ASSESSMENT OF TRAFFIC CONGESTION IN THE CENTRAL AREAS (CBD) OF SOUTH AFRICAN CITIES- A CASE STUDY OF KIMBERLEY CITY

D Das* and M Keetse**

*Department of Civil Engineering,
Central University of Technology, Free State, Bloemfontein, South Africa
Email: ddas@cut.ac.za, Cell: 0848529260
**Principal Engineering Assistant
Sol Plaatje Municipality, Kimberley, South Africa
mkeetse@solplaatje.org.za; mmusho84@gmail.com

ABSTRACT

Traffic congestion is a challenge leading to undesirable consequences in most of the cities of the world. Many large and medium cities of South Africa, specifically the central business districts (CBD) are facing this challenge and are severely affected by this mobility problem. One such city, Kimberley, because of its unique physical, spatial, road network, economic characteristics and requirement of the mobility of heavy vehicles in addition to the normal city traffic faces typical traffic congestion challenges in its CBD area, particularly during the peak hours, which warranted this investigation. So, the objective of this paper is two-fold. First, it examines the various relevant empirical models available and their implication on the assessment of traffic congestion in CBDs under different scenarios. Second, it evaluates the degree of traffic congestion (Level of Service (LOS)) in the roads of CBD area and explores a possible mechanism to ease the problem. The study was conducted based on the critical review of relevant literature to understand the control variables influencing traffic congestion, and examination of the applicability of relevant empirical models for assessing traffic congestion. Followed by the most relevant empirical models were employed to assess the level of traffic congestion and observe possible solutions to ease the traffic congestion in the roads of the CBD area of the Kimberley City. The study revealed that there is appreciable level of traffic congestion in some of the roads of the CBD area of the Kimberley City, specifically during the peak hours, which needs strategic intervention. A reengineering solution, such as, traffic diversion from the congested roads to the underutilised or least congested roads could assist in easing the traffic congestion, increase in speed and reduction in travel time resulting into optimal utilisation of all the roads in the CBD area of the city.

Keywords: Traffic congestion; Level of Service; Central Business District; Peak hours; Diversion of Traffic

1. INTRODUCTION

Traffic congestion has become a disturbing problem in many cities all over the world. It results a range of undesirable consequences, which include negative economic impacts and environmental pollution (Rao and Rao, 2012; Sorensen et al, 2008; Wang, Gao, Xu, Sun, 2014). Many of the South African cities are not away from this challenge. Specifically, the central business districts (CBD) of many large and medium cities of the country are severely affected by this mobility problem. For, instance the Kimberley City in the Northern Cape Province, because of its unique physical, spatial, road network, economic characteristics and requirement of mobility of heavy vehicles in addition to the normal city traffic faces typical traffic congestion challenges in its CBD area, particularly during the peak hours. So, it is essential to assess the level of traffic congestion and the influence of the imperative solutions, which could assist in evolving strategies to meet the challenges. The objective of this paper is therefore two-fold. First, it examines the various relevant empirical models available and their implication on the assessment of traffic congestion in CBDs under different scenarios. Second, it evaluates the degree of traffic congestion in terms of (LOS) and proffers a possible mechanism to ease the problem in the roads of CBD area. The study was conducted based on the critical review of relevant literature to examine the applicable empirical models for assessing traffic congestion. Followed by, the relevant empirical models were employed to assess the LOS and derive a mechanism to ease the traffic congestion challenges. Statistical traffic data were used for this purpose and the Kimberley City was considered as the case study. It was found that Traffic Transmission index (Q index), Level of Service (LOS), Travel Time index (TTI), Segment Delay (Ds), Lane Mile Duration index (LMDIF), and Percent Traffic Diversion (P) are the major empirical models, which are relevant for assessing traffic congestion in the CBDs of the cities. The study also revealed that there is appreciable level of traffic congestion in three important roads (particularly roads, which are carrying heavy vehicles) in the CBD area of the Kimberley City, specifically during the peak hours. It is also seen that LOS in a number of roads are within the permissible limits, and can carry additional traffic without creating much congestion. So, diversion of about 21% – 27% of the total traffic from the heavily congested roads to the underutilised or lesser congested roads will result into higher LOS (lower congestion), increase in speed by 7km/h to 10km/h from the current speed levels, and decrease in travel time by 15% to 20% and vice versa.

2. LITERATURE REVIEW

There is no single definition of traffic congestion and the problem can be interpreted in different ways, although in general it is a situation in which demand for road space exceeds the supply (ECMT, 2007; Lascano Kezic, Durango-Cohen, 2012; Talukdar, 2013). Traffic congestion occur when traffic is delayed due to the presence of excess number of vehicles on the same portion of the road way at a particular time resulting into slower than the normal or "free flow" speeds (Department of transportation U.S., 2005, p. 1; Link et al. 1999, p. 9). There shall be long queues of vehicles, which move in constant start and stop basis because the number vehicles trying to use the road exceeds the design capacity of the road. Consequently, it results into delay in traffic movement and the traveller cannot move in a desirable manner (ECMT, 1999; Goodwin 2004; Levinson et al., 1997; Lomax, 1990; Lomax, Turner and Schunk, 1997; Taylor, 2003; Thomson, 1998, p. 94; Weisbrod, Vary, et al. 2003, p. 1). Thus, traffic congestion can be described in two ways; (1) the high vehicle concentration moving at low flow speed, and (2) the number of vehicles on the road is close to or exceeds the maximum capacity of the road causing an imbalance between travel demand and transport system supply (Hon, 2005, p. 24; Talukdar, 2013). Congestion is generally categorised into recurrent, non-recurrent congestion and pre-congestion state (Brownfield et al, 2003). Recurrent congestion occurs mainly when there are too many vehicles at the same time, consequently reducing traffic speed and increasing commuting time, which may relate to rapid growth in population, urbanization and growth in car ownership and use. It occurs typically during peak hours but can also occur off peak hours. However, non-recurrent congestion is associated with random conditions or special and unique conditions, including traffic incidents (ranging from disabled vehicles to major crashes), work zones which slow traffic down, weather and special events. Pre congestion state occurs where free-flow conditions breakdown but full congestion has not yet occurred (Banjo, 1984; Brownfield et al, 2003; Chakwizira, 2007; HCM, 2000).

According to the Department of transportation, United States (2005, pp.1-2), there are generally seven reasons of traffic congestion. These seven reasons are generally grouped into three broad categories, such as, traffic influencing events, traffic demand and physical road features. Traffic incidents, work zones and weather are the traffic influencing events. Traffic incidents include vehicular crashes, breakdowns, debris in travel lanes, events that occur on the shoulder or roadside, etc. A construction activity on the roadway is the example of a work zone. Reduced visibility, bright sunlight on the horizon, presence of fog or smoke, wet, snowy or icy road way are the examples of poor weather. Traffic demand includes fluctuations in normal traffic, such as day to day variability in demand and special events. Physical highway features include road way physical and geometrical characteristics, poor traffic control devices and physical bottlenecks (capacity) of the road (Talukdar, 2013).

A wide number of indicators have been developed to measure traffic congestion (Dijker, Piet, Bovy, and Vermijs, 1998; Grant-Muller, 2005). However, literature suggests that only a small number form the basis for regular monitoring of the road network and more concrete indicators are needed to measure congestion at a practical level (Grant-Muller & Laird, 2006). One of the major indicators, which mostly favoured is the total amount of delay encountered calculated across all traffic from the difference between the actual speed encountered and free flow speed (Dft, 2000, 2000b; Dodgson, Young, and van der Veer, 2002). This leads to the measurement of average delay by a vehicle travelling per kilometre. It was believed to be advantageous in providing a better picture of how changing traffic levels and different policy packages can affect time lost to congestion, although delays are measured purely in terms of vehicle journey time and no allowances are made for differences in occupancy rates, values of time, or for additional factors, such as additional operating or environmental impacts that congestion can generate. Similarly, simple measures relating to speed are also used to indicate congestion, particularly for a motorway environment (Grant-Muller, 2005). These indicators include mean journey times, variability of journey times, throughput (total number of vehicles per time interval that pass a point on the carriageway), queue lengths, speed differential between lanes and delay per hour/day (Graham and Glaister, 2004; Grant-Muller, 2005; Grant-Muller & Laird 2006; Noland and Polak, 2002). Besides, the congestion reference flow (a quantified measure of congestion for a link -junction must be considered separately) and the level of service (LOS) are other basic congestion measures applied widely in some countries like USA and Scotland, (Highways Agency, 1997; State-wide Planning Scenario Synthesis, 2005).

The concentration of trip destinations in a small area – particularly central area of the cities poses the challenge of providing large transportation capacity in limited physical space, while preserving the historical, political, cultural, economic and environmental heritage/values of the areas. It has been observed that there are larger share of trips to the city centres (with a defined and preeminent central area) in cities. As such, the total number of trips grows exponentially with the city size. Simultaneously, city centres are characteristically areas of high concentration of activities, and space is scarce. Therefore, there exists a dichotomy of high demand for transportation capacity in a geographic environment where space is limited (Lascano Kezic, Durango-Cohen, 2012).

The various approaches to address the problems of congestion in urban areas particularly in the city centers fall in three broad categories: supply management, land use management and transportation demand management**.** Supply management includes all measures taken to increase the number of people and trips served by the transportation system in order to accommodate as much demand as possible. This includes added capacity for vehicles as well as transit, bicycles, pedestrians, and multi-mode facilities (Gao and Song, 2000; Yang and Bell, 1998; Zanjirani Farahani et al., 2013; Meyer, 2003) and traffic signal timing optimization (Ceylan and Bell, 2004; Stevanovic et al., 2013). However, according to critics of this method, majority of the traffic jams are caused by accidents and events – not because of lack of capacity (STPP, 2001), so adding capacity to alleviate the problems becomes controversial on account of induced demand argument and the environmental and health effects of additional travel and land consumption (Gifford, 2005). Besides, supply management methods do little to mitigate congestion caused by non-recurring incidents. Land-use management describes the use of growth management, planning, and zoning to promote local density to encourage transit. Transit oriented development and high-density land use are both examples of this type of management. Critics of the land use management measures cite two major challenges that increased congestion is created by high-density development, and it takes long time to change land-use patterns and behaviors; they also doubt regarding the connection and causality between the two (Taylor, 2002). Transportation demand management (TDM) is a strategy of instituting largely financial incentives and disincentives to encourage motorists to use alternate routes, times and modes, or to defer trips entirely in order to reduce the demand for traffic facilities. TDM arises out of a desire to consider alternatives to "supply-side" measures because of the negative community effects of induced demand. The measures include: congestion pricing, park-and-ride lots, high-occupancy-vehicle lanes, high-occupancy-toll lanes, employer commute option programs, telecommuting, alternative work schedules, and traffic calming measures. Of all the measures, congestion pricing tends to be both most effective and politically legitimate as a funding source (Gifford, 2005); however, due to the cost it places on drivers, it is one of the hardest methods to implement (Bass, 2008).

Besides, meticulous traffic design, use of technology – use of intelligent traffic system, Global Positioning System (GPS), inter vehicle communication and vehicle simulator, and variable message signs approaches are the other ways, which are used to reduce traffic congestion (Alterkawi, 2006; Chen, Yu, Zhang, Guo, 2009;Furth, Muller, 2009; Hardjono, 2011; Salicru, Fleurent, Armengol, 2011; Santos, Coutinho-Rodrigues, Current, 2008; Yin, Lam, Miller, 2004). Efficient vehicle routing, punctuality of routes and diversion of vehicles are also considered as other options to alleviate traffic congestion particularly in the congested urban areas. However, the problem of vehicle routing lies at the heart of the distribution management and the conditions vary from one setting to other; and the objectives and constraints encountered in practice are highly variable. Although, some research has been done in this area, the focus is limited to a number of prototype problems, and the literature on vehicle routing – segregation of vehicular traffic (modal split), optimal traffic assignment on different alternative roads and reengineering of the traffic system at the local level, and their impact on the road network – congestion and travel time under the effect of combination of the parameters is scarce (Cordeau, Laporte, Savelsbergh, Vigo, 2007).

Overall, the studies and practices, which deal with the traffic congestion mitigation, include increasing of road infrastructure supply or decreasing of travel demand, or both. Current studies have however demonstrated that increasing the size of infrastructure could be only part of the answer (OECD, 2013), as many measures are intrinsically interactive, which may need to be addressed jointly. With increased growth of traffic flow, it is crucial to develop cost-efficient policies, which would alleviate traffic congestion and address negative externalities in terms of environmental impact and cost to the economy (Watling, Milne, Clark, 2012).

3. THE STUDY AREA

Kimberley City of South Africa was considered as the study area for this study. It is the capital city of the Northern Cape Province of the country and is situated on the latitude 28.7419°S and longitude 24.7719° E. It is primarily known for its diamond mining activities. However, in recent years the economic functions of the city are changing because of the reduced mining activities. The city has a combined urban population of more than 225000 (Census, 2011). It has a total of 48 suburbs, which includes districts and townships and has a designated CBD. The city is connected to various major cities of the country, such as, Johannesburg, Pretoria, Cape Town, and Bloemfontein by national roads. It is also found that the city is about on an average of 800 km from some of the major cities in South Africa, i.e. Cape Town, Polokwane, Nelspruit and the town of Springbok. Apparently the city is the central point of the country from the road network point of view.

The CBD performs important urban functions of the city. It provides facilities for both commercial and administrative activities. Spatially, it is bounded by Quinn Street in the East, Cecil Sussman/Quinn Street in the North, Cecil Sussman/Bultfontein road in the west, and Lennox Street in the South, and is considered as the primary focused study area of the investigation. The arterial roads, which generally influence the traffic movement in the CBD area, are Long, Barkly, Bishop, Carter, Schnidtsdrif, Memorial and Transvaal Streets. As mentioned above these roads in an around the CBD area are under heavy pressure because of the combined movement of heavy vehicles in and out of the city and normal inter and intra city traffic resulting to inefficient traffic movement. Thus, it was felt pertinent to choose the CBD area of the city as the study area for this investigation.

4. METHODLOGY

The study was conducted based on the critical review of relevant literature to examine the various variables influencing traffic congestion and applicable empirical models for assessing traffic congestion. Followed by, the level of services (LOS) or degrees of traffic congestion were measured by using the most relevant empirical models. LOS for different roads was measured by using volume capacity ratio (V/C) ratio in terms of Passenger Car Units (PCU) both for normal hours and peak hour of day. The reason for which LOS for normal hours and peak hours in different roads are measured are to observe the traffic congestions scenarios separately during normal hours and peak hours of the day and to find the possibility and the quantum of the traffic, which can be diverted or rerouted from the heavily congested roads to the less congested roads at different periods of the day. While calculating the LOS the following models (equations (Eq.)) were employed. They are:

LOS (normal hours) = V/C………………… Eq. (1)
Where, V=Average hourly volume of traffic =Annual Average Daily traffic / Total number of hours in the day experiencing traffic flow.

LOS (peak hours) = V_p/C………………… Eq. (2)
Where, V_p= Average peak hourly volume of traffic = Total peak hour traffic / Total number of peak hours in the day.

C= Capacity of the roads the capacity, estimated to be 1,100 vehicles per hour per lane for arterial roads (Type II and III equivalent to U3-minor arterial roads and U4 roads in South African cities) (TRB, 1994, Appendix B-Traffic Level of Service Calculation Methods, B 6-7; TRH26, COTO, 2012:22). *The capacity was estimated based on a saturation flow rate of 1,900 vehicles per lane per hour (*TRB, 1994, Appendix B-Traffic Level of Service Calculation Methods, B 6-7) *and on the assumption that major roads would receive 60% of the green time and roads perpendicular to the major roads would receive 40% of the green time. Since the vehicle on the roads constitute 80% cars (with PCU 1) and 20% heavy vehicles (with average equivalent PCU of 2.5), the capacity of the roads/lane is estimated to be 1430 PCU/ hour rounded to 1400 PCU/hour (the capacity of the roads/lane = 1100*0.8*1.0+1100*0.2*2.5= 1430 PCU/ hour ≈1400 PCU/hour), and as the roads* *considered in the CBD area are of one way and two lanes system, the total capacity of the roads are estimated to be 2800 (2*1400=2800)PCU/hour.*

Besides, Percent Traffic Diversion model was employed along with LOS in order to examine the traffic congestion scenario, percentage of traffic that can be rerouted or diverted, consequent increase in speed and reduction in travel time.

Percent Traffic Diversion (P) is calculated by using the model given as below.

$P = 100/(1+t_R^6)$ ………………… Eq. (3)
t_R = Travel time ratio = Time on new system/ Time on old system
Statistical traffic (volume and speed) data for different roads in and around the CBD area of the city from secondary sources, such as, Sol Plaatje Municipality were used for this purpose.

5. RESULTS AND DISCUSSION

5.1 Empirical models for analysing traffic congestions and their implications

The various relevant empirical models available and generally used to analyse the traffic congestion are presented in the Table 1. The implications and relevancy of these models with respect to the analysis of traffic scenario in the CBD area of Kimberley city are discussed as below:

5.1.1 Traffic transmission index (Q index)
Traffic transmission index (Q index) is a measure of congestion based on speed. As a result, congestion is considered as a function of the reduction in speeds, which is the direct cause of loss of time that essentially leads to increased vehicle operating costs, fuel consumption, and emissions of air pollutants and Green House Gases (GHGs). Also, setting of a threshold that is directly related to travel speeds is most appropriate. This is in contrast to the conventional planning by use of LOS, which compares volumes with capacity and does not explicitly account for speed. So, a speed based threshold accounts for more of the impacts of congestion than would a threshold based on capacity. However, the use of a range of speed and number and absolute quantum of change of speed in the study area may be difficult to comprehend, thereby its applicability (Levinson and Lomax, 1996; Rao and Rao, 2012).

5.1.2 *Travel Time Index (TTI)*
According to Rao and Rao, (2012) and Schrank and Lomax, (2005), a time-based congestion measure, such as, TTI provides a different view on congestion. It offers guidance on identifying major issues, and enables policy makers to better address the problems and evolve solutions that are more likely to have the greater impact. TTI has the advantage of expressing traffic congestion in terms of both space and time. Therefore, it is easy to understand the main concept of this index. However, it requires separation of recurring and incident delay, and measurement of non-recurring data can be difficult particularly in CBD area of a city. In spite of this limitation TTI offers a stronger basis for more generalized conclusions.

5.1.3 *Segment delay time (Ds)*
Delay is considered as the additional time taken by a road user in comparison to the free flow travel or the acceptable travel time. As delay rate can also be used to estimate the difference between system performance and the expectations for those system elements

(Lomax et al., 1997), relative delay rate reflects the condition of flow that travelers' can relate to their travel experience (Hamad and Kikuchi, 2002). Similarly, total delay offers the possibility to estimate how any improvements within a transportation system could affect a particular corridor or the entire system. Although, total delay shows the effect of congestion in terms of the amount of lost travel time, relative delay is very difficult to comprehend as congested travel or congested roadway length does not represent the different magnitude of congestion.

5.1.4 *Level of Service (LOS)*

One of the measure advantages of LOS to measure congestion is that sophisticated technical knowledge is not essential to understood it and can be comprehended by most non-technical people. Besides, since it is very easy to collect the data required for the computation, it is widely used. However, critics argue that it cannot provide a continuous range of values of congestion and does not offer any distinction between different levels of congestion once congested conditions are reached, although Highway Capacity Manual, USA (HCM, 1985, 2000) provides fairly detailed norms for such measurements. Also, it could only be applicable to location-specific congestion phenomenon and does not reflect overall or regional congestion condition (Mulhall, 1995), and the use of a stepwise LOS measure can be sometimes misleading, especially when the condition is near a threshold (Hamad and Kikuchi, 2002). However, in a CBD area, as the traffic flow is almost similar, it can be more useful to measure congestion.

5.1.5 *Lane-mile duration index*

The lane-mile duration index (LMDI) is a measure of the extent and duration of freeway congestion. It is considered to be more relevant than LOS measures particularly in free way conditions. However, the limitation of this model is that it cannot reflect the effect of having different highway functions on traffic congestion. Besides, it can provide poor results as traffic data is not collected in all freeway segments in an area. Its application in CBD area is limited unless the road segments and the traffic have similar characteristics as of the Freeways (Cottrell, 199; Rao and Rao, 2012).

5.1.6 *Percent of traffic diversion*

Percent traffic diversion is directly not a measure of congestion but one of the frequently used assignment techniques to divert traffic through bypasses or diversion curves. The empirically derived relationships show the proportion of traffic that is likely to be diverted on a new facility (bypass, new expressway, new arterial street etc.), once such a facility is constructed or up to the extent the old facility would remain serviceable when new facilities are created or even when traffic management measures are considered without creation of additional facilities. Such empirical relations can be developed using a variety of variables, such as, travel time saved, distance saved, travel time ratio, distance ratio, travel time and distance saved, distance and speed ratio, and travel cost ratio. Thus, this has more relevance in cases when solutions, such as traffic diversion or rerouting measures are considered to ease the traffic congestion in CBD areas (Kadialli, 2008).

Table 1 Relevant empirical models used for assessing traffic congestion in CBD area of a city

Parameter	**Model**	**Nomenclature**	**References**
Traffic transmission index (Q index)	Q = KS/(ÂsÃf)	Q - quality of traffic transmission index, K = 1000 - constant, S = average speed (mph), Âs- absolute of speed changes per mile, and f = Number of speed changes per mile.	Levinson and Lomax, (1996); Rao and Rao, (2012).
Travel Time Index (TTI)	TTI= (Peak period travel time/ Free flow travel time) = (Free flow travel; speed/ Peak period travel speed)		Rao and Rao, (2012); Schrank and Lomax, (2005)
Segment delay time	Ds = (TTac – TTap)*V_p	TT_{ac} = Actual travel time (minutes) TT_{ap} = Acceptable travel time (minutes) V_p = Vehicle volume in the peak-period (vehicles)	Lomax, Turner, Shunk, Levinson, Pratt, Bay. and Douglas, (1997); Rao and Rao, (2012).
Level of Service (LOS)	LOS= V/C	V= Total volume of vehicles per hour calculated based on Average Annual Daily Traffic (AADT) C=Hourly capacity of roads	HCM (1985)
Lane-Mile Duration Index	LMDIF = _ $\sum^{m}{}_{1}$[Congested Lane − Miles* Congestion Duration (hours)]	Where i equal to an individual freeway segments and m equals the total number of freeway Segments in an urban area.	Cottrell, (1991); Rao and Rao, (2012).
Percent of Traffic diversion	P =100/ $(1+t_R{}^6)$ t_R =Time on new system/ Time on old system	t_R = Travel time ratio	Kadialli, (2008)

5.2 Assessments of traffic congestion scenario and mechanism to ease the congestion problem

5.2.1 *Traffic congestion scenario in terms of Level of Service (LOS) in different roads of the CBD area of the city*

The LOS in the different roads of the CBD area of the Kimberley City is presented in Table 2 (a) and Table 2 (b). It is evaluated for the traffic movement both to the city and from the city. From Table 2 (a), it is revealed that at the current scenario during normal hours, for the traffic moving towards the city, Transvaal road (influenced by Pniel road) has a LOS F (V/C= 1.04) and is highly congested, whereas another road– the Long Street is almost running to its capacity (V/C = 0.93 LOS E) and is a cause of concern. All other roads, such as, Barkly (V/C= 0.16), Bishop (V/C= 0.55), Carter (V/C= 0.37), Schnidtsdrift (V/C= 0.35), Barkly section 2 (impacting Transvaal) (V/C= 0.41), and Memorial Streets (V/C= 0.22) have LOS levels A (V/C = between 0 and 0.5), and as a result experience no congestion problems. Bishop Street, which carries a significant quantum of heavy vehicles is observed to be on the threshold (currently LOS A) although does not experience much congestion now, has the possibility to move to the higher level of congestion (LOS B) in future. Similarly, during peak hours two of the roads – Long Street (Vp/C =1.24) and Transvaal road (Vp/C =1.39) have LOS F (Vp/C > 1.0) and are highly congested. Bishop Street is experiencing LOS C (Vp/C =0.73). All other roads have LOS A and are observed to be not experiencing much congestion even during peak hours. However, the higher values of V_p/C ratio show that there is a possibility of these roads to move to the next level of congestion in future. Similar trend is observed in all the roads for the traffic moving away from the city (Table 2 (b)). Therefore, traffic congestion alleviation interventions are necessary in at least two roads, such as Long Street, Transvaal road, although Bishop Street also needs careful attention.

Table 2 (a) LOS in different roads of CBD area (to City), Kimberley

Roads	No of lanes	Average hourly Volume (in PCU V)	Peak Hourly Volume (in PCU Vp)	Capacity (C) of two lane arterial roads	V/C	LOS (Normal hours)	V_p/C	LOS (Peak hours)
Long	2	2611.9	3482.5	2800	0.93	E	1.24	F
Barkly	2	449.3	599.0	2800	0.16	A	0.21	A
Bishop	2	1531.5	2042	2800	0.55	A	0.73	C
Carter	2	1028.1	1370.8	2800	0.37	A	0.49	A
Schnidtsdrift	2	977.5	1303.4	2800	0.35	A	0.47	A
Barkly section 2 (impacting Transvaal)	2	1134.7	1512.9	2800	0.41	A	0.54	A
Memorial	2	607.6	810.1	2800	0.22	A	0.29	A
Transvaal (influenced by Pniel)	2	2926.8	3902.3	2800	1.04	F	1.39	F

Table 2(b) LOS in different roads of CBD area (from City), Kimberley

Roads	No of lanes	Average hourly Volume (in PCU V)	Peak Hourly Volume (in PCU Vp)	Capacity of two lane arterial roads	V/C	LOS (Normal hours)	V_p/C	LOS (Peak hours)
Long	2	2542.9	3390.6	2800	0.91	E	1.2	F
Barkly	2	415.9	554.9	2800	0.15	A	0.20	A
Bishop	2	1503.4	2004.59	2800	0.54	A	0.72	C
Carter	2	1025.5	1367.3	2800	0.37	A	0.49	A
Schnidtsdrift	2	967.6	1290.1	2800	0.35	A	0.46	A
Barkly section 2 impacting Transvaal	2	1132.8	1510.3	2800	0.40	A	0.54	A
Memorial	2	586.78	782.3	2800	0.21	A	0.28	A
Transvaal influenced by Pniel	2	2924.8	3899.7	2800	1.04	F	1.39	F

5.2.2 *Percent of traffic diversion and future scenarios of LOS, change in travel time and speed*

Table 3 (a) and Table 3 (b) present the future scenario of LOS and associated variables like change in travel time, improvement in speed and requirement of terrific diversion. The traffic scenarios for both to the city and from the city show similar trends. However, the results revealed that if a minimum of 21% of traffic from Long Street and 27% of traffic from Transvaal road are diverted to other roads, the LOS level of these two roads will change to level E from level F during peak hours, and to level C (from level E for Long Street and F for Transvaal road) during normal hours, thereby easing the severe traffic congestion level. Consequently, increase in travel speed of 7 Km/h in Transvaal road and 10 Km/h in Long Street can be experienced. Also, reduction in the travel time can range from 15% to 20% in Transvaal road and Long Street respectively. On the other hand, although, the current LOS levels do not warrant diversion of traffic from all other roads, any such intervention will create LOS levels of A in these roads. However, as these roads have very lower level of congestion (higher level of service (LOS) ranging between A and C); they are seemed to be underutilised both during normal and peak hour. This scenario would allow diversion of traffic from severely congested roads to the roads that are underutilized resulting into optimal level of service in most of the roads in the CBD area of Kimberley city.

Table 3 (a) Travel time reduction, percent traffic diversion and consequent LOS in different roads of CBD area (to City), Kimberley

Roads	Average Speed increase from current actual speed in Km/ h	Travel time ratio = Time in New system / Time in old system	Minimum % vehicle needs diversion 100-100/ (1+ t_R^6)	Average hourly Volume (in PCU V)	Peak Hourly Volume (in PCU V_p)	Capacity (C) of two lane arterial roads in PCU	V/C	LOS Normal hour	Vp/C	LOS Peak hour
Long	10 (40)	0.8	21	2063.4	2751.2	2800	0.74	C	0.98	E
Barkly	10 (50)	0.83	25	336.9	449.3	2800	0.12	A	0.16	A
Bishop	10 (40)	0.8	21	1209.9	1613.2	2800	0.43	A	0.57	A
Carter	10 (50)	0.83	25	771.1	1028.1	2800	0.27	A	0.36	A
Schnidtsdrift	10 (50)	0.83	25	733.2	977.5	2800	0.26	A	0.34	A
Barkly section 2 impacting Transvaal	10 (50)	0.83	25	851.0	1134.7	2800	0.30	A	0.40	A
Memorial	10 (50)	0.83	25	455.7	607.6	2800	0.16	A	0.21	A
Transvaal influenced by Pniel	7 (43)	0.85	27	2107.2	2809.7	2800	0.75	C	1.00	E

Note: The numbers in parenthesis in column 2 represent the current average speed of the roads

Table 3 (b) Travel time reduction, percent traffic diversion and consequent LOS in different roads of CBD area (from City), Kimberley

Roads	Average Speed increase from current actual speed (Km/ h)	Travel time ratio = Time in New system / Time in old system	Minimum % vehicle needs diversion	Average hourly Volume in PCU (V)	Peak Hourly Volume (in PCU Vp)	Capacity (C) of two lane arterial roads	V/C	LOS Normal hour	V_p/C	LOS Peak hour
Long	10 (40)	0.8	21	2008.9	2678.6	2800	0.72	C	0.96	E
Barkly	10 (50)	0.83	25	311.9	415.9	2800	0.11	A	0.15	A
Bishop	10 (40)	0.8	21	1187.7	1583.5	2800	0.42	A	0.57	A
Carter	10 (50)	0.83	25	769.1	1025.5	2800	0.27	A	0.37	A
Schnidtsdrift	10 (50)	0.83	25	725.7	967.6	2800	0.26	A	0.35	A
Barkly section 2 impacting Transvaal	10 (50)	0.83	25	849.6	1132.8	2800	0.30	A	0.40	A
Memorial	10 (50)	0.83	25	440.1	586.6	2800	0.16	A	0.21	A
Transvaal influenced by Pniel	7 (43)	0.85	27	2105.9	2807.8	2800	0.75	D	1.00	E

Note: The numbers in parenthesis in column 2 represent the current average speed of the roads

6. CONCLUSION

Traffic congestion is observed to be a challenge in the Kimberley City particularly in some of the roads in the CBD area, which warranted this investigation. The study was conducted in two parts. First, critical literature review was conducted to understand the various parameters influencing traffic congestion, and to comprehend relevant empirical models useful for assessment of traffic congestion levels, and development of possible solutions to improve the scenarios. Second, empirical analyses were conducted to assess the LOS (congestion scenarios) and to observe scenarios of improvement in travel time, improvement in speed and improvement in LOS in different roads in the CBD areas of the Kimberley city under a traffic congestion reduction intervention like traffic diversion or rerouting.

It is found that Q index, TTI, LOS, Segment delay, Lane-Mile Duration Index are the empirical models which are relevant for assessing congestion and Percent of Traffic Diversion model is useful for finding mechanisms for easing the traffic congestion in the CBD areas. The investigation also revealed that two of the roads (Transvaal road and Long Street) in the CBD area of the Kimberley City are severely congested during both normal and peak hours, while one road (Bishop) can become a cause of concern during peak hours. However, Percent Traffic Diversion based on travel time ratio and change in speed, shows that with a reasonable level of diversion of traffic from congested roads to the roads with lesser congestion can improve LOS, increase speed and reduce travel time in the roads of the CBD area of the city and vice versa, allowing roads to be optimally utilised.

The investigation has a few limitations. The analyses were carried out based on available secondary data alone in a few roads and application of two empirical models, such as, LOS and Percent Traffic Diversion. However, further, analyses, such as, Segment delay, Travel time index, Traffic transmission index, and Lane mile duration index as relevant with the use of a larger data set could provide further insight to the traffic congestion problem in the CBD area, which is the further scope of this investigation.

Despite the limitations, this study revealed that some of the roads in the CBD area of the Kimberley City are severely congested both during normal and peak hours. However, reengineering policy interventions like traffic diversion from highly congested roads to lesser congested/ underutilized roads will ease the traffic congestion problem as well as will improve on travel time and speed, which could result optimal utilisation of all the roads in the CBD area of the city.

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