Framework for Evaluating Traffic Impact of a New Large Commercial Land use—A Case Study from Bengaluru, India

Harihara Subramanian Gayathri, Ashish Verma, G. S. Vishwas, and Raksha Krishnamurthy

Abstract Indian cities are witnessing rampant growth in terms of population and economic growth. The urban population percentage increased from 28.6% in 2001 to 37.7% in 2011. Being a leading IT exporter, Bengaluru sees an increasing number of commercial buildings burdening the existing road infrastructure, leading to heavy congestion in particular areas of Bengaluru. This calls for an understanding of any upcoming commercial development before it is thoroughly established to take adequate measures to reduce the negative impacts. However, the Traffic Impact Assessment (TIA) using the traditional four-stage modeling cannot be used in the current context due to the impact of COVID-19 on the existing traffic. This paper adopts an improved methodological framework that can be used to evaluate the impact of traffic in any situation. An average of 6.6% percentage increase (maximum 25% on some roads) in V/Cs is observed before and after the new development on the adjoining roads. To improve the level of service, several scenarios are considered and analyzed to provide the best mitigation strategies. This improved methodological framework can help to evaluate a new development's impact for any given situation, and what mitigation strategies and types of transportation improvements may be essential to maintain a smooth moving traffic with a satisfactory level of service.

Keywords Traffic Impact Analysis (TIA) · Traffic forecast · Commercial land use · Travel demand model · Scenario analysis

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1   Introduction

Indian cities are witnessing rampant growth in terms of population and economic growth. The urban population percentage increased from 28.6% in 2001 to 37.7% in 2011. There is a substantial increase in India's GDP for most of the last two decades, leading to rising per capita incomes and a reduction in absolute poverty. This growth is physically manifested in increasing employment offices and the associated housing and retail development in the Indian cities. Land use is a fundamental determining factor for movement and activity. The nature of land use influences the source and nature of travel, and consequently, the traffic generation and distribution processes. Among the various land uses, commercial land use contributes more to the traffic flow in cities due to its trip-making nature (built-up area and occupancy are more for commercial [4]). Bengaluru, also known as Silicon Valley of India, is a leading IT exporter, where the number of commercial buildings is more. This rapid growth of employment offices in the city acts as a hub for trip generation and attraction, potentially impacting the existing road infrastructure. This is seen to reflect on the urbanization trends and the mobility choices of people which in turn have resulted in an exponential rise in motorization. This leads to heavy congestion in particular areas of Bengaluru. According to the ninth edition of the Tom Tom Traffic Index report, Bengaluru has the world's worst traffic congestion [13]. Therefore, it is imperative to understand the effect of any upcoming commercial development before it is thoroughly established, to take adequate measures to reduce the negative impacts, if any.

Traffic Impact Assessment (TIA) is a technical analysis of traffic problems and safety issues relating to a specific development. This is done to estimate the impact of a new development's site-generated traffic on the adjoining roads. Upcoming or new projects require a comprehensive TIA to help determine the forecasted traffic on the adjoining roads, identify the potential problems associated with the new development, provide suitable mitigation strategies to tone down the negative impacts, and provide suggestions/ recommendations for hassle-free movement of vehicles on roads. TIA, though recently being studied in India due to the need for developing sustainable solutions to ease out congestion, a few researchers across the world have studied this widely. Most of the studies have used the conventional four-stage modeling [3, 8, 9]. Wagner [17] has studied the impact of logistics-related land use and suggested a methodological improvement of integrating the trip generation and trip distribution estimation into the regional land use and transport models. In a similar study by Sharmeen et al. [11], a generic methodology for TIA is developed by forecasting the background and the developing traffic for a mixed land use in Dhaka city. Mihans et al. [6] did a TIA in the neighborhood of Skudai Town in the Johor Bahru region in which the entry mean trip rate was estimated using trip rate analysis, cross-classification analysis and regression analysis and did a comparison of values obtained from Highway Planning Unit (HPU) Malaysian manual.

Regidor and Teodoro [10] mentioned that detailed description of the traffic conditions around the study site's vicinity is required. At least a few kilometers around

the site should be studied for its impact. Also, the future projected year should be at least 10 years down the line [1] with base year ideally varying by location, extent and purpose of development. To ensure that predictions of traffic impacts are accurate, the TIA should include technical guidance about baseline conditions and key assumptions, with a full assessment of existing transport infrastructure [14]. Environment impacts should also be taken into consideration, as more sustainable solutions are required [1, 15]. The methodology used for predicting trips would have a significant effect on a TIA [7]. Therefore, a more comprehensive methodology which is inclusive of all situations is required.

However, the existing methodologies in the literature cannot be used for the present COVID-19 situation as the traffic is not the same as in the pre-COVID situation, which can overestimate the model values. This necessitates an improved methodological framework that can evaluate the impact of traffic in any situation. A new large commercial land use in Bengaluru is considered the case study to apply the proposed methodology and framework. Therefore, the objectives of this paper are (a) to develop an improved methodological framework to evaluate the traffic impact (b) to perform a traffic impact assessment of a new large commercial land use which is under development in Bengaluru (c) to assess the level of service (LOS) on roads adjoining the new commercial development based on the estimated traffic loads and suggest road improvement measures to maintain a given LOS, wherever possible, and (d) to propose possible ways to reduce traffic loads in the present and near future and ways to integrate with upcoming Bengaluru metro rail station near the new commercial development.

The remainder of the paper is organized as follows: In the next section, details of the case study and data collection are presented. Section 4 describes the methodological framework adopted, and Sect. 5 discusses the results. Finally, we conclude with the discussions of the study and possible future work.

2 Description of the Case Study

2.1 Study Site

ITC Green Centre is an ongoing commercial complex with predominantly office space (buildings 1–6) and a hotel (building 7) in which building 1 and 2 are already existing. It is located on a 13.7-hectare (33.98 acres) site and is approximately 5.5 km northeast of Bengaluru's central business district. The major land use near the campus is residential. The proposed development is planned to be built in 4 phases and will be replacing the existing old buildings on the site, phase-wise. Phase 1 of the campus includes building 1 and 2, which is existing with the ground and 11 floors, and four basement floors for parking in common. Phase 2 includes building 3 with the ground and 12 floors and three basement floors for parking. Phase 3 includes building 4 and 5 with ground and 12 floors each, 2 basements in each building for parking,

and a Multi-Level Car Parking (MLCP) in building 4 to accommodate the overall campus's deficit car parks. Phase 4 includes building 6 with the ground and 11 floors, four basements for parking, and the ITC hotel. Two scenarios are considered for hotel building: (a) Scenario 1–150 rooms with 600 occupancies (includes staff and guest) and (b) Scenario 2–350 rooms with 1400 occupancies (includes staff and guest) The project site in Bengaluru and the layout is shown in Figs. 1 and 2 respectively, and the details of all phases are given in Table 1.
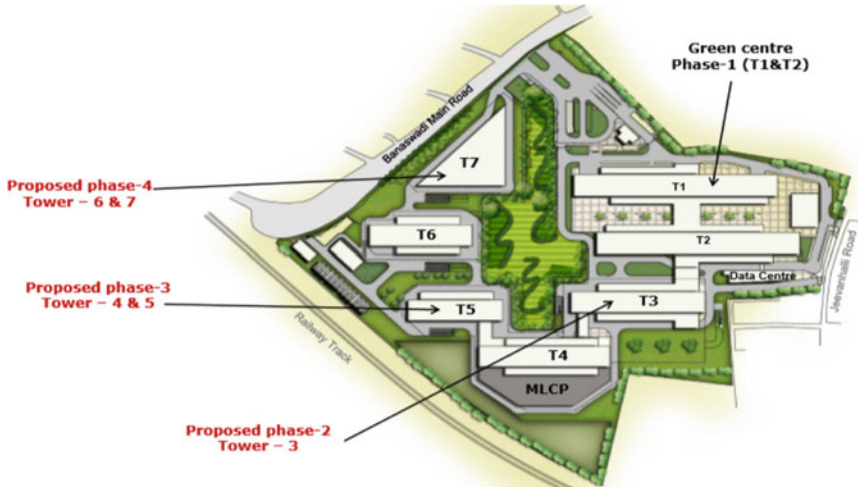

Fig. 1 Project site and the adjoining roads

Fig. 2 ITC green centre layout

Table 1 Details of ITC green centre buildings

Phase no	Building no	Landuse type	Built-up area (Sqft)	Occupancy
Phase 1	Building-1 and 2	Office	23,33,994	10,500
Phase 2	Building-3	Office	9,51,237	5870
Phase 3	Building-4	Office	14,69,510	5865
	Building-5	Office	5,01,384	3750
Phase 4	Building-6	Office	5,23,093	3950
	Building-7 (Scenario 1)	Hotel	5,46,619	600
	Building-7 (Scenario 2)	Hotel	5,46,619	1400

2.2 Data Collection and Assumptions Made

Data collection included both primary and secondary data. The secondary data collected from ITC Green Centre were the entry/exit time of vehicles to ITC, pin codes of cars entering ITC for January 2020 (before lockdown) and the vehicle circulation plan inside the ITC campus. Pin codes represent the area of residence of the car users. The pin code details of the car users were collected to identify the shortest route from their location to ITC Green Centre. For validation, a peak hour volume count survey was done on the three roads adjoining the ITC campus.

Due to the non-availability of data, the following assumptions were made.

i. Mode split for hotel employees was assumed to be the same as office buildings.
ii. From the data gathered for hotel guests and visitors, the maximum entries and exits in one-hour interval were assumed as the entries and exits in peak hour as a worst-case scenario.
iii. Directional split percentages of other modes (except two-wheelers) were assumed to be the same as car distribution.
iv. Directional split percentage of two-wheelers from Gate 4 was assumed based on its connectivity to the main road.
v. The occupancy value of a 13-seater tempo traveler was assumed to be 9.75 (75% occupancy).

3 Methodology

The conventional four-stage modeling involves collecting the volume count data from the adjoining roads and adding the additional volume induced due to the new development. However, in the current pandemic situation, collecting the existing volume count data would give wrong figures due to increasing percentage of people opting for work from home, change in travel patterns, etc. Therefore, a generic methodology using the forecasted values from the Regional Travel Demand Model (TDM) developed for Bengaluru using TransCAD [16] was adopted to assess the

traffic impact of the new development. The flow chart depicting the steps involved in developing Travel Demand Model is shown in Fig. 3. The volume on the adjoining roads of the development center was linearly forecasted for the year 2020 for all 384 Traffic Analysis Zones considered in the TDM. The forecasting was done using the growth rates from the Comprehensive Traffic and Transportation Study for Bengaluru Metropolitan Region, which was determined from the primary data (sixteen different types of surveys pertaining to the network, users and operator) and secondary data (Revised Structure Plan-2031, Draft Master Plan-2015, Plan Bengaluru-2020, Census Data, Public transport, fare structure, etc.) (CTTS Report 2010). Using the volume obtained from the TDM model, the impact of the new development on the adjoining roads was assessed. The methodology adopted for the case study is depicted in Fig. 4.
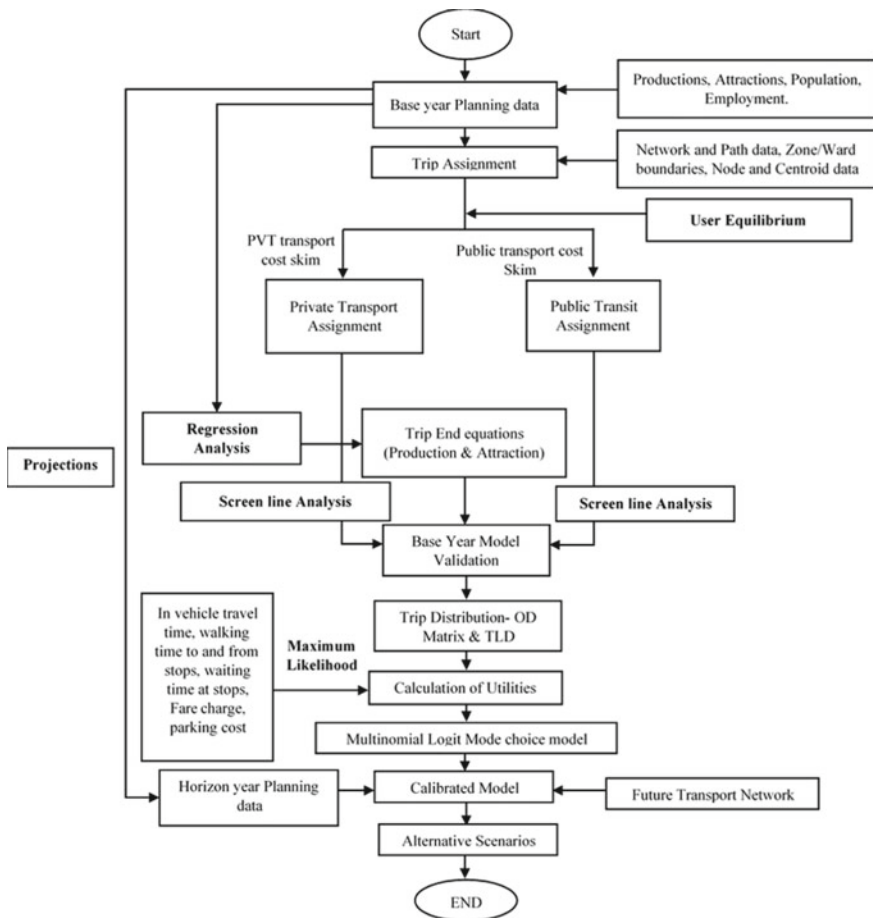

Fig. 3 Process flow chart of the travel demand model [16]
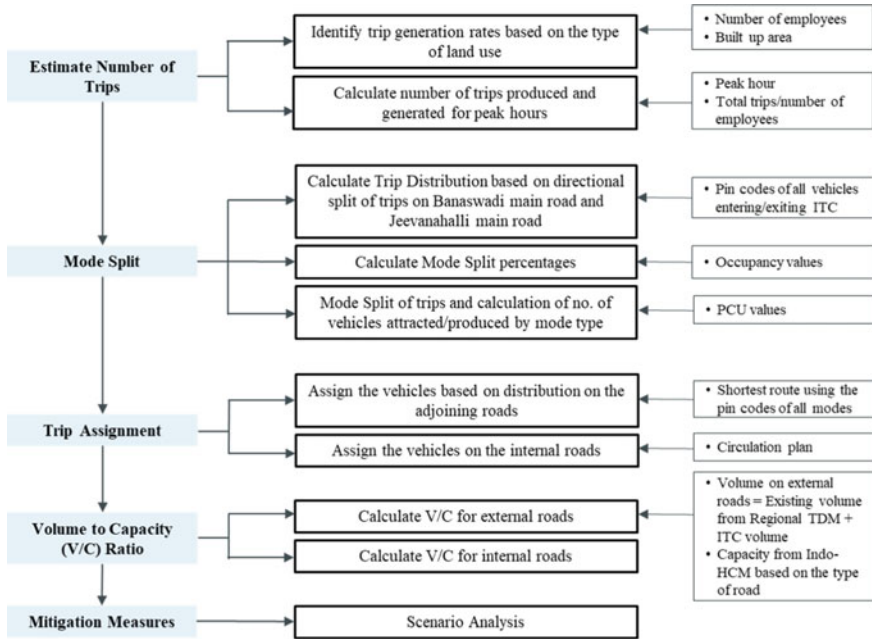
Fig. 4 Methodology adopted for the case study

4 Results

4.1 Trip Rate Analysis

From the built-up area and occupancy details of ITC Green Centre and old campus buildings, average trip generation rates for the peak period of a typical weekday and the number of trips produced and attracted to the development were calculated using the formula

$$Triprate = \frac{Occupancy}{Builtuparea}$$

This is presented in Table 2.

The following representations are to be noted:

a. Scenario 1 a—Employees in scenario 1 of hotel
b. Scenario 1 b—Guests in scenario 1 of hotel
c. Scenario 2 a—Employees in scenario 2 of hotel
d. Scenario 2 b—Guests in scenario 2 of hotel

Table 2 Average trip rates

Buildings	Trip rate (No/1000Sft)
ITC Green Centre	
Building-1 and 2	4.5
Building-3	6.17
Building-4	3.99
Building-5	7.48
Building-6	7.55
Building-7 (Scenario 1 a)	0.55
Building-7 (Scenario 1 b)	0.55
Building-7 (Scenario 2 a)	1.28
Building-7 (Scenario 2 b)	1.28
Old campus	
Corresponding Phase 2 buildings	14.68
Corresponding Phase 3 buildings	11.62
Corresponding Phase 4 buildings	0

4.2 Peak Hour Calculation

The morning peak was identified to be between 9 and 10 AM, and the evening peak was identified to be between 6 and 7 PM for both ITC Green Centre and the old campus. It is seen from Figs. 5 and 6 that 20 and 30% of the total trips in a day were attracted to ITC Green Centre and old campus, respectively, in the morning peak hour and 20% and 24% of the total trips in a day were produced from ITC
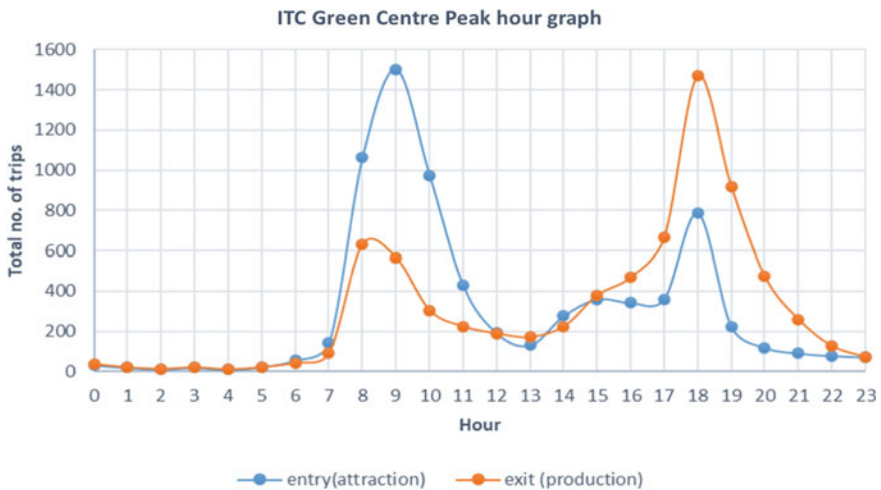

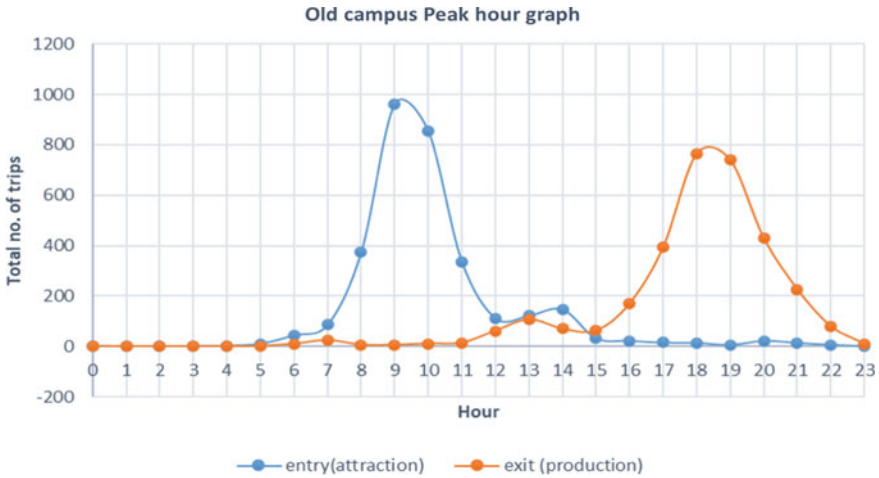**Fig. 5** Peak hour calculation for ITC green centre

Fig. 6 Peak hour calculation for old campus

Green Centre and old campus, respectively, in the evening peak hour. Similarly, 8% of the total trips in a day were produced from ITC Green Centre in the morning peak hour, and 11% of the total trips in a day were attracted to ITC Green Centre in the evening peak hour. Productions from old campus during morning peak and attraction during evening peak were almost 0%. From this and the total trips in a day, the trips produced and attracted to ITC Green Centre and old campus during the morning and evening peak period were calculated, which is summarized in Table 3. The morning trip production and evening trip attraction of ITC Green Centre are more when compared to the old campus trips. This could be due to a greater number of shift-based trips from ITC Green Centre than from the old campus buildings, which needs a further understanding.

4.3 Mode Split

The mode-wise trips were then calculated using the average occupancy values [5]. The mode split percentages considered are reported in Tables 4 and 5. Mode split for hotel employees was assumed to be the same as office buildings. Only two-wheeler and car were considered, and all other modes were distributed to two-wheeler and car according to their percentages.

Using the mode split percentages, the peak hour trips and the average occupancy values, the vehicle trips by mode were calculated for AM and PM peaks. Using the Passenger Car Units (PCU) from the Indo-HCM manual, 2017, the vehicle trips were converted to their equivalent passenger car values.

Table 3 Trips produced and attracted to ITC Green Centre and old campus during peak hour

Buildings	AM Peak Hour(trips)		PM Peak Hour(trips)	
	Produced	Attracted	Produced	Attracted
ITC Green Centre				
Building-1 and 2	803	2149	2086	1128
Building-3	449	1202	1166	631
Building-4	448	1201	1165	630
Building-5	287	768	745	403
Building-6	302	809	785	424
Building-7 (Scenario 1 a)	23	61	60	32
Building-7 (Scenario 1 b)	43	44	43	44
Building-7 (Scenario 2 a)	54	143	139	75
Building-7 (Scenario 2 b)	100	102	100	102
Old campus				
Corresponding Phase 2 buildings	3	546	434	8
Corresponding Phase 3 buildings	5	974	774	14
Corresponding Phase 4 buildings	0	0	0	0

Table 4 Mode split percentages for office buildings

Mode	Percentage
ITC Green Centre	
Two-wheeler	22%
Car	17%
Cab	31%
Bus	22%
Tempo traveler	8%
Old campus	
Two-wheeler	73%
Car	22%
Cab	5%

Table 5 Mode split percentages for employees and guests of hotel

Mode	Percentage
For hotel employees	
Two-wheeler	57%
Car	43%
For hotel guests	
Car	100%

4.4 Trip Assignment

The trips were assigned using User Equilibrium (UE) trip assignment method. The UE method is based on Wardrop's first principle which assumes that "no user can unilaterally reduce their travel costs by shifting to another route". For a given OD pair, the UE conditions can be represented as

$$f_k(c_k - u) = 0 : \forall k \tag{i}$$

$$c_k - u \geq 0 : \forall k \tag{ii}$$

where f_k is the flow on path k, c_k is the travel cost on path k, and u is the minimum cost. Equation (ii) can have two states:

1. If $c_k - u = 0$, from Eq. (i), $f_k \geq 0$. This means that all used paths will have the same travel time.
2. If $c_k - u > 0$, the from Eq. (i), $f_k = 0$.

This means that all unused paths will have travel time greater than the minimum cost path [12].

The initial OD matrix used for assigning the trips included only the existing Phase 1 buildings of ITC and does not include the trips from the other phases. To add the additional trips from the new phase, about 23 links around ITC were considered which is shown in Fig. 7. The pin codes of cars were gathered, and their route to ITC from the origin was identified from google maps. It was observed that 60% of the cars
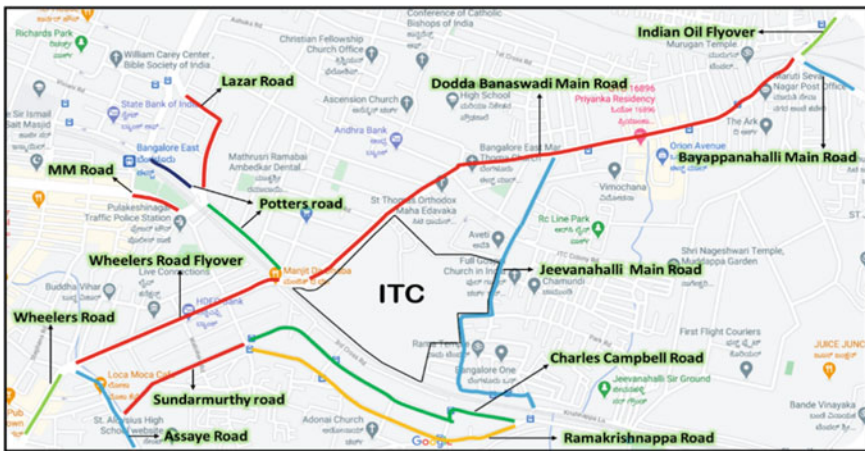

Fig. 7 Adjoining roads considered for assessing the impact of traffic

entered from Wheeler's flyover side and the remaining 40% from Dodda Banaswadi roadside (opposite to Wheeler's flyover side), which was assumed to be the same for all the vehicles entering through the main gate (Gate 1). Similarly, the directional split percentage for two-wheelers entering the campus from Jeevanahalli main road (Gate 4) was also assumed to be 80% from Banaswadi to Jeevanahalli main road and 20% from Ramakrishnappa and Charles Campbell Road, due to unavailability of data.

From the pin codes, it was observed that 60% of the trips came from Wheeler's flyover. Out of the 60%, 78% came straight from Wheeler's flyover and 22% came from pottery to Wheeler's flyover side. Out of the 78%, 67% again came straight from Wheeler's flyover side, and 33% came from Assaye road. Out of the 22%, 95% of the trips were from Lazar road, and 5% were from MM road. Similarly, out of the 40% trips coming from Dodda Banaswdi main road, 95% of the trips came from Indian oil flyover and 5% from Bayappanahalli main road.

For two-wheeler trips, it was assumed that 80% of the trips came from Banaswadi main road to Jeevanahalli main road and 20% from the railway line side. Out of the 80% trips from Banaswadi main road, 60% was from Wheeler's flyover side and 40% from Banaswadi roadside. The 20% from railway line side came from Ramkrishnappa road (one-way road) which diverged from Wheeler's road. The trips were assigned according to these directional split percentages except for one-way roads, where the respective trips were assigned to their alternate roads.

The Regional Travel Demand Model (TDM) was then used to forecast the existing travel demand for 2020 for peak hour, and the existing flow values were derived from the model for the existing condition. Then (Volume/ Capacity) V/C ratio for the adjoining roads was calculated for the existing condition (phase 1 of ITC Green Centre and existing buildings of old campus) to assess the current Level of Service (LOS) on the roads adjoining the campus. The capacity values were obtained from the Indian Highway Capacity Manual (Central Road Research Institute 2017). Similarly, the traffic volume on the adjoining roads was forecasted for the year 2030 using Regional Travel Demand Model (TDM), and the flow values for peak hour were derived from the model.

The peak period classified traffic volume estimates based on the TDM for Bengaluru for the adjoining roads and their corresponding V/C ratios and LOS, for an existing condition, were calculated. Then the incremental impact of traffic due to the development of each phase was also assessed. For this, both the ITC Green Centre and old campus buildings were considered. When a new building was included, the corresponding old buildings that will be replaced were excluded from the assessment. For the existing 2020, in most of the links, volume exceeds the capacity with V/C more than 1 representing LOS F. According to Indo-HCM, this symbolizes a zone of forced or breakdown flow which may result in long queues and delays. For the projected year 2030, the volume to capacity ratio was worse than the current 2020 year. This can lead to queues that are characterized by stop and go waves, which are extremely unstable. Long queues and delays are highly likely. Therefore, proper measures are to be taken to improve the level of service. An average of 6.6%

(maximum 25% on some roads) increase in V/Cs of the adjoining roads was observed due to the development of ITC (before phase 1 and after phase 4).

4.5   Validation

A peak hour traffic volume count survey was done to validate the volumes derived from the Travel Demand Model. The survey was done on a typical working day (Wednesday, 30 December 2020) and under normal weather conditions. Six adjoining roads to ITC were chosen for the survey. The vehicles are counter mode-wise and converted to one unit using PCU values. The total trips are then compared with the volumes derived from TDM and it is seen from Table 6 that the predicted volumes from TDM are higher than the actual volumes on the day of count. Therefore, the calculations are done using TDM volumes which represents a worst-case scenario. However, the survey was done during COVID-19 situation, which is a limitation.

Table 6   Volumes from traffic volume count survey and TDM

Sl no	Road name	Morning peak hour volume (PCU/hr)	Evening peak hour volume (PCU/hr)	Morning peak hour volume from TDM (PCU/hr)	Evening peak hour volume from TDM (PCU/hr)
1	Banaswadi road from Indian oil flyover	1627	1263	3602	3492
2	Banaswadi road from Wheeler's flyover	1584	3294	4118	3954
3	From Banaswadi to jeevanahalli	425	361	4002	3955
4	From Jeevanahalli to banaswadi	472	445	1863	1834
5	From Banaswadi to jeevanahalli gate 4	439	667	4072	3956
6	Railway line to Jeevanahalli gate 4	591	492	1863	1834

4.6   Scenario Analysis

The following scenarios were analyzed to check the effect of those on the estimated traffic volumes, V/C ratios and LOS.

a.   Work from Home (30 and 50% of the employees).
b.   Staggered time

Morning peak hour trips (8-9 AM, 9-10 AM, 10-11 AM) and evening peak hour trips (5-6 PM, 6-7 PM, 7-8 PM).

c.   Mode shift

i.   Change in mode shares of ITC

(10% car, 10% TW, 37% office cabs, 29% office bus, 14% office tempo travelers).

ii.   Mode share used in bundle 3 of CLIMATRANS [16].

Based on the Intergovernmental Panel on Climate Change (IPCC) definition, inputs from multiple stakeholder meetings and a Delphi survey with various government officials of Bengaluru, 4 policy bundles were formulated in CLIMATRANS. Those mitigation policy bundles' main objective was to attain an optimum balance of push and pull strategy by developing policies that encourage public transportation and other sustainable modes. This can help reduce the vehicle kilometers traveled, which lead to a reduction in emissions and traffic congestion compared to the Business-as-usual scenario, thereby improving the quality of life of people in Bengaluru city.

Bundle 3 of CLIMATRANS is a mixture of Planning, Regulatory, and Economic instrument and includes the following policies:

- *Increasing network coverage of Public Transit.*
- *Defining car restricted roads.*
- *Congestion Pricing.*
- *Park and Ride.*
- *Cycling and Walking infrastructure.*
- *Encouraging car-pooling and High Occupancy Lanes.*
- *High-density mix building use along main transport corridors.*

Bundle 3 was identified as the best bundle in CLIMATRANS and so, the mode share percentages of bundle 3 were adopted for this scenario. The mode share percentages were 16% TW, 2% Car, 3% Auto, 40% Bus, 19% Metro, 6% Walk, and 16% Cycle.

d.   Combination of the above scenarios

The following combinations were analyzed.

i.   30% of the employees WFH and staggered time.
ii.   50% of the employees WFH and staggered time.

iii.   30% of the employees WFH and change in the mode share of ITC.
iv.   50% of the employees WFH and change in the mode share of ITC.
v.   Staggered time and change in the mode share of ITC.
vi.   30% of the employees WFH, staggered time and change in the mode share of ITC with the existing volumes on adjoining roads.
vii. 50% of the employees WFH, staggered time and change in the mode share of ITC with the existing volumes on adjoining roads.
viii. 30% of the employees WFH, staggered time and change in the mode share of ITC with estimated volumes on adjoining roads, using the mode shares of bundle 3 of CLIMATRANS.
ix.   50% of the employees WFH, staggered time and change in the mode share of ITC with the estimated volumes on adjoining roads, using the mode shares of bundle 3 of CLIMATRANS.

The combination of three scenarios provided better results out of which while comparing the BAU with the existing volume on the adjoining roads, the scenarios (30% WFH, staggering work time from 10 AM to 7 PM and mode shift in ITC trips) and (50% WFH, staggering work time from 10 AM to 7 PM and mode shift in ITC trips) were best for AM trips and the scenarios (30% WFH, staggering work time from 8 AM to 5 PM and mode shift in ITC trips) and (50% WFH, staggering work time from 8 AM to 5 PM and mode shift in ITC trips) were best for PM trips, for both 2020 and 2030. This is because the morning peak hour is 9 AM–10 AM, and so trips will be proportionately less from 10 AM than in 8–9 AM (as this also has a good number of trips). Similarly, the evening peak hour is 6 PM–7 PM and so the trips will be proportionately less around 5 PM than in 6–7 PM (as this also has a good number of trips). It was also seen that there was not much reduction in V/Cs during the peak hour time as 9 AM–6 PM is the general work time. Also, the percentage decrease in V/Cs due to 30% WFH and 50% WFH were almost similar. Therefore, a combination of staggering the work hours before and after the peak hours, with a proportion of employees working from home, and a proportion of employees shifting to shared modes provided by ITC can substantially reduce the V/Cs on the adjoining roads. Decrease in PM was more than AM could be due to external factors (such as school timings). Percentage decrease of V/C from BAU scenario's V/C and projected 2030s V/Cs due to the combination of three scenarios with the existing volumes on adjoining roads are summarized in Table 7.

Similarly, while comparing the BAU with the volumes obtained from bundle 3 scenario of CLIMATRANS, the scenarios (30% WFH, staggering 10 AM–7 PM and bundle 3 mode shift) and (50% WFH, staggering 10 AM–7 PM and bundle 3 mode shift) were best for AM trips, and the scenarios (30% WFH, staggering 8 AM–5 PM and ITC mode shift) and (50% WFH, staggering 8 AM–5 PM ITC mode shift) were best for PM trips, for both 2020 and 2030. It was also seen that there was not much reduction in V/Cs during the peak hour time. Also, the percentage decrease in V/Cs due to 30% WFH and 50% WFH were almost similar. As bundle 3 mode share values from CLIMATRANS were used for adjoining roads' volumes, the percentage decrease in V/Cs were more (Table 8), as it was more toward using public

Table 7 Percentage decrease of V/C from BAU scenario's V/C and projected 2030s V/Cs due to the combination of three scenarios with the existing volumes on adjoining roads

Phase	Combination of scenarios					
	30% WFH, Staggering 8AM–5PM and ITC mode shift	50% WFH, Staggering 8AM–5PM and ITC mode shift	30% WFH, Staggering 9AM–6PM and ITC mode shift	50% WFH, Staggering 9AM–6PM and ITC mode shift	30% WFH, Staggering 10AM–7PM and ITC mode shift	50% WFH, Staggering 10AM–7PM and ITC mode shift
AM 2020						
Phase 1	29	30	2	3	35	35
Phase 2	30	30	3	4	35	36
Phase 3	31	31	5	5	36	37
Phase 4 (Scenario 1)	31	32	5	6	36	37
Phase 4 (Scenario 2)	31	32	5	6	36	37
PM 2020						
Phase 1	55	56	3	3	38	37
Phase 2	55	55	4	4	38	38
Phase 3	55	56	6	6	39	39
Phase 4 (Scenario 1)	55	56	7	7	39	40
Phase 4 (Scenario 2)	55	56	7	7	39	40
AM 2030						
Phase 1	29	29	2	2	34	35
Phase 2	30	30	3	3	35	35
Phase 3	30	31	4	4	35	36
Phase 4 (Scenario 1)	31	31	5	5	36	36
Phase 4 (Scenario 2)	31	31	5	5	36	36
PM 2030						
Phase 1	55	55	2	3	38	39
Phase 2	54	54	3	4	37	38
Phase 3	54	55	5	5	38	38
Phase 4 (Scenario 1)	55	55	6	6	38	39

(continued)

Table 7 (continued)

Phase	Combination of scenarios					
	30% WFH, Staggering 8AM–5PM and ITC mode shift	50% WFH, Staggering 8AM–5PM and ITC mode shift	30% WFH, Staggering 9AM–6PM and ITC mode shift	50% WFH, Staggering 9AM–6PM and ITC mode shift	30% WFH, Staggering 10AM–7PM and ITC mode shift	50% WFH, Staggering 10AM–7PM and ITC mode shift
Phase 4 (Scenario 2)	54	55	6	6	38	39

transportation and sustainable modes. Therefore, a combination of staggering the work hours before and after the peak hours, with a proportion of employees working from home, and shift of ITC employees and the public to more sustainable modes can substantially reduce the V/Cs on the adjoining roads. Decrease in PM was more than AM could be due to external factors (such as school timings). Percentage decrease of V/C from BAU scenario's V/C and projected 2030s V/Cs due to combination of three scenarios with bundle 3 volumes on adjoining roads is summarized in Table 8.

As the bundle 3 mode shift cannot be attained immediately, the best scenario would be the 50% work from home, staggering of work hours from 8–11 AM to 5–8 PM, and ITC mode shift.

4.7 Effect of Metro on the Best Scenario Results

Bengaluru metro has proposed Pottery town metro station, which is approximately 2.5Kms from ITC Green Centre. Therefore, 6% from two-wheelers trips and 4% from cars trips were shifted to the metro. This analysis was done for the best scenario (50% WFH, staggering 8–11 AM to 5–8 PM, and ITC mode shift), and the results are summarized in Table 9. It was seen that there was a 1%–2% reduction on an average in V/Cs from the best scenario V/Cs due to the shift of trips to the metro. If an exclusive skywalk is provided between ITC and the metro station, then there could be more shift of trips toward the metro.

5 Conclusion

This paper discusses the methodological framework adopted to assess the impact of an upcoming commercial development (ITC Green Centre) in Bengaluru. The Regional Travel Demand Model (TDM) that was developed for Bengaluru using TransCAD [16] was adopted to assess the traffic impact of the new development. The forecasted values from this model were considered for the assessment, which rules

Table 8 Percentage decrease of V/C from BAU scenario's V/C and projected 2030's V/Cs due to the combination of three scenarios with the existing volumes on adjoining roads

Phase	Combination of scenarios					
	30% WFH, Staggering 8AM–5PM and ITC mode shift	50% WFH, Staggering 8AM–5PM and ITC mode shift	30% WFH, Staggering 9AM–6PM and ITC mode shift	50% WFH, Staggering 9AM–6PM and ITC mode shift	30% WFH, Staggering 10AM–7PM and ITC mode shift	50% WFH, Staggering 10AM–7PM and ITC mode shift
AM 2020						
Phase 1	36	36	11	11	41	41
Phase 2	36	37	12	13	41	41
Phase 3	37	38	12	13	42	42
Phase 4 (Scenario 1)	38	38	13	13	42	42
Phase 4 (Scenario 2)	37	38	13	13	42	42
PM 2020						
Phase 1	59	60	11	12	44	45
Phase 2	58	59	13	13	43	44
Phase 3	59	60	14	15	44	45
Phase 4 (Scenario 1)	59	60	15	16	45	45
Phase 4 (Scenario 2)	59	60	15	15	45	45
AM 2030						
Phase 1	35	35	11	11	40	41
Phase 2	35	36	11	11	40	41
Phase 3	36	37	13	13	41	42
Phase 4 (Scenario 1)	37	37	13	14	41	42
Phase 4 (Scenario 2)	37	37	13	14	41	42
PM 2030						
Phase 1	59	59	11	11	44	44
Phase 2	58	58	12	12	43	43
Phase 3	58	59	13	13	43	44
Phase 4 (Scenario 1)	58	59	14	14	44	44

Table 8 (continued)

Phase	Combination of scenarios					
	30% WFH, Staggering 8AM–5PM and ITC mode shift	50% WFH, Staggering 8AM–5PM and ITC mode shift	30% WFH, Staggering 9AM–6PM and ITC mode shift	50% WFH, Staggering 9AM–6PM and ITC mode shift	30% WFH, Staggering 10AM–7PM and ITC mode shift	50% WFH, Staggering 10AM–7PM and ITC mode shift
Phase 4 (Scenario 2)	58	59	14	14	44	44

Table 9 Percentage decrease of V/C from best scenario to V/Cs due to shift of trips to metro

50% WFH, staggering 8 AM–5 PM, ITC mode shift (including metro)

	AM 2020	PM 2020	AM 2030	PM 2030
Phase 1	0	1	0	0
Phase 2	0	1	0	0
Phase 3	1	1	1	1
Phase 4(Scenario 1)	1	2	1	2
Phase 4 (Scenario 2)	1	2	1	2

50% WFH, staggering 9 AM–6 PM, ITC mode shift (including metro)

	AM 2020	PM 2020	AM 2030	PM 2030
Phase 1	0	0	0	0
Phase 2	0	0	1	0
Phase 3	0	1	1	0
Phase 4 (Scenario 1)	1	1	1	1
Phase 4 (Scenario 2)	1	1	1	1

50% WFH, staggering 10 AM–7 PM, ITC mode shift (including metro)

	AM 2020	PM 2020	AM 2030	PM 2030
Phase 1	0	1	0	0
Phase 2	0	0	1	1
Phase 3	2	2	1	0
Phase 4 (Scenario 1)	2	2	1	2
Phase 4 (Scenario 2)	2	2	1	2

out the necessity for data collection in the conventional techniques, which cannot be done during the pandemic. The same can also be used in the post-pandemic situation by forecasting the volume of the background traffic.

An average of 6.6% percentage increase (maximum 25% on some roads) in V/Cs was observed before and after the new development on the adjoining roads. This might lead to heavy congestion on those roads with a poor level of service. Therefore, several scenarios were considered and analyzed to provide the best mitigation

strategies to improve the level of service. The scenarios considered include work from home (30 and 50% employees), staggered time (ITC trips divided equally between 8–11 AM and 5–8 PM), mode share (shifting toward public transportation and other sustainable modes) and combinations of the three. The best scenario obtained from this was a combination of 50% work from home, staggering of work hours from 8–11 AM to 5–8 PM, and ITC mode shift has brought down the V/Cs to an average of 30% during AM and 50% during PM from BAU scenario. This scenario is suggested for implementation for more congestion and hassle-free movement of vehicles on the adjoining roads. Using the methodological framework developed, this work can help evaluate how appropriate a particular development is for a location, for any given situation, and what mitigation strategies and types of transportation improvements may be essential to maintain smooth moving traffic with a satisfactory level of service. The recommended scenarios have to be further investigated to see how feasible these are, post-COVID. Although work from home can continue to some extent, further study on the possibility of 30 and 50% work from home is required.

References

1. Abley S, Durdin P, Douglass M (2010) Integrated transport assessment guidelines, Research Report 422, NZ Transport Agency, Wellington, New Zealand
2. Chandra S, Gangopadhyay S, Velmurugan S, Ravinder K (2017) Indian highway capacity manual (Indo-HCM)
3. Diliman QC (2005) Traffic impact assessment for sustainable traffic management and transportation planning in urban areas. In Proceedings of the *Eastern Asia Society for Transportation Studies* (Vol. 5, pp. 2342–2351)
4. Izanloo A, Rafsanjani AK, Ebrahimi SP (2017) Effect of commercial land use and accessibility factor on traffic flow in Bojnourd. J Urban Plann Devel 143(2):05016016
5. Karnataka Urban Infrastructure Development and Finance Corporation, Comprehensive Traffic & Transportation Study (2011)
6. Minhans A, Zaki NH, Belwal R (2013) Traffic impact assessment: a case of proposed hypermarket in Skudai town of Malaysia. Jurnal Teknologi, 65(3)
7. Muldoon D, Bloomberg L (2008) Development of best practices for traffic impact studies. Transp Res Record: J Transp Res Board 2077:32–38
8. Padma S, Velmurugan S, Kalsi N, Ravinder K, Erramapalli M, Kannan S (2020) Traffic impact assessment for sustainable development in urban areas. Transp Res Proc 48:3173–3187
9. Ponnurangam P, Umadevi G (2016) Traffic Impact Analysis (TIA) for Chennai IT Corridor. Transp Res Proc 17:234–243
10. Regidor JRF, Teodoro RVR (2003) Institutionalizing traffic impact assessment in the Philippines: some issues and challenges. J Eastern Asia Soc Transp Stud 5:3192–3205
11. Sharmeen N, Sadat K, Zaman N, Mitra SK (2012) Developing a generic methodology for traffic impact assessment of a mixed land use in Dhaka city. J Bangladesh Inst Plann ISSN 2075:9363
12. Tom V Mathew (2019) Trip assignment—lecture notes in transportation systems engineering. https://www.civil.iitb.ac.in/tvm/nptel/206_lnTse/web/web.html#x1-50004
13. TomTom Traffic Index: Global Traffic Congestion Up as Bengaluru takes Crown of 'World's Most Traffic Congested City', January 29, 2020
14. Transport for London (2010) Transport assessment best practice: guidance document. United Kingdom, London

15. van Rensburg JF, van As SC (2004) Issues with traffic impact assessments. Paper presented at 23rd South African Transport Conference (SATC), Pretoria, South Africa
16. Verma A, Harsha V, Hemanthini AR (2018) Sustainable Transport Measures for Liveable Bengaluru. Project Sub Report, IISc Bangalore, India
17. Wagner T (2010) Regional traffic impacts of logistics-related land use. Transp Policy 17(4):224–229. https://doi.org/10.1016/j.tranpol.2010.01.012