

ANALYSIS OF CONGESTION ON SOME ROAD LINK SECTIONS USING ROADSIDE FRICTION IN CONGESTION INDEX IN KUMASI

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Abstract: Road networks are known to be long and intertwining narrow stretches, routes or open ways specially made for vehicles that link places together and are typically made up of link sections and intersections or junctions. Link sections in the Kumasi Metropolis have been characterized by long queues and delays for some time now and the roads approaching the Ahodwo roundabout is no exception. Traffic data was collected on all the approaches linking the Ahodwo roundabout using Google Earth and real time traffic data from the field and analyzed. Data on roadside frictional agents as well as road condition survey were also collected. Road congestion indices were computed for all adjoining roads. A multiple and linear regression of the congestion index on the roadside friction revealed a close fit with the data but no statistical difference uncovered using the road condition index. An equation for estimating road congestion index combining roadside friction is proposed by the authors. For future research, the study recommended an extension on other road segments within and outside the Metropolis to validate the findings in this study.

Keywords: road congestion index, congestion severity index, Kumasi, congestion, traffic.

1. Introduction

Managing the transportation system of any city is a very complex phenomenon and is supposed to be totally complimentary in nature in that the system in itself must function inter-relationally and the case should not be different for the city of Kumasi. Berry *et al.* (1970) even described the transportation system as the veins and arteries of urban areas that link together social and functional zones. Intersections and its related link sections are equally a major component of any transportation system designed mainly for safer route changes be it at-grade or grade separated. Roundabouts, though also intersections

are junctions where traffic moves in one direction round a central island to reach one of the roads converging on it. Because of the basic fact that they are a point of route change, most entrances of roundabouts in developing countries where bus scheduling and mass transportation systems are not very efficient have unapproved bus stops and lay-bys located at very close proximities to the intersection approaches.

The Ahodwo roundabout is located within the centre of the city and has four approaches namely; Southern Bypass, Old Bekwai Road (Melcom Road), Dr. Osei Tuffour Bypass and Harper Road. These roads link major areas in the Kumasi metropolis. Due to the nature

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of the roundabout, indiscriminate stops by drivers and passengers at the roundabout approaches and along the roadside pose a major side frictional challenge at the fringes. These indiscriminate stops by commercial vehicle drivers bring about an increase in side friction which in turn cause a reduction in the link capacity resulting in increased levels of congestion and reduced operating levels of service (LOS) on the links. Stream flow variables that are commonly used to assess the effectiveness and efficiency of the link sections are peak hour flows, capacity, volume to capacity (v/c) ratio, delay, and level of service (HCM, 2010).

The link capacity can be defined as the flow rate (maximum) that the roadway is capable of supporting HCM (2010). Degree of saturation also known as v/c ratios, represent the adequacy of any road (link section or intersection alike) to accommodate vehicular demand. A v/c ratio less than 0.85 generally indicates that adequate capacity is available and vehicles are not expected to experience significant queues and delays. As the v/c ratio approaches 1.0, traffic flow may become unstable, and delay and queuing conditions may occur. Traffic flow is unstable and excessive delay and queuing is expected once demand exceeds capacity at v/c ratios greater than 1.0 (HCM, 2010).

Traffic congestion is increasingly becoming an albatross in transportation operations management especially in developing economies and Ghana and for that matter Kumasi Metropolis is no exception. This has resulted due to the changes in economic activities and the gradual shift to more modernized lifestyles by the general populace. There is an increase in the number of vehicles registered yearly though

the available road space to accommodate the vehicles do not necessarily increase in response to the high vehicle numbers as the national budget usually inadequate. As noted by Okpala (1981) and Adamu and Iyaniwura (1977), most of the working areas are concentrated in the same areas so that traffic is unidirectional and opposite for both the morning and evening peak period thereby causing one directional congestion depending on the time of day.

According to the FHWA (2004), traffic congestion is a condition on road networks that occurs as its use increases, and it is characterized by slower speeds, longer trip times, and increased vehicular queuing. At worst, the congestion can be characterized by stop and go conditions prevalent at Level of Service F at which point the facility is deemed to be operating at or beyond full capacity. Traffic congestion is indeed a daily occurrence in many cities throughout the world especially during the morning and evening peak hours. In the Kumasi metropolis, the peak periods normally occur between 07:00 – 10:00 in the mornings and 16:00 – 19:00 in the evenings, (Tuffour *et al.*, 2014). Road traffic congestion poses a serious threat to the healthy economic and national development of an area or nation. It is also directly related to serious health hazards mainly from pollutants from vehicular exhaust fumes that road users may have to inhale. Traffic congestion may also lead to loss of productive time that affects the economy.

Over the years many researchers have found different methods of assessing congestion on urban roads. For instance, in 1985, the Highway Capacity Manual (HCM, 2015) published six degrees of Levels of Service

from A to F with A denoting free flow conditions and F congested conditions. In 1994, the Texas Transportation Institute adopted the Road Congestion Index (RCI) as reported by Lomax and Shrank (2005) whereas in 2000, the Ministry of Public Security in China evaluated congestion using average travel speed. He et al. (2016) also proposed a methodology for congestion assessment based on speed performance index. Patel and Mukherjee (2015) also proposed a Traffic Congestability Value (TCV) to quantify traffic congestion of study zones.

In this paper, some of the methodologies for computing and quantifying congestion on urban road link sections are evaluated for local congestions using side friction, lane indiscipline and indiscriminate stops at approaches as parameters. The case study selected are the four roads approaching

the Ahodwo roundabout in Kumasi. The paper further proposes some transportation systems management measures that will offer quicker, better and more economical ways of improving the congestion situation on the road links.

2. Description of Study Area

The Ahodwo roundabout is a four-leg roundabout leading to four suburbs in the Kumasi metropolis. The suburbs are Adum which is also the Central Business District (CBD), Santasi, Ahodwo and Asokwa. The four roads adjoining the Ahodwo roundabout will for this study be referred to as Dr. Osei Tuffour Bypass (Santasi road), Old Bekwai Road (Melcom Road), Southern Bypass (Asokwa road) and Harper Road (Adum road.) A google screenshot of the Ahodwo roundabout with its adjoining roads is shown in Fig. 1 below.

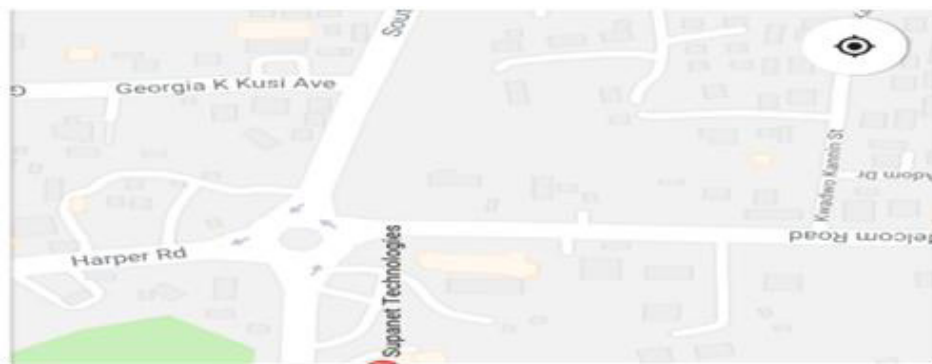


Fig. 1.
A Google Map Picture of the Ahodwo Roundabout Showing all Four Adjoining Roads
Source: Google Map

The Ahodwo roundabout is by no means a very active intersection situated in the center of town that links many other suburbs and sub

suburbs within the Kumasi Metropolis. Table 1 gives a summary of the link lengths (obtained from Google Earth) for the adjoining roads.

Table 1*Summary of Selected Roads*

Road Name	Road Length (km)
Dr. Osei Tuffour Bypass	1.315
Old Bekwai Road (Melcom Road)	1.350
Southern Bypass to Lake Road Int	0.750
Harper Road	2.082

Source: Google Earth

The entire road lengths as the names depict were not considered as whole but were truncated at the major intersections on the roads. This was done because the nature of the traffic operations changes as the major intersections approach. On the Dr. Osei Tuffour Bypass, the road segment ends at the Adiebeba intersection, that of the Old Bekwai Road also ends at Atinga junction whereas the Southern Bypass ends at the beginning of the interchange. The Harper road was truncated at the Edwenase road intersection (Police Depot).

3. Methodology

Real time traffic data such as average speeds, side frictional conditions, land use patterns and functional classification were collected along all four adjoining roads. Average travel speeds for a number of vehicles moving along each of the selected road sections were recorded by measuring the lengths and times that it takes the vehicle to traverse an already marked out section. The travel speed was taken from direct field measurements and it is the result of the distance divided by the time taken. Side frictional conditions were taken through visual observation by doing a reconnaissance survey or a walk over the entire road sections to record the actual side friction issues at the lanes. Land use pattern and functional classification were

obtained from the Department of Urban Roads (DUR), Kumasi.

Lane and shoulder widths and distances of road segments considered were also estimated using the Google Earth application with the ruler icon on the toolbar. The distances of each lane were measured using the path option in the ruler toolbox whilst the width was measured with the line option. The path option was used because the lanes are not straight routes and using the line option could give wrong distance estimations.

4. Results and Discussion

Results of average travel speeds recorded along the road corridors are shown in Table 2 below. Also included in the table are the functional classification, land use type and the geometric parameters of the subject roads. It can be seen from the Table that the average travel speeds are much lower than the posted speed limit of 50km/hr for urban areas as stipulated by the local road agency. Average travel speeds are only about 56% of the posted speed limit. The shortage of the 44% could be attributed to the land use type and the side frictional agents listed in Table 3. It is worthy to note that the roads with a commercial land-use type has a shortage of about 70% in terms of the travel speed (GHA, 1997).

Table 2*Traffic Parameters for the Selected Roads*

Road Name	Avg Speed (km/hr)	Land-use Type	Functional Class	Lane Width	Shoulder Width
Dr. Osei Tuffour Bypass	37.5	Semi-Residential and Commercial	Major Arterial	3.24m	1.25m
Old Bekwai Road (Melcom Road)	15.0	Highly Commercial	Minor Arterial	3.00m	1.69m
Southern Bypass	15.0	Commercial	Major Arterial	3.03m	1.37m
Harper Road	31.5	Semi-Residential	Minor Arterial	3.65m	N/A

Source: Project Survey Data, Google Earth, DUR

The evening peak traffic was ignored due to the unidirectional nature of the flow and adequate queue lengths acquired for the traffic flow analysis from the morning peak data.

4.1. Functional Classification

The functional classification of roads gives information on the class and use that a particular road is put. The classification is usually based on a certain hierarchy. In Ghana, the urban road network has been classified into major arterials, minor arterials, collectors, local accesses and of course bicycle and footpaths. According to Malenkovska Todorova *et al.* (2009), arterial roads have higher mobility as against accessibility, collectors have equal mobility and accessibility needs and local roads have lower mobility needs as against

accessibility. The four adjoining roads all fall in the major and minor arterial road classes. High traffic volumes and appreciable delays are thus expected on these roads and are indeed prevalent on the roads.

4.2. Side Friction and Road Surface Conditions

Weightings were attributed to each roadside friction agent identified on the road corridors based on its assumed and perceived impact and contribution to the levels of congestion experienced by motorists (see Table 3). The assumed weighting scale is 0.0 – 2.0 with 0.0 contributing nothing and 2.0 having the most contribution. The assumption is based on visual observations made on the road corridor over a long period.

Table 3*Roadside Friction Weightings*

SRNO	Roadside Friction Agent	Weight
1	Vegetable market	0.3
2	Lay-bye	0.9
3	Mechanic shop	1.3
4	Crossing pedestrians	0.5
5	Vulcanizing activities	0.9
6	Fruit and animal market	0.3
7	Street-side hawking	0.5
8	Food vendors	0.9
9	Washing Bay	0.3
10	Fuel Station	0.9
11	Walking Pedestrians	0.1
12	Calling card vendors	0.1
13	Mini marts	1.5
14	Barbering Studios	0.3
15	Vehicle Sellers	0.2

Source: Project Study

It is believed that both side friction and road surface conditions have an impact on delays experienced by motorists on the road segments. Data on the surface condition was obtained through direct field road condition survey observation along the

project corridors. Hypothetical values of the road surface condition were given as an index on a scale of 0.0 – 1.0 scale where 0.0 is very poor and 1.0 is very good. The indices for the study roads are given in Table 4 below.

Table 4
Side Friction and Surface Conditions

Road Name	Side Friction Present	Side Friction Condition (SFC)	Road Surface Condition (RSC)	RSC Index
Dr. Osei Tuffour Bypass	Vegetable market Lay-bye Mechanic shop Vulcanizing activities Crossing Pedestrian Walking pedestrians Vehicle Sellers Food vendors Mini Mart	High	Rutting Shoving Potholes Alligator Cracks	0.65
Old Bekwai Road (Melcom Road)	Lay-bye Fruit and animal market Crossing Pedestrians Walking pedestrians Street-side hawking Food vendors Vulcanizing Activities Fuel station Mini mart	High	Severe potholes Cracking	0.6
Southern Bypass	Street-side hawking Crossing Pedestrians Walking pedestrians Food vendors Mechanic shop Calling card vendors	Medium	Potholes Cracking	0.55
Harper Road	Street-side hawking Crossing Pedestrians Walking pedestrians Food vendors	Medium	Good	0.8

Source: Project Study

4.3. Land Use Patterns

The land use pattern of the study area is a mixture of residential, business and commercial activities. The southern bypass is characterized by roadside activities such as a car garage, restaurants and retail shops. The Melcom road equally has retail shops and

business centers as well as some residential facilities. Notable among the commercial centers are the Melcom Supermarket and the Royal Park Hotel. The Harper road can boast of hotels (Golden Bean Hotel), restaurants and other business centers. All these facilities usually and sometimes occasionally attract a lot of motorized and

non-motorized traffic. The Dr. Osei Tuffour Bypass is also characterized by car garages and retail shops. The details of the land use characteristics have been given in Table 3 above.

5. Assessment of Congestion

Congestion is a relative phenomenon that links the demand and supply of availability of road space. Chakrabartty and Gupta (2015) defined it as the impedance of vehicles imposed on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches capacity. Congestion increases with increased traffic flow when there is an obvious lack of overtaking opportunity. The result is high journey times and vehicle operating costs, often accompanied by more accidents as frustrated drivers tend to take uncalculated risks. More often than not these accidents

are fatal or near fatal. Congestion also results in environmental pollution and destroys bituminous surfaces of pavements as well as reducing the economic activity of the nation. Congestion also creates a negative impact on people’s psychological state which in turn can lead to unproductivity at the workplace.

Congestion is usually as a result of unplanned urban economic development, employment, housing and lack of policy measures in regulating traffic and land-use. In the transportation sector, congestion can be measured by a number of ways such as average travel speed, roadway Level of Service (LOS) and average vehicular delay. These can be measured manually or by the use of models. He et al. (2016) after a series of speed data analysis proposed an equation to estimate speed performance index (SPI) with an index value ranging from 0-100. The evaluation criteria is as shown in Table 5 below.

Table 5
Congestion Index Evaluation Criteria

Speed Performance Index	Traffic State Level	Description of Traffic State
0-25	Heavy Congestion	The average speed is lower, road traffic state poor
25-50	Mild Congestion	The average speed is low, road traffic state bit weak
50-75	Smooth	The average speed is high, road traffic state better
75-100	Very Smooth	The average speed is higher, road traffic state good

Source: (He et al.,2016)

The speed performance index was computed from Eq. (1):

$$R_v = \frac{v}{v_{max}} \cdot 100 \tag{1}$$

Where: R_v -speed performance index; v -average travel speed in km/h; v_{max} - maximum permissible roads speed in km/h.

He et al. (2016) further described road segment congestion index as expressed in Eq. (2):

$$R_i = \frac{R_v}{100} \cdot R_{NC}; \quad R_{NC} = \frac{t_{NC}}{T_t} \tag{2}$$

Where: R_i -road segment congestion index; R_{NC} -proportion of non-congestion state; t_{NC} - duration of non-congestion state, minutes; T_t -length of observation period, minutes.

Tuffour et al. (2014) developed a criterion for the classification of the severity of roadside friction agents into low/none, medium and high for the signalized intersection

approaches in Kumasi. In the criteria, prevalence of one or more combinations of the presence of taxi ranks, lay-by/bus bay, fuel station and trotro station were attributed to low/none, medium or high roadside friction areas. This paper adopted a similar criterion in this congestion analysis to incorporate side friction effects

in congestion analysis. The paper further investigated the effect of the road surface condition on the congestion by multiple regression analysis. Using Microsoft Excel and the roadside friction weights in Table 3, the roadside frictional agent weighting factor for the road segments were computed and tabulated as in Table 6 below.

Table 6
Computed Roadside Friction Weighting Factors for the Road Segments

Road Name	Total Roadside Friction Weight (R_{fw})	Roadside friction Factor (f_{RSA})
Dr. Osei Tuffour Bypass	6.6	1.2
Old Bekwai Road (Melcom Road)	6.5	1.3
Southern Bypass	3.4	0.7
Harper Road	2.0	0.1

The total roadside friction weight (R_{fw}) in Table 6 above was obtained from an aggregate sum of all the roadside friction agent weights for each road segment under study. The roadside friction factor was then obtained from Eq. (3):

$$f_{RSA} = \frac{0.1}{[0.5 \times \ln(R_{fw} + \sqrt{R_{fw}}) - \ln(R_{fw} - \sqrt{R_{fw}})]^2} \quad (3)$$

Where: R_{fw} -total roadside friction weight.

Eq. (3) is a modification of the expression

by Curell (2015) for assigning weightings to variables using a scientific data analysis model. The weighting was necessary to adjust for discrepancies that may have occurred in the assumptions made earlier based on perceptions and visual inspection of the roadside friction agents and their impacts on congestion.

The road segment congestion indices were then computed using Eq. (2) and the results shown in Table 7 below. The length of observation period was 120 minutes.

Table 7
Road Segment Congestion Indices

Road Name	Average Speed	Speed Performance Index (R_v)	Duration of Non-Congestion State (t_{nc})	Proportion of Non-Congestion State (R_{nc})	Road Segment Congestion Index (R_i)
Dr. Osei Tuffour Bypass	37.5	75	35	0.29	0.22
Old Bekwai Road (Melcom Road)	15.0	30	45	0.38	0.11
Southern Bypass	15.0	30	55	0.46	0.14
Harper Road	31.5	63	30	0.25	0.16

Using the equation developed by incorporating the roadside frictional agents,

the modified road congestion index (R_{im}) is given in Table 8.

Table 8*Parameters to Modify Road Congestion Index*

Road Name	R_1	f_{RSA}	Road condition index (R_{im})
Dr. Osei Tuffour Bypass	0.22	1.2	0.65
Old Bekwai Road (Melcom Road)	0.11	1.3	0.6
Southern Bypass	0.14	0.7	0.55
Harper Road	0.16	0.1	0.8

Source: Project Study

The parameters in Table 8 were then subjected to a multiple regression. Though the null hypothesis assumed that roadside friction and road condition index have a significant impact on the congestion experienced on the roads, the results of the multiple regression showed otherwise. Therefore, it is not statistically significant that there is any correlation between the three variables thus; road congestion index, roadside friction factor and road condition index. A further linear regression using the two parameters showed an 84% goodness of fit for the roadside friction as against the 23% for the road surface condition.

The resultant equation for the modification of the road segment congestion index incorporating roadside friction is thus given as in Eq. (4) below. This is not applicable to this research alone but may also be workable in other areas where roadside friction is prevalent.

$$RCI_{RSA} = 1.8 - 0.39 \cdot f_{RSA} \quad (4)$$

Where: RCI_{RSA} -Road congestion index with roadside friction agent; f_{RSA} -roadside frictional agent factor.

It can therefore be concluded that roadside friction affects roadside congestion but not road surface condition. The paper therefore proposes for streamlining in the roadside friction agents littered along the

roads studies and other roads within the Metropolis. The authors propose additional lanes on the roads studied if an improvement in the congestion situation is anticipated.

6. Conclusions and Recommendations

The paper has looked at the four roads approaching the Ahodwo roundabout in the Kumasi metropolis by computing the road congestion indices. The road congestion index was regressed against roadside frictional weights developed and the road surface conditions. A linear regression was also performed using the two parameters of roadside friction and road surface condition. It can be concluded from the results that there is no statistically significant contribution from either the road condition or the side friction on the congestion of the roads when put in combination. However, there is a good correlation from the roadside friction when linearly regressed. The paper concludes therefore that roadside friction is an agent for roadside congestion index. An equation for estimating road congestion index combining roadside friction is also postulated. The authors recommend an extension of study to other road segments to validate the findings.

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