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Priority Level Mutualism for Emergency Vehicle using Game Theory

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Abstract— **Congestion growth problem is a daily life experience all over the world, especially in large cities. The motion of Emergency Vehicles (EVs) like Ambulances, police, and firefighting vehicles are highly affected by traffic Congestion, by which rescue time may cost a life. The Priority Level Mutualism for Emergency Vehicle (PLMEV) algorithm aims to reduce the waiting time by giving higher priority for the EVs at the intersection. According to the vehicle's priorities, The Game Theory will control the traffic at the intersection. The PLMEV classifies EVs according to their emergency levels. The algorithm has a highly scalable property with a different number of vehicles. Also, has adaptive property to different vehicle type distribution and work with multiple EVs. Simulation evaluates the PLMEV's performance by comparing it with the Fixed Traffic Control System. The Simulation's results proved that The PLMEV reduced the waiting time for EVs to 42.7% on average, on the other hand, the normal vehicle's time has been reduced to 15.1% on average, while the maximum vehicle waiting time is reduced to 22.3% on average. In case there is no EVs at the intersection, the PLMEV works in optimising the traffic flow.**

Keywords— Intelligent Vehicles, Game Theory, Emergency Vehicle, Traffic Control.

I. INTRODUCTION

IN the recent decades, traffic congestion problem has grown all over the world especially in the urban areas. According to the previous studies, the congestion happened in 471 urban areas in the United States causing a travel delay around 3.7 billion hours [1]. The Intelligent Transportation Systems (ITS) have developed an efficient solution to recover the congestion problems, which reflects a less travelling time and less fuel consumption.

The main congestion problem initiated mainly in the intersections. Fixed Traffic Control is the method used to control the intersection by using fixed time plan. There are other approaches that are proposed to replace Fixed traffic control, such as neural network method, fuzzy method, and reinforcement learning. The fuzzy control system is applied to control isolated intersection with a limited application in the large-scale system [2, 3]. The neural network is applied to adapt a high traffic flow variation in the intersection [4, 5].

The congestion affects all vehicles in the intersection; rescue time is critical for EVs. That is why Many emergency vehicle preemption approaches are proposed to reduce the emergency rescue time. Preemption system manipulates traffic signals in the direction of an EV. Preemption main principle is detecting the EV by sensors at each intersection, such as acoustic sensors, infrared sensors, light sensors, and radio wave system, which produce a negative impact on the other normal vehicles and doesn't differentiate between emergency levels of EVs.

According to the different conflict of interest between the vehicles with various levels of priority the research interactive cooperation and coordination relationship is needed among many rational participators. PLMEV uses the Game Theory to develop mathematical framework between vehicles. Also, PLMEV gives different levels of priority to vehicles according to their emergency levels, to reduce the waiting time of EVs and achieves a positive impact on the normal vehicles at the same time. The algorithm has a high scalable property with different intersection capacity. Also, it adapts with various vehicles type distribution and multiple EVs at the intersection. The proposed algorithm can detect and prevent intersection blockage by monitoring the intersection output road.

The rest of this paper is organised as the follows, Section II discuss the Literature Review. Section III provides a brief introduction to the Chicken Game. Section IV introduces the Proposed Algorithm. Section V shows the simulation results and Section VI discusses the conclusion.

II. LITERATURE REVIEW

According to the previous studies, there are many methodologies for EV preemption. In Acoustics, the siren is used at the preemption system for EV. The acoustic sensors quality are highly affected by building reflection and distortion sources, which produce false trigger in this scheme[6]. In optical based EV detection system, the main requirement for the transmitters and receivers is a line of sight (LOS), which can be distorted by light and obstruction in the environment[7]. The GPS and Radio Frequency (RF) communication system are used to communicate for far non-line of sight. The radio waves are highly affected by the interference of the same frequency band [8]. The recent researches solution for EV preemption reflects a negative impact on the normal vehicle[9, 10].

Game Theory is used to design a mathematical framework between vehicles at the intersection where Cooperation and conflicts are modelled between rational vehicles. In [11], the author applied the Game Theory to an isolated intersection without considering the priority of vehicles, using four vehicles at the intersection.

III. CHICKEN GAME

The chicken game is the basic game used in our algorithm[12]. The chicken game is a two-player game, which can be presented as two vehicles coming from the opposite directions in the same lane towards each other. Each player has two actions either to continue driving straight or to swerve away from the road. The game payoff matrix is shown in Table 1, where SW and ST are swerve and straight strategy respectively. The matrix payoff has to fulfil the inequalities in (1) and (2) [1], where S, W, L, and C are player payoffs.

Table 1. Game Payoff Matrix

	Swerve(SW)	**Straight(ST)**
Swerve(SW)	S, S	L, W
Straight(ST)	W, L	C, C

$$W > S > L > C \tag{1}$$

$$2S > L + W \tag{2}$$

The player in the chicken game has two strategies, either to select swerve or straight. If both players select straight, they would have the worst payoff. If both players select swerve, they would have the same neutral payoff. In case each player chooses a different strategy, the player who selects the straight strategy would get a higher payoff as a reward. The game has no dominant strategy for any player. The best response for player 2 (P2) is to swerve when player 1(P1) selects straight. Also, P2 selects straight if P1 selects swerve. This game has two pure Nash equilibrium and mixed equilibrium. In the mixed equilibrium, a player selects to swerve with probability P(SW). U_{sw2} is P2 swerve utility for all P1 different strategies (3). U_{st2} is P2 straight utility for all P1 different strategies (4) [1]. If both players play the Mixed strategy, player gain would be as shown in (7). The gain when playing the Mixed -Nash would be less than playing minimax strategy swerve.

$$U_{sw2} = P(sw1)(S) + (1 - P(sw1))(L) \tag{3}$$

$$U_{st2} = P(sw1)(W) + (1 - P(sw1))(C) \tag{4}$$

$$U_{sw2} = U_{st2} \tag{5}$$

$$P(SW1) = \frac{L - C}{(W - S) + (L - C)} \tag{6}$$

$$G = \frac{ST - RP}{(T - R) + (S - P)} \tag{7}$$

IV. THE PROPOSED ALGORITHM

In this section, the proposed method would be presented in three main phases as follows: (1) communication architecture, (2) Utility Processing Unit (UPU) and (3) Game Theory Algorithm unit(GTAU). Our solution would consist of Mobile application in the vehicle and main control Unit for each city which controls the traffic light at each intersection.

A. Communication Architecture

The communication architecture is shown in Fig.1 One intersection represented with four roads, each has *N* number of vehicles. The V1 is the first vehicle in the row, and VN is the last vehicle. There are two types of vehicles normal and emergency. The intersection is connected to the Main Control Unit (MCU), where MCU consists of UPU and GTAU. The UPU is responsible for receiving the data from the vehicles and calculating the Road Utility (RUx). GTAU is in charge of controlling the Traffic Control Unit (TCU).

Vehicles communicate with the MCU by the mobile application which is linked to the Web Server through the Internet connection. All vehicles send their GPS coordination, and EVs send their emergency level.

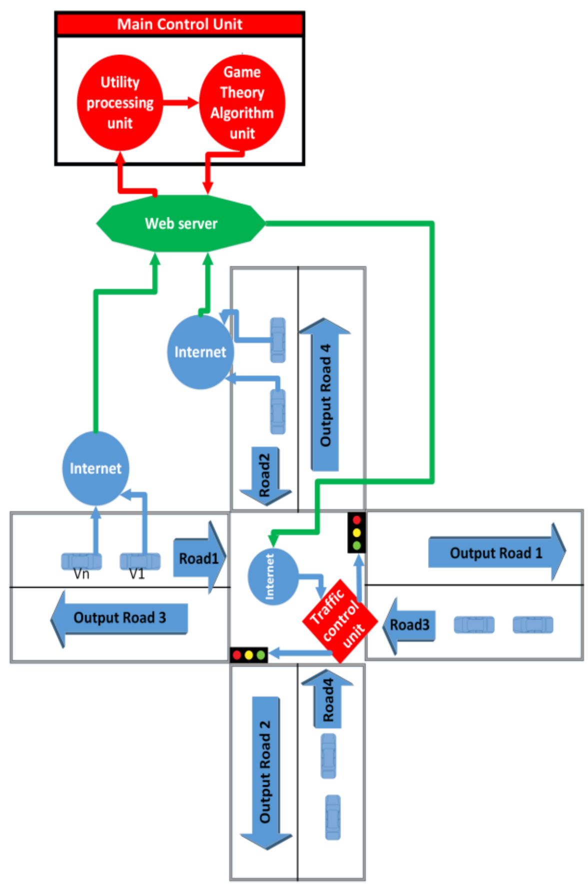

Figure 1. Communication Architecture

B. Utility Processing Unit

UPU is responsible for calculating the RUx and the Output Road Block factor (ORBx). RUx is the sum of all the Normal Vehicles Rank (NVR) and Emergency Vehicles Rank (EVR) in the road. The RUx is calculated for each road in the intersection.

NVR is the constant low-rank value for all normal vehicles. EVR is calculated as shown in (8), where VRR and EVCR are the Vehicle Road Rank and the Emergency Vehicle Custom Rank. The UPU calculates VRR according to the road capacity and the distribution of the vehicles in the intersection. If any of the road parameters are changed, the VRR will change to adapt to the new condition. EVCR is a specific rank for each EV, where it represents the emergency level of the vehicle. This rank is a real-time rank, where it can be changed at any time from the vehicle according to the emergency level update. EVCR is ranged from zero to seven, where seven represents the highest emergency level, and zero represents the least emergency level. The motivation of using seven emergency levels is to allow PLMEV to handle multiple EVs, where it can prioritize one EV to other according to its EVCR.

$$EVR = VRR + \frac{EVCR}{7} VRR \tag{8}$$

Sometimes the fixed traffic control opens the road to a blocked output road. The PLMEV detects and prevents the vehicle's supply to a blocked output road. ORBx equals one if the output road is opened. If the output road gets full more than 95% of its maximum capacity, then ORBx is changed to negative one.

C. Game Theory Algorithm Unit

GTAU is responsible for controlling the TCU. The unit takes RUx and ORBx as input, and then it selects the appropriate strategy to apply at the intersection.

In our game there are two players, Each player controls two roads. P1 controls road one and three. P2 controls road two and four. Each player has two actions to selects between either green or red for each road. The Player has four strategies to select from, as shown in Table 2.

Algorithm Matrix is presented in Table 3. it contains all the possible strategies for both players in terms of the RUx and ORBx. GTAU will fill the matrix with the input data from the UPU; then it finds the Nash Equilibrium solution for the matrix. The GTAU will apply the strategy corresponding to the Nash Equilibrium in the intersection. It sends the selected strategy through the internet to the TCU.

Table 2. Player strategy

Player 1		Player 2	
Road 1	**Road 3**	**Road 2**	**Road 4**
Green	Green	Green	Green
Green	Red	Green	Red
Red	Green	Red	Green
Red	Red	Red	Red

V. Simulation Results

For testing the PLMEV, four Matlab Monte Carlo Simulations is held assuming one intersection with four roads and two players. Simulations will compare the proposed algorithm with the Fixed Traffic Control as shown in Fig. 2.

Table 3: Algorithm Matrix

		Player 2 (Road 2 / Road 4)			
Player 1 (Road 1 / Road 3)	**Action**	**Green Green**	**Green Red**	**Red Green**	**Red Red**
	Green Green	-100 -100	-100 -100	-100 -100	$(RU_1 \times ORB_1) + (RU_3 \times ORB_3) - RU_2 - RU_4$
	Green Red	-100 -100	-100 -100	-100 -100	$(RU_1 \times ORB_1) - RU_2 - RU_4$
	Red Green	-100 -100	-100 -100	-100 -100	$(RU_3 \times ORB_3) - RU_2 - RU_4$
	Red Red	$- RU_1 - RU_3 + (RU_2 \times ORB_2) + (RU_4 \times ORB_4)$	$- RU_1 - RU_3 + (RU_2 \times ORB_2)$	$- RU_1 - RU_3 + (RU_4 \times ORB_4)$	$- RU_1 - RU_3 - RU_2 - RU_4$

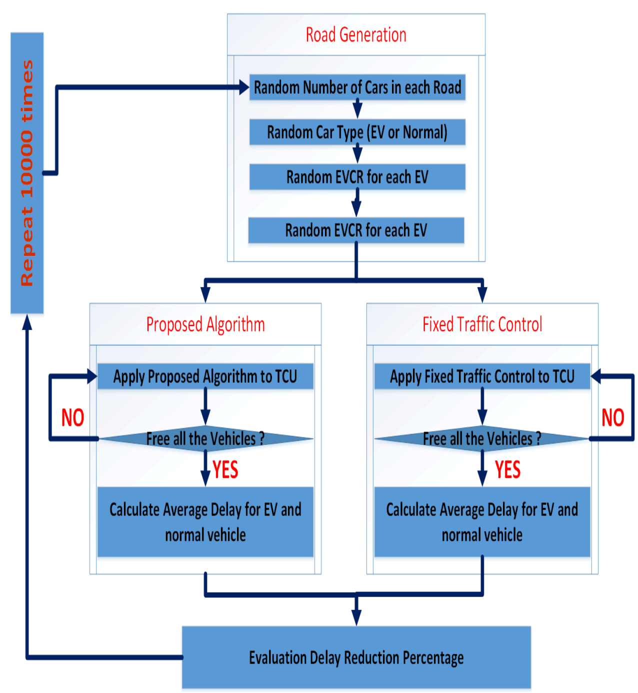

Figure 2. Simulation Flow Chart

Each of the following variables has random uniform distribution along the 10000 simulation cases:

- Number of vehicles in each road varies from 1 to MVN, where MVN is the maximum number of vehicles on each road.
- The type of each vehicle either normal or emergency varies randomly but follows specific Emergency Vehicle Distribution Percentage (EVDP). Number of EV is still random, but it is only upper limited by the EVDP.
- EVCR varies from zero to seven.
- Random Blockage is in any of the four output roads.

The four simulations can be classified as following:

A. Low capacity intersection.
B. High capacity intersection.
C. Scalability Property testing.
D. Different EV distribution percentage testing

A. Low Capacity Intersection:

Intersection capacity is the maximum number of vehicles passing during a specific period. Low capacity has small arrival rate of vehicles which produces short queue length. Based on the previous study for Beacon Street, Boston, USA [13] Assume that MVN is 20 for small arrival rate and short queue length. Simulation of EVDP is equal to 5%. This percentage is selected to have multiple EV at the intersection. Monte Carlo Simulation is repeated for 10000 cases.

The histogram in Fig. 3 shows the average delay reduction percentage for EVs in the low capacity intersection relative to the frequency of occurrence for each reduction percentage. PLMEV decreased the overall delay of the EVs to 35.8 % on average. Positive reduction values verify that PLMEV provides less waiting time for EVs compared to the Fixed Traffic control.

The histogram in Fig. 4 shows the average delay reduction percentage for normal vehicles in the low capacity intersection relative to the frequency of occurrence for each reduction percentage. While achieving 35.8% reduction for EVs, PLMEV succeeded to have a positive reduction on normal vehicles by 9.1% on average. Most of the cases have positive reduction values which verify that the PLMEV provides less waiting time for all vehicles compared to the Fixed Traffic control. The negative reduction comes from the cases when PLMEV fails to give both the emergency and normal vehicles positive reduction. In this case, PLMEV has to prioritise the EVs.

The PLMEV time resource allocation has to be fair among all the vehicles in the intersection; This can be achieved by reducing the maximum delay for any vehicle at the intersection. Vehicle maximum delay is the delay calculated for the last vehicle leaving the intersection. The Histogram in Fig. 5 shows the vehicle maximum delay reduction percentage for last vehicle relative to the frequency of occurrence for each reduction percentage. Positive reduction proves that the PLMEV is not only improving the waiting time for the EVs but it also enhances the fairness of vehicles allocation by reducing the average maximum delay by 18.5% on average.

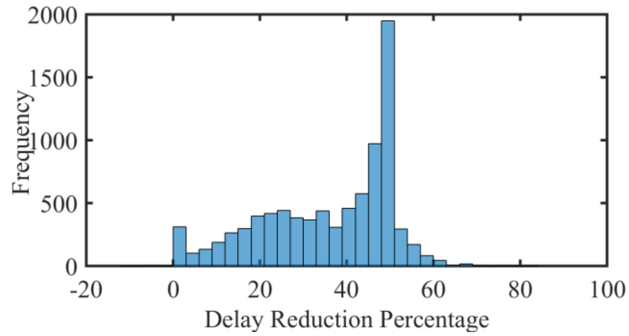

Figure 3. Histogram Delay Time Reduction Percentage for Emergency Vehicles at Low Capacity Intersection

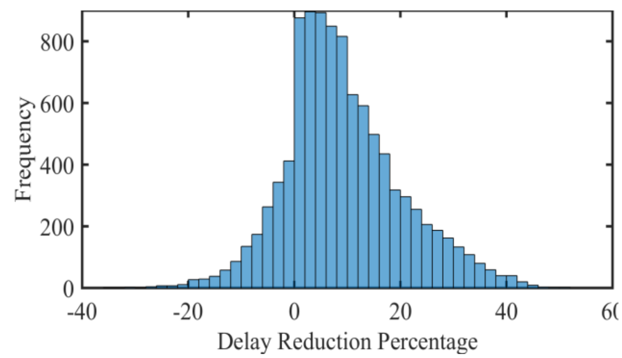

Figure 4. Histogram Average Delay Time Reduction Percentage for Normal Vehicles at Low Capacity Intersection

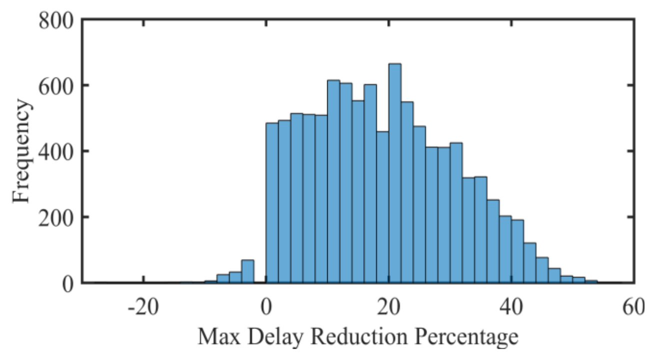

Figure 5. Histogram Vehicle Maximum Delay Reduction Percentage at low Capacity Intersection

B. High Capacity Intersection

In this simulation, the MVN is assumed to be 100 to represent the high capacity intersection with long queue length. EVDP is set to 1%; This percentage is selected to have multiple EVs at the intersection. Monte Carlo Simulation is repeated for 10000 cases.

The histogram in Fig. 6 shows the average delay reduction percentage for the EVs at a high capacity intersection relative to the frequency of occurrence for each reduction percentage. PLMEV decreased the overall delay of the EVs to 49 % on average. A higher reduction percentage is achieved in a high capacity compared to the low capacity intersection.

The histogram in Fig. 7 shows the average delay reduction percentage of normal vehicles at high capacity intersection relative to the frequency of occurrence for each reduction percentage. While achieving 49% reduction for EVs, PLMEV succeeded to have a positive reduction on normal vehicles by 21.1% on average.

The histogram in Fig. 8 shows the vehicle maximum delay reduction percentage for the last vehicle at high capacity intersection relative to the frequency of occurrence for each reduction percentage. The simulation shows an average reduction of the maximum delay by 26.3% on average. Higher reduction rates can be achieved in a high capacity compared to the low capacity intersection.

C. Scalability Property Testing

In this simulation, scalability property is verified by testing the PLMEV on different queue lengths. Assume that MVN changes from 1 to 100 with step size 1. The simulation will consist of 100 Monte Carlo Simulations each has 10000 cases.

The histogram in Fig. 9 shows the average delay reduction percentage of EVs relative to different MVN. Reduction percentage of EVs is relatively proportional to the number of vehicles. PLMEV proves to be scalable with the intersection size. The mean reduction for EVS for the 100 simulations is equal to 42.7%.

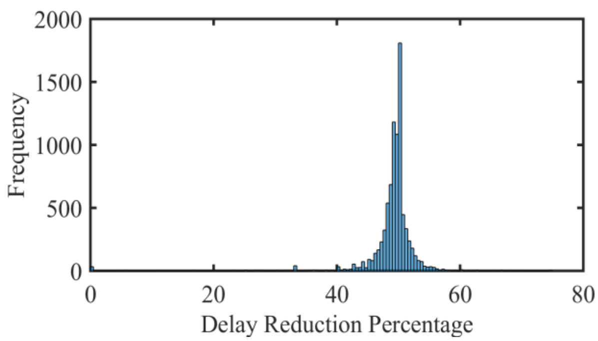

Figure 6.Histogram Average Delay Reduction Percentage for Emergency Vehicles at High Capacity Intersection

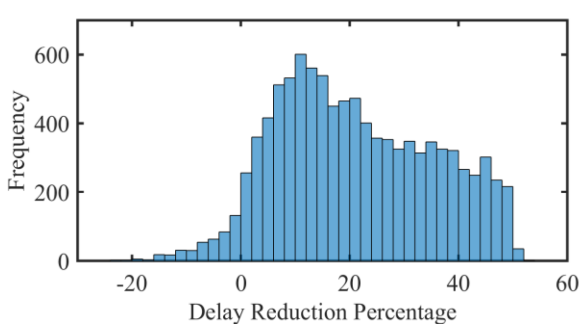

Figure 7. Histogram Average Delay Reduction Percentage for normal Vehicles at High Capacity Intersection

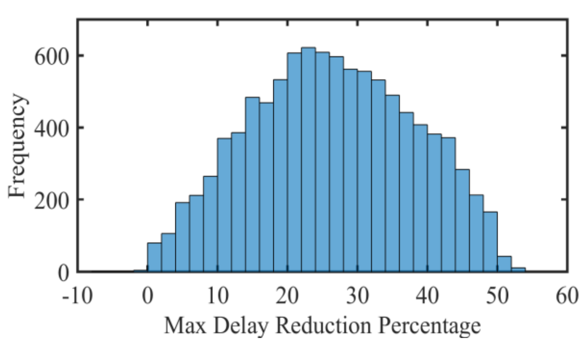

Figure 8. Histogram Vehicle Maximum Delay Reduction Percentage at High Capacity Intersection

The histogram in Fig. 10 shows the average delay reduction percentage for normal vehicles relative to different MVN. The reduction percentage is relatively proportional to the number of vehicles. The proposed algorithm proves to be scalable with the intersection size. The mean reduction for normal vehicles for the100 simulations is equal to 15.1%.

D. Different EV Distribution percentage testing

In this simulation, PLMEV is tested with different EV distribution percentage. Assume that EVDP changes from 1 to 100 with a step size of 1. The simulation will consist of 100 Monte Carlo Simulations each has10000 cases.

The histogram in Fig. 11 shows the average delay reduction percentage of EVs relative to different EVDP. If EVDP is equal to zero, then the reduction percentage is also will be equal to zero due to the missing EVs. As the number of EVDP increases, the Reduction percentage will increase to 47% and be stable around this value.

The histogram in Fig. 12 shows the average delay reduction percentage for normal vehicles relative to different EVDP. With low EVDP the normal vehicle will have low reduction rate compared to the EVs because PLMEV gives a higher priority to the EVs. As the EVDP increases the reduction percentage for the normal vehicle increases due to the lane link between both types of vehicles. Finally, when EVDP is equal to zero, the reduction percentage will reach zero due to the absence of normal vehicles. PLMEV proves to be adaptive to different EV distribution percentages.

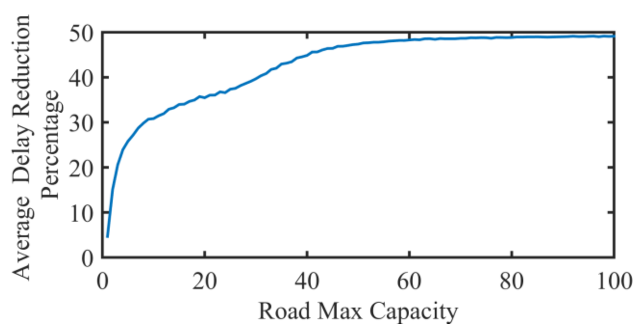

Figure 9. Average Delay Reduction for Emergency Vehicles with Different Capacity

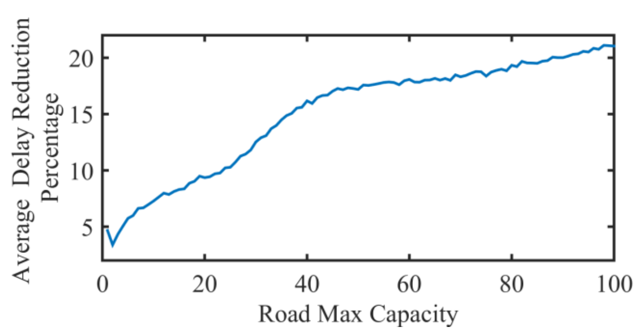

Figure 10. Average Delay Reduction for Normal Vehicles with Different Intersection Capacity

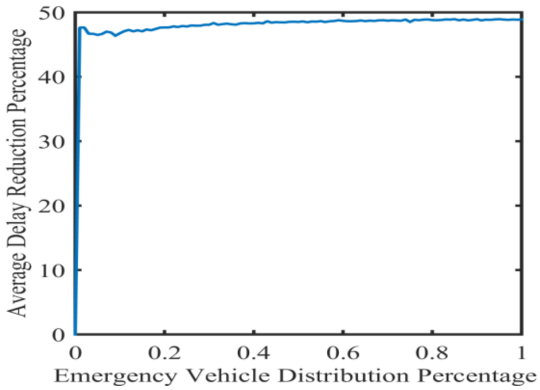

Figure 11. Average Delay Reduction for Emergency Vehicles with Different Emergency vehicle distribution percentages

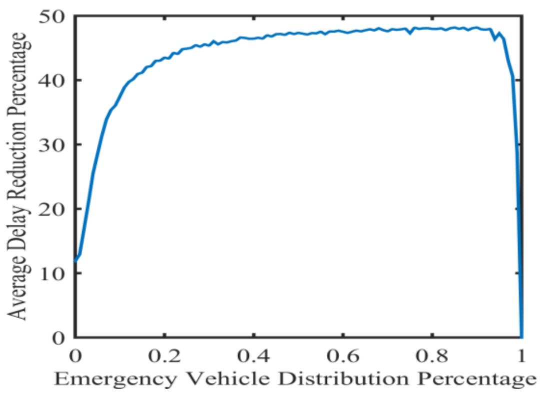

Figure 12. Average Delay Reduction for normal Vehicles with Different Intersection Capacity

VI. CONCLUSION

In this paper, PLMEV gives different vehicle priorities according to their emergency level based on the Game Theory by developing a mathematical framework. The system was tested by the low and high capacity intersection. In Low Capacity Intersection, PLMEV reduces the overall delay of the EVs to 35.8%, while having a positive reduction with normal vehicles by 9.1% at the same time. The average reduction of the maximum delay is reduced by 18.5%. In the High Capacity Intersection, PLMEV reduces the overall delay of the EVs to 49% while having a positive reduction with normal vehicles by 21.1%. The average reduction of the maximum delay is reduced by 26.3%.

Further simulations are done to test the scalability and the adaptation of different EV distributions. In the Scalability Property testing, PLMEV proves to be scalable with different intersection size, the mean reduction for the EVs is equal to 42.7% and for normal vehicles is 15.1%. PLMEV is capable of prioritising multiple EVs successfully. Intersection blockage is detected and prevented by selecting the optimum strategy.

The future work aims to test PLMEV with multi-intersections and multiple lanes roads. Compare PLMEV with one of the state of the art methods for traffic intersection control.

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