Mehmet Akif Ersoy Üniversitesi Uygulamalı Bilimler Dergisi
Journal of Applied Sciences of Mehmet Akif Ersoy University

Environmental Impact of Vehicles Waiting at the Signalized Intersections: A Case Study of a Four-Phase Intersection

Emre ARABACI[1*], Recep Çağrı ORMAN[2], Bayram KILIÇ[3], Kerem HEPDENİZ[4], Bekir YİTİK[5]

[1]Asst. Prof. Dr., Burdur Mehmet Akif Ersoy University, Bucak Emin Gülmez Vocational School of Technical Sciences, Department of Automotive Technology, Burdur, Turkey

[2]Instructor, Gazi University, Tusaş-Kazan Vocational School, Department of Automotive Technology, Ankara, Turkey

[3]Asst. Prof. Dr., Burdur Mehmet Akif Ersoy University, Bucak Emin Gülmez Vocational School of Technical Sciences, Department of Automotive Technology, Burdur, Turkey

[4]Instructor, Asst. Prof. Dr., Burdur Mehmet Akif Ersoy University, Bucak Emin Gülmez Vocational School of Technical Sciences, Department of Geographic Information Systems, Burdur, Turkey

[5]Asst. Prof. Dr., Burdur Mehmet Akif Ersoy University, Bucak Emin Gülmez Vocational School of Technical Sciences, Department of Desing, Burdur, Turkey

Geliş Tarihi/Received: 27.05.2019
Kabul Tarihi/Accepted: 26.08.2019
Doi: doi.org/10.31200/makuubd.570622
Araştırma Makalesi/Research Article

ABSTRACT

With the increase in the number of vehicles in traffic, there are many scenarios for traffic flow. On the other hand, the waiting times of the vehicles in traffic are constantly increasing. A misplaced traffic plan leads to traffic congestion and environmental problems. In this study, CO2 equivalent emission values (carbon footprint) were calculated in order to examine the environmental effects in a four-phase intersection. Equations were derived to calculate CO2 equivalent emission at the intersection. The effect of the idle stop-start system and the number of electric vehicles was also considered as a future scenario. As a result of the study, it was observed that the small number of electric vehicles decreased the CO2 equivalent emission at the intersection significantly. However, with the use of the idle stop-start system, it has been observed that CO2 equivalent emissions can be reduced.

Keywords: Intersection, Carbon Footprint, Emission, Idle Stop-Start.

* Sorumlu yazar/Corresponding author
E-mail/e-ileti: earabaci@mehmetakif.edu.tr

Sinyalize Kavşaklarda Bekleyen Taşıtların Çevresel Etkileri: Dört Fazlı Bir Kavşak Üzerinden Durum Değerlendirmesi

ÖZET

Trafikteki taşıt sayısının artması ile birlikte trafik akışı için birçok senaryo oluşturulmaktadır. Bununla birlikte taşıtların trafikteki bekleme süreleri de sürekli artmaktadır. Yanlış tasarlanmış bir trafik planı trafik sıkışıklığına ve çevresel problemlere neden olmaktadır. Bu çalışmada dört fazlı bir kavşaktaki çevresel etkilerin incelenebilmesi için CO2 eşdeğeri emisyon değerleri (karbon ayak izi) hesaplanmıştır. Kavşaktaki CO2 eşdeğeri emisyonunun hesaplanabilmesi için eşitlikler türetilmiştir. Bu hesaplamalar yapılırken rölanti stop-start sisteminin ve elektrikli taşıt sayısının etkisi de bir gelecek senaryosu olarak ele alınmıştır. Yapılan çalışma neticesinde elektrikli taşıt sayının az miktarda değişimi, kavşakta oluşan CO2 eşdeğeri emisyonunu önemli derecede azalttığı görülmüştür. Bununla birlikte rölanti stop-start sisteminin kullanılması ile birlikte CO2 eşdeğeri emisyonun az da olsa azaltılabileceği görülmüştür.

Anahtar kelimeler: Kavşak, Karbon Ayak İzi, Emisyon, Rölanti Stop-Start.

1. INTRODUCTION

Human beings have always considered vehicles as a necessity to make life easier. Roads have been created as the vehicles become widespread. Although many methods have been developed to create the layout on these roads, traffic lights are undoubtedly the most effective of these methods (Daganzo&Daganzo, 1997, Pignataro et al., 1973).

Traffic lights were first used in London in 1868 and are still widely used today to keep traffic under control. The only task of the traffic lights used is not to keep traffic under control. With the expansion of motor vehicles, two main environmental problems occurred. These are exhaust gases (exhaust emission) and engine noise (acoustic emission) that threaten the environment directly. Both are the biggest problem that threatens the environment in which we live. When arranging traffic lights, these two environmental problems are taken into account (Pursula, 1999, Kumar et al., 2011).

Nowadays, various models and algorithms have been developed for synchronization of traffic lights. Many factors are considered to determine the duration of these traffic lights. By this time, the characteristic of the signalization changes depending on the traffic density at certain times of the day. In fact, the use of intelligent traffic light systems in which synchronization is regulated according to the traffic density is also widespread (Zhao et. al., 2011, Malakorn & Park, 2010, Sundar et. al., 2014, Choy et. al., 2003, Polson & Sokolov, 2017).

One of the sources that increase the carbon footprint, which is an important indicator of environmental pollution, is vehicle exhaust emissions. Methods for reducing carbon footprint are an invaluable investment for future generations. There are many considerations such as limiting the number of vehicles, reducing the use of vehicles and dissemination of electric vehicles in order to reduce the primary carbon footprint from vehicles. However, a more important issue to consider is how to reduce the carbon footprint in the current situation (Sovacool & Brown, 2010, Piecky & McKinnon, 2010, Sharma & Mishra, 2013, Qi et. al., 2016).

Thanks to traffic lights, vehicles are stopped for a short time to regulate traffic flow and prevent traffic congestion. The traffic lights allow not only the vehicles but also the pedestrians to move in heavy traffic. However, unnecessary traffic light can cause traffic congestion. Also, a traffic light synchronization may vary depending on the current situation. For example, those who want to go to school in the morning, who want to go to the stadium for a football match, a holiday celebration or a social event can change the traffic flow for a short or long term. However, the morning school going time can be foreseen in a time period and often occurs regularly, while a sudden social event occurs in an unpredictable time period (Polson and Sokolov, 2017, Qi et. al., 2016, Cao et. al., 2016).

Roads were quite simple and traffic lights were not needed before motor vehicles became widespread. With the increase in the number of motor vehicles, intersections have to be formed on intersecting roads. On the other hand, in areas with very heavy and fast traffic, a partial solution to traffic congestion has been established with lower or overpass. As the number of vehicles increases, the waiting time in the red light increases and the green light time decreases. However, vehicles waiting at the red light discharge the intersection as fast as possible. One of the important factors in the arrangement of intersections is parking places with short stops on the road. The increase in the number of vehicles brings along the parking problem in the traffic.

In the literature, there are studies on regulation of traffic flow and improvement of effective traffic flow in order to prevent traffic congestion (Nigarnjanagool & Hussein, 2005, Vallati et. al., 2016, Li et. al. 2016, Qi et. al., 2016, D'Andrea & Marcelloni, 2017, Fouladgar, 2017, Mannion et. al. 2016). In all of these studies, models aimed at preventing traffic congestion were discussed in detail and optimization of green light duration was taken into consideration. The main purpose here is to ensure that the vehicles wait at the red light for a reasonable period of time and that no traffic flow rupture during the green light. However, unlike the literature, in this study, the effect of red light waiting time instead of green light was investigated. For this, a four-phase intersection model has been created and 〖CO〗_2 equivalent emissions from vehicles waiting at the intersection for various situations are examined in detail.

2. THEORETICAL AND CONCEPTUAL FRAMEWORK

In addition to the written rules in traffic, the rules that occur naturally can occur over time. However, the natural (or traditional) rules of traffic from country to country and even from city to city may be different. Traffic flow and congestion may vary depending on the geographical, cultural and economic characteristics of the region. In order to ensure the correct flow of traffic, more importantly, the intersection must be positioned correctly. As the population in cities increases, settlements are growing and because of increased transportation distances, it is desirable to have faster traffic flow. However, the urban transportation network, which cannot be designed correctly, brings with it the big problems with the increase of the population and the number of vehicles.

Although intersection structures have various accepted applications, they may also vary according to many factors such as the culture, geographical location, economy and intended use of the country (or region) (Figure 1).

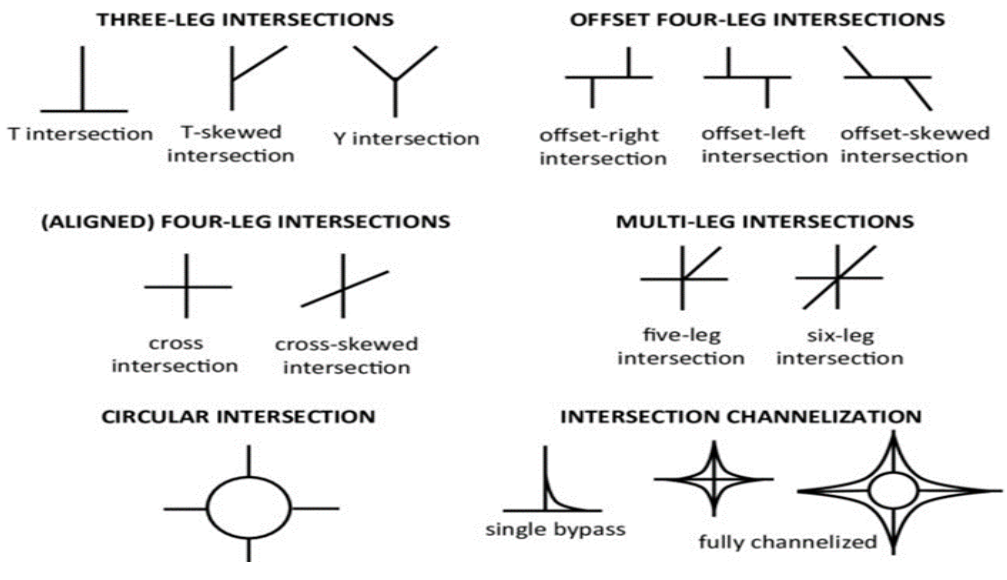

Figure 1. Various intersection layouts (Czarnecki, 2018)

Factors such as the number of lanes in the intersection legs, the number of legs connected to the intersection, the number of phases, and the timing of lights may also change the intersection layout. In addition, special lanes can be created for U-turn at some intersections. The main purpose of all these regulations is to ensure the continuity of traffic flow. However, the four leg cross-intersection (or the intersection) layout chosen here is a simple and classic intersection layout that comes to mind especially in urban traffic. This type of intersection is often preferred because traffic can be arranged for four directions. There are several accepted strategies for the transition order here. For this study, the intersection type formed at the intersection of the boulevard and the secondary road was taken as a reference for the city (Figure 2).

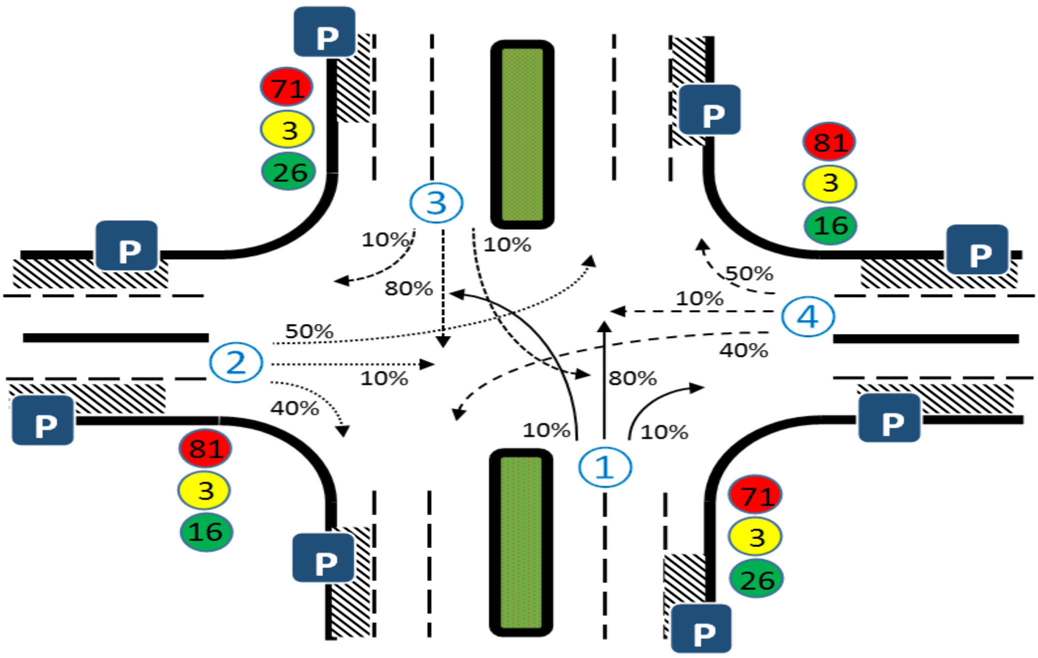

Figure 2. Intersection scheme used in the study

In general, the phase time at the intersections is determined to allow the desired number of vehicles to pass, and this need may vary for each intersection. What is important here is the dwell time between the two green lights. Although it is desirable that the sum of the dwell time and the transition time do not exceed 100 seconds, this is sometimes not possible.

Many different types of route phases can be created at such intersections. These route phases can change several times depending on the traffic density if required. For the intersection scheme used for the study, the layout of a real intersection in the coordinates of 37.456312 and 30.584769 was taken as the numerical study. The period for this intersection is 100 seconds. The green light duration for the boulevard and the secondary road is 26 and 16 seconds, respectively. The yellow light time is 3 seconds per phase. In each phase, the vehicles can move forward, right or left. In this intersection, rotating vehicles prioritize pedestrian passage. The ratios of the vehicles passing in phases are shown in Figure 2. These times are the actual values for the intersection at the coordinated position.

3. METHODOLOGY

CO_2 equivalent emission value ($\mathbf{CO2e}$, g/L)of a fuel with chemical formula $\mathbf{C_\alpha H_\beta}$, can be calculated as in Eq. 1. Where ρ_f (g/L) and η_b, mean fuel density and combustion efficiency respectively. η_b is generally acceptable as 98%.

$$\mathbf{CO2e} = \frac{12\alpha}{12\alpha+\beta}\rho_f \frac{44}{12}\eta_b \quad (1)$$

$\mathbf{CO2e}$ values for gasoline (C_8H_{18}), LPG ($C_{3.7}H_{9.4}$) and Diesel ($C_{16}H_{34}$) were calculated as 2431 g/L, 1573 g/L and 2580 g/L, respectively. It is seen that LPG is a greener fuel in terms of $\mathbf{CO2e}$ values. However, when the idle fuel consumption is evaluated, the average fuel consumption of gasoline and diesel vehicles in idling conditions can be accepted as 0.8 L/h and 0.5 L/h respectively. The average fuel consumption for cruising vehicles is 15 L/h and 10 L/h respectively for gasoline and diesel vehicles. Although these values appear to be very high, it can be said that there are acceptable values when considering the parameters such as the speed of the vehicles during the crossings and gear shift. It can be assumed that LPG vehicles have 30% more fuel consumption than gasoline vehicles (≈1 L/h for idling, and 19.5 L/h crossing the intersection). Here, the average fuel consumption in the idle depends on the operating condition of the vehicle accessories (radio, air conditioning, headlamps, etc.), climate (hot-cold, wet-dry, rainy-rainy, etc.) and the condition of the vehicle (maintenance of the vehicle on time, vehicle mileage value etc.) should be considered.

The number of vehicles waiting at the intersection may be different at any time of the day. However, the red light waiting time of all vehicles waiting in the red light may be different. With the red light on, the number of vehicles waiting in the red light until the green light comes on increases continuously. This increase may not be regular. It is assumed that the number of vehicles waiting in red light in terms of ease of calculation increases linearly depending on time. The vehicle is expected to arrive every 5 seconds ($\mathbf{t_r = 5}$) and to the secondary road every 10 seconds ($\mathbf{t_r = 10}$). It is assumed that all vehicles waiting due to red light pass through the intersection during the green light. The number of vehicles waiting in a period for a single phase at a intersection was calculated by the following equation.

$$\mathbf{w} = \frac{\mathbf{t_{red}}}{\mathbf{t_r}} \tag{2}$$

Where w is an integer. The total waiting time (t_(r,tot)) for one phase is calculated by the following equation.

$$\mathbf{t_{r,tot}} = \mathbf{0.5w(w+1)t_r} \tag{3}$$

Many strategies and algorithms for crossing scenarios in green light at intersections are available in the literature. However, a more simplified model was used for this study. When the green light is on, there may be big differences between the intersection abandonment time of the foremost vehicle and abandonment of the intersection of the rear end of the vehicle. A green light transition is designed in which the first vehicle leaves the intersection in 2 seconds ($\mathbf{t_g} = \mathbf{2}$) and the next vehicle leaves 2 seconds later than the vehicles in the previous order. Accordingly, the intersection time ($\mathbf{t_{g,tot}}$) can be calculated as follows in the green light period for a phase.

$$\mathbf{t_{g,tot}} = \mathbf{0.5w(w+1)t_g} \tag{4}$$

Here the yellow light duration is considered as the uncertainty period. This can sometimes be included in the red light period, sometimes in green light time. This has been neglected for this study because it is too small compared to other times. According to the literature, it is known that there is a certain delay time during the passage of vehicles in green light. This delay time has also been neglected for this study. Forward-moving vehicles move faster than rotating vehicles. The total $\mathbf{CO2e}$ resulting from vehicles using “i” fuel (gasoline, LPG or diesel) in a period of light for a phase can be calculated as follows.

$$(\mathbf{CO2e_{tot}})_\mathbf{i} = \mathbf{60^{-2}}\left(\mathbf{F_v CO2e}\left(\mathbf{t_{r,tot}}\dot{\mathbf{v}}_\mathbf{r} + \mathbf{t_{g,tot}}\dot{\mathbf{v}}_\mathbf{g}\right)\right)_\mathbf{i} \tag{5}$$

Here, $\dot{\mathbf{v}}_\mathbf{r}$ and $\dot{\mathbf{v}}_\mathbf{g}$ values are the hourly fuel consumption of vehicles in red and green light respectively. The fuels used by the vehicles in the traffic are different from each other. In Turkey, gasoline LPG and diesel utilization ($\mathbf{F_v}$) respectively 25%, 45% and 30%. Accordingly, $\mathbf{CO2e_{tot}}$ value for a phase “j” can be calculated as follows.

$$(\mathbf{CO2e_{tot}})_\mathbf{j} = \sum_{\mathbf{i=1}}^{\mathbf{3}}(\mathbf{CO2e_{tot}})_\mathbf{i} \tag{6}$$

$\mathbf{CO2e_{tot}}$ value at the intersection is calculated as follows. The calculated value is the value for a period at the intersection.

$$(\mathbf{CO2e_{tot}})_{\mathbf{intersection}} = \sum_{\mathbf{j=1}}^{\mathbf{4}} (\mathbf{CO2e_{tot}})_{\mathbf{j}} \tag{7}$$

$(\mathbf{CO2e_{tot}})_{\mathbf{intersection}}$ value for an hour is expressed as $\mathbf{CO2e_{flow}}$ and the following equation should be used to calculate this value.

$$\mathbf{CO2e_{flow}} = \frac{\mathbf{60^2/1000}}{\mathbf{t_{intersection}}} (\mathbf{CO2e_{tot}})_{\mathbf{intersection}} \tag{8}$$

Here $\mathbf{t_{intersection}}$ is the period designed to provide a traffic light cycle in the intersection. The formulas thus indicated are intended for use in a conventional vehicle. With the development of technology, the number of electric and hybrid electric vehicles is increasing day by day. However, in order to incorporate electric and hybrid electric vehicles into these calculations, these vehicles must be located in a number of traffic. Nowadays, idle stop-start system is widely used especially in the vehicles produced in 2015 and later. However, it is not known exactly how efficiently this system is used in vehicles equipped with this technology. In a simple definition, the idle stop-start system is a short stop of the engines of vehicles waiting for the red light. In this way, the $\mathbf{CO2e}$ value of the vehicle waiting in the red light of a vehicle using the idle stop-start system is zero. However, the $\mathbf{CO2e}$ value during the passage of the electric vehicles at the intersection is also accepted as zero. In this study, if the vehicle ratio $\mathbf{F_{iss}}$ using the idle stop-start system for the effect of this system and the electric vehicle ratio are expressed as $\mathbf{F_{ev}}$, Eq. 5 can be rearranged as follows.

$$(\mathbf{CO2e_{tot}})_{\mathbf{i}} = \mathbf{60^{-2}} (\mathbf{F_v CO2e})_{\mathbf{i}} \left((\mathbf{1} - \mathbf{F_{iss}}) \mathbf{t_{r,tot}} \dot{\mathbf{v}}_{\mathbf{r}} + (\mathbf{1} - \mathbf{F_{ev}}) \mathbf{t_{g,tot}} \dot{\mathbf{v}}_{\mathbf{g}} \right)_{\mathbf{i}} \tag{9}$$

$\mathbf{F_{iss}} \geq \mathbf{F_{ev}}$ requirement must be met here. Because electric vehicles are also vehicles with idle stop-start system. With the help of the equations presented above, $\mathbf{CO2e_{flow}}$ value can be calculated for the intersection in Figure 1. Unlike the literature, the equations presented here are simplified without applying any strategy or algorithm for the intersection.

4. NUMERICAL STUDY AND RESULTS

Assuming that all vehicles in the intersection do not use the idle stop-start system, which is not electric or hybrid electric, the results in table 1 are obtained.

Tablo 1. Numerical study results

Parameter	Unit	Using Equation	Intersection Phases				Total
			1st	2nd	3rd	4th	
w	-	2	14	8	14	8	44
$t_{r,tot}$	s	3	525	360	525	360	1770
$t_{g,tot}$	s	4	210	72	210	72	564
$(CO2e_{tot})_{gasoline}$	g/s	5	602.69	230.95	602.69	230.95	1667.26
$(CO2e_{tot})_{LPG}$	g/s	5	908.41	346.85	908.41	346.85	2510.51
$(CO2e_{tot})_{diesel}$	g/s	5	507.94	193.50	507.94	193.50	1402.88
$(CO2e_{tot})_{j}$	g/s	6 and 7	2019.03	771.29	2019.03	771.29	5580.64
$CO2e_{flow}$	kg/h	8	72.69	27.77	72.69	27.77	200.90

Here the $CO2e_{flow}$value is 8 hours and when it is calculated for 360 days, 578.34 tons/annual CO2e is formed. This is equivalent to the amount of carbon kept by a forest area of 2.76 km2 in a year or 1340 barrels of oil (EPA, 2019).

According to the above scenario, approximately 4.562 million vehicles pass through this intersection annually. In addition to this scenario, if vehicles and electric vehicles using the idle stop-start system are included in this calculation, the change of $CO2e_{flow}$ depending on F_{iss} and F_{ev} change is as follows (Figure 2).

Figure 2 shows that the effect of F_{ev} is higher than F_{iss}. Assuming that all vehicles have idle stop-start system and use this system, the reduction in $CO2e_{flow}$ e is about 13%. In the case of electric vehicles, the $CO2e_{flow}$ value decreases depending on the electric vehicle ratio. For example, the effect of 10% F_{ev} and 70% F_{iss} is equal to each other.

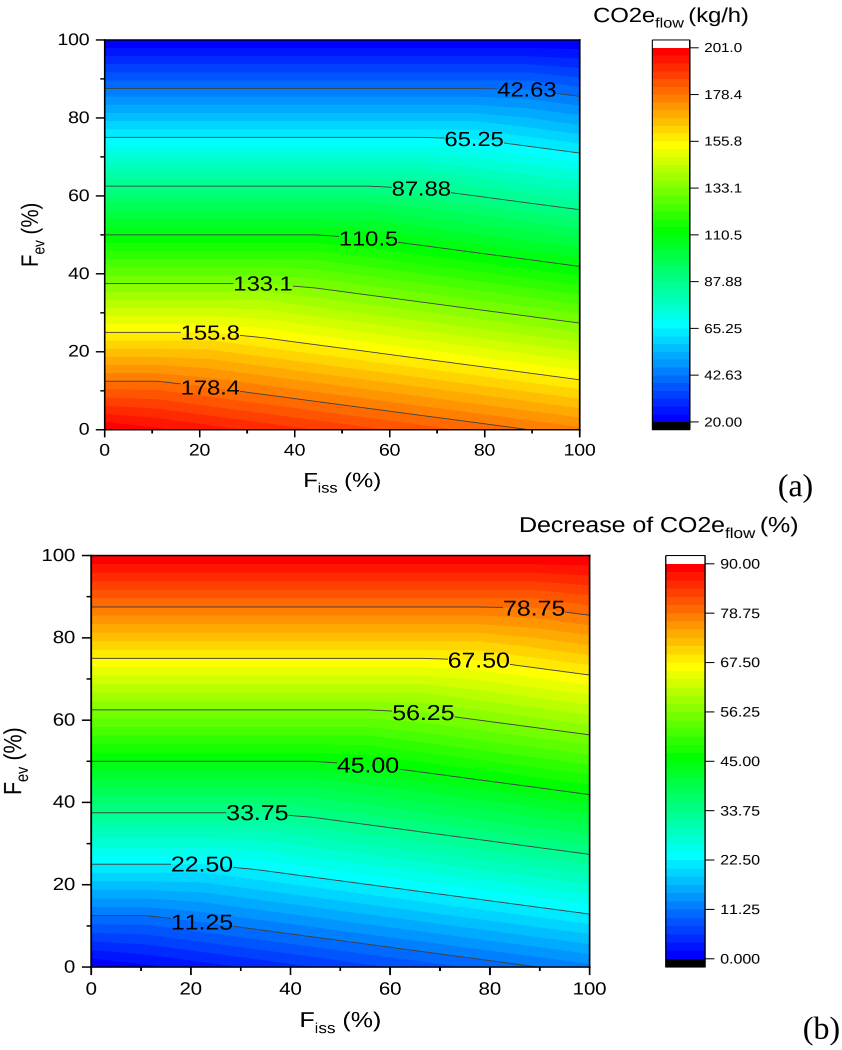

Figure 3. Effect of (a) $\mathbf{F_{iss}}$ and (b) $\mathbf{F_{ev}}$ on $\mathbf{CO2e_{flow}}$

5. CONCLUSION

In this study, CO2 equivalent emission formation for a simple four phase intersection was investigated with a numerical example. Equations are derived to calculate CO2 equivalent emission at the intersection. However, the effect of the number of vehicles using idle stop-start technology and the number of electric vehicles on CO2 equivalent emissions was investigated. The small number of electric vehicles has significantly reduced CO2 equivalent emissions at the intersection. However, with the use of the idle stop-start system, it has been observed that CO2 equivalent emissions can be reduced. The idle stop-start system not only prevents CO2 equivalent emissions, but also significantly reduces the acoustic emissions from vehicles. Roadside vehicle parks should also be kept under control to ensure an effective flow of traffic at intersections. Thus, the intersection light cycle process can be optimized as the number of vehicles passing through the intersection in a green light period will be increased.

REFERENCES / KAYNAKLAR

Cao, Z., Jiang, S., Zhang, J. & Guo, H. (2016). A unified framework for vehicle rerouting and traffic light control to reduce traffic congestion. *IEEE Transactions on Intelligent Transportation Systems*, *18*(7), 1958-1973. https://doi.org/10.1109/TITS.2016.2613997

Choy, M. C., Srinivasan, D. & Cheu, R. L. (2003). Cooperative, hybrid agent architecture for real-time traffic signal control. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, *33*(5), 597-607. https://doi.org/10.1109/TSMCA.2003.817394

Czarnecki, K. (2018). Operational world model ontology for automated driving systems - part 1: road structure. *Waterloo Intelligent Systems Engineering (WISE) Lab, University of Waterloo*. https://doi.org/10.13140/RG.2.2.15521.30568

Daganzo, C. & Daganzo, C. F. (1997). *Fundamentals of transportation and traffic operations (Vol. 30)*. Oxford: Pergamon.

D'Andrea, E. & Marcelloni, F. (2017). Detection of traffic congestion and incidents from GPS trace analysis. *Expert Systems with Applications*, 73, 43-56. https://doi.org/10.1016/j.eswa.2016.12.018

EPA. *Greenhouse gas equivalencies calculator*. Accessed: 24.05.2019, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Ewing, R. & Dumbaugh, E. (2009). The built environment and traffic safety: a review of empirical evidence. *Journal of Planning Literature*, *23*(4), 347-367. https://doi.org/10.1177%2F0885412209335553

Fouladgar, M., Parchami, M., Elmasri, R. & Ghaderi, A. (2017). Scalable deep traffic flow neural networks for urban traffic congestion prediction. *In 2017 International Joint Conference on Neural Networks (IJCNN)* (pp. 2251-2258). IEEE. https://doi.org/10.1109/IJCNN.2017.7966128

Kumar, P., Ketzel, M., Vardoulakis, S., Pirjola, L., & Britter, R. (2011). Dynamics and dispersion modelling of nanoparticles from road traffic in the urban atmospheric environment—a review. Journal of Aerosol Science, 42(9), 580-603. https://doi.org/10.1016/j.jaerosci.2011.06.001

Li, Z., Shahidehpour, M., Bahramirad, S., & Khodaei, A. (2016). Optimizing traffic signal settings in smart cities. IEEE Transactions on Smart Grid, 8(5), 2382-2393. https://doi.org/10.1109/TSG.2016.2526032

Malakorn, K. J., & Park, B. (2010). Assessment of mobility, energy, and environment impacts of IntelliDrive-based Cooperative Adaptive Cruise Control and Intelligent Traffic Signal control. In Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology (pp. 1-6). IEEE. https://doi.org/10.1109/ISSST.2010.5507709

Mannion, P., Duggan, J., & Howley, E. (2016). An experimental review of reinforcement learning algorithms for adaptive traffic signal control. In Autonomic Road Transport Support Systems (pp. 47-66). Birkhäuser, Cham. https://doi.org/10.1007/978-3-319-25808-9_4

Nigarnjanagool, S., & Hussein, D. I. A. (2005). Evaluation of a dynamic signal optimisation control model using traffic simulation. IATSS research, 29(1), 22-30. https://doi.org/10.1016/S0386-1112(14)60115-1

Piecyk, M. I., & McKinnon, A. C. (2010). Forecasting the carbon footprint of road freight transport in 2020. International Journal of Production Economics, 128(1), 31-42. https://doi.org/10.1016/j.ijpe.2009.08.027

Pignataro, L. J., Cantilli, E. J., Falcocchio, J. C., Crowley, K. W., McShane, W. R., Roess, R. P., & Lee, B. (1973). *Traffic engineering: theory and practice*. New Jersey, ABD: Prentice-Hall.

Polson, N. G., & Sokolov, V. O. (2017). Deep learning for short-term traffic flow prediction. Transportation Research Part C: Emerging Technologies, 79, 1-17. https://doi.org/10.1016/j.trc.2017.02.024

Pursula, M. (1999). Simulation of traffic systems-an overview. Journal of geographic information and decision analysis, *3*(1), 1-8.

Qi, L., Zhou, M., & Luan, W. (2016). A two-level traffic light control strategy for preventing incident-based urban traffic congestion. IEEE transactions on intelligent transportation systems, *19*(1), 13-24. https://doi.org/10.1109/TITS.2016.2625324

Sharma, S., & Mishra, S. (2013). Intelligent transportation systems-enabled optimal emission pricing models for reducing carbon footprints in a bimodal network. Journal of Intelligent Transportation Systems, *17*(1), 54-64. https://doi.org/10.1080/15472450.2012.708618

Sovacool, B. K., & Brown, M. A. (2010). Twelve metropolitan carbon footprints: A preliminary comparative global assessment. Energy policy, *38*(9), 4856-4869. https://doi.org/10.1016/j.enpol.2009.10.001

Sundar, R., Hebbar, S., & Golla, V. (2014). Implementing intelligent traffic control system for congestion control, ambulance clearance, and stolen vehicle detection. IEEE Sensors Journal, *15*(2), 1109-1113. https://doi.org/10.1109/JSEN.2014.2360288

Vallati, M., Magazzeni, D., De Schutter, B., Chrpa, L., & McCluskey, T. L. (2016). Efficient macroscopic urban traffic models for reducing congestion: a PDDL+ planning approach. In Thirtieth AAAI Conference on Artificial Intelligence.

Zhao, D., Dai, Y., & Zhang, Z. (2011). Computational intelligence in urban traffic signal control: A survey. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), *42*(4), 485-494. https://doi.org/10.1109/TSMCC.2011.2161577