A cost-effective Geographic Information Systems for Transportation (GIS-T) application for traffic congestion analyses in the Developing World

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Abstract

In recent times, the Geographic Information Systems for Transportation (GIS-T) has gained prominence in the research and management of real-world transportation problems such as urban traffic congestion, especially in the developed countries. In developing countries, however, constraining factors such as initial prohibitive costs and inadequate expertise have limited the widespread application of GIS-T.

Consequently, a comparatively cost-effective and simple GIS-T method of congestion data generation known as the 'traditional stopwatch and traffic congestion registration technique' is presented in this paper. This technique involves the use of a Global Positioning Systems receiver, a digitally formatted table, among others, to generate travel time data for analytical purposes.

Initial application of the 'traditional stopwatch and traffic congestion registration technique' was done on the very busy 'Kimbu-Adenta' corridor in the Ghanaian capital city of Accra. Results obtained through this new technique does not only confirm the severity and spread of congestion on this corridor but most importantly, makes it possible for scientists, urban policy makers and transportation planners to visualise the trends of congestion at individual segments of the road network on maps. Thus, specific measures could be adopted to ensure free flow of traffic on the corridor.

Keywords: Accra, Traffic congestion, Traditional stopwatch and traffic congestion registration technique, Geographic Information Systems, Global Positioning System

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Introduction

It is now widely recognised that urban transport plays a crucial role for growth and development of societies all over the world. However, recent urbanisation and population growth have posed serious challenges for urban transport. Thus, recent efforts have focused on tools and techniques scientists and practitioners could employ to address these challenges and to aid planning and decision-making. The Geographic Information Systems for Transportation (GIS-T) have evolved over the years as one of the most efficient tools to research, plan and manage transportation. Transportation scientists at the University of Washington and North-western University were among the early pioneers of geographical information systems. However, it was not until the late 1980s that GIS-T entered mainstream literature as one of the most significant GIS application fields (Rodrigue et al., 2009; Fletcher, 2000; Wiggins et al 2000).

GIS-T applications are enormous, including: infrastructure planning and management, transportation safety analysis, travel demand analysis, traffic monitoring and control, public transit planning and operations and environmental impacts assessment. Other applications include intelligent transportation systems (ITS), routing and scheduling, vehicle tracking and dispatching, fleet management, site selection and service area analysis, supply chain management and urban traffic congestion management.

However, it appears that the full potential of GIS-T have been realised primarily in the developed countries (Taylor et al., 2000; Quiroga, 2000; Quiroga & Bullock 1998; Harding et al., 1996; Zito & Taylor 1996; Guo & Poling, 1995; Zito et al., 1995). In developing countries, however, a number of factors have limited the application of GIS-T. First, while GIS-T applications in developed countries have emphasised the use of sophisticated incident detection procedures (Govind et al., 1999), most scientists and practitioners in developing countries find the initial financial cost prohibitive and a barrier to the adoption of the technology. Second, extra technical skills and training are required to operate these devices for which most developing countries lack qualified personnel. Finally, tuition fees in available institutions are very high resulting in a dearth of personnel equipped to work in this area.

In the light of these constraints, this paper contributes to GIS-T applications in developing countries with a comparatively cost-effective method of data generation to aid decision-making and planning purposes. The added advantage is that while GIS-T applications are many and varied; this paper has chosen to focus on urban traffic congestion management. This is due to the following reasons: first, it is generally recognised that urban traffic congestion imposes huge economic costs on developing countries. According to Dulal et al., (2011) and ESCAP (2007), the costs of traffic congestion in Manila, Jakarta, Kuala Lumpur, and Bangkok in 1996 were 0.7 %, 0.9 %, 1.8 %, and 2.1 % of GDP. In South Africa, the SACCI (2010) estimates that traffic congestion costs businesses about 15 million Rand per hour, excluding costs on fuel and vehicle maintenance; late freight deliveries; accidents and collisions. In Ghana, various scientists including Oteng-Ababio and Agyemang (2012), Agyekum (2008) and Danquah (2008) have found that traffic congestion costs an estimated USD 1,095 per annum in major cities, including Accra and Kumasi. Apart from economic costs, traffic congestion imposes other negative social, environmental and atmospheric costs as well. These include road traffic accidents, poor air quality and emissions of greenhouse gases such as carbon monoxide, nitrogen oxide, sulfur dioxide, and ozone that could potentially lead to climate change and climate variability.

Therefore, an effective management of urban traffic to minimise congestion is required to ensure sustainable economic growth and development as well as climate mitigation in developing countries including Ghana.

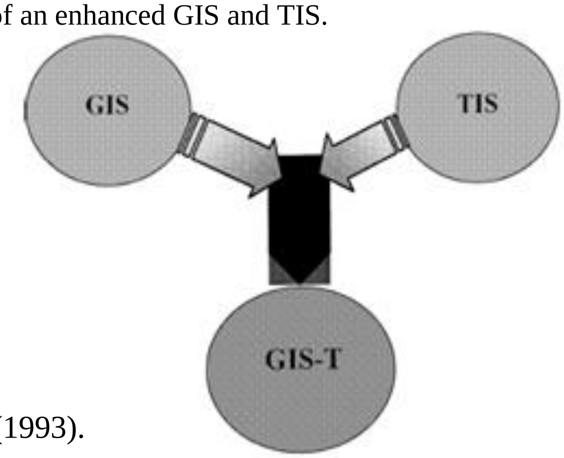
The paper begins with an introduction detailing GIS-T and the plethora of possible applications. A literature review on GIS-T applications in congestion studies and management follows, after which a step-by-step description of the 'traditional stopwatch and traffic congestion registration technique' is presented. Results obtained from a field survey using the new technique are also discussed. The paper concludes with a reflection on the viability of GIS-T in developing countries.

Geographic Information Systems for Transportation: State of the art and Practice

According to Miller and Shaw (2001), Geographic Information Systems for Transportation (GIS-T) are interconnected hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analysing and communicating particular types of information about the earth. The particular types of information are transportation systems and geographic regions that affect or are affected by these systems.

Thus, as illustrated in Figure 1, GIS-T may simply be conceptualised as a cross-fertilization of an enhanced GIS and Transportation Information System (TIS), (Thill, 2000; Vonderohe et al., 1993).

Figure 1: GIS-T, a product of an enhanced GIS and TIS.



Source: Vonderohe et al. (1993).

Rodrigue et al., (2009) further outline four major components of GIS-T as encoding; management; analysis and reporting. *Encoding* means representing real-world transportation system and its spatial components as nodes and links; *management* means generating a GIS database to store encoded transport data; *analysis* refers to the tools and methodologies one could employ, including simple queries and complex models to investigate transportation issues; and finally, in *reporting*, both spatial and non-spatial information on transport are presented in a map format to aid planning and decision-making.

In GIS-T, these four components are very important as they enable the possibility of reducing complex real-world transport features into manageable units that could be manipulated and used for transportation planning and management purposes.

With respect to employing GIS-T in studying urban traffic congestion, a number of performance measures and techniques have evolved (Lomax et al., 1997; Francois &Willis, 1995; Schwartz et al., 1995).

According to a review by Lomax et al. (1997), these measures can be grouped under *highway capacity manual (HCM)*; *queuing-related*; and *travel time-based* respectively.

Quiroga (2000) explains that the first group –HCM – is composed of *volume to capacity* (V/C) *ratio*; *average intersection delay* and *level of service* (LOS). V/C ratios are frequently used because of the relative ease of traffic volume data collection and because surrogate measures such as LOS can be derived from V/C values. Average intersection delays are normally used on arterial streets. LOS measures normally range from "A" - best service to "F" - worst service. While conceptually simple and easy to understand by the professional transportation community, these HCM performance measures tend to be somewhat abstract for the traveling public. Again, they usually require detailed, location-specific input data, which make them more appropriate for localized analyses and design than for area-wide planning.

The second group i.e. queuing-related measures – usually include *queue length* and *lane occupancy*. Quiroga (2000) again explains that queue length and duration can be determined by direct observation and from vehicle detectors that are part of roadway surveillance and control systems. Queuing-related measures are becoming popular due to increasing availability of vehicle detectors and other sensors. Again, they best reflect the public's perception of congestion. However, their main limitations are that they are laborious, site-specific, and time-specific. Therefore, they are inappropriate for planning and policy-related analyses.

The third group i.e. travel time-based measures include *travel time, travel speed*, and *delay* According to Quiroga, (2000), these travel time-based measures are easily understood by both professionals and the travelling public. Also, their flexibility makes it easy to describe traffic conditions at various resolutions in both space and time. Travel time-based measures translate easily into other measures like user costs, and can be used directly to validate planning models such as travel demand forecasting models (Quiroga, 2000; Laird, 1996). Unfortunately, budgetary limitations usually impose severe restrictions on the number and coverage of travel time studies.

Apart from the measures discussed above, the actual processes involved in generating travel time data can be grouped under *'road side'* and '*in-vehicle'* techniques respectively.

Roadside techniques, including license plate matching and automatic vehicle identification (AVI) are based on the use of detecting devices physically located along the study routes at pre-specified intervals. They obtain travel time data from vehicles traversing the route by recording passing times at those predefined checkpoints (Quiroga, 2000).

In-vehicle techniques, including the traditional stopwatch and clipboard technique as well as the automatic vehicle location (AVL) are based on the use of detection devices carried inside the vehicle. In the stopwatch and clipboard technique, travel time and passage of specific landmarks are manually recorded along the route. Two technicians are required in the vehicle: one of them to drive and the other one to manually record items such as the location and time of individual checkpoints and the length and time spent in queues.

Unfortunately, this process tends to be 1abor intensive during the data collection and data reduction phases, and spatial resolution and coverage are often limited. In addition, problems such as missing checkpoints or inaccurately marked checkpoints are common. To avoid some of these problems, many transportation agencies use distance measuring instruments (DMIs) in their probe vehicles. With a DMI, only one technician is needed in the vehicle. In some cases, it is even possible to log route and checkpoint locations. However, DMIs require frequent calibrations to avoid inaccurate speed and distance readings. In addition to this, DMIs are relatively expensive at US $2000 per unit (Quiroga, 2000; Quiroga & Bullock, 1998; Benz and Ogden, 1996).

Apart from DMIs, the global positioning system (GPS) device is an important in-vehicle technique adopted in congestion studies (Jiang et al., 2005). GPS receivers are more versatile than DMIs because they can be used for inventories as well as fleet tracking with little or no modification in hardware. However, similar to DMIs, GPS receivers are equally expensive. A GPS receiver compliant with the 2±3m positional accuracy of requirement could cost no less than US $2000 (Quiroga and Bullock, 1998).

The prohibitive financial costs associated with these sophisticated techniques of travel-time data generation have limited GIS-T applications developing countries compared to the industrialised countries. In the developing countries, research applications that have witnessed a comparatively higher proportion of GIS and GPS usage are found in epidemiological studies such as in malaria research and control in South Africa and other places in sub-Saharan Africa (Martin et al, 2002; Hay et al, 2000) risk models based on climate and satellite-retrieved data on temperature and vegetation coverage to analyze snail-borne diseases caused by *Schistosoma* spp. and *Fasciola* spp. (Kristensen et al, 2001); and analyzing improved access to tuberculosis treatment through a community-based programme in Hlabisa, South Africa (Tanser and Wilkinson, 1999).

Although urban traffic congestion has been identified as a major problem in cities of the developing countries, literature on GIS applications generally, and GIS-T specifically, to address the problem are virtually non-existent except one study (to my knowledge) carried out in Ghana's second largest city, Kumasi by Owusu et al. (2006).

Owusu et al. (2006) adopted the 'floating car' technique which relies on GPS technology to research the second-to-second positional changes in speed and directions of vehicles travelling within the Kumasi metropolis. The novelty in this study lies in the possibility of visualising portions of the road network where travel speeds were unacceptably low on maps. However, their study was limited in universal application because the data generation took just seven days. Again, in the 'floating car' technique, two technicians are required in the car: one to drive the vehicle, and the other one to use a clipboard and a stopwatch to manually record distance driven and the location and time stamp associated with individual checkpoints. Thus, accuracy will vary and depend on the technician. Lastly, data from the floating car technique can be compromised by missing checkpoints or inaccurately marked checkpoints (Quiroga& Bullock, 1998).

While acknowledging the contributions of these earlier studies, this author believes that further cost-effective techniques are needed to make GIS-T applications more widespread and readily accessible to city planners, transportation planners and scientists.

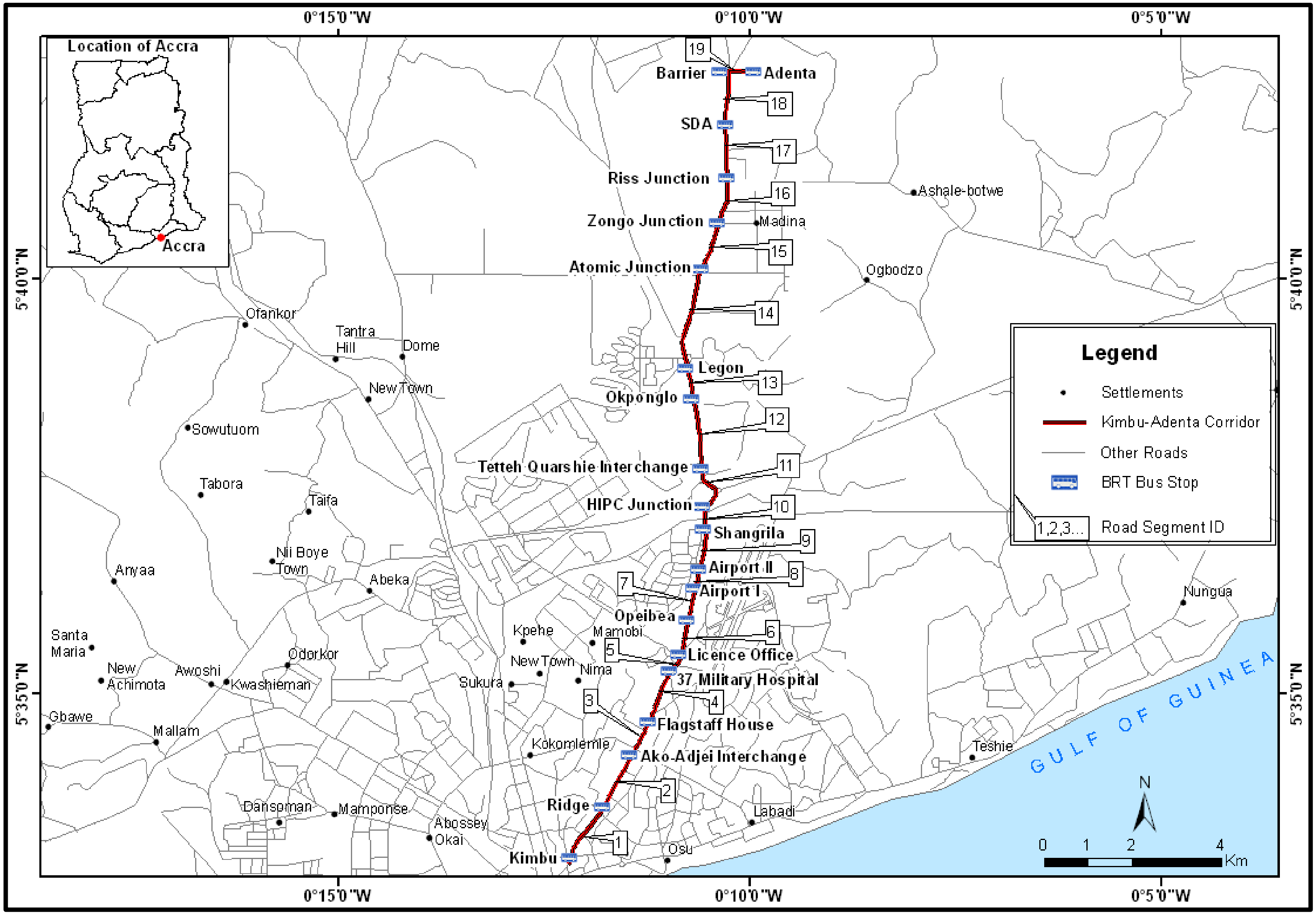
Data and Methods

The Study Area

The travel time data generation occurred in the Ghanaian city of Accra, home to about 4 million inhabitants (Ghana Statistical Service, 2010). The provision of an efficient public transport for this rapidly urbanising city has been constrained by a number of challenges including congested central areas, poor level of service from public operators and high exposure to road accidents (Kwakye and Fouracre, 1998). Previous studies have shown that over 70 % of major roads in Accra are congested with observed travel speeds as low as 20 km/hr. (Oteng-Ababio and Agyemang, 2012; Armah et al., 2010).

However, in this study, the 20-kilometre 'Kimbu-Adenta' corridor in Accra was purposively selected as the study area. The selection of this particular corridor is justified by the fact that it was on this network that Ghana's first-ever bus rapid transit system (BRTS) was introduced by the Metro Mass Transit Limited (MMTL) -a quasi-public transport service provider–in September, 2005. The BRT service was a special high frequency bus service that connected commuters from 'Kimbu' in downtown Accra to the peripheral town of 'Adenta' with 'Tetteh Quarshie' serving as central transport hub and change over point (see Figure 2). This express bus service was well patronised by commuters in Accra with over 20,000 tickets sold daily (MMTL, 2008).

Figure 2: A Map of Accra showing locations of pilot BRTS stops on the Kimbu-Adenta Corridor



However, in less than two years, the pilot project was abandoned and instead replaced with a regular, low frequency bus service. Agyemang (2009) questioned the reasons for the collapse of the pilot BRT and argued that the collapse was primarily due to traffic congestion on the 'Kimbu-Adenta' corridor. Thus, the desire to provide empirical findings to support this view led to the 'traditional stopwatch and traffic congestion registration' technique, which is an adapted version of the traditional stopwatch and clipboard technique widely used in measuring travel time.

The Traditional Stopwatch and Traffic Congestion Registration Technique

The traditional stopwatch and traffic congestion registration technique is a GIS-T based application that uses a GPS receiver; a digitally formatted table (see Table 1); a stopwatch and a pen to generate travel time data for analytical purposes.

Table 1: A digitally formatted table used in generating travel times[a]

SEG	FBS	TBS	Departure	Arrival	Day	Trip
1	1	2	:	:		
2	2	3	:	:		
3	3	4	:	:		
4	4	5	:	:		
5	5	6	:	:		
6	6	7	:	:		
7	7	8	:	:		
8	8	9	:	:		
9	9	10	:	:		
10	10	11	:	:		
11	11	12	:	:		
12	12	13	:	:		
13	13	14	:	:		
14	14	15	:	:		
15	15	16	:	:		
16	16	17	:	:		
17	17	18	:	:		
18	18	19	:	:		
19	19	20	:	:		

As illustrated in Table 1, individual route segments, marked by bus stop locations on the Kimbu-Adenta corridor have been coded with numbers from 1 to 19. The travel time is a measure of when a probe bus connects two nodes or bus stops per segment. For example, when a probe bus departs

[a] Note: 'SEG' denotes 'Route Segment'; 'FBS' denotes 'From Bus Stop'; 'TBS' denotes 'To Bus Stop'

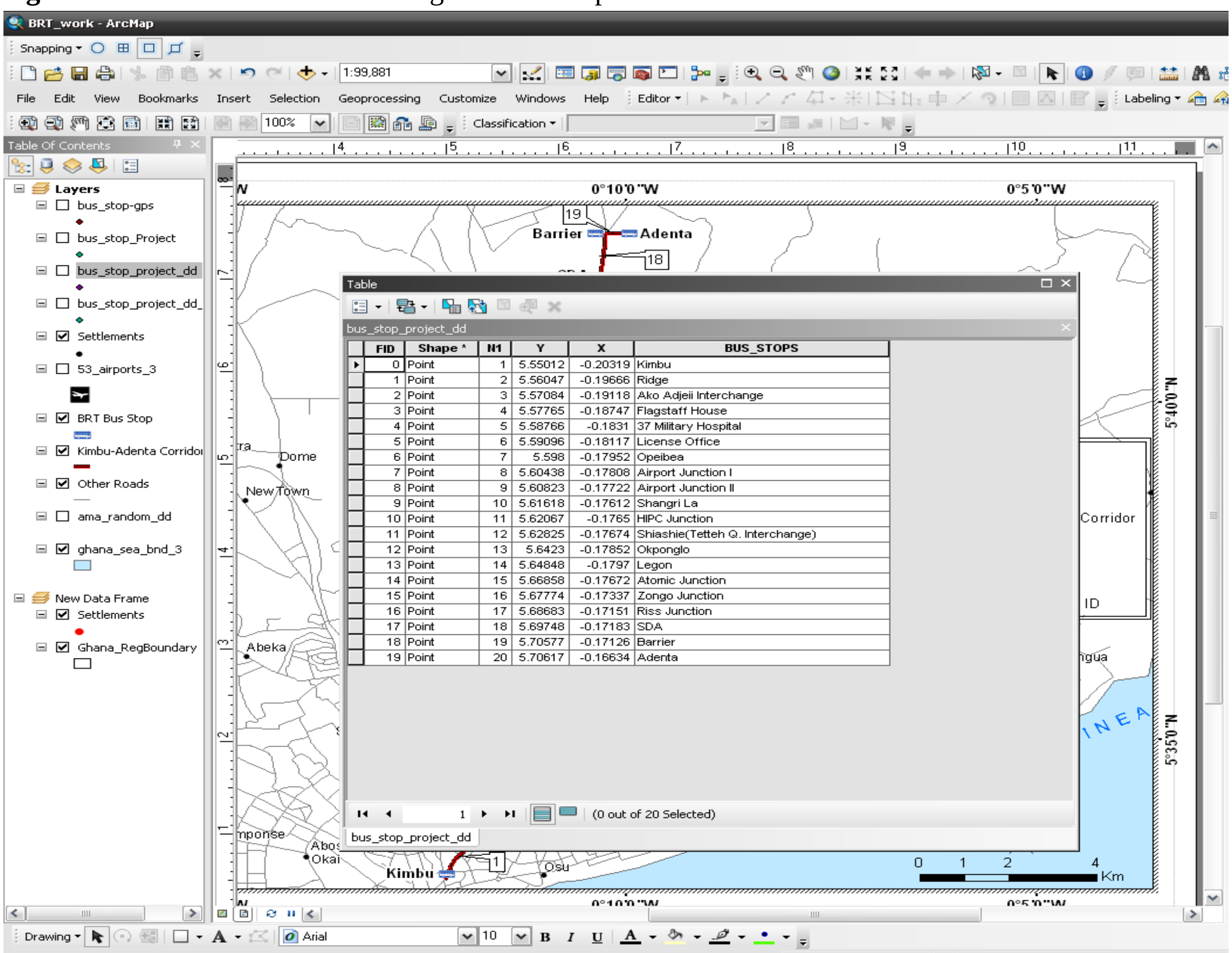
from say Bus Stop 1 to Bus Stop 2, the arrival and departure times are recorded in the appropriate columns in a 24 hour format. The day and trip numbers are also entered.

As mentioned earlier, this technique is an adapted version of the traditional stopwatch and clipboard technique, one of the in-vehicle travel time data collection methods identified in Quiroga (2000). In the original version, two technicians are required in the vehicle: one of them to drive and the other one to manually record items such as the location and time of individual checkpoints and the length and time spent in queues.

In the adapted traditional stopwatch and traffic congestion registration technique, only one technician is required. This is because the researcher relied heavily on randomly selected Metro Mass Transit limited drivers who were originally part of the pilot BRT project and who still drive on the Kimbu-Adenta corridor.

Prior to testing the traditional stopwatch and traffic congestion registration technique on the field, a base map of Accra was composed.

Figure 3: Attribute data of BRT-designated bus stops on the Kimbu-Adenta corridor.



FID	Shape *	N1	Y	X	BUS_STOPS
0	Point	1	5.55012	-0.20319	Kimbu
1	Point	2	5.56047	-0.19666	Ridge
2	Point	3	5.57084	-0.19118	Ako Adjeii Interchange
3	Point	4	5.57765	-0.18747	Flagstaff House
4	Point	5	5.58766	-0.1831	37 Military Hospital
5	Point	6	5.59096	-0.18117	License Office
6	Point	7	5.598	-0.17952	Opeibea
7	Point	8	5.60438	-0.17808	Airport Junction I
8	Point	9	5.60823	-0.17722	Airport Junction II
9	Point	10	5.61618	-0.17612	Shangri La
10	Point	11	5.62067	-0.1765	HIPC Junction
11	Point	12	5.62825	-0.17674	Shiashie(Tetteh Q. Interchange)
12	Point	13	5.6423	-0.17852	Okponglo
13	Point	14	5.64848	-0.1797	Legon
14	Point	15	5.66858	-0.17672	Atomic Junction
15	Point	16	5.67774	-0.17337	Zongo Junction
16	Point	17	5.68683	-0.17151	Riss Junction
17	Point	18	5.69748	-0.17183	SDA
18	Point	19	5.70577	-0.17126	Barrier
19	Point	20	5.70617	-0.16634	Adenta

Base Map Preparation

In consonance with a view that rigorous GIS-T spatial analysis is only possible when the appropriate map databases are available (Taylor et al., 2000), the ArcMap software was used to compose a base vector map. This map had links to the spatial and attributes data of Accra. The existing GIS database, however, was limited in the sense that specific data for the study area, including locations of bus stops used for the pilot BRT service were unavailable. In order to compensate for this, a hand-held GPS receiver was used to record the geographic coordinates of all BRT-designated bus stops on the Kimbu-Adenta corridor, as illustrated in Figure 3.

The GPS receiver used in generating the geographic coordinates of bus stops was configured to the World Grid System of 1984 (WGS84) reference system. The GPS generated points were corrected and saved in a dBase file format. This is a simple data base management system that stores fixed field tables of textual and numeric data.

The dBase file was later incorporated into the existing spatial database of Accra. The shapefile or road line feature representing the *Kimbu-Adenta* corridor was then selected in ArcMap and converted into individual route segments using the GPS generated points as nodes.

Each route segment was assigned a unique identification number. This was done to ensure that the dynamic patterns of congestion could be visualised at the level of individual route segment, as well as on the entire corridor.

Following the base map composition, the actual field work involving the use of the traditional stopwatch and traffic congestion registration technique commenced.

Field Data Generation

Given the dynamic nature of traffic congestion, travel time data was recorded at three different times of the day. These were the ‘am peak’ (06:00-08:30); ‘off-peak’ (12:00-14:30) and ‘pm peak’ (17:00-19:30).

Before commencement of data generation, the research objective was discussed with management of the Metro Mass Transit limited and their permission was sought. However, none of the six randomly selected drivers were informed. The researcher and an assistant took turns to monitor travel times while acting like passengers. This approach was adopted so as not to influence driving patterns of drivers under observation.

The criterion for selection is that a particular driver must have participated in the pilot BRT and must still be operating on the Kimbu-Adenta corridor. The drivers worked on rotational basis so this study considered any driver who drove at the specified time period and met the set criterion as a potential candidate for data generation. This approach was also necessary in order to avoid the danger of the data being unduly influenced by a particular driver's driving style, in line with Taylor et al., (2000).

It should also be noted that all Metro Mass Transit Limited drivers are trained and obliged to drive only on the main corridor, in contrast with commercial or 'trotro' drivers who usually drive on the shoulders of the road to avoid traffic jam. Thus, by simply driving or floating with the general traffic flow, the true traffic conditions could be best captured and analysed.

It is acknowledged that the data may be limited for not considering situations where the probe buses do not stop at particular bus stops simply because no passengers alighted there. There were other instances where the bus drivers stopped to pick up passengers who were not necessarily waiting at the designated bus stops. At certain times too, traffic could either be static or flow freely. In order to address these limitations, a total of 120 runs were made. This is made up of six runs daily (i.e. two runs for each time period) for four continuous weeks. This sample size is considered large enough to compensate for errors in the computation of average speeds per route segment.

Data Processing and Reduction

In order to reduce the data into manageable proportions, aggregated travel times for each segment was computed. This was done by taking the total length of each route segment and the associated travel time into consideration. Thus, mean speed per segment was then calculated, according to Quiroga and Bullock's (1998) formula:

$$\overline{t_i} = \frac{1}{m_i}\sum_{j=1}^{m_i} t_{Lj} = \frac{1}{m_i}\sum_{j=1}^{m_i}\frac{L_i}{u_{ji}} = L_i\,\frac{1}{m_i}\sum_{j=1}^{m_i}\frac{1}{u_{ji}}$$

Where $\overline{t_i}$ is travel time at segment i; L_i is the length of segment i; m_i is the number of runs (or sample size) per segment i, and u_{ij} is the jth speed record associated with segment i.

Calculations based on the above formula could also be termed as arithmetic mean speeds. However, Duncan (1986) and Quiroga & Bullock (1998) have argued that in analysing travel time, it is more preferable to calculate median speed per segment instead of the arithmetic mean speed per segment. This is because a median segment speed is a good measure of central tendency. In view of this, the median speed per segment was also calculated, according to Quiroga's (2000) formula:

$$\bar{u}_L = \frac{L_T}{\sum_{i=1}^{n} t_{mi}} = \frac{1}{\sum_{i=1}^{n}\left[\frac{L_i}{} \frac{1}{u_{mi}}\right]}$$

Where $\bar{u}_L$ is the overall average speed; t_{mi} is the median travel time associated with segment i; u_{mi} is the median speed associated with segment i.

The travel time data was saved in a dBase management format and incorporated into the existing database of the study area in ArcMap. A simple query was built to retrieve and classify route segments according to average speed ranges (e.g. <10 km/hr, 10-20 km/hr etc.). It was also identified that classifying average speeds into ranges and representing them with a homogenous hue may obscure individual congestion characteristics at each route segment.

To address this challenge, buffers were created from the numeric distance field containing individual travel time data for each route segment. The buffers were meant to depict the severity of traffic congestion at each route segment on the corridor. As illustrated in Figure 4, wider buffers represent very severe traffic congestion, and vice versa.

Figure 4: An illustration of congestion severity through buffers.

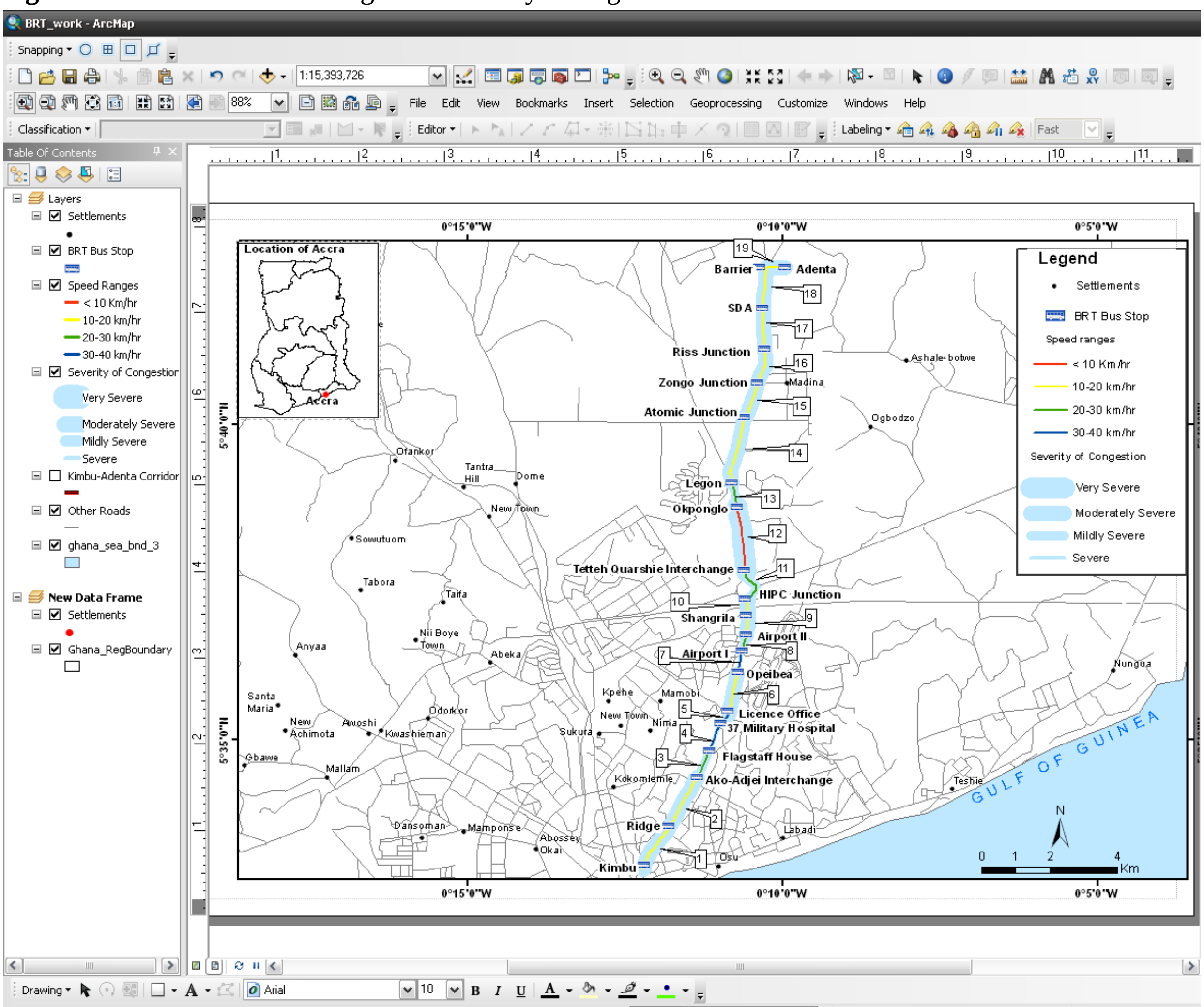


Table 2: Computation of travel time and Segment lengths on the Kimbu-Adenta Highway in Accra, Ghana.

Source: Field survey

Segment ID	1	2	3	4	5	6	7	8	9	10
Segment Length (in Metres)	1786.94	1343.05	853.85	1251.33	391.31	799.3	725.58	434.8	494.93	568.43
AM Peak										
Median Speed (Km/h)	12.66	13.43	25.62	37.54	11.74	15.99	43.53	26.09	14.85	17.05
Off Peak										
Median Speed (Km/h)	21.44	40.29	25.62	37.54	11.74	23.98	21.77	26.09	22.27	34.11
PM Peak										
Median Speed (Km/h)	26.8	18.13	14.94	15.02	11.74	23.98	21.77	26.09	14.85	34.11
Segment ID	11	12	13	14	15	16	17	18	19	
Segment Length (in Metres)	1094.2	1894.75	745.1	2299.2	727.64	1408.87	1137.36	899.21	540.38	
AM Peak										
Median Speed (Km/h)	24.62	9.47	22.35	12.54	14.55	16.91	11.37	13.49	13.51	
Off Peak										
Median Speed (Km/h)	32.83	37.9	22.35	27.59	14.55	14.09	17.06	17.98	16.21	
PM Peak										
Median Speed (Km/h)	12.04	18.95	14.9	27.59	7.28	14.09	11.37	4.15	10.81	

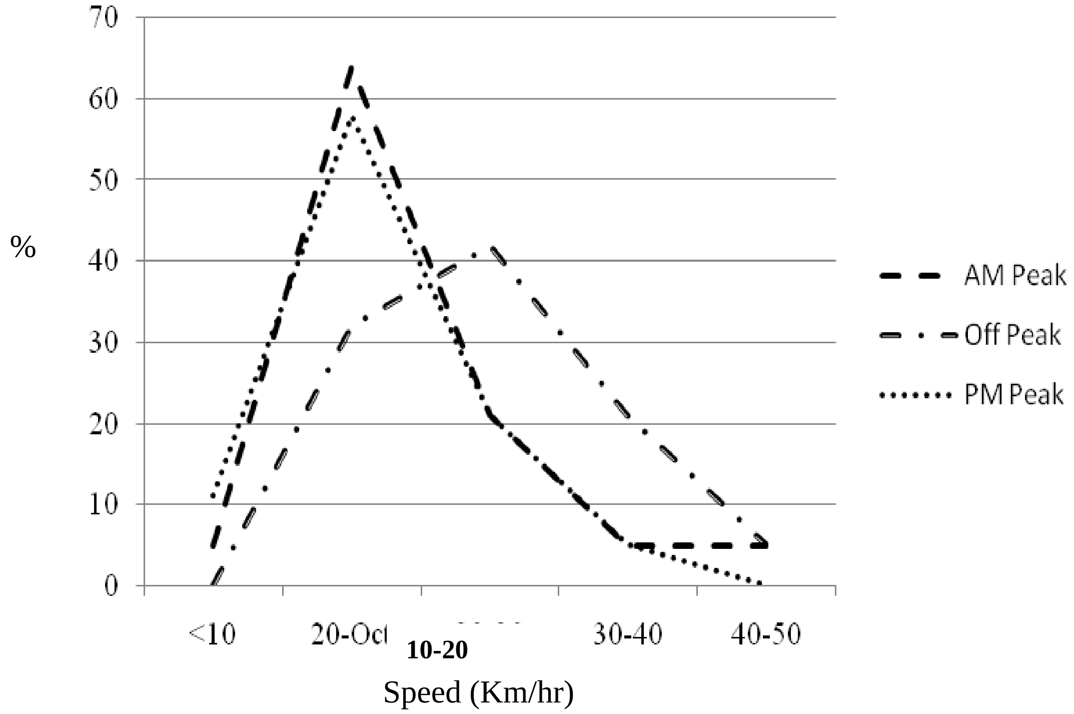
The next section present results of travel-time data obtained from using the traditional stopwatch and traffic congestion registration technique on the Kimbu-Adenta corridor in Accra.

Results and Discussions

The traditional stopwatch and traffic congestion registration technique is presented as a simple and comparatively cost-effective travel time data generation method that could be used to analyse the spatial and temporal patterns in urban traffic congestion. As shown in Table 2 which summarises the attribute data obtained through the traditional stopwatch and traffic congestion registration technique, none of the route segments on the Kimbu-Adenta corridor has average speed values that is equal to or more than the posted speed limit of 50 km/hr. At this posted speed limit, the buses could travel the entire corridor in about 24 minutes, barring traffic congestion. However, the study found that buses spend on the average 87 minutes; 59 minutes and 86 minutes during the morning, afternoon and evening times respectively on this major corridor.

A further analysis was performed on the percentage distribution of congestion on the Kimbu-Adenta corridor. The results are illustrated in Figure 5.

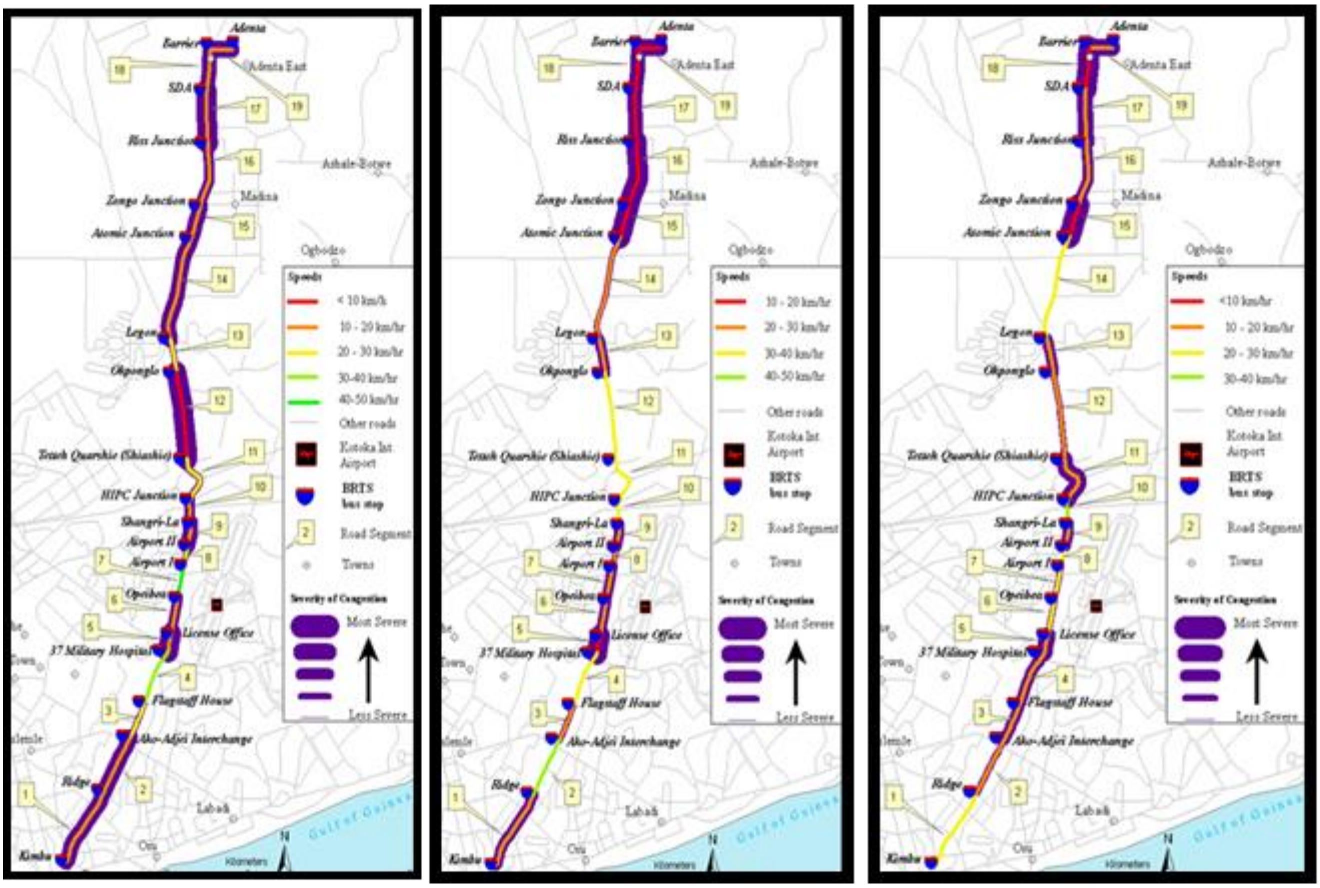
Figure 5: Percentage share of road segments according to speed classification during AM Peak, off-Peak and PM Peak on the Kimbu-Adenta corridor



Source: Field Survey

In percentage terms, over 60 % of road segments fall within 10-20 km/hr speed bracket during the AM peak hours. In the Off-Peak, however, a little above 40 % of segments on the corridor register speeds of between 20-30 km/hr. During the PM peak period, a little close to 60 % rhythmic fashion of the corridor is observed to have reduced speeds in the range of 10-20 km/hr.

The above findings show that congestion on the Kimbu-Adenta corridor occurs in, corresponding to levels and scheduling of socio-economic activities dependent on the road for commuting. In the morning, most vehicles head towards the business district area of Accra, where majority of the high value socio-economic centres and activities are localised.



b. c.

Figure 6: Colour-coded thematic maps of traffic congestion during:

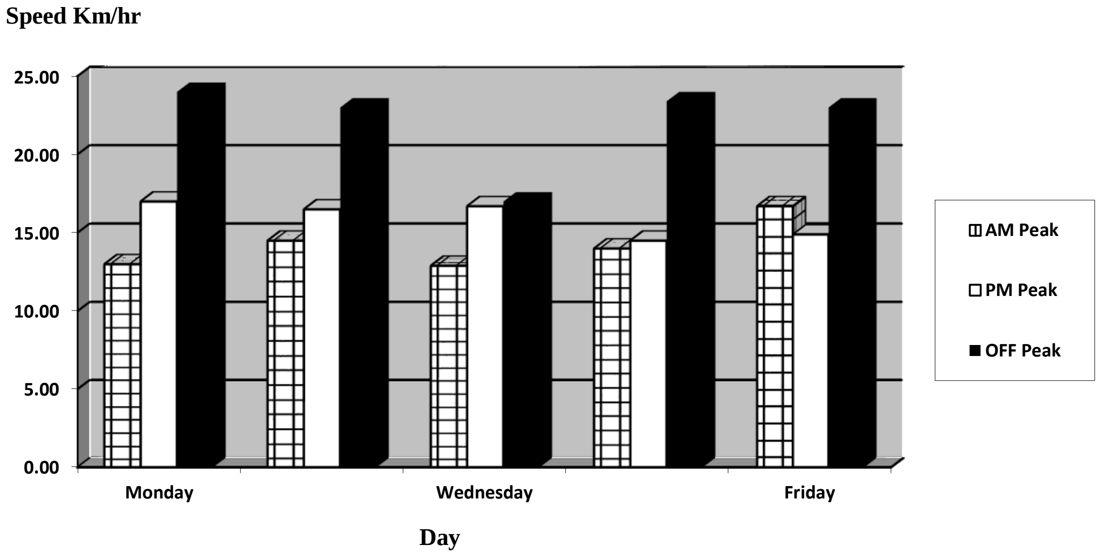
AM Peak hours; b. Off Peak hours and c. PM Peak hours on the Kimbu-Adenta corridor. **Source**: Field Survey

This is the time commuters frequent these areas to shop, work, school or visit public agencies. In the evening, however, many commuters are returning home. Thus, traffic congestion occurs towards the outskirts of the city. These findings corroborate earlier studies in Accra (Addo, 2005; Oppong, 2000) which found that vehicles move slowly during the morning and evening rush hours. The findings also resonate with Owusu et al. (2006) who concluded that travelling within Kumasi's city centre in the morning is more difficult as a result of increased vehicular volume, dense pedestrian interference coupled with a number of hawkers occupying portions of the roadway. Such activities tend to limit the road capacity and also affect vehicle travel speeds.

Using the query and buffer analyses provided in Arc Map, traffic situation on each route segment was conducted. This was to offer the possibility of visualising the trends of congestion at various portions of the road network. The results of the query and buffer analyses are shown in Figure 6 as colour-coded maps. Speed levels are portrayed in colours which depict the severity of congestion per segment. A wider buffer represents a much reduced speeds or severe traffic congestion, and vice versa.

The study also found that the pattern of traffic congestion varies with the days of the week.

Figure 7: Cumulative weekly median travel speeds reflecting traffic congestion



Source: Field Survey

As illustrated in Figure 7, at an average speed of about 14 km/hr, trips made during morning rush hours on Mondays and Wednesdays are the slowest. Comparatively, trips made on Fridays during the same period are marked by slightly improved speeds averaging around 16 km/hr. The speed averages obtained for the morning peak hour trips reflects trips that originated at Adenta and terminated at Kimbu only.

The data shows that for trips made in the evening peak hour period, Thursdays and Fridays were the slowest with an average speed of about 15 km/hr. The evening peak hour averages represent out-bound journeys from Kimbu towards Adenta.

With the exception of Wednesdays which recorded an average speed of about 16 km/hr, trips made during the afternoon off-peak periods were much faster, averaging 24 km/hr.

These trends may also be accounted for by socio-economic considerations similar to those factors which necessitate daily commuting between Adenta and the business district of Accra.

The adverse effects of the observed congestion on the operation of Ghana's first-ever BRT service introduced by the Metro Mass Transit Limited on the Kimbu-Adenta corridor has been the focus of an earlier study by Agyemang, who found that unpredictable traffic conditions on the corridor was primarily responsible for the collapse of the express service.

Nevertheless, this present study focuses on the processes involved in the generation of travel time data, especially with the use of the 'traditional stopwatch and congestion registration' technique. A discussion of possibilities and challenges that emerged in the application of this GIS-T technique ensues.

Concluding Remarks

The application of GIS-T in solving real-world transportation problems have been growing remarkably since the last decades. An overwhelming majority of these GIS-T applications, however, have occurred in the developed countries. This paper posits that existing devices and approaches which are sophisticated and/or expensive have limited the utility of GIS-T in developing countries like Ghana. Thus, the 'traditional stopwatch and traffic congestion registration' technique, as described in this paper is meant to suit local budgetary and expertise constraints of developing countries.

As demonstrated in this paper, the 'traditional stopwatch and traffic congestion registration' technique for generating congestion data, in principle, is akin to the 'floating car' technique which paints an unadulterated picture of congestion scenarios (Owusu et al., 2006; Taylor et al., 2000; Robertson, 1994; Wardrop and Charlesworth, 1954).

The major difference between these data generation techniques is that, compared to the sophisticated 'floating car' technique, the 'traditional stopwatch and traffic congestion registration' technique costs far less and is easy to use with minimal training. This is not to suggest that the existing technique is wrong or deficient but this paper is intended to offer a complementary cost-effective and efficient tool with the ultimate aim of encouraging GIS-T applications generally, and specifically, traffic congestion studies in developing countries.

While previous studies have established that majority of corridors in Accra are congested and that deficiencies in land use and transport infrastructure create and exacerbate the prevalence of congestion (Oteng-Ababio and Agyemang, 2012; Agyemang, 2009; Ghana Institution of Engineers (GhIE), 2008; Addo, 2005; Oppong, 2000), the novelty in this paper lies in the possibility of visualising the patterns of traffic congestion on road networks at a disaggregated scale through maps.

The author believes that what can be seen can be solved. Thus, with respect to the patterns observed on the Kimbu-Adenta highway, it is now easier to identify which road segments are problem areas and what appropriate measures need to be taken to ensure free flow of traffic. Taylor et al., (2000) have argued strongly that the spread, duration and intensity of congestion are of special concern in urban policy making and transport planning. Thus, inspired by these authors, Agyemang (2009) recommended to city authorities the commencement of the Tetteh

Quarshie-Adenta road expansion to consider the construction of flyovers/overpasses at points of major road intersections to ensure free flow of traffic.

Specifically, the author recommended for priority attention road segments 13 and 15 (i.e. Legon and Atomic Junction) among others. These were segments that recorded very low speed levels in the analysis. At the time of writing this paper, there are indications to show that the recommendation seems to have been heeded to as overpasses have been constructed at these points. This scenario is a further demonstration of the practical utility of the 'traditional stopwatch and traffic congestion registration' technique in generating data that could be used to address real world traffic problems.

Notwithstanding its practical utility, this new technique could be seen as leading the efforts to make GIS-T applications widespread in developing countries. Given the variability in patterns of traffic congestion, it is recommended that real-time travel data be generated at regular intervals. To this end, future studies could further modify and apply the technique in several geographical scales and on different thematic research areas as well.

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