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VALIDATION OF CROWDSOURCED GOOGLE TRAVEL TIME DATA ON SELECTED ROAD CORRIDOR IN KUMASI

By

Gideon Appau Akomea

(BSc. Geomatic Engineering)

A thesis submitted to the Department of Civil Engineering, Kwame Nkrumah University of Science and Technology in partial fulfillment of the requirements for the award degree of

MASTER OF SCIENCE IN ROAD AND TRANSPORTATION ENGINEERING

December, 2021

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Kwame Nkrumah University of Science and Technology, Kumasi or any other educational institution, except where due acknowledgment is made in the thesis.

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Name of Head of Department	Signature	Date

DEDICATION

This work is dedicated to my beloved, Barbara Sam Osei for her love and encouragement.

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ABSTRACT

An accurate and reliable traffic information is essential for efficient transport and management. Getting reliable traffic data for city-wide coverage is very expensive to do by conventional means and yet transport planners need this traffic data to manage and plan day-to-day activities of mobility. However, we have this crowdsourced Google traffic data that is globally available, which has not been validated for specific localities. Through the use of Google Distance Matrix Application Programmable Interface (API), distance and travel time are can be obtained at multiple locations simultaneously at a wide scale. This study focuses on validating traffic information collected via Google Distance Matrix API on selected road corridors in Kumasi, Ghana. The travel time collected from Google Distance Matrix API was verified with the travel time information collected by field measurements through the use of test vehicles. The results indicate that there is significant agreement between the travel time obtained from Google Distance Matrix API and field test vehicle data. Google and field travel time data were compared statistically, where the averages of the mean travel time of both data were calculated and compared to identify their differences. Using the field data as reference, the morning peak has Wednesday as the highest difference of 5-minutes underestimated by Google and Saturday has the lowest difference of 2-minutes underestimated by Google. But for the afternoon peak, Wednesday has the highest difference of 9-minutes underestimated by Google, and Friday has the lowest difference of 3-minutes underestimated by Google. The evening peak has Monday as the highest difference of 5-minutes underestimated by Google and Friday has the lowest difference of 1-minute overestimated by Google. Finally, linear regression analysis was conducted with both datasets and it was identified that Google traffic data has 99% accuracy. This study showed that crowdsourced Google travel time information is an accurate, consistent and economical method of collecting travel time information. However, Google traffic data must be validated for a specific locality, so it can become improved data for more consistent and efficient transport planning and management in the city.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX LIST

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Cascetta (2001) defined a transport system as the combination of elements and their interaction, which produce the demand for travel within a given area and the supply of transportation services to satisfy this demand. Transport systems are developed to foster trade and commerce. But several issues are arising with the development of transportation systems and continuous transport demand. Urban city officials are regularly faced with the issue of traffic congestion and there had been several interests to curb this situation. Transport planning and management are the major factors that can provide solutions for major problems related to transportation.

Congestion is a major problem faced by many urban transport systems which need to be managed and maintained at optimum levels to ensure efficient service for customers (Kamarage, 2018). Andrea and Marcelloni (2017) noted that traffic congestion in cities and towns is often present in cities with vital economic development. Therefore, the planning and management of urban traffic congestion become a daily activity faced by city authorities and transport planners or managers. The availability of data becomes an essential requirement to provide traffic solutions. Several methods and ways are used over the years for the collection of traffic data which aid in the transport planning and management process.

Getting reliable traffic data for very larger areas or city-wide coverage is very expensive to do by field investigations or by other means and yet transport planners need this traffic data to manage and plan day-to-day activities of mobility. However, we have this crowdsourced Google traffic data that is globally available, which has not been validated for specific locations. There is the variability of Google traffic data due to the local usage of mobile phones and their connectivity to online connections and Google services. Due to the large coverage of Google traffic data, validated Google traffic data will facilitate the work of city authorities and transport planners to better plan and manage congestion with confidence. Accordingly, this study seeks to validate Google traffic data using field data on selected road corridors in Kumasi. It is noteworthy that other studies have been undertaken to validate Google traffic data in some areas but this has not been done in Kumasi.

1.2 Problem Statement

This research seeks to tackle the problem of how to validate and upscale crowdsourced Google traffic data on selected road corridors in Kumasi. Getting city-wide traffic data is expensive to do either by using Intelligent Transport Systems (ITS) or conventional means. Using crowdsourced Google traffic data becomes a solution that needs further verification to accurately suit the area of interest. Google obtains traffic data through the use of mobile phones and the accuracy of the Google traffic data varies due to differences in locations and the usage of the mobile phones by local road users on a road network.

1.3 Research Objectives

The study sought to achieve the following objectives.

1. Undertake field investigation to assess vehicular traffic on selected road corridor in Kumasi.
2. Use crowdsourced Google Distance Matrix API to determine vehicular traffic on selected road corridor.
3. Compare field and Google traffic data to validate and upscale crowdsourced Google data.

1.4 Research Questions

The study was guided by the following research questions.

1. How can vehicular traffic be assessed on selected road corridors through field investigation?
2. How can vehicular traffic be determined on selected road corridors in Kumasi through crowdsourced Google Distance Matrix API?
3. How can crowdsourced Google traffic data be validated and upscale on selected road corridors in Kumasi?

1.5 Research Hypothesis

The hypothesis of the research is:

Null hypothesis: a validated crowdsourced Google traffic data on selected road corridors will lead to improved traffic data city-wide.

Alternate hypothesis: a validated crowdsourced Google traffic data on selected road corridors will not lead to improved traffic data city-wide.

1.6 Research Purpose and Significance

Google predicts travel time by crowdsourcing locational information from mobile phones users, where the information is made available globally. However, this traffic data has not been validated for specific locations. Therefore, this study sought to validate and upscale Google traffic data on selected road corridor in Kumasi which can be used by city authorities and transport managers to help in the transport planning process.

1.7 Structure of the Thesis

This study sought to validate crowdsourced Google traffic data on selected road corridor in Kumasi. With that focus, this thesis is structured into five chapters. The first is the Introduction chapter. The chapter comprises the following: background of the study, the problem statement, the research questions and hypothesis, the purpose or significance of this research, the research objectives, and the structure of the report.

The second chapter is the Literature review. Several related literatures were reviewed. Flaws, new ideas and suggestive concluding remarks by past researchers on this similar research were described. Also, the conceptual framework of traffic parameters was explained. Also, the Google Distance Matrix API and the field travel time measurement methods were described.

The research methodology is covered in Chapter three. The data collection methods (field travel time measurements and crowdsourcing traffic data) were outlined. Chapter four presents the results and discussions of the findings. These results include the data obtained from the field investigations and the crowdsourced Google Distance Matrix API. Chapter five summarizes the main findings of the study and conclusions: which would inform subsequent researchers of the accuracy of traffic data, crowdsourced from Google Distance Matrix API. This chapter also shows the need for further research to extend the use of Google Distance Matrix API service.

1.8 Study Area

The study area shown in Figure 1.1 covers the Kumasi Metropolitan area. It is a center for major economic and commercial activities. It is the second-largest city in Ghana and the administrative capital of the Ashanti region. It is a fast-growing Metropolis with an estimated population of more than two million people and an annual growth rate of about 5.4%. The Metropolis is about 254 kilometers; its physical structure is circular with a centrally located commercial area (KMA, 2011).

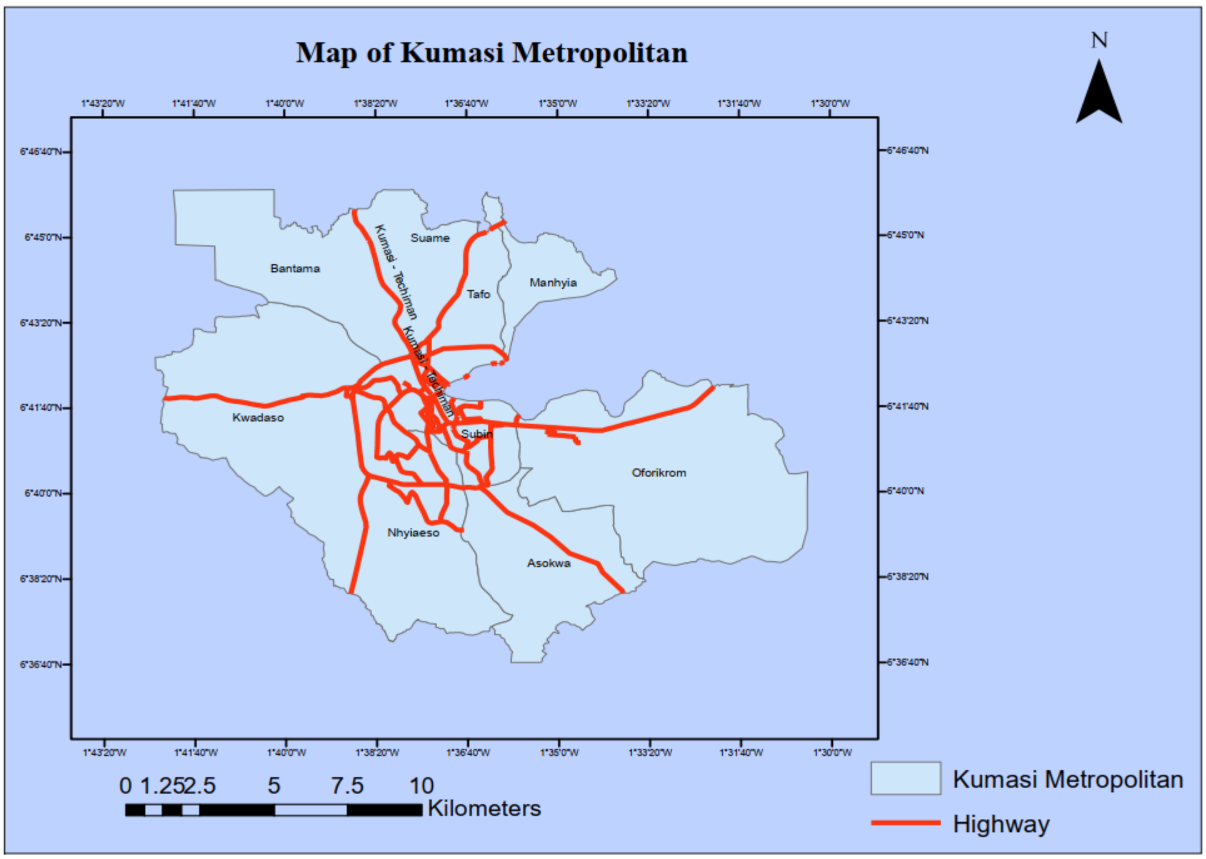


Figure 1.1: Map of Kumasi Metropolitan showing the major roads

1.8.1 Characteristics of the selected road corridor in Kumasi

The selected road corridor shown in Table 1.1 has the total distance of 7.9 km. The selected road corridor is Abrepo road corridor in Kumasi. For this study, the selected road corridor was divided into five segments. Each segment was assigned to have origin and destination. The Bohyen – Abrepo road segment has the lowest distance of 1 km and Ohwim – Amanfrom road segment has the highest distance of 2.1 km. The geographic coordinates of the multiple origins and destinations are also given (see Table 1.1).

The Abrepo road corridor is characterized by a) low to moderate posted speeds; b) intersections; c) moderate to heavy residential or commercial development and d) on-street parking. The road corridor shown in Figure 1.2 has two– lanes showing the flow of vehicles in both directions. It is seen that there are no road marks and designated sidewalks on this road corridor. Pedestrians use the shoulders of the road. Abrepo road corridor is an arterial urban road. It serves the purpose of connecting flows between major commercial centres of activity. The road surface condition is asphaltic in nature. Mostly there is a lot of hawking activities at the bus stops on the road corridor.

Figure 1.2 Photo showing a section on the selected road corridor

Table 1.1: Road segments on selected road corridor for the study

SN	Origin	Destination	Distance (km)	Origin (Lattitude, Longitude)	Destination (Lattitude, Longitude)
1	Bohyen	Abrepo	1.0	6.71947, -1.64802	6.72387, -1.65493
2	Abrepo	Atafua	1.3	6.72387, -1.65493	6.73434, -1.65626
3	Atafua	Ohwim	1.8	6.73434, -1.65626	6.74242, -1.66918
4	Ohwim	Amanfrom	2.1	6.74242, - 1.66918	6.75753, -1.68007
5	Amanfrom	Asuofua	1.7	6.75753, -1.68007	6.77181, -1.68474
TOTAL			**7.9**		

CHAPTER TWO

LITERATURE REVIEW

2.1 Basic Terms

This chapter begins with the definition of the various terminologies:

i. **Travel Time:** The duration of travel between two interesting points is known as travel time.

ii. **Time-mean speed:** The arithmetic average speed of all vehicles for a specified time.

$$\text{Time mean speed (TMS)} = \frac{\text{Sum of Speed of Vehicles}}{\text{Number of Vehicles}}$$

iii. **Space-mean speed:** The average speed of vehicles traveling a given segment of the roadway during a specified time**.**

$$\text{Space-mean speed (SMS)} = \frac{\text{Distance Travelled}}{\text{Average Travel Time}}$$

2.2 Importance of Travel time data in traffic management

Travel time is a fundamental source of traffic information from one point to the other. Travel time is mostly compared with other parameters like speed to determine the nature of traffic on road corridors. Travel time index is being used on several occasions to rank and prioritize transportation improvement projects for funding. Also, travel time assists in calibrating demand forecasting models (Bartholemew et al., 2011). Also, travel time could be used in estimating parameters such as emissions fuel consumption, and particulate matter concentration in road environments (Pyakunal et al., 2016).

2.3 Field measurements

Travel time is the duration of travel from one point to the desired destination. It is one of the fundamental measures of traffic. Travel time data assists transport planners and engineers to prepare and plan for future transport demands. One important use of travel time in traffic studies is to monitor to evaluate and monitor traffic congestion (Matthew, 2019). There are several methods of obtaining travel time on the field. They include the use of test vehicle techniques, license plate matching techniques, and ITS probe vehicles.

2.3.1 Test Vehicle Techniques

This technique includes the use of test vehicles and other varying instrumentation: whether manual (stopwatch and clipboard), an electronic distance measurement instrument or a Global Positioning System (GPS) receiver. In this technique, the observer records the data at checkpoints on the road as the test vehicle moves. This information can be converted to running time, speed, and delay. There are several different methods for performing this type of data collection, depending upon the instrumentation used in the vehicle. These vehicles are instrumented and then sent into the field for travel time data collection, they are sometimes referred to as "active" test vehicles (Ulberg, 1994). A setback of this technique is that errors can be possibly generated whether by human or electronic means. Therefore, there must be adequate quality control.

2.3.2 ITS probe vehicles

Travel times using ITS components and passive probe vehicles in the traffic stream equipped with signpost-based transponders, automatic vehicle identification (AVI) transponders, ground-based radio navigation, cellular phones, or GPS receivers (Ulberg, 1994). To find its position and to register experienced traffic conditions, a probe vehicle is equipped with onboard electronics, such as a location and a communication device. Using the location device, the probe vehicle keeps track of its geographic position (Ulberg, 1994). Examples of ITS data collection systems are shown in Figures 2.1 and Figure 2.2.

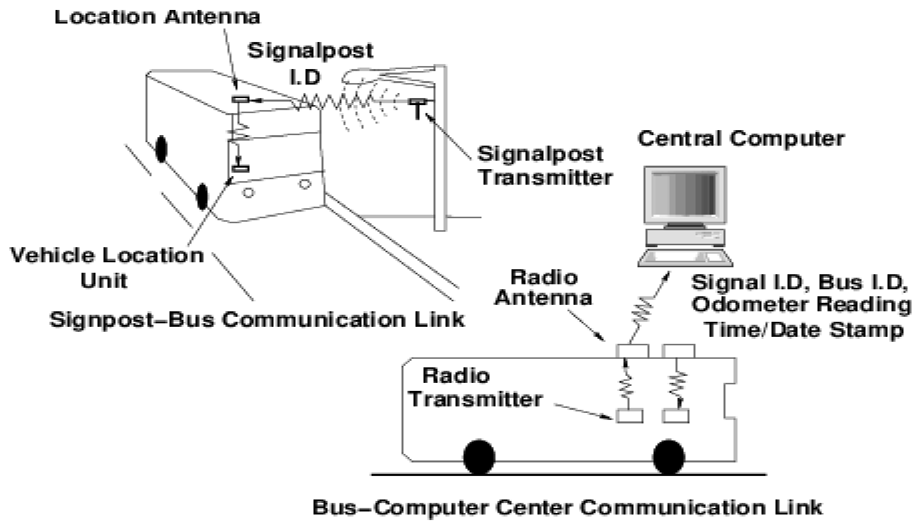


Figure 2.1: Signpost-Based AVL Communication Processes, Source: Travel Time Detection Hand Book, 2006

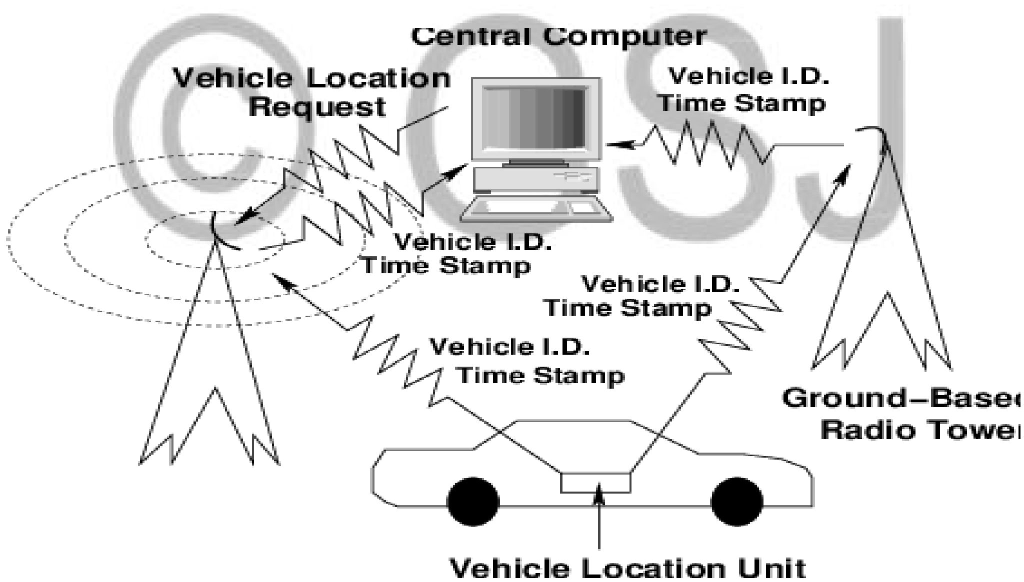


Figure 2.2: Ground-Based Radio Navigation Communication Process, Source: Travel Time Detection Hand Book, 2006

For the signpost-based AVL processes as displayed in Figure 2.1 where the probe vehicles communicate with transmitters mounted on existing signpost structures. In relation to the ground-based navigation communication system, data is collected by communication between probe vehicles and a radio tower. ITS data collection systems have setbacks including (a) the cost of implementation is high; (b) the system requires skilled personnel; and (c) it has infrastructure constraints of low coverage area.

2.4 Crowdsourcing Traffic data

2.4.1 Introduction

In relation to this concept; soliciting people's ideas and opinions on a task is the same concept of crowdsourcing. So, crowdsourcing can be called an "*old, new technique".* This is because people have been crowdsourcing for information (looking for people's views and opinions) to complete a particular task. The large increase of internet and mobile devices have increased the potential of this method. The handheld mobile devices such as smartphones, tablet PCs, smart wearables have increased the involvement of people in generating a huge amount of data (Maldeniva et al., 2015). Crowdsourcing has been categorized into two; passive and active crowdsourcing.

Passive crowdsourcing as an activity in which the people are being traced as data and people are not actively taking part in the project (Reed et al., 2015). An example of such a situation includes the use of people's online comments to enable or assist a particular objective. The user is not focused directly on this type of crowdsourcing, however, as an appropriate practice, people could be informed about their information to be used and it becomes a mandatory fact to protect the people's information. But people who get involved in active crowdsourcing are aware of the objectives, and they work towards the tasks and are actively involved in the tasks. Examples of such situations include; surveys and polls.

2.4.2 How Google collects traffic information

In 2005, Google introduced a mobile mapping service called Google maps. It was to provide the service related to locations. This mapping service provided users with information about traffic, local businesses or interesting points, etc. Currently, Google uses a crowdsourced hybrid positioning system to identify the location of its users (Lane et al., 2010). Leiteritz (2010) noted that the crowdsourced hybrid geolocation system of Google Maps is being supported by many smartphone users and mobile phone users all around the world. Google Maps gather user location as passive crowdsourced information for their platforms from mobile phone users.

In November 2007, Google Maps Mobile launched an app feature called “My Location” which was considered as a major transition in gathering crowdsource information. By 2007 GPS sensors were not much popular in smartphones. Less than 15% of the mobile phones had GPS technology at that time (Lane et al., 2010 & Leiteritz, 2010). My Location technology uses cell tower ID information to provide users with their approximate location and help them to find places around them. Initially, the cell tower ID information was given by cellular providers. However, Google transmitted the cell tower ID information to their servers and the location database of cell tower IDs was created. Hence Google could provide location information without relying on the cellular service provider (Leiteritz, 2010).

2.4.3 Previous work on Crowdsourcing Traffic data

Aside from Google, there are other traffic data providers like WAZE, TomTom, and INRIX. They use aggregated historical and real-time traffic information. Few researchers have so far pursued this discipline – the use of the crowdsource data made available by these providers to analyze traffic. Nair et al. (2019) undertook a study that compared the traffic conditions across 40 cities on a common datum using crowdsourced data. Using any other means of traffic data collection for the 40 cities would have made it a very expensive task to pursue.

Some had argued that the proportion of users whose travel data is recorded and processed by these apps is relatively small resulting in a potential bias in representing the real traffic situation, but with the continuous increment of smartphones and the internet, this flaw is gradually diminishing thus resulting in more reliable and accurate traffic information. However, a major traffic data provider, Google had lamented that factors such as lack of awareness (about the benefits of crowdsourced data), data privacy, and more phone battery consumption among smartphone users can also result in the users avoiding keeping the location services "on". Google only shares this aggregated traffic information through the API for the sake of ensuring the confidentiality of the collected data.

2.4.4 Importance of crowdsourced Google Traffic data

Google obtains traffic data through the use of mobile phones of road users of local road network. Through this capability, appropriate determination of the nature of traffic can be carried out. Crowdsourcing of traffic data from the use of smartphones and the internet is one of the fastest and reliable methods since Google especially uses this crowdsource data to improve their maps for high efficiency.

Notwithstanding, research that seeks to validate the traffic information derived from Google Travel API is quite essential. This would inform stakeholders especially, the road users of the accuracy and reliability of the information. Uber and bolt drivers mostly depend on Google maps for locating their passengers. There are still significant issues in the area of using data in an active traffic management in a fully distributed traffic management system, with no lasting solution yet to address this issue (Appiah- Twum and Egyin,2021).

Managing the traffic situation in the city is a difficult task since traffic data is not collected consistently. The methods used for collecting traffic data do not have city-wide coverage. The ITS especially the CCTV used for collecting the data can be seen on a few roads in the urban area. Appiah- Twum, and Egyin (2021) also lamented that large and continuous activities on the roadside, including hawking, make the manual data collection method difficult to apply. The safety of the field investigators becomes an issue since there can be irrational behavior of road users, particularly drivers. Also, most of the automated data collection systems are used when particular research is about to take place. Google keeps track of mobility patterns on all their users when in motion or not. Through this available information, the historical data of traffic on a particular road corridor can be determined through the use of smartphones and the internet while driving.

2.5 Using Google Distance Matrix API

Google through the service, Distance Matrix API gives information of travel including distance and time for a matrix of origins and destinations. It is seen that, with the use of Google Maps, users can get access to information of traffic from one point to the other. Also, Distance Matrix API helps users to access information about different routes, different origins, and destinations at the same time. Through a secured hypertext transfer protocol (HTTP), the Distance Matrix API is requested. The API gives back information based on the recommended route between origin and destination. Google Distance Matrix API makes the calculation and presents rows containing duration and distance values for each pair. The output format and the parameters have to be defined appropriately to satisfy syntax required by Google.

```
https://maps.googleapis.com/maps/api/distancematrix/outputFormat?parameters
```

Figure 2.3: Basic method for calling the Distance Matrix API, Source: Google Maps API

2.5.1 Input Parameters to the API

Through the use of some elements which are known as input parameters, users can make the needed requests to the API. There are two types of these parameters; mandatory and optional parameters. With the mandatory parameters, users must define them while with the optional ones, users can choose them to meet a requirement.

2.5.2 Mandatory Parameters

The mandatory parameters must be defined, as the API cannot be called without defining them. When they are wrongly defined, the displayed results would be error or failure. Examples of mandatory parameters are origin, destination and API key.

- **Origin:** This is the element for which the origin of the route is to be passed. A single origin or multiple numbers of origins at a single API call can be called, either with the address or latitude and longitude coordinates or a place ID. The use of latitude and longitude is recommended, since it minimizes errors

- **Destination:** The destination is also a required element to include in the request. It accounts for the endpoints of the travel. The destination value is also passed as latitude and longitude coordinates to help minimize errors. When calling the API always a single pair of origin and destination can be used.

- **API Key:** API keys are unique identifiers. It helps users to make API calls. For each API call, an authorized API key should be passed and the Google service has to authenticate the key. To get the API key, the user has to select a project on the Google API Console. The user can obtain an API key when he/she creates a project and enable a payment method. The API calls are limited, and they are being limited according to predefined regulations. There is a free limit set out by Google based every month and even daily. Users have to call the API as a paid service if the free limit is exceeded. The paid services are provided either based on a pay-as-you-go basis or as a premium plan under a contract between Google and the user.

Table 2.1: Cost Structure of the Distance Matrix API

Standard limit	Pay-as-you-go	Premium
2500 API calls / Day	$0.50 /1000 extra calls up to 100000 API calls/day	After contact with Google

Source: Google Maps API

2.5.3 Optional Parameters

These parameters add to the request the user requires. It is not mandatory though but can be relevant to the search interest of the user. The optional parameters are explained in the following. The mode parameter is used to enable the travel mode. The travel mode could be the use of public transport, walking and cycling. In the driving mode, the travel time and distance are calculated using the road network. For this study, the mode parameter was set to driving.

Language and Units parameters are also optional. There are 50 or more languages that are available for the data collection. For this research, English Language was used. The Unit parameter specifies the unit system to be used in data collection. This element is very important if the distance and travel time values are expressed in a text format. The departure time is an optional parameter. It helps to find the travel time. When the departure time is set to “now,” the real-time traffic information is considered in calculating travel time. If the departure time is set to a time in the future, the travel time prediction could be obtained. With the arrival time parameter, travel time information can be collected. The time must always be in the future and not in the past or present. There is another parameter called the traffic model.

2.5.4 Output Parameters

The output parameters are the results given by the API if the API calls are made correctly. Google Distance Matrix API allows JavaScript Object Notation (JSON) format or Extensible Markup Language (XML) format to release results. The information requested is placed in a row array, and JSON decoder or XML decoder can be used to access the output results and store them in a file. The results to be displayed may include the distance and duration. The parameters as displayed in Table 2.2 was chosen to make the Google Distance Matrix API calls.

Table 2.2: Structure for the Distance Matrix API calls parameters

Parameters	Value
Origin	Address
Destination	Address
API Key	Key
Travel mode	Driving
Traffic model	Best guess
Departure time	Now
Language	English (en)

2.5.5 Drawbacks of using Google Distance Matrix API

Google Distance Matrix API has among the many the advantages of taking multiple origins and destinations and providing their travel times and distances. However, there are a few drawbacks to the use of the service. The use of Google Distance Matrix API does not give back detailed route information. Route information can be obtained by passing the single origin and destination to the Directions API. Also, the choice of route and duration are based on the road network and average time-independent traffic conditions, if the departure time is not specified.

2.6 Measuring Traffic Congestion

2.6.1 Introduction

Litman (2004) noted that traffic congestion is a major problem in urban transportation. Many researchers have come up with a lot of definitions for traffic congestion, However, there is no universally accepted definition for traffic congestion (Dows, 2004). These definitions are categorized into three main groups: a) demand – capacity; b) Delay -travel time and c) Cost.

Rosenbloom (1978) defined; traffic congestion occurs when travel demand is greater than the existing road system capacity. ECMT (1999) also defined traffic congestion as the impedance vehicles impose on each other due to the speed-flow relationship, in conditions where the use of a transport system approaches its capacity. These two definitions are example definitions of demand capacity-related traffic congestion.

An example definition of delay travel time-related congestion was provided by Dows (2004); traffic congestion is a situation where traffic is moving at speeds below the designed capacity of a roadway. VPTI (2005) defined traffic congestion as the relation to the incremental costs resulting from interference among road users. VPTI's (2005) definition is an example of cost-related traffic congestion. Managing urban traffic congestion has led to three major causal factors of traffic congestion (ECMT, 2007). These factors are shown in Table 2.3.

Table 2.3: Categories of causal factors of traffic congestion

Causes of Traffic congestion	**Examples**
Macro- Level (Congestion – triggers)	• Land use patterns • Car ownership trends • Regional economic dynamics
Micro-Level (Congestion- drivers)	• Design of roadway • Dynamic changes in roadway capacity
Random variables	• Weather • Visibility

Adapted from ECMT (2007)

The negative effects of traffic congestion include wasted productivity, noise, pollution, road traffic crash risk, and safety risks for pedestrians, not to mention the impact of greenhouse gas emissions on the environment (Ubillos, 2008). For individual drivers, a recent study estimated that adding 20 min to a commute can be equated to the level of dissatisfaction in receiving a 19% pay cut (Chatterjee et al., 2017).

2.6.2 Homburger measure of Vehicular Traffic Congestion

Congestion can be analyzed as a physically measurable phenomenon or as perceived by users of the road network, residents and others, and the level of congestion in these approaches will be different (Mussone, 2015). Congestion indices (CI) for all the identified roads were formulated using the formula: CI = 1 - $\frac{A}{M}$

Where,

A: Average journey speed observed on the selected road corridor

M: Estimated average journey speed which is assumed as 50 km/h.

The congestion index as shown in Table 2.4 is formulated such that, the lower the congestion index (0≤ CI≤ 0.5), the better the performance of the road. However, the performance of the road is worse, if the CI approaches to 1 (0.5<CI≤ 1).

Table 2.4: Congestion Index and Categories of Traffic Congestion

Congestion Index	Congestion Category
0.00 – 0.25	Free flow
0.26 – 0.50	Moderate
0.51 – 0.75	Heavy
0.76 – 1.00	Severe

Adapted from Homburger et al., 1992

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

Google traffic information which is globally available but must be verified to accurately suit the area of study. That is what the study seeks to do: to validate crowdsourced Google travel time data on selected road corridor in Kumasi. Google through its Distance Matrix API can provide traffic information for multiple origins and destinations in the city. Hence, a validated crowdsourced Google traffic data on selected road corridor will lead to improved traffic data city-wide. This chapter explains the procedures in Field and Google travel time data collection.

3.1.1 Methodology in Test Vehicle technique

Test vehicle technique may have few setbacks; data storage difficulties and the possibility of human and electronic errors, but it has a rewarding end of low initial cost and this technique can be advanced (through the use of GPS and others to provide detailed traffic data). In the study, this technique was conducted to determine the travel times of test vehicles. The test vehicle was representative of moving vehicular traffic on the road corridor. The data collected using this technique was considered as the field travel time data.

For the study, Bohyen bus station was chosen as first origin and Asuofua Cedar Crest Junction was chosen as the last destination (see Figure 3.1). It was divided into five segments with each segment having origin and destination point. Each segment was considered a shorter trip. The test vehicle started on the first origin at the peak periods and ends on the first destination. The travel time was determined using a stop watch. The destination of the first trip becomes the origin of the next trip (see Table 1.1 for details). It continues till the test vehicle completes the whole journey.

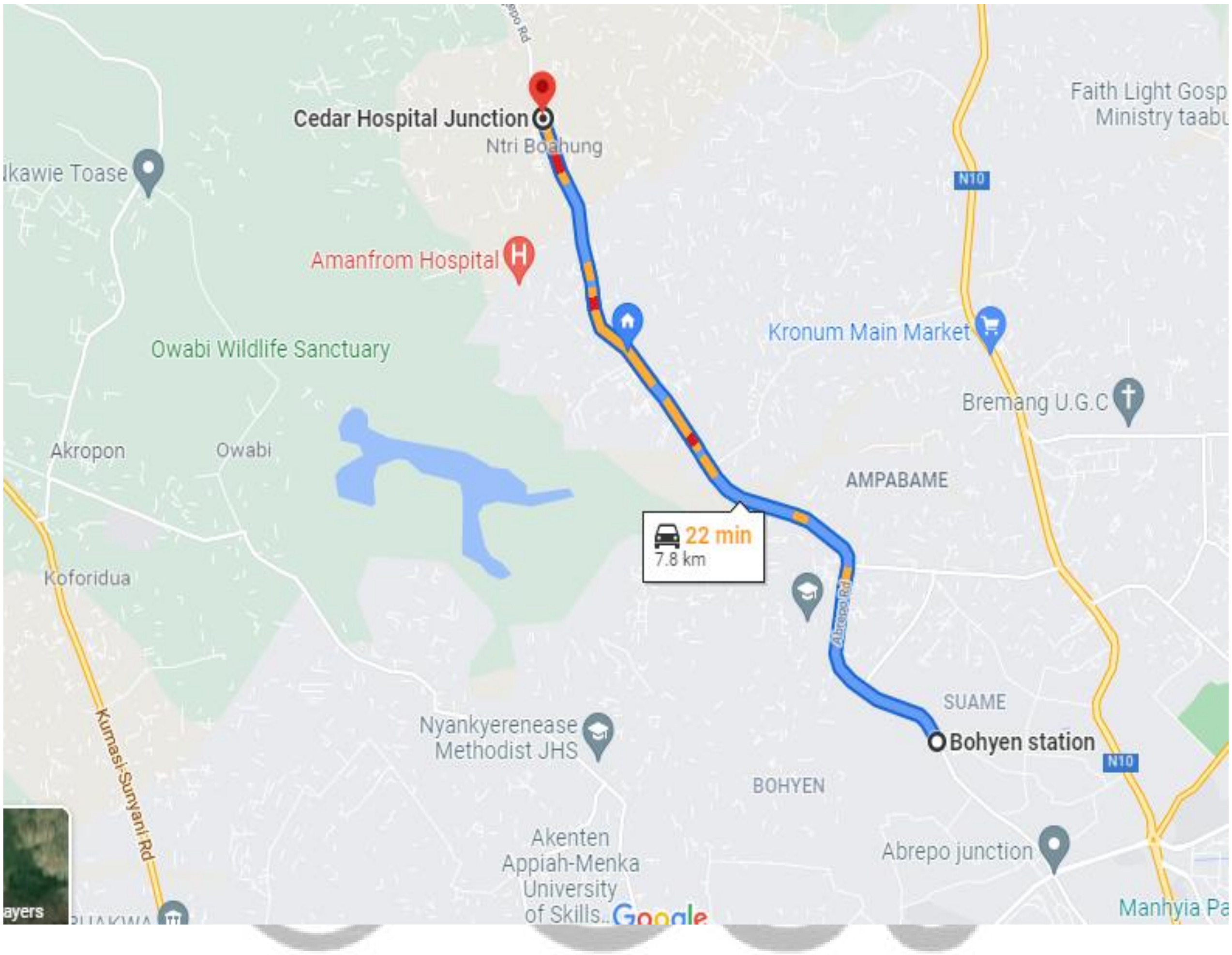


Figure 3.1 Google Map image showing the selected road corridor in Kumasi

The field data collection method started on 1st November, 2021. The duration of data collection was four (4) weeks. Measurements were done on Mondays, Wednesdays, Fridays and Saturdays for each week. The morning and evening were considered as on-peak times whiles the afternoon is considered as off- peak time. Special care was taken in driving to ensure that the motor vehicle act as a representative vehicle of the moving vehicle fleet.

Figure 3.2: Test vehicle moving on selected road corridor in Kumasi

3.1.2 Google traffic data collection

In the study, Google travel time data on the selected road corridor was collected via Google Distance Matrix API for the 4-week duration. The times of the Google traffic data collection was the same as the used for the field travel time measurements. The reason was that, both travel times collected from these two sources would be compared to see whether they agree significantly or not.

Google gathers and sums up speed data from smartphone users to estimate travel times. The data is recorded from devices that use the “Google Maps” feature or have their “My Location” feature turned on (Google, 2017). The procedures followed to obtain the distances and travel times of the multiple origins and destinations are listed in Figure 3.3.

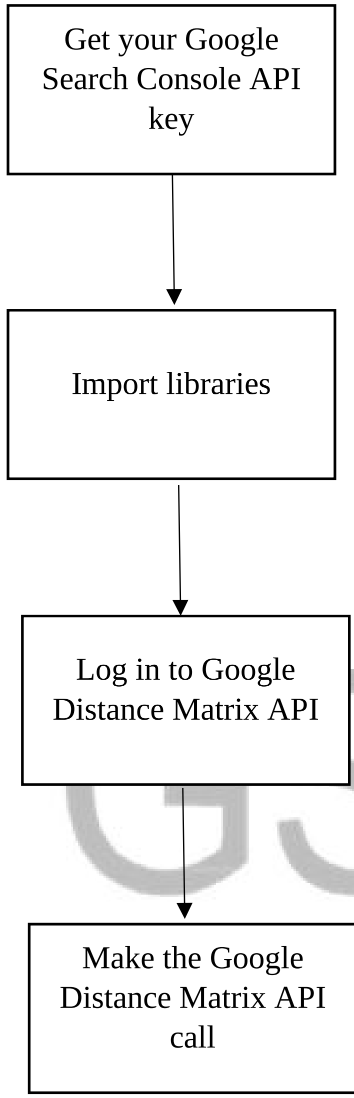


Figure 3.3: Flowchart for obtaining traffic information via Google Distance Matrix API

When the Google Distance Matrix API was called for a single origin-destination pair, the response to the API call was produced in a JSON format by the Google Distance Matrix API. The script read the JSON output and find the elements in the JSON output such as the distance in meters and duration in traffic in minutes.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Kumasi has not been spared of the issue of vehicular traffic congestion. It takes longer time to commute from one point to the other. Appiah – Twum (2018) developed a vehicular traffic management model which could assist in managing vehicular traffic in Kumasi. This model and others would need an important ingredient – reliable city-wide traffic data. Getting a city-wide traffic data becomes expensive to do by field investigation. However, crowdsourced Google traffic data is a potential solution that needs further verification to accurately suit the area of interest. Consequently, the study seeks to validate and upscale crowdsourced Google traffic data. The results of this study provide the nature of vehicular traffic based on Field and Google travel time data. Both datasets were compared to assess the validity of Google traffic data on selected road corridor in Kumasi.

4.2 Field Traffic data: Results and Discussion

4.2.1 Introduction

The first objective was to determine the nature of vehicular traffic on selected road corridor in Kumasi through field investigation. The test vehicle technique was used to obtain travel time data from the field. The results of Field travel time data determined the nature of vehicular traffic of the road segments on selected road corridor. Travel time data was obtained through field investigation and it was recorded in minutes (mins). The distances of road segments were also recorded in kilometers (km). The speeds for the road segments were calculated using data of travel time and distances. The congestion index was also estimated for road segments on the road corridor. Each segment on road corridor is assigned a congestion index value (within 0.00 – 1.00) interval. Based on congestion index, a congestion category is assigned. A free flow and moderate congestion index lie the intervals (0.00 - 0.25) and (0.26 – 0.50) respectively whiles heavy and severe congestion lie the intervals (0.51 – 0.75) and (0.71 – 1.00) respectively (refer to section 2.6.3).

4.2.2 Nature of vehicular traffic based on Field travel time data for Morning peak

From Table 4.1 it can be seen that, Wednesday and Friday have the highest congestion index of 0.55, which is heavy congestion. The congestion index on Monday is 0.54, which is also heavy congestion situation. Saturday has seen the lowest congestion situation with the congestion index of 0.46. The heavy congestion situation on Monday, Wednesday and Friday suggests that, most trips are made to workplaces at the morning peak (see Table 4.1). However, Saturday has moderate congestion situation for the morning peak**.**

Table 4.1: Average Congestion Index for the Morning peak from Field Travel time data

Days of the Week	Average Congestion Index	Congestion Category
Monday	0.54	Heavy
Wednesday	0.55	Heavy
Friday	0.55	Heavy
Saturday	0.46	Moderate

Source: Authour's Construct, 2021

4.2.3 Nature of vehicular traffic based on Field travel time data for Afternoon peak

Monday, Wednesday and Saturday have heavy congestion situation for the afternoon peak (see Table 4.2). It is seen that, traffic patterns at morning peak, as shown in Table 4.1 is quite similar to traffic pattern at afternoon peak, as shown in Table 4.2. The congestion situation is mostly heavy congestion for the afternoon peak

Table 4.2: Average Congestion Index for the Afternoon peak from Field Travel time data

Days of the Week	Average Congestion Index	Congestion Category
Monday	0.55	Heavy
Wednesday	0.59	Heavy
Friday	0.48	Moderate
Saturday	0.55	Heavy

Source: Authour's Construct, 2021

4.2.4 Nature of vehicular traffic based on Field travel time data for Evening peak

Okyere (2012) noted that, most trips are made away from Kumasi CBD at evening peak. This explains the results as clearly shown in Table 4.3. There is heavy congestion situation for Monday, Wednesday, Friday and Saturday (see Table 4.3). The selected road corridor lies in a residential developing area. For that reason, most people travel back from their day-activities (either work or school) to the homes.

Table 4.3: Average Congestion Index for the Evening peak from Field Travel time data

Days of the Week	Average Congestion Index	Congestion Category
Monday	0.63	Heavy
Wednesday	0.63	Heavy
Friday	0.66	Heavy
Saturday	0.58	Heavy

Source: Authour's Construct, 2021

4.3 Google Traffic data: Results and Discussion

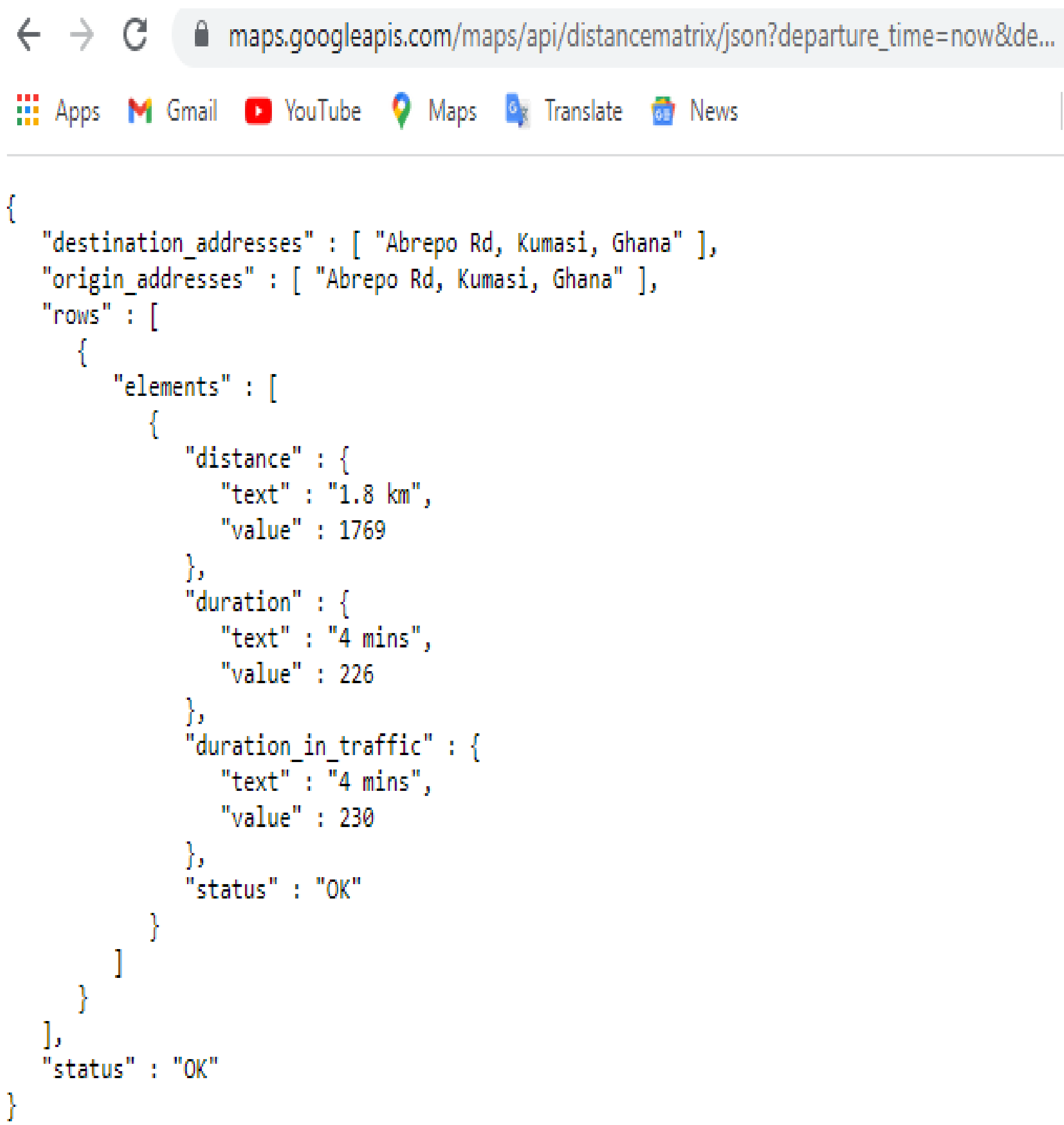
4.3.1 Introduction

The second objective was to use crowdsourced Google Distance Matrix API to determine vehicular traffic on selected road corridor. Using Google Distance Matrix API services, call requests were made via Uniform Resource Locator (URL) to retrieve travel time and distances of multiple origins and destinations on the road corridor (see Figure 4.1).

```
BOHYEN - ABREPO
https://maps.googleapis.com/maps/api/distancematrix/json
  ?departure_time=now
  &destinations=Abrepo_market%2C
  &origins=Bohyen_station%2C
&key=AIzaSyCW0SERs27doJS0C_8cDPYTeBwvyx-t8OU

ABREPO - ATAFUA_AKOKO_SPECS
https://maps.googleapis.com/maps/api/distancematrix/json
  ?departure_time=now
  &destinations=Atafua_Akoko_specs%2C
  &origins=Abrepo_market%2C
&key=AIzaSyCW0SERs27doJS0C_8cDPYTeBwvyx-t8OU

ATAFUA_AKOKO_SPECS - TIGO JUNCTION
https://maps.googleapis.com/maps/api/distancematrix/json
  ?departure_time=now
  &destinations=Tigo_Junctions%2C
  &origins=Atafua_Akoko_specs%2C
&key=AIzaSyCW0SERs27doJS0C_8cDPYTeBwvyx-t8OU

TIGO JUCTION - AMANFROM GOIL
https://maps.googleapis.com/maps/api/distancematrix/json
  ?departure_time=now
  &destinations=Amanfrom_Goil%2C
  &origins=Tigo_Junction%2C
&key=AIzaSyCW0SERs27doJS0C_8cDPYTeBwvyx-t8OU

AMNANFROM GOIL - CEDAR_CREST_JUNCTION
https://maps.googleapis.com/maps/api/distancematrix/json
  ?departure_time=now
  &destinations=Cedar_Crest_Junction%2C
  &origins=Amanfrom_Goil%2C
&key=AIzaSyCW0SERs27doJS0C_8cDPYTeBwvyx-t8OU
```

Figure 4.1: Google Distance Matrix API call requests using URL

Figure 4.2 shows the output of the request via the Google Matrix Distance API service. The addresses of the origin and destination are shown, and the distance and duration of travel for the peak period are given (see Figure 4.2).




```
{
   "destination_addresses" : [ "Abrepo Rd, Kumasi, Ghana" ],
   "origin_addresses" : [ "Abrepo Rd, Kumasi, Ghana" ],
   "rows" : [
      {
         "elements" : [
            {
               "distance" : {
                  "text" : "1.8 km",
                  "value" : 1769
               },
               "duration" : {
                  "text" : "4 mins",
                  "value" : 226
               },
               "duration_in_traffic" : {
                  "text" : "4 mins",
                  "value" : 230
               },
               "status" : "OK"
            }
         ]
      }
   ],
   "status" : "OK"
}
```


Figure 4.2: Results obtained from calling the Distance Matrix API

4.3.2 Nature of vehicular traffic based on Google travel time data for Morning peak

The nature of vehicular traffic on selected road corridor was also determined through the use of crowdsourced Google Distance Matrix API. Using the obtained Google traffic data, it was identified that vehicular traffic congestion situations for Monday, Wednesday, Friday and Saturday are quite similar for morning peak. These days have seen a moderate congestion situation (see Table 4.4) Monday has the highest congestion index of 0.48, which is moderate congestion situation. The congestion index on Wednesday and Friday are 0.46 and 0.45 respectively. Saturday has the lowest congestion situation with the congestion index of 0.43.

Table 4.4: Average Congestion Index for the Morning peak from Google Travel time data

Days of the Week	Average Congestion Index	Congestion Category
Monday	0.48	Moderate
Wednesday	0.46	Moderate
Friday	0.45	Moderate
Saturday	0.43	Moderate

Source: Authour's Construct, 2021

4.3.3 Nature of vehicular traffic based on Google travel time data for Afternoon peak

Using the obtained Google traffic data, it was identified that vehicular traffic congestion situations for Monday, Wednesday, Friday and Saturday are quite similar for afternoon peak (see Table 4.5). Saturday has the highest congestion index of 0.50, which is moderate congestion situation. The congestion index on Wednesday and Monday are 0.49 and 0.45 respectively. Friday has the lowest congestion situation with the congestion index of 0.44.

Table 4.5: Average Congestion Index for the Afternoon peak from Google Travel time data

Days of the Week	Average Congestion Index	Congestion Category
Monday	0.45	Moderate
Wednesday	0.49	Moderate
Friday	0.44	Moderate
Saturday	0.50	Moderate

Source: Authour's Construct, 2021

4.3.3 Nature of vehicular traffic based on Google travel time data for Evening peak

Using obtained Google traffic data for evening peak, it was identified that, vehicular traffic congestion situations for Monday, Wednesday, Friday and Saturday are quite similar for afternoon peak (see Table 4.6). Friday has the highest congestion index of 0.60, which is heavy congestion situation. The congestion index on Monday and Wednesday are 0.59 and 0.50 respectively. Saturday has the lowest congestion situation with the congestion index of 0.47.

Table 4.6: Average Congestion Index for the Evening peak from Google Travel time data

Days of the Week	Average Congestion Index	Congestion Category
Monday	0.59	Heavy
Wednesday	0.50	Moderate
Friday	0.60	Heavy
Saturday	0.47	Moderate

Source: Authour's Construct, 2021

4.4 Validation of Google Traffic data

4.4.1 Introduction

A validation procedure was carried out to ensure the accuracy of Google travel time obtained from Google Distance Matrix API service. Field travel time measurements were conducted using probe vehicle technique. Google travel time data were compared with field travel time data to check the validity of the Google traffic data. It is important to identify the significant correlation of Google travel time data with travel time data obtained from field mode. If the correlation between two travel time observations results in a higher agreement, then it could be concluded that Google travel time data has a significant accuracy in travel time estimation.

4.4.2 Analysis to verify Google Travel time data for Morning peak

Google travel data were compared with field travel data for morning peak (see Figure 4.3). Using the field data as reference, the morning peak has Wednesday as the highest difference of 5-minutes underestimated by Google whiles Saturday has the lowest difference of 2-minutes underestimated by Google.

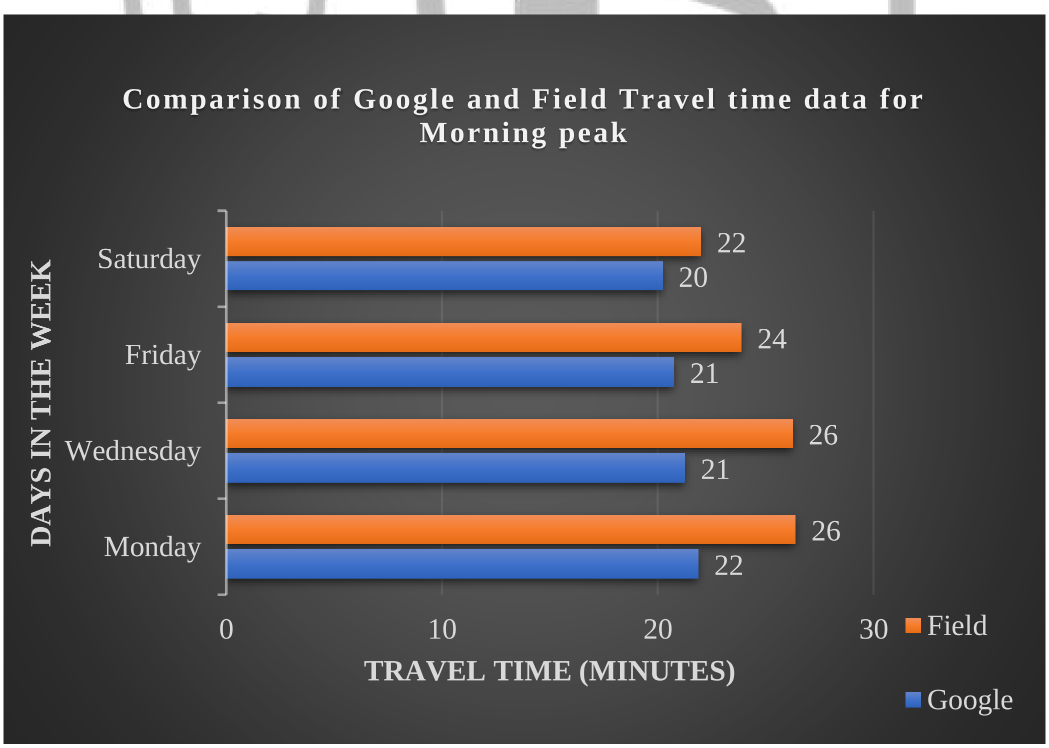


Figure 4.3: Comparison of Google and Field Travel time data for Morning peak

The regression analysis was conducted to verify Google traffic data for morning peak (see Table 4.7). The Field travel time data was set as a reference. There is a linear unitary relationship between the two-travel time estimates. It could be observed that, the linear regression model moved through the origin, indicating that the regressor coefficient is closer to 1. The R square of the least square of the estimates gives a value of 0.99, indicating that there is a very high association between the two parameters. The estimates have low standard error of 1.148 indicating that the sample mean is close to the population mean. In simpler terms, Google traffic data for the morning peak has 99% accuracy. The value of significance F is 0.0007 which is much closer to zero. Therefore, we fail to reject the null hypothesis; a validated crowdsourced Google traffic data on selected road corridors will lead to improved traffic data city-wide.

Table 4.7: Statistical Analysis of Google travel times and Field travel times for Morning peak

Regression Statistics					
Multiple R	0.999				
R Square	0.998				
Adjusted R Square	0.664				
Standard Error	1.148				
Observations	4				
ANOVA					
	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1765.7349	1765.7349	1338.9104	0.0007
Residual	3	3.9564	1.3188		
Total	4	1769.6913			

4.4.3 Analysis to verify Google Travel time data for Afternoon peak

Google travel data was compared with Field travel data for afternoon peak (see Figure 4.4). afternoon peak. Using the Field travel time data as reference, the afternoon peak has Wednesday as the highest difference of 9-minutes underestimated by Google, and Friday has the lowest difference of 3-minutes underestimated by Google.

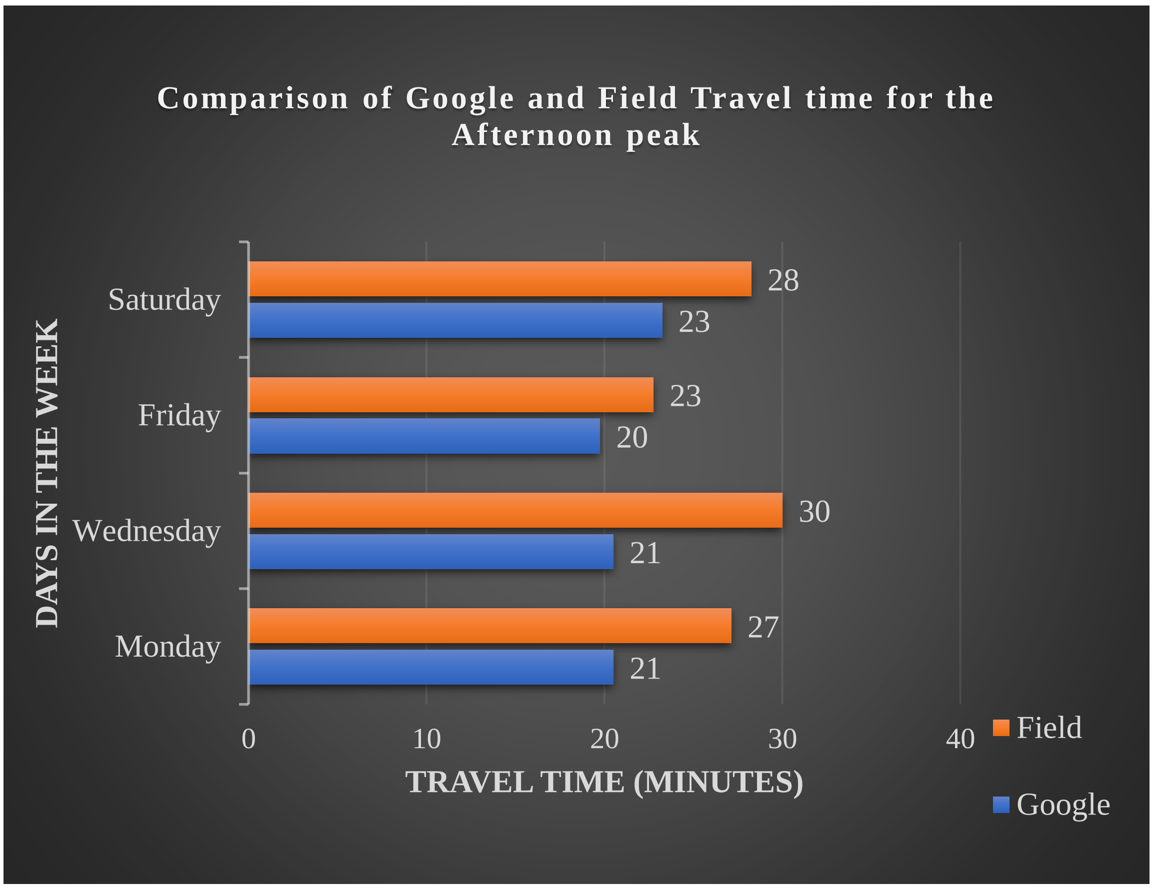


Figure 4.4: Comparison of Google and Field Travel time data for Afternoon peak

The regression analysis was conducted to verify Google traffic data for afternoon peak (see Table 4.8). The R square of the least square of the estimates gives a value of 0.99, indicating that there is a very high association between the two estimates. The estimates have low standard error of 2.17 indicating that the sample mean is close to the population mean. In simpler terms, Google traffic data for the morning peak has 99% accuracy. The value of significance F is 0.003 which is much closer to zero. Therefore, we fail to reject the null hypothesis; a validated crowdsourced Google traffic data on selected road corridors will lead to improved traffic data city-wide.

Table 4.8: Statistical Analysis of Google travel times and Field travel times for Afternoon peak

Regression Statistics					
Multiple R	0.996				
R Square	0.992				
Adjusted R Square	0.659				
Standard Error	2.170				
Observations	4				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1756.996	1756.996	373.074	0.003
Residual	3	14.129	4.710		
Total	4	1771.125			

4.4.4 Analysis to verify Google Travel time data for Evening peak

Google travel data were compared with Field travel data for evening peak (see Figure 4.5). Using the Field data as reference, the evening peak has Wednesday as the highest difference of 5-minutes underestimated by Google whiles Friday has the lowest difference of 1-minute overestimated by Google.

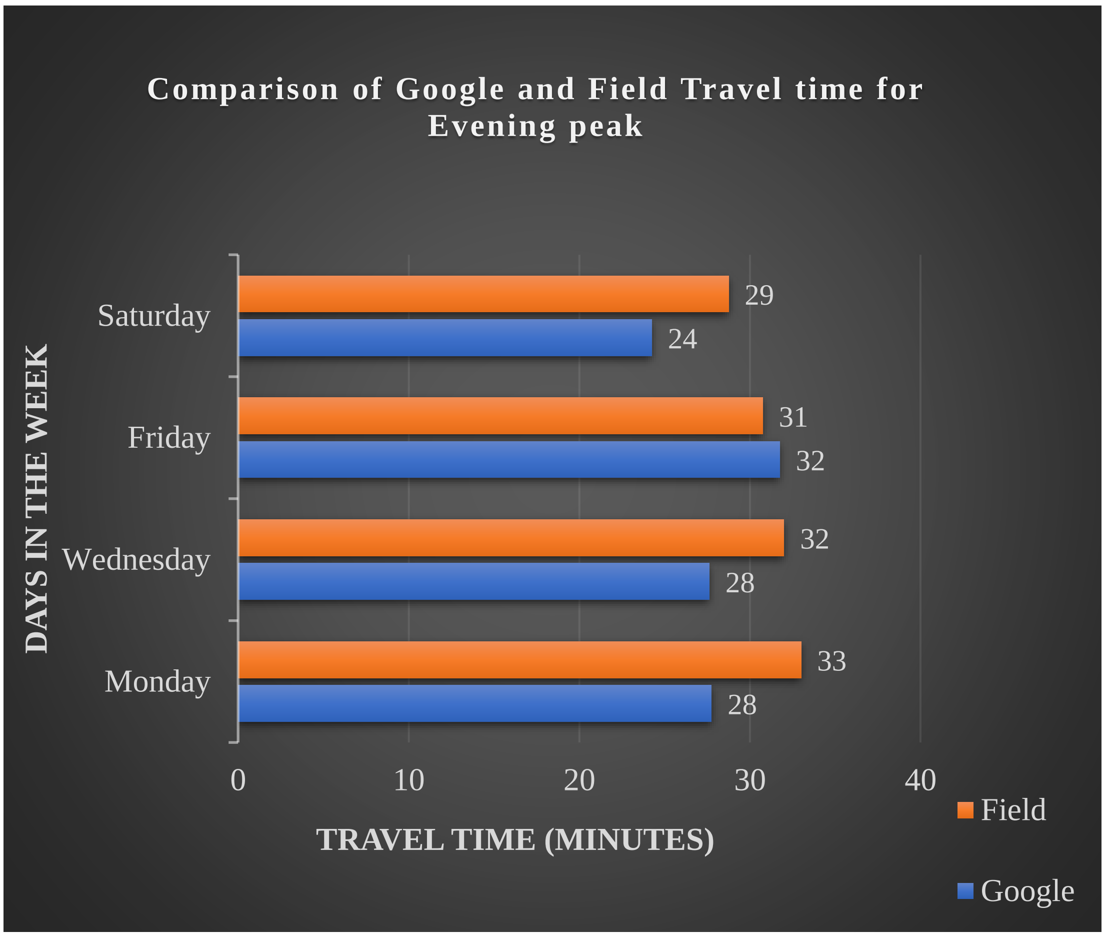


Figure 4.5: Comparison of Google and Field Travel time data for Evening peak

The regression analysis was conducted to verify Google traffic data for evening peak (see Table 4.9). The R square of the least square of the estimates gives a value of 0.99, indicating that there is a very high association between the two estimates. The estimates have low standard error of 2.84 indicating that the sample mean is close to the population mean. In simpler terms, Google traffic data for the morning peak has 99% accuracy. The value of significance F is 0.003 which is much closer to zero. Therefore, we fail to reject the null hypothesis; a validated crowdsourced Google traffic data on selected road corridors will lead to improved traffic data city-wide.

Table 4.9: Statistical Analysis of Google travel times and Field travel times for Evening peak

Regression Statistics					
Multiple R	0.9961				
R Square	0.9922				
Adjusted R Square	0.6589				
Standard Error	2.8454				
Observations	4				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3105.039	3105.039	383.514	0.003
Residual	3	24.289	8.096		
Total	4	3129.328			

4.5 Discussion of findings

The use of mini-van (trotro) for trips is dominant in Kumasi (Okyere, 2012). Consequently, these mini-vans were mostly used test for the study. Observations were made during the use of mini-vans as test vehicles; a) The mini-van makes approximately 11 temporal stops before completing the journey of 7.9km; b) The average time for the temporal stops was 10 seconds. The reasons for the temporal stops included alighting and picking up passengers. The temporal stops which increased the travel times were not accounted for by Google. This explains why Google mostly under-estimates the field data on the selected road corridor in Kumasi. Also, Google travel time data were verified with the travel time data obtained from the Field. Using the Field data as reference, the morning peak has Wednesday as the highest difference of 5-minutes under-estimated by Google and Saturday has the lowest difference of 2-minutes under-estimated by Google. But for the afternoon peak, Wednesday has the highest difference of 9-minutes under-estimated by Google, and Friday has the lowest difference of 3-minutes underestimated by Google. The evening peak has Monday as the highest difference of 5-minutes under-estimated by Google and Friday has the lowest difference of 1-minute over-estimated by Google. The choice of the test vehicles influenced the differences in the validation for the morning, afternoon and evening peaks. Mini-vans (trotro) and private cars were both selected randomly for the test drives. There were no temporal stops when private cars were used as test vehicles for the study. However, there were some temporal stops for drives made with the mini-vans (trotro). Therefore, the use of private cars and mini-vans in the test vehicle technique gave field travel time estimates which led to the respective smaller and larger differences in the validation.

The traffic situations on the road corridor reflect the general use of the road. The selected road corridor is one of the major urban arterials that leads to Kumasi Central Business District (CBD). The CBD in Kumasi is the center of major of economic activities. It was seen that, trips made within the city are generally towards the Kumasi CBD in the morning. This is because, most workplaces are located at Kumasi CBD. Also, most trips are made away from Kumasi CBD in the evening. This explains why there is heavy congestion situation at morning and evening peaks on working days (Mondays to Fridays). Also, the high residential densities along the selected road corridor have led to decrease of the demand of travel on Saturday. Most people do not make trips to workplaces on Saturdays. This explains why there was moderate congestion situation on

Saturdays for morning, afternoon and evening peaks. The study has validated Google traffic data on selected road corridor in Kumasi. The Field data was used as reference for the validation of Google travel time data. A linear regression analysis was conducted with both datasets and it showed that Google traffic data has 99% accuracy. It is reliably concluded that, a validated crowdsourced Google traffic data on selected road corridor will lead to improved traffic data city-wide.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Summary of findings

The first objective was to undertake a field investigation to assess vehicular traffic on a selected road corridor in Kumasi. This was realized by conducting a detailed literature review which illustrated the appropriate field travel time measurement, which was used for the study. Field travel time measurement was conducted using the test vehicle technique, where travel time data were recorded and analyzed. The speeds and congestion index of the multiple origins and destinations based on field data were calculated (see Appendix A for details).

The second objective was to use crowdsourced Google Distance Matrix API to determine vehicular traffic on the selected road corridor in Kumasi. Distances and travel times on multiple origins and destinations on the selected road corridor were obtained from Google Distance Matrix API service. The speeds and congestion index of the multiple origins and destinations based on crowdsourced Google travel time data were calculated (see Appendix B for details).

The third objective was to compare Field and Google traffic data to validate the crowdsourced Google data. Using the field data as reference, the morning peak has Wednesday as the highest difference of 5-minutes underestimated and Saturday has the lowest difference of 2-minutes underestimated by Google. But for the afternoon peak, Wednesday has the highest difference of 9-minutes underestimated by Google, and Friday has the lowest difference of 3-minutes underestimated by Google. The evening peak has Monday as the highest difference of 5-minutes underestimated by Google and Friday has the lowest difference of 1-minute overestimated by Google. Finally, linear regression analysis to verify Google traffic data. It was identified that; Google traffic data has 99% accuracy.

5.2 Direction for future research

The method used to get the Google traffic information was set to the driving mode. For future work, it is possible to extend to other modes such as walking, cycling, and public transportation.

With the availability of public transportation schedules and frequencies, the travel time information could be obtained for transit mode. To get cycling travel time information, it is required to define cycling lanes on the map. Also, getting Google traffic data required basic knowledge in computer programming. This is because the methodology is based on a web application. Therefore, it is proposed to develop a graphical user interface based on the web application to collect travel time data from Google Distance Matrix API. In that way, the accessibility and convenience of using the methodology could be enhanced. This method could also be used to develop a travel time database in which the historical travel time variation could be analyzed. By obtaining traffic data for a long time, it is possible to identify increasing trends of road traffic and the average time spent by passengers on the road.

5.3 Concluding Remarks

The less capital and time involved in determining city-wide traffic situation from the use of Google API services is an enticing factor. However, Google traffic data needs verification to accurately suit the area of interest. The study is a proof that, a validated crowdsourced Google traffic data on selected road corridors would lead to improved traffic estimation city-wide. It is therefore recommended that city transport officials, planners, and organizations use this method to assist them in obtaining reliable city-wide traffic information.

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APPENDIX A

Appendix A1: Field Traffic data from 1/11/2021 to 6/11/2021 for the Morning peak

DATE				6am - 9am			
	From	To	distance (km)	Travel Time (mins)	**Speed (km/hr)**	Congestion Index	**Congestion Category**
1/11/2021	Bohyen	Abrepo	1	3	**20**	0.60	**heavy**
	Abrepo	Atafua	1.3	6	**13**	0.71	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	10	**13**	0.72	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM			**7.9**	**29**	**18**	**0.60**	
3/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**26**	**21**	**0.53**	
5/11/2021	Bohyen	Abrepo	1	1.5	**40**	0.11	**free flow**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM			**7.9**	**22.5**	**25**	**0.46**	
6/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**20**	**26**	**0.42**	

Appendix A2: Field Traffic data from 1/11/2021 to 6/11/2021 for the Afternoon peak

DATE				**11am - 1pm**			
	From	To	distance (km)	Travel Time (mins)	**Speed (km/hr)**	Congestion Index	**Congestion Category**
1/11/2021	Bohyen	Abrepo	1	3	**20**	0.60	**heavy**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM			**7.9**	**28**	**18**	**0.59**	
3/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	13	**8**	0.83	**severe**
SUM			**7.9**	**32**	**18**	**0.60**	
5/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	3	**34**	0.24	**free flow**
SUM			**7.9**	**21**	**30**	**0.46**	
6/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM			**7.9**	**26**	**21**	**0.53**	

Appendix A3: Field Traffic data from 1/11/2021 to 6/11/2021 for the Evening peak

DATE				4pm - 6pm			
	From	To	distance (km)	Travel Time (mins)	**Speed (km/hr)**	Congestion Index	**Congestion Category**
1/11/2021	Bohyen	Abrepo	1	3	**20**	0.60	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	10	**13**	0.72	**heavy**
	Amanfrom	Asuofua	1.7	11	**9**	0.79	**severe**
SUM			**7.9**	**33**	**17**	**0.63**	
3/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	16	**6**	0.86	**severe**
SUM			**7.9**	**38**	**16**	**0.66**	
5/11/2021	Bohyen	Abrepo	1	4	**15**	0.67	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	8	**13**	0.72	**heavy**
SUM			**7.9**	**30**	**16**	**0.64**	
6/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	10	**13**	0.72	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**26**	**21**	**0.54**	

Appendix A4: Field Traffic data from 8/11/2021 to 13/11/2021 for the Morning peak

DATE				**6am - 9am**			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
8/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	6	**13**	0.71	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	10	**13**	0.72	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM				**28**	**20**	**0.56**	
10/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**27**	**20**	**0.56**	
12/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM			**7.9**	**24**	**21**	**0.53**	
13/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**22**	**24**	**0.46**	

Appendix A5: Field Traffic data from 8/11/2021 to 13/11/2021 for the Afternoon peak

DATE				11am - 1pm			
	From	To	distance (km)	Travel Time	Speed (km/hr)	Congestion Index	Congestion Category
8/11/2021	Bohyen	Abrepo	1	3	20	0.60	heavy
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	8	14	0.70	heavy
	Ohwim	Amanfrom	2.1	7	18	0.60	heavy
	Amanfrom	Asuofua	1.7	8	13	0.72	heavy
SUM			**7.8**	**28**	**18**	**0.60**	
10/11/2021	Bohyen	Abrepo	1	3	20	0.56	heavy
	Abrepo	Atafua	1.3	4	20	0.57	heavy
	Atafua	Ohwim	1.8	4	27	0.40	moderate
	Ohwim	Amanfrom	2.1	8	16	0.65	heavy
	Amanfrom	Asuofua	1.7	12	9	0.81	severe
SUM			**7.9**	**31**	**18**	**0.60**	
12/11/2021	Bohyen	Abrepo	1	2	30	0.33	moderate
	Abrepo	Atafua	1.3	4	20	0.57	heavy
	Atafua	Ohwim	1.8	6	18	0.60	heavy
	Ohwim	Amanfrom	2.1	8	16	0.65	heavy
	Amanfrom	Asuofua	1.7	3	34	0.24	free flow
SUM			**7.9**	**23**	**24**	**0.48**	
13/11/2021	Bohyen	Abrepo	1	2	30	0.33	moderate
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	8	14	0.70	heavy
	Ohwim	Amanfrom	2.1	9	14	0.69	heavy
	Amanfrom	Asuofua	1.7	6	17	0.62	heavy
SUM			**7.9**	**28**	**20**	**0.55**	

Appendix A6: Field Traffic data from 8/11/2021 to 13/11/2021 for the Evening peak

DATE				**11am - 1pm**			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
8/11/2021	Bohyen	Abrepo	1	3	**20**	0.60	**heavy**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	8	**13**	0.72	**heavy**
SUM				**28**	**18**	**0.60**	
10/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	12	**9**	0.81	**severe**
SUM			**7.9**	**31**	**18**	**0.60**	
12/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	6	**18**	0.60	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	3	**34**	0.24	**free flow**
SUM			**7.9**	**23**	**24**	**0.48**	
13/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM			**7.9**	**28**	**20**	**0.55**	

Appendix A7: Field Traffic data from 15/11/2021 to 20/11/2021 for the Morning peak

DATE				6am - 9am			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
15/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	6	**13**	0.71	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	10	**13**	0.72	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM				29	**19**	0.58	
17/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**free flow**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM				27	**20**	0.56	
19/11/2021	Bohyen	Abrepo	1	4	**15**	0.67	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	8	**13**	0.72	**heavy**
SUM				28	**17**	0.61	
20/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM				22			

Appendix A8: Field Traffic data from 15/11/2021 to 20/11/2021 for the Afternoon peak

DATE				11am - 1pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
15/11/2021	Bohyen	Abrepo	1	3	**20**	0.60	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**heavy**
	Atafua	Ohwim	1.8	9	**12**	0.73	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	8	**13**	0.72	**heavy**
SUM				30	**18**	0.61	
17/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**free flow**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	12	**9**	0.81	**heavy**
SUM				31	**18**	0.60	
19/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	3	**34**	0.24	**heavy**
SUM				22	**24**	0.46	
20/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**heavy**
	Atafua	Ohwim	1.8	9	**12**	0.73	**free flow**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	7	**15**	0.68	**heavy**
SUM				29			

Appendix A9: Field Traffic data from 15/11/2021 to 20/11/2021 for the Evening peak

DATE				4pm - 6pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Category**
15/11/2021	Bohyen	Abrepo	1	4	**15**	0.70	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	10	**13**	0.72	**heavy**
	Amanfrom	Asuofua	1.7	10	**9**	0.81	**severe**
SUM				35	**14**	0.68	
17/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	10	**7**	0.85	**severe**
SUM				33	**15**	0.66	
19/11/2021	Bohyen	Abrepo	1	4	**15**	0.67	**heavy**
	Abrepo	Atafua	1.3	5	**16**	0.65	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	8	**13**	0.72	**heavy**
SUM				31	**15**	0.66	
20/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	5	**16**	0.65	**heavy**
	Atafua	Ohwim	1.8	6	**18**	0.60	**heavy**
	Ohwim	Amanfrom	2.1	11	**11**	0.75	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM				29			

Appendix A10: Field Traffic data from 22/11/2021 to 27/11/2021 for the Morning peak

DATE				6am - 9am			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
22/11/2021	Bohyen	Abrepo	1	1.5	**40**	0.20	**free flow**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM				19.5	**27**	0.40	
24/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	7	**15**	0.68	**heavy**
				25	**21**	0.54	
26/11/2021	Bohyen	Abrepo	1	4	**15**	0.67	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	8	**13**	0.72	**heavy**
				21	**17**	0.61	
27/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	5	**16**	0.65	**heavy**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**24**			

Appendix A11: Field Traffic data from 22/11/2021 to 27/11/2021 for the Afternoon peak

DATE				11am – 1pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
22/11/2021	Bohyen	Abrepo	1	1.5	**40**	0.20	Free flow
	Abrepo	Atafua	1.3	3	**26**	0.42	moderate
	Atafua	Ohwim	1.8	4	**27**	0.40	moderate
	Ohwim	Amanfrom	2.1	7	**18**	0.60	heavy
	Amanfrom	Asuofua	1.7	7	**15**	0.68	heavy
SUM				**22.5**	**25**	**0.44**	
24/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	moderate
	Abrepo	Atafua	1.3	3	**26**	0.42	moderate
	Atafua	Ohwim	1.8	7	**15**	0.66	heavy
	Ohwim	Amanfrom	2.1	8	**16**	0.65	heavy
	Amanfrom	Asuofua	1.7	6	**17**	0.62	heavy
SUM				26	**21**	0.54	
26/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	moderate
	Abrepo	Atafua	1.3	6	**13**	0.71	heavy
	Atafua	Ohwim	1.8	5	**22**	0.52	heavy
	Ohwim	Amanfrom	2.1	8	**16**	0.65	heavy
	Amanfrom	Asuofua	1.7	4	**26**	0.43	moderate
SUM				25	**21**	0.53	
27/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	moderate
	Abrepo	Atafua	1.3	3	**26**	0.42	moderate
	Atafua	Ohwim	1.8	9	**12**	0.73	heavy
	Ohwim	Amanfrom	2.1	9	**14**	0.69	heavy
	Amanfrom	Asuofua	1.7	7	**15**	0.68	heavy
SUM			**7.9**	**30**			

Appendix A12: Field Traffic data from 22/11/2021 to 27/11/2021 for the Evening peak

DATE				4pm – 6pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
22/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	10	**10**	0.77	**severe**
SUM				**29**	**19**	**0.57**	
24/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	6	**13**	0.71	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM				**25**	**20**	**0.56**	
26/11/2021	Bohyen	Abrepo	1	4	**15**	0.67	**heavy**
	Abrepo	Atafua	1.3	5	**16**	0.65	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	8	**13**	0.72	**moderate**
SUM				**31**	**15**	**0.66**	
27/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	5	**16**	0.65	**heavy**
	Atafua	Ohwim	1.8	6	**18**	0.60	**heavy**
	Ohwim	Amanfrom	2.1	12	**11**	0.77	**severe**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
SUM				**32**		**0.64**	

APPENDIX B

Appendix B1: Google Traffic data from 1/11/2021 to 6/11/2021 for the Morning peak

DATE				**6am - 9am**			
	Origin	Destination	distance (km)	Travel time (mins)	**Speed (km/hr)**	Congestion Index	**Congestion Category**
1/11/2021	Bohyen	Abrepo	1	1.5	**40**	0.20	**free flow**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	6	**18**	0.60	**heavy**
	Ohwim	Amanfrom	2.1	5	**25**	0.44	**moderate**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**21**	**26**	**0.44**	
3/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			7.9	21	24	0.46	
5/11/2021	Bohyen	Abrepo	1	2	30	0.33	moderate
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	3	36	0.20	free flow
	Ohwim	Amanfrom	2.1	6	21	0.53	heavy
	Amanfrom	Asuofua	1.7	5	20	0.55	heavy
SUM			7.9	19	27	0.41	
6/11/2021	Bohyen	Abrepo	1	1.4	43	0.05	free flow
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	4	27	0.40	moderate
	Ohwim	Amanfrom	2.1	5	25	0.44	moderate
	Amanfrom	Asuofua	1.7	4	26	0.43	moderate
SUM			7.9	17	29	0.35	

Appendix B2: Google Traffic data from 1/11/2021 to 6/11/2021 for the Afternoon peak

Date				**11am - 1pm**			
	From	To	distance (km)	Travel time (mins)	**Speed (km/hr)**	Congestion Index	**Congestion Category**
1/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**19**	**27**	**0.41**	
3/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**19**	**27**	**0.41**	
5/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**19**	**27**	**0.41**	
6/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**24**	**22**	**0.51**	

Appendix B3: Google Traffic data from 1/11/2021 to 6/11/2021 for the Evening peak

DATE				4pm - 6pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
1/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	9	**12**	0.73	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	9	**11**	0.75	**heavy**
SUM			**7.9**	**31**	**18**	**0.60**	
3/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	11	**9**	0.79	**severe**
SUM			**7.9**	**30**	**20**	**0.56**	
5/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	10	**10**	0.77	**severe**
SUM			**7.9**	**33**	**16**	**0.65**	
6/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	7	**15**	0.68	**heavy**
SUM			**7.9**	**25**	**22**	**0.50**	

Appendix B4: Google Traffic data from 8/11/2021 to 13/11/2021 for the Morning peak

DATE				6am - 9am			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
8/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**23**	**22**	**0.51**	
10/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**21**	**24**	**0.46**	
12/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	3	**36**	0.20	**free flow**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**20**	**26**	**0.42**	
13/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	6	**18**	0.60	**heavy**
	Ohwim	Amanfrom	2.1	5	**25**	0.44	**moderate**
	Amanfrom	Asuofua	1.7	4	**26**	0.43	**moderate**
SUM			**7.9**	**20**		**0.44**	

Appendix B5: Google Traffic data from 8/11/2021 to 13/11/2021 for the Afternoon peak

DATE				**11am - 1pm**			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
8/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**21**	**24**	**0.46**	
10/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	5	**22**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**21**	**24**	**0.47**	
12/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
SUM			**7.9**	**20**	**25**	**0.45**	
13/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**moderate**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**moderate**
SUM			**7.9**	**23**	**22**	**0.50**	

Appendix B6: Google Traffic data from 8/11/2021 to 13/11/2021 for the Evening peak

DATE				4pm - 6pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
8/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	9	**11**	0.75	**heavy**
SUM			**7.9**	**29**	**19**	**0.59**	
10/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	11	**9**	0.79	**severe**
SUM			**7.9**	**29**	**21**	**0.53**	
12/11/2021	Bohyen	Abrepo	1	3	**20**	0.56	**heavy**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	10	**10**	0.77	**severe**
SUM			**7.9**	**32**	**16**	**0.64**	
13/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**moderate**
	Amanfrom	Asuofua	1.7	7	**15**	0.68	**moderate**
SUM			**7.9**	**25**	**22**	**0.53**	

Appendix B7: Google Traffic data from 15/11/2021 to 20/11/2021 for the Morning peak

DATE				6am - 9am			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
15/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	4	**19.5**	0.57	**heavy**
	Atafua	Ohwim	1.8	5	**21.6**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20.40**	0.55	**heavy**
				23	**21.90**	0.51	
17/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27.00**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	8	**15.75**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	5	**20.40**	0.55	**moderate**
				22	**23.83**	0.47	
19/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27.00**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
				22	**23.60**	0.48	
20/11/2021	Bohyen	Abrepo	1	2	**30.0**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	6	**18.00**	0.60	**heavy**
	Ohwim	Amanfrom	2.1	6	**21.00**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	4	**25.50**	0.43	**moderate**
				21			

Appendix B8: Google Traffic data from 15/11/2021 to 20/11/2021 for the Afternoon peak

DATE				11am - 1pm			
	From	To	distance (km)	Travel Time	Speed (km/hr)	Congestion Index	Category
15/11/2021	Bohyen	Abrepo	1	2	30	0.40	moderate
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	3	36	0.20	free flow
	Ohwim	Amanfrom	2.1	7	18	0.60	heavy
	Amanfrom	Asuofua	1.7	6	17	0.62	heavy
				21	25	0.44	
17/11/2021	Bohyen	Abrepo	1	2	30	0.33	moderate
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	5	22	0.52	heavy
	Ohwim	Amanfrom	2.1	6	21	0.53	heavy
	Amanfrom	Asuofua	1.7	5	20	0.55	heavy
				21	24	0.47	
19/11/2021	Bohyen	Abrepo	1	2	30	0.33	moderate
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	4	27	0.40	moderate
	Ohwim	Amanfrom	2.1	6	21	0.53	heavy
	Amanfrom	Asuofua	1.7	5	20	0.55	heavy
				20	25	0.45	
20/11/2021	Bohyen	Abrepo	1	2	30.0	0.33	moderate
	Abrepo	Atafua	1.3	3	26	0.42	moderate
	Atafua	Ohwim	1.8	7	15	0.66	heavy
	Ohwim	Amanfrom	2.1	6	21	0.53	heavy
	Amanfrom	Asuofua	1.7	5	20	0.55	heavy
SUM				23			

Appendix B9: Google Traffic data from 15/11/2021 to 20/11/2021 for the Evening peak

DATE				4pm - 6pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
15/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	8	**14**	0.70	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	9	**11**	0.75	**heavy**
				31	**18**	0.60	
17/11/2021	Bohyen	Abrepo	1	1.5	**40**	0.11	**free flow**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	9	**14**	0.69	**heavy**
	Amanfrom	Asuofua	1.7	11	**9**	0.79	**severe**
				28.5	**23**	0.48	
19/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	8	**16**	0.65	**heavy**
	Amanfrom	Asuofua	1.7	10	**10**	0.77	**severe**
				31	**18**	0.60	
20/11/2021	Bohyen	Abrepo	1	1.5	**40**	0.11	**free flow**
	Abrepo	Atafua	1.3	4	**20**	0.57	**heavy**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	7	**15**	0.68	**heavy**
				23.5			

Appendix B10: Google Traffic data from 22/11/2021 to 27/11/2021 for the Morning peak

DATE				6am - 9am			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
22/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**severe**
				21	**24**	0.46	
24/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**
				21	**24**	0.46	
26/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	6	**17**	0.62	**heavy**
				22	**24**	0.48	
27/11/2021	Bohyen	Abrepo	1	1.5	**40**	0.11	**free flow**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	7	**15**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20**	0.55	**heavy**

Appendix B11: Google Traffic data from 22/11/2021 to 27/11/2021 for the Afternoon peak

DATE				11am – 1pm			
	From	To	distance (km)	Travel Time	**Speed (km/hr)**	Congestion Index	**Congestion Category**
22/11/2021	Bohyen	Abrepo	1	2	**30**	0.40	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	5	**21.60**	0.52	**heavy**
	Ohwim	Amanfrom	2.1	5	**25.2**	0.44	**moderate**
	Amanfrom	Asuofua	1.7	6	**17.00**	0.62	**heavy**
				21	**23.96**	0.47	
24/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27.00**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	7	**18**	0.60	**heavy**
	Amanfrom	Asuofua	1.7	5	**20.40**	0.55	**heavy**
				21	**24.28**	0.46	
26/11/2021	Bohyen	Abrepo	1	2	**30**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	4	**27.00**	0.40	**moderate**
	Ohwim	Amanfrom	2.1	6	**21**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20.4**	0.55	**heavy**
				20	**24.88**	0.45	
27/11/2021	Bohyen	Abrepo	1	2	**30.0**	0.33	**moderate**
	Abrepo	Atafua	1.3	3	**26**	0.42	**moderate**
	Atafua	Ohwim	1.8	7	**15.43**	0.66	**heavy**
	Ohwim	Amanfrom	2.1	6	**21.00**	0.53	**heavy**
	Amanfrom	Asuofua	1.7	5	**20.40**	0.55	**heavy**
				23			

Table 28 Congestion Analysis of selected road corridor in Kumasi for the Afternoon (off-peak) period

Appendix B12: Google Traffic data from 22/11/2021 to 27/11/2021 for the Evening peak

DATE				4pm – 6pm			
	From	To	distance (km)	Travel Time	**Congestion index**	Congestion category	**Speed (km/hr)**
22/11/2021	Bohyen	Abrepo	1	3	**0.60**	heavy	**20**
	Abrepo	Atafua	1.3	3	**0.42**	moderate	**26**
	Atafua	Ohwim	1.8	4	**0.40**	moderate	**27**
	Ohwim	Amanfrom	2.1	7	**0.60**	heavy	**18**
	Amanfrom	Asuofua	1.7	3	**0.83**	severe	**8**
SUM				**20**	**0.56**		**20**
24/11/2021	Bohyen	Abrepo	1	2	**0.33**	moderate	**30**
	Abrepo	Atafua	1.3	3	**0.42**	moderate	**26**
	Atafua	Ohwim	1.8	5	**0.52**	heavy	**22**
	Ohwim	Amanfrom	2.1	7	**0.60**	heavy	**18**
	Amanfrom	Asuofua	1.7	6	**0.62**	heavy	**17**
SUM				**23**	**0.50**		**23**
26/11/2021	Bohyen	Abrepo	1	2	**0.33**	moderate	**30**
	Abrepo	Atafua	1.3	4	**0.57**	heavy	**20**
	Atafua	Ohwim	1.8	7	**0.66**	heavy	**15**
	Ohwim	Amanfrom	2.1	8	**0.65**	heavy	**16**
	Amanfrom	Asuofua	1.7	10	**0.77**	severe	**10**
SUM				**31**	**0.60**		**18**
27/11/2021	Bohyen	Abrepo	1	1.5	**0.11**	free flow	**40**
	Abrepo	Atafua	1.3	4	**0.57**	heavy	**20**
	Atafua	Ohwim	1.8	4	**0.40**	moderate	**27**
	Ohwim	Amanfrom	2.1	7	**0.60**	heavy	**18**
	Amanfrom	Asuofua	1.7	7	**0.68**	heavy	**15**
SUM				**24**			