



Effect of Turning Lane at Busy Signalized At-Grade Intersection under Mixed Traffic in India

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Abstract

Traffic congestion on urban roads has become a serious concern, particularly, at intersections. The performance of an intersection controls the performance of urban roads meeting at that intersection. The paper presents the effect of addition of turning lane in the middle of approach road at busy signalized at-grade intersection, narrowing the width of all lanes to keep total road width the same, in heterogeneous traffic. The traffic at intersection comprises both of vehicles and pedestrians. Their interactions along with signal cycle decide the efficiency of an intersection. A microscopic simulation tool VISSIM, has been used to model the heterogeneous (mixed) traffic under constraints of roadway geometry, vehicle characteristics, driving behaviour and traffic controls. The effect is investigated with different random seeds to obtain reasonable results for analysis. The performance evaluation is done in terms of vehicle throughput, average queue length, maximum queue length, average delay time per vehicle, average speed and emission of Carbon monoxide CO, mono-nitrogen oxides NO_x, Volatile organic compounds (VOC) etc. It has been observed that on adding turning lane in the middle of approach road the average queue length, maximum queue length, average delay time per vehicle and emission per vehicle get considerably reduced, while there is an increase in vehicle throughput and average speed of all the vehicles. The results reported in this paper clearly shows that addition of turning lane in existing intersection can reduce congestion considerably, enhancing performance of intersections and network.

Keywords: average delay time per vehicle, average speed, heterogeneous traffic, intersection, Level of service (LOS), microscopic simulation, queue length, traffic congestion, turning lane.

1. Introduction

Traffic congestion on urban roads results in tremendous economic loss, additional delay and user cost (Bhargab *et al.*, 1999). Intersections play an important role in the road network, where traffic flows in different directions converge. Because of disturbance of pedestrians, mixed traffic and lost green time for beginning and clearance etc., the capacity of intersections is much lower than their approach links. Thus, intersections are usually the bottlenecks of the network and are the greatest and immediate source of the traffic accidents. Hence, LOS at intersection significantly

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affects the overall LOS of road (Lakkundi *et al.*, 2004). The critical aspect of increasing the throughput of any road system lies in increasing the throughput of the intersection. Traffic signals are used at many at-grade junctions in urban areas to maximize traffic efficiency and safety by separating conflicting traffic movements in time. To increase the efficiency or the capacity of the intersection, the cycle length of the signal should be minimized. Because, as the cycle length increases, the average waiting time for the vehicles in approaches increases and so the throughput decreases (Gadepalli, 2008). The LOS at an intersection gets adversely affected by frequently allowing the right turning (in case of left hand drive traffic; left turning in case of right hand drive traffic) vehicles to block the through traffic. Crash rates also tend to be higher at intersection than on through sections of a road. The separation of right turning (in case of left hand drive traffic; left turning in case of right hand drive traffic) vehicles from through traffic can be an important condition for the safe and effective operation of an intersection (Lakkundi *et al.*, 2004).

Traffic in India is highly heterogeneous, comprising of different types of vehicles with widely varying static and dynamic characteristics (Arasan *et al.*, 2004). In order to study the behaviour and various interactions at intersection, simulation studies are carried out. A microscopic simulation tool VISSIM (version 5.3, official license available) (PTV Vision, 2009) is used to model urban traffic. VISSIM is a microscopic, time step and behaviour based simulation tool. The program can simulate multi-modal traffic flows, including cars, goods vehicles, buses, heavy rail, trams, light rail, 2-wheelers (scooter, motorcycles), 3-wheelers (auto rickshaw, tuk-tuk), bicycles and pedestrians. This paper presents the effect of addition of turning lane in the middle (right turning in case of left hand drive; left turning in case of right hand drive) of approach roads. The turning lane is created by narrowing the width of all lanes and using part of central median so that total width of the road remains same. Thus, the effect is a cumulative impact of both addition of turning lane as well as reduction in the width of existing lanes. The heterogeneous (mixed) traffic is modelled under constraints of existing roadway geometry, vehicle characteristics, Indian driving behaviour and traffic controls. The effect is investigated with different random seeds to obtain reasonable results for analysis. The performance evaluation is done in terms of vehicle throughput, average queue length, maximum queue length, average delay time per vehicle, average speed and emission of CO, NO_x and VOC etc. It has been observed that the net effect of (i) addition of turning lane in the middle of approach road, (ii) reduction in width of lane (to create turning lane) and (iii) reduction in signal cycle time, is the considerable reduction in average queue length, maximum queue length, average delay time per vehicle and emission per vehicle, while there is an increase in vehicle throughput and average speed of all the vehicles. Thus, addition of turning lane in existing intersection can reduce congestion considerably, enhancing the performance of network thereby.

2. Simulation model

VISSIM uses the psycho-physical driver behaviour model developed by WIEDEMANN (PTV Vision, 2009). The basic concept of this model is that the driver of a faster moving vehicle starts to decelerate as he reaches his individual perception threshold to a slower moving vehicle. Since he cannot exactly determine the speed of that vehicle, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold. This results in an iterative

process of acceleration and deceleration. Stochastic distributions of speed and spacing thresholds replicate individual driver behaviour characteristics. VISSIM's traffic simulator not only allows drivers on multiple lane roadways to react to preceding vehicles, but also neighbouring vehicles on the adjacent travel lanes are taken into account. Moreover, approaching a traffic signal results in a higher alertness for drivers at a distance of 100 meters in front of the stop line. VISSIM simulates the traffic flow by moving "driver-vehicle-units" through a network. Every driver with his specific behaviour characteristics is assigned to a specific vehicle. As a consequence, the driving behaviour corresponds to the technical capabilities of his vehicle. Attributes characterizing each driver-vehicle-unit are : (1) Technical specifications of the vehicle, e.g. length, maximum speed, potential acceleration, actual position in the network, actual speed and acceleration (2) behaviour of driver-vehicle-unit, e.g., psycho-physical sensitivity thresholds of the driver (ability to estimate, aggressiveness), memory of driver, acceleration based on current speed and driver's desired speed (3) interdependence of driver-vehicle-units, e.g. reference to leading and following vehicles on own and adjacent travel lanes, reference to current link and next intersection, reference to next traffic signal (PTV Vision, 2009).

3. Data collection

Jaipur city with a population of approx 3.5 million has number of roads where traffic congestion is a regular and daily phenomenon. Rambagh intersection, one of the busiest at-grade signalised intersection in Jaipur, handles a large number of vehicles and pedestrians and witnesses daily traffic congestion. Henceforth, it was chosen to study the effect of turning lane. The entire geometry of the intersection was measured to replicate the intersection in simulation. Eight cameras were used to capture traffic at intersection on all approach roads in the same time interval; with placement of two cameras on each approach road. The cameras were placed in such a manner that one camera observed the through and right turning traffic (hence queue length), the other recorded the vehicle coming in to the left turning lane till the point they merge with the traffic coming across. The synchronization of two camera data provided traffic data for traffic composition, traffic moving through, right and left, queue length as well as time spent by vehicle in queue. The data was supplemented with manually collected data on road geometry and classified traffic survey to cover any omission during video recording. Travel times of vehicles going straight and turning right are also collected. The travel times were measured as the time taken to travel from first reference line (distance of 110m from stop line) to second reference line (stop line). Stop watch was started when front wheels of a vehicle crossed the first reference line and stopped when same wheels of the vehicle crossed second reference line. The traffic surveys were carried out during the peak period of 5.30 pm to 6.30 pm. The peak 15 minutes data of this 'peak period' is used for simulation by multiplying it by 4 to get hourly data. In fig-1 the Rambagh intersection at Jaipur, India is shown and Table -1 incorporates the traffic data.

Table 1: Traffic data existing intersection

Approach	Traffic composition (% vehicle)												Through (% vehicle)	Right turning (% vehicle)	Left turning (% vehicle)	Total volume (veh/hr)
	Car	taxi	SUV	ambulance	utility	Mini bus/van	Bus	LCV	3* - wheel er	2** - whe eler	bike	Indian cyc le rick shaw				
From Stadium	20.5	3	4	0.5	1	4	6	3	9	46	2	1	55.56	22.22	22.22	1708
From Ajmeri-gate	20.5	3	4	0.5	1	4	6	3	9	46	2	1	50.00	20.00	30.00	3032
From JDA circle	22.5	3	4	0.5	1	4	6	3	10	43	2	1	53.85	30.77	15.38	1540
From Ambedkar circle	22.5	3	7	0.5	1	4	6	3	10	40	2	1	25.00	37.50	37.50	2300

*Auto-rickshaw (Indian) ** motorcycle and scooter

4. Model calibration and validation

The model construction procedure consists of (i) identification of important geometric features (ii) collection and processing of traffic data (iii) analysis of mainline data to identify recurring bottlenecks (iv) VISSIM coding (v) calibration based on observations from (iii). Calibration is the process by which individual components of simulation model are refined and adjusted so that simulation model accurately represents field measured or observed traffic conditions. With regard to calibration, traffic simulation model contain numerous variables to define and replicate traffic control operations, traffic flow characteristics and driver behaviour. VISSIM simulation model contains default values for each variable, but also allows a range of user applied values for each variable. These variables are changed as per field measurements and observed conditions (PTV Vision, 2009).

The geometry of existing Rambagh intersection was created using links and connectors which are the building blocks of VISSIM network. The number of lanes per road and width of each lane, left turning lanes on each approach road, central median, traffic islands and other road features were specified as per existing. After creation of network, the vehicle input for various links was given. This is followed by specifying the various routes in which vehicles travelled and the volume of these vehicles in each route is specified. The other features viz. positioning of speed limits, conflict zones, stop signs, signal heads are specified as per existing. The data collection points, travel time sections, queue counters and nodes are placed. The **Indian driving behaviour** is calibrated for the following parameters: standstill longitudinal distance between the stopped vehicles, headway time in seconds, following variation which restricts the longitudinal oscillation and indicates how much more distance than desired distance a driver allows before he intentionally moves closer to vehicle in front, threshold for entering 'following' controlling the start of deceleration process, following threshold which controls the speed differences during the 'following' state, speed dependency of oscillation, oscillation acceleration, standstill acceleration, minimum headway, maximum deceleration of vehicle and trailing vehicle for lane change, overtaking characteristics, minimum lateral distance at different speeds, waiting time for diffusion. The **Indian vehicles** are calibrated for desired speed distribution, weight distribution, power distribution and model distribution. The links are assigned behaviour according to driving behaviour. On Indian roads, because of heterogeneity of traffic, it is difficult to enforce lane discipline. Hence, vehicle occupies lateral positions on any part of road based on space availability; overtake within lane from both the sides. The validation of the model was carried out by comparing maximum queue length simulated by model for **existing intersection** on each approach road with field observed values. The simulation model was given multirun with 20 random seed numbers and average of 20 simulation runs was taken as final output of the model. The value of t-statistic, calculated based on observed data (t_o) for all the four approach road is below 2.00. The critical value of t-statistics for level of significance of 0.05, at 19 degrees of freedom is 2.093. Thus, value of t-statistic, calculated on the basis of observed data, is less than the corresponding table value. This shows that there is no significant difference between the simulated and observed average queue lengths.

5. Intersection modified for turning lane in the middle of approach road

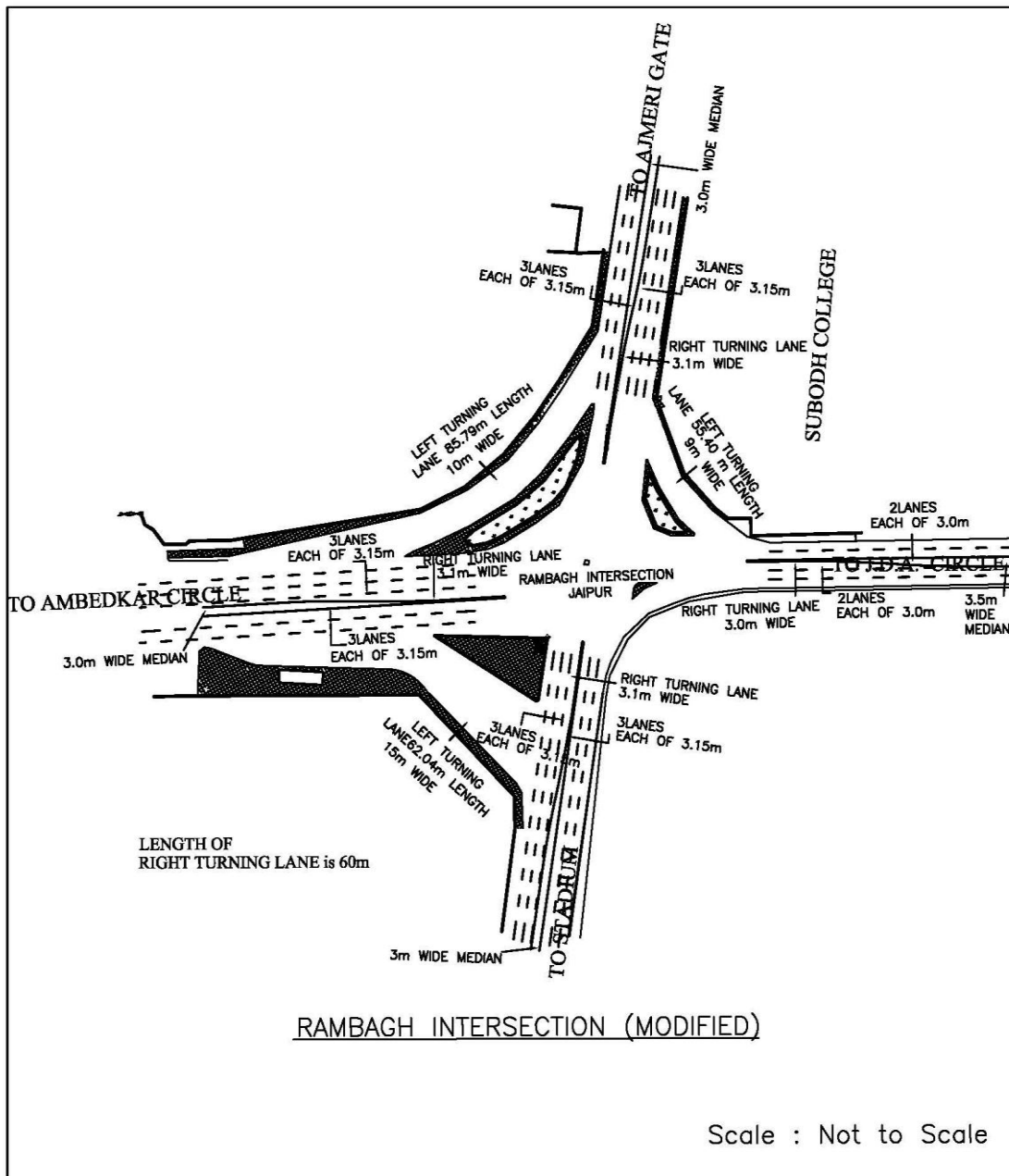
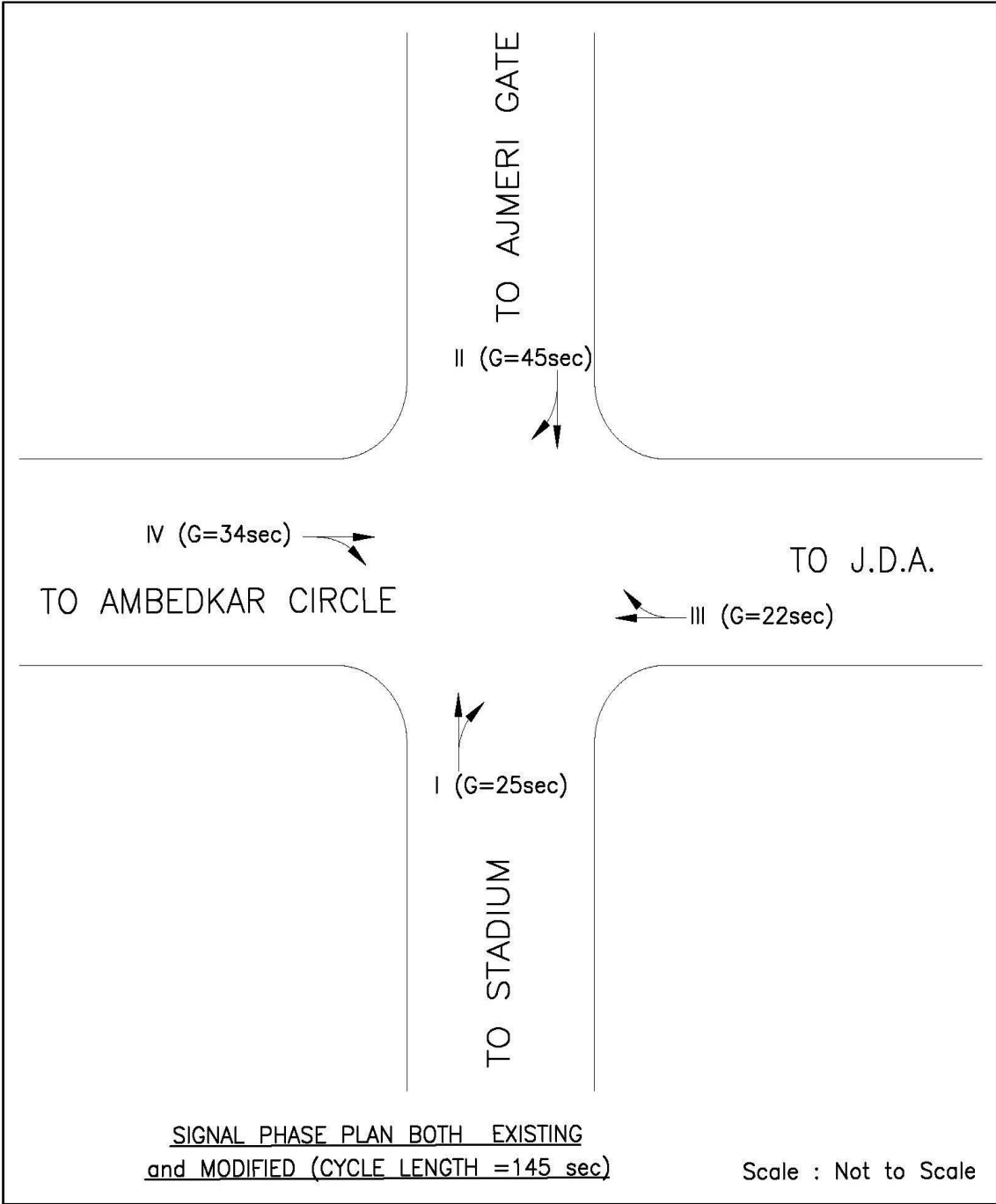


Fig 2: Rambagh Intersection (modified)



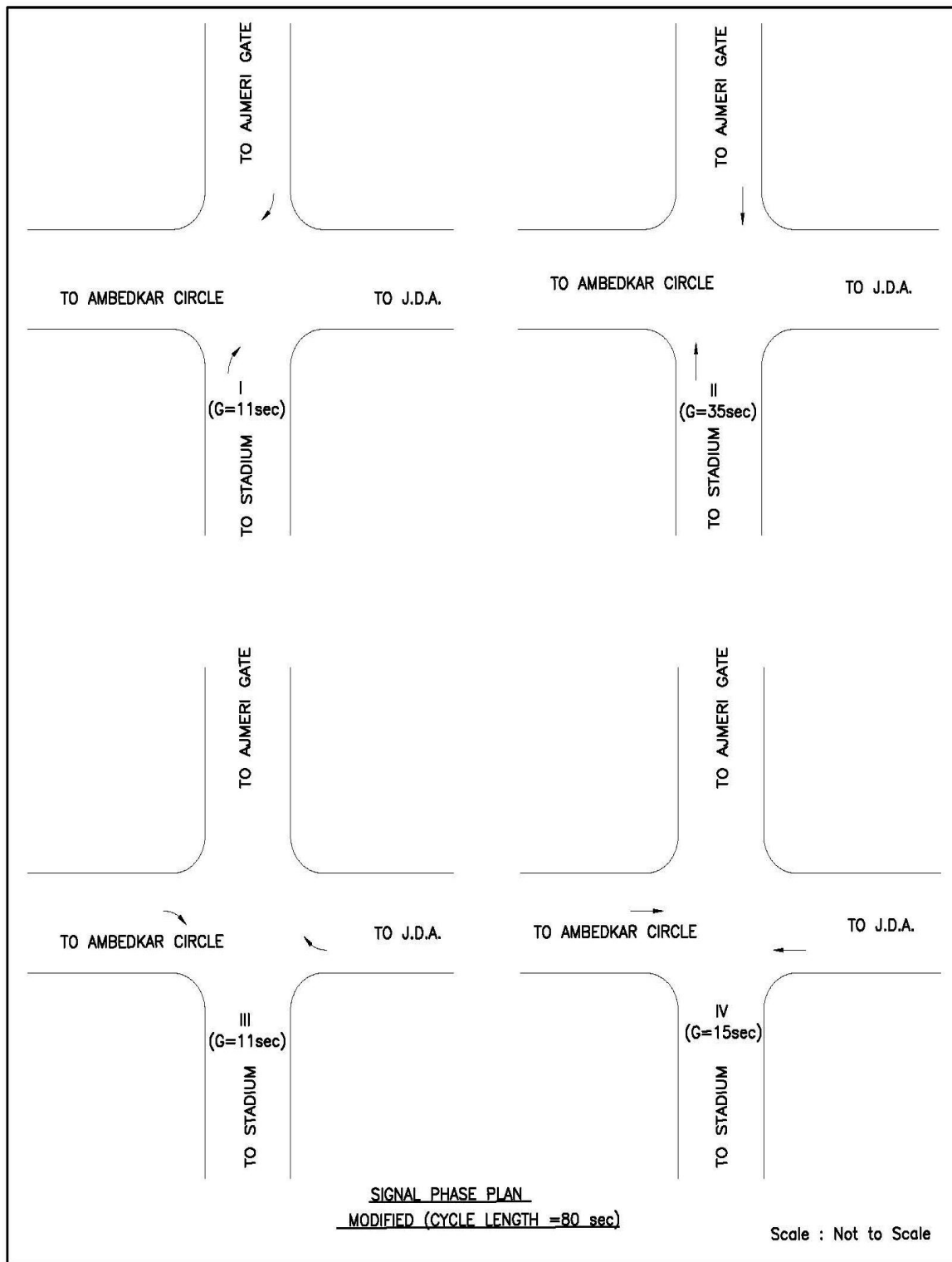


Fig 3: Signal Phase Plan (Existing & Modified)

The model validated as above is used to study the effect of addition of turning lane in the middle of approach road. The existing approach roads from stadium, from Ajmeri Gate and from Ambedkar Circle are 6 lanes (lane width being 3.5m) with 1.5m

central median. Thus total width of each of these 3 approach roads is 22.5m. The approach road from JDA is 4 lane (3.5m lane width) with central median. The turning lane in the middle is created in simulation model by narrowing the width of each lane to 3.15m and using the space of central median. Thus, width space for turning lane on three approach roads is 3.1m, while it is 3.0m in case of approach road from JDA (Jaipur Development Authority). The other road features including signals are kept same to study the changes made as above. The modified intersection is shown in Fig 2). The signals at intersection are fixed time signals with signal cycle 145 sec.

In order to study the effect of reduction in signal cycle time a case is studied with cycle time 80 sec.

The signal phase plan for signal cycle 145 sec (for both existing and modified intersection) and 80 sec (for modified intersection) is shown in Fig 3.

6. Performance evaluation of intersection existing v/s modified (with turning lane in middle and narrowing of lanes)

Evaluation of performance of intersection is carried out for measurements of effectiveness (MOEs) such as average queue length, average delay per vehicle, emissions (CO, NO_x, and VOC), fuel consumption, maximum queue length, number of vehicles, average speed etc. The various results are shown below:

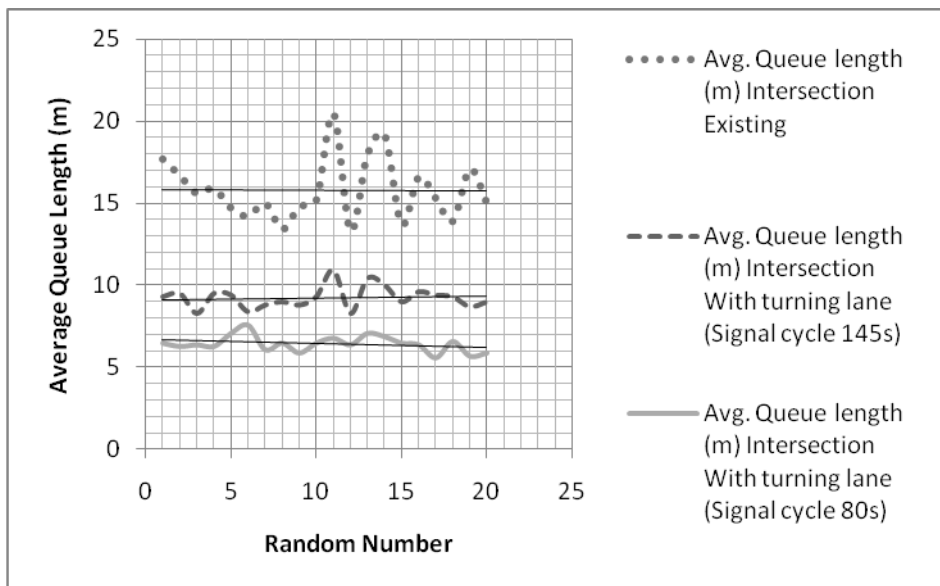


Fig 4: Comparison-Average Queue Length

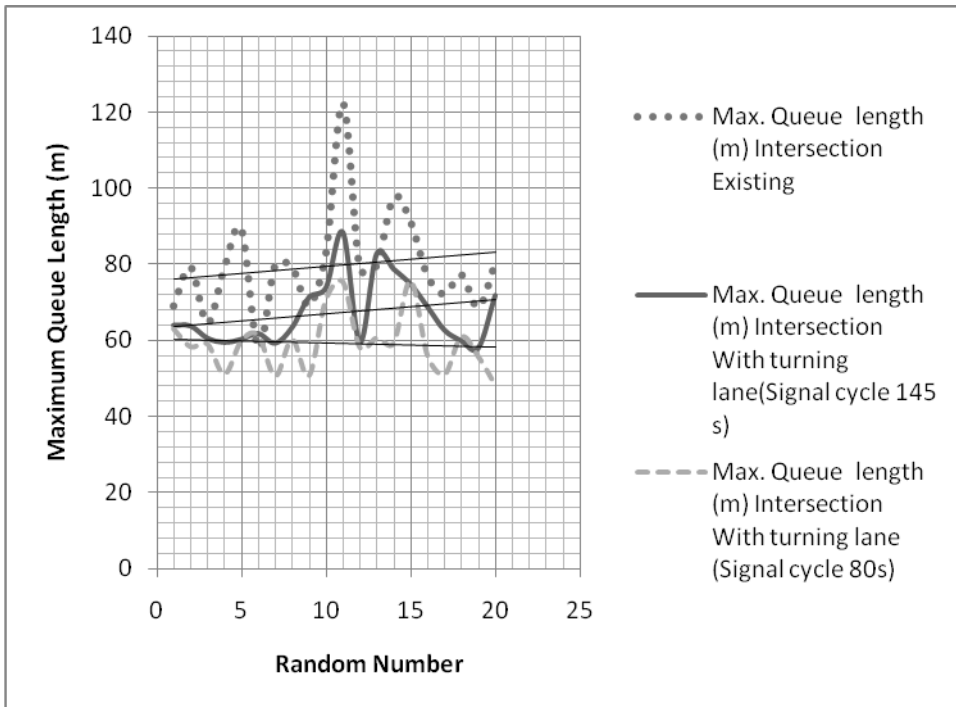


Fig 5: Comparison-Maximum Queue Length

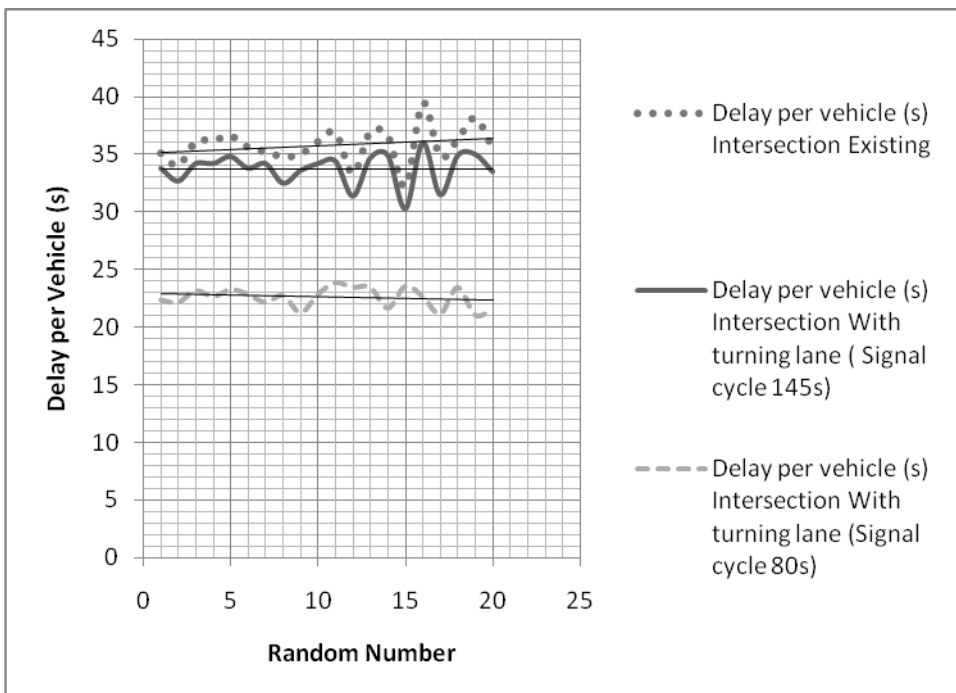


Fig 6: Comparison -Delay time per vehicle

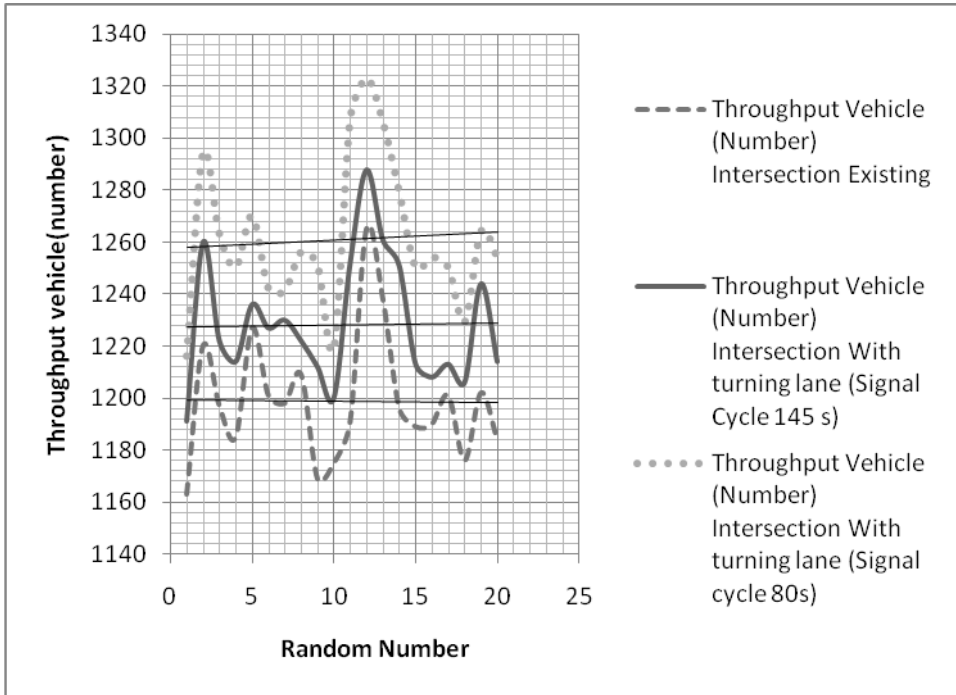


Fig 7: Comparison-Throughput

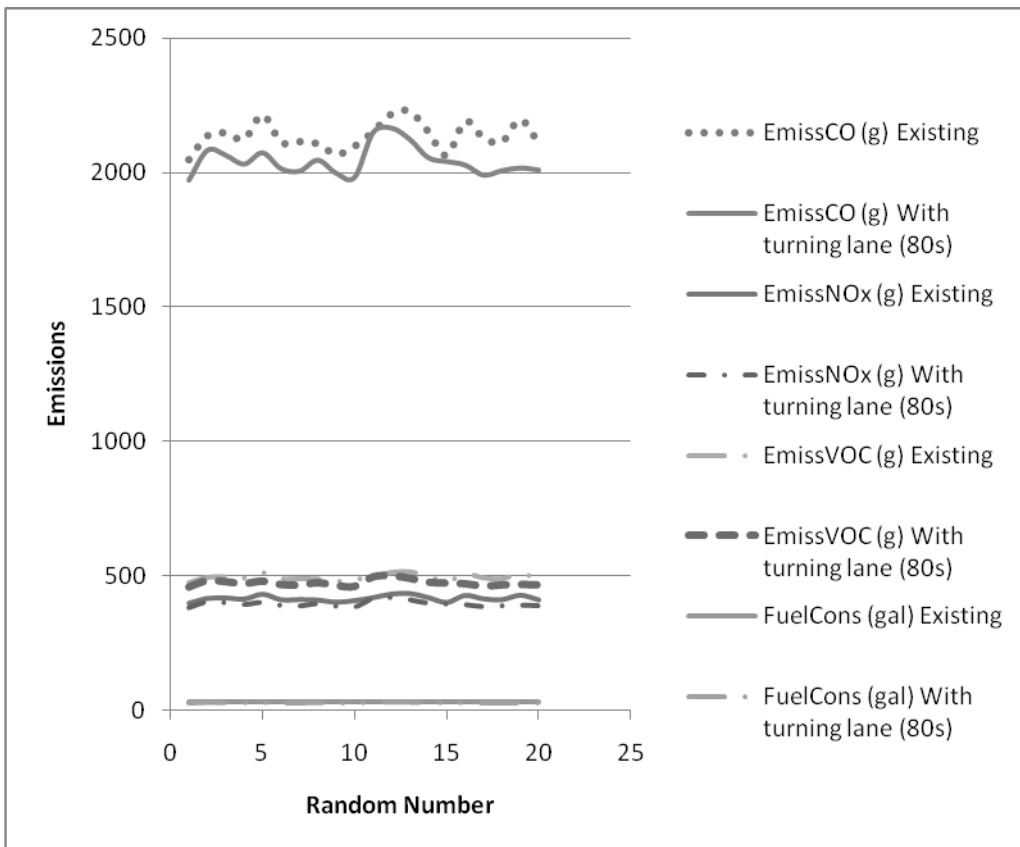


Fig 8: Comparison- Emission CO, NO_x, VOC, Fuel Consumption

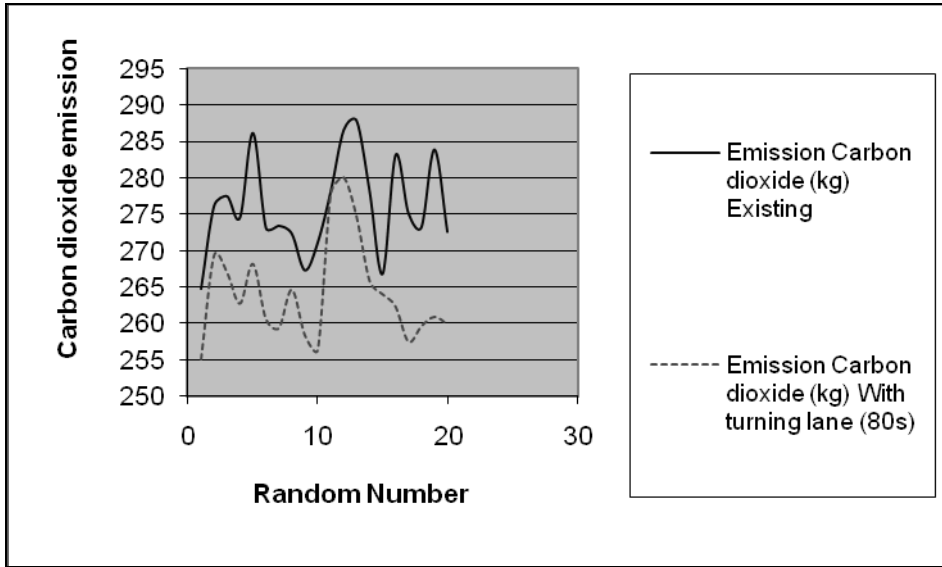


Fig 9: Comparison- Emission CO₂

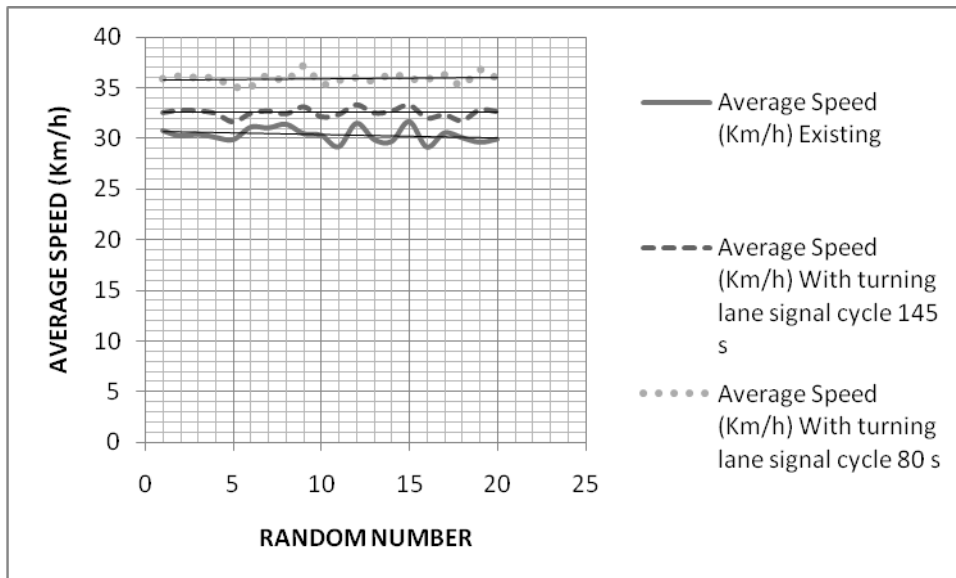


Fig 10: Comparison- Average Speed

7. Results

Fig (4) to (10) shows net effect of addition of turning lane in the middle of approach road and narrowing of lane width from 3.5m to 3.15m for fixed time signal cycle 145 second and 80 second respectively. Fig (4) shows that average queue length decreases significantly by approx. 40% when turning lane is added in the middle of approach road. This is further decreased by approx. 20% when signal cycle is reduced by 45%. Fig (5) shows that maximum queue length is reduced by 15% when turning lane is added in the middle of approach road. This is further decreased by approx. 10% when signal cycle is reduced. Fig (6) shows that average delay time per vehicle gets slightly reduced i.e; by approx 5% when turning lane is added. However, it is significantly reduced i.e; by more than 35% when signal cycle time is reduced. Fig (7) shows that throughput is increased by 2.5% when turning lane is added in the middle of approach road. This is increased by

approx. 5% when signal cycle is reduced. Fig (8) and Fig (9) depicts the effect on emissions. Emissions are reduced as the average delay time is reduced; however, it gets increased when the number of vehicle passing through intersection increases. The net effect is the reduction in emission by 5%. Figure (10) shows that average speed of vehicles in the network gets increased by approx. 9% when turning lane is introduced. It gets further increased by 11% when signal cycle is reduced.

8. Conclusion

The above reported results can be used with advantage to study the effect of various traffic improvement measures. The heterogeneous traffic under Indian driving behaviour can be modelled under constraints of roadway geometry, vehicle characteristics and traffic control. If turning lane is created in the middle (of approach roads) of existing intersection by narrowing existing lane width of approach roads, to segregate turning traffic from through traffic, the effect is significant decrease in average queue and maximum queue length. The average delay time per vehicle also gets reduced but with little effect. However, the average delay time per vehicle gets significantly reduced and average queue length and maximum queue length is further reduced, if signal cycle length is reduced. The throughput gets increased, while there is reduction in emissions and fuel consumption. The average speed of all the vehicles in the network also gets increased. Thus the net result of effects of addition of turning lane in middle of approach road (positive), narrowing of lane width (negative) and reduction in cycle length of signal (positive) is significant improvement in performance of intersection.

Acknowledgement

Authors wishes to acknowledge the able guidance and supervision of Professor B. L. Swami, MNIT, Jaipur, India and support from Mrs. Ritu Sharma, Asst. Prof. MNIT, Jaipur, India.

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