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Effect of Emergency Interrupt Complexity on the Performance of Adaptive Network Based Fuzzy Inference Traffic Light Control System

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Abstract

ANFIS controller is an advance technique of controlling in Traffic Light Control System (TLCS) which adjusts signal timing parameters in response to real time traffic flow fluctuations. However, the performance of ANFIS controller has not been investigated in an emergency environment. Hence, this paper investigates the effect of emergency lane sensor signal interrupt complexity on the performance of an Adaptive Network Based Fuzzy Inference System (ANFIS) TLCS. The cross roads junction with two lanes per road was considered. One Pedestrian and one Railway lane were considered as emergency lanes. One Traffic Light (TL) was used to control vehicle on each road. ANFIS-TLCS was simulated using graphic user interface tool of the MATLAB. The GUI was simulated for the four different cases of emergency interrupt complexity at some specific simulation periods and the preset number of vehicles for each lane using slide button. Performance of the ANFIS controller was tested for: no, more and most complexity emergency Interrupt cases using Cost Efficiency (CE) as a performance metric. The results obtained showed that ANFIS controller performed differently in all tested cases and worse as the complexity increases but performed relatively equal and better at a higher simulation period regardless of the interrupt complexity. Hence, ANFIS controller is recommended as a better Traffic Light controlling technique regardless of any complexity at the road junction.

Keywords: Cross road, Traffic Light, Emergency Interrupt Complexity, ANFIS Object, and Cost Efficiency

1. Introduction

The traffic congestion problem such as productive time loss, high rate of fuel consumption, environmental pollution which can lead to respiratory health hazard and ozone layer depletion due to high rate of carbon monoxide (CO) emission are challenges facing the area where the high traffic volume exists. Therefore, traffic management and control have become a major problem in both developing and developed countries. Governments have been spending huge amounts to develop traffic control system using different methods, by incorporating the advanced information technology (Khaled, 2010).

Most current traffic signal control systems used in real world are either pre-timed or actuated control. One major problem with the pre-timed signal control is that it does not have the capability to respond to short-term traffic demand and pattern changes. Traffic actuated control can partially solve this problem by extending green phases in response to real-time traffic arrivals. However, this green phase extension strategy makes decision primarily based on traffic arrivals of the movements being served. Even very long queues on other movements may not stop the extension of the current green phase. When traffic demand is heavy, actuated control can result in unsatisfying control performance (Yuanchang, 2007).

Artificial Neural Fuzzy Inference System (ANFIS) based traffic light control, which adjusts signal timing parameters in response to real time traffic flow fluctuations, has a great potential to outperform both pre-timed and actuated control and has been researched for the last few decades. ANFIS can also be refered to an Adaptive Network Based Fuzzy Inference System. Badrudeen, Akanni, Ajayi, Adepoju and Sobowale (2014) proposed the deployment of Adaptive Network Based Fuzzy Inference System (ANFIS) for correcting the inefficiency performance of the fixed delay (pre-timed) controller (FDC) in the Traffic Light Control System (TLCS) at a typical cross road junction.

MATLAB Graphic User interface was used to simulate the developed Fixed Controller and ANFIS controller. Cost Efficiency was used as a performance metrics. The result of the work revealed that ANFIS controller has better cost efficiency performance as against the fixed controller. However, Badrudeen *et al* (2014) failed to investigate the effects of emergency lane(s) such as pedestrian cross, Railway cross to mention but few on the performance of ANFIS controller. Therefore, this paper investigated the effect of emergency lane(s) on the cost efficiency performance of ANFIS controller.

2. Materials and Method

It is very important to model the field template, which will be simulated into the Graphical User Interface (GUI) of the MATLAB. The ANFIS controller system with a road network model was presented in Figure 1. Figure 1 is a typical cross road junction of the four (double lanes) main roads. At the center was a circle, representing the roundabout. Four traffic lights were used, with one controlling each of the four roads as shown in figure 1. The traffic lights were named as TFA, TFB, TFC and TFD for controlling lanes R1, R3, R6 and R8 respectively. The arrow lines indicate the direction of vehicles flow. The sensors were placed in the middle of each road, which was fixed to a length of 100 meters apart to sense the numbers of vehicles waiting. The traffic lights control only the vehicles that want to cross the junction.

At the top right corner of the model in figure 1 is the ANFIS controller. The ANFIS controller senses the number of vehicle through the vehicle counter, from the sensors and compares this to the state monitor, then the state monitor feeds back to the ANFIS controller that decides how to govern the controlling of the 4 traffic lights. The process is repeated every time there is changes in the state monitor and the vehicle counter responses. Pedestrian lane and railway were assumed in this paper as emergency lanes. During vehicular movement on the West roads, if there is an oncoming train, the ANFIS controller receives the signal from a sensor and thereby automatically puts the vehicles on the roads on hold by signaling the red light until the train has passed. On the other hand, during vehicular movement on the East roads, if there are pedestrians waiting to cross the roads, a sensor sends the signal to the ANFIS controller and thereby automatically puts the vehicles on the roads on hold by signaling the red light until all the pedestrians have passed.

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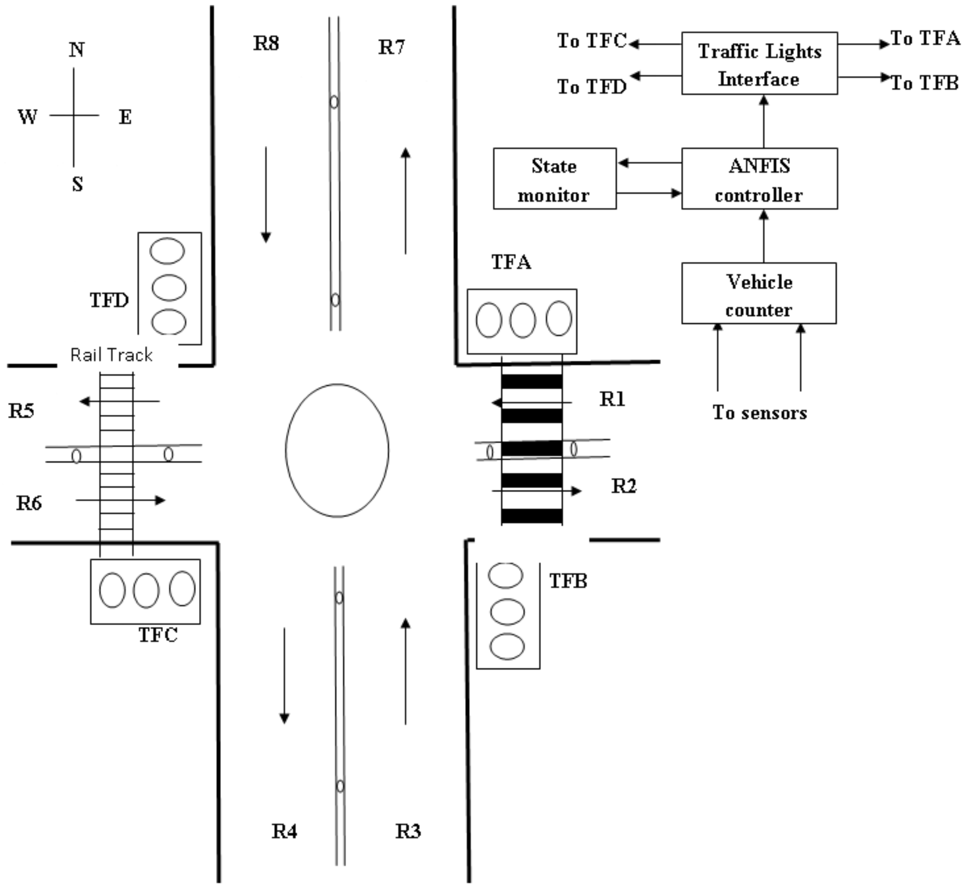

Figure 1: A road network with ANFIS Traffic Light Control System

Effect of the emergency lanes crossing on the performance of ANFIS are tested for different cases. Case 1 simulate the ANFIS controller for 60secs while varying the emergency condition from no interruption of emergency sensors through: when either of the train or pedestrian sensor signal interrupts the ANFIS controller and to when both the train and pedestrian interrupt. Case 1 was repeated for case 2, case 3 and case 4 but at 120 secs, 180 secs and 240 secs respectively.

2.1 Development of the ANFIS Objects

An ANFIS traffic controller object was developed for the system. The ANFIS object consists of two inputs variables namely “Arrival” and “Queue”. The Arrival denotes the number of vehicles on the arrival side while the Queue denotes the number of vehicles on the queuing side. If the North-South lane is the Arrival, then the West-East lane will be the Queue and vice versa. The ANFIS object has 1 output variable namely “Extension”. The “Arrival” has 3 membership functions namely “Very Few”, “Few” and “Many”. The “Queue” has 3 membership functions namely “Very Small”, “Small” and “Large”. The extension time also has 3 membership functions namely “None”, “Short” and “Long”. These membership functions are determined numerically as presented in Figure 2

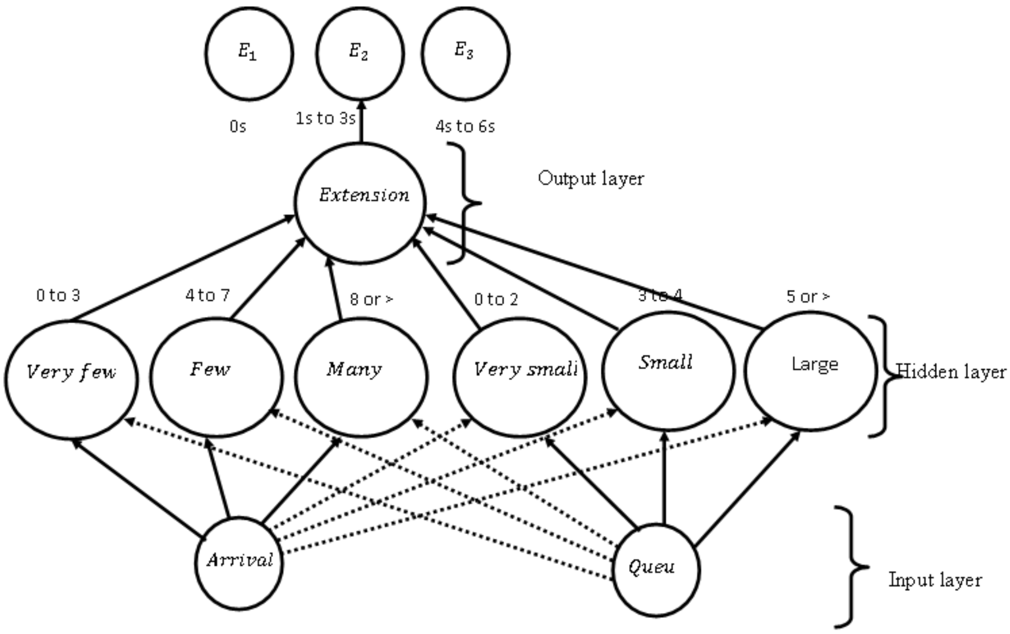

Figure 2: ANFIS Object

2.2 Design Assumptions and Constraints

The following assumptions and constraints were made for the successful simulation of the ANFIS controller

i. Vehicles going out of the junction cannot go through roads Road 1, Road 3, Road 6 and Road 8
ii. Road 2, Road 4, Road 5 and Road 7 are meant for vehicles leaving the junction so no vehicle can come into the junction through these roads.
iii. When traffic from the North and South moves, traffic from the West and East stops and vice versa.
iv. When the pedestrian or railway is passing, no vehicle must pass across these emergency lanes.
v. The minimum time for "GO" (green light) is 5 seconds while the maximum time is 20 seconds.

2.3 Fuzzy Logic Rule List

The fuzzification of the input was done by a function evaluation, which represents an input variable with an MF value. An example of the rule of the ANFIS traffic controller is as follows:

IF Arrival is "Very Few" VF and Queue is "Very Small" VS, THEN Extension is "Short" S

IF Arrival is "Many" M and Queue is "Small" S, THEN Extension is "Long" L

IF Arrival is "Few" F and Queue is "Long" L, THEN Extension is "None" N

"Arrival" and "Queue" are the antecedents and "Extension" is the consequent.

The antecedents are the training data inputs while the consequents are the target output to an Artificial Neural Network (ANN). The "Arrival" and "Queue" data (in number of vehicles) together with the corresponding "Extension" data in seconds are first transformed into a fuzzy logic Rule Lists. The fuzzy logic rules are the then used to train an ANN object to form the ANFIS object. The trained ANFIS object is used to provide an appropriate "Extension" time based on the values of "Arrival" and "Queue".

2.4 Simulation of the ANFIS Traffic Controller System

The ANFIS traffic light controller system was implemented in the MATLAB environment followed the graphical user interface (GUI) developed and associated MATLAB code were written to simulate the system. The GUI provided an option for simulating either the conventional Fixed Controller (FC) or the proposed ANFIS controller.. In FC, the "GO" (green light) configured to: stay for 15 seconds; "STOP" (red light) stay for 13 seconds while "STAND BY" (amber light) stay for 2 seconds. Also there are two input buttons where the train and pedestrian can be run at the same time or one after the other during emergency condition.

The GUI is an event-driven platform and consists of the road lanes, pedestrian lane, railway, sensors, sliders and vehicles. The slider for each lane can be used to set the traffic density. The maximum number of vehicles passing a lane was set to 6. At the start of the simulation, the North-South lanes were the main approach. The time of simulation, in seconds, can be set before the start of the simulation. At the end of a simulation, the values of performance parameters were displayed for evaluation when the emergency control interrupted the ANFIS control or not interrupted. Performance metric was Cost Efficiency (CE) which can be obtained using equation (1) and expressed as proposed in Tan and Marzuki (2013). CE should be low for a better performance. It can be expressed as:

$$CE = \left(\frac{vehicle\ in}{vehicle\ out}\right) * \left(\frac{waiting\ time}{driving\ time}\right) \quad (1)$$

Where:

Vehicles In is the number of vehicles entering the sensors area (back sensors)
Vehicles Out is the number of vehicles passing the junction (front sensor)
Drive Time (seconds) is the total time allowed for vehicles to drive pass a particular lane; that is "GO" time.
Wait Time (seconds) is the total time vehicles on particular lanes are disallowed from driving; that is "STOP" time.
Arrival are lanes that are given green light ("GO")
Queue are lanes that are given red light ("STOP")
Extension Time is the extension time of green light (in seconds)

One way ANOVA test was carried out to determine the significant of difference between the four group (CE) performances of the ANFIS controller with emergency interruption means are statistically significant at $p < 0.05$. The initial hypothesis; H_0 is that there is no significant difference between the mean CE performances of the four groups (population means are equal). Figure 3 is the GUI of the simulated ANFIS/Fixed Traffic Controller, showing the simulation of a typical TLCS with and without emergency lane at the cross road junction.

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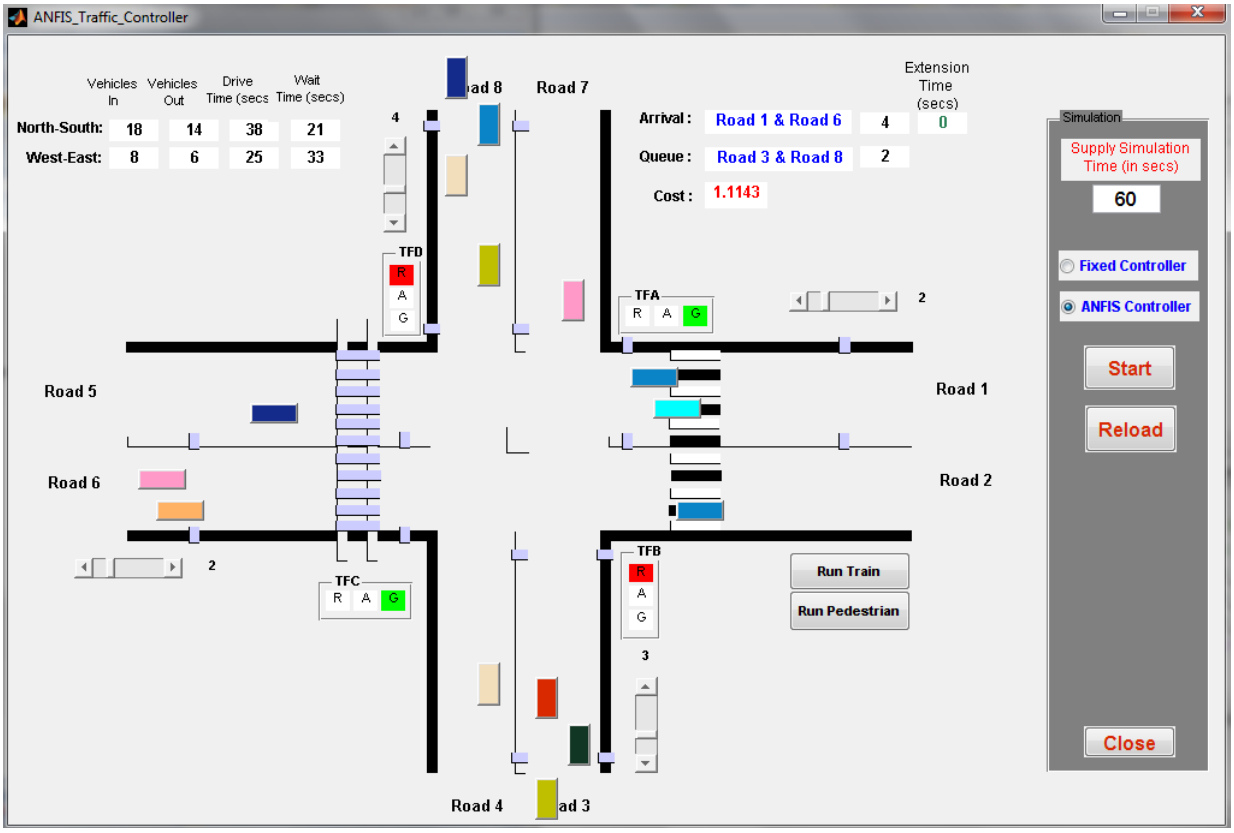

Figure 3: ANFIS Traffic controller for a typical cross road junction with Pedestrian lane and Railway as the emergency lanes.

3. Results

Following a set of rules in which the number of vehicles at the arrival (Road 3 and Road 8) is high, and the number of vehicle at the queue (Road 1 and Road 6) is less as presented in Table I. Therefore the total number of vehicles at the arrival (R3 and R8) is 7 and the numbers of vehicles at the queue (R6 and R1) is 4. Table II is the table of simulated result when the ANFIS Traffic Controller was run for simulation period of 60 Secs, 120 Secs, 180 Secs and 240 Secs with the emergency interruption condition varied as: No emergency, one time pedestrian crossing only, one time train crossing only and one time pedestrian and train crossing. The results showed that as the simulation period increases from 60 secs to 240 secs, the CE performance becomes (lower) better at all the 4 groups of different emergency cases. This indicates that during no emergency case, ANFIS controller performance variation flow agreed with that of the various emergency cases performances as shown in Figure 4.

It can also be observed that as the interruption becomes more complex, the CE performance becomes worse. The degree of difference was determined to show that ANFIS Traffic controller performances is relatively the same or not. ANOVA statistical test was performed using data in Table II at $p < 0.05$ using Microsoft Excel, The result of this analysis was presented in Table III and IV. Table III showed that the higher the complexity in interruption, the higher the sum, average and variance with an exception of one time

TABLE I: Number of vehicle setting at the arrival and queue lanes using slide

Road Names	Number of Vehicles
8	4
6	2
3	3
1	2

Table II: Simulation results of the ANFIS traffic Controller at variation in the complexity of Emergency condition

Period (sec)	No emergency Interruption	One time Pedestrian crossing only	One time train crossing only	One time train and pedestrian crossing
60	1.1143	1.1278	1.5101	1.5621
120	1.0827	1.1092	1.3810	1.3986
180	1.0405	1.0082	1.1925	1.1988
240	1.013	0.9976	1.1360	1.1752

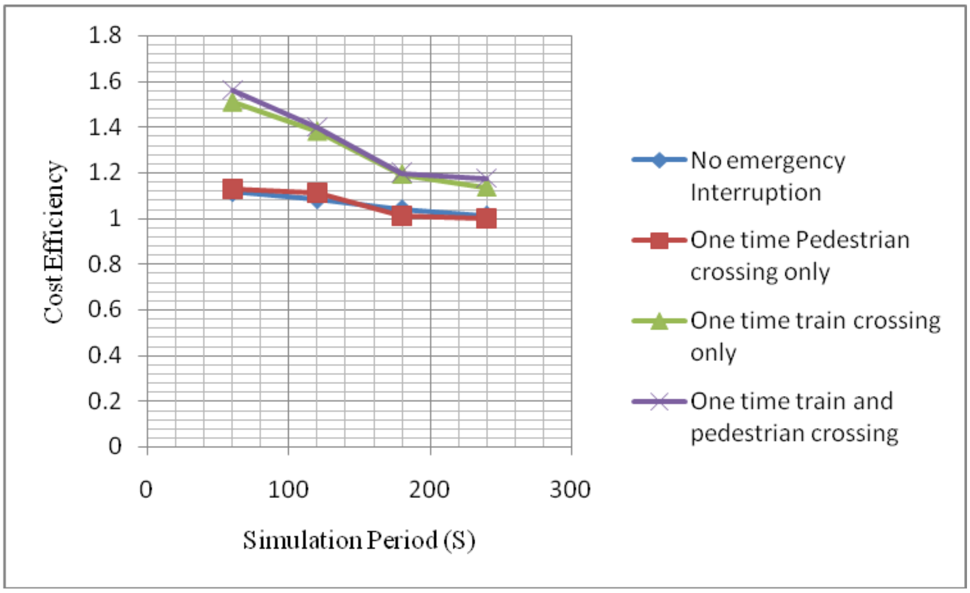

Figure 4: The Graphical representation of simulation results in Table II

Table III: SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
No emergency Interruption	4	4.2505	1.062625	0.002008489
One time Pedestrian crossing only	4	4.2428	1.0607	0.00453084
One time train crossing only	4	5.2196	1.3049	0.029686407
One time train and pedestrian crossing	4	5.3347	1.333675	0.033232942

Table IV: ANOVA Test Result

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.26715	3	0.089049	5.128151613	0.016393	3.490295
Within Groups	0.20838	12	0.017365			
Total	0.47552	15				

pedestrian crossing which is comparatively lower to No Emergency interruption. In Table IV, *F* value is 5.1282 which is > 3.4903 of *F crit*. Also the *P-value* obtained was 0.0164 which is $< \alpha = 0.05$. With these two conditions, the null hypothesis is rejected and the alternative hypothesis which states that differences between some of the means are statistically significant. This work is not interested in the where the difference lies in the four population of the CE performance group otherwise the T-test could have been necessary.

This paper is interested in determining the effect of emergency complexity on the CE performance of ANFIS controller. The significant difference between the CE performances of the some of 4 groups indicating that the ANFIS controller mean performance performs significantly different and worse as the interruption on the emergency lane becomes more complex. This can be well observed in figure 4 where the four groups curves have two less complex interrupt curves (pink and blue) at the lower part matched and the other two with more complex interrupt curves (green and purple) at the upper part matched. Therefore the degree of different between the two sub groups in Figure 4 can be said significant as shown in the result of ANOVA test in Table IV. As the simulation period increases all the four curves in Figure 4 approaches minimum which can be closed if the simulation period increases further.

4. Conclusion

The TLC system has been developed using the GUI tool of the MATLAB. All the necessary parameters such as the sensors, the TL and the cross-roads template were also incorporated into the system. The sliders were used in order to pre-set the traffic density on each arriving lanes, approaching the junction. Pedestrian lane crossing and Railway crossing have been deployed on the cross road to interrupt the traffic flow controller during emergency condition. Performance of the system was tested with the ANFIS controller at no (complexity) interrupt through the complex interrupt, more complex interrupt and most complex interrupt, using the Cost Efficiency as a performance metric. ANFIS controller has been shown to perform worse as the complexity increases. The degree of difference in mean performance of the four different emergency interrupt cases has been shown to be significant, which indicated that ANFIS controller performed differently in one or more of the four cases.

However, It has been shown that ANFIS controller perform better and the same as simulation period increases regardless of the interrupt complexity. Therefore, ANFIS controller is recommended for Traffic Light control where the traffic flow complexity may be high or not and to be run for a longer period. This will drastically reduce the waiting time and hence reduce the environmental pollution due to carbon mono oxide (CO) emission and eventually reduce global warming.

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