KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

OPERATIONAL PERFORMANCE ASSESSMENT OF THE SANTASI ROUNDBOUNT FROM GPS DATA

By:

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DECLARATION

I, Adjei Marfo Richard, hereby declare that this piece is my own work, and I state with emphasis that this work has not been published or submitted elsewhere for a degree or diploma in Kwame Nkrumah University of Science and Technology or any tertiary institution. Any literature work done by other and quoted within this submission has given acknowledgement and stated in the reference section.

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ABSTRACT

The increase in the number of vehicles in urban centres has caused significant rise in traffic congestion. The arterials in Kumasi are not left out of this situation. Highway facilities in the sub-region are faced with slow vehicular movements, long queues and long delay to travel time. Traffic Congestion is described as a situation where there are long queues, slow movement of vehicles and delays in travel time occurs on various roadways. In Africa, studies have shown that, traffic congestion mostly results from road side frictions like trading along roadways and on-street packings. Intersections also contributes to congestion and total delay on a facility. Traffic congestion creates a lot of problems like delay in reaching to your destination, excessive use of fuel for travelling and high amount of transportation fees in such areas.

This study assesses the operational performance of the Santasi roundabout in terms control delay for direction of travel and time of day using historical data. For east-bound and west-bound direction of the intersection was used in the analysis. For the time-of-day analysis, the study only considered the AM peak and the PM peak periods. The level of Service indicator was used to evaluate the effectiveness of the intersection. Google earth aided in analyzing the geographic formation of the location in the administrative studies. A mobile tracking application was used to collect the historical data by the use floating car method. All data analyzed and tabulated are GPS data and calculations done in Microsoft excel. The criteria for the design in accordance with the Highway capacity manual. The study recommended measures that can help in future studies of the topic.

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LIST OF ABBREVIATIONS

LOS – Level of Service

HCM – Highway Capacity Manual

EB – East-bound

WB – West-Bound

GPS – Global Positioning System

NCHRP – National Cooperative Highway Research Program

TMC – Transportation Management Centres

AVI – Automated Vehicle Identifier

FFS – Free Flow Speed

GPX – GPS Exchange Format

KML – Keyhole Markup language

KMZ – Keyhole Markup language Zipped

CSV – Comma-separated Values

MTTD - Motor Traffic and Transport Department

GIS – Geographic Information System

DMIs - Electronic Distance Measuring Instruments

SEMCOG – Southeast Michigan Council of Government

N8 – National road eight (8)

CHAPTER I

1 INTRODUCTION

1.1 Background

Traffic Congestion has caused a lot of problems among Ghanaians living in urban centres like Accra and Kumasi. It has been predicted by local transportation experts that congestion would even become worse in the future to come (Jones, et al., 2014). Congestion in the urban centres is mainly due to the increase in the use of private cars as a means to reach destinations. Even though private cars give a sense of security and brings a lot of social respect to users, they are not so efficient as a means for carrying passengers from one place to another.

Also, the bottlenecks along the arterial attributes partly to the problem of congestion. Road intersections also contribute greatly to congestion and the total delays

Traffic delay in urban areas occur from several factors. Some of these include the rapid increase in population at these urban areas, increase in the number of employment opportunities which requires people to travel to such places and also with the increase in number of private cars as mentioned earlier. Also, market centres are major contributors to traffic Congestion due to the poor traffic management systems (Jain & Vazirani, 2010). One of the consequences of traffic congestion is the increase in travel time especially during peak periods. Some economic reports have drawn attention to the effects these delays have on the economy. Some statistics shows that delay in travel time is one of the factors which contributes to the inability of the country's daily per-capita income to rise substantially, hence contributing to economic loss in the country (Muneera & Kris, 2018). On the aspect of health, a lot sick people have died before their arrival at the various hospitals centers due to the delay which they may encounter in the quest to receive proper medical attention. Other psychological problems results from road rage on the part of drivers.

It is therefore necessary to alleviate the problem of traffic congestion in our country so as to improve the upon the level of Service (LOS) of the urban roadway facilities and also the efficiency of the roadway. Traffic Congestion level evaluation of road networks is an important tool for managing traffic and controlling traffic because it could allow various agencies an accurate and vivid foresight of traffic operation network status which includes the information of time and location for the congested roadway.

1.2 Problem statement

Traffic congestion has become a serious issue in Kumasi these days. Vehicles using various routes in the region are expected to join several long queues before arriving at their various destinations. Passengers sometimes finds it difficult to cope with this situation and the kind of problems associated with this situation and sometimes plans to explore other means of transport. This problem has resulted in both regional and national crises, especially with the issue of low productivity. Research has shown that intersection contributes greatly to traffic congestion and total delays on the roadway during peak periods. This has prompted the need to access the operational performance of certain intersections in Kumasi. The operational performance of arterials in Kumasi are mostly identified by high congestion during peak periods and its major characteristics are long queues, slow vehicular movements and long delay to travel time.

The study will assess the operational performance of the Santasi roundabout which lies on the N8 roadway by establishing the total delays and recommend measures to improve upon the operational performance.

The traditional method of estimating travel time that is the use of the stop watch does not give the major area of influence of an intersection. Opoku-Agyekum (2016) assessed the capacity and efficiency of roundabout using Micro-simulation software packages, specifically the Verkrhr in Stadten – Simulations model (VISSIM) which reveals a more efficient way to control traffic. Osei, et al. (2018) analyzed ways to improve the capacity at roundabout using microsimulation approach but this study seeks to establish the performance by using GPS methodology estimating travel time. Hence, the study will capitalize on using a more accurate technique for estimating travel time other than the traditional method.

1.3 Scope of study

In order to achieve the objectives of this study, the following should be made:

The control delay would be used to describe the roadway performance.

The data set to be used for the study would be a validated historical data set and which were obtained from GPS devices.

With the time-of-day study, A.M. peak periods and P.M. peak periods would be used to determine the average travel time of the intersection.

The direction of travel will be EAST-BOUND (EB) and WEST-BOUND (WB) directions.

The control delay of the intersection would be calculated for each trip made.

The level of service will be the based on the HCM control delay criteria.

1.4 Objectives of the study

The main objective of the study is to explore the use of GPS data to determine the operational performance of the Santasi roundabout which lies on the N8 roadway.

The following are the specific objectives of the study:

- To estimate the control delay of the intersection
- To determine whether or not control delay vary by direction of travel and time of day
- To identify the level of service for the major approaches of the intersection.

1.5 Significance of study

The study will analyze the Level of Service and capacity which are relevance indicators used by traffic engineers to determine the operational performance and functionality of a roadway.

Information obtained can be applied in traffic control management by the MTTD and traffic engineers.

The conclusions and recommendations at the end of the day will be useful in inform policy regarding roundabouts and also help in subsequent study regarding roundabouts.

1.6 Organization of report

The first chapter of this study gives a general introduction to the study by providing a brief summary of the concept of traffic congestion, level of service and control delay. It also presents the purpose and significance of the study. The second chapter contains relevant information and literature based on the study from traffic engineers and other scholars in the field. The Chapter three of this report explains the method used in the collection of data and validates the data used in this study. Chapter four gives a comprehensive analysis to the data and addresses all objectives of this study. Also, the chapter provided charts which makes the data easier to read and understand. The Chapter five is the concluding section of the study. The chapter also gives possible recommendations for future study and planning.

CHAPTER II

2 LITERATURE REVIEW

This chapter has been given the name literature review because it contains information based on latest findings about the topic.

2.1 Overview of roundabouts

A roundabout is a form of circular intersection where traffic travels around a central island in a counter-clockwise direction NCHRP (2010). The vehicles entering the roundabout are expected to yield to vehicle vehicles within the circulating roadway. Roundabouts serves as a form of traffic control intersection. Also, the circulating vehicle are not subjected to any other right-way conflicts and no parking is allowed on the roadway. The travel time of within the intersection contributes partly to the traffic congestion on the roadway.

Roundabouts have specific characteristics that differentiate them from other circular intersections. Some of these are Yield Control at entry/exit approach and Separation of conflicting traffic movements by markings of pavements. The central island has geometric characteristics which allows travel speed of less than 50km/h.

For efficient work rate, enough gaps must appear in the circulating flows on the intersection that drivers traversing the roundabout accept. Movement of vehicles from the entry arms enter, circulate then leave their preferred exit arm.

Notwithstanding its efficient ability to resolve conflict in a traffic according to (Garber & Hoel, 2009), roundabouts are used in situations where there is

- A change in functional class of a roadway
- A clear change in the road direction
- A change from a rural environment to an urban environment.

On the other hand, a roundabout intersection is very complex to deal with since there is not clear identifiable major roadway that can be used for designing the junction. The circulating flow depends the operation of the entry arms of the intersection.

2.2 The concept of traffic congestion

According to the Websters Third International Dictionary, the word Congestion is defined as "a condition of overcrowding and overburdening". Technically, Congestion is defined as a condition where there is the introduction of an additional vehicle into a traffic flow which increases the travel time of the other vehicles (Thompson, 2011). Many transportation departments and transport engineers have come with various definitions to Traffic Congestion. Some transport engineers classify traffic congestion as a physical and a relative phenomenon (Rahane & Saharkar U,R, 2014). (Kiunsi, 2013) defined the relative phenomenon as a situation when there's a difference between the performance of the road user and the performance of the road. The physical phenomenon on the other hand, relates to a situation where vehicles impede the progression of each other when demand for limited road space reaches full capacity (Transport Research Centre, 2007)

2.2.1 Types of Traffic Congestion

From the Victoria Transport Institute (2009), Traffic Congestion is grouped in two. These are:

- Recurrent Congestion
- Non-Recurrent Congestion

Recurrent Congestion are those Congestion which are more predictable during peak hours but non-recurrent congestion is the unexpected or unplanned large events which cannot be predicted easily example road works, accidents.

2.2.2 Causes of congestion

Congestion occurs from different factors. These factors can be variable or fixed, predictable or non-predictable. The following are some of the factors that has led to congestion in the Kumasi.

- Unplanned Cities: Most of the roads in the roads in Kumasi are narrowly built. For a number of years, no provision has been made to scale the existing road capacities to battle the increase the traffic density (Jain & Vazirani, 2010).
- Increased in the use of private transportation: In recent years Kumasi has experienced an increase in the number of private vehicles. From last year 2020, news reports suggests that a lot of people have sort to the use of private transportation due to the fear of covid-19. Also, social stigma, where people have the perception that private vehicle is a sign of riches, goodness and prosperity while people using public transport are regarded as poor and are less endowed. And lastly, the increase in "uber-driving" has

caused the increased in the number of vehicles and thereby causing congestion in our roads in recent years.

- Indiscipline on the part of drivers: Some drivers in attempt to get to their destinations on time jump red lights and block the intersection which causes traffic congestion. Other drivers lack sufficient training on lane management mostly at traffic junctions. Also, there have seen large number of tricycles popularly known locally as “Pragya” (name in a popular telenovela) invading into the roadways these days. The “Pragya” riders refuse to join the approved roadway and maneuver their own ways into traffic streams which causes sudden stops by other vehicles and this causes congestion. In effect, several bottleneck roads remain congested for a period of time. The poor law enforcement procedures in the sub-region have made this possible and hence allows drivers to do whatever they assume it’s the best for them according to Jain and Vazirani (2010).
- Loading of passengers in traffic lanes: Mini-buses also known locally as “Trotro” and taxi drivers have access to few terminals along the roadway and hence resort to picking on passengers on the roadway. Aside this, some recalcitrant drivers also forgo the use of the terminals and lay-bys (where provided) and carry-on to pick passengers in the traffic lane. Drivers coming from behind have to stop or reduce speed to allow these recalcitrant drivers finish with the loading. This attitude has become rampant on the roadway and has led to a lot of congestion on the roadway (Mensah, et al., 2014).
- Obstruction by pedestrian: According to Mensah et al (2014), some sections of the roadway lack crosswalks. Hence, pedestrians are compelled to cross at different paths which leads to congestion.
- Traffic signals to control traffic Congestion: The traffic control devices cause congestion. Vehicles are obligated to stop when the meets the red light in the cause of the travel (Armah, et al., 2010).
- Trading activities along the roadway: Along the roadway, there are a lot of trading activities going on. Drivers, passengers and other road users have to stop in the course of travel to buy from these traders before they carry on with their journey. This is one of the main causes of congestion on the roadway (Jain & Vazirani, 2010).

2.2.3 Effects of congestion

Traffic Congestion has brought up many effects on our economic, health, environmental and social affairs (Mahmud, et al., 2012).

- On the economic aspect, traffic congestion leads to high consumption of fuels which account to the increase in transportation prices. Increase in transportation also leads to increase in the cost of goods and services. Again, people waste a lot of time which could have been used for work in platoons, there is also delay in delivery services.
- On the health front, study shows that when vehicles stop in traffic, they can still produce high emission of harmful carbon which can cause localized and short-term respiratory diseases (Agyapong & Kolawole, 2018). Also, fumes from the vehicles causes air pollution. Time spent in vehicles causes tiredness, stress and backaches. Other psychological problems come from road rage and by aggressive driving of impatient drivers.
- The environment experiences the worst of it all, as mentioned early on, fumes from the vehicles pollutes the air we breathe.

2.2.4 Other negative impact of Congestion include:

- Slow moving vehicles causes to pavements
- It results in cost for signal installation
- There is increase in the occurrence of accident
- Brings delays and frustration to road users
- Pavement damage imposes greater vehicle operating costs.

2.2.5 How can we minimize Traffic Congestion?

Traffic congestion can be eliminated completely but we can minimize it. (Rodrigue, et al., 2009). The following are some ways by which we can put in place to minimize traffic congestion:

- Increasing the capacity of roads: Congestion can be reduced when the capacity of the road is increased. This can be achieved by addition of lanes to existing ones, creating of new routes, providing access roads and road space rationing.
- The use of public transport: The general public should be encouraged to use various public transportation or commercial vehicles as a means of transportation. Provision of good and cheap public transport will reduce the number of private cars on the street.

- Implementing Mobility management: A lot of mobility strategies can be put in place to reduce congestion. Some of these include promoting bicycling, ride-sharing, targeting large trips by supporting mobility management efforts
- Widening of Intersections: Intersections acts as bottlenecks during peak hours, hence widening it will reduce the congestion to some extent
- Provision of lay-bys: To reduce on-street parking, there's the need to provide lay-bys for vehicles
- Restrain Procedures such as user taxes, parking restraint, congestion pricing and vehicle ownership restraint.
- Provision of footbridge and underpass for pedestrian

2.3 Measures of effectiveness (MOE's)

In order to characterize the performance of an intersection, several MOE's are key in the evaluation process. Key MOE's are would be described below.

2.3.1 Delay

Delay characterizes intersections to assess the benefit of the operational improvement of a given highway facility. For a roundabout, the delay measures are defined separately for each of the entry approach. The delay for the entry of a roundabout consists of two major components. These are:

- **Queuing delay**: This type of delay occurs when drivers are waiting for an appropriate gap in the circulating traffic.
- G**eometric delay**: This occurs when vehicles slowdown in the process of traversing the roundabout.
- **Control delay:** from the (HCM 2000) is defined as the delays experienced while a vehicle is decelerating, being stopped at the intersection while waiting for an acceptable gab, and then accelerating back at a particular running speed downstream of the intersection

2.3.2 Queue Length

The measurement of queue is very useful when detecting hot spots, operation problems at points on a facility. At roundabouts, the queue length is very useful for determining the capacity and to dimension lane lengths. (FHWA, 2007).

The length of Queue also gives detailed appreciation to the functional performance of a roundabout as compared to other intersections (Galleli, 2008).

2.3.3 Travel Time

The Travel time describes the total time for a vehicle to complete a trip over a section of a facility to a specified facility.

2.3.4 Quality and level of service

To be able to characterize the operational conditions with a traffic stream, the quantitative measure is the Quality of Service. The LOS on the other hand is a quality measure that represents the operational conditions within a traffic stream, generally in such measures as speed and travel time, convenience, freedom to maneuver, comfort of the driver and traffic interruptions (HCM 2000). For each type of roadway facility, the HCM 2000 has defined Six LOS that has analytical procedures which are currently available. For each LOS, alphabets are used to designate, from A to F. LOS A represents the best operating performance and, in that order, LOS F signifies the worst operating condition. Here, Safety measures are not included.

LOS A shows primarily free-flow operations at average travel speed. This is usually about 90 percent of the free-flow speed (FFS) for a given street class. Control delays these intersections are minimal.

LOS B represents unimpeded operations at average travel speeds about 70 percent of the FFS for the type of street class. There are slight restrictions when a driver wants to maneuver within the traffic stream. Control delays at these points are not significant

LOC C represents a stable operation but the ability to maneuver within the traffic stream is more restricted as compared to the LOS B. The average travel speed for the stream is about 50 percent of the FFS for the street class.

LOS D has an average travel speed of 40 percent of the FFS. Factors leading to this include signal progression, inappropriate timing of signals and high volume of vehicles.

LOS E describes significant delays and average travel speed of about 33 percent or less of the FFS for the street class. Again, high volumes, poor timing of signals, extensive delays at critical intersection are the leading factors for such impediments.

LOS F is the worst and characterized by a lot of delays. This LOS describes one fourth of one third of the FFS.

2.4 Field data collection techniques for travel time

The methods which are used presently to collect travel time data can be grouped into three major groups:

- Test Vehicle Technique
- Traffic Sampling Technique
- Probe Vehicle Technique

2.4.1 Test Vehicle Technique

This is commonly known as floating car Method is the commonest method of travel time collection. In this method, there is a vehicle(s) that is dispatched specifically to drive with the traffic stream for the purpose of collecting data. Travel time collection earlier depended on the use of stopwatch or timers to determine the time taken by a vehicle to travel from one reference point to another but these days, study depend solely on the use of automated equipment which provide information such as speed and position and mostly recorded on a second-by-second basis SEMCOG (2008).

GPS receivers and electronic Distance Measuring Instruments (DMIs) are the most commonly used monitoring devices in recent study.

- GPS receivers: These locate the position of a vehicle by the use of signals which are emitted by an array of satellites and also identify the speed by triangulation. Basically, GPS devices have a typical accuracy of 50ft when determining the position and 0.1 mph for steady-state measurement. Factors such as atmospheric effects, multi-path effects from reflecting off signals which surrounds buildings can affect measurement. Hence in order to achieve greater accuracy the use of Differential GPS (DGPS) is used to correct factors for the GPS measurements.
- Electronic DMIs: These estimate speed and travelled distances by using sensors which are normally fixed to the transmission of a vehicle. The sensors monitor the pulses sent as the vehicle moves and then convert the pulses in to distances measurements. The instrument is calibrated before the field data collection in order to ensure accuracy. Factors such as weather, user operation and differing tire pressure can affect measurement.

  According to SEMCOG (2008), the main advantage of electronic DMI is its ability to provide higher accurate measurement of distance but the GPS measurement has reduced accuracy since measurement is based on the communication between satellites which are located over a hundred miles in the sky and therefore brings about certain kinds of delays. The SEMCOG (2008) highlights the fact that GPS provide direct location positioning and therefore facilitates collected data on the GIS maps but the DMIs only measures distances and hence distance measurements are obtained from the use of DMIs while the GPS sensing abilities are used for location positioning, checks on data consistency and in GIS mapping software.

There are three different ways of conducting the test vehicle method according SEMCOG (2008). These are:

- **Floating Car Method:** In this method a vehicle travels along a roadway at the average travel speed. This is done by making sure that the floating car passes as a lot of vehicles as the number of vehicles passing it overtime.
- **Average Car Method:** This is similar to the floating car method but there is less restriction in the average car method as compared to floating car method. Here the driver does attempt to pass many vehicles that passes it but rather the driver selects the speed that matches the general traffic condition at a particular point in time.
- **Maximum Car Method:** Here, the driver travels at the speed limit of the roadway unless the driver is impeded by traffic.
- **Chase Car Method:** This method randomly selects individual vehicles from the traffic streams and follows. This provides not only the performance of the test driver but also the performance of actual vehicles passing the traffic stream.

2.4.2 Traffic Sampling Techniques

The traffic sampling technique is done by collecting travel time data by monitoring the time taken by individual vehicles to traverse a roadway segment remotely rather than depending on the information provided by one specific vehicle by SEMCOG (2008). There are various techniques used in this method some include:

- License Plate Matching Techniques: This is done by collecting Vehicle license plate characters and arrival times at specific checkpoints, license plates are matched between consecutive checkpoints and finally the travel times are computed from the difference between the arrival times.
- Automatic Vehicle Identification (AVI): This method is done by assigning unique identifications on vehicles by using electronic signature of a transponder which are installed on the vehicle onboard. The AVI systems then establish the travel time between two locations by matching the data recorded by each vehicle at each location.

- Cellular Geolocation Tracking: This is an emerging technique that requires the use of cell phones which have GPS locator. The GPS locator determines the position and the speed of the vehicle at all times.
- Vehicle Signature Matching: This method calculates travel time by matching unique signatures to vehicles in a step-by-step observation point. Here, it requires no specific instrument to be installed on the vehicles.

2.4.3 ITS probe vehicle techniques

In this method, travel time is collected by the use of passive instrumented vehicles in the traffic stream and remote sensing devices. This can be done personally, by public transits or by commercial vehicles. The various transportation management centers (TMC) receive travel time reports from probe vehicles. A probe vehicle may be equipped with several receivers or transponders. Inside a probe vehicle is an AVI transponder which is used in electronic toll collection applications. To locate radio transponders on probe vehicles, a Ground-based radio navigation system is required, this use triangulation techniques and its essential for personal communication system and route guidance. GPS receivers in cellular telephone to determine travel time also use a 24-satellite network to determine the position of vehicles and these are now the commonest means of route guidance by SEMCOG (2008).

CHAPTER III

3 METHODOLOGY

3.1 Geometry of the intersection

The Santasi Roundabout was the site selected for the study. The intersection lies on the N8 road and has relatively high volumes and congestion during morning peak hours and evening peak hours. All approaches are also characterized by high queues and high delays and as a result the Motor Traffic and Transportation Department (MTTD) staff are always around to control the traffic flow manually, especially during peak periods.

The roundabout is a four-legged intersection with two entry/exit lanes for each of the legs. These are the Western-Bypass approach (West Direction), Dr. Osei Tutu Bypass (Eastern Direction), The Adum Approach (North Direction) and Santasi Approach/Bekwai Approach (South Direction)

Figure 1: Aerial View of Santasi Round about (Source: Google Earth)

3.1.1 Geometric Data of Intersection

The geometric data of the intersection such as the approach width is 7m for all the approaches, the width of the circulatory roadway is 10.20m, the inscribed circle has a diameter 50.60m and the central island has a diameter of 37.5m. This data was obtained from Google earth.

3.2 My Track App

My track app is a mobile phone application that keep track of person's route. It is easy to understand like any other application and was developed by Daniel Qin in 2014. The app is used to record a route by showing the current location on google map along time, duration and distance which comes along with its respective latitude and longitude. Along the travel, the application displays a chart about the speed and altitude. The application allows users to save routes and export routes to GPX/KML/KMZ/CSV files. The application also makes it possible for users to insert markers at desired positions on the map.

3.3 Data Collection

The set of data to be used for the analysis of the study is a historical data obtained in 2019 and 2020 from the use of a mobile application called the "My Track" by the application of the floating car technique for the collection of travel time data. This research was conducted by M/s EDCIV 2019 and 2020 students. During the research, the floating vehicle method was used. A car was set off purposely for the collection of travel time data. The data collection personnel ensured that the vehicle was moving at the appropriate speed according to the guidelines set for the use of the floating car technique. The My Track application was installed on a mobile phone with high GPS accuracy. The app recorded the speed, location, time and the bearing for every distance the vehicle moves. This was done in the morning and evening of the particular day the test was conducted. In order to give precise and accurate report of the existing conditions, way markers were inserted at certain locations. This was to demonstrate the cause of traffic congestion at that instance. Figure 2 shows the nature of data provided using the application.

.ocation	Time	Latitude	Longitude	Altitude	Accuracy	Speed	Bearing
1	2021-07-22T06:57:44.353Z	6.698023	-1.63995	269.8613	139.184	1.664517	301.6639
2	2021-07-22T06:57:49.375Z	6.698047	-1.63999	270.2416	204.47	1.171895	301.7177
3	2021-07-22T06:59:05.287Z	6.699563	-1.64875	275.5504	1299.999	0.21476	102.3178
4	2021-07-22T06:59:10.302Z	6.699733	-1.64892	274.5412	899.999	0.111805	51.28047
5	2021-07-22T06:59:15.348Z	6.699814	-1.649	274.2852	899.999	0.147978	0.927795
6	2021-07-22T06:59:20.362Z	6.699848	-1.64906	274.0179	2200	0.20274	336.5881
7	2021-07-22T06:59:40.503Z	6.698199	-1.65315	277.2776	1000	0.006564	0
8	2021-07-22T06:59:46.547Z	6.698829	-1.65445	278.4466	116.1	0.188576	297.8127
9	2021-07-22T06:59:59.909Z	6.698768	-1.65559	283.079	92.9	11.42111	266.3341
10	2021-07-22T07:00:04.911Z	6.698685	-1.65674	284.228	96.633	17.33887	266.0189
11	2021-07-22T07:00:08.906Z	6.69862	-1.65757	285.3545	156.035	19.06624	265.8117
12	2021-07-22T07:00:14.956Z	6.698601	-1.6585	285.7029	149.251	18.46846	267.6094
13	2021-07-22T07:00:19.975Z	6.698632	-1.6596	286.1267	118.732	20.26828	269.5172
14	2021-07-22T07:00:23.964Z	6.698651	-1.65977	286.4294	150.257	12.66275	270.3557
15	2021-07-22T07:00:44.792Z	6.697999	-1.66382	288.8264	128.899	0.05683	311.7069
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 2: A sample of the test result (Source: From Study)

3.4 Validation of Test Results

On the 22nd of July, 2021, an exercise was undertaken during the morning peak period to check for the validity of the historical data. This was done between the hours of 6:00am-8:30am. The same test vehicle model was used to conduct the test with the My Track application. Afterwards data analysis for both present and historical data set was made by using Microsoft excel. Speed profiles, control delay, and travel time analysis were made on some of the data set. All analysis made concluded that the conditions (long queues, slow movements, delay to travel time) on the roads are still existing and still the same. This was done for east- bound (EB) and west-bound (WB) directions. Hence, I conclude the historical data accurate and fit to be used for the purpose of this study.

3.5 GPS Data Methodology

GPS data collected from the exercise were exported to a computer system and analysis were made. Speed profile of the intersection were observed and the control delay for the different trips were calculated at a later time. The average speed at the intersection was 11.739m. The intersection lies on latitude 6.672004 and longitude -1.63998. Figure 3 demonstrates the nature of the speed at the intersection in the PM peak period.

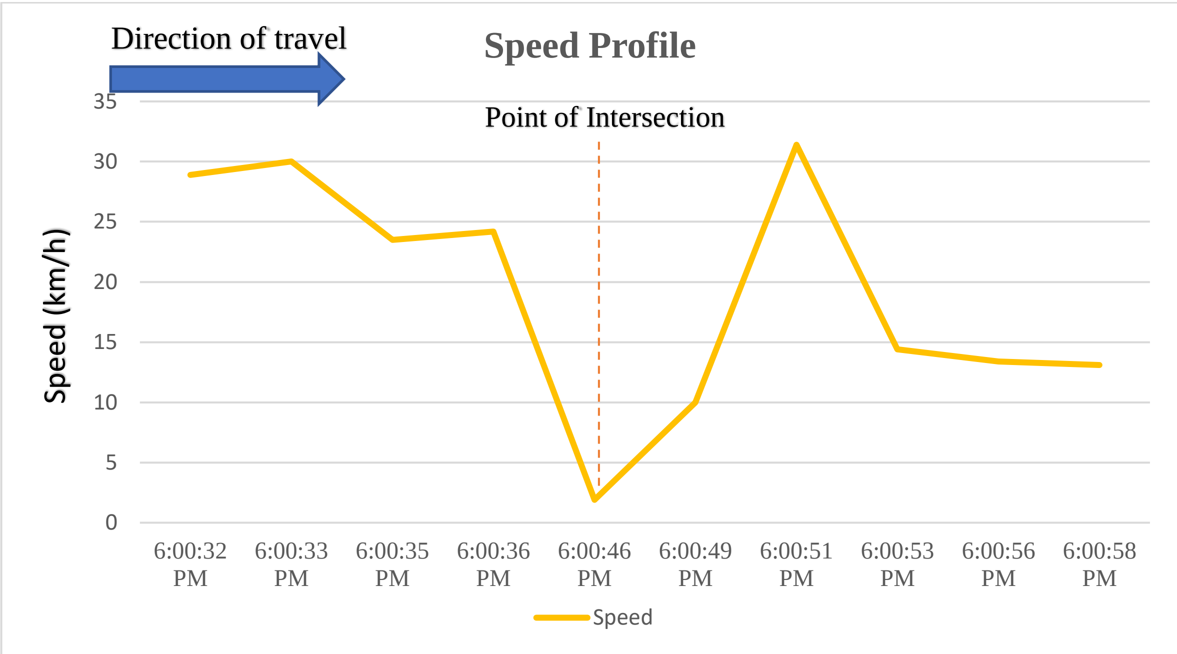

Figure 3: Speed Profile at the P.M. peak period. (Source: From Study)

The characteristics of the speed profile was used estimate the control delay of the intersection. For accuracy and precision of results, the google earth was used to obtain the exact location of the intersection so as to draw the exact speed profile for the results.

3.6 Control delay estimation

The total traffic delay is made up of two components namely the Segment delay and the Control delay. The sum of the segment delay and the control delay gives the total traffic delay. Control delay is a principal measure in evaluating lane adequacy, determining of Level of Service at an Intersection (LOS) and in fuel consumption estimation. Delays is the additional travel time experienced by a driver, a passenger or by a pedestrian. Control delay is defined as the delays experienced while a vehicle is decelerating, being stopped at the intersection, and then accelerating back at a particular running speed downstream of the intersection (HCM, 2000).

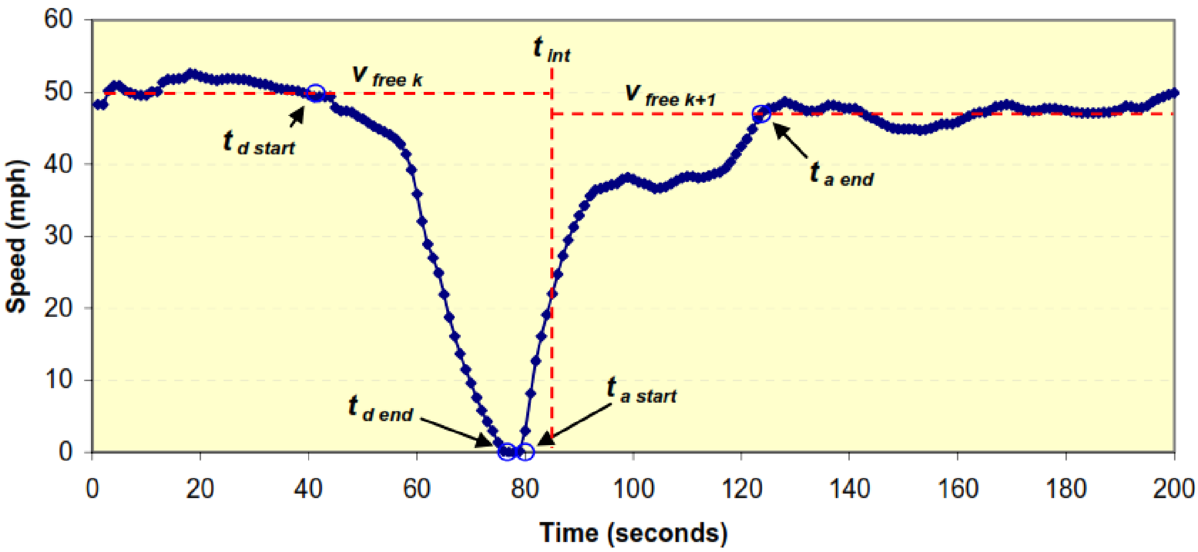

Figure 4: A graph showing the control delay of an intersection

dc = (t_{aend} -t_{dstart}) - -$\frac{L6-L1}{Sr}$

dc = Control delay

t_{dstart} = Time when deceleration begins

t_{aend} = Time when deceleration begins

L_1 = Location where deceleration begins

L_2 = Location where acceleration ends

CHAPTER 1V

4 RESULTS AND DISCUSSION

This section gives comprehensive analyses of the collected data and makes the data easy to understand. To be able access the operational performance at the intersection (longitude -1.641007849093105 and latitude 6.672941612021156 (source: google earth)) and to evaluate whether or not control delay vary by time of day and direction of travel, the data analysis was grouped into AM periods and PM periods, East-bound and West-bound directions. This chapter gives a summary of the of the data.

4.1 Existing Performance of the Roadway

Table 1 represents the average control delay for the data set provided. The Darkodwom to Patasi represents the East-bound (EB) direction and the Patasi to Darkodwom direction represents the West-bound (WB) direction. The AM period was chosen between the hours of 6:30am to 11:30am while the PM period was between 12:00pm to 6:30pm. This period included the peak periods for both time of the day. The AM period consist of an average of four (4) trips for the east-bound period and five (5) trips for the west-bound period (WB). The east-bound for the PM period is an average of three (3) trips and seven (7) trips for the west-bound direction. The results from the study is tabulated in Table 1 below.

Table 1: Representing of average control delay based on time of day and direction of travel

DIRECTION OF TRAVEL	**AVERAGE CONTROL DELAY (Sec/veh)**	
	AM	**PM**
DARKODWOM TO PATASI (EB)	18.945	30.124
PATASI TO DARKODWOM (WB)	31.912	16.153

From the table 1, it was observed that there were variations in the control delay. For example, it was seen that the control delay for the AM periods of the EB direction was 18.945sec/veh while the delay for the PM period was 30.124sec/veh. This signifies there are more delays in the PM period as compared to the AM period. Also, for the direction of travel, the control delays were different for EB and WB directions for both AM and PM period. In the PM period, the delay in the EB direction is almost twice of the WB direction.

The level of Service (LOS) indicator is used to determine the operational performance of the intersection. The HCM (2010) gives six analytical procedures for measuring level of service with various corresponding control delays (from A-F) to identify the effectiveness of a roadway. The HCM level of Service is shown in table.

Table 2: The analytical procedure for measuring level of service based on control delay

Source (HCM, 2010)

Level of Service	**Control delay (sec/veh)**
A	≤10
B	10-20
C	20-35
D	35-55
E	55-80
F	<80

LOS A shows the best operational function while LOS F describes the worst operational function.

Table 3: Showing the Control delay of the intersection based on time and direction and their corresponding LOS

DIRECTION OF TRAVEL	**AM**		**PM**	
	AVERAGE CONTROL DELAY (sec/veh)	**LOS**	**AVERAGE CONTROL DELAY (sec/veh)**	**LOS**
DARKODWOM TO PATASI (EB)	18.945	LOS B	30.124	LOS C
PATASI TO DARKODWOM (WB)	31.912	LOS C	16.153	LOS B

From table 3, the EB direction is operating at LOS B in the morning with a corresponding control delay of 18.945sec/veh but the PM period was operating at LOS C with a control delay of 30.124sec/veh.

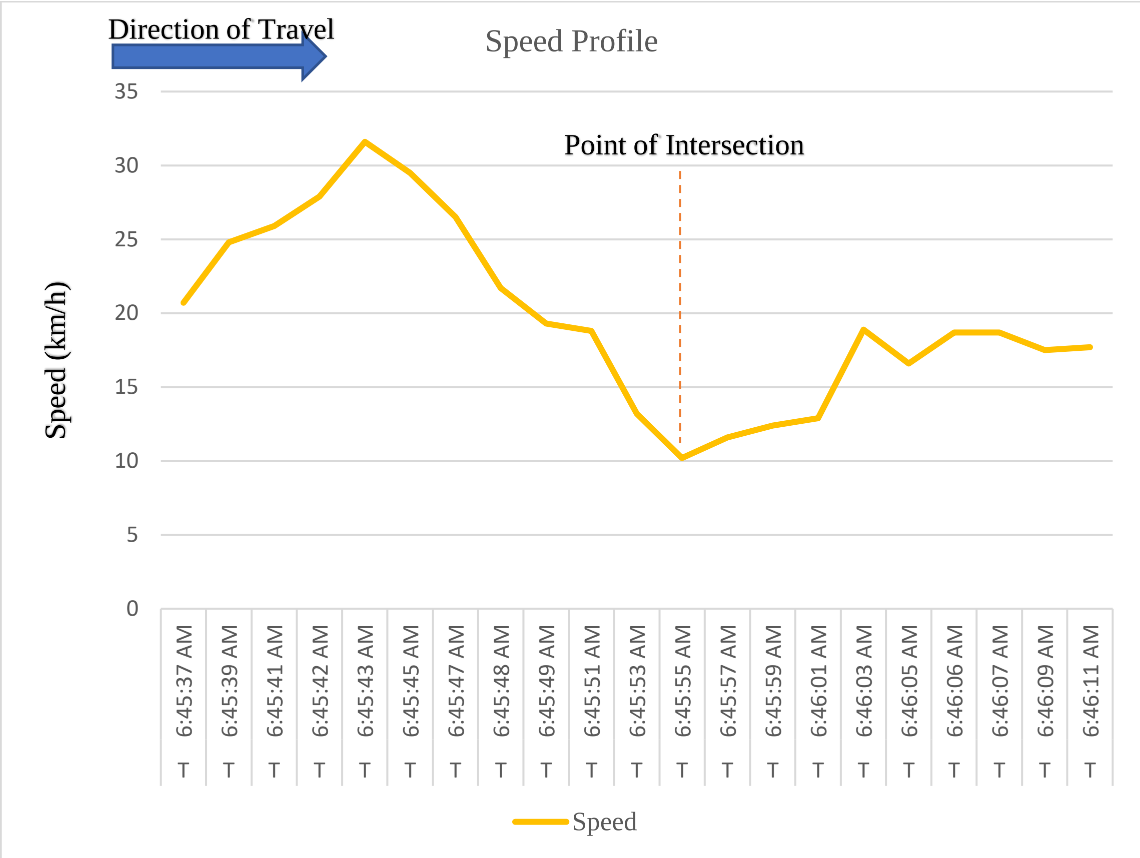

Figure 5: A typical nature of the speed profile at the Santasi roundabout during the AM period EB direction. (Source: From Study)

The speed profile demonstrated in Figure 5 represents the nature of the traffic flow at the intersection. The LOS B signifies that there are less restrictions when a driver wants to manoeuvre traffic operations. It also signifies that there are unimpeded operations at the intersection during the AM periods. The average speed at the intersection at EB direction in the AM period averages 19.77km/h.

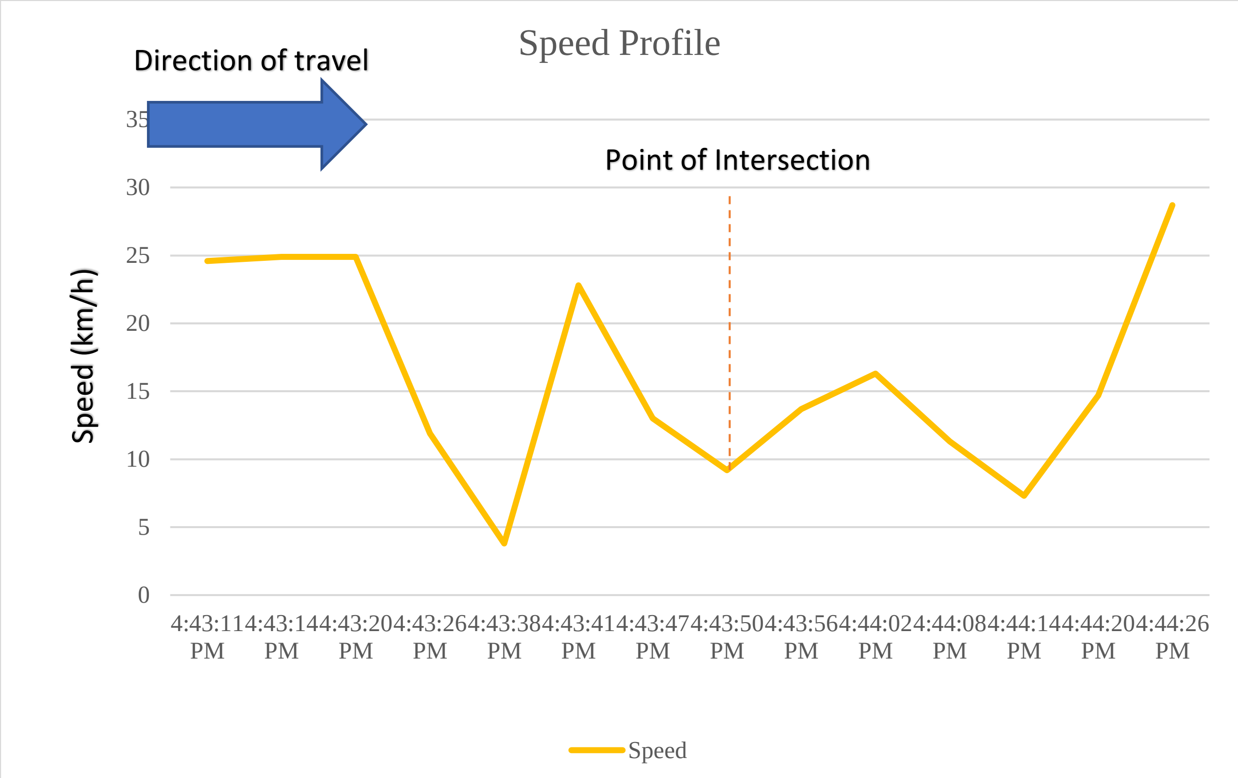

Figure 6: A typical nature of the speed profile at the Santasi roundabout during the PM period EB direction. (Source: From Study)

During the PM period for Darkodwom to Patasi (EB) direction, the intersection operates at LOS C. This means there are slight restriction to traffic operations in the evening and with more traffic impediments as compared to the morning. The average speed at the intersection at this period averages 14.8km/h. The figure 6 shows the nature of the speed of the PM period from Darkodwom to Patasi (EB).

For the west-bound (WB) direction, the AM period operates at LOS C with an average control delay of 31.912 sec/veh. The average speed at the intersection is estimated to be 20.4km/h.

This means that traffic impediments occur when traversing the intersection. The average speed is at the WB direction in the AM period is 0.63km/h higher than the EB direction. This establish that travel speed at the intersection is almost the same irrespective of the direction of travel.

Figure 8 depicts a typical nature of traffic operation at the intersection during AM peak period in the West-Bound direction.

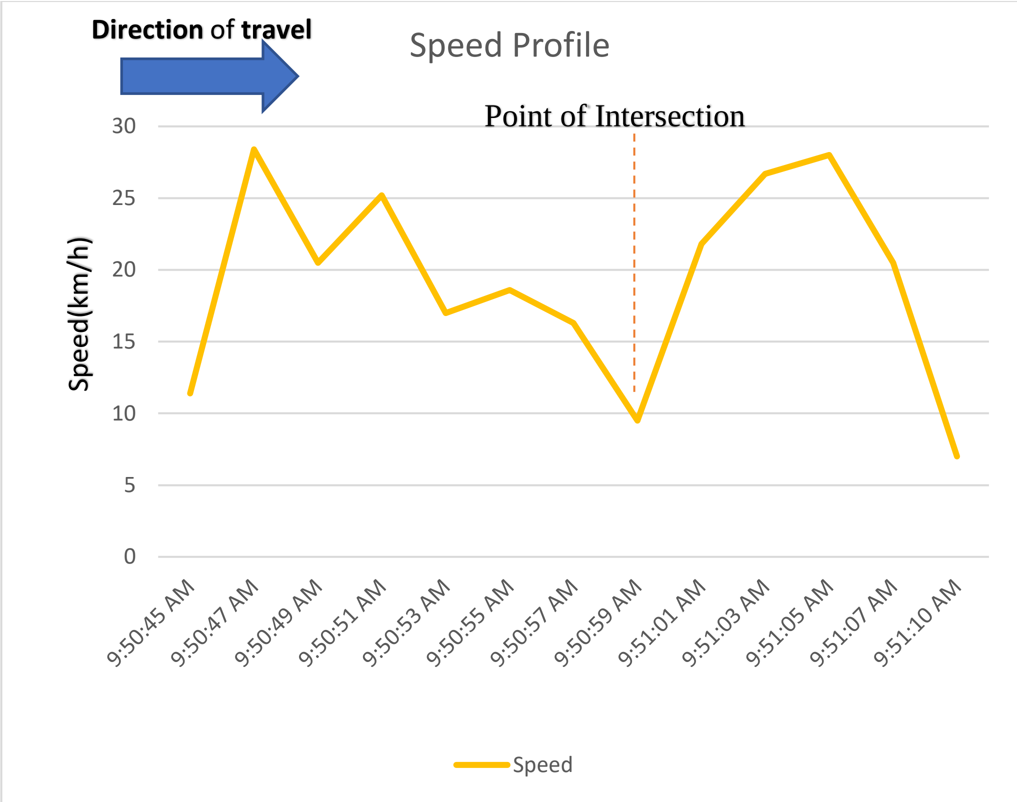

Figure 7: A typical nature of the speed profile at the Santasi roundabout during the AM period WB direction. (Source: From Study)

For traffic movement in the PM West-Bound direction, the average control delay was estimated to be 16.153sec/veh. This means the intersection operates at LOS B for this time. This implies that there are less impediments in this time period as compared to the morning period. Also, restrictions to traffic operations at this period is less as compared to the AM periods. The average speed at the intersection for this time and direction of travel is estimated to be 23.28km/h.

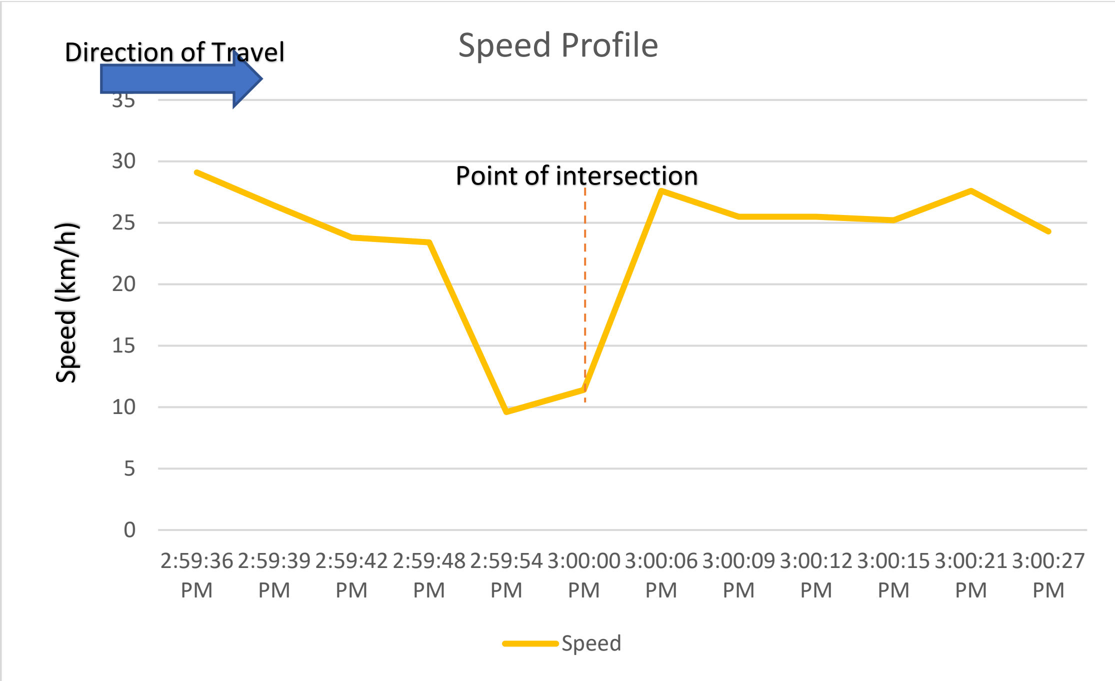

Figure 8: A typical nature of the speed profile at the Santasi roundabout during the PM period WB direction. (Source: From Study)

The study demonstrated that there are variations in the control delay for both direction of travel and time of day. Hence the objective of the study has been achieved. The study also provided the LOS at the intersection for the directions and time of day. The level of indicator has demonstrated the operational performance of the roadway by categorizing the average control delays with their corresponding level of service.

The performance of the intersection will improve if the capacity of the roadway is increased. This will reduce approach delays on the east-bound and the west-bound approach. Observation through site inspection has shown that the Motor Traffic and Transport Department (MTTD), a division of the Ghana Police service directs the traffic movement at the intersection, there is an improvement in the speed vehicles takes to traverse the intersection and this reduces the total delay at the intersection. Continuous practice of this will resolve conflicts at the intersection, thereby improving the level of service. Signalization of the roundabout will also improve on the level of service of the intersection.

CHAPTER V

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The rate at which traffic congestion occur in Kumasi in recent years is becoming excessive and therefore analyzing the performance parameters of the arterials in Kumasi will be effective for future transportation planning and traffic study. This report aimed at accessing the operational performance of the Santasi roundabout by determining the control delay of the intersection and measuring the effectiveness using the level of service indicators. Validated historical GPS data from 2019 and 2020 traffic study was used in the analysis.

The following conclusions were drawn based on the results obtained from the traffic study:

Intersection on arterial roadways contributes to congestion and total delays since the study identified drop in speed at the intersection.

The average control delay at the intersection from the east-bound direction in the AM period is 18.945sec/veh and operates at LOS B while the average control delay for the intersection at the PM period at the intersection is 24.535sec/veh and operates at LOS C for the same direction of travel.

Also, the average delay at the west-bound direction shown and average of 31.912sec/veh and 16.153sec/veh for AM and PM periods respectively. Which means the west-bound operates at LOS C for AM period and LOS B for the PM period.

The study has also proved that control delay varies with time of travel and direction of travel.

5.2 Recommendation

From the data results generated from the control delay study conducted, the following recommendations are made:

- The study did not consider the effect of side friction at the downstream of the intersection and therefore future study can consider the impact of downstream side friction
- The method is more accurate as compared to some other methods for estimating control delay and therefore it should be adopted by traffic agencies.
- The information should inform policies and traffic control management by the MTTD

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6 APPENDIX

6.1 Speed Profile and Control delay for individual trips

Table 4: Control delay at the intersection for trip 7 EB direction PM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 7	2:44:50 PM	2:44:37 PM	0:00:13	13	12.252	12.194	0.058	55	3.796364	9.203636

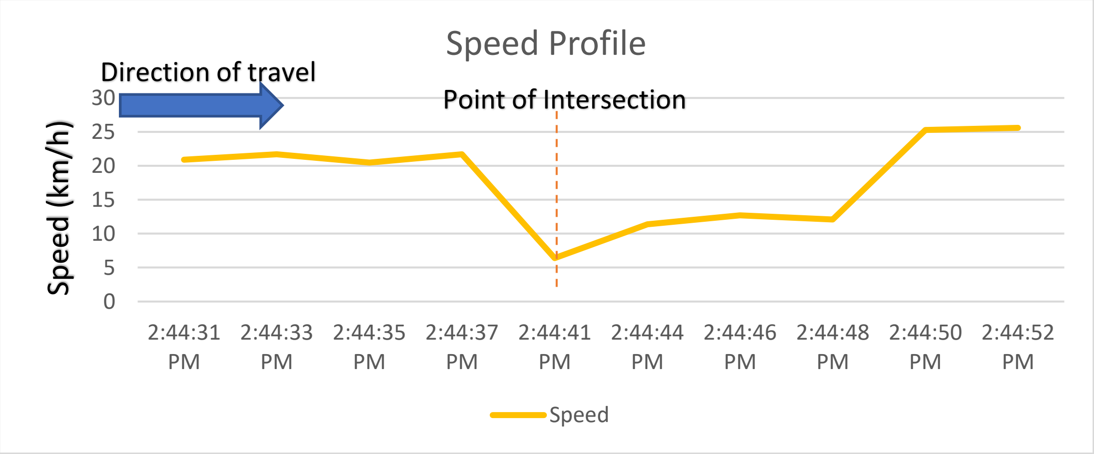

Figure 9: Speed Profile at the Intersection for Trip 7 EB PM period

Table 5: Control delay for trip 3 EB PM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 3	9:03:38 AM	9:02:53 AM	0:00:45	45	12.335	12.217	0.118	55	7.723636	37.27636

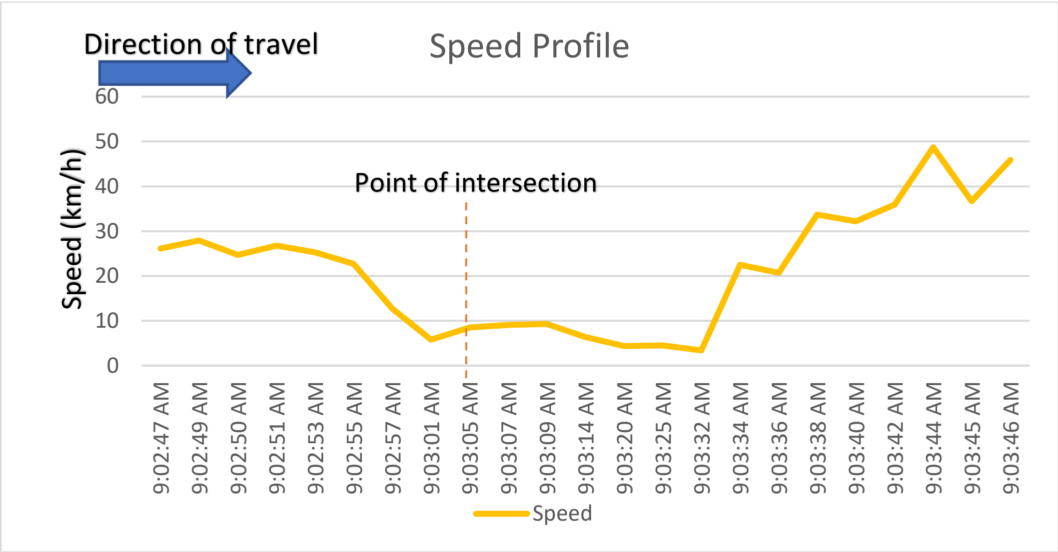

Figure 10: Speed profile at the intersection for trip 3 AM period EB

Table 6: Control delay for trip 5 EB direction AM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 5	11:31:15 AM	11:31:06 AM	0:00:09	9	12.38	12.341	0.039	55	2.552727	6.447272

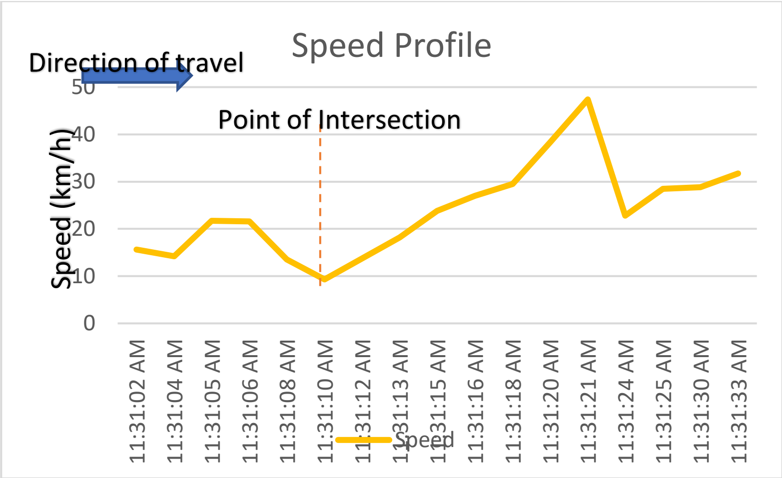

Figure 11: Speed Profile at the Intersection for trip 5 EB direction PM period

Table 7: Control delay for trip 5 EB direction PM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 5	5:11:13 PM	5:10:46 PM	0:00:27	27	12.17	12.061	0.109	55	7.134545	19.86545

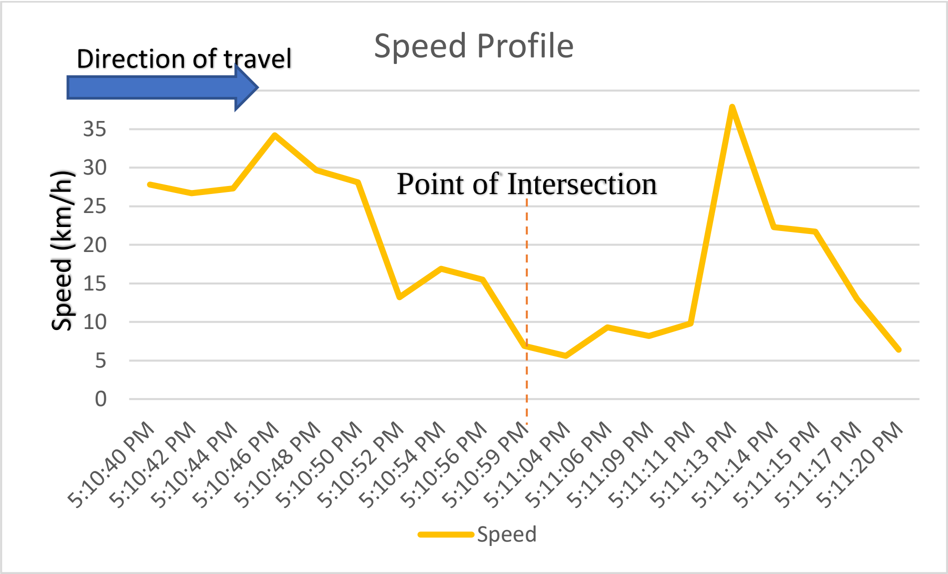

Figure 12: Speed profile at the Intersection for trip 9 EB PM period (2019)

Table 8: Control delay of Trip 1 EB AM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 1	6:46:03 AM	6:45:45 AM	0:00:18	18	11.698	11.618	0.08	55	5.236364	12.76364

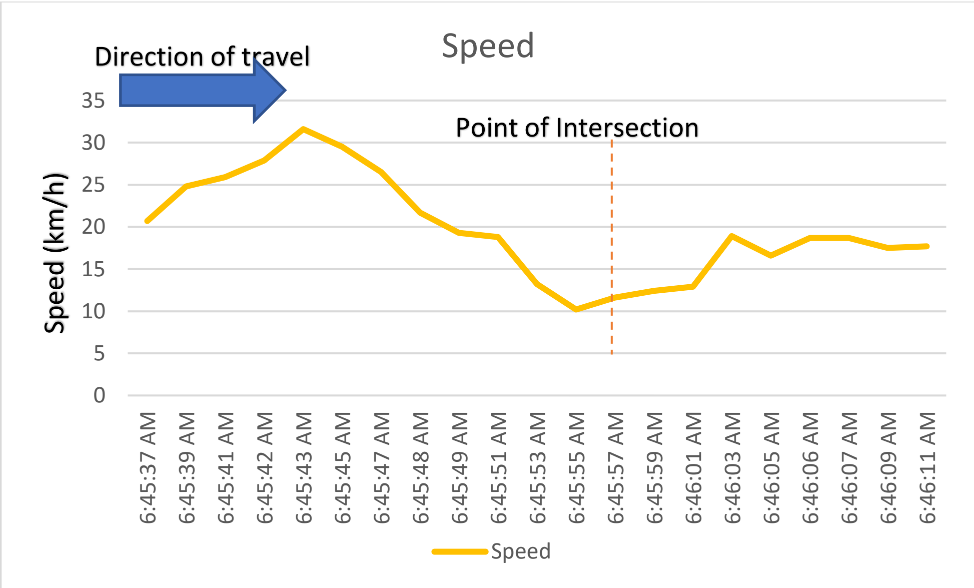

Figure 13: Control delay at the Intersection for trip 1 EB AM period

Table 9: Control delay for trip 4 WB AM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 4	9:51:05 AM	9:50:49 AM	0:00:16	16	7.54	7.449	0.091	55	5.956364	10.043636

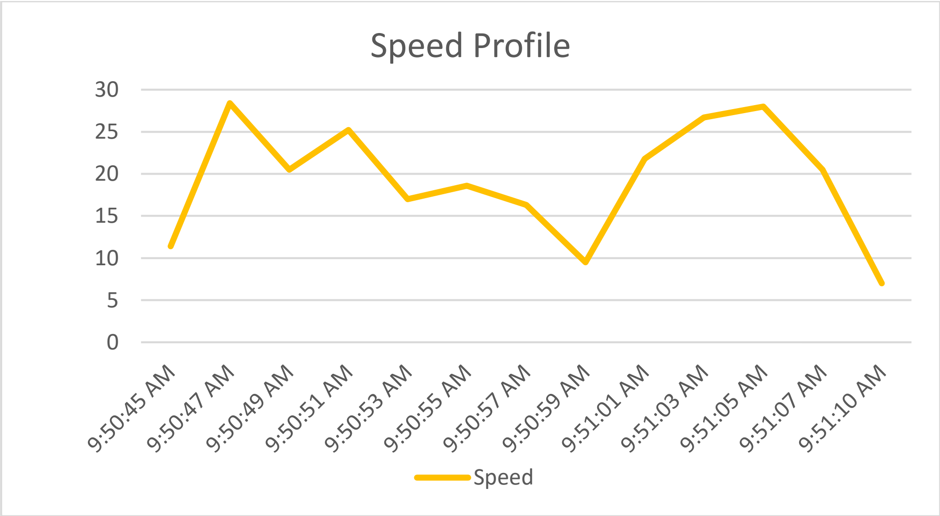

Figure 14: Speed Profile at the intersection for trip 4 WB AM period (2019)

Table 10: Control delay for trip 7 EB PM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 7	5:43:19 PM	5:42:39 PM	0:00:40	40	12.775	12.593	0.182	55	11.91273	28.08727

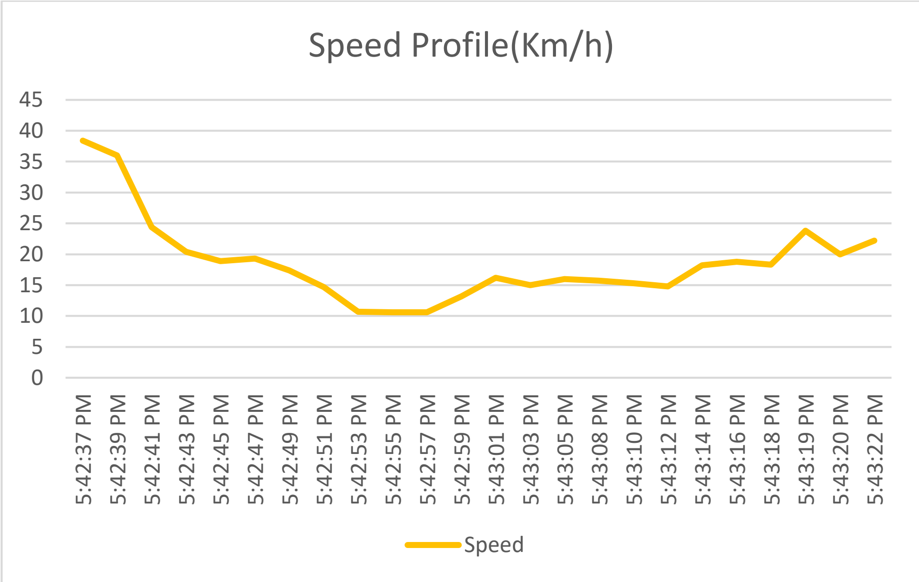

Figure 15: Speed Profile at the intersection for trip 7 EB PM period (2019)

Table 11: Control delay for trip 3 EB AM period

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 3 EB AM	10:37:04 AM	10:36:50 AM	0:00:14	14	12.649	12.558	0.091	55	5.956364	8.043636

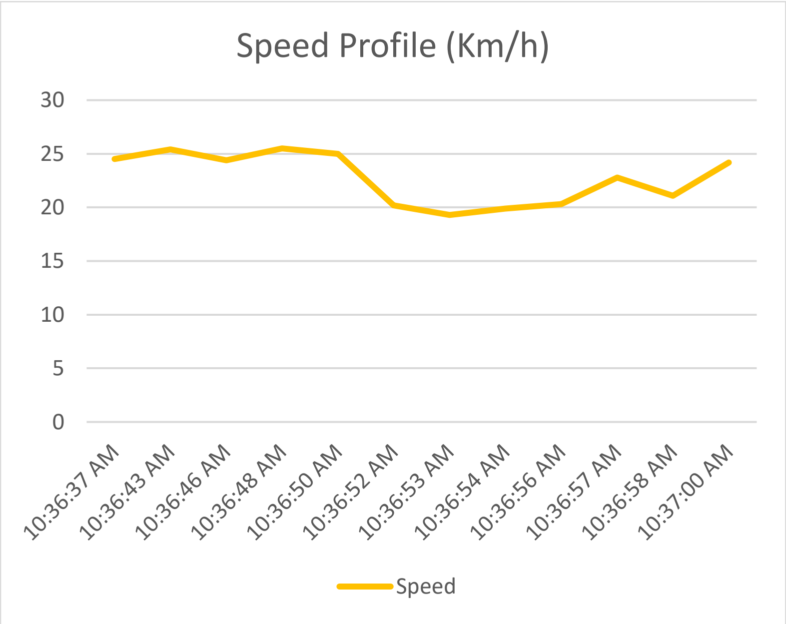

Figure 16: Speed Profile at the intersection for trip 3 EB AM period (2019)

Table 12: Control delay of trip 7 EB PM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 7 EB PM	5:43:25 PM	5:42:39 PM	0:00:46	46	12.817	12.593	0.224	55	14.66182	31.33818

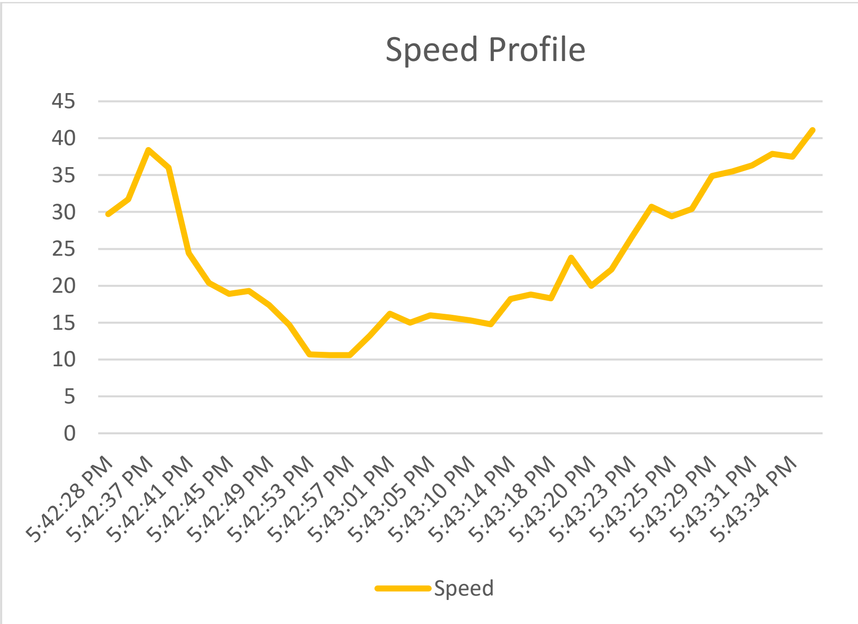

Figure 17: Speed Profile at the intersection for trip 7 EB PM period

Table 13: Control delay for trip 8 WB PM period

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRRIP 8 WB	3:50:31 PM	3:49:37 PM	0:00:54	54	7.423	7.357	0.066	55	4.32	49.68

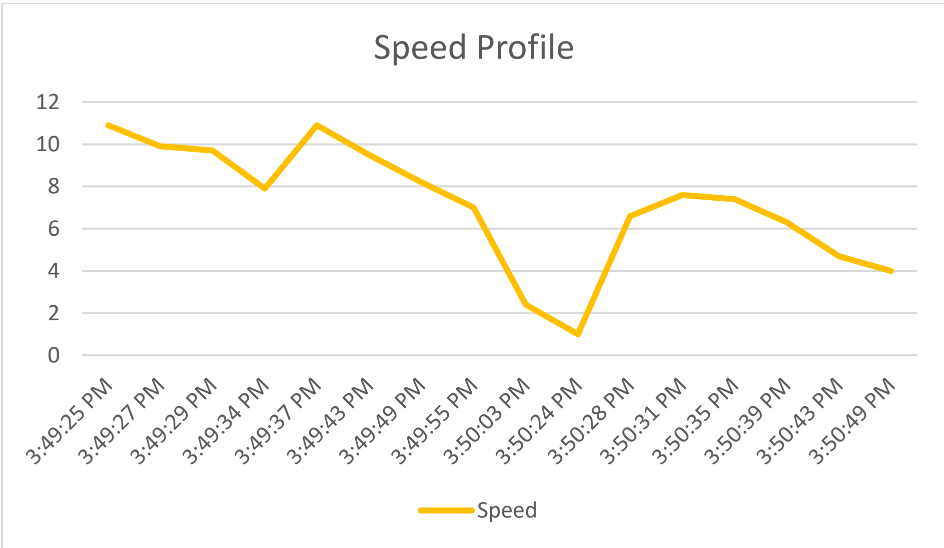

Figure 18: Speed Profile at the intersection for trip 8 PM period WB

Table 14: Control delay for trip 10 WB PM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 10 WB PM	6:00:51 PM	6:00:36 PM	0:00:15	15	7.488	7.457	0.031	55	2.029091	12.97091

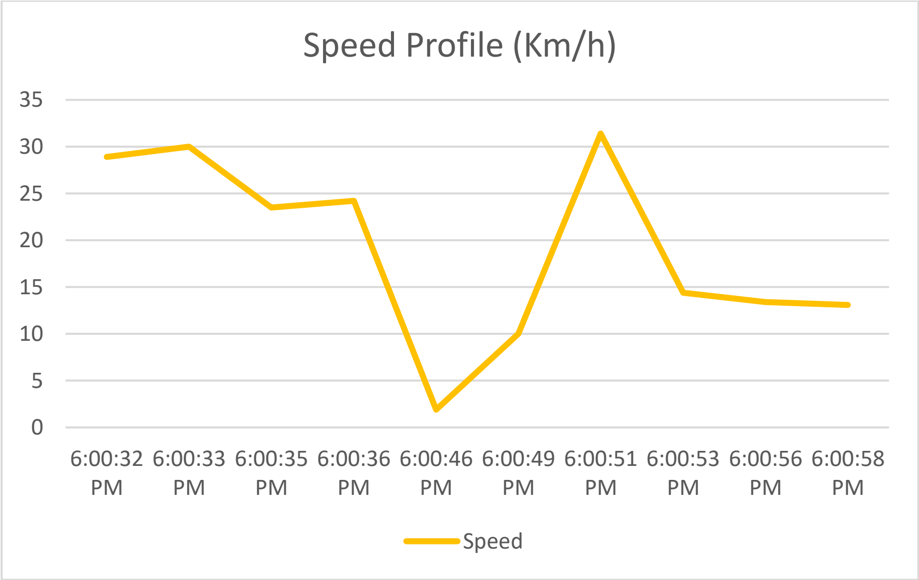

Figure 19: Speed Profile at the Intersection for trip 10 WB PM period (2019)

Table 15: Control delay for trip 2 WB AM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
WB AM	8:47:38 AM	8:46:46 AM	0:00:52	52	7.207	6.999	0.208	55	13.61455	38.38545

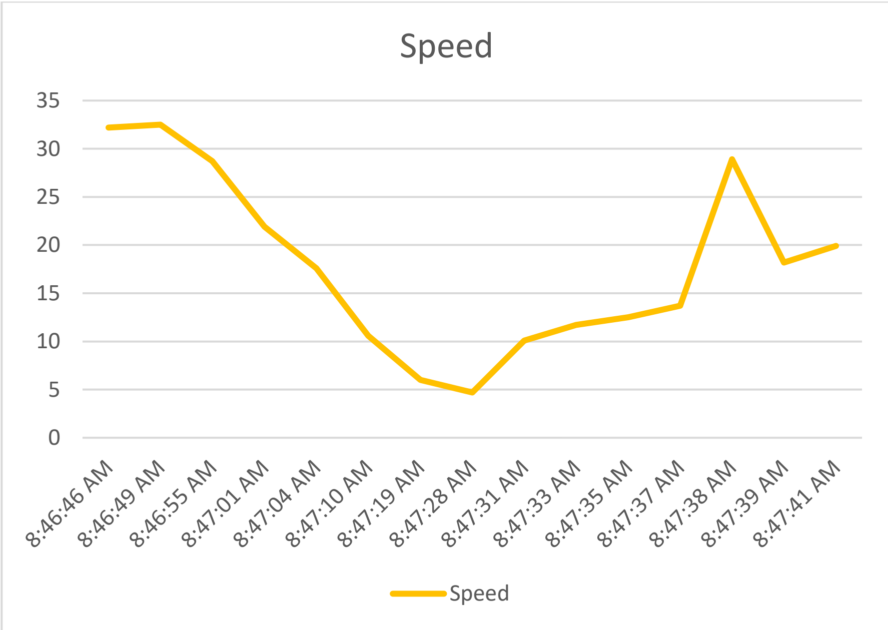

Figure 20: Speed Profile at the intersection for trip 2 WB AM period (2019)

Table 16: Control delay for trip 7 for WB AM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 7	4:08:18 PM	4:07:51 PM	0:00:27	27	7.439	7.32	0.119	55	7.789091	19.21091

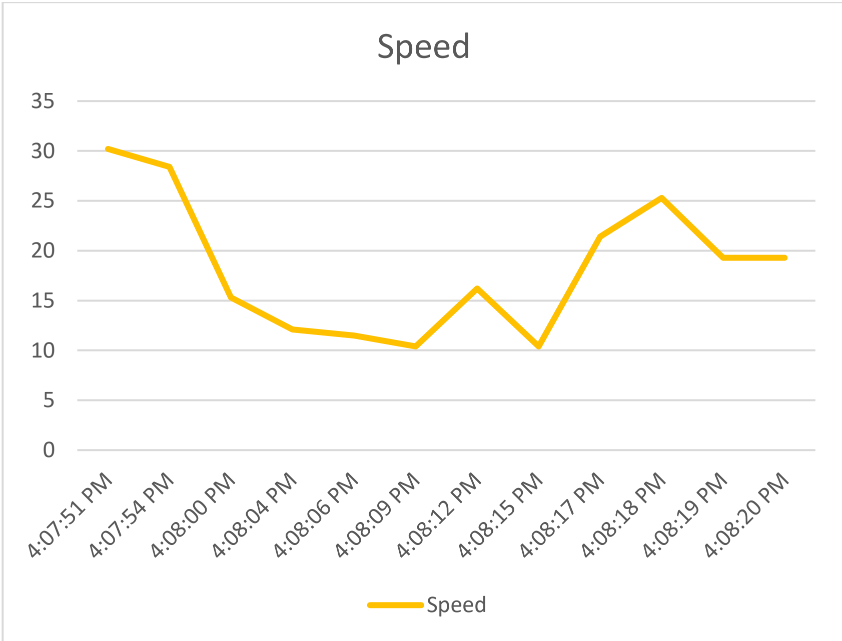

Figure 21: Speed profile of the intersection for trip 7 for WB AM period (2019)

Table 17: Control delay for trip 6 WB PM period (2019)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
WB PM	12:21:40 PM	12:21:16 PM	0:00:24	24	7.806	7.688	0.118	55	7.723636	16.27636

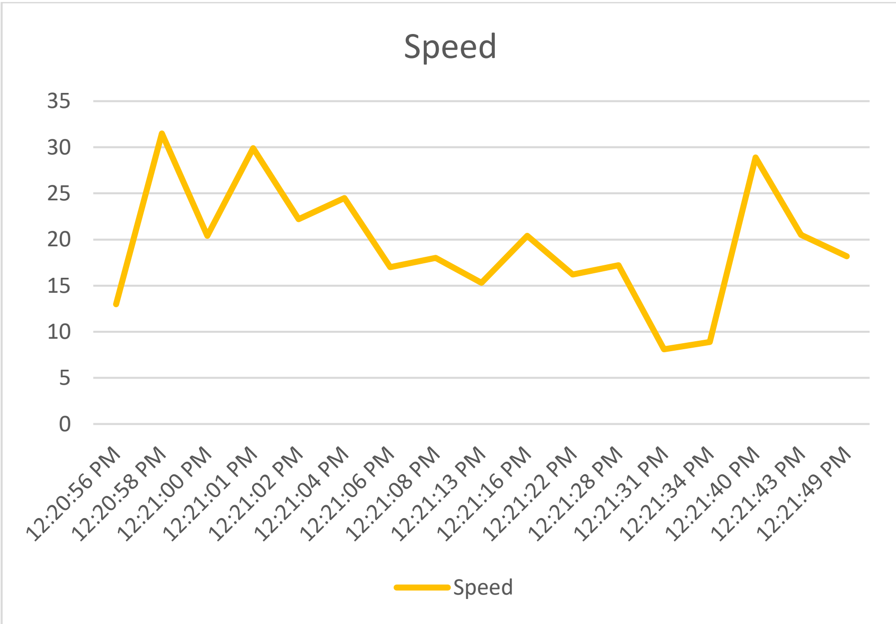

Figure 22: Speed Profile of the intersection for trip 6 WB PM period (2019)

Table 18: Control delay for trip 1 EB AM period (2020)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
EB AM 2020	8:28:49 AM	8:28:01 AM	0:00:48	48	13.717	13.417	0.3	55	19.63636	28.36364

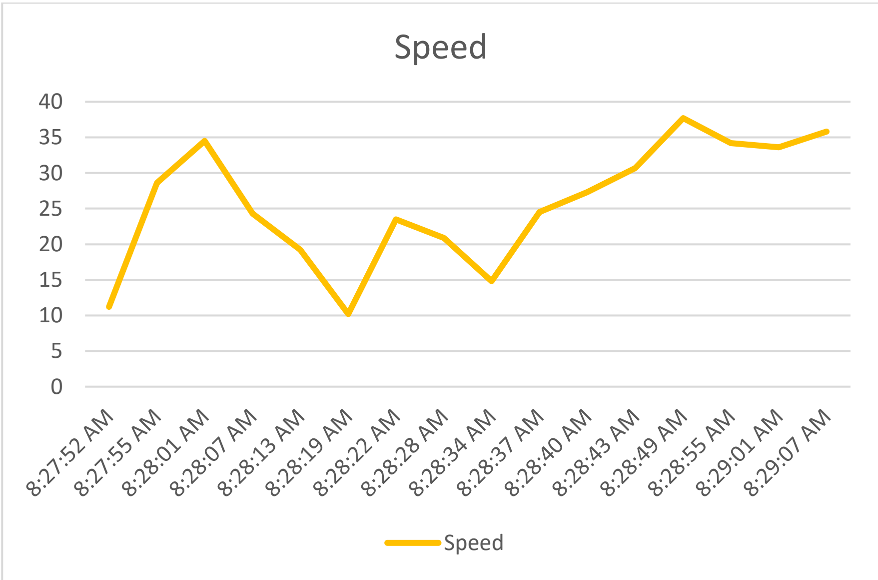

Figure 23: Speed Profile at the intersection for trip 1 EB AM period (2020)

Table 19: Control delay for trip 1 WB AM period (2020)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
WB AM 2020	9:34:40 AM	9:33:25 AM	0:01:15	75	7.189	7.073	0.116	55	7.592727	67.40727

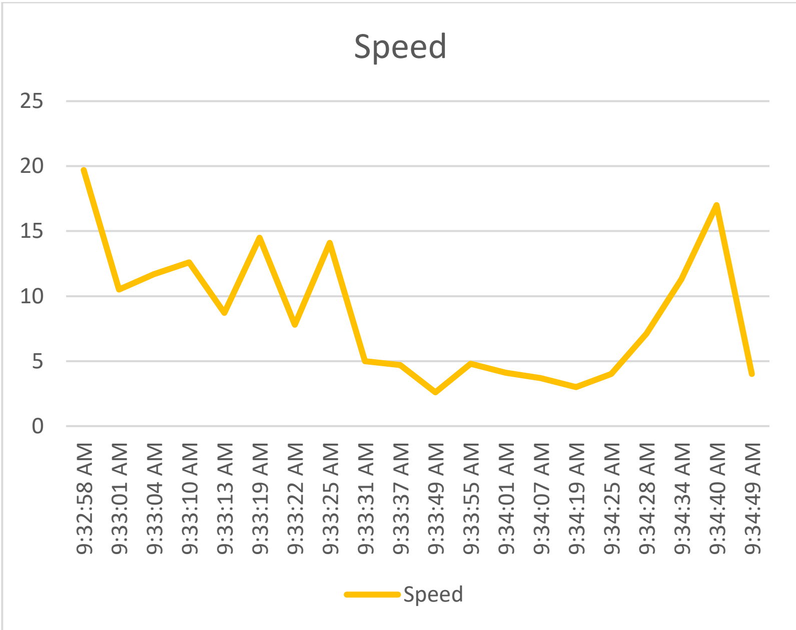

Figure 24: Speed profile for the Intersection for trip 1 WB AM period

Table 20: Control delay of trip 2 EB AM period (2020)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
WB AM 2020	11:12:12 AM	11:11:27 AM	0:00:45	45	12.062	11.781	0.281	55	18.39273	26.60727

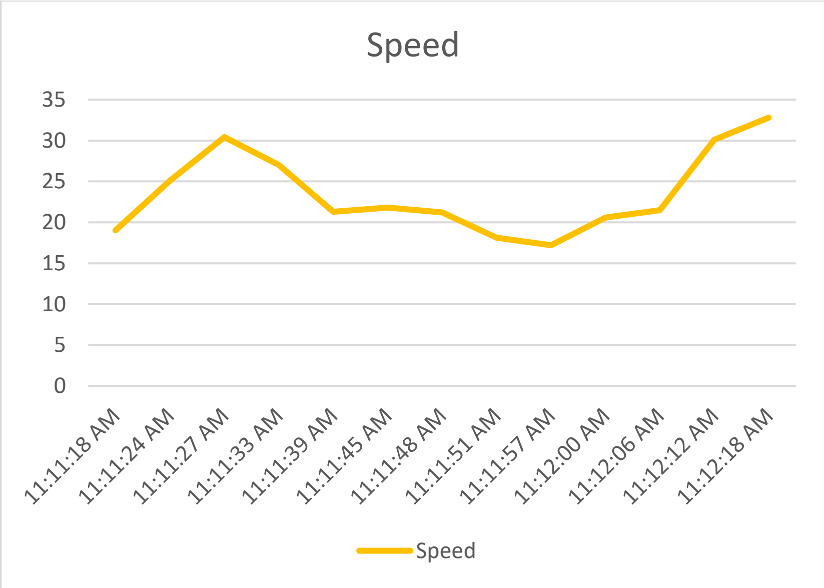

Figure 25: Speed Profile of the intersection for trip 2 WB AM period (2020)

Table 21: Control delay of trip 3 EB PM period

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
EB AM 2020	3:32:52 PM	3:32:31 PM	0:00:21	21	7.159	7.122	0.037	55	2.421818	18.57818

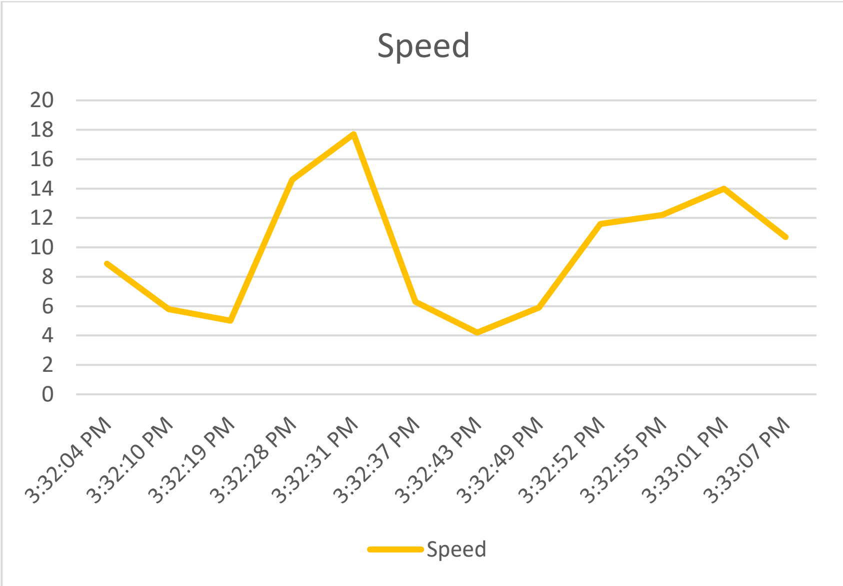

Figure 26: Speed Profile of the intersection for trip 3 EB PM period

Table 22: Control delay for trip 3 WB PM period (2020)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 3	3:00:06 PM	2:59:48 PM	0:00:18	18	11.86	11.779	0.081	55	5.301818	12.69818

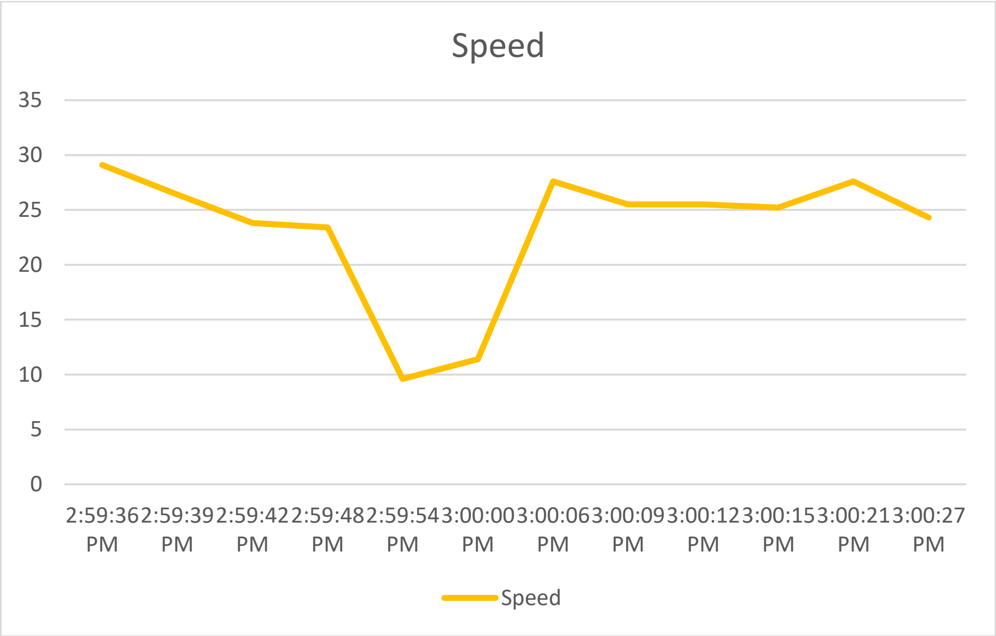

Figure 27: Speed Profile for trip 3 WB PM period (2020)

Table 23: Control delay of trip 4 EB PM period (2020)

Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
EB AM 2020	4:44:26 PM	4:43:20 PM	0:01:06	66	12.037	11.802	0.235	55	15.38182	50.618182

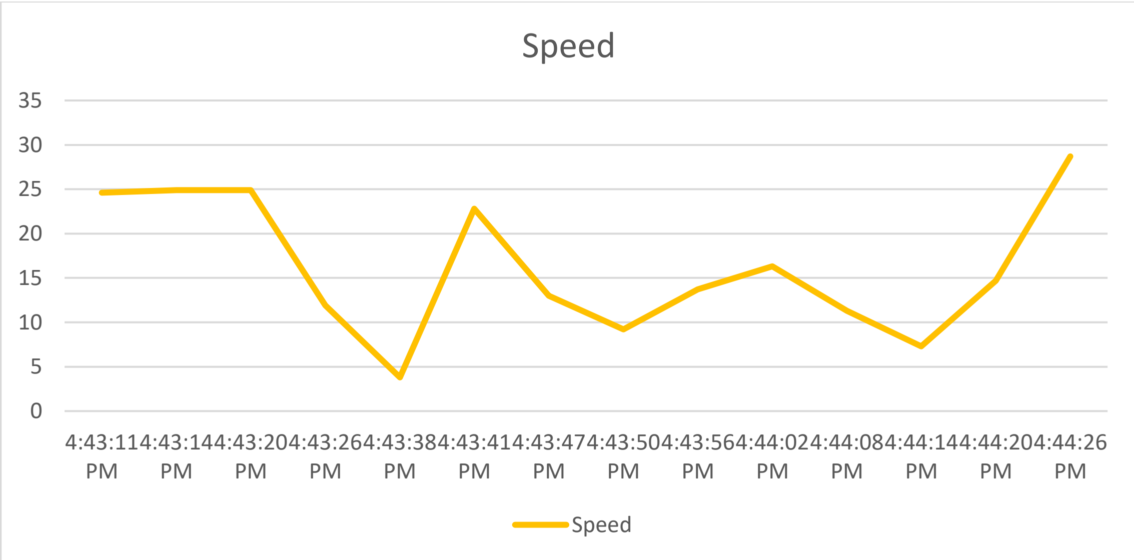

Figure 28: Speed profile of the intersection for trip 4 EB PM period (2020)

6.2 Calculating the average Control delay

Table 24: *S*howing the average control delay for EB AM period

EAST-BOUND DARKODWOM TO PATASI										
Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 7 EB AM	6:46:03 AM	6:45:45 AM	0:00:18	18	11.698	11.618	0.08	55	5.236364	12.764
TRIP 3 EB AM	10:37:04 AM	10:36:50 AM	0:00:14	14	12.649	12.558	0.091	55	5.956364	8.044
TRIP 1 EB AM	8:28:49 AM	8:28:01 AM	0:00:48	48	13.717	13.417	0.3	55	19.63636	28.364
TRIP 2 EB AM	11:12:12 AM	11:11:27 AM	0:00:45	45	12.062	11.781	0.281	55	18.39273	26.607
AVERAGE CONTROL DELAY FOR EB AM PERIOD									**18.945**	

Table 25: A table showing the average control delay for WB AM period

WEST-BOUND PATASI TO DARKODWOM										
Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 5 AM EB	11:31:15 AM	11:31:06 AM	0:00:09	9	12.38	12.341	0.039	55	2.552727	6.447
ST RB EB AM	9:51:05 AM	9:50:49 AM	0:00:16	16	7.54	7.449	0.091	55	5.956364	10.044
TRIP 2 AM EB	8:47:38 AM	8:46:46 AM	0:00:52	52	7.207	6.999	0.208	55	13.61455	38.385
TRIP AM EB	9:03:38 AM	9:02:53 AM	0:00:45	45	12.335	12.217	0.118	55	7.723636	37.276
TRIP 1 EB AM	9:34:40 AM	9:33:25 AM	0:01:15	75	7.189	7.073	0.116	55	7.592727	67.407
AVERAGE CONTROL DELAY FOR WB AM PERIOD									**31.912**	

Table 26: Table showing the control delay for WB PM periods

WEST-BOUND PATASI TO DARKODWOM										
Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 10 WB PM	6:00:51 PM	6:00:36 PM	0:00:15	15	7.488	7.457	0.031	55	2.029091	12.971
TRIP 6 WB PM	4:08:18 PM	4:07:51 PM	0:00:27	27	7.439	7.32	0.119	55	7.789091	19.211
TRIP 11 WB PM	12:21:40 PM	12:21:16 PM	0:00:24	24	7.806	7.688	0.118	55	7.723636	16.276
AVERAGE CONTROL DELAY FOR WB PM PERIOD									**16.153**	

Table 27: Table showing the control delay for WB *PM* periods

EAST-BOUND DARKODWOM TO PATASI										
Intersection	Time when acceleration ends (Ta)	Time when deceleration starts (Td)	Actual travel time (Ta-Td)	Actual travel time (Ta-Td)/sec	Location when acceleration ends (Da)	Location when deceleration starts (Dd)	(Da-Dd)/km	Free flow speed (km/h)	Free flow travel time (G*3600/H) /sec	Control delay (D-K)/sec
	A	B	C	D	E	F	G	H	K	
TRIP 9 PM EB	5:11:13 PM	5:10:46 PM	0:00:27	27	12.17	12.061	0.109	55	7.134545	19.865
TRIP 7 PM EB	5:43:19 PM	5:42:39 PM	0:00:40	40	12.775	12.593	0.182	55	11.91273	28.087
TRIP 5 EB PM	5:43:25 PM	5:42:39 PM	0:00:46	46	12.817	12.593	0.224	55	14.66182	31.338
TRIP 8 EB PM	3:50:31 PM	3:49:37 PM	0:00:54	54	7.423	7.357	0.066	55	4.32	49.680
TRIP 12 EB PM	3:32:52 PM	3:32:31 PM	0:00:21	21	7.159	7.122	0.037	55	2.421818	18.578
TRIP 3 EB PM	3:00:06 PM	2:59:48 PM	0:00:18	18	11.86	11.779	0.081	55	5.301818	12.698
TRIP 4 EB PM	4:44:26 PM	4:43:20 PM	0:01:06	66	12.037	11.802	0.235	55	15.38182	50.618
AVERAGE CONTROL DELAY FOR EB AM PERIOD									**30.124**	