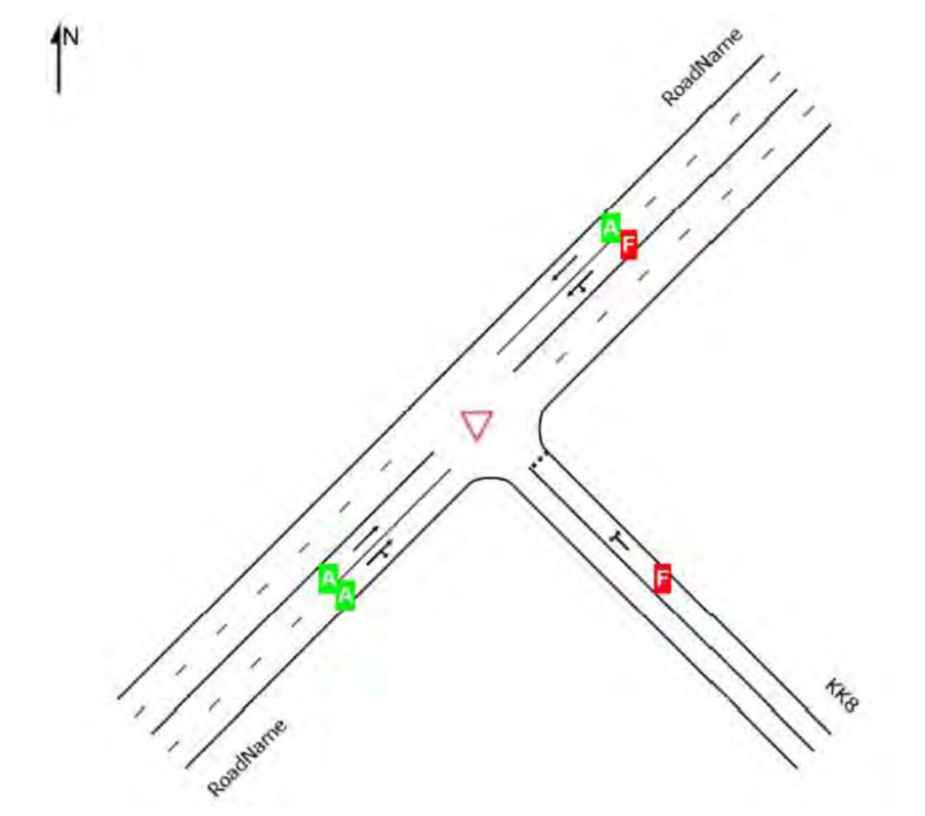
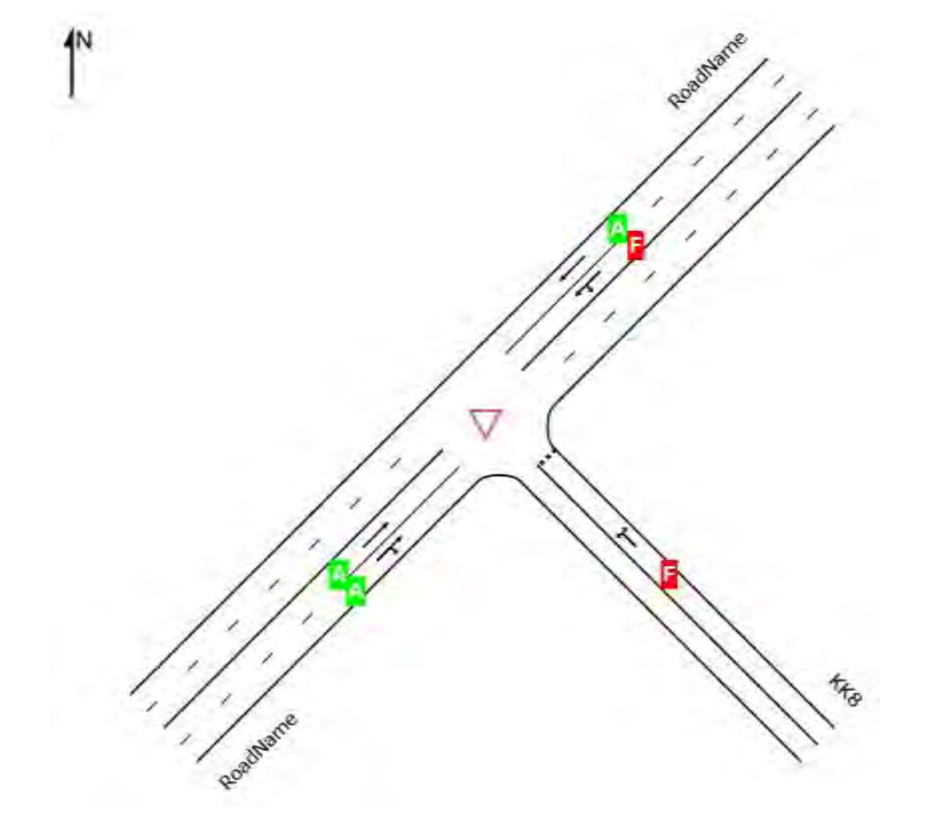
AM Peak: Intersection 27	PM Peak: Intersection 27
	

Notes:

Intersection 27 fails along the western and southern approaches during the AM and PM peak with unacceptable delays and queue lengths

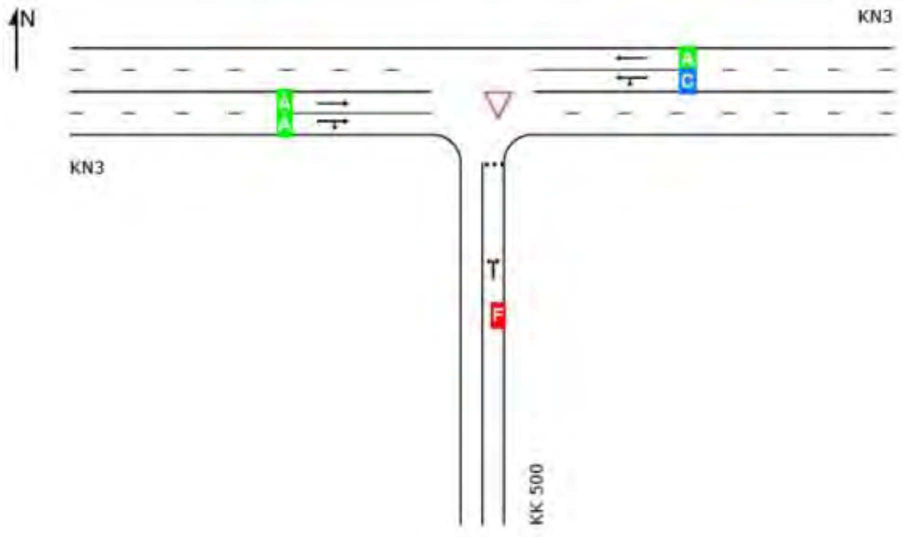
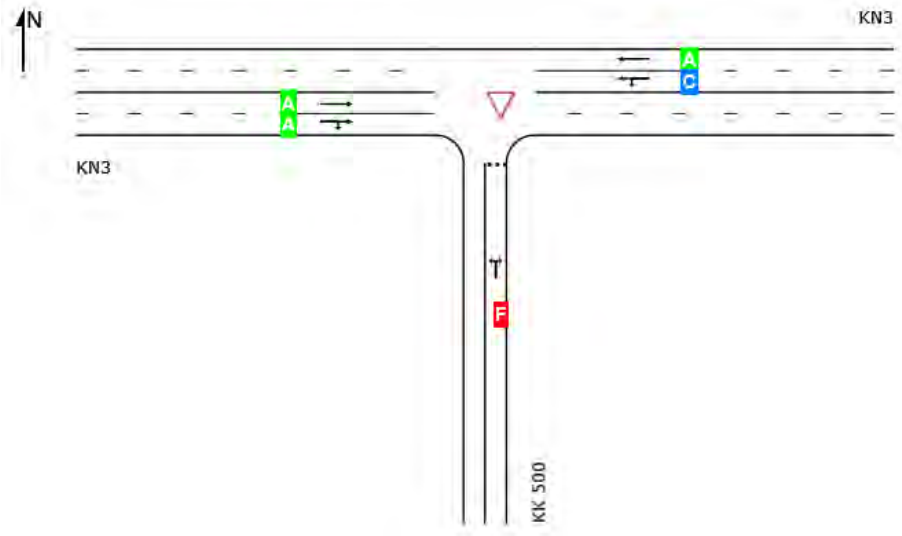
AM Peak: Intersection 28	PM Peak: Intersection 28
	

Notes:
The AM and PM peak functions acceptably.

AM Peak: Intersection 29	PM Peak: Intersection 29
	

Notes:

Intersection 29 was under construction during the traffic counting period. However, the assessment of the existing infrastructure during the AM and PM peak as a priority controlled intersection indicates that the south-eastern approach and the north-eastern left turn approach fails with an unacceptable LOS F.

AM Peak: Intersection 30	PM Peak: Intersection 30
	

Notes:

Intersection 30 fails with an unacceptable LOS F on the southern approach. However, this intersection functions acceptably in the Vissim model.

5.3. Proposed Solutions

The results of the proposed solutions to alleviate the congestion of the 31 intersections are shown in Table 5-4 and Table 5-5. The movement summaries are shown in **Annexure D**. The 31 intersections were revised to 16 traffic signals, 12 roundabouts and only three priority-controlled intersections.

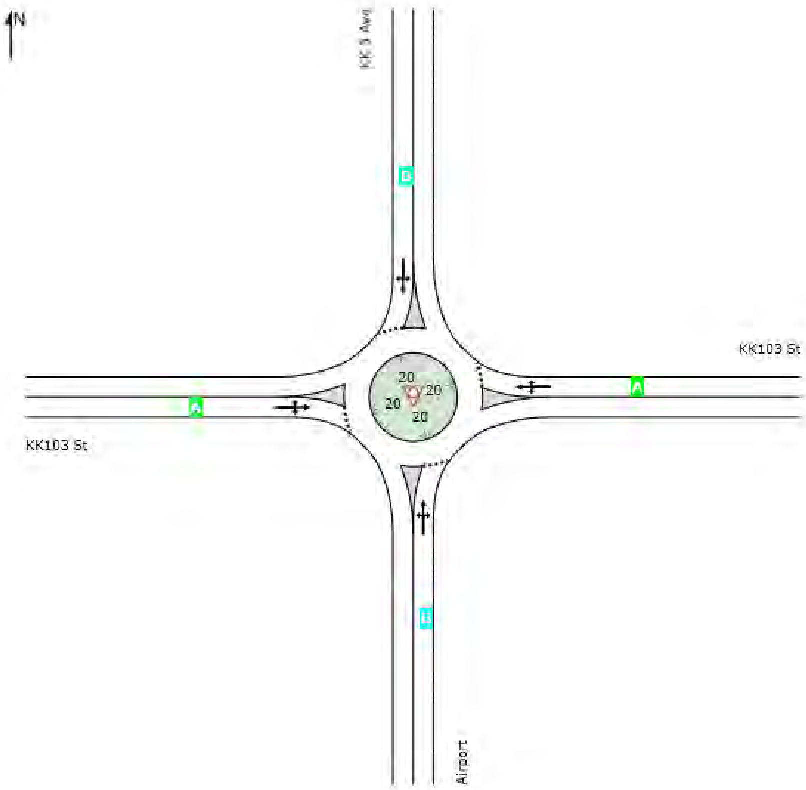
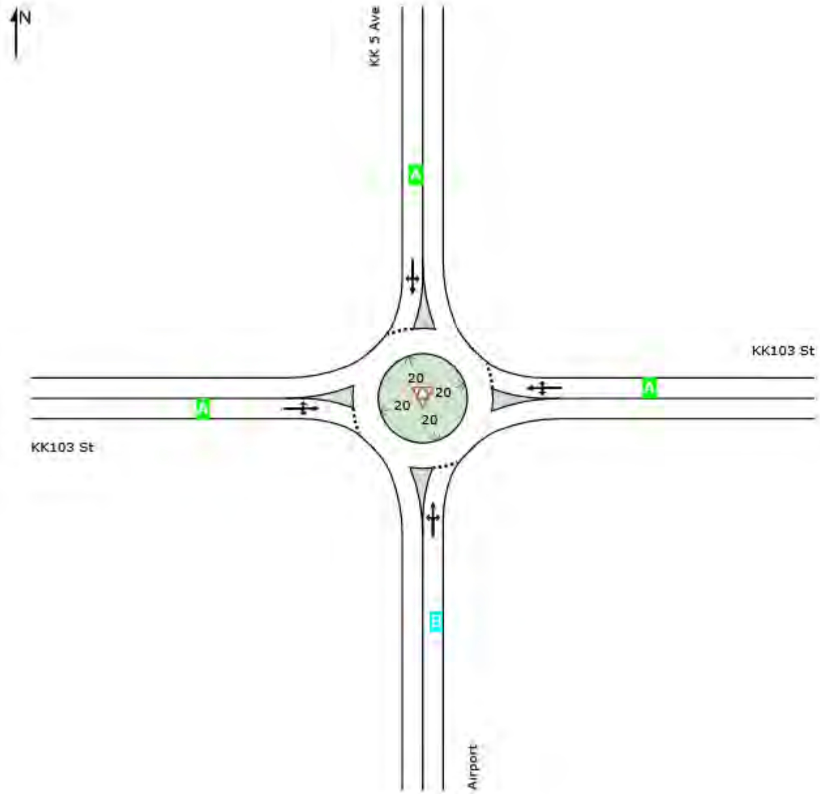
Table 5-4: SIDRA results of the Proposed AM peak Options

AM PEAK					
NUMBER	PROPOSED UPGRADES			STATUS	DESCRIPTION
	TYPE	MAX QUE	LOS	ACCEPTABLE/ FAIL	
1	Circle	3,1	A	Acceptable	No Change
2	Signal	27,9	B	Acceptable	Signal and Geometric Upgrade
3	Signal	35,6	C	Acceptable	Geometric and Phasing Upgrade
4	Signal	25,4	C	Acceptable	Signal and Geometric Upgrade
5	Circle	14,6	B	Acceptable	Geometric Upgrade
6	Signal	45	C	Acceptable	Signal and Geometric Upgrade
7	Circle	2,9	A	Acceptable	Geometric Upgrade
8	Circle	0,4	A	Acceptable	No Change
9	Circle	N/A	No conflict	Acceptable	No Change
10	Unsolvable in SIDRA (Solved in Vissim as Grade Separation)				Flyover left turn Northern Approach
11	Signal	21	D	Acceptable	Signal and Geometric Upgrade
12	Signal	14	B	Acceptable	Signal and Geometric Upgrade
13	Circle	5,8	A	Acceptable	Geometric Upgrade
14	Signal	16,6	A	Acceptable	Vissim Resolved as priority with left lane
15	Signal	31,7	B	Acceptable	Signal and Geometric Upgrade
16.1	Signal	29	B	Acceptable	Signal and Geometric Upgrade
16.2	Signal	21,6	B	Acceptable	Signal and Geometric Upgrade
17	Signal	12,9	C	Acceptable	Signal and Geometric Upgrade
18	Signal	20,4	C	Acceptable	Signal and Geometric Upgrade
19	Circle	6,3	A	Acceptable	Circle and Geometric Upgraded
20	Circle	20,9	A	Acceptable	Circle and Geometric Upgraded
21	Signal	44,1	C	Acceptable	Signal and Geometric Upgrade
22	Circle	12,8	B	Acceptable	Circle and Geometric Upgraded
23	Circle	14,7	B	Acceptable	Geometric Upgrade
24	Priority	4	D (East)	Acceptable	No Change
25	Circle	17,8	A	Acceptable	Circle and Geometric Upgraded
26	Priority	2,4	B (East)	Acceptable	No Change
27	Signal	21,1	B	Acceptable	Signal and Geometric Upgrade
28	Priority	1,9	C (South)	Acceptable	South East Left Turn Lane
29	Signal	27	C	Acceptable	Signal and Geometric Upgrade
30	Signal	11,1	B	Acceptable	Signal and Geometric Upgrade
	16 Signals **12 Circles** **3 priority**			**31 Acceptable**	**All intersections are resolved to have an acceptable LOS and queue length for the type of intersection**

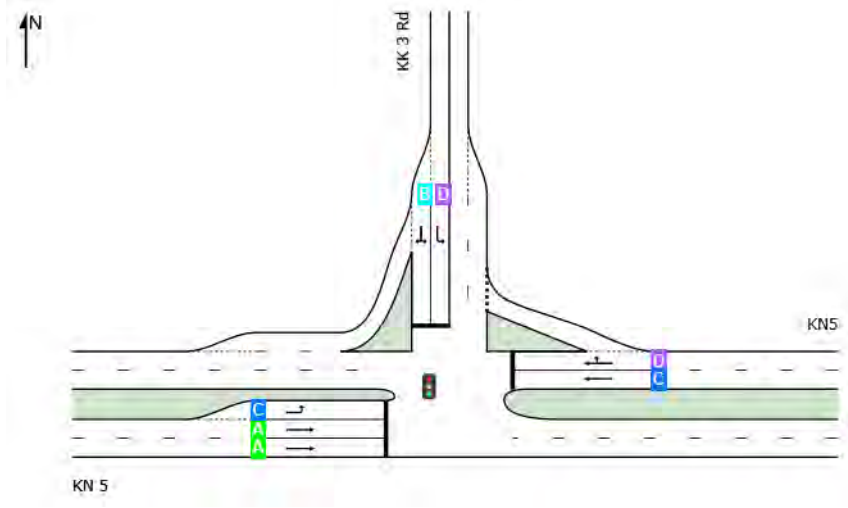
Table 5-5: SIDRA results of the Proposed PM peak Options

NUMBER	PM PEAK				
	PROPOSED UPGRADES			STATUS	DESCRIPTION
	TYPE	MAX QUE	LOS	ACCEPTABLE/ FAIL	
1	Circle	2,4	A	Acceptable	No Change
2	Signal	23,3	C	Acceptable	Signal and Geometric Upgrade
3	Signal	30,7	C	Acceptable	Geometric and Phasing Upgrade
4	Signal	27,9	C	Acceptable	Signal and Geometric Upgrade
5	Circle	11	B	Acceptable	Geometric Upgrade
6	Signal	24,9	C	Acceptable	Signal and Geometric Upgrade
7	Circle	3	A	Acceptable	Geometric Upgrade
8	Circle	0,5	A	Acceptable	No Change
9	Circle	N/A	No conflict	Acceptable	No Change
10	Unsolvable in SIDRA (Solved in Vissim as Grade Separation)				Flyover left turn Northern Approach
11	Signal	16	C	Acceptable	Signal and Geometric Upgrade
12	Signal	19,7	C	Acceptable	Signal and Geometric Upgrade
13	Circle	3,2	A	Acceptable	Geometric Upgrade
14	Signal	8,3	A	Acceptable	Vissim Resolved as priority with left lane
15	Signal	31,4	B	Acceptable	Signal and Geometric Upgrade
16.1	Signal	22,2	B	Acceptable	Signal and Geometric Upgrade
16.2	Signal	31,3	C	Acceptable	Signal and Geometric Upgrade
17	Signal	20,8	C	Acceptable	Signal and Geometric Upgrade
18	Signal	27,1	B	Acceptable	Signal and Geometric Upgrade
19	Circle	5,5	A	Acceptable	Circle and Geometric Upgraded
20	Circle	25,6	B	Acceptable	Circle and Geometric Upgraded
21	Signal	38,8	C	Acceptable	Signal and Geometric Upgrade
22	Circle	7,9	A	Acceptable	Circle and Geometric Upgraded
23	Circle	6,8	B	Acceptable	Geometric Upgrade
24	Priority	11,3	F (East)	Fail	Vissim resolved the intersection
25	Circle	19,6	A	Acceptable	Circle and Geometric Upgraded
26	Priority	1,8	B (East)	Acceptable	No Change
27	Signal	19,9	B	Acceptable	Signal and Geometric Upgrade
28	Priority	3,7	B (East)	Acceptable	South East Left Turn Lane
29	Signal	17,5	B	Acceptable	Signal and Geometric Upgrade
30	Signal	14,8	B	Acceptable	Signal and Geometric Upgrade
	16 Signals **12 Circles** **3 priority**			**31 Acceptable**	**All intersections are resolved to have an acceptable LOS and queue length for the type of intersection**

All 31 of the assessed intersections' congestion issues were resolved with the proposed solutions. Furthermore, 27 of the 31 intersections required geometric upgrades to resolve the congestion concerns. All queue lengths and V/C ratio issues were resolved with the proposed solutions either in SIDRA or in Vissim. The proposed geometric conceptual layouts are shown in **Annexure D.**

AM Peak: Intersection 1	PM Peak: Intersection 1
	

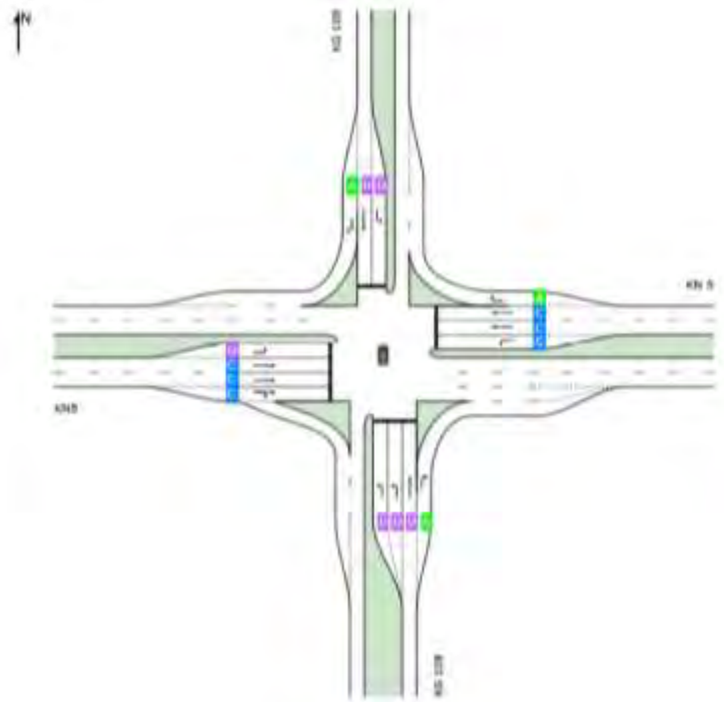
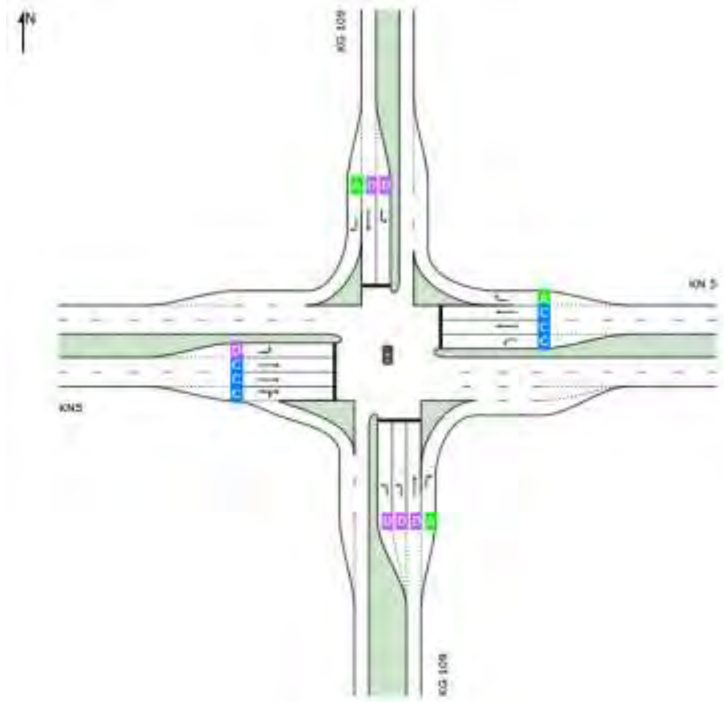
Notes:
The AM and PM peak functions acceptably regarding the LOS. No change was required to the existing geometric configuration.

AM Peak: Intersection 2	PM Peak: Intersection 1
	

Notes:

This intersection requires the following upgrades:

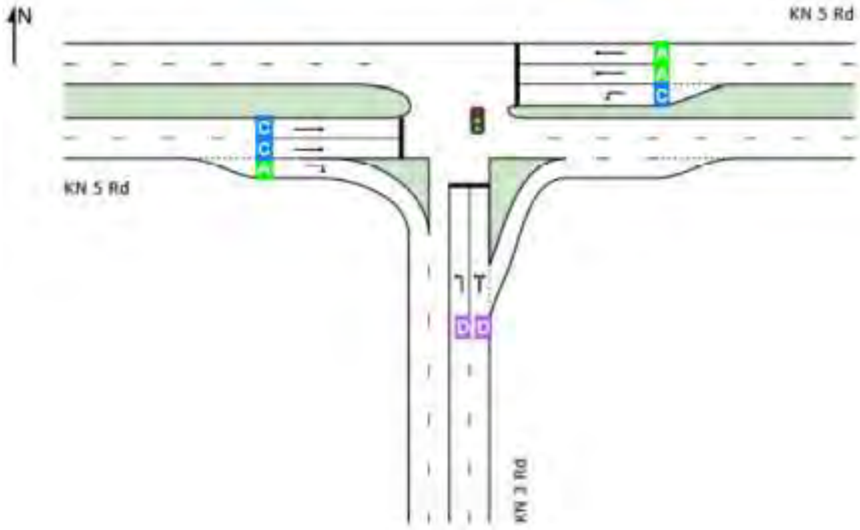
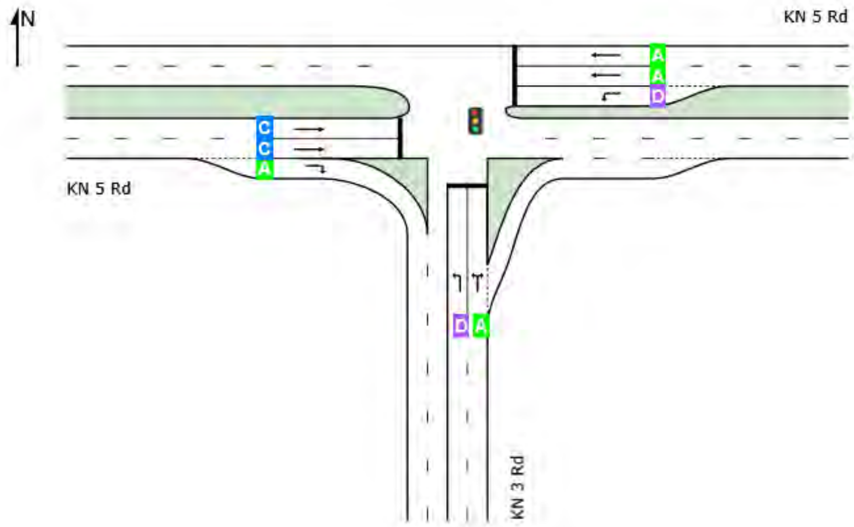
- Signalisation
- Additional left turn lane and short exit lane on northern approach
- Short exit lane on western approach

AM Peak: Intersection 3	PM Peak: Intersection 3
	

Notes:

This intersection requires the following upgrades:

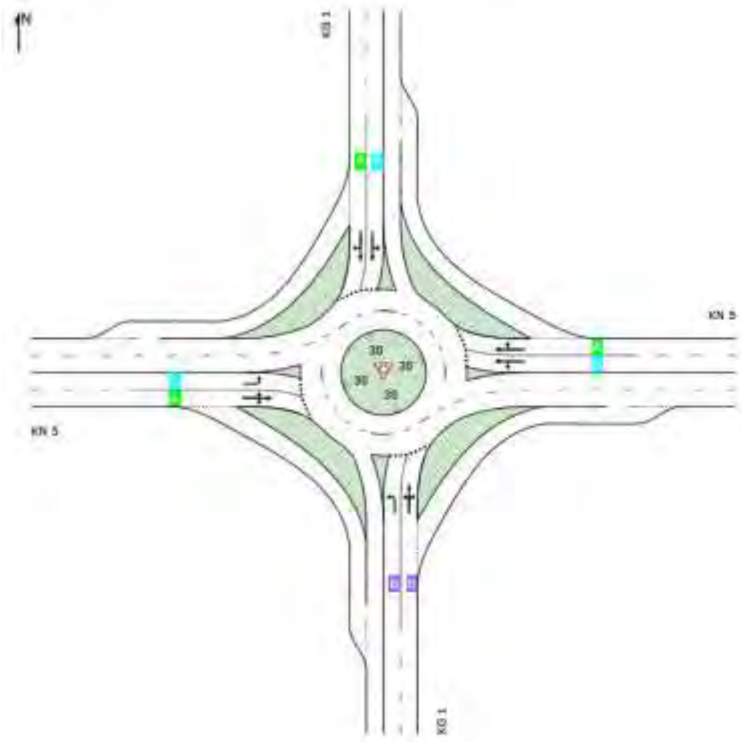
- Short right turn slip lane and short left turn lane on northern approach
- Right-turn slip lane and additional exit lane on eastern approach
- Double left turn lanes and right-turn slip lane on southern approach
- Additional through lane, right-turn slip lane and additional exit lane on western approach

AM Peak: Intersection 4	PM Peak: Intersection 4
	

Notes:

This intersection requires the following upgrades:

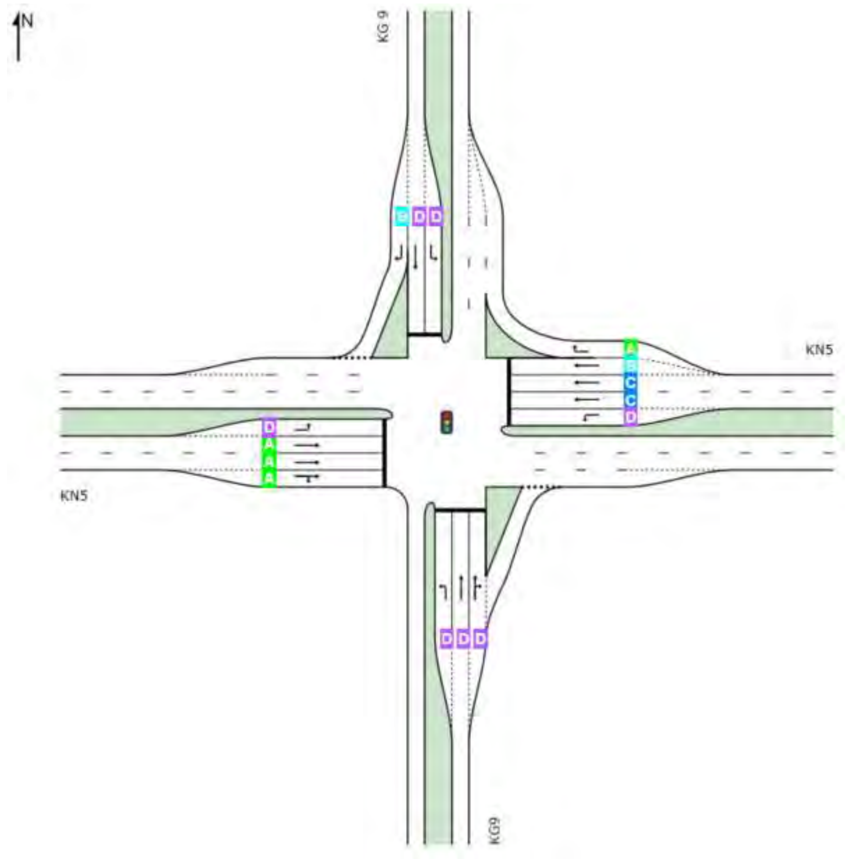
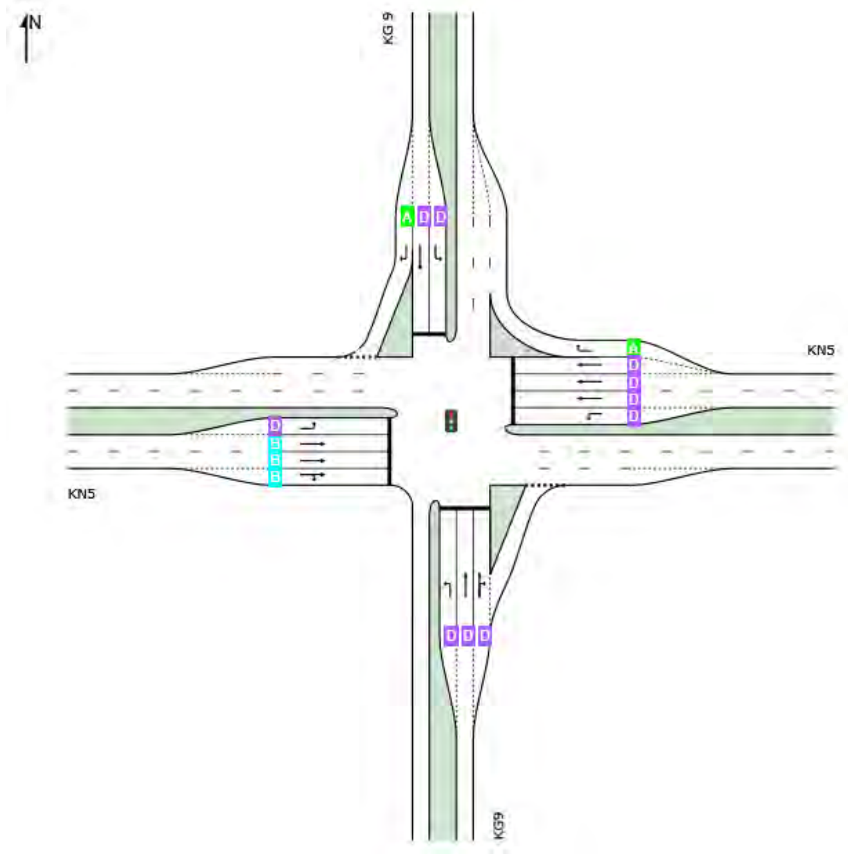
- Signalisation
- Left-turn lane on southern approach

AM Peak: Intersection 5	PM Peak: Intersection 5
	

Notes:

Intersection 5 has a very large through and right movement from the east. This movement conflicts with the large left movement from the west and the large right and left movement from the north. However, if the right turn movements are removed from the intersection, the intersection functions acceptably with a LOS B. Therefore, this intersection requires the following upgrades:

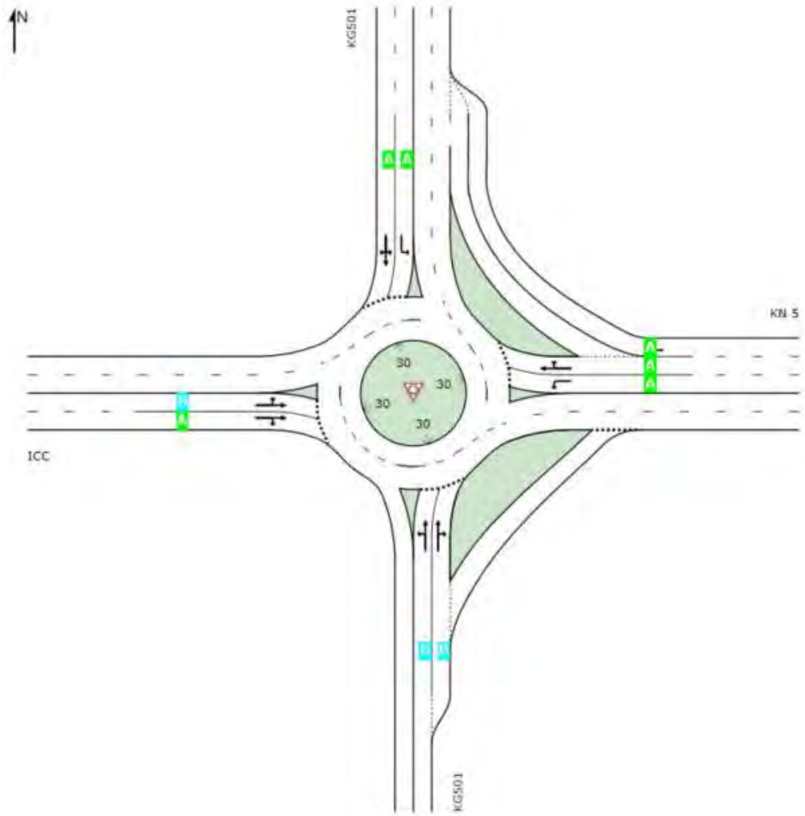
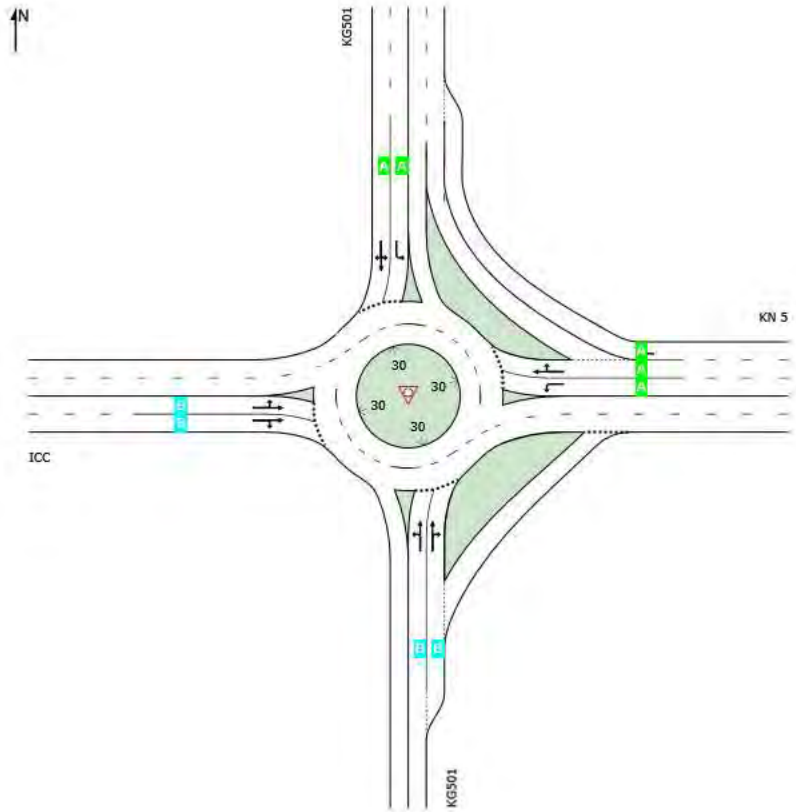
- Right-turn slip lane, additional approach lane and short exit lane on northern approach
- Right-turn slip lane and short exit lane on eastern approach
- Right-turn slip lane, additional approach lane and short exit lane on southern approach
- Right-turn slip lane on western approach

AM Peak: Intersection 6	PM Peak: Intersection 6
	

Notes:

This intersection requires the following upgrades:

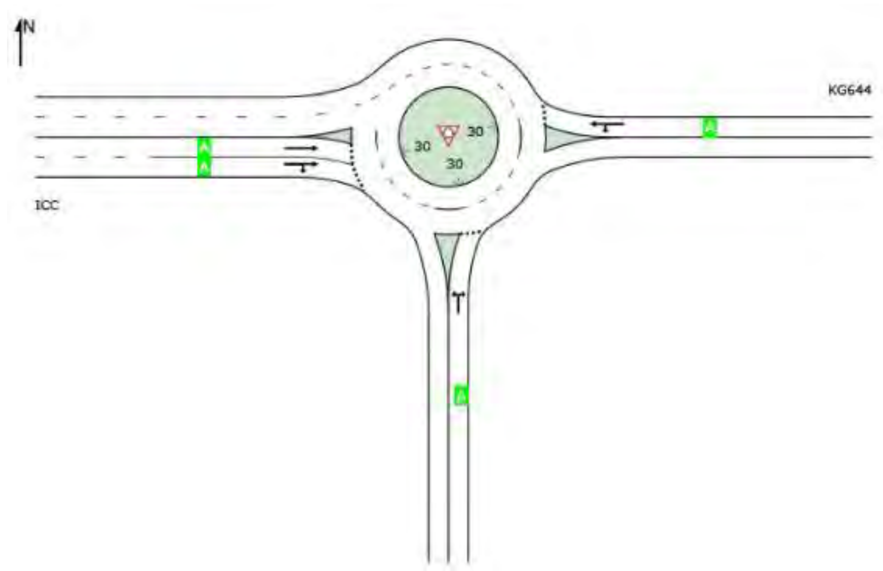
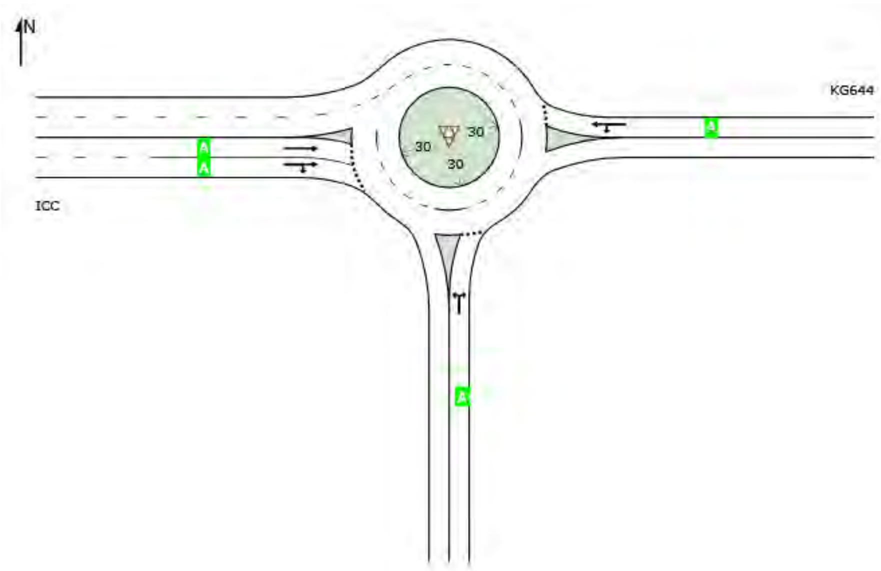
- Right-turn slip lane and additional short exit lane on northern approach
- Right-turn slip lane, additional short through lane, and short exit lane on eastern approach
- Right-turn slip lane, additional short through lane and short left-turn lane on southern approach
- Additional short through lane, and short exit lane on western approach

AM Peak: Intersection 7	PM Peak: Intersection 7
	

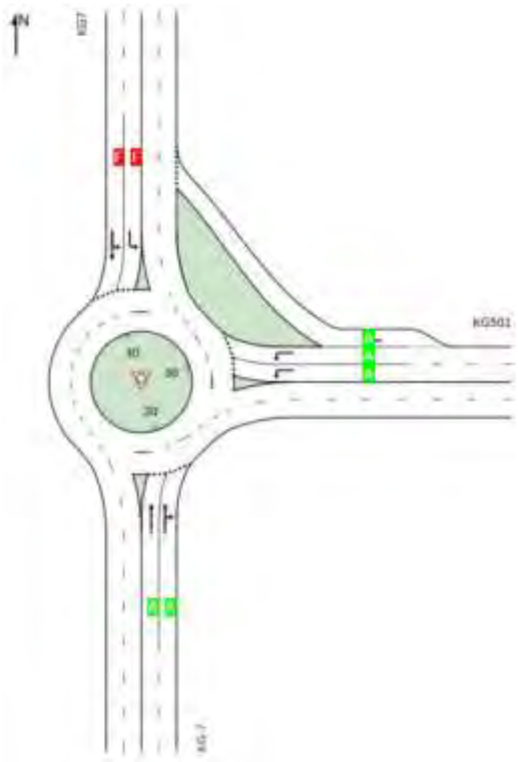
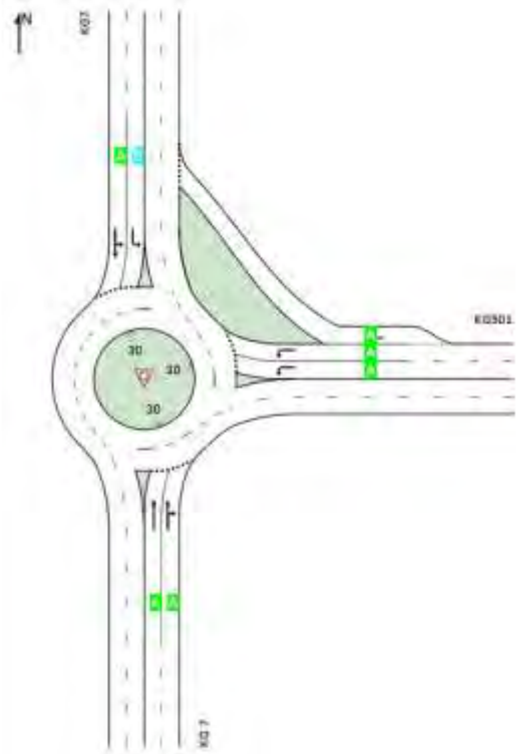
Notes:

This intersection requires the following upgrades:

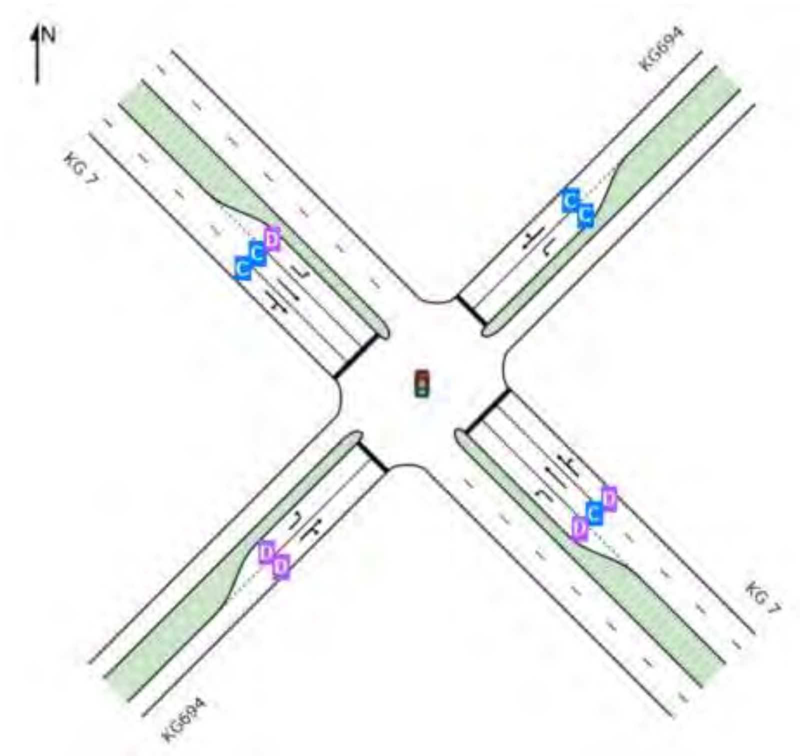
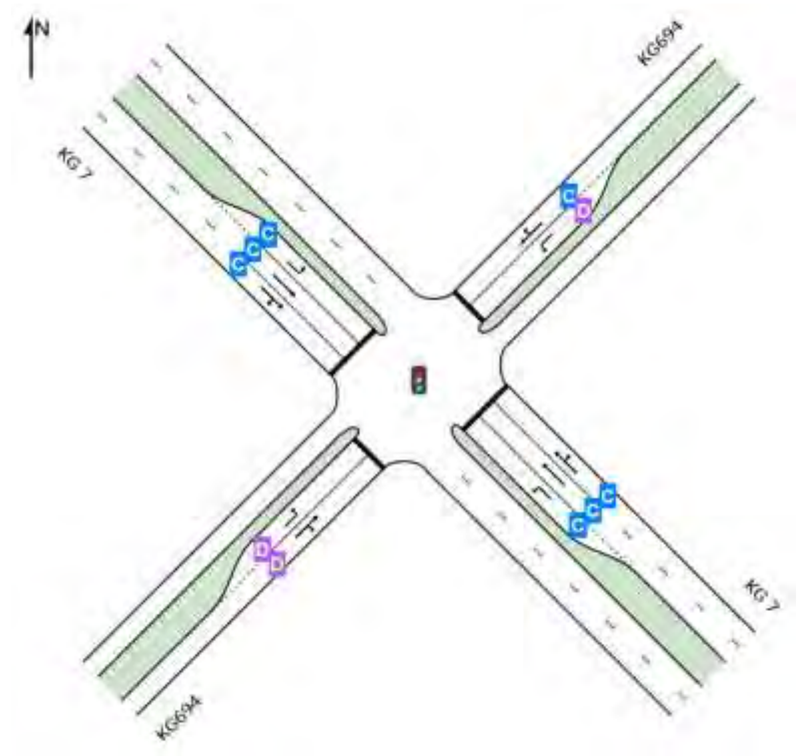
- Two short exit lanes on the northern approach
- Right-turn slip lane, combined with a second, full right-turn slip lane on eastern approach
- Additional short approach lane on southern approach

AM Peak: Intersection 8	PM Peak: Intersection 8
	

Notes:
The AM peak functions acceptably and no geometric changes are required.

AM Peak: Intersection 10	PM Peak: Intersection 10
	

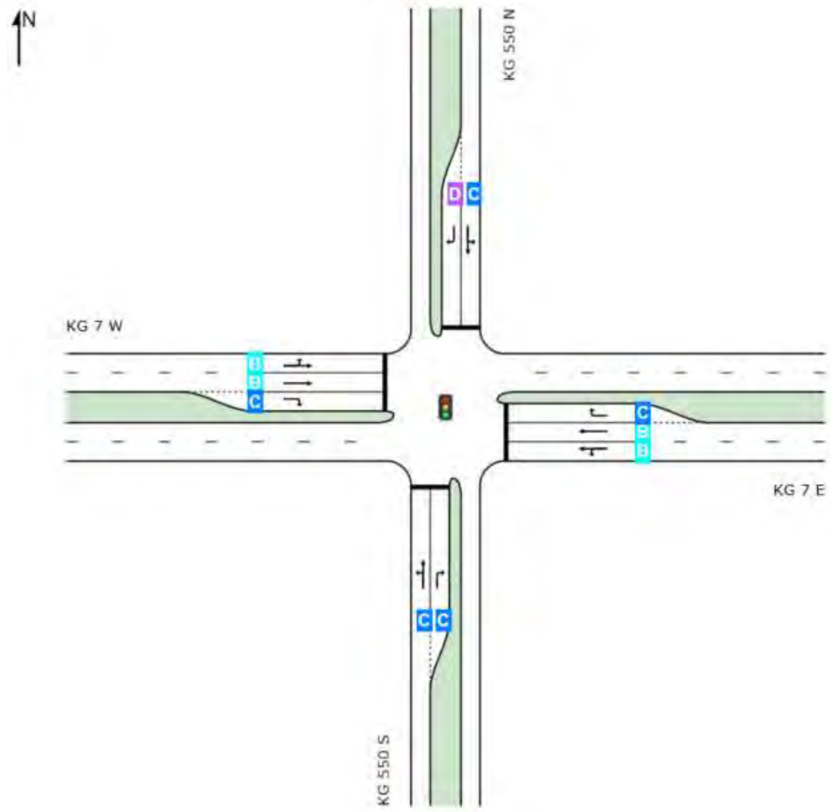
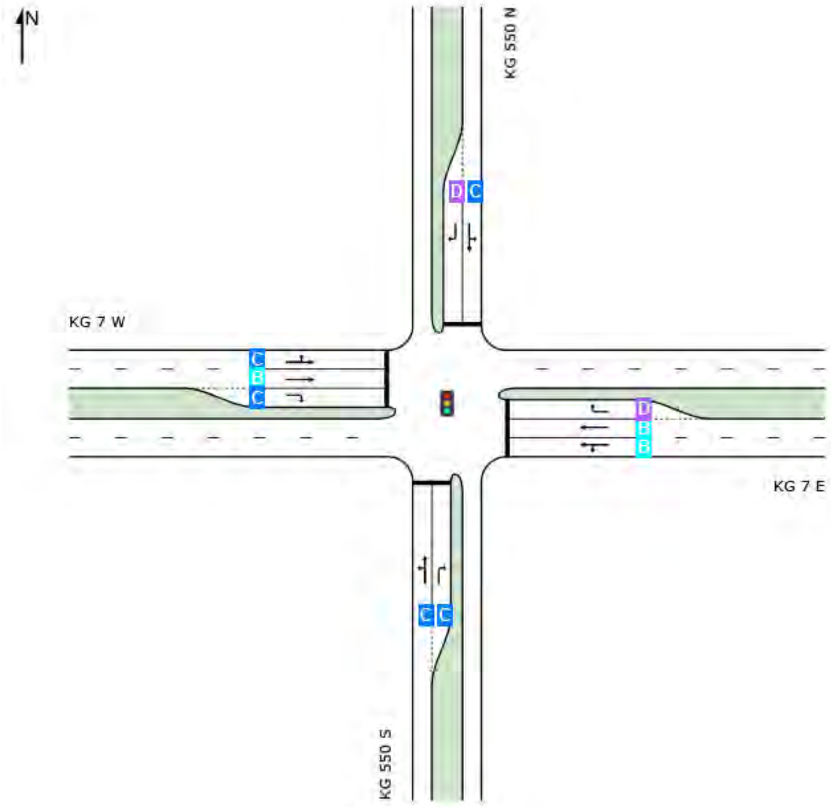
Notes:
This intersection could not be resolved using SIDRA as the there exists a large conflicting movement between the eastern approach left turn and the northern approach left turn movements. This results in the northern approach functioning with an unacceptable LOS F. Therefore, grade separation is required between the northern and eastern left turn movements. The geometric changes as assessed in Vissim include an eastern approach right turn slip lane and a northern approach left turn flyover. The flyover from the northern approach was selected as there is enough space to construct the flyover from this approach and the radius required for the flyover is acceptable from the northern approach.

AM Peak: Intersection 11	PM Peak: Intersection 11
	

Notes:

This intersection requires the following upgrades:

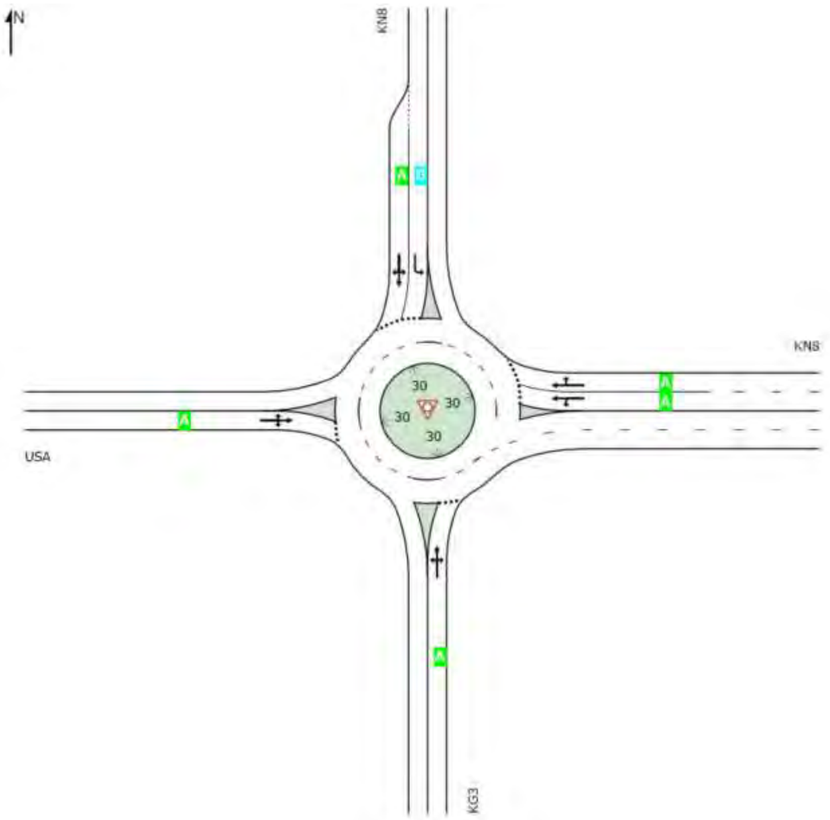
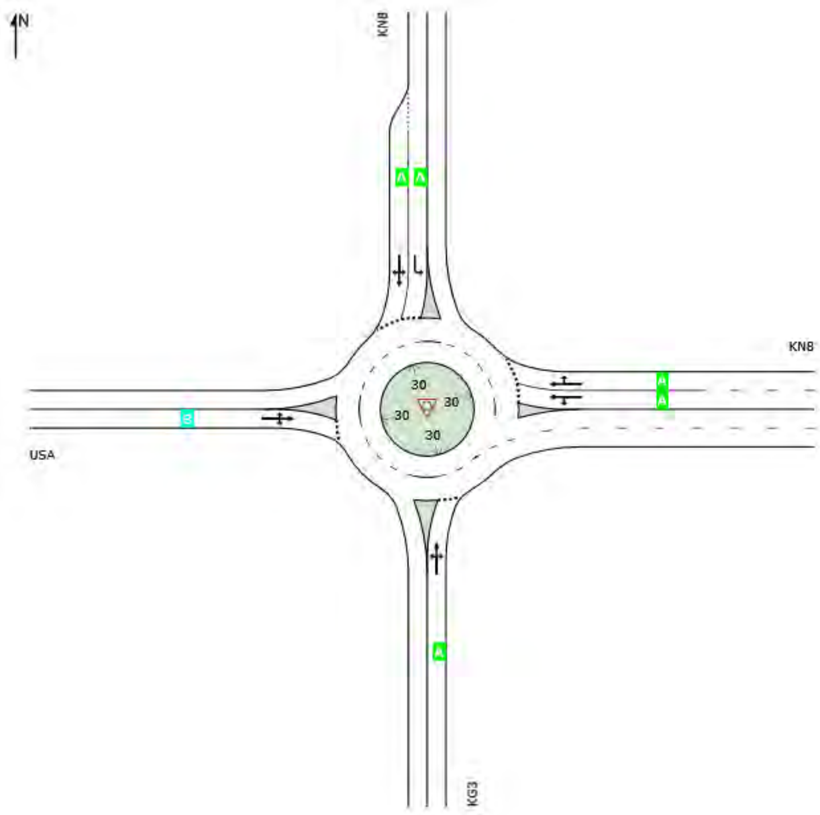
- Signalisation
- Short left-turn lane on north-eastern approach
- Short left-turn lane on south-eastern approach
- Short left-turn lane on south-western approach
- Short left-turn lane on north-western approach

AM Peak: Intersection 12	PM Peak: Intersection 12
	

Notes:

Intersection 12 requires both geometric changes and signalisation. The geometric changes include an auxiliary left turn lane for all the approaches. This intersection requires the following upgrades:

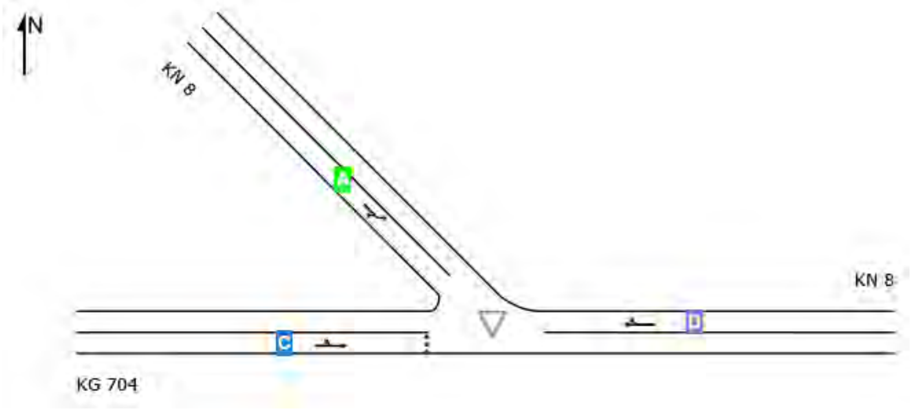
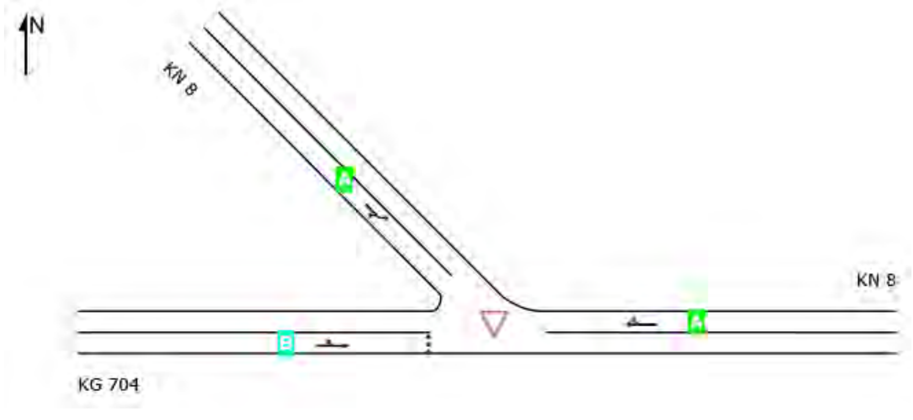
- Signalisation
- Short left-turn lane on northern approach
- Short left-turn lane on eastern approach
- Short left-turn lane on southern approach
- Short left-turn lane on western approach

AM Peak: Intersection 13	PM Peak: Intersection 13
	

Notes:

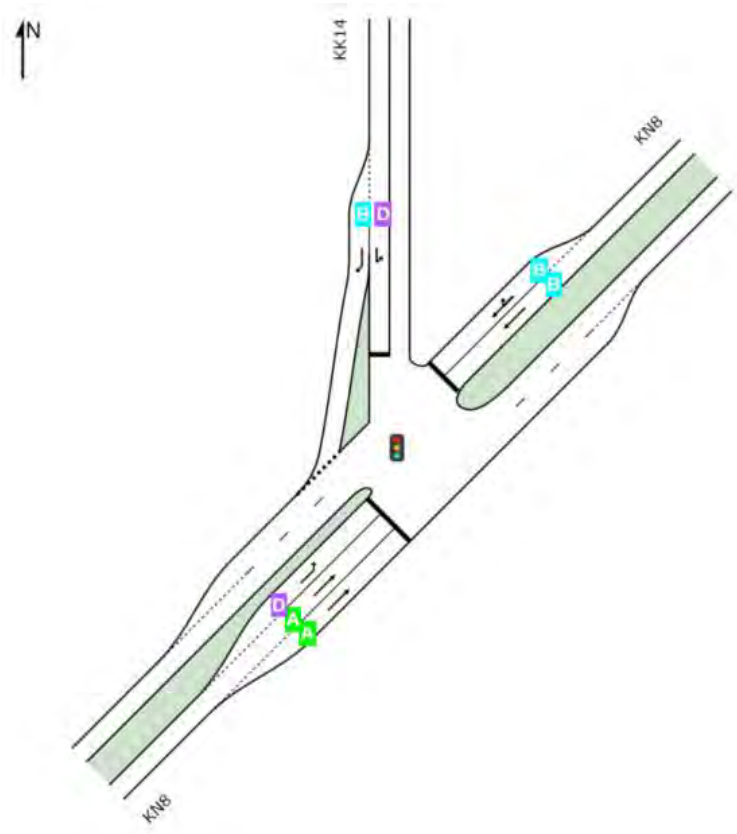
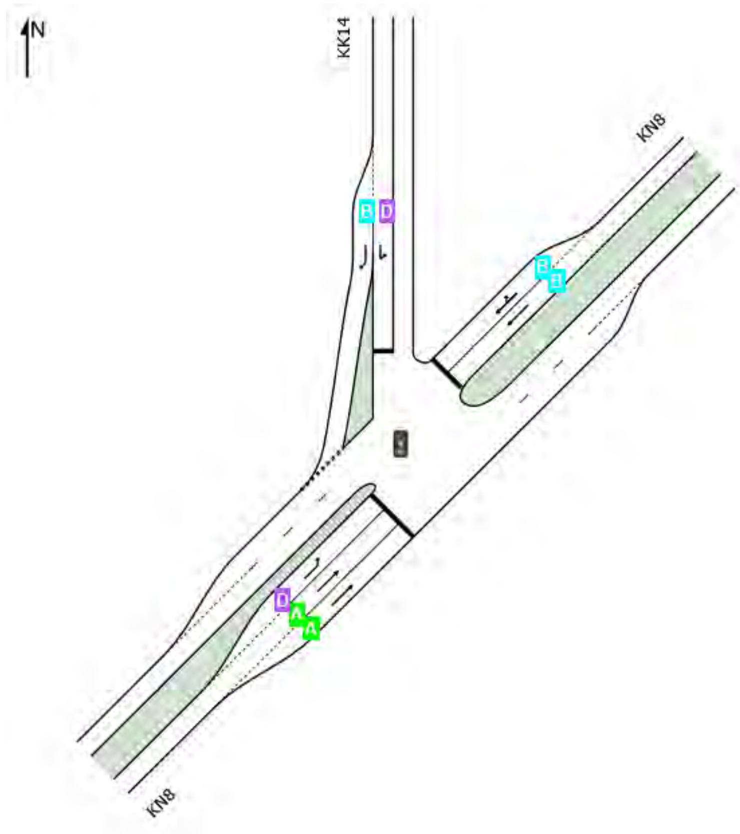
This intersection requires the following upgrades:

- Additional short approach lane on the northern approach

AM Peak: Intersection 14	PM Peak: Intersection 14
	

Notes:

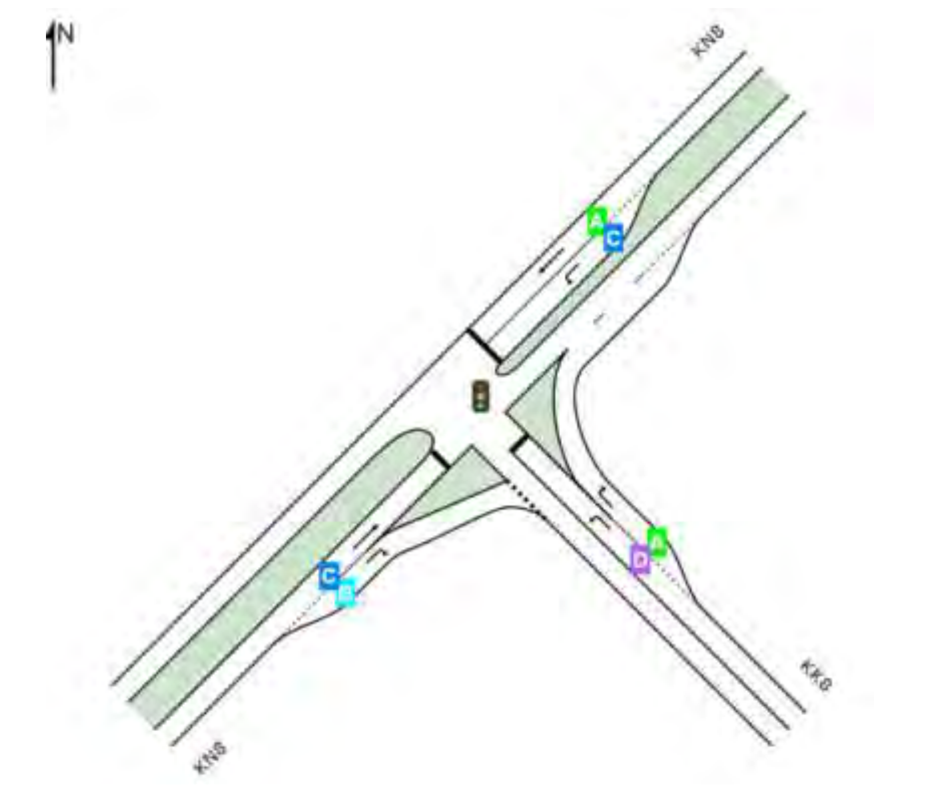
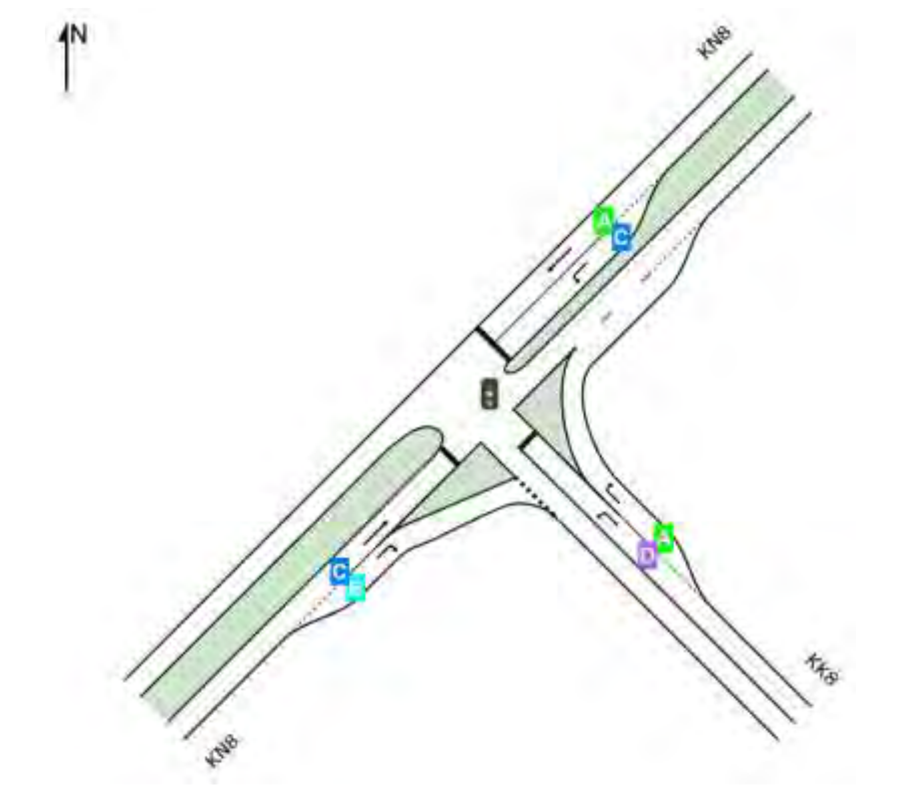
Intersection 14 requires a left turn lane from the eastern approach, to prevent left-turning vehicles from blocking the through movement while yielding to oncoming traffic. This was modelled in the network analysis.

AM Peak: Intersection 15	PM Peak: Intersection 15
	

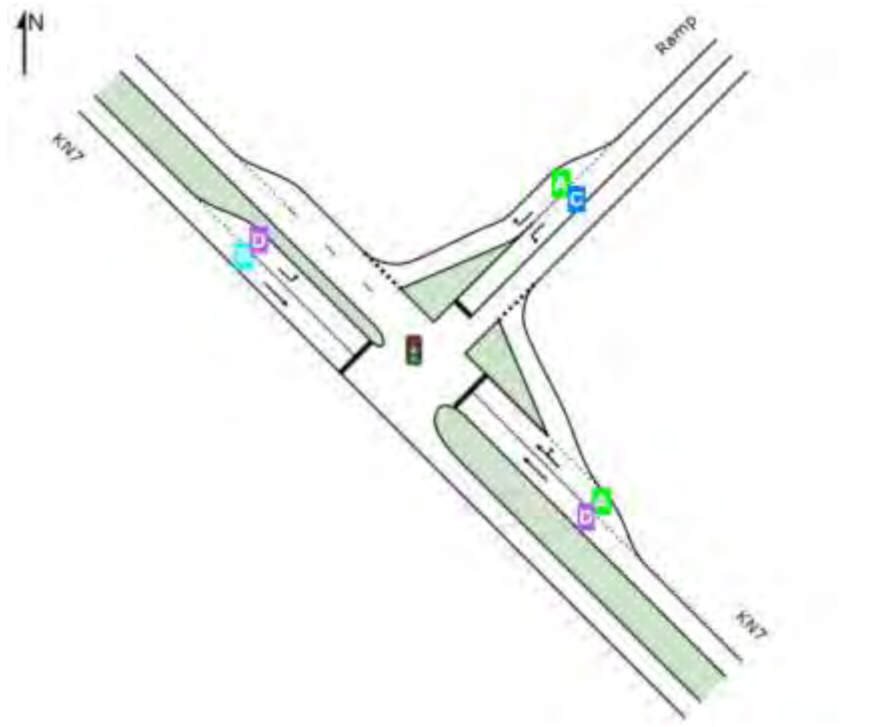
Notes:

This intersection requires the following upgrades:

- Signalisation
- Additional short right-turn slip lane on northern approach
- Additional short through lane, and short exit lane on north-eastern approach
- Additional short through lane, short left-turn lane and short exit lane on south-western approach

AM Peak: Intersection 16-1	PM Peak: Intersection 16-1
	

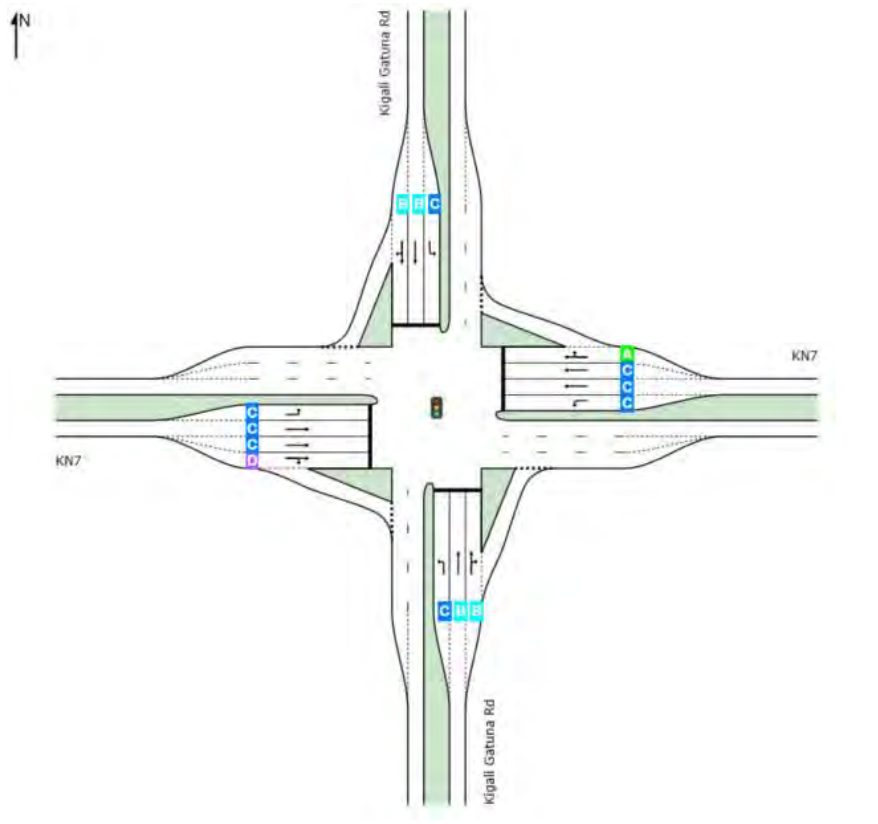
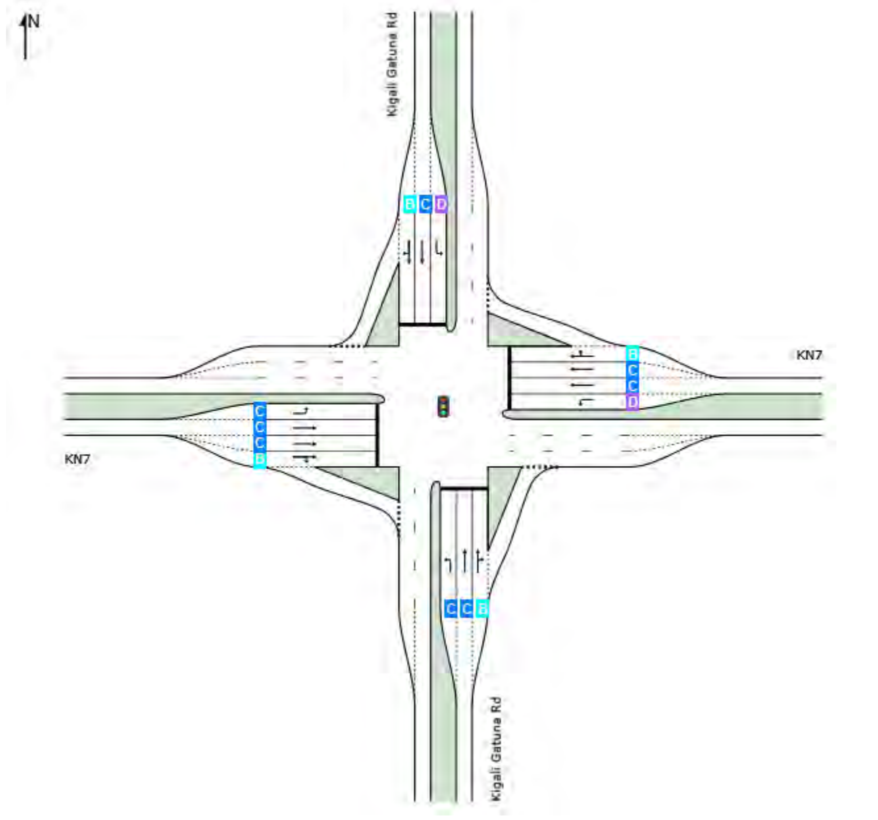
Notes:
This intersection requires the following upgrades: • Signalisation • Additional short left-turn lane and short exit lane on north-eastern approach • Additional short right-turn slip lane on south-eastern approach • Short right-turn slip lane on south-western approach

AM Peak: Intersection 16-2	PM Peak: Intersection 16-2
	

Notes:

This intersection requires the following upgrades:

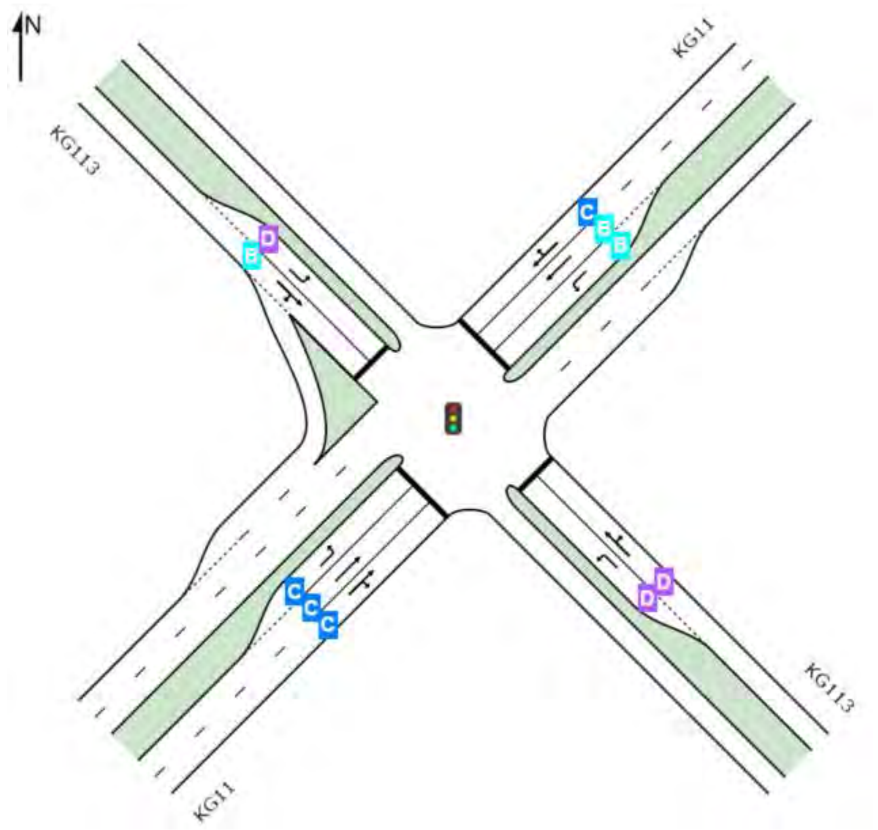
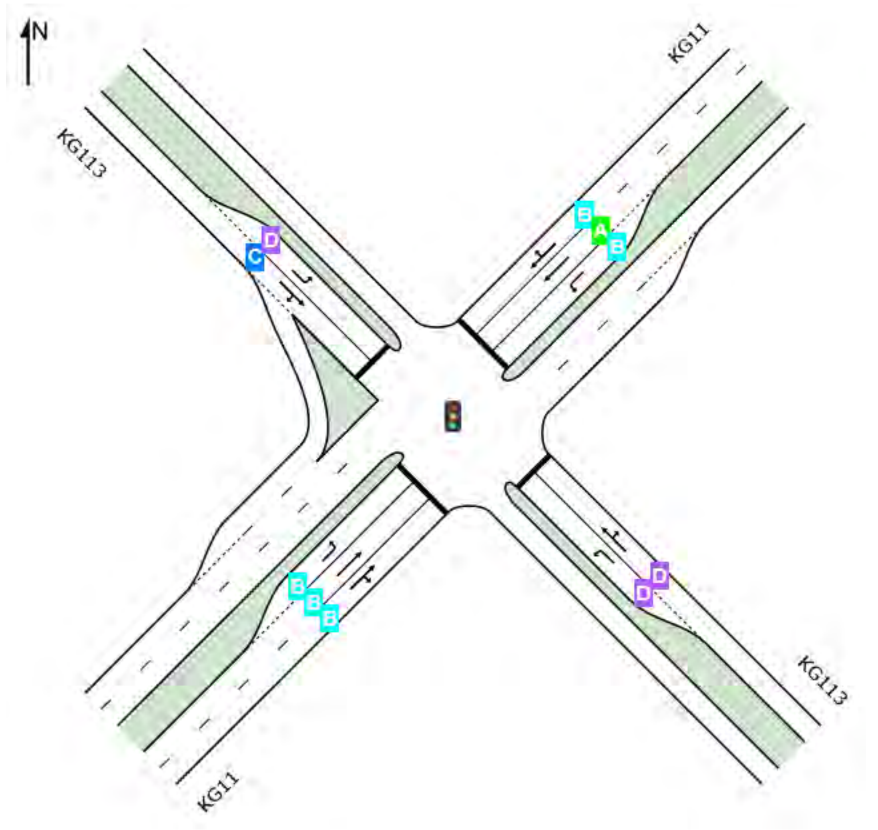
- Signalisation
- Short right-turn slip lane on north-eastern approach
- Additional short through lane on south-eastern approach
- Short left-turn lane and short exit lane on north-western approach

AM Peak: Intersection 17	PM Peak: Intersection 17
	

Notes:

This intersection requires the following upgrades:

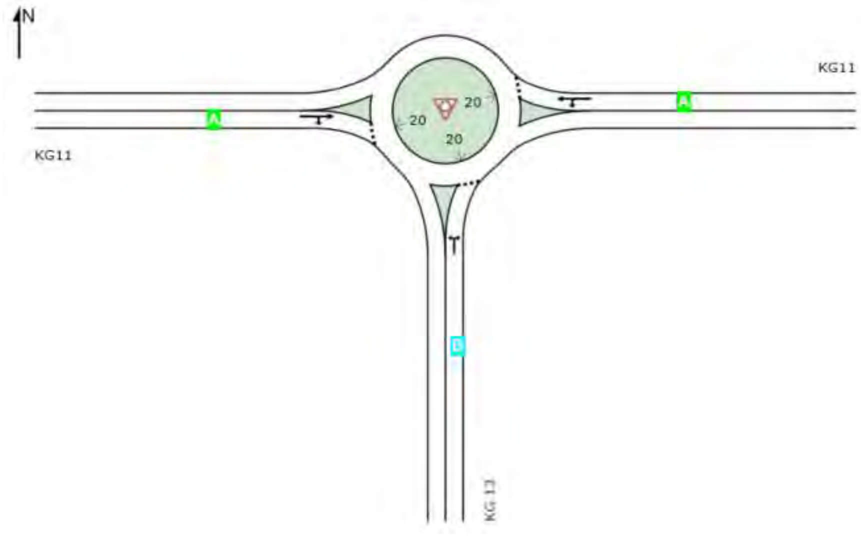
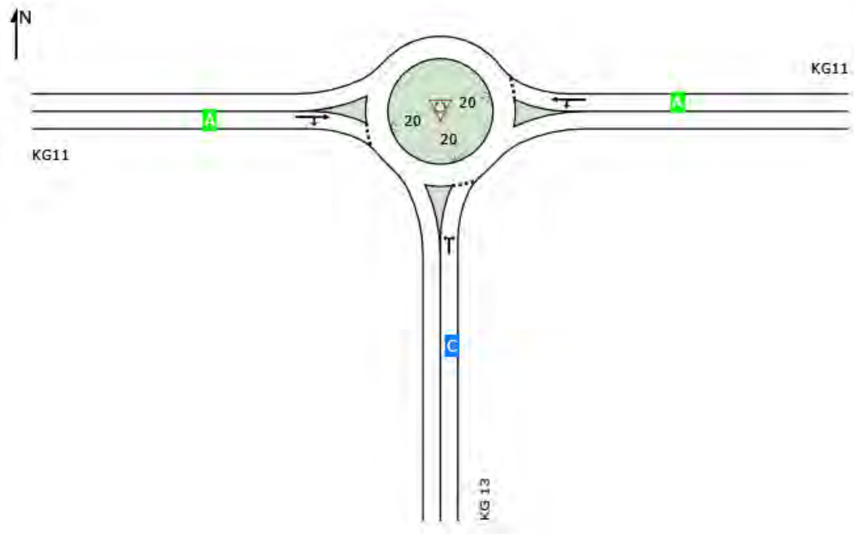
- Signal reactivated
- Short left-turn lane with right-turn slip lane on northern approach
- Short left-turn lane, additional short through lane, right-turn slip lane and additional short through lane on eastern approach
- Short left-turn lane and right-turn slip lane on southern approach
- Short left-turn lane, additional short through lane, right-turn slip lane and additional short through lane on western approach

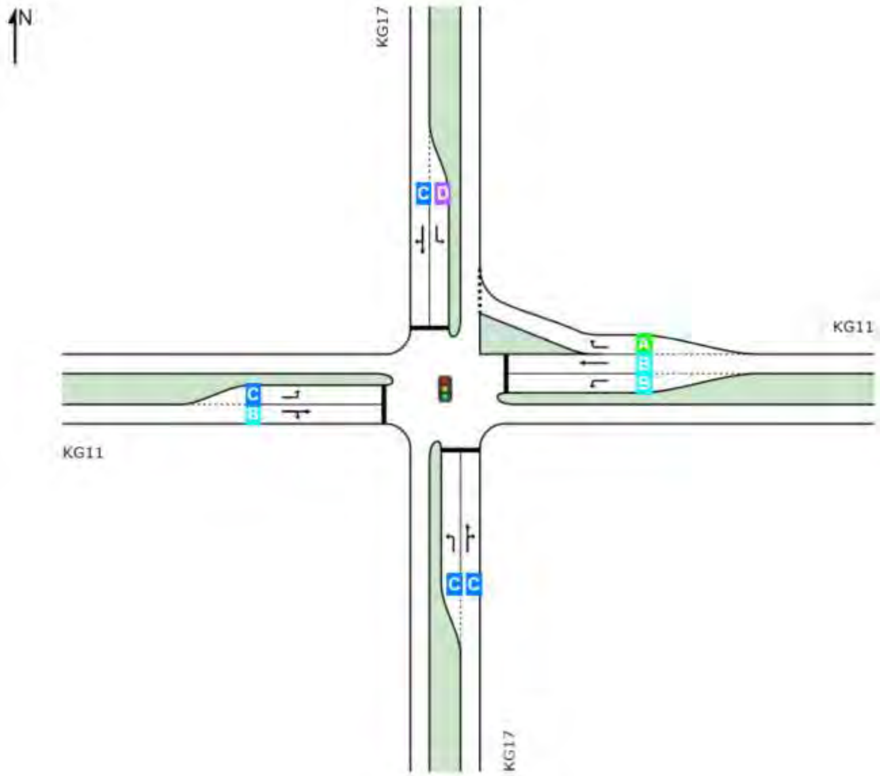
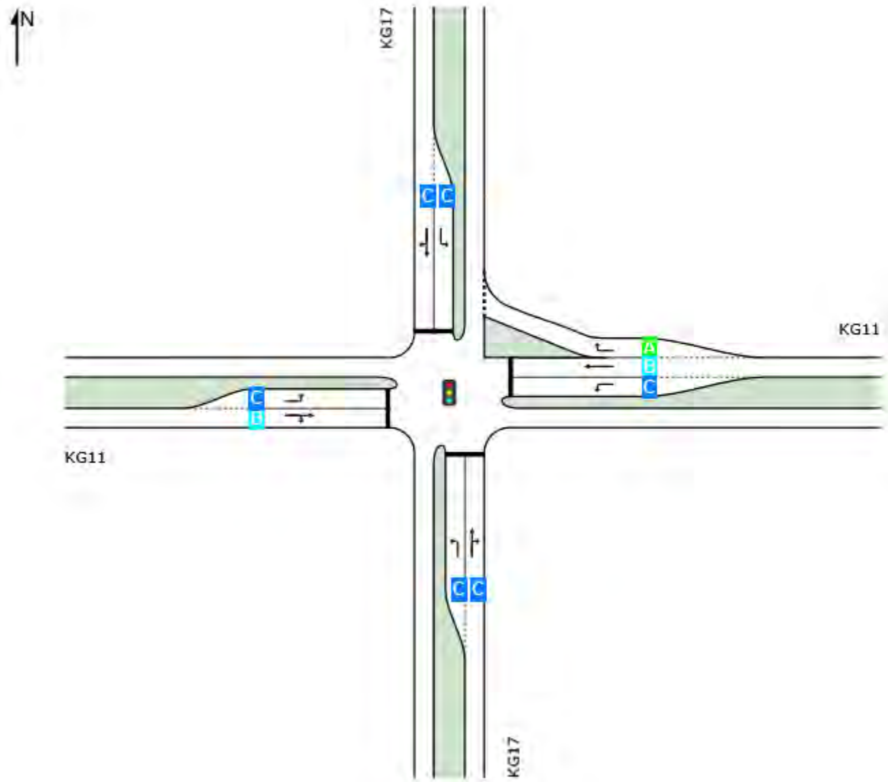
AM Peak: Intersection 18	PM Peak: Intersection 18
	

Notes:

This intersection requires the following upgrades:

- Signalisation
- Short left-turn lane, additional through lane and short exit lane on north-eastern approach
- Short left-turn lane on south-eastern approach
- Short left-turn lane, additional through lane, short exit lane and full length exit lane on south-western approach
- Short left-turn lane and right-turn slip on north-western approach

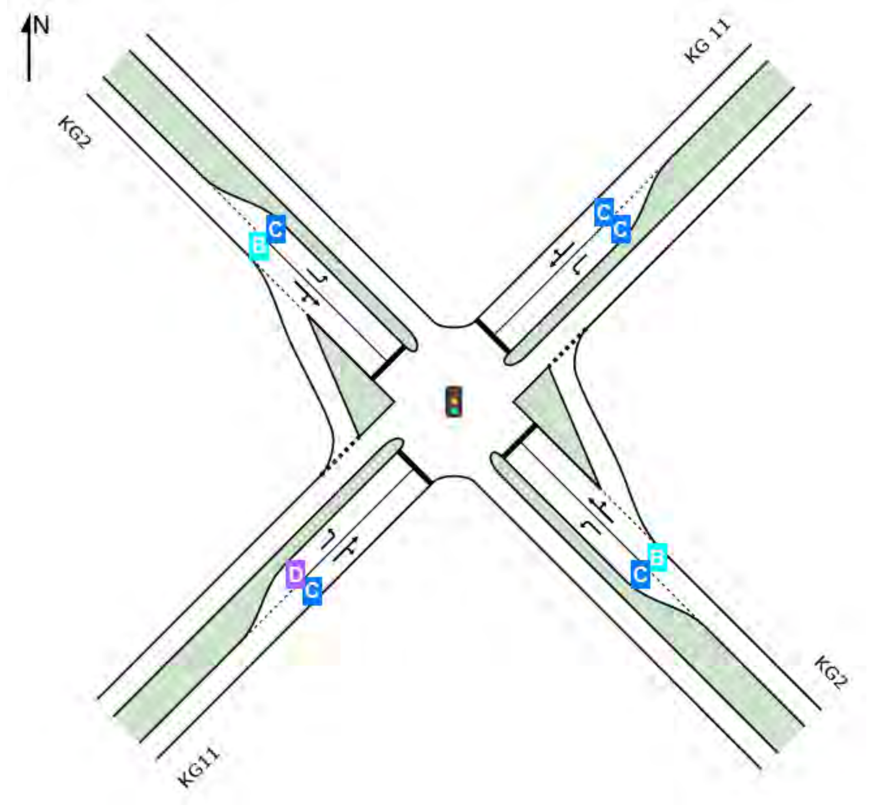
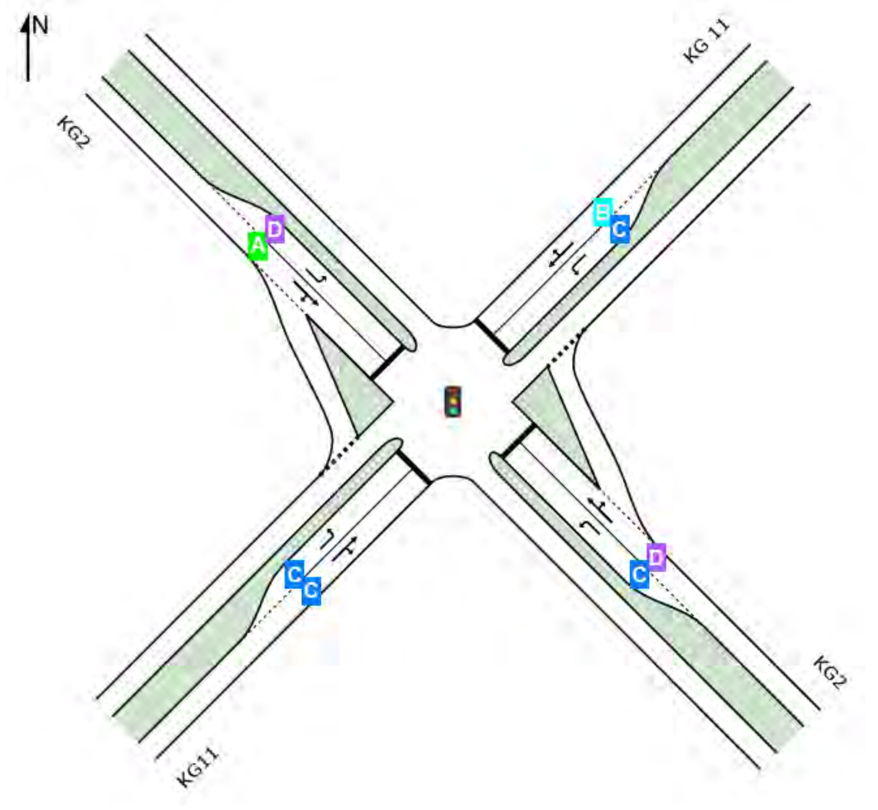
<table>
<tr><th>AM Peak: Intersection 19</th><th>PM Peak: Intersection 19</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th colspan="2">Notes:</th></tr>
<tr><td colspan="2">Intersection 19 requires a conversion to a single-lane roundabout.</td></tr>
</table>

AM Peak: Intersection 20	PM Peak: Intersection 20
	

Notes:

This intersection requires the following upgrades:

- Signalisation
- Short left-turn lane on northern approach
- Short left-turn lane and right-turn slip lane on eastern approach
- Short left-turn lane on southern approach
- Short left-turn lane on western approach

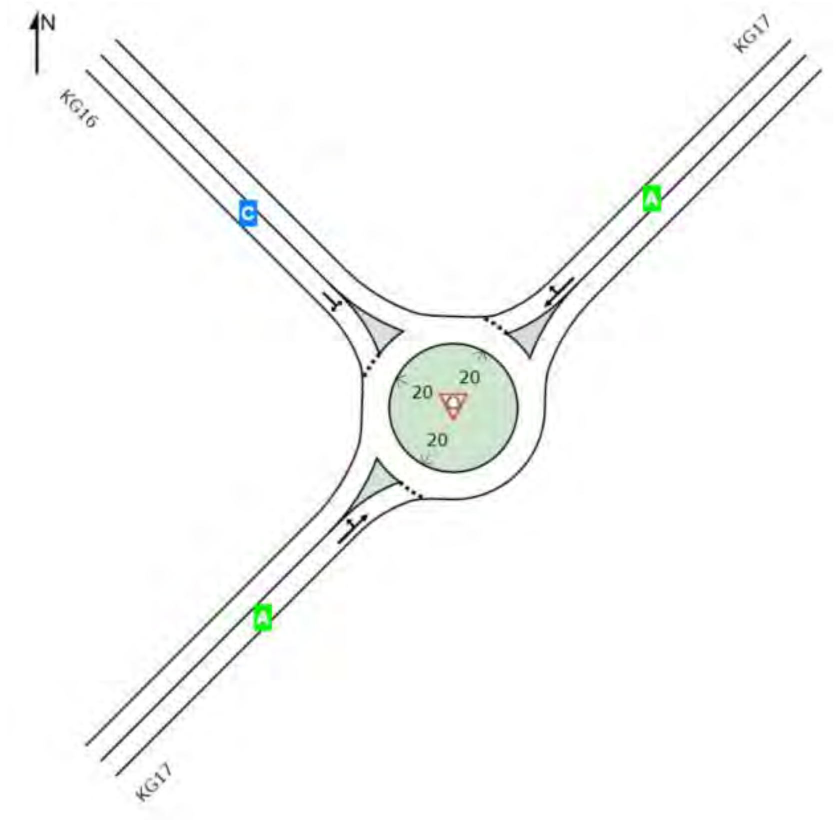
AM Peak: Intersection 21	PM Peak: Intersection 21
	

Notes:

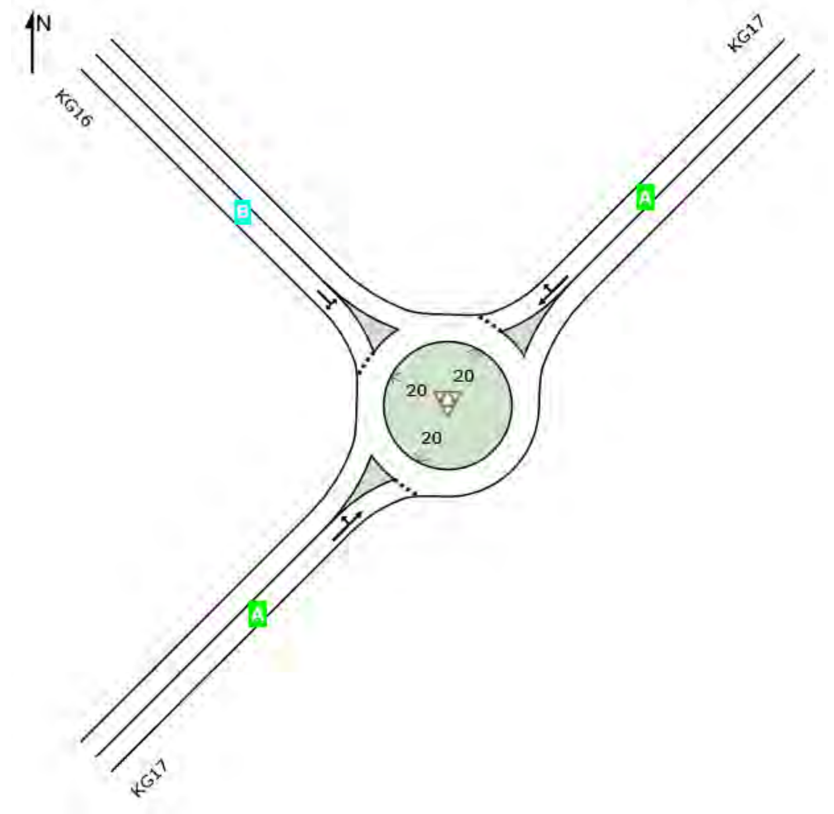
This intersection requires the following upgrades:

- Signalisation
- Short left-turn lane on north-eastern approach
- Relocation of south-eastern approach, with short left-turn lane and right-turn slip lane
- Short left-turn lane on south-western approach
- Short left-turn lane and right-turn slip lane on north-western approach

AM Peak: Intersection 22

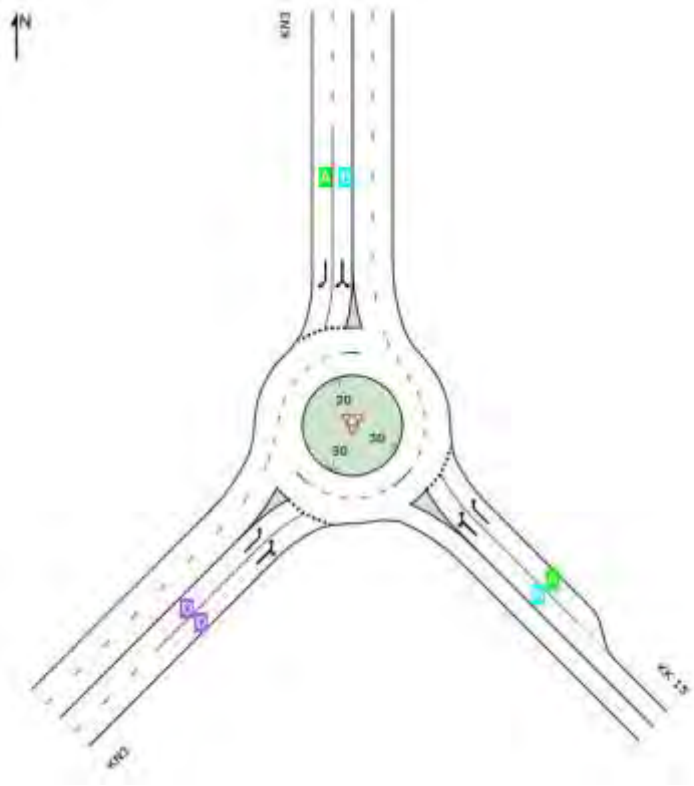
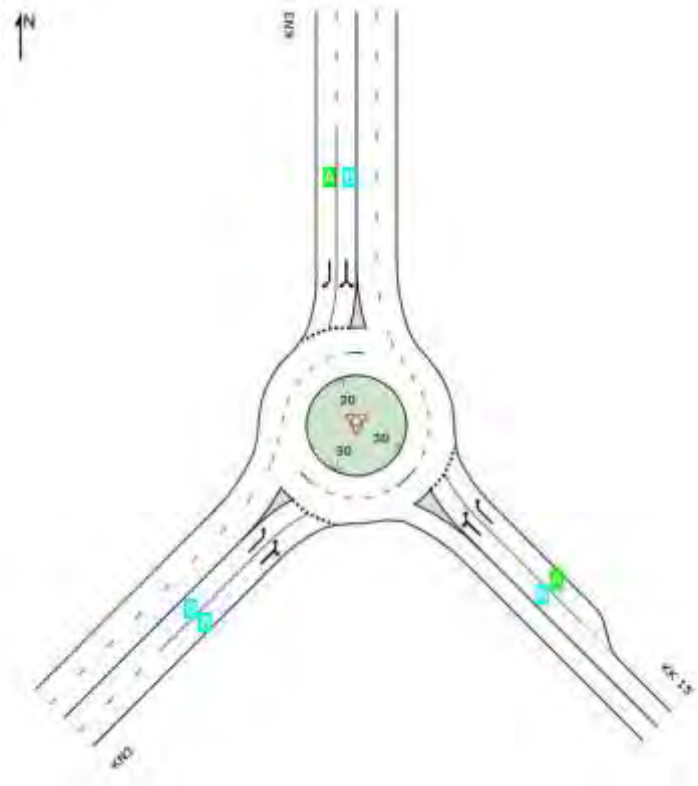


PM Peak: Intersection 22



Notes:

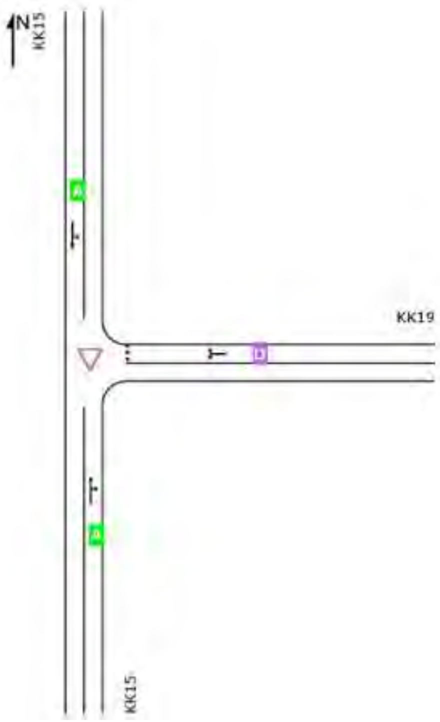
Intersection 22 requires a geometric conversion of the intersection to a single-lane roundabout.

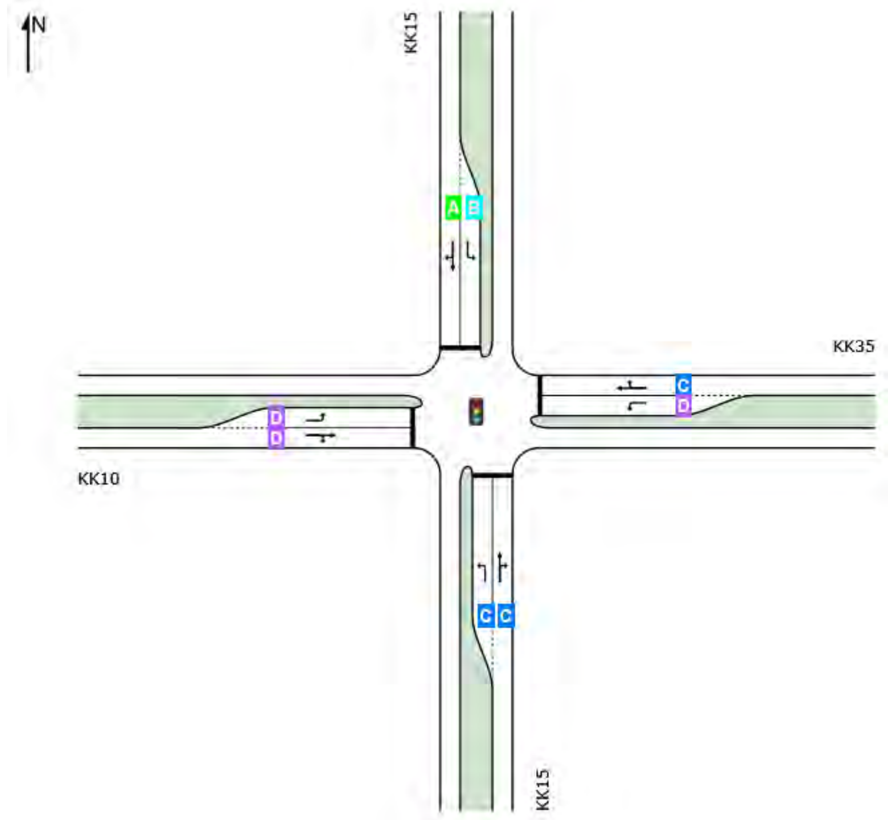
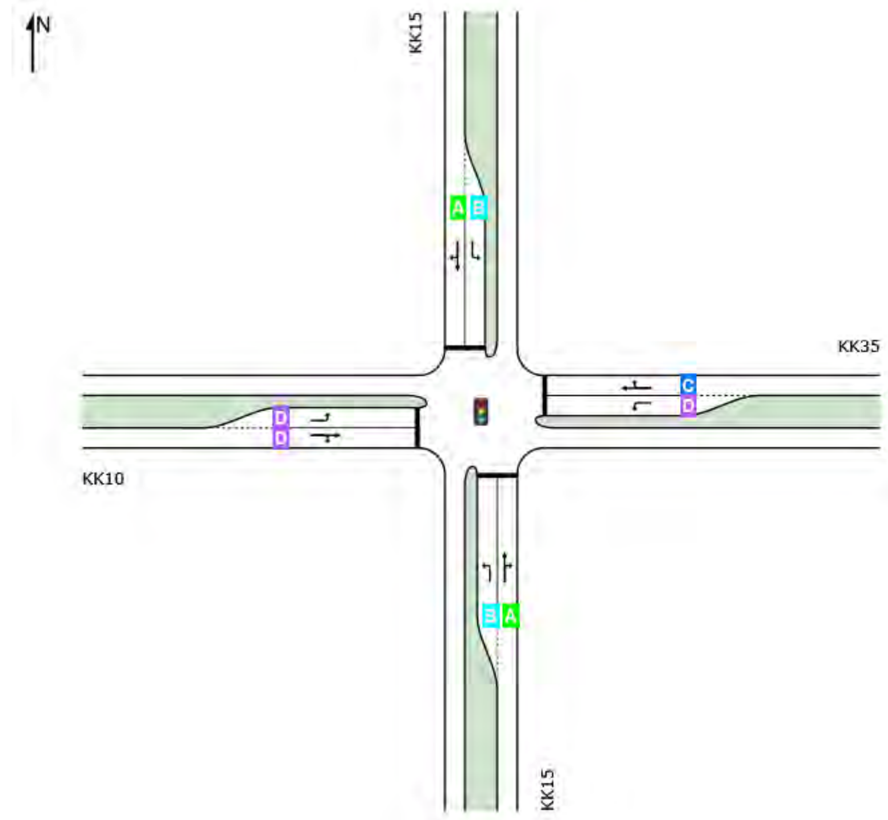
AM Peak: Intersection 23	PM Peak: Intersection 23
	

Notes:

This intersection requires the following upgrades:

- Additional short approach lane on south-eastern approach

AM Peak: Intersection 24	PM Peak: Intersection 24
	
Notes:	
The AM peak functions acceptably with regards to LOS and V/C ratios. However, it must be noted that the eastern approach queue length is at 4 vehicles. A short left-turning lane is added to the main movement in the network (Vissim) analysis to prevent yielding traffic from blocking the through movement.	

AM Peak: Intersection 25	PM Peak: Intersection 25
	

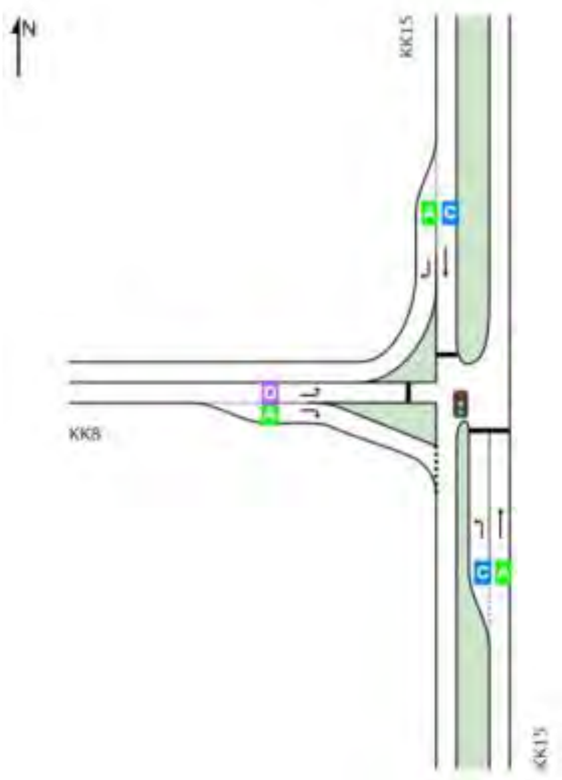
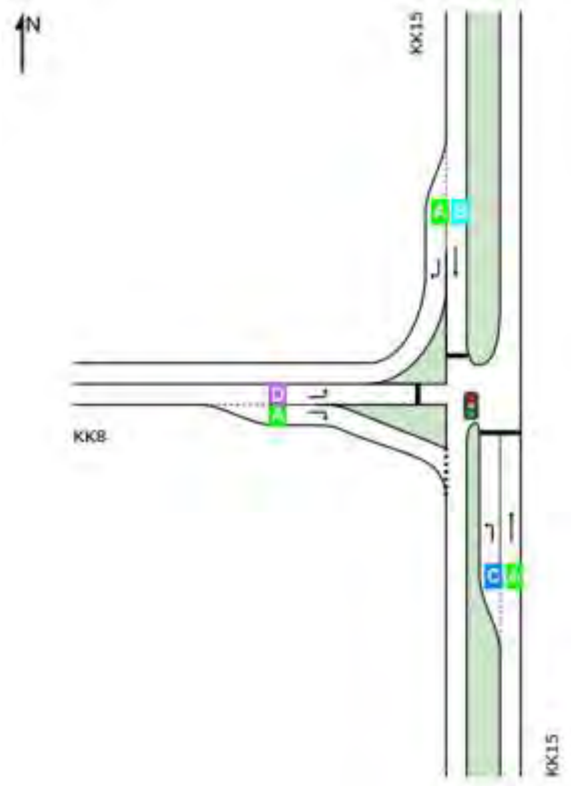
Notes:

This intersection requires the following upgrades:

- Signalisation
- Short left-turn lane on northern approach
- Short left-turn lane on eastern approach
- Short left-turn lane on southern approach
- Short left-turn lane on western approach

AM Peak: Intersection 26	PM Peak: Intersection 26
	

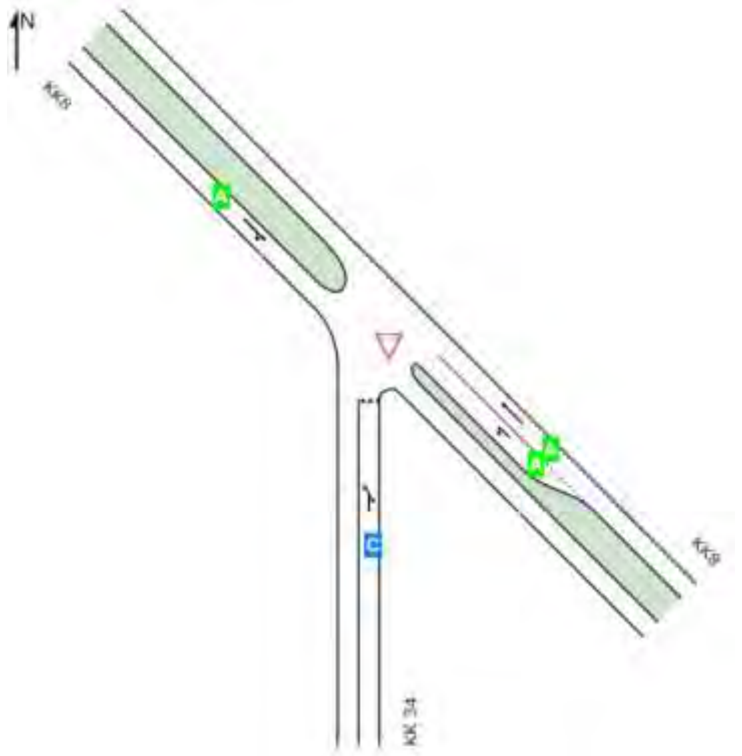
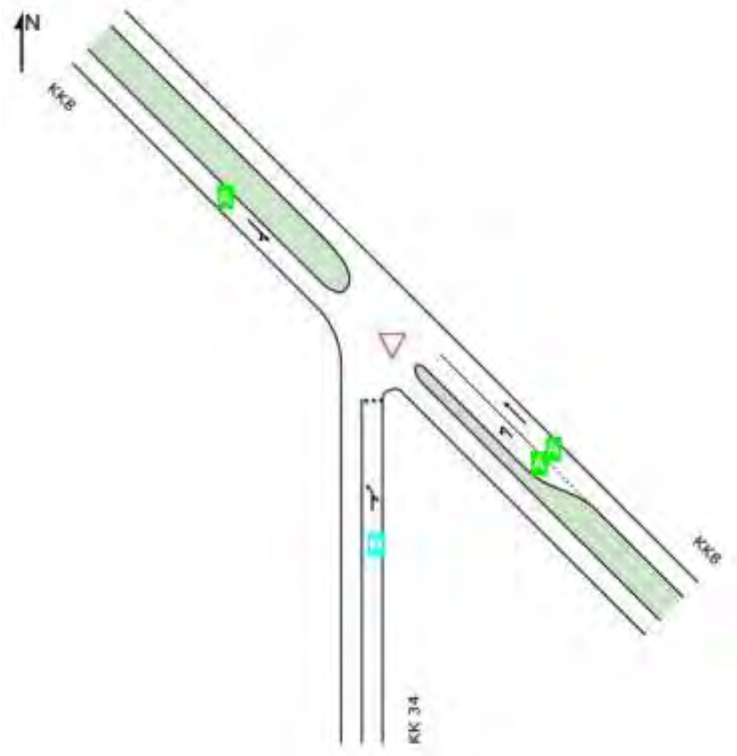
Notes:
The AM and PM peak functions acceptably and does not require geometric upgrades. A short left-turning lane is added to the main movement in the network (Vissim) analysis to prevent yielding traffic from blocking the through movement.

AM Peak: Intersection 27	PM Peak: Intersection 27
	

Notes:

This intersection requires the following upgrades:

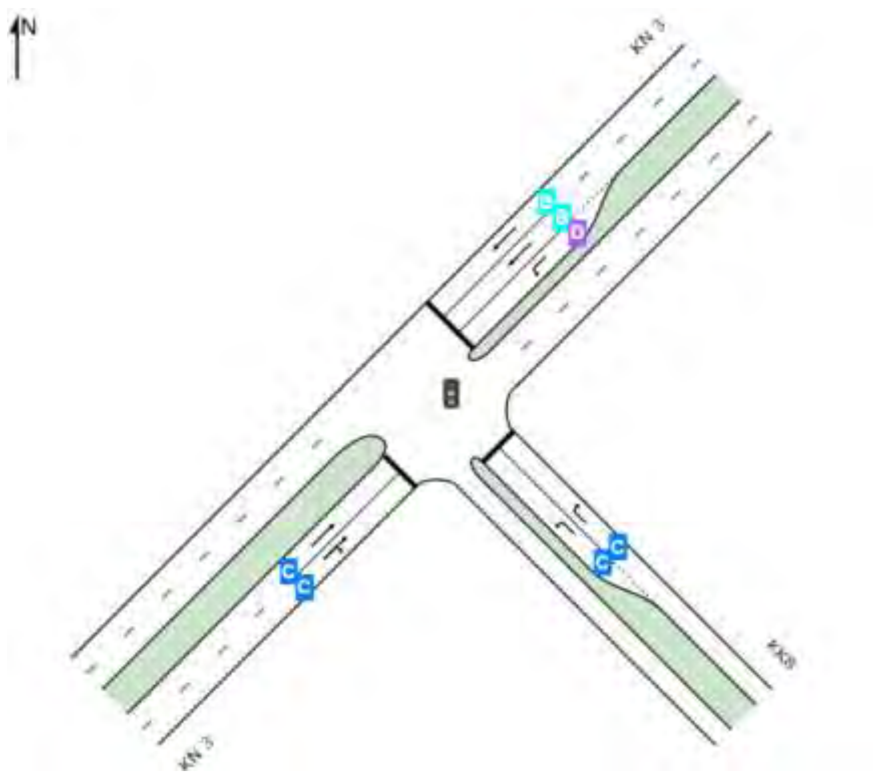
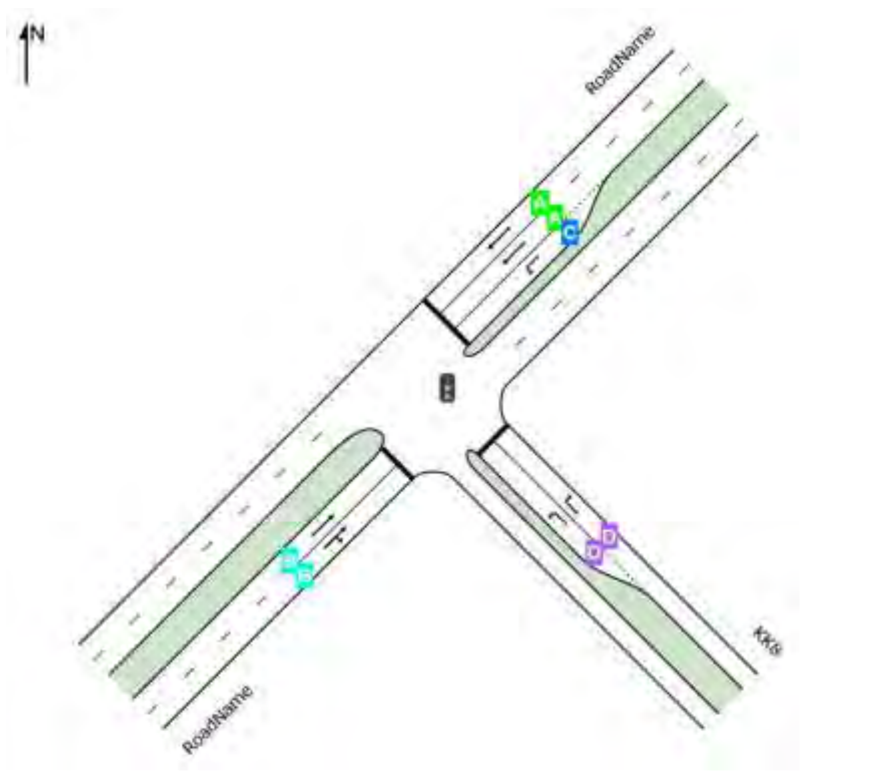
- Signalisation
- Short right-turn slip lane on northern approach
- Short left-turn lane on southern approach
- Short right-turn slip lane on western approach

AM Peak: Intersection 28	PM Peak: Intersection 28
	

Notes:

This intersection requires the following upgrades:

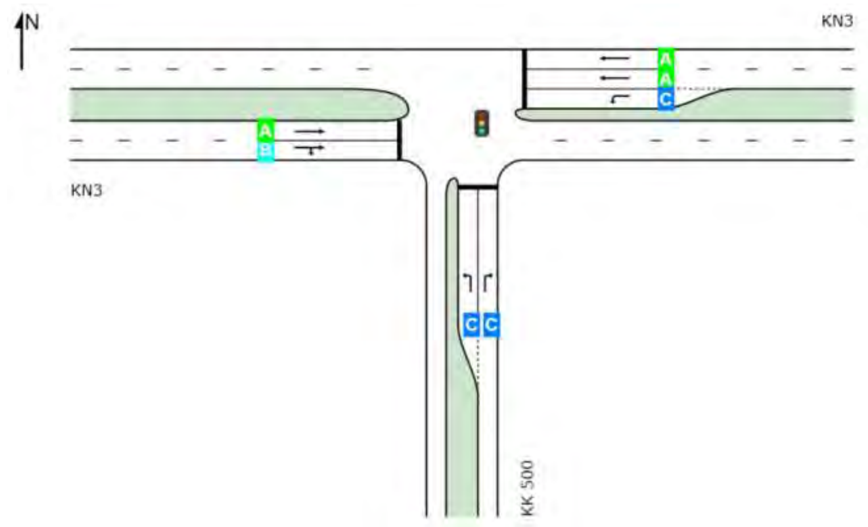
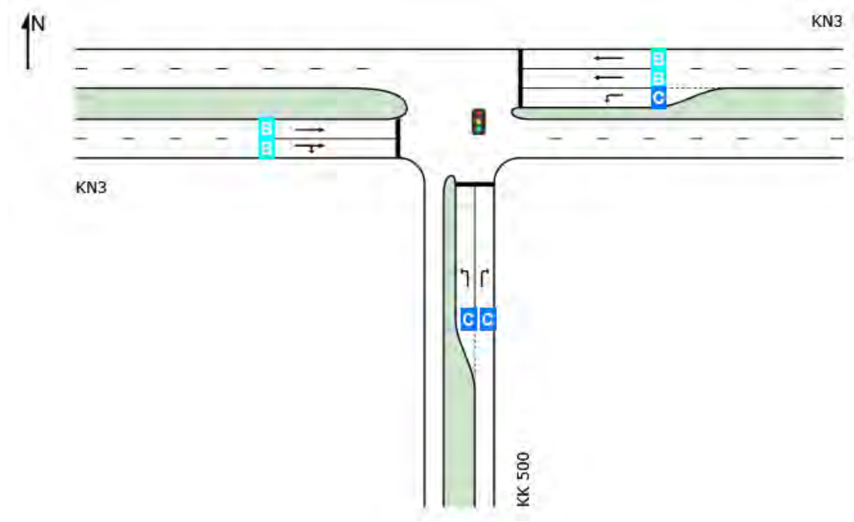
- Short left-turn lane on south-eastern approach

AM Peak: Intersection 29	PM Peak: Intersection 29
	

Notes:

This intersection requires the following upgrades:

- Signalisation
- Short left-turn lane on north-eastern approach
- Short left-turn lane on south-eastern approach

AM Peak: Intersection 30	PM Peak: Intersection 30
	

Notes:

This intersection requires the following upgrades:

- Signalisation
- Short left-turn lane on eastern approach
- Short left-turn lane on southern approach

It should be noted that this intersection did not require any upgrade in the network (Vissim) analysis and functioned acceptably with current geometry

5.4. Future Analyses

The future analysis was done using the calculated growth rate (as detailed in Chapter 0) and applying the additional traffic to the corridors. This was to determine the sensitivity for traffic growth and available capacity of the proposed solutions (Quick Wins). The movement summaries of the future analysis can be found in **Annexure E.**

The results of the future analysis indicate that, with the proposed traffic growth, four of the 31 intersections fail (

Table 5-6 and

Table 5-7). However, intersection 24 is resolved in the network analysis using a left turn lane. Intersection 14 shows acceptable levels of service for the network analysis, due to the difference in gap acceptance.

As a result, only intersections 5 and 23 are failing. Intersection 23 was under construction during the site traffic counts and should be monitored regarding the capacity improvements. Intersection 5, during the PM peak is a major concern. The proposed solutions for intersection 5 already utilise the available space in the area. There are two possible options to alleviate the congestion.

One option would be to grade separate the intersection. However, there are quite a number of business' accesses that are served by this location and the space required for grade separation is large. Moreover, there is a BRT network planned for this route, which would require stations in this area. The other alternative would be to allow for the development of alternative mobility corridors to alleviate the traffic congestion and demand on the KN5 route. This option is further discussed in the future road network in the transportation model.

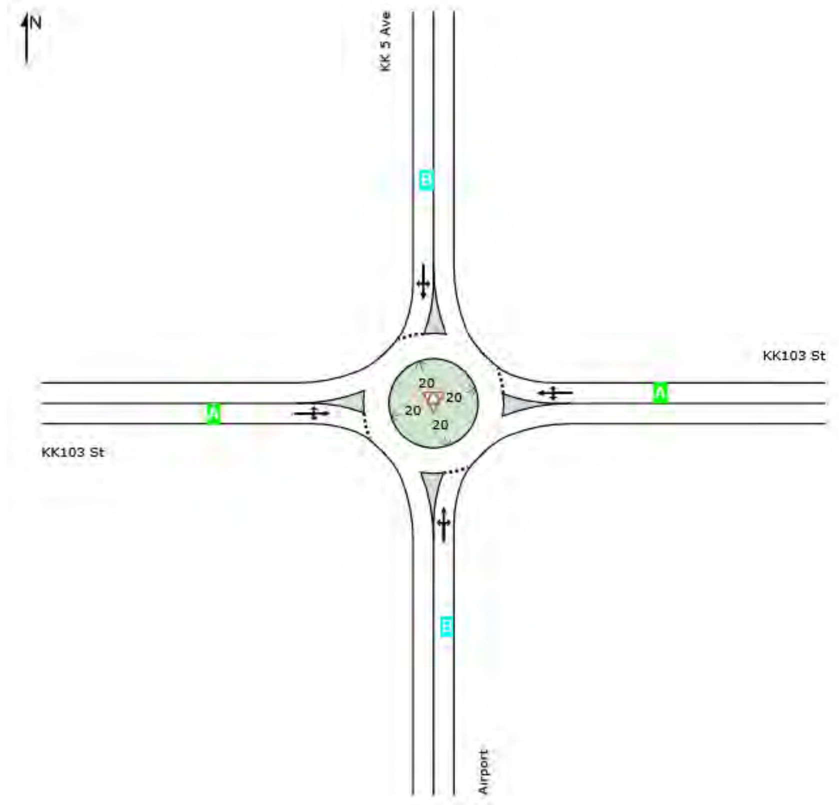
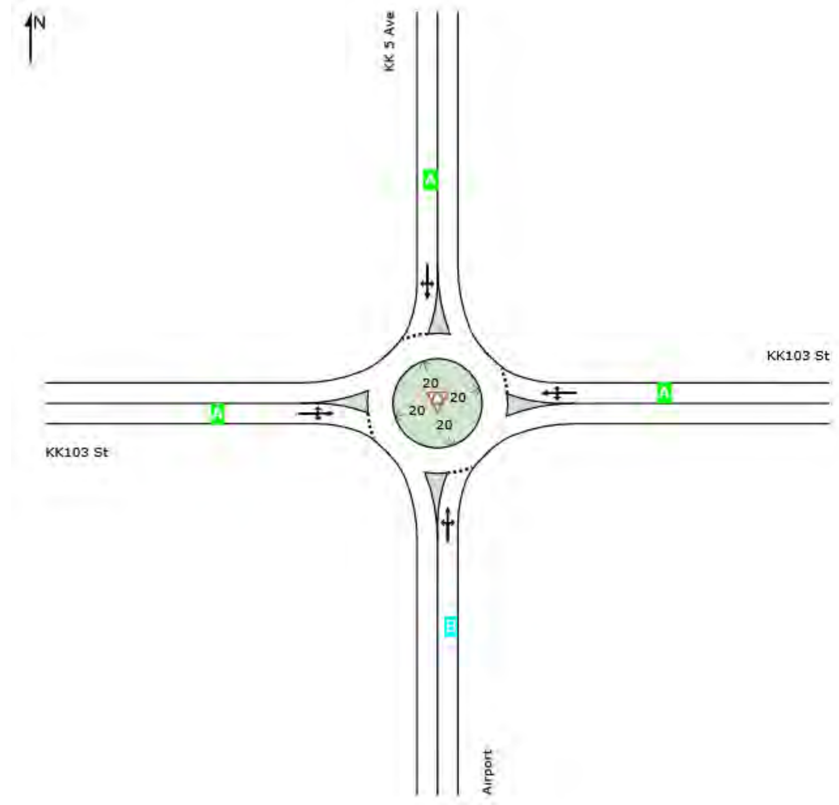
Nevertheless, the remaining 27 intersections are all functioning with acceptable delays, queue lengths and V/C ratios with the applied future growth. This means that 27 of the 31 intersections have an excess of 1.16 times the current capacity available for future traffic expansion. The LOS results are shown below. The majority of the intersections are functioning with an average LOS B for all the movements. This is a substantial improvement from the Status Quo functioning of a LOS E.

Table 5-6: SIDRA results of the AM peak future analysis

AM PEAK					
NUMBER	PROPOSED UPGRADES			STATUS	DESCRIPTION
	TYPE	MAX QUE	LOS	ACCEPTABLE/ FAIL	
1	Circle	4,1	A	Acceptable	No Change
2	Signal	35	C	Acceptable	Signal and Geometric Upgrade
3	Signal	55	D	Acceptable	Geometric and Phasing Upgrade
4	Signal	23,5	C	Acceptable	Signal and Geometric Upgrade
5	Circle	37,5	C	Acceptable	Requires grade separation
6	Signal	60,5	C	Acceptable	Signal and Geometric Upgrade
7	Circle	6,1	A	Acceptable	Geometric Upgrade
8	Circle	0,4	A	Acceptable	No Change
9	Circle	N/A	No conflict	Acceptable	No Change
10	Unsolvable in SIDRA (Solved in Vissim as Grade Separation)				Flyover left turn Northern Approach
11	Signal	25,9	D	Acceptable	Signal and Geometric Upgrade
12	Signal	18	B	Acceptable	Signal and Geometric Upgrade
13	Circle	16,9	B	Acceptable	Geometric Upgrade
14	Priority	347	F (East)	Fail	Requires Conversion to Signal
15	Signal	40,3	B	Acceptable	Signal and Geometric Upgrade
16-1	Signal	33,4	B	Acceptable	Signal and Geometric Upgrade
16-2	Signal	44,9	C	Acceptable	Signal and Geometric Upgrade
17	Signal	14,9	C	Acceptable	Signal and Geometric Upgrade
18	Signal	22,9	C	Acceptable	Signal and Geometric Upgrade
19	Circle	8	A	Acceptable	Circle and Geometric Upgraded
20	Circle	15,1	B	Acceptable	Circle and Geometric Upgraded
21	Signal	70,1	C	Acceptable	Signal and Geometric Upgrade
22	Circle	24,7	B	Acceptable	Circle and Geometric Upgraded
23	Circle	276	F (South West)	Fail	Geometric Upgrade
24	Priority	91,9	F (East)	Fail	Requires Changes
25	Circle	12,9	B	Acceptable	Circle and Geometric Upgraded
26	Priority	3,5	C (East)	Acceptable	No Change
27	Signal	25,9	B	Acceptable	Signal and Geometric Upgrade
28	Priority	6,3	D (South)	Acceptable	South East Left Turn Lane
29	Signal	32,6	C	Acceptable	Signal and Geometric Upgrade
30	Signal	15,3	B	Acceptable	Signal and Geometric Upgrade
	16 Signals **12 Circles** **3 priority**			**31 Acceptable**	**96% of the intersections still function with an acceptable LOS and queue length with the proposed solutions**

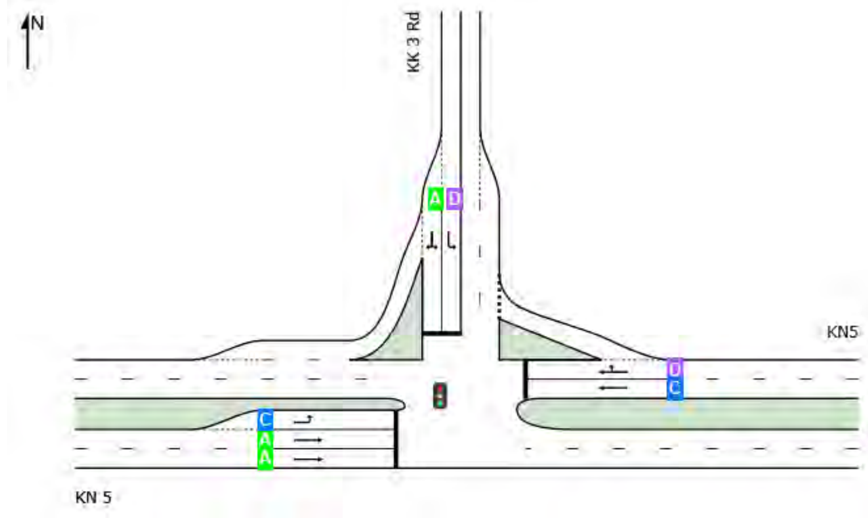
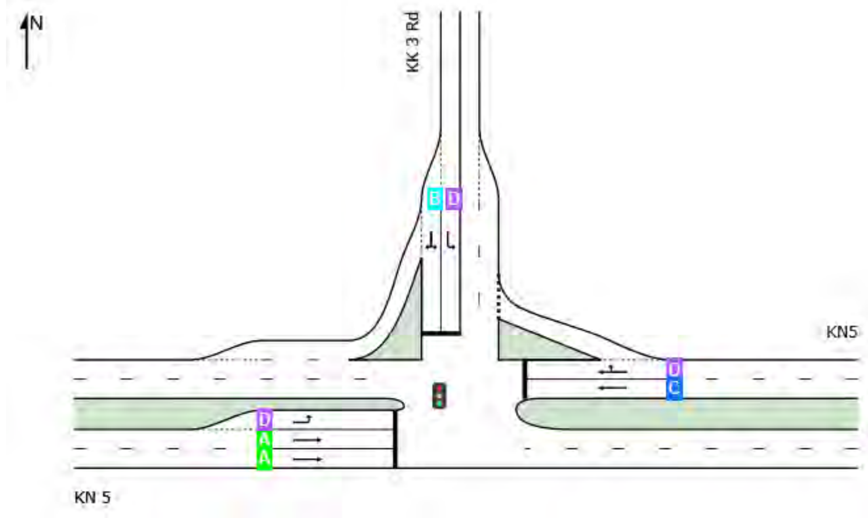
Table 5-7: SIDRA results of the AM peak future analysis

PM PEAK					
NUMBER	PROPOSED UPGRADES			STATUS	DESCRIPTION
	TYPE	MAX QUE	LOS	ACCEPTABLE/ FAIL	
1	Circle	2,9	A	Acceptable	No Change
2	Signal	36,1	C	Acceptable	Signal and Geometric Upgrade
3	Signal	41,4	C	Acceptable	Geometric and Phasing Upgrade
4	Signal	40,9	C	Acceptable	Signal and Geometric Upgrade
5	Circle	113	F (South)	Fail	Requires grade separation
6	Signal	26,8	C	Acceptable	Signal and Geometric Upgrade
7	Circle	4,2	A	Acceptable	Geometric Upgrade
8	Circle	0,5	A	Acceptable	No Change
9	Circle	N/A	No conflict	Acceptable	No Change
10	Unsolvable in SIDRA (Solved in Vissim as Grade Separation)				Flyover left turn Northern Approach
11	Signal	20,3	C	Acceptable	Signal and Geometric Upgrade
12	Signal	23,6	C	Acceptable	Signal and Geometric Upgrade
13	Circle	4,4	A	Acceptable	Geometric Upgrade
14	Priority	36,4	F	Fail	Requires Conversion to Signal
15	Signal	42,2	B	Acceptable	Signal and Geometric Upgrade
16-1	Signal	24,2	B	Acceptable	Signal and Geometric Upgrade
16-2	Signal	54,2	D	Acceptable	Signal and Geometric Upgrade
17	Signal	26,2	C	Acceptable	Signal and Geometric Upgrade
18	Signal	38,7	C	Acceptable	Signal and Geometric Upgrade
19	Circle	7,3	A	Acceptable	Circle and Geometric Upgraded
20	Circle	28,7	B	Acceptable	Circle and Geometric Upgraded
21	Signal	45,8	C	Acceptable	Signal and Geometric Upgrade
22	Circle	11,3	A	Acceptable	Circle and Geometric Upgraded
23	Circle	19,9	B	Acceptable	Geometric Upgrade
24	Priority	22,5	F	Fail	Requires Changes
25	Circle	20,5	B	Acceptable	Circle and Geometric Upgraded
26	Priority	2,5	C (South East)	Acceptable	No Change
27	Signal	28,2	B	Acceptable	Signal and Geometric Upgrade
28	Priority	5,5	D (South)	Acceptable	South East Left Turn Lane
29	Signal	23,3	B	Acceptable	Signal and Geometric Upgrade
30	Signal	7,6	A	Acceptable	Signal and Geometric Upgrade
	16 Signals			**31 Acceptable**	**96% of the intersections still function with an acceptable LOS and queue length with the proposed solutions**
	12 Circles				
	3 priority				

AM Peak: Intersection 1	PM Peak: Intersection 1
	

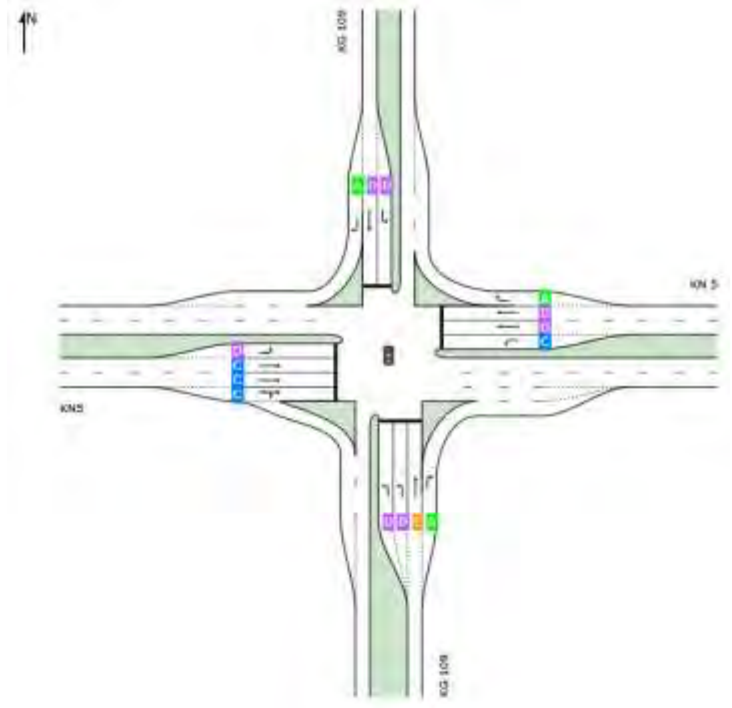
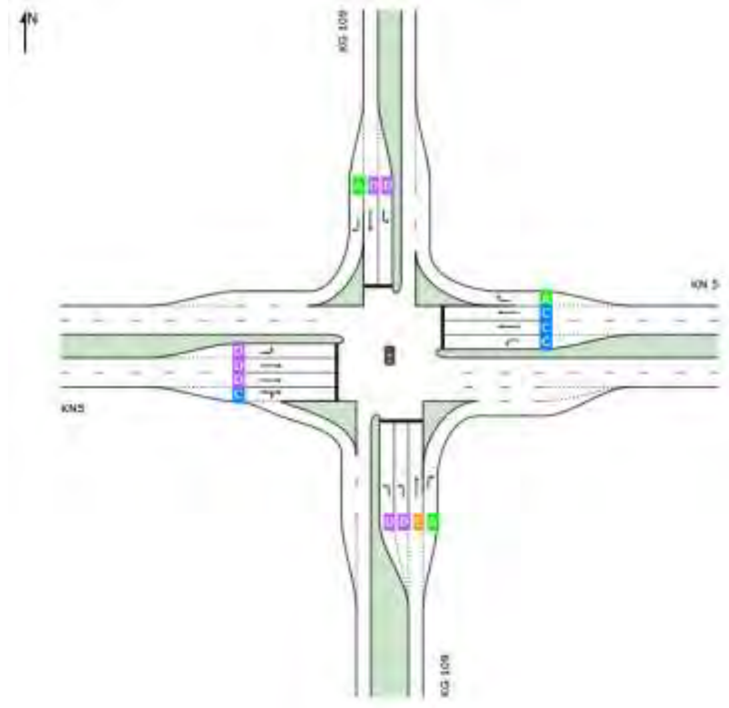
Notes:

The AM and PM peak functions acceptably regarding the LOS. No change was required to the existing geometric configuration.

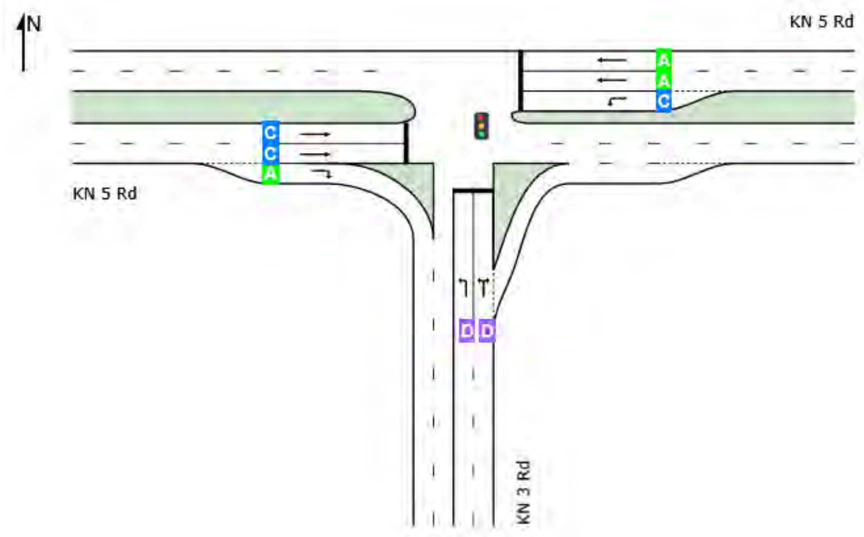
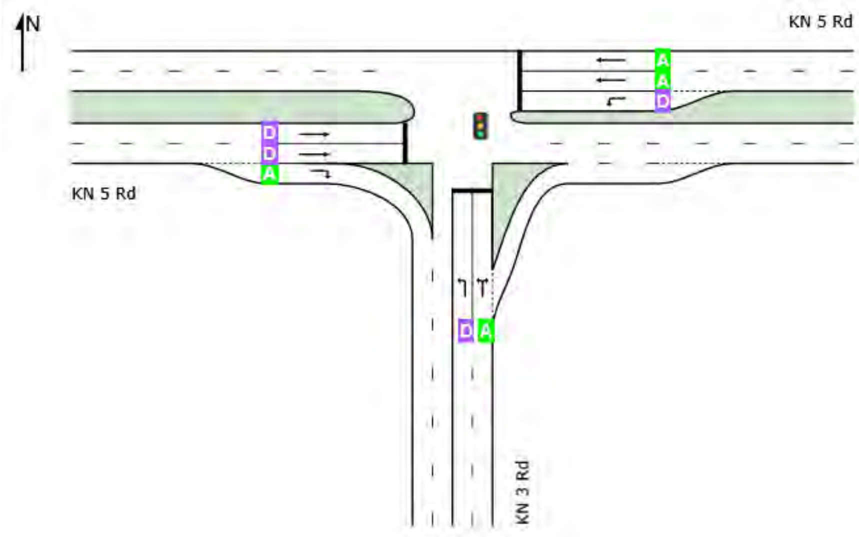
AM Peak: Intersection 2	PM Peak: Intersection 1
	

Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 3	PM Peak: Intersection 3
	

Notes:
The proposed solution satisfies both the AM and PM peak future traffic demands. However, the southern through movement lane is functioning with an unacceptable LOS E. This can be resolved during the detailing of the signal phasing.

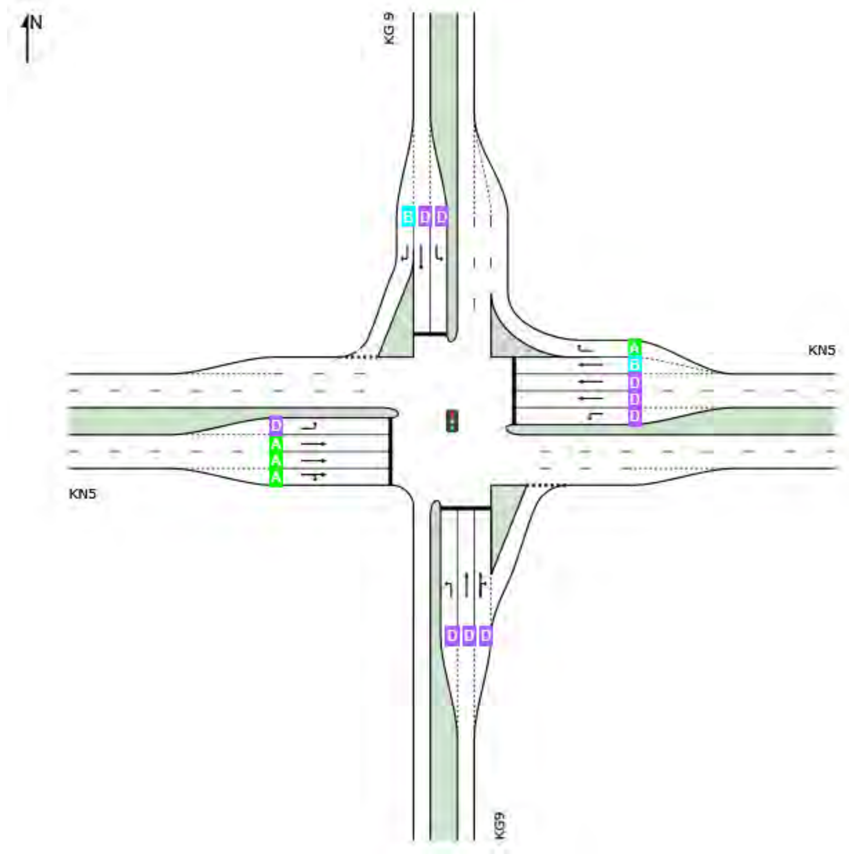
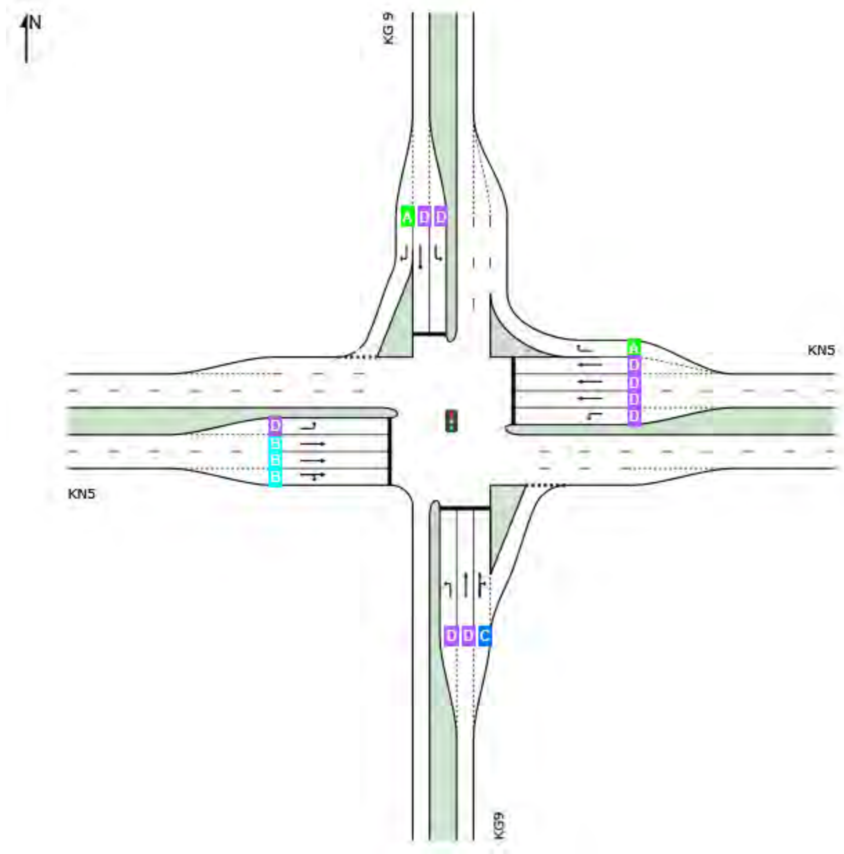
AM Peak: Intersection 4	PM Peak: Intersection 4
	

Notes:
The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 5	PM Peak: Intersection 5
	

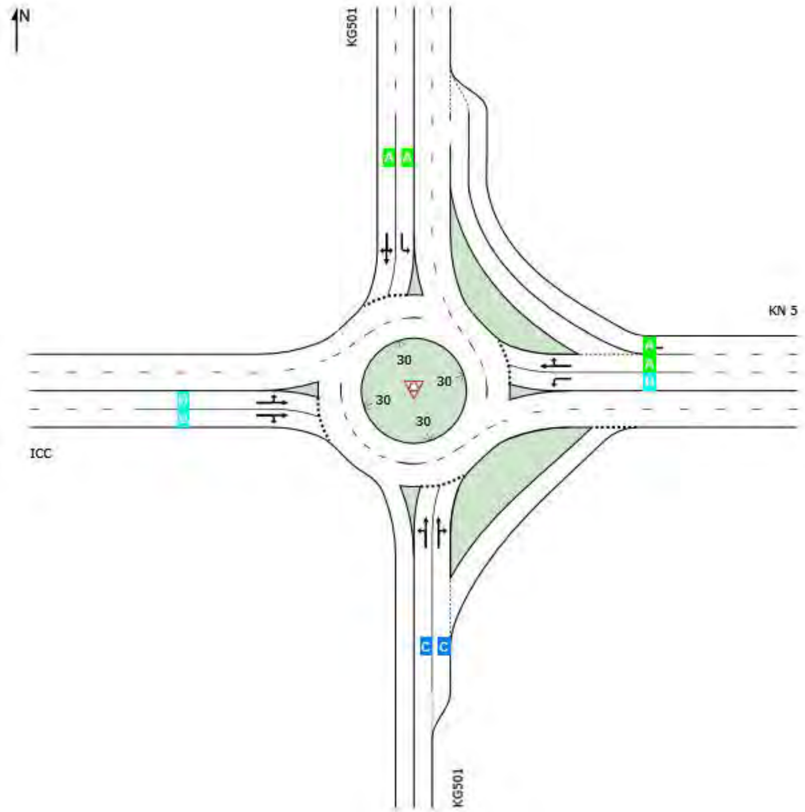
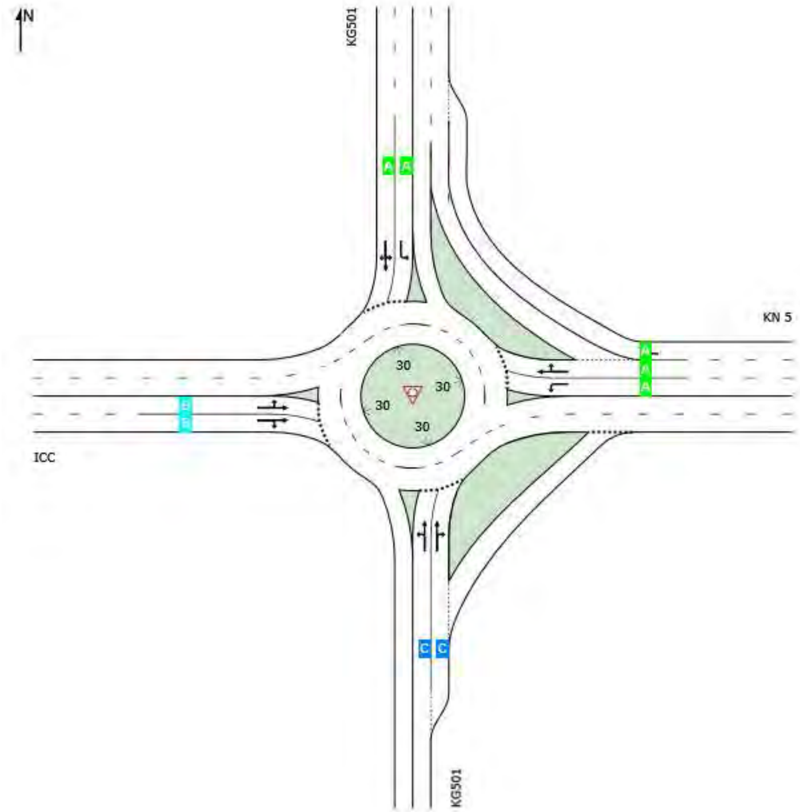
Notes:

The proposed solution satisfies the AM peak future traffic demands overall LOS. Yet in both the AM and PM peak, the southern approach fails with an unacceptable LOS F.

AM Peak: Intersection 6	PM Peak: Intersection 6
	

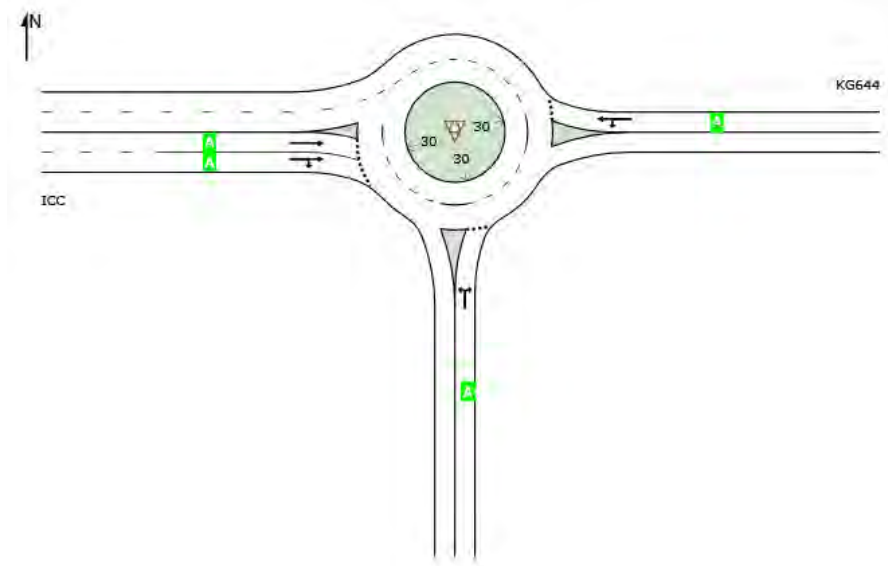
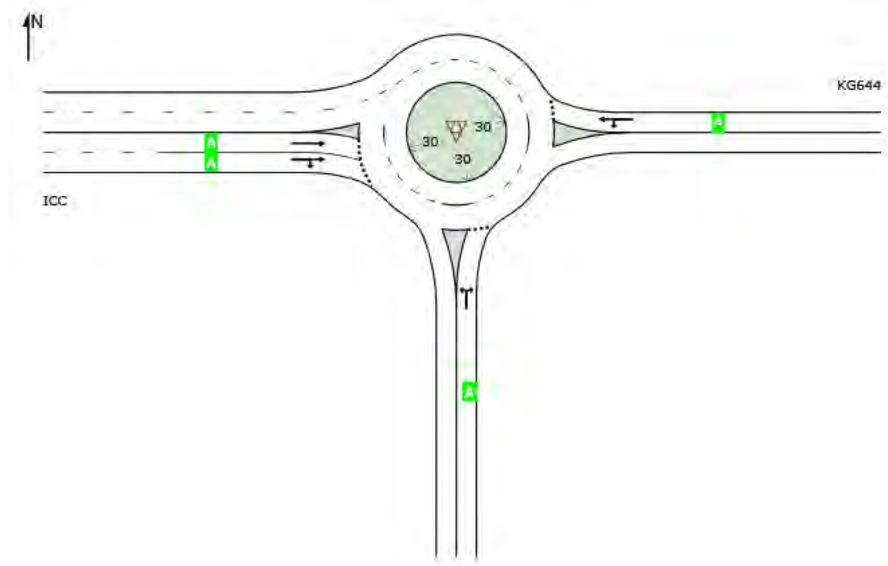
Notes:

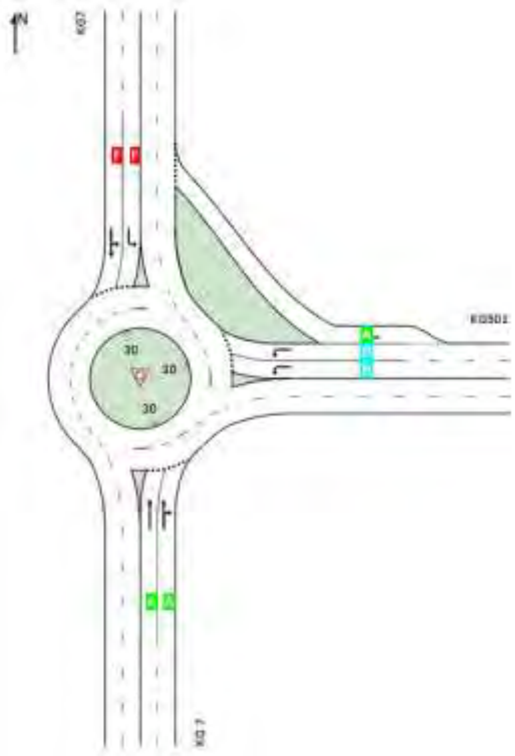
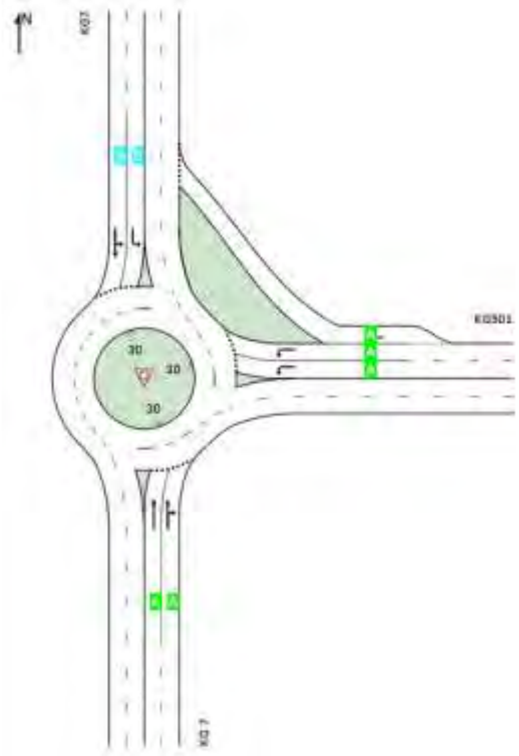
The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 7	PM Peak: Intersection 7
	

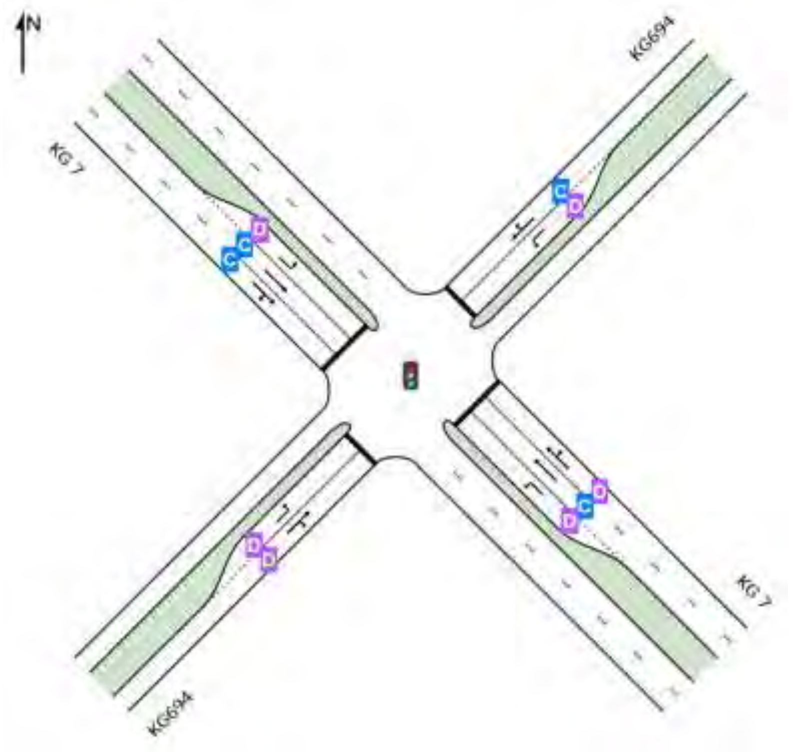
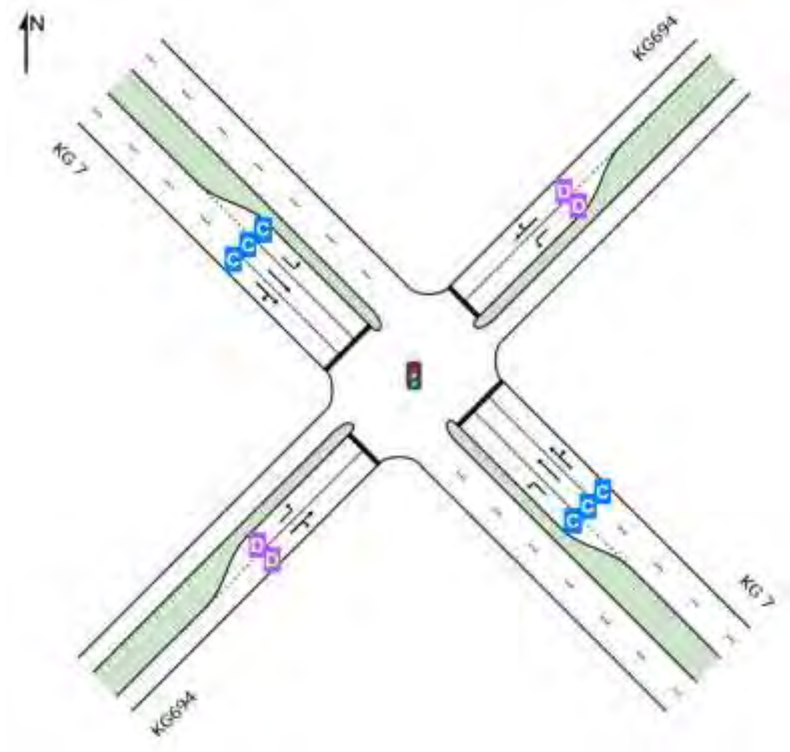
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

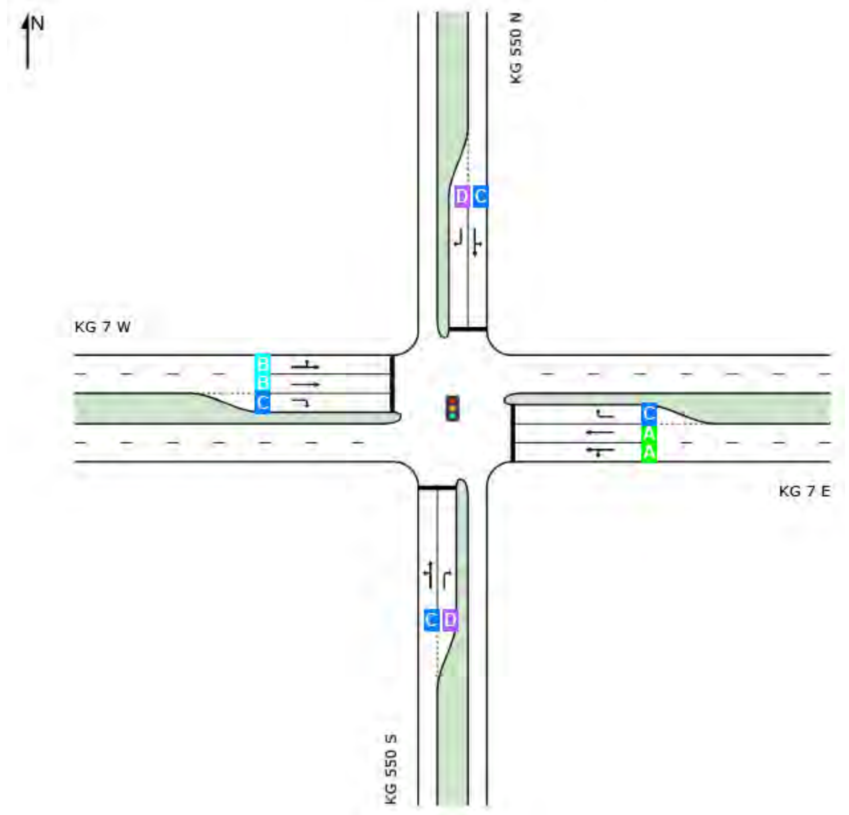
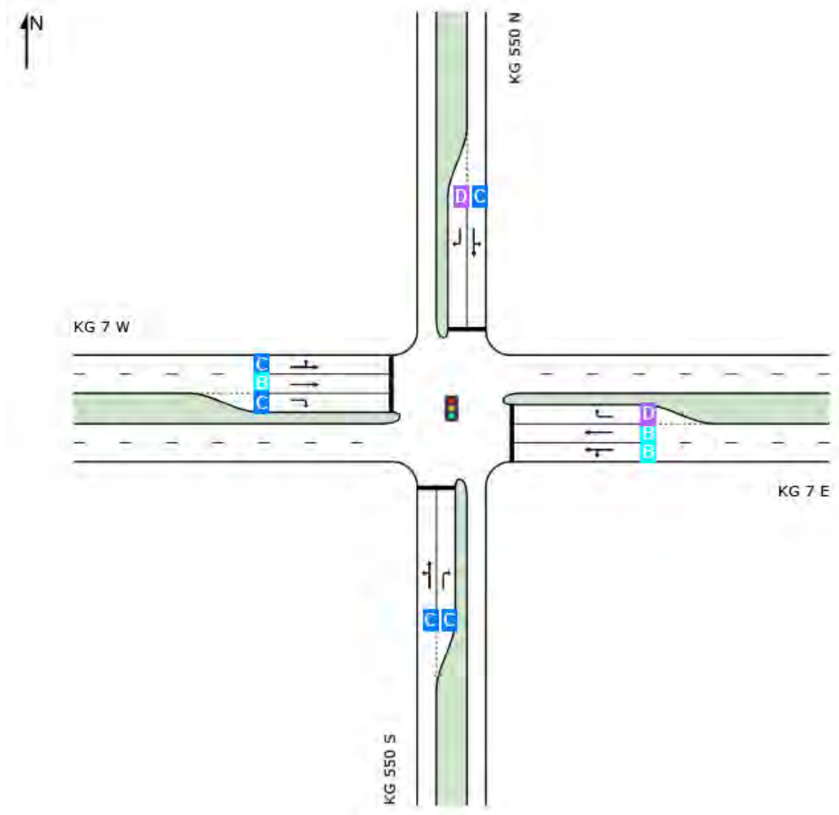
AM Peak: Intersection 8	PM Peak: Intersection 8
	
Notes:	
The proposed solution satisfies both the AM and PM peak future traffic demands.	

AM Peak: Intersection 10	PM Peak: Intersection 10
	

Notes:
This intersection is resolved in the network analysis in Vissim.

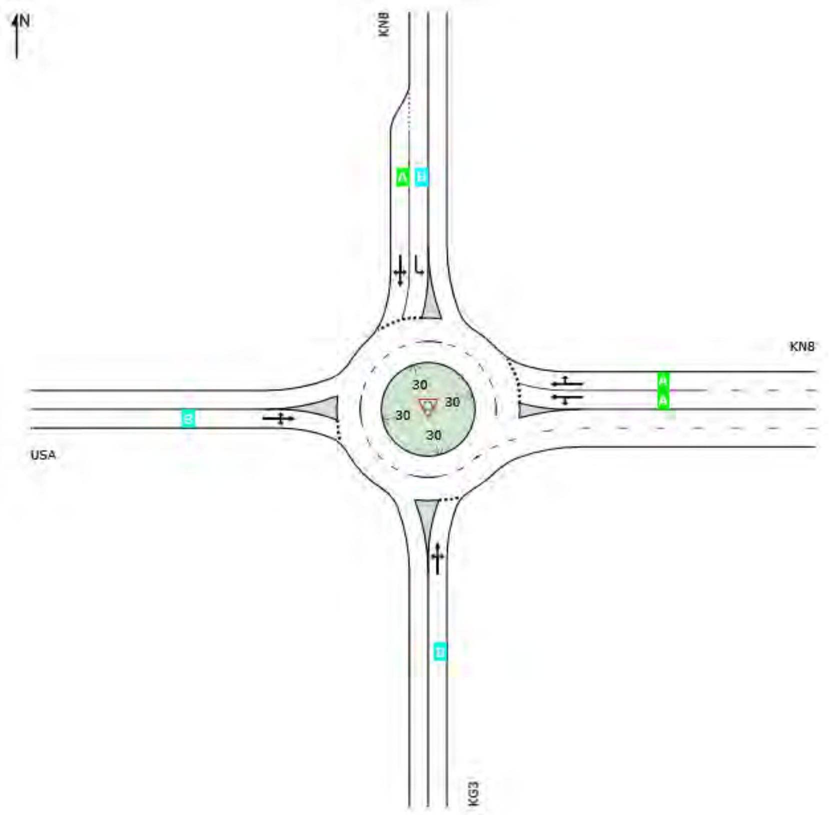
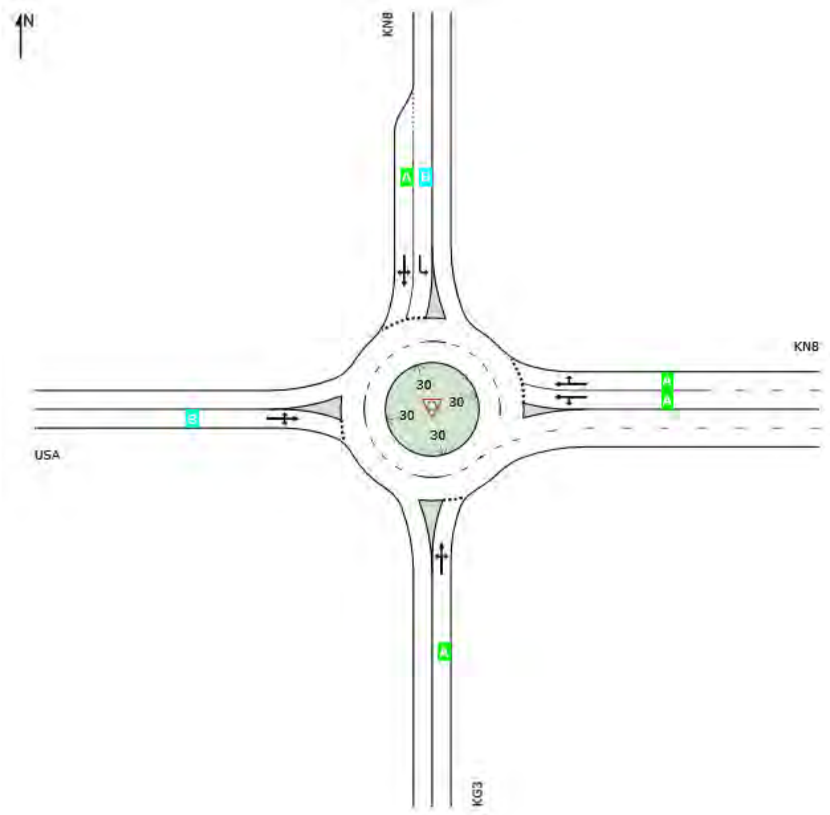
AM Peak: Intersection 11	PM Peak: Intersection 11
	

Notes:
The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 12	PM Peak: Intersection 12
	

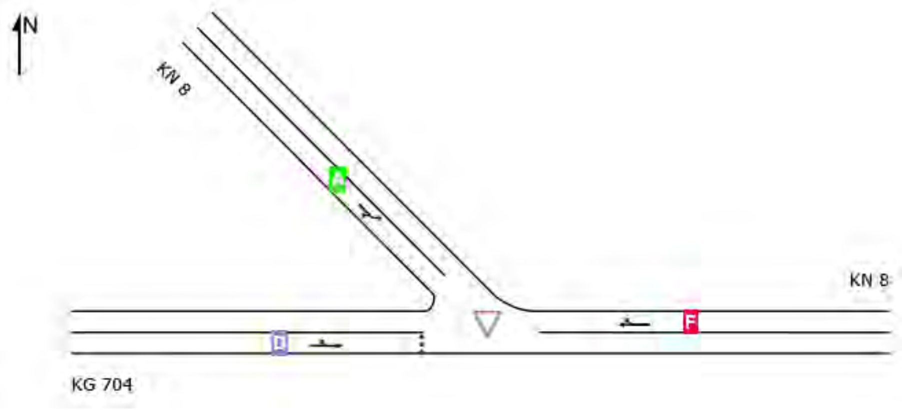
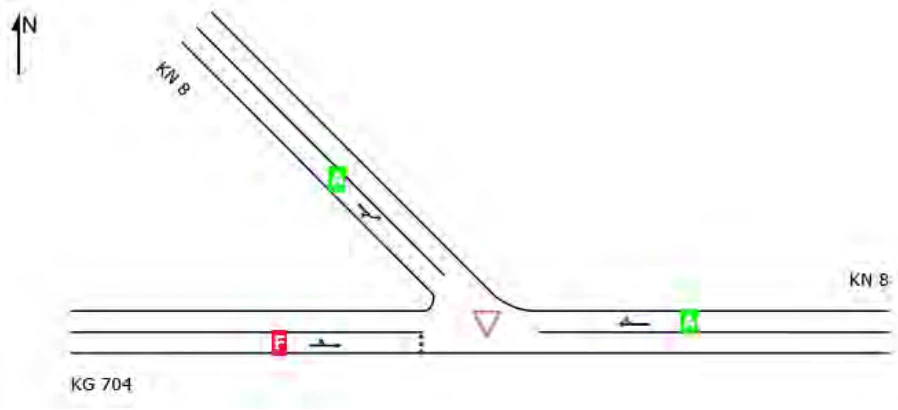
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 13	PM Peak: Intersection 13
	

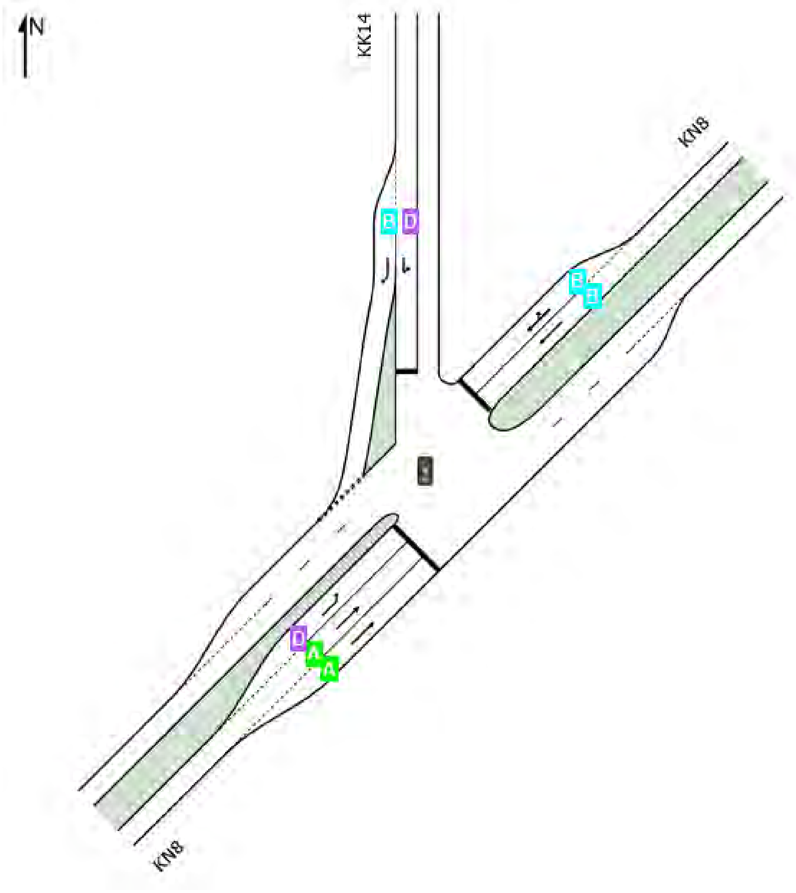
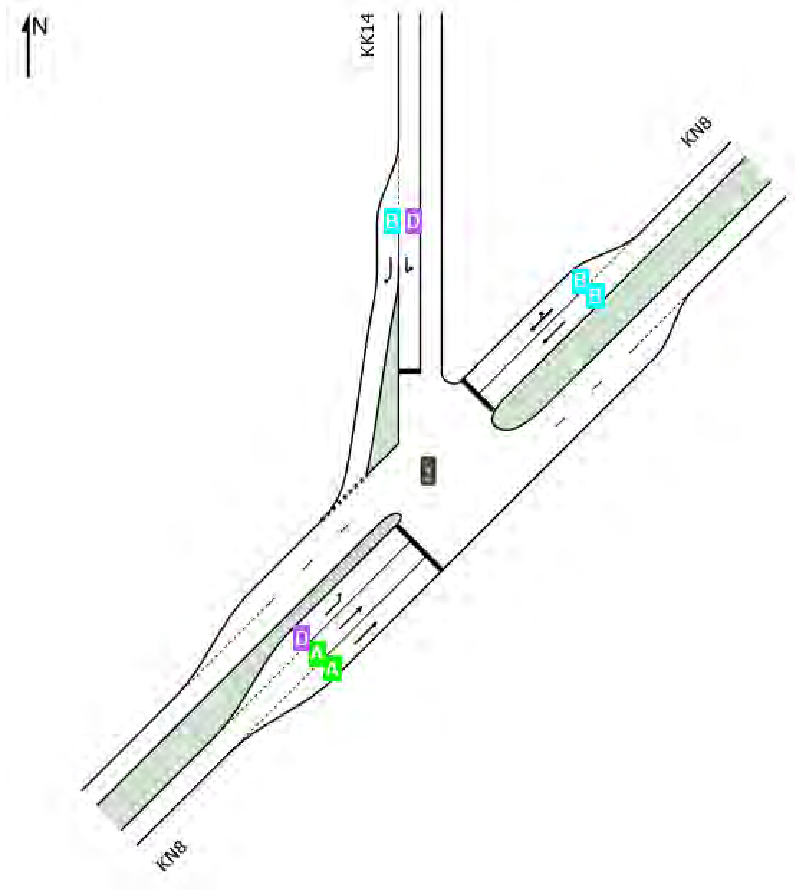
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

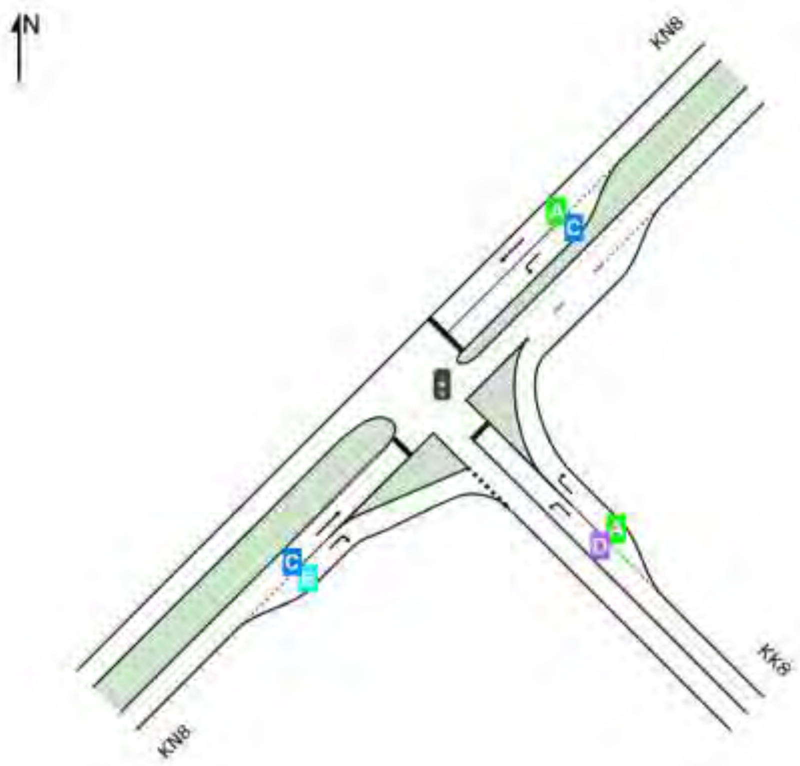
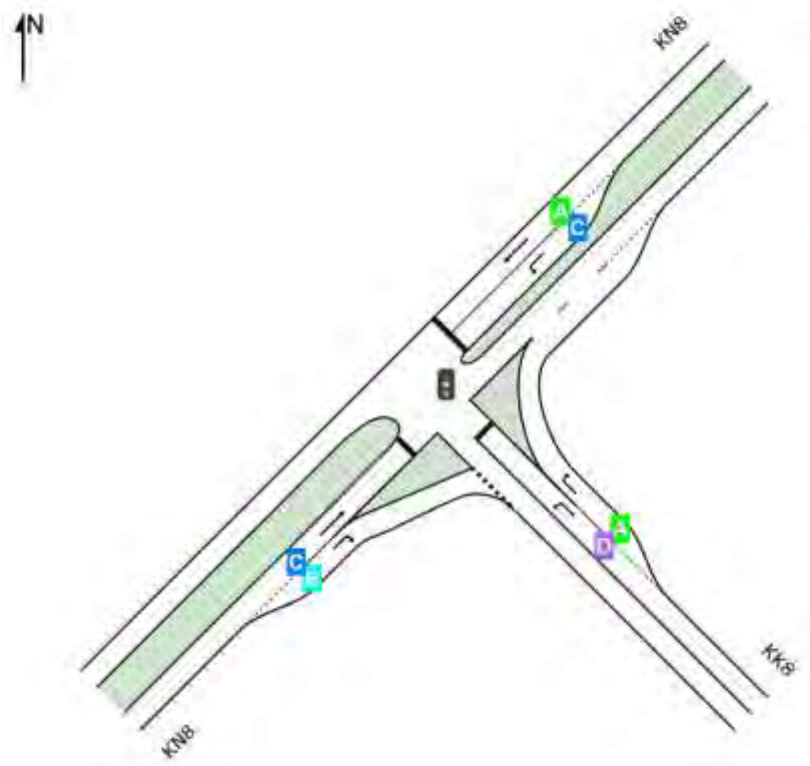
AM Peak: Intersection 14	PM Peak: Intersection 14
	

Notes:

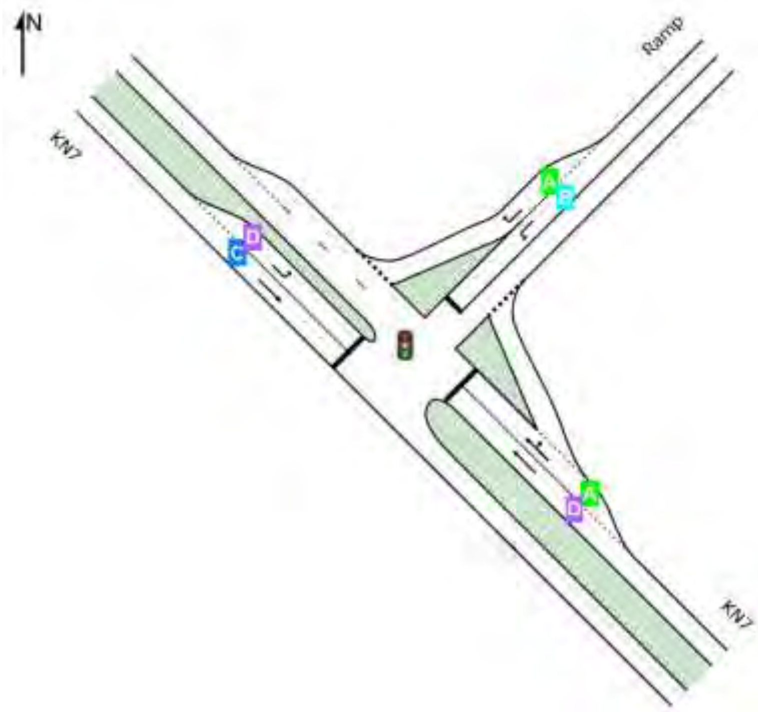
Intersection 14 requires a left turn lane from the eastern approach. This was modelled in the network analysis, where the intersections operate at acceptable levels of service due to more accurate gap acceptance.

AM Peak: Intersection 15	PM Peak: Intersection 15
	

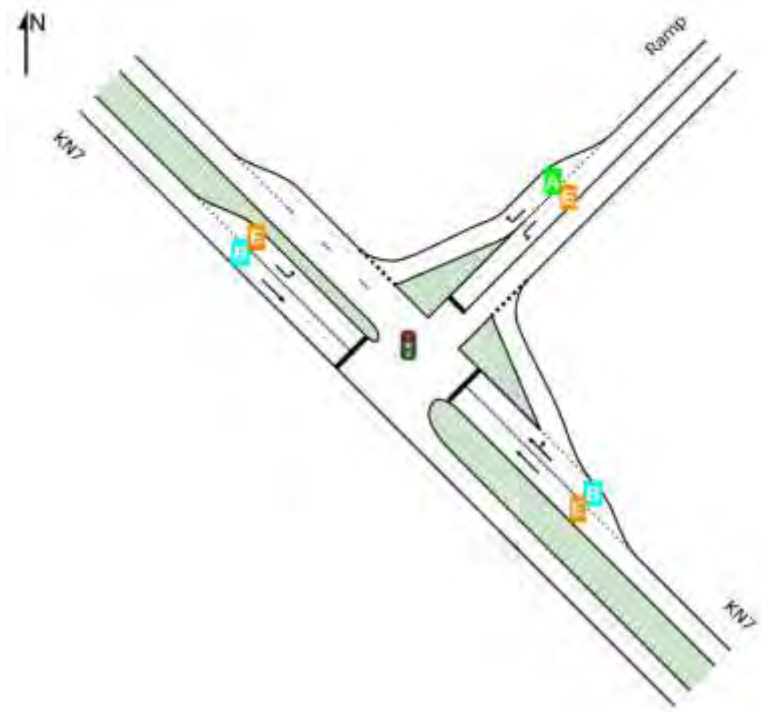
Notes:
The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 16-1	PM Peak: Intersection 16-1
	
Notes:	
The proposed solution satisfies both the AM and PM peak future traffic demands.	

AM Peak: Intersection 16-2

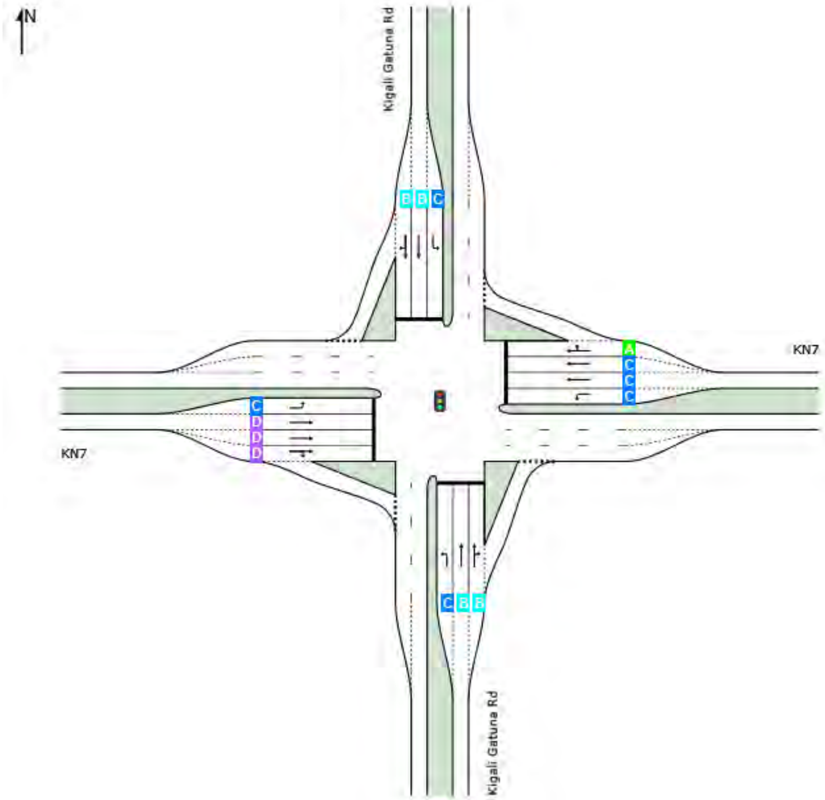
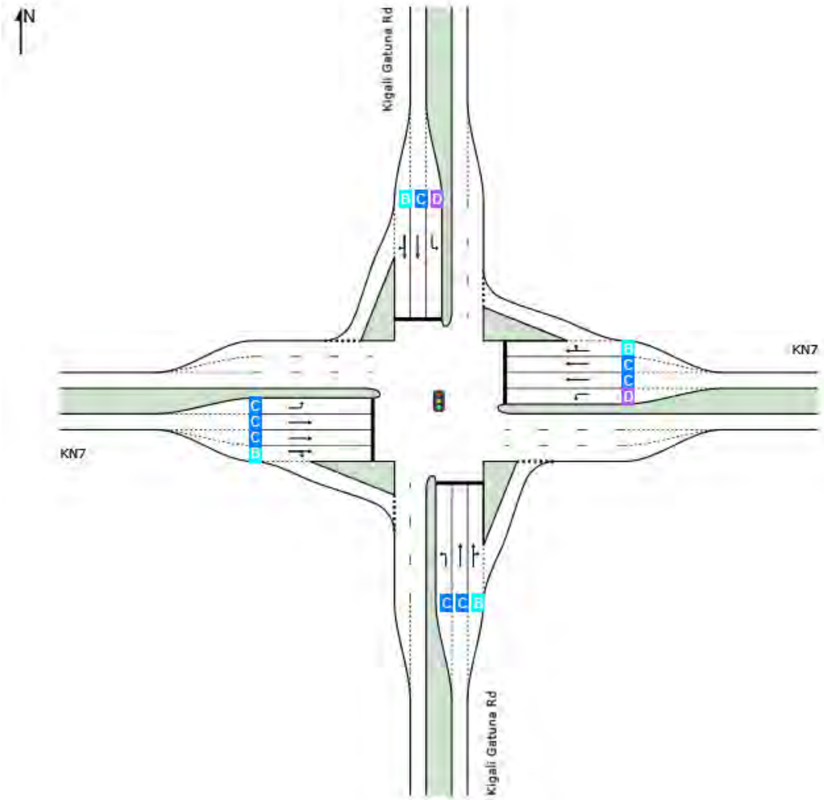


PM Peak: Intersection 16-2

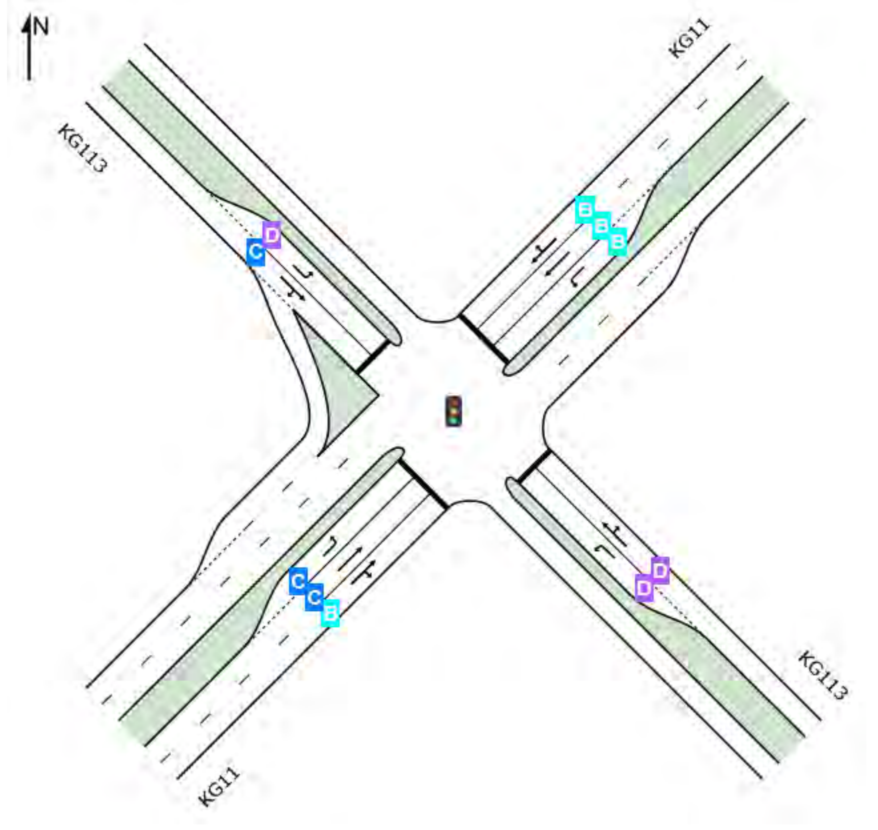
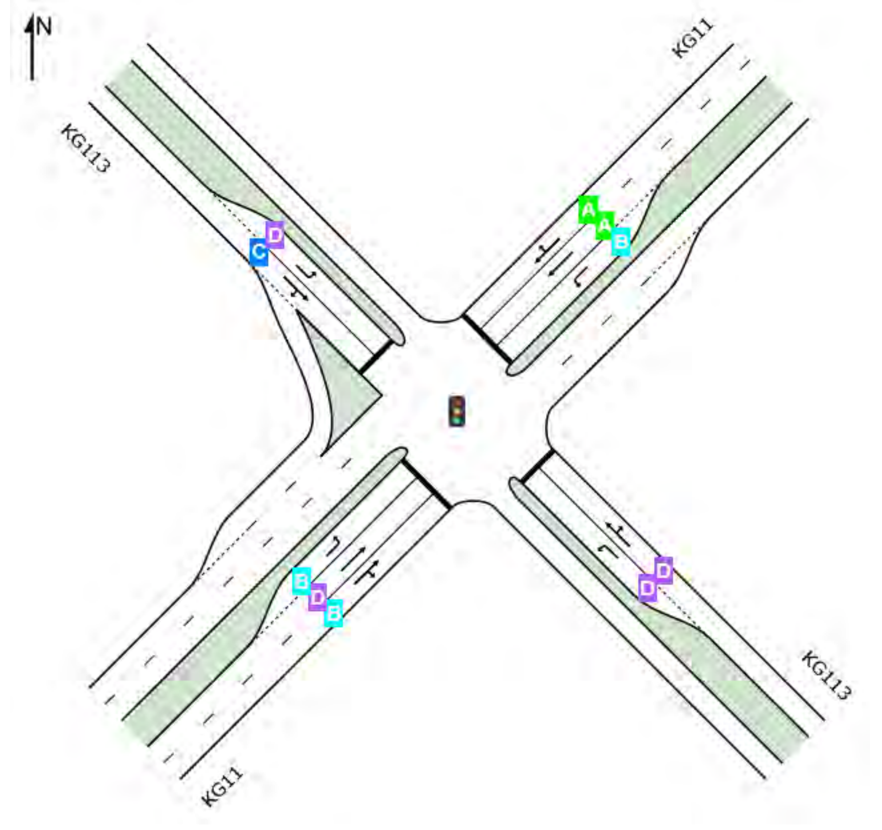


Notes:

The proposed solution satisfies the AM peak future traffic demands. This intersection will experience slight congestion on all approaches during the PM peak. Additional lanes can be added to resolve this.

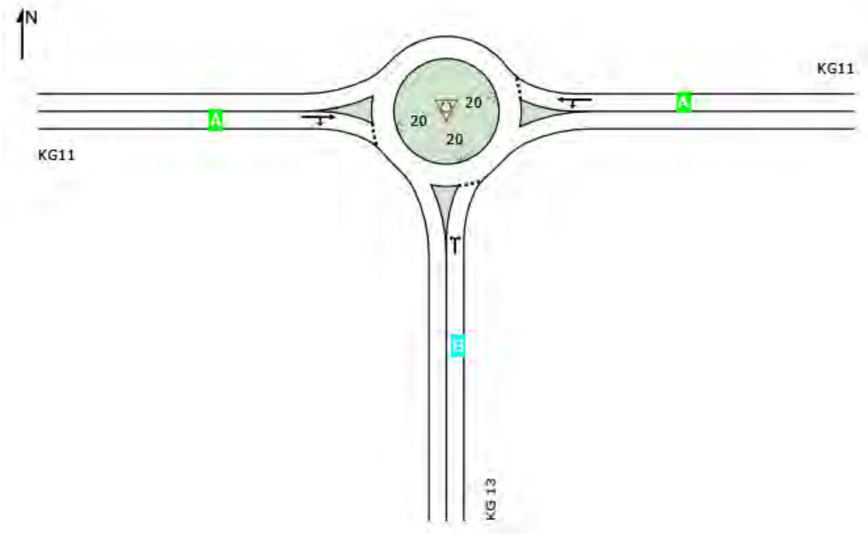
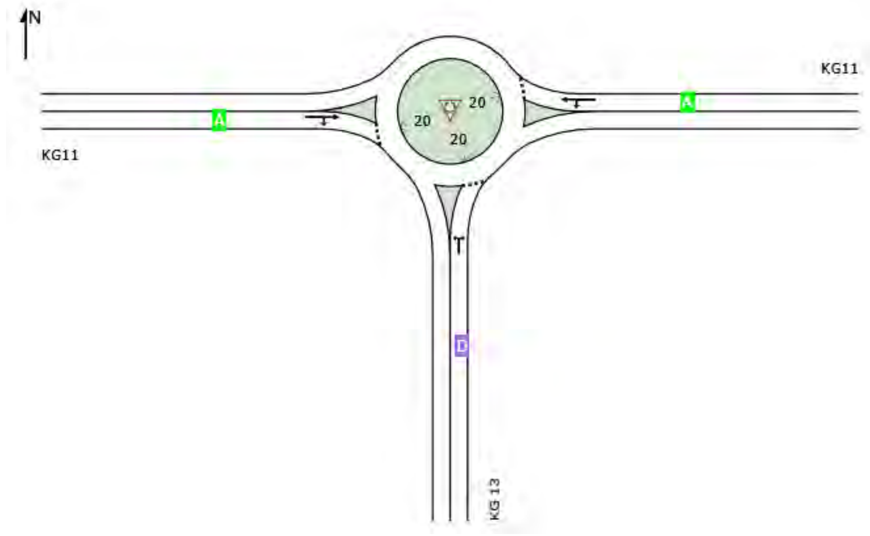
AM Peak: Intersection 17	PM Peak: Intersection 17
	

Notes:
The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 18	PM Peak: Intersection 18
	

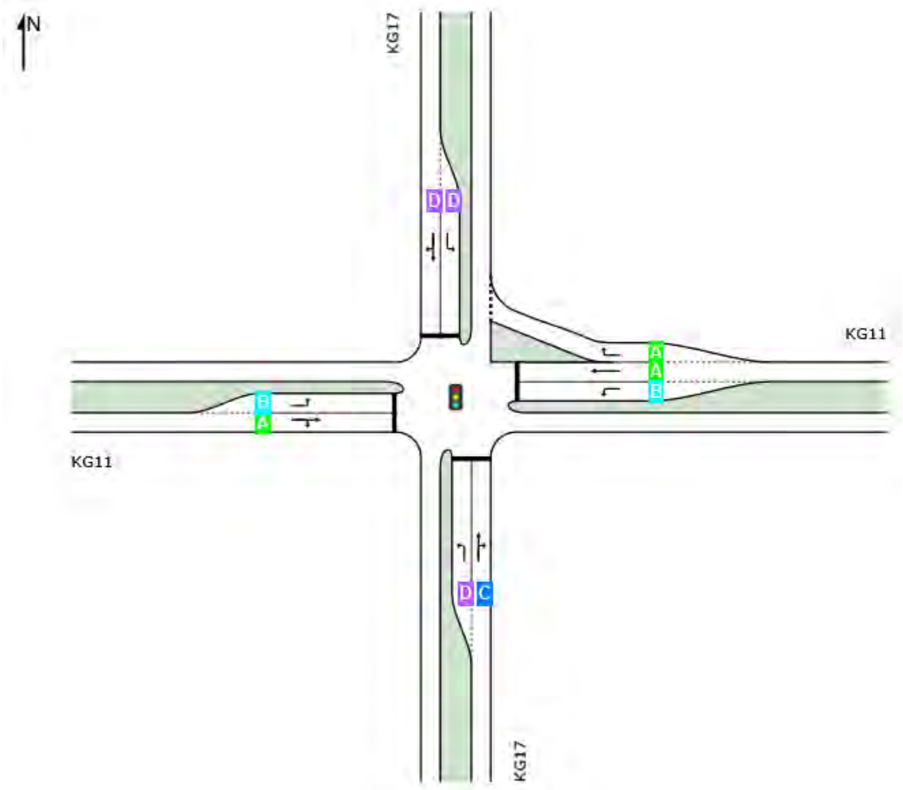
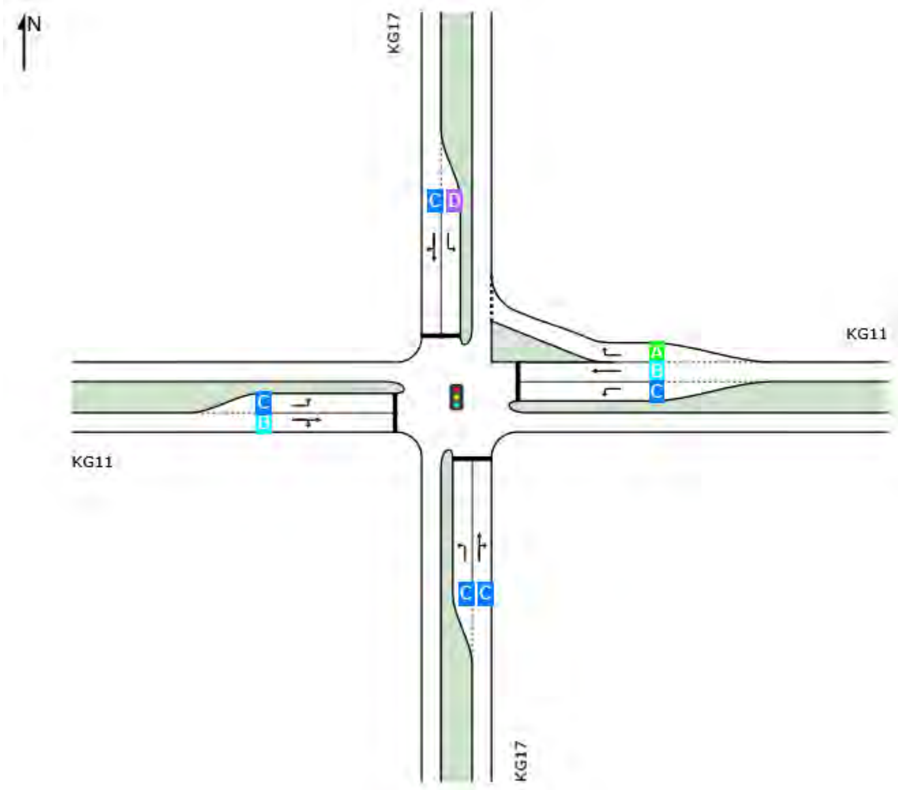
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 19	PM Peak: Intersection 19
	

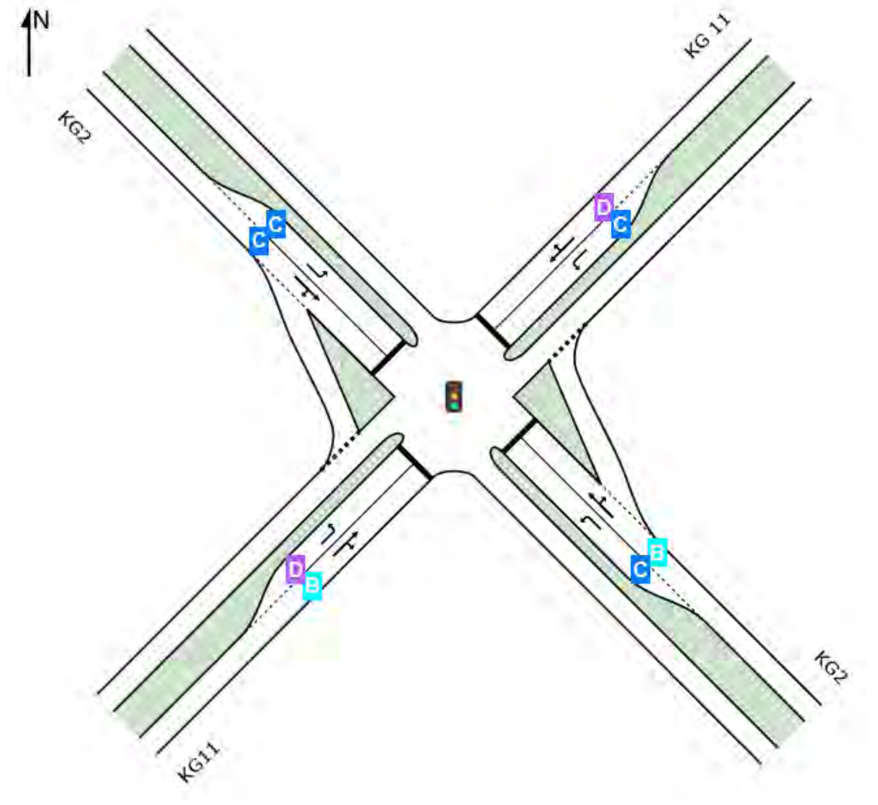
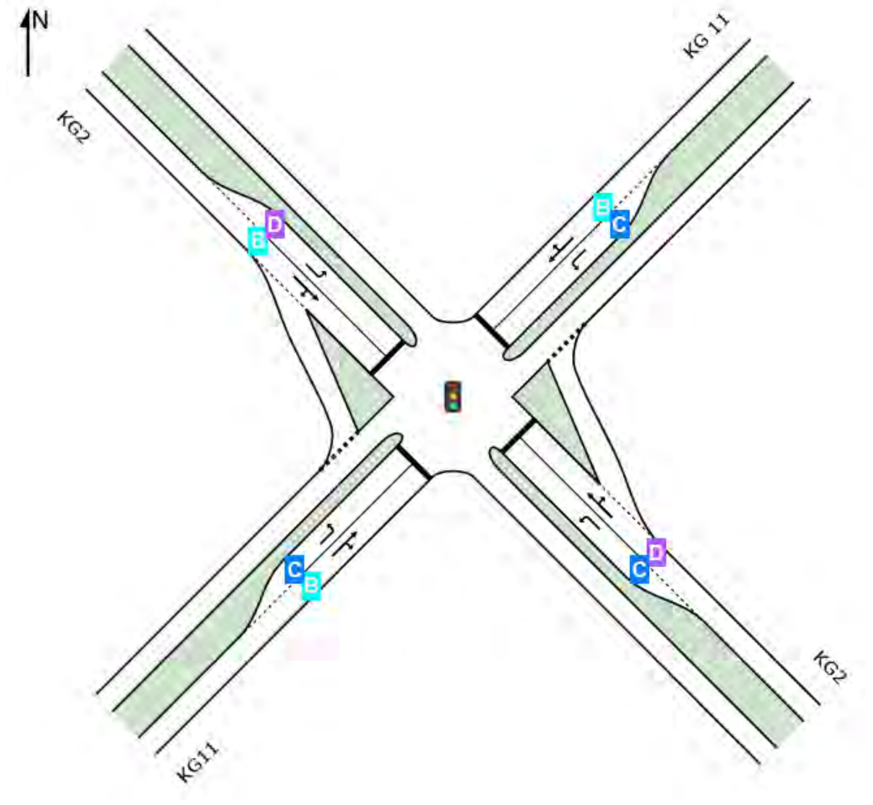
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

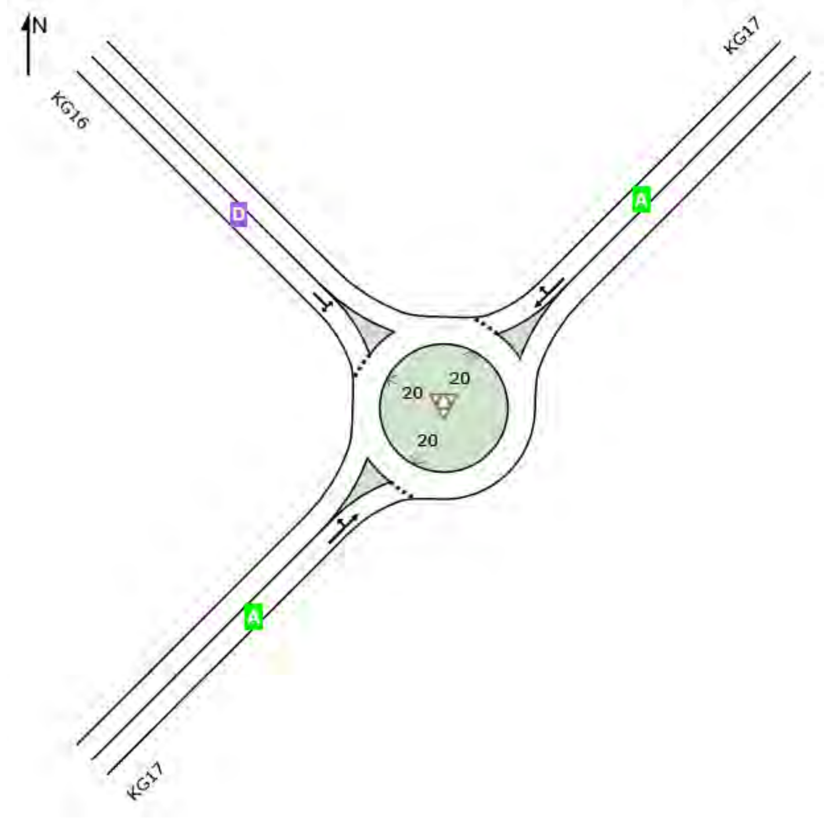
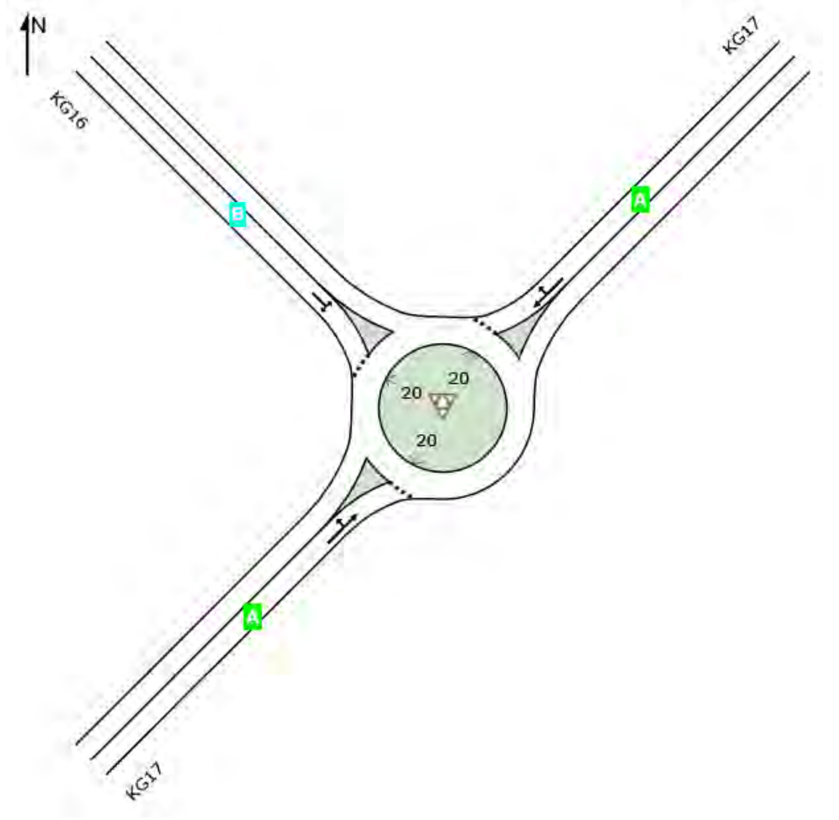
AM Peak: Intersection 20	PM Peak: Intersection 20
	

Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

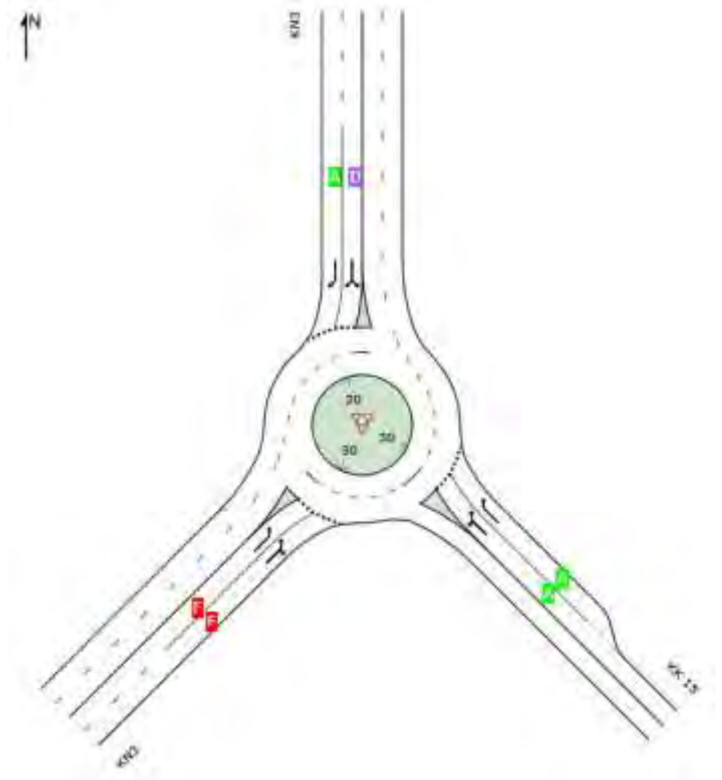
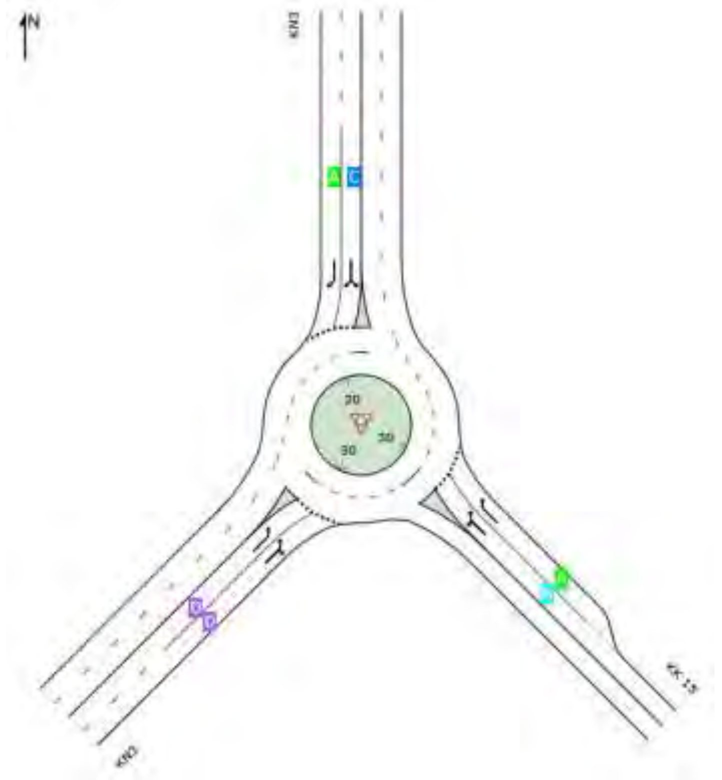
AM Peak: Intersection 21	PM Peak: Intersection 21
	

Notes:
The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 22	PM Peak: Intersection 22
	

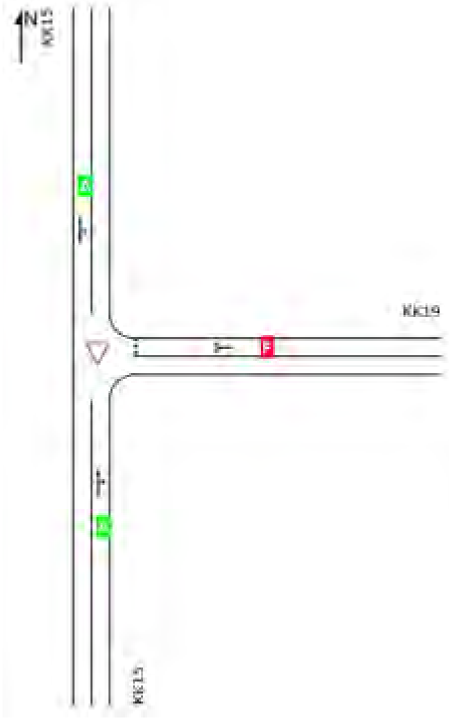
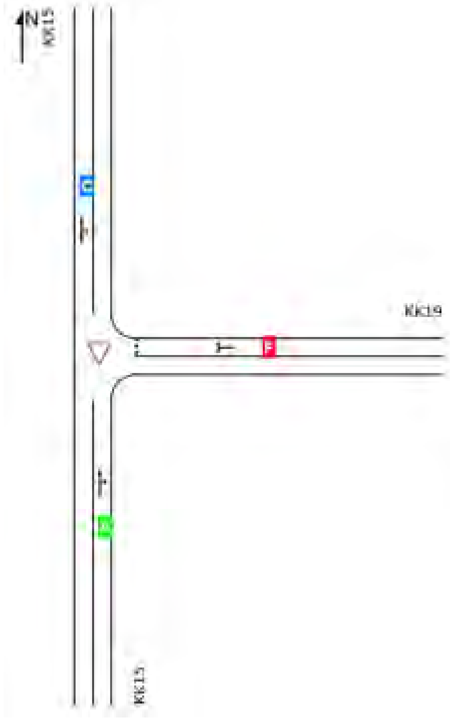
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 23	PM Peak: Intersection 23
	

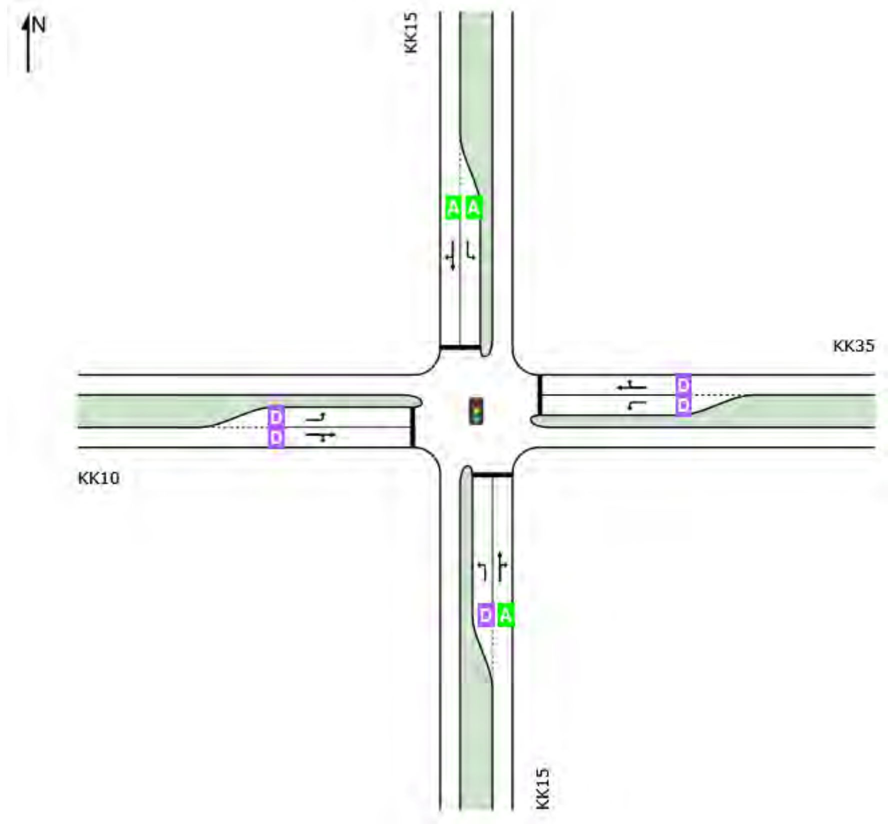
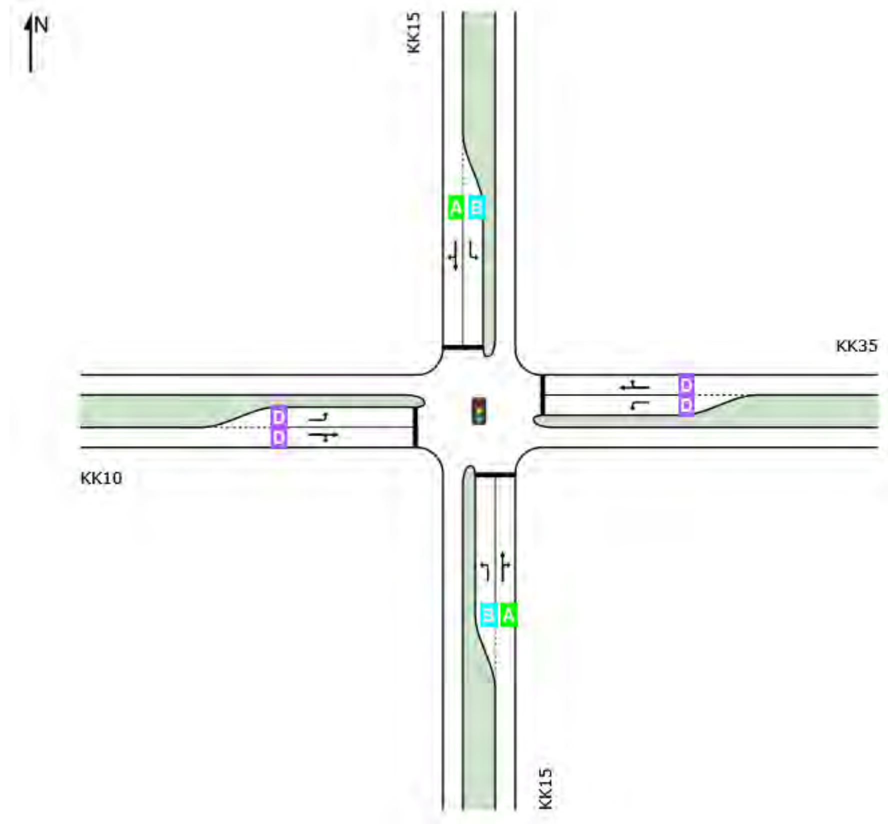
Notes:

The proposed solution satisfies the PM peak future traffic demands. However, during the AM peak, the south western approach fails. Again, it must be noted that this intersection was under construction during the investigation.

AM Peak: Intersection 24	PM Peak: Intersection 24
	

Notes:

Intersection 24 fails during the future analysis. However, in the network analysis a left-turn lane is added to the northern approach, and due to more accurate gap acceptance, this intersection functions acceptably.

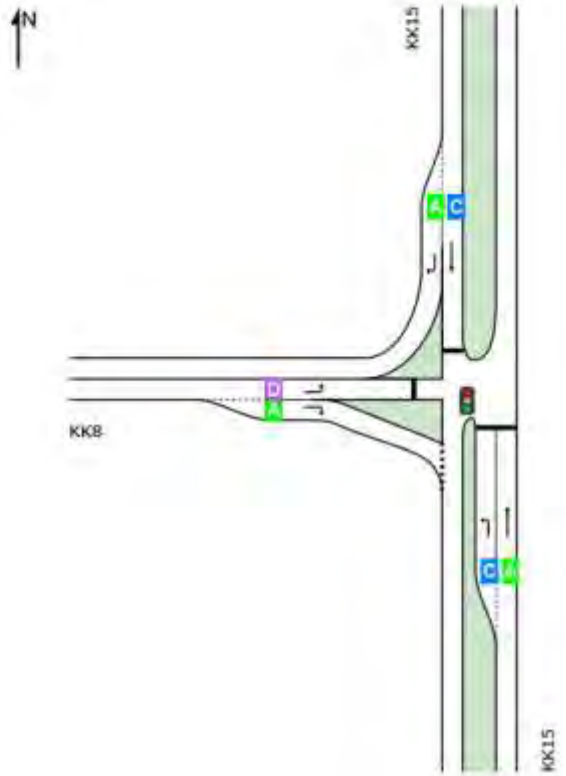
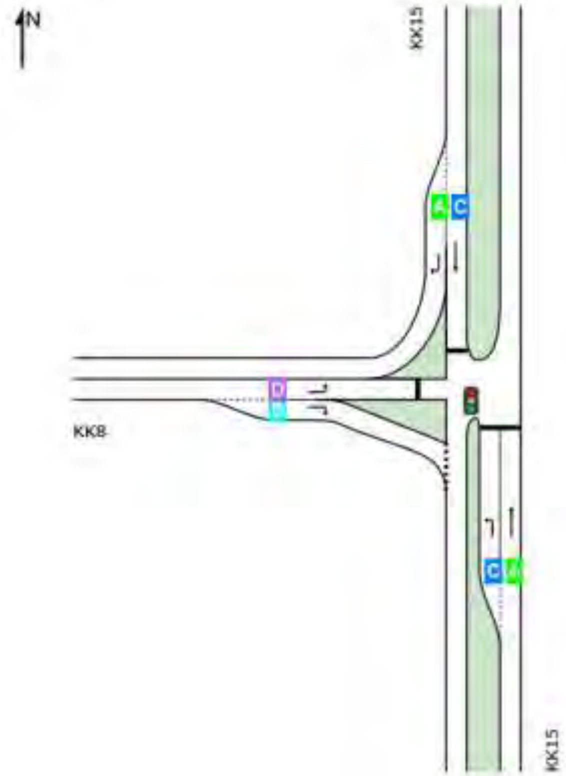
AM Peak: Intersection 25	PM Peak: Intersection 25
	

Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

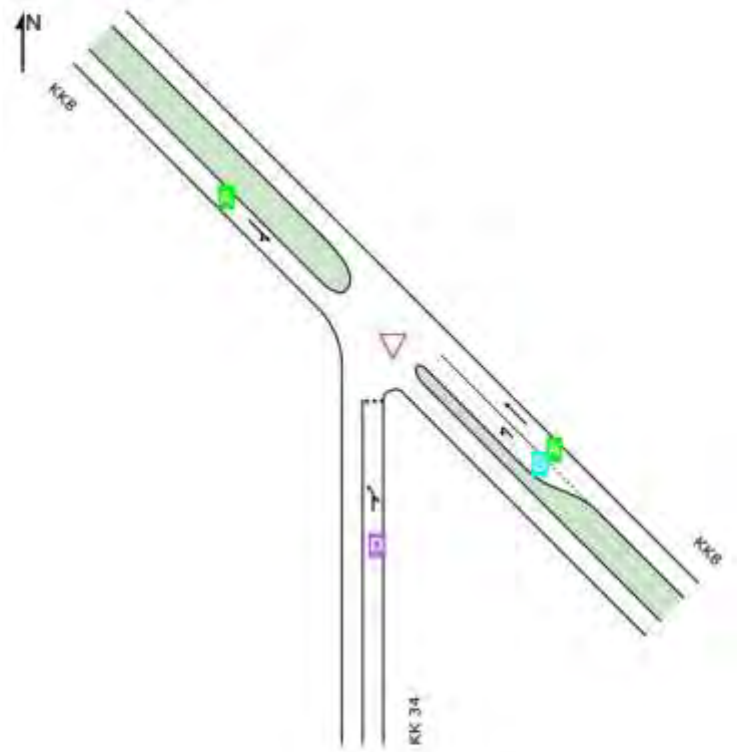
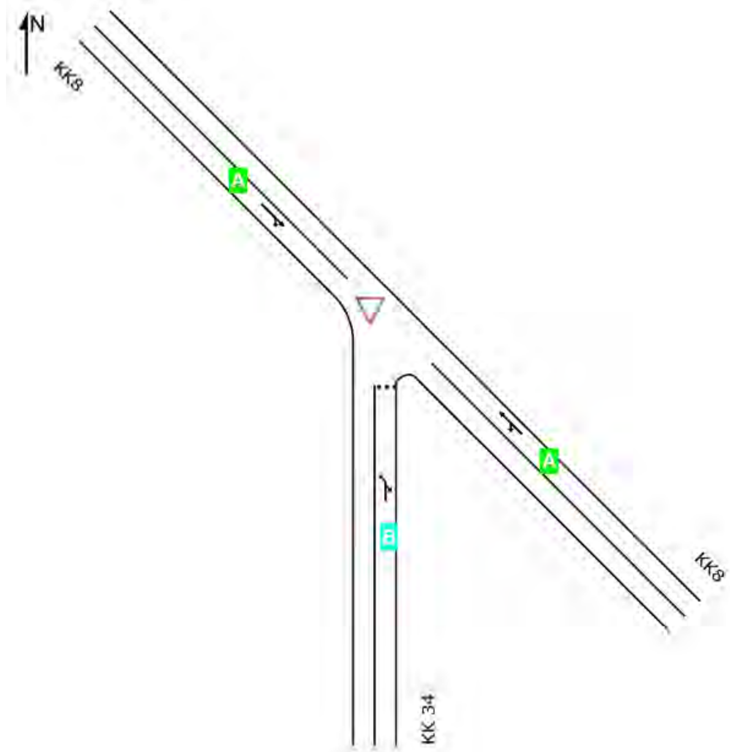
AM Peak: Intersection 26	PM Peak: Intersection 26
	

Notes:
The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 27	PM Peak: Intersection 27
	

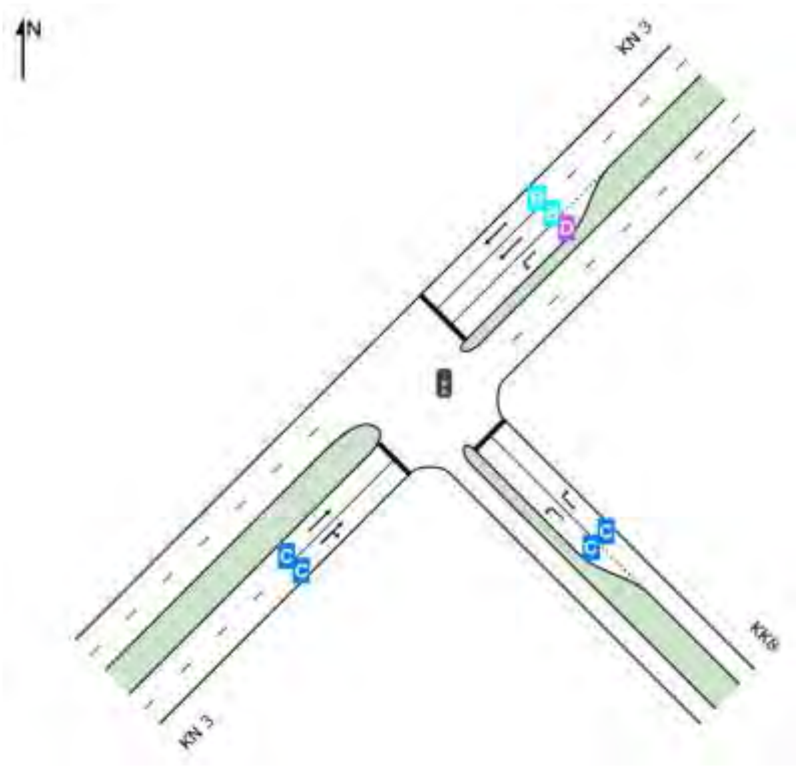
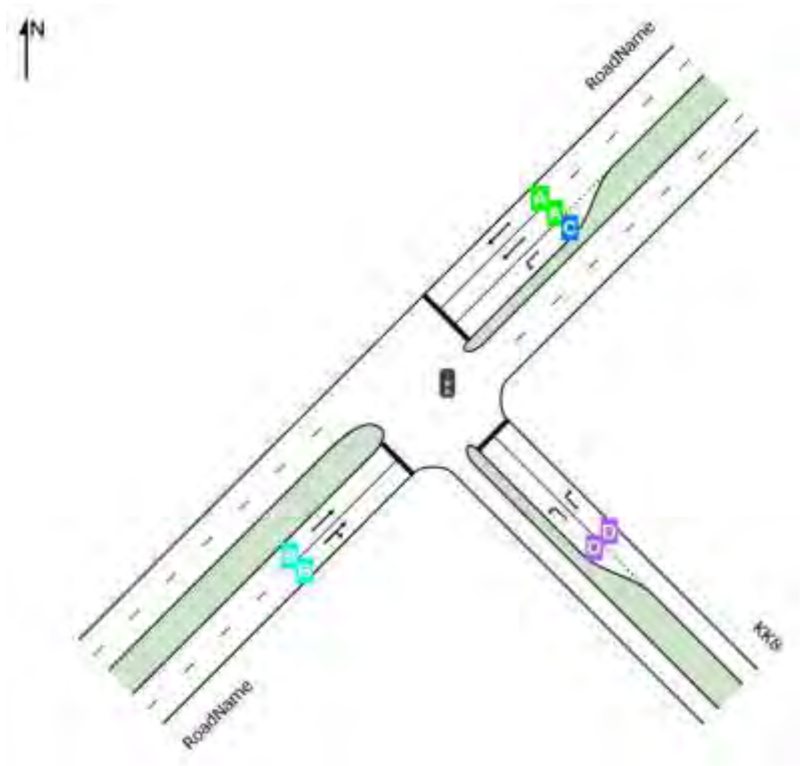
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 28	PM Peak: Intersection 28
	

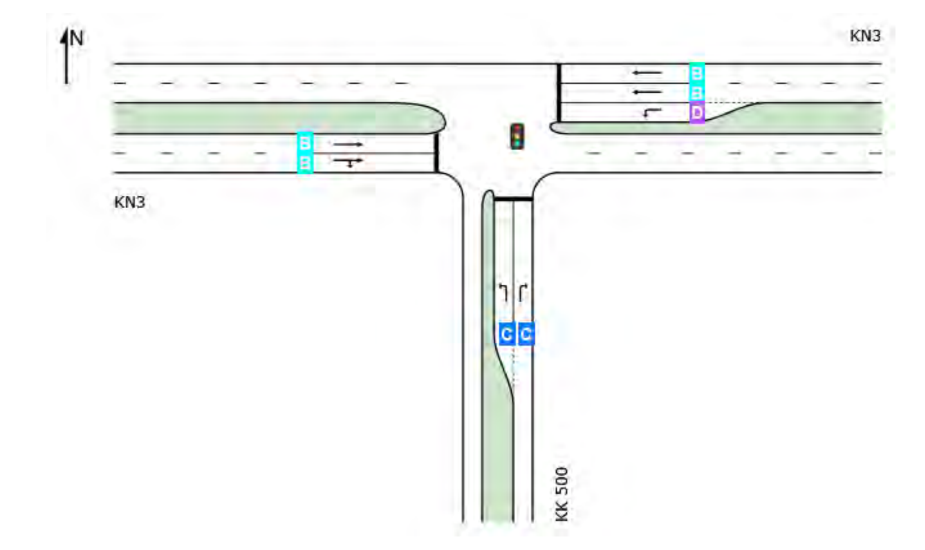
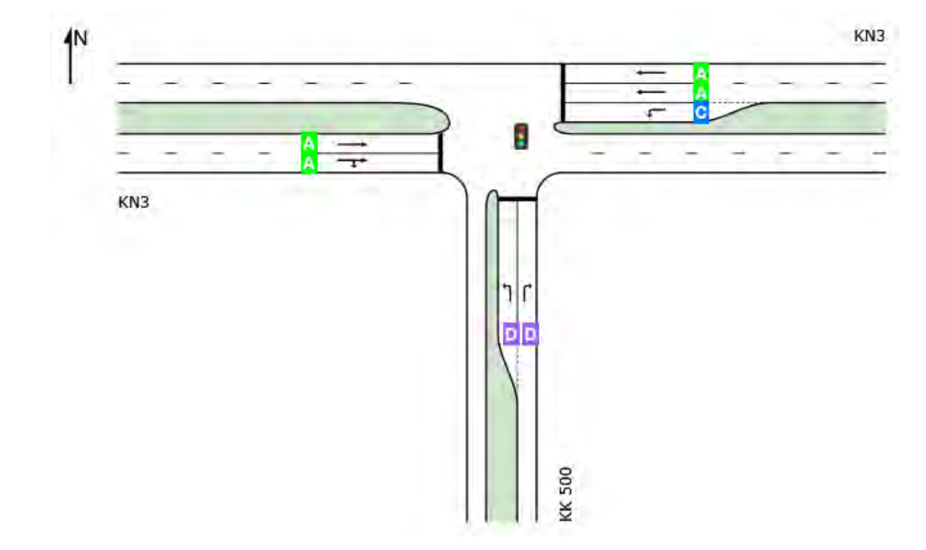
Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 29	PM Peak: Intersection 29
	

Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

AM Peak: Intersection 30	PM Peak: Intersection 30
	

Notes:

The proposed solution satisfies both the AM and PM peak future traffic demands.

6

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6. Network Analysis (Vissim)

6.1. Methodology

6.1.1. Network

To analyse the network as a whole, micro-simulation was used. The benefit of this type of analysis is the inclusion of the “domino effect”. This means that solving one intersection’s capacity problems could cause an adjacent intersection to fail, due to the increased volumes now accessing this intersection.

Where SIDRA analyses an intersection in isolation, Vissim can analyse the network as an interacting unit.

Figure 6-1 shows the network that was modelled and used as the base scenario.

Figure 6-1: Vissim Network Overview

6.1.2. Vehicle Inputs

The counts obtained through data collection, as detailed in Chapter 0, were utilised. For a network analysis the counts have to be balanced, to ensure that approximately the same volumes of vehicles leaving one intersection will arrive at the next adjacent intersection. The reason this is important, is that the vehicles on the network of a Vissim model, is fed into the edges of the road network. The so-called external zones. These vehicles are then routed to various turning movements, according to the counts. So, to ensure that the volumes at each intersection is accurate, these balanced counts are required.

Where large discrepancies existed between counts, additional feeder links were used. This occurs mainly on Corridor 1. This corridor is less formal than other corridors modelled. Thus, there are quite a number of smaller intersections between the counted intersections, where vehicles can exit, or enter the network. These smaller feeder links were included in the model, to ensure accuracy. However, for these feeder links, no priorities were defined, as the goal is not to analyse the smaller intersections, but to ensure accurate volumes on the network. An example of these feeder links is shown in Figure 6-2.

Figure 6-2: Feeder Link Example

6.1.3. Traffic Signals

In Kigali, there are quite a low number of traffic signals. Of these traffic signals, an even smaller portion are operational. For the modelled sections, there are three traffic signals. One traffic signal has been shut down completely. The second one flashes yellow during the peak hours and is thus not effective. The third signal is operational. For this signal, on-site measurements were taken of the timings, and included in the model.

6.1.4. Driving Behaviour

The simulation software, Vissim, is developed by the PTV Group. PTV is a German company specialising in software solutions and consulting services for traffic and transportation, mobility, and logistics. As such, the default settings and parameters cater to a more first-world driving behaviour. To replicate the driving behaviour, and congestion, in Kigali, some alterations are required.

The default average speed limit for urban models is 60km/h. For the Kigali model, the speed was reduced to 40km/h, as it was observed that the vehicles travel at much lower speeds in the city.

The second adjustment that was made, and probably the most important, is the gap acceptance. Due to Kigali's cooperative driving behaviour, accepted gaps are very small. Vehicles tend to "push" into traffic streams, should the delay become too long. This is a very difficult concept to model, as the software does not allow for this type of behaviour. To replicate this, a combination of conflict areas and priority rules were used. The priority rules prioritise the main traffic streams, and the conflict areas are mainly set to undermined, which leads to a "first come, first served" situation. This gives quite a realistic representation of the traffic, as the main movements are prioritised, but also provide gaps for smaller traffic streams to enter, especially when congestion becomes excessive.

Combined with the above, other values related to gap acceptances and driving behaviour were altered. These values are explained in sections 6.1.4.1 - 6.1.4.3 below.

6.1.4.1. Conflict Areas

Front Gap: Minimum gap time in seconds between the rear end of a vehicle in the main traffic stream and the front end of a vehicle in the minor traffic stream. Default 0.5 seconds to adhere to the minimum gap time, the yielding vehicle slows down as it approaches the conflict area and stops in front of it, as long as the vehicle that has priority is the front of or in the conflict area. Once the vehicle with the right of way has left the conflict area, the yielding vehicle can enter it and no longer considers the Front gap.

Rear Gap: Minimum gap time in seconds between the rear end of a vehicle in the minor traffic stream and the front end of a vehicle in the main traffic stream. This is the time, which must be provided, after a yielding vehicle has left the conflict area and before a vehicle with the right of way enters it. Vehicles are perceived within a maximum distance of up to 100 m.

Safety distance factor: only for the type merging conflicts: This factor is multiplied with the normal desired safety distance of a vehicle in the main traffic stream in order to determine the minimum distance a vehicle of the yielding traffic stream must keep, when it is completely in the conflict area of merging conflicts.

Additional stop distance: only relevant for vehicles that are required to yield: Distance in meters that moves an imaginary stop line upstream of the conflict area. As a result, vehicles required to yield stop further away from the conflict and thus have to travel a longer distance to pass the conflict area.

6.1.4.2. Priority Rules

Gap Time: Minimum gap time (in seconds) between the conflict marker and the next vehicle driving towards it.

Headway: Minimal headway (distance) between the conflict marker and the next vehicle upstream.

Maximum Speed: Vehicles, which are traveling towards the conflict marker, are only considered for the headway condition when their *speed is ≤ max. speed.*

6.1.4.3. Driving Behaviours

The car following model used for this micro-simulation model is the Wiedemann 74 model, which is suitable for urban traffic and merging areas. The following values were modified:

Average Standstill Distance: Defines the average desired distance between two cars. The tolerance lies from –1.0 m to +1.0 m, which is normally distributed at around 0.0 m, with a standard deviation of 0.3 m.

Additive Part of Safety Distance: Value used for the computation of the desired safety distance *d*. Allows to adjust the time requirement values.

Multiplicative Part of Safety Distance: Value used for the computation of the desired safety distance *d*. Allows to adjust the time requirement values. Greater value = greater distribution (standard deviation) of safety distance.

It should be noted due to this aggressive driving behaviour, instances occur where vehicles in the model clip each other. This is mainly a visual anomaly and does not have an impact on the congestion of the model. The reason why this occurs is due to the afore mentioned reduction in gap acceptance, a vehicle will “push” into the main traffic flow. The vehicle in the main flow will fail to detect this movement, and thus not slow down.

6.1.5. Calibration

Three methods were used to ensure the model is calibrated.

6.1.5.1. Travel Times

Travel times were recorded for the routes during the peak hours. These were done by physically driving the route, and measuring the time taken to complete the journey. These were then compared to the travel times in the micro-simulation model to determine accuracy. The measured travel times were also compared to travel times obtained from Google Maps' traffic data. Parallel to the travel times, a visual test was also conducted to compare the congestion in the model to the congestion in the city.

6.1.5.2. SmartyCam Videos

Further to the visual test mentioned in section 6.1.5.1, a SmartyCam, which was mounted to the windscreen of the vehicle, was used to record the traffic congestion during the peak hours in the city. These videos were then compared to the traffic flows of the model to determine if congestion sections and congestion amounts are accurate. More info on the SmartyCam videos can be found in Section 0.

6.1.5.3. Volumes

Due to how network modelling works, it is essential to ensure volumes at intersections are accurate. This is not a straightforward process, as vehicles are only added to the edges of the model and distributed through the network. Thus, if vehicle inputs are incorrect, or the routing decisions, which dictate directional split, is not accurate, intersection volumes will not be correct. To determine volume accuracy, the vehicles arriving and departing at each intersection in the model was compared to the traffic counts.

6.2. Model Outputs

To determine the effectiveness of the proposed upgrades, the model had to be analysed. The preferred criteria used to determine effectiveness are levels-of-service. Each movement of each intersection was analysed, for all the scenarios. The scenarios that were looked at is:

- Base Year
  - Status Quo
  - Optimised
- Horizon Year
  - Optimised

Three scenarios were analysed. The first scenario is the base year status quo. This model represents the traffic during the base year (2018), with the current geometric layout. Thus, this shows the present traffic situation in the City of Kigali.

The second scenario is the base year optimised model. This model uses the current traffic, with proposed, optimised layouts. For this scenario, the aim was to obtain acceptable levels of service throughout the study area corridors. To achieve this, the upgraded intersections were tested using SIDRA, as detailed in Chapter 5 and implemented into the model. The isolated (standalone) and network (micro-simulation) results were considered when determining the success of intersection upgrades. To achieve acceptable levels of service, the following upgrades were looked at:

- Signalisation
- Roundabouts
- Additional Slip-Lanes
- Additional Lanes

- Grade Separation, where necessary

Grade separation was only considered, should all other options fail to yield desired results.

The thirds scenario, which was analysed, is the horizon year optimised model. This scenario uses the optimised network layout from the second scenario, with growth applied to the base year traffic. It was agreed that a five-year horizon model would be built. The main purpose of this model is to provide a sensitivity analysis for how the optimised intersections would perform in a five-year horizon. It was decided that an industry standard of 3% traffic growth per annum would be applied, as detailed in Chapter 0.

6.2.1. Morning Peak Analysis

The results of the morning peak analysis of the Vissim models are shown in Table 6-4.

When analysing this table, it is clear that there is major congestion currently in the city. The majority of the movements fail, when considering vehicle delays. The breakdown of level of service and failure rate of turning movements in the City of Kigali is shown in Table 6-1 below,

Table 6-1: LOS Breakdown for Turning Movements (Base Year – Status Quo - Morning Peak)

TOTAL	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F	% FAILURE
247	98	22	19	16	12	80	37%

When looking at specific delays per intersection type, the average delay of turning movements at an un-signalised intersection is 48.2 seconds. This means the average level of service of un-signalised intersections is level of service E, which is outside the parameters of acceptable delays. The situation is similar for signalised intersections, with an average delay of 60.4 seconds for the turning movements. Which is again a level of service E. For the first scenario, the majority of intersections are un-signalised. It is then clear that there are currently major traffic problems during the morning peak in the City of Kigali.

When looking at the second scenario, the picture looks quite different. For this model, a large number of upgrades were proposed and implemented. The majority of these proposals include the signalisation of intersections. Where intersections did not require signalisation, left-turning lanes were provided to remove left-turning traffic from the main traffic stream, to prevent them from blocking through movements, while yielding. The breakdown of the level of service and failure rate of turning movements for the optimised scenario is shown in Table 6-2.

Table 6-2: LOS Breakdown for Turning Movements (Base Year - Optimised - Morning Peak)

TOTAL	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F	% FAILURE
247	113	42	55	37	0	0	0%

For this scenario there is a 0% failure rate, thus the levels of congestion are within acceptable ranges. When looking at average delay of turning movements at un-signalised intersections, this is also acceptable at 7.4 seconds, which yields a level of service A. For signalised intersections, this value is 23.7 seconds, which is a favourable level of service C throughout the city. It is clear then that the proposed solutions do improve congestion throughout the city significantly.

The majority of intersections require signalisation; however, for one intersection grade separation will be required. This is intersection 10, which is the intersection between KG501 Street and KG7 Avenue. Currently this intersection is a two-lane roundabout. The only modification possible is the addition of slip lanes, which does not address the problem. The main problem at this intersection is two, high-volume, conflicting movements. This is shown in Figure 6-3.

Figure 6-3: Intersection 10 Status Quo

The white and grey arrows indicate the conflicting movements. Because both are left turning movements, it is not possible to solve this with conventional means. An option that was considered is signalisation, but due to the high volume of these movements, this will lead to a very impractical intersection with a large number of left-turning lanes.

The only viable solution would be grade separation. The proposal is shown in Figure 6-4.

Figure 6-4: Intersection 10 Optimised

This proposal separates the north to east movement, from the east to south movement, which adds a significant amount of capacity.

The third scenario that was looked at is using the proposed road network, but adding growth at 3% per annum, for 5 years. This provides a sensitivity analysis for how the road upgrades will perform in the future. The breakdown of the level of service and failure rate of turning movements for the optimised, horizon year, scenario is shown in Table 6-3.

Table 6-3: LOS Breakdown for Turning Movements (Horizon Year - Optimised - Morning Peak)

TOTAL	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F	% FAILURE
247	113	32	55	40	6	2	3%

For the 5-year horizon, the network will have a 3% failure rate on the turning movements. When looking at the network as a whole, the average delay for un-signalised intersections will be 10.6 seconds, level of service B. For signalised intersections, this average delay will increase to 26.1 seconds, which is a level of service C. It is evident that the network, as a whole is still functioning very well, with the exception of one or two turning movement throughout the model. The main intersection of concern is intersection 5. This is the intersection between KN 5 Road, KG 1 Avenue and KG 11 Avenue. The current layout is that of a two-lane roundabout.

To achieve the favourable level of service shown in the second scenario, slip lanes are added to each approach, which removes the right-turning vehicles from the roundabout, and subsequently increases capacity. This is shown in Figure 6-5.

Figure 6-5: Intersection 5 Slip Lanes

From Table 6-4 it is evident that this solution is not future proof. Due to the high volumes, a signalised intersection will not be sufficient. The only alternative is grade separation, which will prove difficult due to the location of the intersection. There is a large density of buildings around this intersection, with accesses. Thus, grade separating at this intersection will cause just as much problems as it solves.

The only plausible solution would thus be providing alternate arterial routes in the city, to alleviate the congestion on KN 5 Road. This is also discussed in Chapter 0.

Table 6-4: Morning Peak Vissim Output

Morning Peak LOS	Base Year																								Horizon Year											
	Approach (Status Quo)												Approach (Optimised)												Approach (Optimised)											
	North			East			South			West			North			East			South			West			North			East			South			West		
	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R	L	T	R
Intersection 1	B	N/A	B	N/A	A	A	A	A	A	A	A	N/A	B	N/A	B	N/A	A	A	A	A	A	A	A	N/A	A	N/A	A	N/A	A	A	A	A	A	A	A	N/A
Intersection 2	F	N/A	F	N/A	A	A	N/A	N/A	N/A	F	B	N/A	C	N/A	A	N/A	C	A	N/A	N/A	N/A	C	A	N/A	D	N/A	A	N/A	C	A	N/A	N/A	N/A	C	A	N/A
Intersection 3	F	F	D	A	B	A	F	F	E	B	A	A	D	D	A	C	D	B	D	D	A	D	C	A	D	D	A	B	D	A	D	D	A	C	D	A
Intersection 4	N/A	N/A	N/A	C	C	N/A	F	N/A	E	N/A	A	A	N/A	N/A	N/A	C	B	N/A	D	N/A	A	N/A	C	A	N/A	N/A	N/A	D	B	N/A	C	N/A	A	N/A	D	B
Intersection 5	F	F	F	F	F	F	F	F	F	D	D	C	C	C	A	D	D	C	A	B	A	A	A	A	B	B	A	B	B	A	F	F	E	D	D	C
Intersection 6	F	F	F	D	D	C	F	F	F	F	E	C	D	D	A	D	C	A	D	D	A	D	A	A	D	D	A	D	C	A	D	D	A	D	B	A
Intersection 7	A	A	A	A	F	F	N/A*	F	F	N/A*	N/A*	N/A*	A	A	A	A	A	B	N/A*	B	A	N/A*	N/A*	N/A*	A	A	A	A	A	A	N/A*	C	A	N/A*	N/A*	N/A*
Intersection 8	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 9	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	A	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	A	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	A
Intersection 10	F	F	N/A	F	N/A	F	N/A	C	C	N/A	N/A	N/A	A	B	N/A	B	N/A	A	N/A	A	A	N/A	N/A	N/A	A	C	N/A	B	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 11	F	F	F	N/A*	A	A	C	D	B	A	A	A	C	C	C	N/A*	D	D	D	D	D	D	C	D	C	C	C	C	C	C	D	C	C	D	C	D
Intersection 12	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A
Intersection 13	B	B	B	A	A	A	B	A	B	C	A	A	B	B	B	A	A	A	A	A	A	D	C	A	C	C	C	A	A	A	A	A	A	C	B	B
Intersection 14	N/A	N/A	N/A	D	C	N/A	D	N/A	B	N/A	A	A	N/A	N/A	N/A	C	A	N/A	C	N/A	B	N/A	A	A	N/A	N/A	N/A	C	A	N/A	B	N/A	B	N/A	A	A
Intersection 15	F	N/A	F	N/A	F	E	N/A	N/A	N/A	D	A	N/A	D	N/A	A	N/A	B	B	N/A	N/A	N/A	D	A	N/A	D	N/A	C	N/A	B	A	N/A	N/A	N/A	B	A	N/A
Intersection 16.1	F	E	N/A	F	N/A	F	N/A	A	A	N/A	N/A	N/A	D	B	N/A	C	N/A	A	N/A	C	A	N/A	N/A	N/A	C	A	N/A	D	N/A	A	N/A	C	A	N/A	N/A	N/A
Intersection 16.2	A	N/A	A	N/A	F	F	N/A	N/A	N/A	F	B	N/A	B	N/A	A	N/A	D	A	N/A	N/A	N/A	C	A	N/A	C	N/A	A	N/A	D	A	N/A	N/A	N/A	D	B	N/A
Intersection 17	A	A	A	A	A	A	A	A	A	A	A	A	C	B	A	C	C	A	B	B	A	B	D	A	D	C	A	E	B	A	A	C	A	C	D	A
Intersection 18	F	F	F	A	B	A	D	D	B	D	A	A	C	C	A	B	B	B	D	C	C	C	C	C	D	C	A	C	A	A	D	D	D	C	B	B
Intersection 19	N/A	N/A	N/A	A	A	N/A	F	N/A	F	N/A	A	A	N/A	N/A	N/A	C	C	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 20	F	F	F	A	A	A	F	F	F	E	B	B	C	C	C	C	B	A	C	C	B	D	B	B	C	B	B	D	C	A	C	B	B	C	C	C
Intersection 21	F	F	F	A	A	A	F	F	F	E	E	A	C	B	B	D	C	C	A	C	A	D	B	B	D	C	A	D	C	C	B	B	B	D	E	E
Intersection 22	D	N/A	E	N/A	B	A	N/A	N/A	N/A	C	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A
Intersection 23	B	B	N/A	F	N/A	E	D	E	N/A	N/A*	N/A*	N/A*	B	B	N/A	A	N/A	A	B	B	N/A	N/A*	N/A*	N/A*	D	E	N/A	C	N/A	B	C	C	N/A	N/A*	N/A*	N/A*
Intersection 24	A	A	N/A	C	N/A	C	N/A	F	F	N/A	N/A	N/A	B	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	C	A	N/A	C	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 25	A	A	A	E	C	B	F	F	F	D	C	C	C	A	A	D	C	C	C	A	A	D	D	D	C	A	A	D	C	C	D	B	B	C	C	C
Intersection 26	A	A	N/A	F	N/A	F	N/A	F	F	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A	A	N/A	B	N/A	A	A	N/A	N/A	N/A
Intersection 27	N/A	A	A	N/A	N/A	N/A	F	F	N/A	F	N/A	F	N/A	C	B	N/A	N/A	N/A	C	A	N/A	C	N/A	A	N/A	B	A	N/A	N/A	N/A	C	A	N/A	D	N/A	A
Intersection 28	N/A	N/A	N/A	A	A	N/A	D	N/A	F	N/A	F	F	N/A	N/A	N/A	B	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 29	N/A	N/A	N/A	B	A	N/A	F	N/A	F	N/A	A	A	N/A	N/A	N/A	D	B	N/A	C	N/A	C	N/A	C	C	N/A	N/A	N/A	C	A	N/A	E	N/A	D	N/A	A	A
Intersection 30	N/A	N/A	N/A	C	A	N/A	C	N/A	C	N/A	A	A	N/A	N/A	N/A	C	A	N/A	B	N/A	B	N/A	A	A	N/A	N/A	N/A	D	A	N/A	C	N/A	B	N/A	A	A
Network Delay (Non Signalised)	48.2 Seconds												7.4 Seconds												10.6 Seconds											
Network LOS (Non Signalised)	LOS E												LOS A												LOS B											
Network Delay (Signalised)	60.4 Seconds												23.7 Seconds												26.1 Seconds											
Network LOS (Signalised)	LOS E												LOS C												LOS C											

6.2.2. Afternoon Peak Analysis

The results of the afternoon peak analysis of the Vissim models are shown in Table 6-8

When considering the first scenario, base year status quo, it is evident that similar to the morning peak period, the afternoon peak period also experiences a significant amount of congestion. The breakdown of level of service and failure rate of turning movements in the City of Kigali is shown in Table 6-8.

Table 6-5: LOS Breakdown for Turning Movements (Base Year – Status Quo - Afternoon Peak)

TOTAL	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F	% FAILURE
247	101	24	30	15	20	57	31%

During the afternoon peak period, a failure rate of 31% is experienced on the turning movements of the intersections. This is slightly less than the morning peak period, at 37%. This is common occurrence in urban environments. Generally, the morning peak period is the most congested.

For unsignalised intersections, the average delay is 32.4 seconds, which results in a level of service D. This is slightly better than the morning peak period, which has a level of service E for unsignalised intersections. However, for signalised intersections, the average delay is 88.5 seconds, which yields a level of service F. This is worse than the morning peak period. It is thus obvious that for both main peak periods, there is a significant delay in the City of Kigali.

The situation looks much better for the second scenario. The optimisations improve delays throughout the city drastically. The majority of the proposals were driven by the morning peak period. These upgrades are also sufficient for the afternoon peak period.

Table 6-6 shows the level of service and failure rate for turning movements in Kigali for the optimised scenario.

Table 6-6: LOS Breakdown for Turning Movements (Base Year – Optimised - Afternoon Peak)

TOTAL	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F	% FAILURE
247	121	36	53	37	0	0	0%

From the above it is evident that the proposed upgrades are sufficient to ensure a 0% failure rate during the afternoon peak period.

For this scenario, the unsignalised intersection will have an average delay of 11.3 seconds. This means the level of service will improve from a current D, to a B. For the signalised intersections, this average delay will be 22.6 seconds, or level of service C. This is a significant improvement from LOS F.

Adding the five-year horizon growth, yield the following level of service and failure rate for turning movements:

Table 6-7: LOS Breakdown for Turning Movements (Horizon Year – Optimised - Afternoon Peak)

TOTAL	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F	% FAILURE
247	107	45	51	37	3	4	3%

Table 6-7 shows a 3% failure rate for the whole network. Again, intersection 5, which was discussed in section 6.2.1, is experiencing problems in the future scenario.

The average delay for unsignalised intersections for this scenario is 12.1 seconds, or level of service B. For signalised intersections, this value is 24.9 seconds, or level of service C. Thus, the network as a whole will still function very well in the horizon year.

Table 6-8: Afternoon Peak Vissim Output

Afternoon Peak LOS	Base Year											
	Approach (Status Quo)											
	North			East			South			West		
	L	T	R	L	T	R	L	T	R	L	T	R
Intersection 1	A	N/A	A	N/A	A	A	A	A	A	A	A	N/A
Intersection 2	D	N/A	C	N/A	A	A	N/A	N/A	N/A	C	A	N/A
Intersection 3	F	E	C	B	A	A	D	E	C	B	B	A
Intersection 4	N/A	N/A	N/A	A	A	N/A	F	N/A	A	N/A	A	A
Intersection 5	F	F	F	E	E	E	F	F	F	E	E	E
Intersection 6	F	F	F	D	C	C	F	F	F	E	E	E
Intersection 7	A	A	N/A*	B	C	C	N/A*	F	F	N/A*	N/A*	N/A*
Intersection 8	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 9	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	A
Intersection 10	D	D	N/A	F	N/A	F	N/A	D	D	N/A	N/A	N/A
Intersection 11	C	C	C	A	A	A	A	C	A	A	A	A
Intersection 12	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A
Intersection 13	C	A	A	A	C	A	A	B	B	A	B	B
Intersection 14	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 15	F	N/A	F	N/A	D	C	N/A	N/A	N/A	B	A	N/A
Intersection 16.1	F	E	N/A	F	N/A	F	N/A	A	A	N/A	N/A	N/A
Intersection 16.2	C	N/A	C	N/A	F	F	N/A	N/A	N/A	F	E	N/A
Intersection 17	E	D	B	F	F	C	D	C	A	F	F	F
Intersection 18	F	F	F	F	F	F	F	F	F	B	A	A
Intersection 19	N/A	N/A	N/A	F	E	N/A	E	N/A	C	N/A	A	A
Intersection 20	B	B	A	A	A	A	C	E	B	B	A	A
Intersection 21	C	B	B	A	A	A	F	F	F	F	F	C
Intersection 22	B	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A
Intersection 23	C	C	N/A	F	N/A	E	E	D	N/A	N/A*	N/A*	N/A*
Intersection 24	A	A	N/A	B	N/A	D	N/A	F	F	N/A	N/A	N/A
Intersection 25	C	A	A	B	B	B	F	F	F	F	F	D
Intersection 26	A	A	N/A	C	N/A	C	N/A	F	D	N/A	N/A	N/A
Intersection 27	N/A	A	A	N/A	N/A	N/A	B	A	N/A	F	N/A	F
Intersection 28	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 29	N/A	N/A	N/A	A	C	N/A	E	N/A	D	N/A	A	A
Intersection 30	N/A	N/A	N/A	C	A	N/A	B	N/A	A	N/A	A	A

Afternoon Peak LOS	Base Year											
	Approach (Optimised)											
	North			East			South			West		
	L	T	R	L	T	R	L	T	R	L	T	R
Intersection 1	A	N/A	A	N/A	A	A	A	A	A	A	A	N/A
Intersection 2	D	N/A	A	N/A	C	A	N/A	N/A	N/A	C	B	N/A
Intersection 3	D	D	A	B	D	A	D	D	A	C	D	A
Intersection 4	N/A	N/A	N/A	C	A	N/A	C	N/A	A	N/A	C	A
Intersection 5	A	A	A	B	A	A	D	D	A	C	C	A
Intersection 6	D	D	A	C	C	A	D	D	A	C	B	A
Intersection 7	A	A	N/A*	A	A	A	N/A*	B	A	N/A*	N/A*	N/A*
Intersection 8	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 9	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	A
Intersection 10	A	C	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 11	C	C	C	D	C	C	D	C	D	C	C	C
Intersection 12	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A
Intersection 13	A	A	A	A	A	A	A	A	A	A	A	B
Intersection 14	N/A	N/A	N/A	D	A	N/A	B	N/A	A	N/A	A	A
Intersection 15	D	N/A	A	N/A	B	B	N/A	N/A	N/A	C	A	N/A
Intersection 16.1	C	A	N/A	D	N/A	A	N/A	C	A	N/A	N/A	N/A
Intersection 16.2	C	N/A	A	N/A	D	B	N/A	N/A	N/A	C	B	N/A
Intersection 17	D	C	A	D	B	A	A	B	A	C	C	A
Intersection 18	D	C	A	D	A	A	D	D	D	C	B	B
Intersection 19	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 20	C	C	C	D	C	A	C	B	B	C	B	B
Intersection 21	D	C	A	D	C	C	B	B	B	C	D	D
Intersection 22	C	N/A	B	N/A	B	A	N/A	N/A	N/A	B	B	N/A
Intersection 23	C	B	N/A	B	N/A	A	B	A	N/A	N/A*	N/A*	N/A*
Intersection 24	B	A	N/A	B	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 25	C	A	A	D	C	C	D	B	B	C	C	C
Intersection 26	A	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 27	N/A	B	A	N/A	N/A	N/A	C	A	N/A	D	N/A	A
Intersection 28	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 29	N/A	N/A	N/A	C	A	N/A	D	N/A	D	N/A	B	B
Intersection 30	N/A	N/A	N/A	C	A	N/A	C	N/A	A	N/A	A	A

Afternoon Peak LOS	Horizon Year											
	Approach (Optimised)											
	North			East			South			West		
	L	T	R	L	T	R	L	T	R	L	T	R
Intersection 1	A	N/A	A	N/A	A	A	A	A	A	A	A	N/A
Intersection 2	D	N/A	A	N/A	C	B	N/A	N/A	N/A	C	A	N/A
Intersection 3	D	D	A	B	D	A	D	D	A	C	D	A
Intersection 4	N/A	N/A	N/A	D	B	N/A	C	N/A	A	N/A	D	B
Intersection 5	A	A	A	B	A	A	F	F	C	C	C	B
Intersection 6	D	D	A	E	C	A	D	D	B	F	B	B
Intersection 7	A	A	N/A*	A	A	A	N/A*	C	B	N/A*	N/A*	N/A*
Intersection 8	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 9	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	A	N/A	A
Intersection 10	A	C	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 11	C	C	C	C	C	C	D	C	D	C	C	C
Intersection 12	N/A	N/A	A	N/A	A	A	N/A	N/A	A	N/A	A	A
Intersection 13	B	B	A	A	A	A	A	A	A	B	B	C
Intersection 14	N/A	N/A	N/A	D	C	N/A	B	N/A	B	N/A	A	A
Intersection 15	D	N/A	A	N/A	B	A	N/A	N/A	N/A	C	A	N/A
Intersection 16.1	C	A	N/A	D	N/A	A	N/A	C	A	N/A	N/A	N/A
Intersection 16.2	C	N/A	A	N/A	D	B	N/A	N/A	N/A	A	B	N/A
Intersection 17	D	C	A	F	B	A	A	B	A	C	D	A
Intersection 18	D	C	A	C	A	A	D	D	D	C	B	B
Intersection 19	N/A	N/A	N/A	A	A	N/A	A	N/A	A	N/A	A	A
Intersection 20	C	B	B	D	C	A	C	B	B	B	B	B
Intersection 21	D	C	A	D	C	C	C	B	B	D	E	D
Intersection 22	A	N/A	A	N/A	A	A	N/A	N/A	N/A	A	A	N/A
Intersection 23	D	D	N/A	C	N/A	B	C	B	N/A	N/A*	N/A*	N/A*
Intersection 24	C	A	N/A	C	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 25	C	A	A	D	C	C	D	A	B	C	C	C
Intersection 26	B	A	N/A	A	N/A	A	N/A	A	A	N/A	N/A	N/A
Intersection 27	N/A	B	A	N/A	N/A	N/A	C	A	N/A	D	N/A	A
Intersection 28	N/A	N/A	N/A	B	B	N/A	B	N/A	B	N/A	B	B
Intersection 29	N/A	N/A	N/A	C	A	N/A	D	N/A	E	N/A	B	B
Intersection 30	N/A	N/A	N/A	D	A	N/A	C	N/A	A	N/A	A	A

Afternoon Peak LOS	Base Year – Approach (Status Quo)	Base Year – Approach (Optimised)	Horizon Year – Approach (Optimised)
Network Delay (Non Signalised)	32.4 Seconds	11.3 Seconds	12.1 Seconds
Network LOS (Non Signalised)	LOS D	LOS B	LOS B
Network Delay (Signalised)	88.5 Seconds	22.6 Seconds	24.9 Seconds
Network LOS (Signalised)	LOS F	LOS C	LOS C

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7. Conclusions & Recommendations

7.1. Conclusions

- The current road network in the City of Kigali has a severe lack of capacity. This is evident when observing delays experienced by road users, and the subsequent adjustments to driver behaviour;
- During the morning peak period, the delays are slightly worse than the afternoon peak period, but during both peaks, significant delays are experienced;
- The delays for the current geometry are:
  - AM Peak
    - Un-signalised: 48.2 seconds (LOS E)
    - Signalised: 60.4 seconds (LOS E)
  - PM Peak
    - Un-signalised: 32.4 seconds (LOS D)
    - Signalised: 88.5 seconds (LOS F)
- Proposed solutions:
  - Three intersections are kept as priority controlled, but small geometric changes are added to these intersections;
  - Twelve of the intersections are kept as roundabouts, or upgraded to roundabouts;
  - The three signalised intersections in the study area are upgraded and optimised;
  - The remaining thirteen intersection are upgraded and signalised.
- The proposed solutions will improve LOS for the AM peak from E and E to A and C for signalised and un-signalised intersections respectively. For the PM peak, the LOS will improve from D and F to B and C for signalised and un-signalised intersections respectively;
- The 5-year horizon analysis showed generally acceptable levels of service across the network, with a small number of movements failing;
- For the horizon year, the LOS for both the AM and PM peak will be B and C for signalised and un-signalised intersections respectively.

7.2. Recommendations

- The proposed solutions and upgrades should move to the detailed design and implementation phase;
- Other corridors and intersections should be identified for similar studies, to reduce congestion throughout the city.

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Annexures

(Attached Electronically)

Annexure A: Inception Report

Annexure B: Traffic Counts

Annexure C: SmartyCam Videos

Annexure D: Base year SIDRA Output

Annexure E: Horizon year SIDRA Output

Annexure F: Vissim Videos

SURBANA JURONG

SMEC
Member of the Surbana Jurong Group

Institute of Policy Analysis and Research - Rwanda