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Evaluation of Earliest Deadline based schedulers for Reduction of Traffic Congestion in Dense Urban Areas

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***Abstract*—The unwanted delay experienced by priority vehicles as a consequence of traffic congestion is one of the major problems faced while efficiently managing priority traffic. Two adaptive traffic light algorithms namely the Earliest Deadline First (EDF) and Fixed Priority (FP) have been proposed and evaluated in the paper to reduce the traffic congestion experienced by priority vehicles. The performance of the algorithms has been evaluated at isolated intersections and their resulting efficiency has been compared against a static traffic lights control implementation as well. It has been shown and deduced through different performance metrics that the overall performance of EDF is better than the FP in controlling traffic congestion for priority vehicles when evaluated against static control.**

***Index Terms*—Earliest deadline First (EDF), Fixed Priority (FP), Intelligent Transportation System (ITS), Sumo (simulation of urban mobility), Adaptive Traffic Light Control**

I. Introduction

One very intersecting and hotly researched topic is the reduction of vehicular traffic congestion on heavy traffic intersections, especially in the presence of high priority vehicles. These high priority vehicles include ambulances, public transportation, and vehicles of other law enforcement agencies. The Intelligent Transportation System based traffic systems are thus gaining immense interest to lessen this vehicular congestion havoc. ITS works by introducing an intelligent communication oriented framework to add intelligence to the transportation systems, using operationally advanced and smart techniques for traffic management [1]. Most notable among these techniques include the Global Positioning System(GPS), mobile telephony, wireless networks, infrared beacons and Dedicated Short Range Communications (DSRC) etc. Advanced Transportation management system is an area among the many ITS techniques gaining a lot of interest. It involves the use of control devices like traffic signals, ramp metering and dynamic highway message signs [1]. These devices work by gathering information and traffic data and making accurate and timely decisions based on this data to manage traffic.

Adaptive Traffic Lights Control (TLC) methods have been popular for a long a time in reducing traffic congestion. Adaptive TLC controls the duration for which a signal remains green or red based on the statistics gathered regarding the traffic state at a particular instant of time. Techniques as old as Exhaustive Algorithm (EA) [2], [3] for controlling the duration of green light till a queue gets empty have been proposed for this purpose. Other contemporary research [4][5][6] greatly highlight the benefits of using Adaptive TLC for effectively reducing vehicular traffic congestion. The current research is an effort to devise an effective adaptive mechanism to control traffic signals adaptively as opposed to the fixed traffic signal control. A smart adaptive traffic signal controller collects the information regarding the state of traffic at different time intervals and then takes timely decisions based on this information thus controlling the duration for which a traffic light remains red or green. We have proposed evaluating the scheduling algorithms particularly the Earliest Deadline First(EDF) and the Fixed Priority(FP) algorithms for the adaptive control of traffic lights in the context of reducing traffic congestion especially for priority vehicles. The term deadline refers to the time frame within which a vehicle should reach its intended destination.

The rest of the research is arranged as follows: Section II gives the Adaptive TLC design specifics for the EDF and FP algorithm implementation. Section III gives details of the simulation setups used for evaluation and the results obtained during simulation and Section IV concludes the discussed work.

II. Adaptive Traffic Lights Design Specifics

The current research focuses on the application of the adaptive traffic lights algorithms, i.e. the EDF and FP for adaptive control of traffic lights in order to control traffic congestion especially in the presence of priority vehicles. To test the feasibility of both the algorithms, they are being applied on two different types of intersections(see Figure 1).

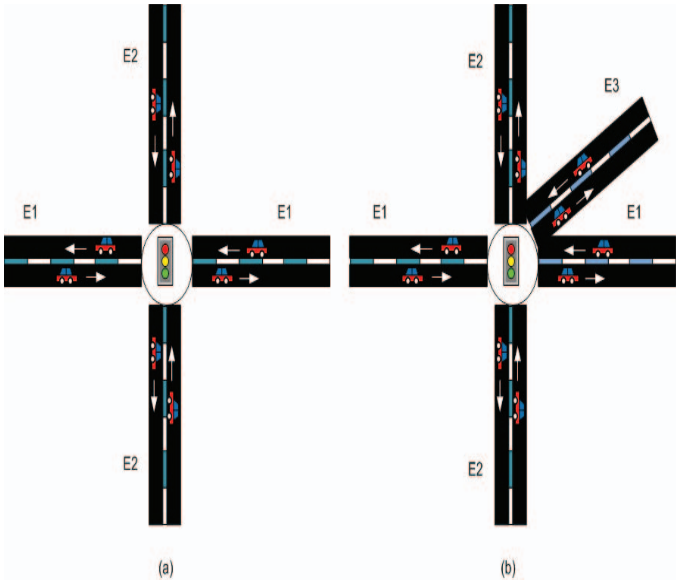


Fig. 1. (a) Simple Traffic Intersection (b) Complex Traffic Intersection

One is the simple intersection(figure 1(a)) comprising of four edges with two way lanes. The other is a relatively complex intersection(figure 1b) having a diagonal fifth edge with all the edges having two way lanes. Two sensors will be installed at the entry and exit points of each lane to detect whether a vehicle has entered or left the lane. These lanes will thus be acting as queues. Each vehicle entering or exiting a queue will convey its priority or deadline to a traffic control unit via a road side unit. This communication will take place using a wireless medium like Zigbee, Wifi etc. The information being received by the controller includes

- Total number of vehicles within a lane.
- Vehicle type (i.e. priority or non priority).
- Total travel time of a vehicle.
- initial assigned deadline of each vehicle.

In the current research, opposite edges are coupled as is the norm. This implies that while serving one edge, the opposite edge is served as well.

A. Fixed Priority (FP) Implementation Considerations

To apply the FP algorithm, the vehicles have been assigned four separate types of priorities namely:

- High Priority Vehicles (HV)
- Medium or Moderate Priority Vehicles (MV)
- Low Priority Vehicles (LV)
- Nil Priority Vehicles (NV)

While serving the different edges, the FP based controller will first serve all edges with HV type vehicles, then MV type vehicles, followed by LV type vehicles and then NV type vehicles. FP is static nature as it serves vehicles according to priorities from highest to lowest and the priority of a vehicle does not change with time. Figure 2 shows a flowchart demonstrating the FP algorithm.

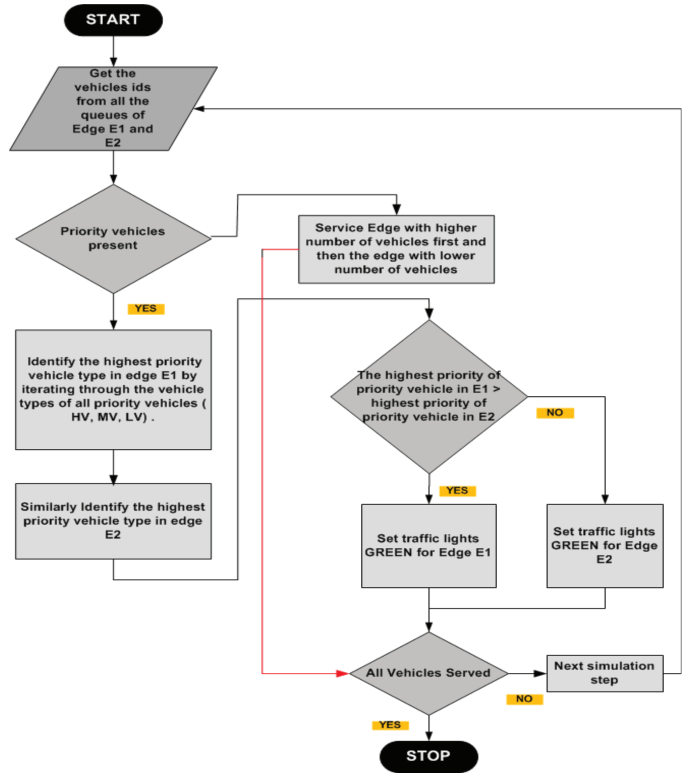


Fig. 2. Fixed Priority Flow Diagram

B. Earliest Deadline First (EDF) Implementation Considerations

EDF uses the deadlines of processes to prioritize their implementation. EDF implementation on priority vehicles assigns the smallest deadline to HV type vehicle, intermediate absolute deadline to MV type vehicles and highest absolute deadline is assigned to the LV type vehicles. While NV type vehicles are not assigned a deadline. These deadlines keep on decreasing till the vehicles reach their destinations. The EDF services vehicles based on their remaining deadline. It serves those edges within an intersection having a vehicle with the lowest deadline first. The EDF thus acts as a dynamic algorithm as it takes its decisions on dynamic deadlines of priority vehicles. The implementation flow of EDF on the intersections of Figure 1 can be seen from figure 3

1) EDF Mathematical Model: The EDF mathematical model for adaptive traffic lights control is based on the model proposed in [7]. Consider a system of N traffic intersections (indexed $n = 1, 2, \ldots, N$), with each intersection having L queues (indexed $l = 1, 2, \ldots, L$) and currently the system having V traveling vehicles (indexed $v = 1, 2, \ldots, V$). The traffic intensity rate i.e. the priority vehicle rate is defined as μ. The rate of missed deadlines is defined as α_v. Each vehicle is assigned a κ_v deadline according to the vehicle priority. Let $\tau \in \mathbb{R}_{>0}$ be a positive real number associated with every vehicle in the system, such that at a time t, $\gamma(t, \tau)$ gives during a time frame $[t, t + \tau]$ the probability that a vehicle misses its deadline.

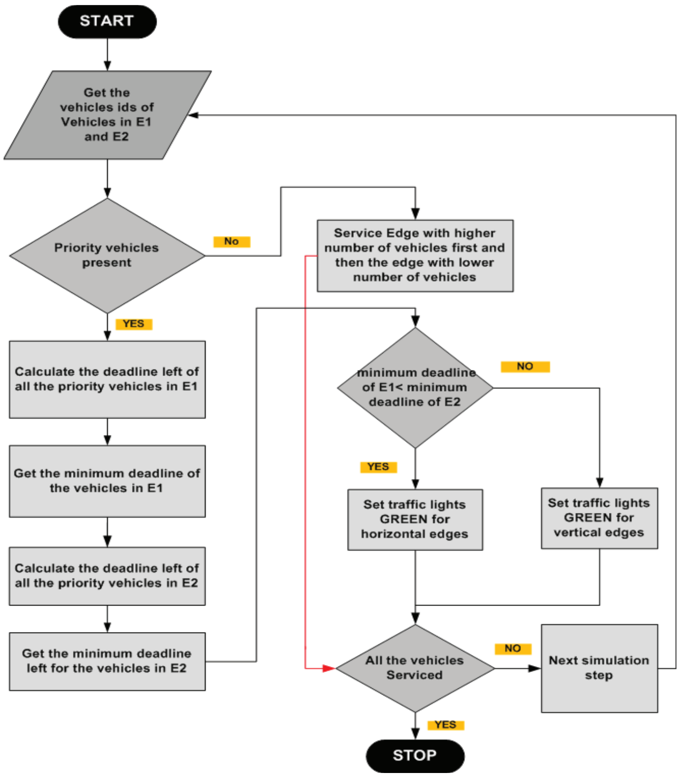


Fig. 3. Earliest Deadline First Flow Diagram

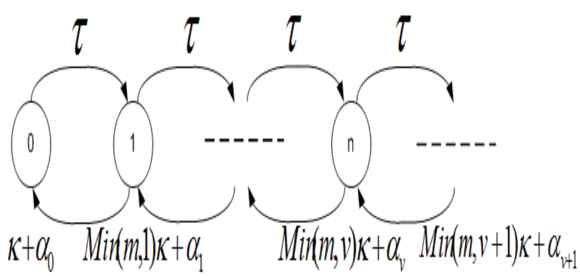


Fig. 4. Markov Model M showing the State Transition Rate

Let us define the rate of missed deadlines as

$$\alpha_v(t) = \frac{\gamma(t,\tau)}{\tau} \tag{1}$$

For a system statistically at equilibrium,

$$\alpha_v = \lim_{\tau \to 0} \alpha_v(t) \tag{2}$$

When the system has v vehicles (moving and waiting at the intersection), the steady state loss rate is defined as α_v. A Markov chain model M derivation (see Figure 4) for the system under consideration shows that at a current value of v vehicles traveling in the system, the number of vehicles can be reduced by 1 owing to the fact that either a vehicle misses its deadline (at the rate α_v) or reaches its destination (at the rate $Min(m,v)\kappa$).

Barrer [8] introduced the steady state rate α_v concept to hep in ascertaining in a deterministic scenario the relative missed deadlines. The EDF scenario being discussed here follows the Deadline till End of Service(DES) and Movaghar [9] has derived the α for this type of EDF.

Letting ρ be the steady state probability in the presence of v vehicles, the solution to the model M (Fig. 4) along with the state probabilities can be derived. For a system at a state of equilibrium, the balanced equations are

$$0 = \begin{cases} -\tau\rho_0 + (\kappa + \alpha_1)\rho_1, & if\ v = 0 \\ \tau\rho_{v-1} + (\tau + Min(m,v)\kappa + \alpha_v)\rho_v & \\ + (Min(m,v+1)\kappa + \alpha_{v+1})\rho_{v+1}, & if\ v > 0 \end{cases} \tag{3}$$

For the conditions at equilibrium in equation 3, solving we get equation 4

$$\rho_v = \frac{\tau^v}{\prod_{j=1}^{v}(\alpha_j + Min(m,j)\kappa)} \tag{4}$$

The normalized condition after derivation becomes,

$$\sum_{v=0}^{\infty} \rho_v = 1 \tag{5}$$

Using equation 4 and 5, it can be derived that

$$\rho_0 = \left(1 + \sum_{v=0}^{\infty} \frac{\tau^v}{\prod_{j=1}^{v}(\alpha_j + Min(m,j)\kappa)}\right)^{-1} \tag{6}$$

Equation 7 now gives the probabilities for the vehicles missing their deadlines.

$$\kappa_{dead} = \frac{\sum_{v=1}^{\infty} \rho_v \alpha_v}{\sum_{v=0}^{\infty} \rho_v \tau} = \frac{\sum_{v=1}^{\infty} \rho_v \alpha_v}{\tau} \tag{7}$$

Equation 7 shows the average rate of deadlines being missed by the average arrival time of vehicles in an intersection.

III. Simulations and Results

EDF and FP algorithms have been simulated for both the intersections shown in Fig. 1. However most simulation results discussed in the paper are performed while considering the simple four-edged intersection.

A. Simulation Setup

For the simulations of the adaptive TLC algorithms i.e. the EDF and FP, a traffic simulator by the name SUMO (Simulation Of Urban Mobility) [10] has been utilized. SUMO has been chosen because it provides better evaluation of the two algorithms as it is a microscopic traffic simulator. XML scripting has been utilized to code the 2-D traffic networks and the routes for the vehicles. This is done because SUMO can work efficiently with XML files whenever large networks of traffic are being simulated and managed [11]. An additional advantage of SUMO is the support it lends for different vehicle types [10]; hence perfectly tailored for the scenarios which are being studied in this research.

A python-based controller receives the traffic statistics from the simulator and takes a decision regarding the lanes which

TABLE I
DIFFERENT TRAFFIC INTENSITIES ASSUMED FOR SIMULATION

Traffic Intensity	Number of Vehicles	Vehicles per Second
Low	400	0.8
Medium	600	1.2
High	800	1.6
Very High	1000	2.0

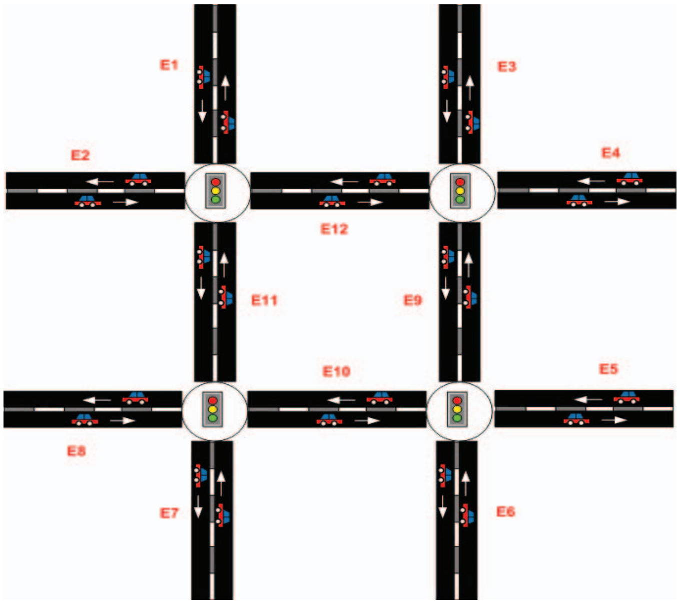


Fig. 5. Network containing Simple Intersections

need to be served. This scheme is based on a client/server model, where the controller is a client with SUMO acting as a server. The EDF or FP algorithm inside the controller act as queue scheduler for a given intersection.

B. Network Containing Simple Intersections

A network of roads having simple intersection can be viewed from Fig. 5. The length of all edges or roads has been fixed at 500 meters. Whereas the trip time for a particular vehicle, in the absence of congestion and commuting on the longest route has been fixed at 163 seconds. In the presence of congestion a congestion-free latency of about 48% has been assumed for all the vehicles. Initially the HV,MV and LV type vehicles have been assigned a deadline of 240, 250 and 260 seconds respectively while simulating the EDF algorithm.

To make matters simple table. I shows the traffic intensities assumed:

The simulations for the network shown in Fig. 5 were carried out for different scenarios by changing the number of lanes within intersecting edges. The parameters used for the evaluation of results are:

- the mean waiting steps,
- mean trip time,
- average speed and
- deadlines missed by the priority vehicles.

Fig. 6(a),(b) and (c) show the mean waiting steps of priority vehicles under different traffic intensities for edges having

TABLE II
PERCENTAGE REDUCTION IN WAITING STEPS FOR DIFFERENT TRAFFIC INTENSITIES AS COMPARED TO STATIC(%)

Algorithms	No of Lanes	Percentage Reduction in waiting steps for Intensities			
		Low (400)	Medium (600)	High (800)	Very High (1000)
EDF	1	83	70	55	20
	2	86	82	50	21
	3	90	71	56	15
FP	1	70	60	49	15
	2	79	70	47	10
	3	81	57	36	10

TABLE III
MEAN WAITING STEPS COMPARISON FOR DIFFERENT VEHICLE TYPES

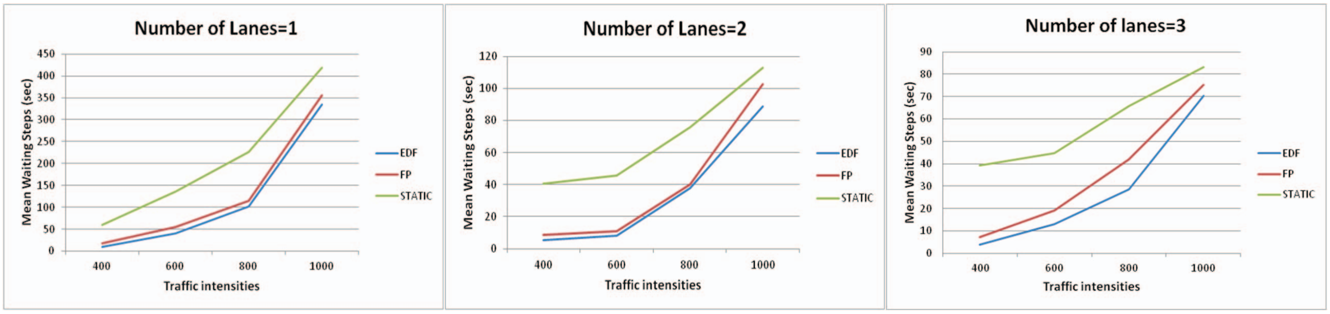
Algorithms	Vehicle Types	Initial Fixed Priority	Mean Waiting Steps
EDF	HV	High	67.44
	MV	Moderate	71.66
	LV	Low	72.2
	NV	None	-
FP	HV	High	53.71
	MV	Moderate	78.7
	LV	Low	94.27
	NV	None	-

different number of lanes and following the network with simple intersections (Fig. 5). However the results for mean waiting steps are compiled irrespective of the number of lanes. The results in Fig. 6(a),(b) and (c) are compiled to compare the mean waiting steps reduction of the two TLC algorithms against static traffic light intersections. Table. II shows the mean waiting steps reduction percentage as compared to static algorithm. From the Table it is clear that EDF gives a better performance in reducing the mean waiting steps.

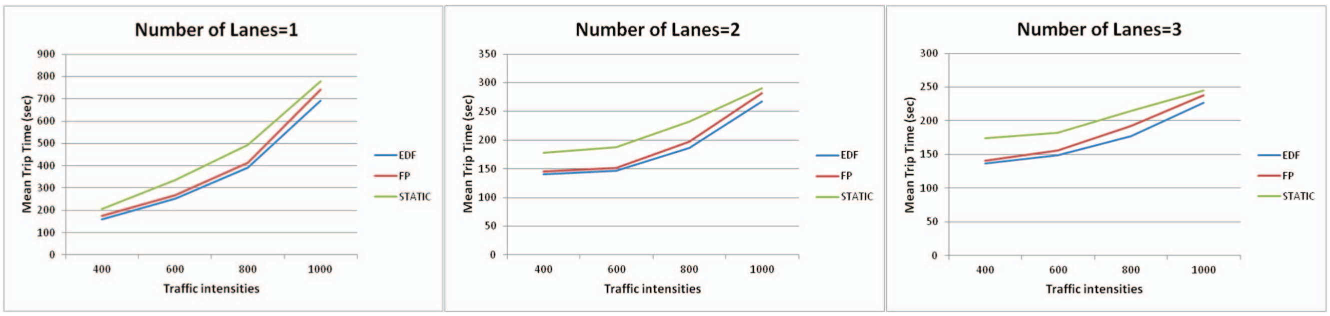
Table III shows that while simulation of FP, for the HV type vehicles we get low mean waiting steps, while MV and LV type vehicles experience higher waiting steps. The EDF simulation in comparison gives almost identical waiting steps irrespective of the type of priority vehicle.

Another measure for evaluating the performance of the two TLC algorithms is to measure the average time consumed bey priority vehicles in reaching their destination. Fig. 6(d), (e) and (f) show that the FP and EDF algorithms greatly reduce the mean trip time of priority vehicles. From the figures it can be seen that for low traffic intensities, EDF and FP give identical performance. For the high traffic intensities, the EDF reduces the mean trip time by 21%,20% and 18% for 1-lane, 2-lanes and 3-lanes edges respectively when compared against static algorithm. While the FP algorithm reduces the mean trip time by 16%, 15% and 11% for 1-lane, 2-lanes and 3-lanes edges respectively.

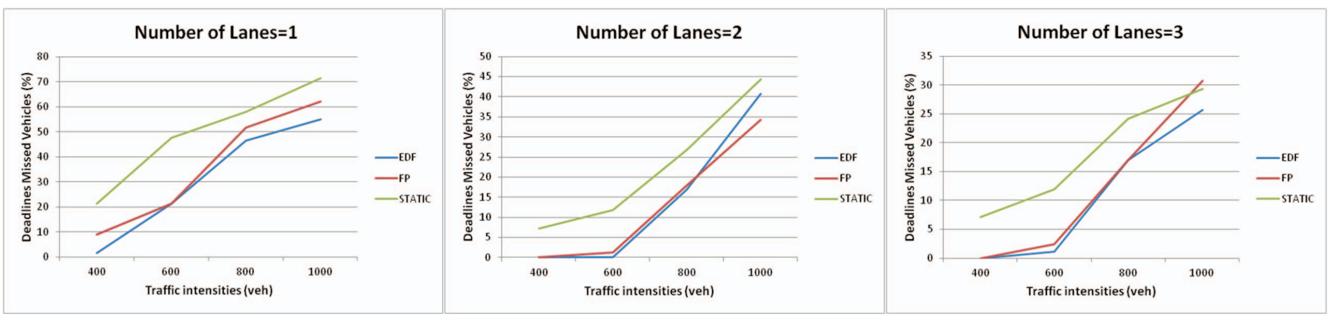
Another criteria for judging the performance of the two TLC algorithms is to evaluate the deadlines missed by priority vehicles. Fig. 6(g), (h) and (i) amount the deadlines missed by priority vehicles for different number of lanes, when compared against the static algorithm. From the three figures it can be seen that the EDF and FP at low to medium traffic intensities reduce the missed deadlines by 60% and by 15% at high traffic intensities. It is also evident that the EDF outperforms the FP



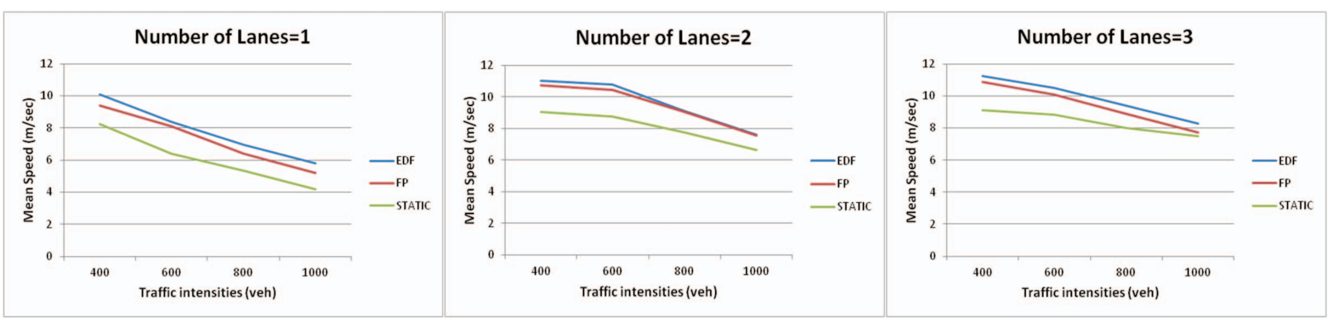
(a) Mean Waiting Steps $Lanes = 1$ (b) $Lanes = 2$ (c) $Lanes = 3$



(d) Mean Trip Time $Lanes = 1$ (e) $Lanes = 2$ (f) $Lanes = 3$



(g) Deadlines Missed $Lanes = 1$ (h) $Lanes = 2$ (i) $Lanes = 3$



(j) Mean Speed $Lanes = 1$ (k) $Lanes = 2$ (l) $Lanes = 3$

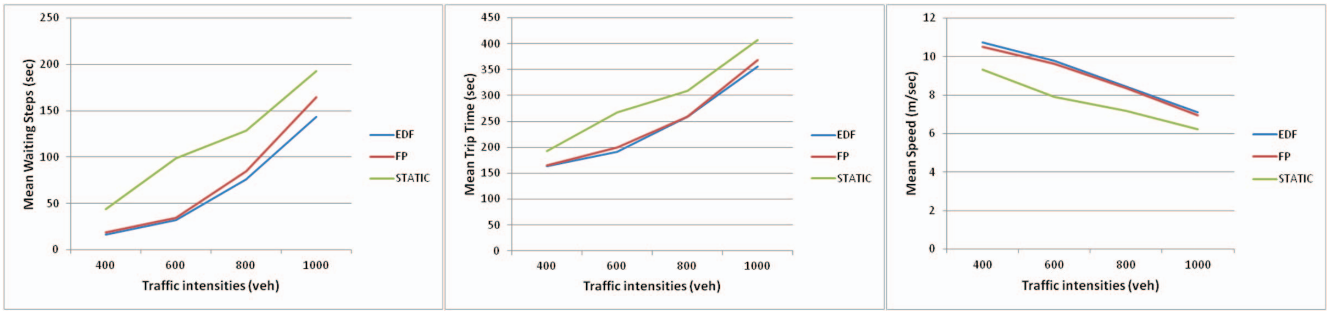
Fig. 6. Performance Evaluation for Priority Vehicles with Different number of Lanes per Edges for Network with Simple Intersections

in reducing missed deadlines as it operates on the remaining deadline of priority vehicles, while FP operates on the static vehicle priorities which remain fixed.

Fig. 6(j),(k) and (l) show that using the EDF and FP algorithm greatly reduces the waiting steps and thus increase the speed of priority vehicles as compared to static implementation.

C. Network Containing Complex Intersections

Performance evaluation of EDF and FP algorithms has also been carried out on the network containing complex intersections shown in Fig. 8. All the edges of Fig. 8 have the same length as edges of simple network of Fig 5 except for edge E13 which is 500 meters long. The vehicle generation



(a) Mean Waiting Steps of Priority Vehicles (b) Mean Trip Time of Priority Vehicles (c) Mean Speed of Priority Vehicles

Fig. 7. Performance Evaluation for Priority Vehicles for Network with Complex Intersections

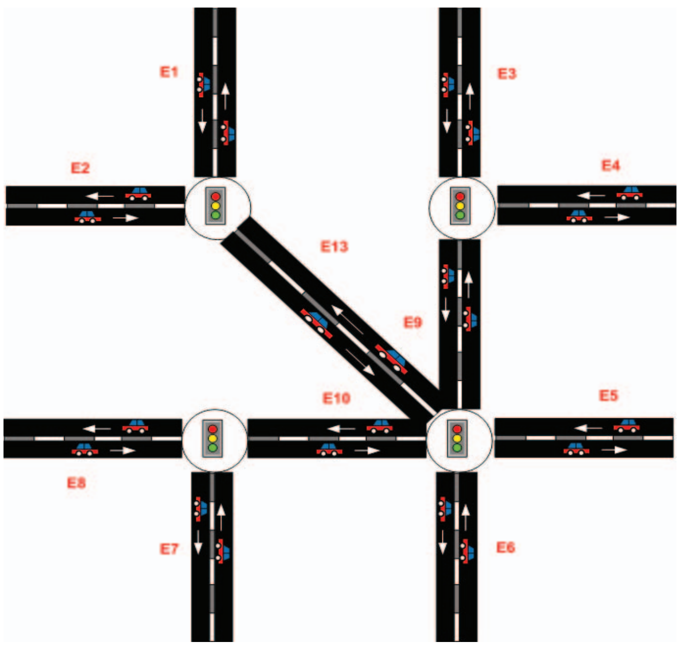


Fig. 8. Network containing Complex Intersections

is assumed at 500 seconds and the traffic intensity of priority vehicles is set at 14% of the total traffic.

The mean waiting steps (see Fig. 7(a)) are reduced by 50% by using the EDF and FP algorithm when compared to static implementation. Furthermore it can be seen that EDF gives a better performance than FP. Comparing the simple and complex network intersections of Fig. 5 and Fig. 8, it can be seen that the two TLC algorithms perform better at the simple intersection network as the traffic is uniformly distributed on all edges of simple network. While in the complex network E13 is the only edge accommodating traffic from Edges E1 and E2 thus resulting in some traffic congestion on E13.

The mean trip time and mean speed parameters (see Fig. 7(b) and (c)) of priority vehicles are greatly improved by using FP and EDF algorithms. However the congestion at Edge E13 of complex intersection (Fig. 8) results in considerable but lesser improvement in these parameters when compared against the simple intersections of Fig. 5.

IV. Conclusion

We presented in this paper, an evaluation of two scheduling algorithms i.e. the EDF and FP for eradicating the unwanted delay experienced by priority vehicles as a consequence of traffic congestion. The comparison of the two algorithms show that these outperform the static fixed control algorithm. Using different performance measuring parameter e.g. the mean waiting steps and the mean trip time, we can observe a considerable performance improvement by using the two adaptive TLC algorithms. It has been further observed that the EDF gives a better performance than FP while controlling the congestion for priority vehicles.

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