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AN ENHANCED WALABI METHOD FOR EMERGENCY VEHICLE PRIORITY SYSTEM

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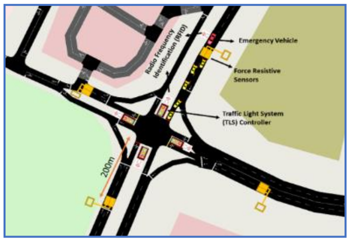
Graphical abstract



Abstract

Emergency response time (ERT) is a critical emergency provider's performance indicator. Traffic congestion, particularly at traffic light system (TLS) intersections, substantially impacts the ERT of emergency vehicles (EVs). In order to achieve ERT, it is crucial to have an emergency vehicle priority (EVP) system. EVP with Walabi (EVP-Walabi) method has been introduced but the existing approach caused EV to slow down when approaching TLS. This is because the existing EVP-Walabi method is only able to allow a green signal when the EV joins the queue at the TLS intersection. Therefore, this research introduced an enhanced Walabi method (EVP-Enhanced Walabi) to enhance the EV movement through the intersections. The simulation setup in this research used a series of TLS intersections in Simulation of Urban Mobility (SUMO) operating under uncongested and congested traffic flows. According to the simulation results, the EVP-Enhanced Walabi method mitigated the effect of EV slowing in the lowest and most congested traffic, which TLS without EVP and the original Walabi cannot handle. This can be proven when the improvement percentage range for Time Taken (TT) to reach accident site by EVP-Enhanced Walabi is between 7.05% and 35.18%. In addition, the EV travels at a higher average speed through the intersections, indicating smoother movement to the accident site.

Keywords: Intelligent Traffic Light System, Emergency Vehicle Priority System, Walabi Method, Emergency Response Time, Emergency Vehicle

Abstrak

Masa respon kecemasan merupakan penunjuk prestasi utama bagi agensi kerajaan yang menguruskan kecemasan. Namun, kesesakan lalu lintas, terutama yang melibatkan persimpangan yang mempunyai sistem lampu isyarat, memberi kesan besar pada tempoh masa respon bagi sesebuah kenderaan kecemasan. Sistem lampu isyarat yang mampu memberikan keutamaan kepada kenderaan kecemasan dilihat penting untuk mencapai penunjuk prestasi yang telah ditetapkan bagi masa respon kecemasan. Kajian sistem keutamaan kenderaan kecemasan dengan kaedah walabi telah lama diperkenalkan. Namun kaedah walabi sedia ada ini dilihat hanya mampu membenarkan isyarat hijau jika kenderaan kecemasan menyertai baris giliran sistem lampu isyarat. Oleh yang demikian, kajian ini dilaksanakan dengan memperkenalkan sistem lampu isyarat pintar dengan kaedah walabi-dipertingkatkan,yang mampu meningkatkan pergerakan kenderaan kecemasan di persimpangan lampu isyarat. Bagi mengkaji kebolehupayaan dan prestasi kaedah walabi-dipertingkatkan, simulasi SUMO ditetapkan pada beberapa siri persimpangan dengan aliran trafik yang rendah, tinggi dan sangat tinggi. Keputusan simulasi menunjukkan kaedah walabi-dipertingkatkan lebih baik kerana simulasi kaedah walabi sedia ada hanya mampu menguruskan kenderaan kecemasan pada satu persimpangan sahaja. Selain itu, keputusan simulasi kajian ini juga mendapati kaedah walabi-dipertingkatkan juga mampu mengurangkan masa perjalanan diambil kenderaan kecemasan di bawah perlbagai aliran trafik, dimana ianya tidak mampu dikendalikan oleh sistem lampu isyarat tanpa-keutamaan dan kaedah walabi sedia ada. Ini dapat dibuktikan apabila julat peratusan peningkatan untuk masa perjalan diambil oleh walabi-dipertingkatkan adalah antara 7.05% sehingga 33.18%. Di samping itu, pergerakan EV didapati bergerak dengan halaju purata yang lebih tinggi pada setiap persimpangan, menjadikan pergerakan EV lebih lancar ke kawasan kemalangan.

Kata kunci: Sistem Lampu Isyarat Pintar, Sistem Keutamaan Kenderaan Kecemasan, Kaedah Walabi, Masa Respon Kecemasan, Kenderaan Kecemasan

1.0 INTRODUCTION

Traffic light system (TLS) is one of the most effective methods for urban traffic control available to city authorities [1]–[9]. TLS assigns the right-of-way to different traffic movements, significantly affecting traffic flow at signalised intersections [1]–[3], [10]. The overall purpose of TLS is to provide a secure and effective traffic flow across intersections, along routes, and through traffic networks [10]. TLS also helps maximise capacity, decrease delays, and avoid conflicts. Moreover, TLS is crucial for controlling traffic, especially during peak hours and seasons [11].

According to [1]–[3], [11], many TLS lack a system in place that gives emergency vehicle priority during emergencies in most of the countries in the world. Research in [1]–[3], [11] also revealed that emergency vehicles (EVs), like ambulances and fire engines, have trouble passing TLS at intersections during emergencies, particularly when there is traffic congestion. Driving an EV is challenging for a driver to arrive at the accident location in the shortest time [12]. As a result, EVs often get stuck at intersections while waiting for other vehicles to yield at TLS intersections, which delay the emergency evacuation of accident victims. Therefore, many EVs fail to meet the required emergency response time (ERT), which is the time taken for EVs to arrive at the scene of an accident. Besides traffic congestion, the lack of communication between emergency service providers significantly affects ERT's performance [11], [13]–[18].

Emergency vehicle priority (EVP) system was developed to prioritize the arrival of an EV at intersections to reduce the ERT [4]. The situation where an EV is stuck at a traffic intersection and EV accidents may result from the absence of intelligent TLS that can provide EVP, during an emergency. This may be particularly true in South East Asia, where its TLS could not differentiate between EVs and conventional vehicles. Therefore, the necessity for EVP system in TLS is required to solve the difficulty of EVs becoming stuck in traffic congestion at TLS intersections [11], [19]. Moreover, EVP systems are crucial for avoiding EV delays caused by traffic congestions and can increase EV safety [1]–[3], [11].

Various works have developed EVP systems to solve the issue of EVs getting stuck in traffic congestion at TLS intersections. Researchers[1]–[3] concentrated on EVP using two approaches: 1) to offer an appropriate emergency priority code (EPC); and 2) to provide the EVP system with a method for detecting EVs and pre-empting TLS signals. For example, the smart emergency vehicle priority (SEVP) system developed by researchers in [1] can determine the priority code and provided an innovative way for calculating the number of green signal pre-emptions necessary to provide a quicker travel path for an EV. The SEVP was tested using SUMO to demonstrate the system's performance using real-time traffic data from VicRoads. Based on simulation results, SEVP successfully gave an EV proper priority to achieve the desired ERT to the accident location.

Researchers in [2] proposed the intelligent traffic system (ITS) for the EV to infrastructure (EV2I) system using an RFID-based traffic control system to mitigate the effects of poor synchronisation and demonstrated how it improves the ERT for an EV using simulation of urban mobility (SUMO). The priority of an EV is also considered by the ITS based on the type of event and traffic signal pre-emption in order to reduce traffic congestion and increase the system's reliability. IoT was reportedly used to assist the ITS based on green wave technology to enable a series of TLS to turn green when an EV approaches. Similar to [2], an intelligent traffic management system (ITMS) developed in [3] attempts to integrate the vehicular Ad-hoc network (VANET) and internet of things (IoT) for EVP. The ITMS gives EVs priority at intersections after it has received the emergency priority codes (EPC). EPC is processed to determine and assign different EV types, referring to the types and severity of accidents.

Moreover, researchers in [4], proposed emergency vehicle priority with self-organised traffic control (EVP-STC) that comprised three components for managing EVs at TLS intersections. In addition, researchers in [5] proposed an ambulance traffic management program using a real-time EVP system to prioritise ambulances travelling between hospitals and accident location.

Research in developing signal pre-emption in an EVP is still ongoing [6]–[9], [20]–[23]. For example, the Walabi method (EVP-Walabi) was introduced in [6] to prioritise EVs and reduce ERT by providing calculations to get the optimal distance for switching the traffic light. The main contribution of research [6] is to keep the red signal phase for EVs as short as possible while keeping the green signal phase as long as possible to create a green wave. According to the simulation findings of the simple intersection scenario using SUMO; the EVP-Walabi method is significantly better for higher traffic densities [6]. However, the optimal distance only happens when the EV has joined or is about to join the queue at the TLS intersection. This may slow down EV movement. Hence, the EVP-Walabi method needs to be improved to allow smooth movement of EV with algorithms that regulate the EV even before it joins the queue at the TLS intersection. In addition, the EVP-Walabi method was only simulated for one intersection and needed to be validated with a series of intersections.

In view of the limitations found in [6], this research proposed a TLS with EVP based on an enhanced Walabi (EVP-Enhanced Walabi) method. The objectives of this paper are as follows: I) to enhance the EVP-Walabi method for smoother movement of EV at TLS intersections and II) to evaluate the performance of the EVP-Enhanced Walabi method on a series of TLS intersections using SUMO via comparison with the original EVP-Walabi method and TLS without EVP. This article is organized as follows: Section 2 outlines the methodology of EVP-Walabi (in section 2.1) as described by the researcher in [6] and subsequently proposed its enhanced version a.k.a. EVP-Enhanced Walabi method in section 2.2 and the simulation setup in section 2.3. Section 3 presents the simulation results of the performance of the EVP-Enhanced Walabi compared to the EVP-Walabi method and TLS without EVP. Finally, Section 4 concludes this paper with the recommendation for future research.

2.0 METHODOLOGY

This section describes the methodology of EVP-Walabi developed by [6] in sub-section 2.1 and the proposal for an enhanced EVP-Walabi method called EVP-Enhanced Walabi in sub-section 2.2.

2.1 Emergency Vehicle Priority (EVP) with WALABI Method

According to [6], the EVP-Walabi method aims to minimise the length of the red traffic phase by extending the green phase for the EV. Walabi is a method that recommends providing EVP to EVs at every TLS intersection, also called a "green signal" to allow EVs to move through a TLS intersection. Thus, the optimal distance between the EV and the TLS's intersection was calculated; to ascertain the ideal distance to switch the TLS to green. Equation (1) is used to determine the time (T_{free}) needed for the EV to pass through the TLS intersection depending on the number of vehicles in queue (#waiting) at the intersection. T_{safety} is safety time and T_{β} is the time required for one vehicle to pass the intersection.

$$T_{free} = (\#waiting + 1) * T_{\beta} + T_{safety} \quad (1)$$

T_{β} is set to 1.8 seconds and T_{safety} is set to 3 seconds in [6] based on the German Guidelines for Dimensioning Road Traffic Facilities. Subsequently, the ideal distance to switch TLS to green is calculated using equation (2) based on T_{free} and V_{EV} which is the speed of the emergency vehicle (km/h). All possible sources, such as vehicle communication, induction loops, and floating vehicles, were used to obtain required data such as queue and EV speed.

$$Distance = T_{free} \times V_{EV} \quad (2)$$

According to [6], this EVP method is not just for one specific intersection but two TLS intersections. Therefore, a condition to determine whether the next TLS has the possibility of accommodating the waiting vehicles at two consecutive intersections is shown in (3):

$$\#waiting_1 + waiting_2 \geq capacity \quad (3)$$

where, $\#waiting_1$ is number of waiting vehicles in front of the first intersection and $\#waiting_2$ is number of waiting vehicles of the second intersection.

If the condition in (3) holds true, it is essential to turn the second intersection green earlier and the following equation in (4) applies. T_{free2} is the time which is needed to let EV and the other vehicle pass the traffic light for second intersection.

$$T_{free2} = (\#waiting_1 + \#waiting_2) \times T_{\beta} + T_{safety} \quad (4)$$

The distance is then calculated from T_{free2}, and the amount of time z that must be increased. Time z is the time required to pass the distance between the two intersections without waiting vehicles.

$$Distance = (T_{free2} + z) \times V_{EV} \quad (5)$$

2.2 Emergency Vehicle Priority (EVP) with Enhanced Walabi Method

Equation (2) is the ideal distance to trigger the TLS to green. This ideal distance indicates the condition when an EV joined or about to join the queue at the TLS intersection. However, triggering the TLS using this ideal distance will cause the EV to slow down to join the queue, resulting in slower speeds at the TLS intersection, which can directly affect the arrival time at the accident location. This section proposed the enhancement to the Walabi method, as mentioned in objective 1.

Table 1 presents the pseudo code for the EVP-Enhanced Walabi for all TLS intersections. The system starts when the TLS detects the RFID and GPS location of the EV when it is within 200 m from the TLS intersection (Line 2). The vehicle queue at the TLS intersection is then determined (Lines 2 to 4). The pseudo code iterates all the TLS $(k = 1,\ldots n)$. If the EV is detected in any of the TLS lanes; the system measures the actual distance, $EV_{mea\_distance}$ from the EV location to the TLS intersection using the GPS location of the EV and the location of the TLS intersection (Line 8). TLS current signal state and TLS phase state index number for the *EV* lane will be determined (Lines 9 to 10). Subsequently, the Walabi method is then used to calculate T_{free} using equation (1). The Walabi method is also used to calculate the ideal distance to trigger TLS, i.e. $EV_{cal\_distance}$ from the EV location to the TLS intersection based on equation (2) in Line 11.

Table 1 Pseudo code of TLS with EVP System using EVP-Enhanced Walabi Method

```
1  :
2  :  If EV within 200 m from TLS do
3  :      Obtain $Queue$ at TLS lane
4  :  End If
5  :
6  :  For each TLS $k$ do
7  :      If EV detect in TLS $k$ lane do
8  :          Obtain $EV_{mea\_distance}$
9  :          Determine TLS $currentState$ for EV lane
10 :          Determine TLS $phaseStateIndex$ for EV lane
11 :          Calculate $EV_{cal\_distance}$
12 :              If $EV_{mea\_distance} > EV_{cal\_distance}$ or
                  $EV_{cal\_distance} \leq 1$
13 :                  $T_{free} = (Queue + 1) \times T_B + T_{safety}$
14 :                  $Trigger = 1$
15 :              Else
16 :                  $T_{free} = \frac{EV_{mea\_distance}}{occ} \times T_B + T_{safety}$
17 :
18 :                  $Trigger = 1$
19 :              End If
20 :
21 :              If $currentState$ for EV lane is 'red' or
                  'yellow and $Trigger = 1$
22 :                  Determine TLS $phaseState$
23 :                  If 'green' state in TLS $phaseState$
24 :                      Set all states in $phaseState$ to 'red'
                          for 3 seconds
25 :                  Else
26 :                      Exexute current $phaseState$ for 3
                          seconds
27 :                  End If
28 :              Identify $phaseNumber$ that control EV
29 :              lane using $phaseStateIndex$
                  Set TLS signal phase = $phaseNumber$
30 :              Set TLScurrentsignal phase duration =
                  $T_{free}$
31 :              Else
32 :              Set TLScurrentsignal phase duration =
33 :              $T_{free}$
                  EndIf
34 :      Else
35 :          Pass
36 :  End for
```

Two conditions were derived from the $EV_{mea\_distance}$ and $EV_{cal\_distance}$. When $EV_{mea\_distance}$ is equal or less than $EV_{cal\_distance}$ or $EV_{cal\_distance}$ is equal to or less than one meter; this indicates the situation where the EV has joined the queue at the TLS intersection and meets the ideal distance to trigger the TLS to green according to the Walabi method using the calculated T_{free} in equation (6). On the other hand, the Walabi method is enhanced with an additional condition in equation (7) where $EV_{mea\_distance}$ is more than $EV_{cal\_distance}$; which indicates the EV has not join the queue. Hence, T_{free} in equation (7) which is the time needed to clear the moving EV is introduced.

When $EV_{mea\_distance} \leq EV_{cal\_distance}$ or $EV_{cal\_distance} \leq 1$

$$T_{free} = (\#waiting + 1) \times T_{\beta} + T_{safety} \tag{6}$$

When $EV_{mea\_distance} > EV_{cal\_distance}$

$$T_{free} = (EV_{mea\_distance} / Occ) \times T_{\beta} + T_{safety} \tag{7}$$

The *Occ* is occupancy length of one vehicle on the lane. The value of T_{safety} has the same value as in [6], which is 3 seconds. However, value of T_{β} is set to 2.0 seconds as prescribed by some researches [6] The occupancy length of a vehicle is set to 6.6 m as prescribed in [24]–[26].

The above conditions stated in (6) and (7) are stated in Lines 12 to 19 in pseudo code. If any conditions in (6) or (7) are fulfilled, it will trigger the related signal phase of TLS to green to give the right of way for the EV. Next, the current signal state of the TLS lane is evaluated in Line 21. If the current state of the TLS lane is either 'red' or 'yellow', the pseudo code executes an all red state in Line 23 to 27 for 3 seconds. Subsequently, the phase number of the signal phase that controls the EV lane is identified in Line 28. The pseudo code executes the identified signal phase together with the calculated T_{free} in Line 29 to 30. On the other hand, if the current state of the TLS lane is 'green' (Line 31), the current signal phase will be continued with the calculated phase duration, T_{free} as shown in Line 32. The same process is then repeated to all TLS intersection.

2.3 Simulation Setup

This study was conducted using SUMO version 1.11.0. SUMO is an open-source software that provides microscopic description of traffics and traffic simulations platform that provides a flexible and reliable simulation functions for studying urban mobility, investigating and evaluating traffic patterns, and optimising traffic management systems [27]. According to [27], SUMO is a useful tool for transportation experts, researchers, and policymakers due to its realistic modelling, customisation options, extensibility, and validation capabilities. The level of practicality makes SUMO appropriate for this study, in particular to assess the effectiveness of the TLS without EVP, with Walabi, and with the EVP-Enhanced Walabi method. This section explains the simulation setup of the traffic scenario in SUMO. The performance of TLS with EVP-Enhanced Walabi method is compared with TLS without EVP system and TLS with EVP-Walabi method for various traffic conditions.

Figure 2 shows the traffic scenario that comprised of seven intersections controlled by TLS controller namely TLS1 to TLS7, that the EV will go through from the station to the accident location. The traffic scenario was created by utilizing the SUMO NETEDIT. Next, the EVP control algorithm in Table 1 was implemented to the traffic system using Python 3.10. This simulation configuration will require the EV moving through several TLS intersections, i.e., TLS1, TL2, TLS3, TLS4, TLS5, TLS6 and TLS7 until it reaches the accident location. Simulation was conducted for traffic flow of 300, 500, 900, 1200, 1500, 1800, 2700 and 3000 vehicles per hour (veh/h) respectively along the route travelled by the EV. In this study, all TLS intersections control was simulated using: i) TLS without EVP; ii) TLS with EVP-Enhanced Walabi method and iii) TLS with EVP-Walabi method respectively. The effectiveness of these control methods will be analysed by recording the time when the EV crosses each traffic signal intersection (i.e., TLS1 to TLS7) and finally the arrival time at the accident location. The average speed of the EV moving through TLS1 to TLS7 will also be tabulated and analysed.

Figure 2 Scenario for Emergency Vehicle (EV) from Station to Accident Location

Figure 3 depicts a detailed dedicated TLS controller and sensors set up at a four-legged road intersection. Radio Frequency Identification (RFID) is used by an EV approaching the intersection to connect with the TLS controller. The force resistive sensors are positioned on each lane, 200 m away from the TLS intersection, to perform vehicle count and collect data for vehicles waiting at TLS intersection. The 200 m distance was specified for testing purposes; however, it can be increased and is application dependent, especially in dense urban areas where long vehicle queues occur at intersections.

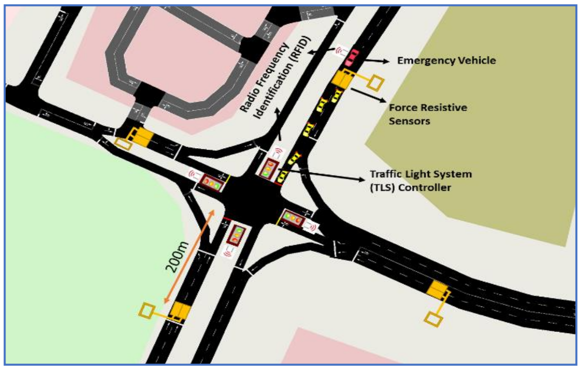


Figure 3 Intelligent Traffic Light System (TLS) controller and sensors setting

The performance evaluation in this research focuses on two performance indicators. The first performance indicator is the time taken (TT) for the EV to travel from the original location to the accident location and the TT as it passed each TLS intersection for the respective TLS control methods and traffic flow. The second indicator is the comparison of the average EV speed when travelling through the intersections (i.e., TLS1 to TLS7) in varying traffic flows regulated by these three types of TLS respectively. According to [28], the time used in SUMO is called a "time step". Each time step can represent the start of time period when the most recent data integration interval began or the time step at the end of the period when it was completed. Hence unit for time in this paper is based on simulation time step.

3.0 RESULTS AND DISCUSSION

3.1 Performance of Time Taken (TT)

Figure 4 shows time taken (TT) by the EV that passes TLS1 to TLS7 intersections and finally to accident location simulated under traffic flows of 300, 500, 900, 1200, 1500, 1800, 2700 and 3000 veh/h respectively. TT for TLS without EVP (labelled as without EVP) is shown in the blue plot, TT for Walabi (EVP-Walabi) is shown by the orange plot and TT for the enhanced Walabi (EVP-Enhanced Walabi) is shown by the grey plot.

As shown in Figure 4, the TT value for TLS using the EVP-Walabi and EVP-Enhanced Walabi were lower than the TT value for the TLS without EVP. As observed in Figure 4, TT values for TLS using EVP-Enhanced Walabi is lower than the TT value for TLS using Walabi for all the traffic flows. This clearly shows that TT to reach the accident location using EVP-Enhanced Walabi is more effective compared to TLS using EVP-Walabi. This resulted in better ERT for the EV.

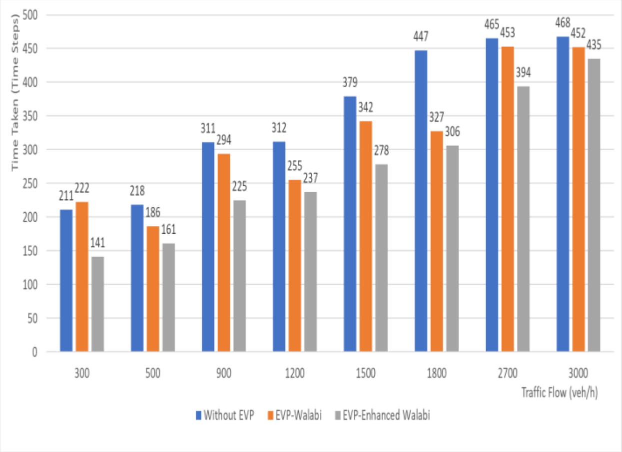


Figure 4 Time Taken (TT) Plot at Accident Location under Varying Traffic Flows

To show more clearly the improvement in the TT to reach the accident location for varying traffic flows; TT percentage of improvement were compared for TLS using the EVP-Walabi contrasted with TLS without EVP and TLS using the EVP-Enhanced Walabi contrasted with TLS without EVP in Figure 5. As observed in Figure 5, the EVP-Enhanced Walabi brought about improvement in TT ranging from 7.05% to 33.18% when compared with the TLS without EVP. The highest improvement of 33.18% was achieved when traffic flow is 300 veh/h.

On the other hand, the EVP-Walabi method improves TT ranging from -5.21% to 26.85% when contrasted with TLS without EVP. It is observed here that the EVP-Walabi did not improve the TT when traffic flow is 300 veh/h. This may indicate that the EVP-Walabi may not be effective under extreme low traffic flow. However, improvement in TT was observed for the other traffic flows, with the highest percentage of improvement at 26.85% when traffic flow is 1800 veh/h. Overall, the EVP-Enhance Walabi achieved higher margins of improvement in TT compared to EVP-Walabi.

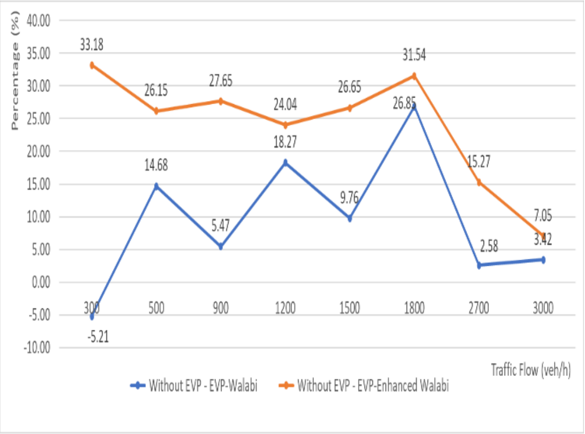


Figure 5 Percentage of Improvement in Time Taken (TT)

The TT of the EV when it passes each TLS intersection for the three types of TLS simulated under different traffic flows are plotted in Figures 6, 7, 8, 9, 10, 11, 12, and 13 respectively. The graphs show the TT taken by the EV to pass TLS1, TLS2, TLS3, TLS4, TLS5, TLS6, and TLS7 respectively.

Figure 6 shows that when traffic flow of 300 veh/h were simulated, TLS using the EVP-Walabi recorded the highest TT, followed by TLS without EVP and TLS using the EVP-Enhanced Walabi. The TLS using the EVP-Walabi shows high TT values at almost all TLS intersections, namely TLS1, TLS2, TLS3, TLS4, TLS5, TLS6, and TLS7. Although the expected result is TLS without EVP will exhibit the highest TT compared to TLS using the EVP-Walabi and EVP-Enhanced Walabi; the results show EVP-Walabi has the least performance. This is contrary to what was expected, but somewhat provided some insights that the EVP-Walabi method may not be effective during extreme low traffic flow. The EVP-Walabi method may only be effective in congested traffic conditions.

Figure 7 shows the result of TT plots for traffic flow of 500 veh/h. The highest TT values were observed in TLS without EVP when compared to TLS using the EVP-Walabi and TLS using the EVP-Enhanced Walabi. For example, at TLS1, the TT value for TLS without EVP is 32, which is higher than TLS using EVP-Walabi and EVP-Enhanced Walabi that recorded TT of 25 and 20 respectively. Similar higher TT value of 49 for TLS2 was produced by TLS without EVP, which is longer than TLS using the EVP-Walabi, which is 46, and TLS using the EVP-Enhanced Walabi, which are 37. Overall, it can be observed that the TLS without EVP produced the highest TT for all TLS intersections among the three TLS methods.

Based on the results in Figure 7, the TT values for TLS1, TLS2, TLS3, TLS4, TLS5, TLS6, and TLS7 can provide the second observation that TLS using the EVP-Enhanced Walabi had the lowest TT values, followed by TLS using the EVP-Walabi and TLS without EVP. Figures 8 to 13 show TT plots simulated using traffic flow of 900, 1200, 1500, 1800, 2700, and 3000 veh/h, respectively. All the plots also displayed similar results as shown in Figure 7, which proves the validity of the second observation that the TLS using the EVP-Enhanced Walabi has displayed superior performance in TT compared to the other two TLS.

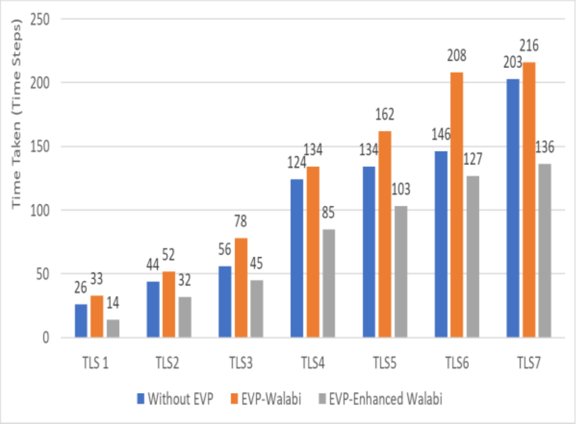


Figure 6 Time Taken (TT) Plot at TLS1 to TLS7 under 300 veh/h

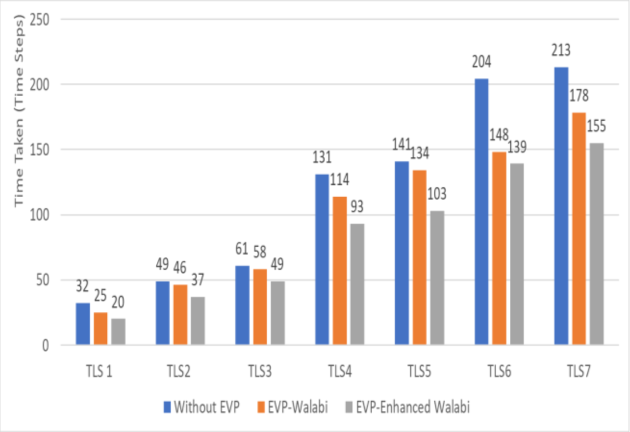


Figure 7 Time Taken (TT) Plot at TLS1 to TLS7 under 500 veh/h

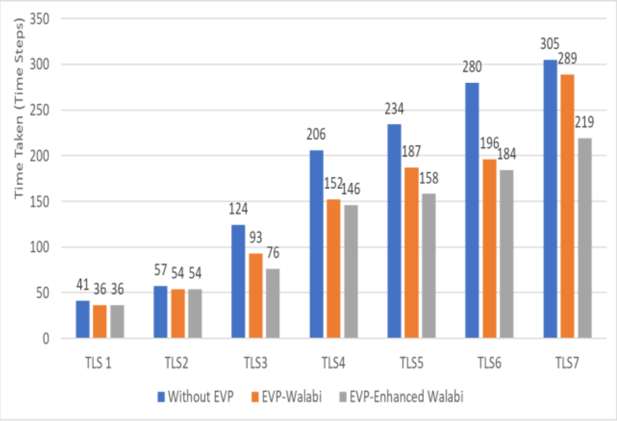


Figure 8 Time Taken (TT) Plot at TLS1 to TLS7 under 900 veh/h

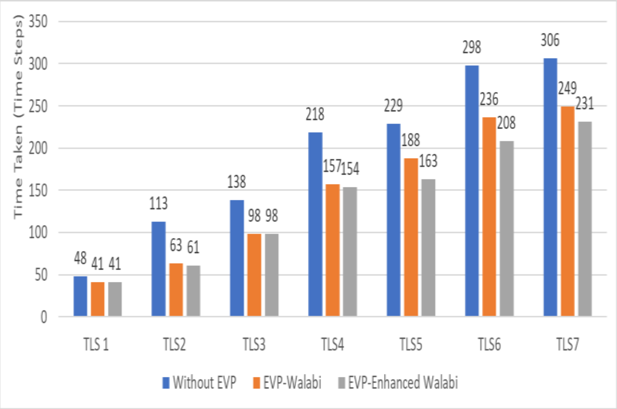


Figure 9 Time Taken (TT) Plot at TLS1 to TLS7 under 1200 veh/h

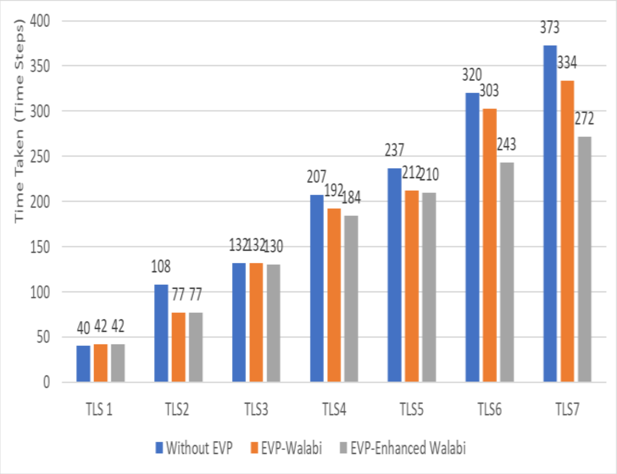


Figure 10 Time Taken (TT) Plot at TLS1 to TLS7 under 1500 veh/h

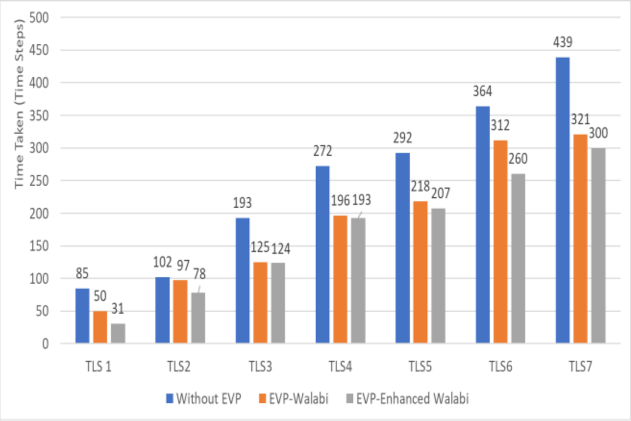


Figure 11 Time Taken (TT) Plot at TLS1 to TLS7 under 1800 veh/h

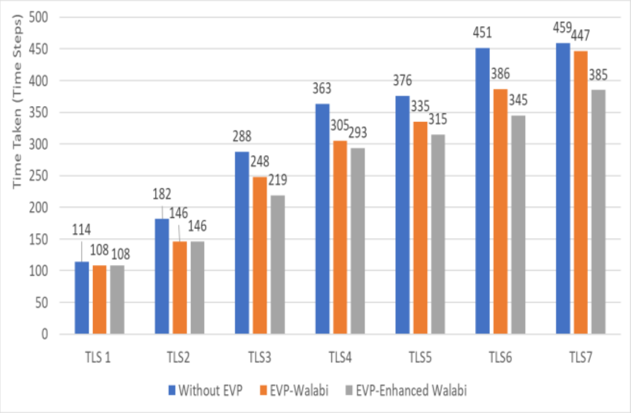


Figure 12 Time Taken (TT) Plot at TLS1 to TLS7 under 2700 veh/h

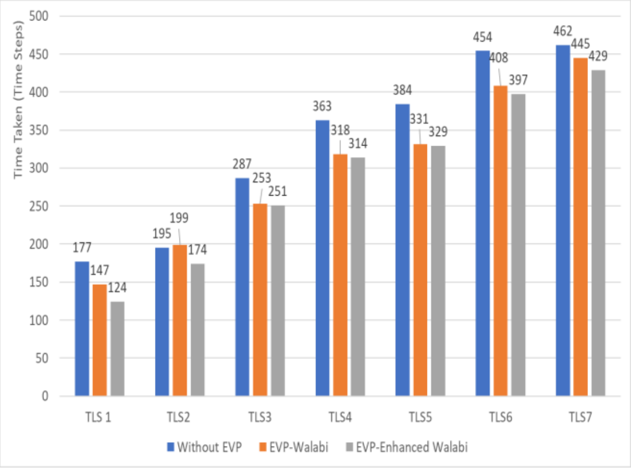


Figure 13 Time Taken (TT) Plot at TLS1 to TLS7 under 3000 veh/h

The results clearly indicated the EVP-Walabi method was inferior compared to enhanced Walabi. TLS using the EVP-Enhanced Walabi has a unique algorithm based on equation (7) that provides intelligent control even before the EV reaches the queue. The enhanced Walabi algorithm did not only control EV that has joined the queue at TLS intersection, but also extends control for EV as far as 200 meters from the TLS intersection. For this reason, the enhanced Walabi provides smoother movement of EV across the TLS intersection.

3.2 Performance of average Emergency Vehicle (EV) speed

This section reports the behaviour of the average EV speed when moving from the original location until it reaches the final TLS intersection (i.e. TLS7), simulated under the traffic flows set in this study. Figure 14 shows the plot of the average speed when the EV moves from TLS1 to TLS7 simulated under traffic flows of 300, 500, 900 1200, 1500, 1800, 2700 and 3000 veh/h respectively.

Figure 14 shows that the average EV speed ranges for TLS using the EVP-Enhanced Walabi are higher than those for TLS using the EVP-Walabi for varying traffic flow. For example, with a traffic flow of 300 veh/h, the average EV speed for TLS using the EVP-Enhanced Walabi is 59.15 km/h, higher than TLS using the EVP-Walabi, which is only 43.04 km/h. Similarly, for traffic flows of 500, 900, 1200, 1500, 1800, 2700, and 3000 veh/h, the average EV speed values for TLS using the EVP-Enhanced Walabi are respectively 69.88, 53.02, 52.45, 36.80, 45.86, 32.77 and 32.35 km/h, higher than the average EV speed values for TLS using the EVP-Walabi, which are 63.37, 45.63, 42.59, 35.34, 30.84, 28.54 and 31.93 km/h respectively.

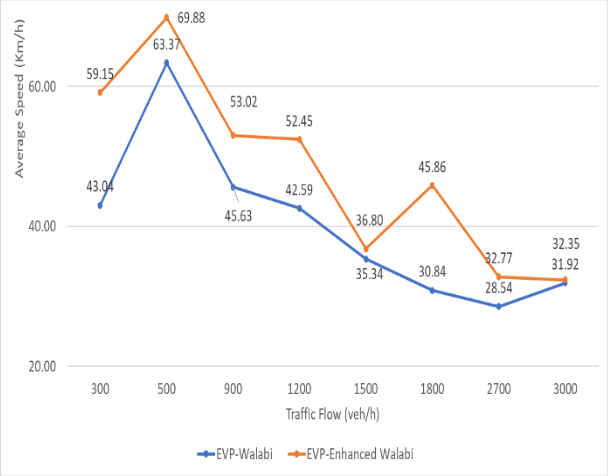


Figure 14 Average Speeds of EV under Varying Traffic Flows

For this second performance indicator, it was found that the average EV speed through all TLS intersections for TLS using the EVP-Enhanced Walabi is higher than TLS using the EVP-Walabi for all traffic flow scenarios. This shows that the EVP-Enhanced Walabi that provides signal intervention before the EV join the queue resulted in smoother movement (reflected by higher average speed) of the EV through the TLS intersections. On the contrary, the EVP-Walabi method may cause the EV to slow down as it only intervenes when the EV joined the queue at the TLS intersection.

4.0 CONCLUSION

TLS with an EVP adopting the enhanced Walabi method was proposed in this research by extending the Walabi method to achieve smoother EV movement, not just at single TLS intersections, but also at series of TLS intersections. This method accelerates EV travel time to achieve ERT for every traffic condition, whether it is for uncongested or congested traffic flow. TLS with EVP-Enhanced Walabi outperformed TLS without EVP and EVP-Walabi.

The improvement percentage range for TT by the EVP-Enhanced Walabi ranged from 7.80% to 35.07% when simulated under various traffic flows. This is because TLS with EVP-Enhanced Walabi has a unique algorithm that provides intelligent control even before the EV reaches the queue, and the algorithm is able to operate for even congested situations. The results show that the EVP-Enhanced Walabi mitigated the effect of EV slowing down, which cannot be handled by the original Walabi method.

This resulted in the EV achieving better ERT and moving with higher average speed. On the other hand, The TLS using EVP-Walabi performed better than TLS without EVP for higher traffic flow (above 500 veh/h). However, it seemed to be inferior compared to the TLS without EVP when operating under low traffic flow (below 500 veh/h). However, the necessity for an accident might require multiple EV services from various emergency providers whereas this investigation just involved one EV. Future studies can expand this study by considering EVP that handles more than one EV from various emergency providers.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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