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RESEARCH OF THE LIGHT DUTY VEHICLES EQUIVALENTS AT THE MIXED LANES OF THE SIGNAL CROSSROADS AT THE CENTRAL CITY ZONE

Marko Subotić, Vladan Tubić, Dejan Anđelković

msubota@gmail.com, vladan@sf.bg.ac.rs , aaa.dejo@gmail.com

MSc, Faculty of Transport and Traffic Engineering, University of East Sarajevo, Vojvode Mišića 52 Doboj,
BOSNIA & HERCEGOVINA
Ph.D., Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305 Belgrade,
MSc, Faculty of Technical Science, University of Kosovska Mitrovica, Knez Miloša 7, Kosovska Mitrovica,
SERBIA

Abstract: *This work analyses the influence of the light duty vehicles at the capacity of mixed traffic lanes at the signal crossroads. The influence of the light duty vehicles is pointed at the Passenger Car Equivalents (PCE). The gathering of information has been conducted in Republic of Srpska (Bosnia and Herzegovina), at the location of the town of Doboj, where the observation has been conducted at the representative four-end crossroads. PCE factors have been targeted and analyzed through determining of the time intervals of lagging, and their influence at the crossroads capacity. Total measured PCE factor value at the mixed lane of the crossroads is 1.6155, while the value was 1.50 in relation to HCM-2000, which had a goal of development of deterministic mathematic model of dependency, for determining the PCE, which is based on determining the time distance of lagging, which is in function of the length of vehicles on mixed lanes, awaiting on a discharge. Overview of the result of research has been made with software set MATLAB 2010.*

Key words: *PCE, light duty vehicles, four-end signal crossroads, saturated flow*

INTRODUCTION

In order to understand the effect of different vehicle categories on a traffic flow, many researchers have been made. PCE is used in order to evaluate the effect of the traffic flow of passenger cars. Since the traffic flow is composed of various types of vehicles, PCE values are used to render the real traffic flow with the equivalent of homogenous traffic. The beginnings of PCE are related to 1965, and further on, many researchers attempted to determine quantity of effects of heavy duty vehicles in the traffic flow, towards the development of HCM (*Highway Capacity Manual*), with use of different methodologies and equality criteria. According to the last version of HCM-2000. [1] PCE represent the number of passenger cars distributed in accordance to the equal category of vehicle units, in dependence from the prevailing conditions in the traffic, and average number of passenger cars which would use the same percent of the road capacity as well as other vehicle (TV, BUS, AV), at the given road and traffic conditions. Thus, it dimensions the measurement unit of capacity as passenger car/hr (PC/h). Presence of the duty vehicles in traffic flow of the road junctions is resulted in reduced

capacities of the traffic lanes at the crossroads. [2] The influence of the duty vehicles at the traffic flow is reflected in the fact that the duty vehicles are bigger from the passenger vehicles, and therefore, they are taking more space in the traffic flow. Also, duty vehicles have more inferior technical-exploitation possibilities (acceleration and deceleration), than passenger vehicles, and they demand larger space between vehicles. This also implies that the other vehicles drivers in the flow are keeping the larger distances in relation to the duty vehicles. [3]

HISTORICAL OVERVIEW AND INFLUENCE FACTORS

PCE has been incorporated into the HCM-1965 for the first time, and the majority of the researches from the past has been undertaken with the goal in determining the PCE for heavy duty vehicles. However, one unique factor has been used in 1950, out of two necessary for calculation of the duty vehicles influence on the multiple lane highways at the level terrain (*Highway Research Board*, 1950) has been used. There are different chronological approaches for determining the PCE. For example, HCM-1965 is using the *method of speed reduction* for determining the PCE for highways, known as Walkers method.

According to Huber, [4] there are three measures of PCE performances: *speed, density and speed of passenger car in the both lanes.* Cunagin i Messer [5] are using the *relations of delay* as a measure of performance for estimation of PCE of duty vehicles at the multiple-lane highways. Sumner [6] is using the *number of vehicles per hour*, to point out the equivalent of density, since the veh/h is the function of speed and the length of the vehicle. Bhuvanesh Singh [7] are using concentration of the vehicles as the characteristic of traffic for estimation of model of simulation, defined as a part of the road with number of vehicles at the given moment. Khan i Maini [8] gave the wide overview of flow model of heterogeneous traffic flow and they concluded that lineary density measurement is not adequate for mixed category of vehicles, and that the measuring should be performed at the segments of the vehicle movements. Chandra i Sikdar [9] are proposing the method for PCE estimation for mixed traffic flow, as the function of the vehicle surface (length x width), and speed. The study made by Ahmed et al. [10] brought to conclusion that the effect of duty vehicles on traffic is much easier to notice in the periods of congestion, than in the less dense conditions.

Al-Kaisy [11] is using the *factor of queue vehicle discharge,* as a measure of performances for estimation of PCE during the congestion of traffic flow. Bham i Benekohal [12] are using the percentage of department taken from the vehicle sides to present the conditions of traffic congestion when the traffic flow is consisted from the vehicles of heterogeneous length. Chitturi i Benekohal [13] estimated the influence of work zones to PCE and they concluded that the values of equivalents are reducing when the percentage of cargo trucks is increasing, as well as with increase of traffic load.

Considering the motorcycles, Rongviriyapanich i Suppattrakul [14] are calculating the PCE values nearby the crossroads and loops, using the time interval of lagging. They came to conclusion that the PCE for motorcycles is constantly reducing, with proportion of increase of other categories of vehicles. Also, Ahmed [3] studied the identifying of characteristics of duty vehicles, which has an influence to the vehicle flow at the highways in different conditions of congestion, with emphasis at the level of service.

RESEARCH HYPOTHESES

The background of this research is based on the hypothesis that the effect of light duty vehicles at the mixed lane of signal crossroads, in relation to the passenger vehicles, is larger in the over-congested conditions of traffic flow, than in less congested conditions (conditions below

capacity). This hypothesis is related to the light duty vehicles in general (as combined vehicles, busses and mini-busses), and it is not related to the trucks and medium/heavy duty vehicles.

Hypothesis is also based on the attitude to the acceleration and deccelaration of light duty vehicles in the real traffic flow, which is carried out in the mixed lanes at dry weather and better weather conditions, than at the rain or snow conditions, with worse weather conditions.

It is important to clear out the fact of focus on the events when the vehicles are moving on the front side of the queue, and not inside the queue or traffic flow, as well as the events inside the queue, which are guided with nature of disturbances, as well as with the quantity of overload. Finally, our assumption is resumed to the condition where the larger influence of light duty vehicles at the traffic flow of mixed lane, during the discharge of the longer queue of the vehicles, with the flashing of green signal concept, rather than in the case of discharge of smaller queue of vehicles at the real traffic flow. If this claim points out as a true, it can explan the deviations in the crossroads capacity, after the congestion starts, and it can be applied at the different locations in B&H.

RESEARCH ACCESS

There are several access types for determining the influence of light duty vehicles to the vehicle movement at the traffic flow. The most common approaches for determining PCE values are resumed to [3]:

- *Approach of constant relation of flow and capacity* has been the adequate for calculation of PCE, when the level of services has been taken in consideration, for oveviewing the PCE calculation.
- *The equal density approach* is related to the diference between two traffic flows (only PC, mixed traffic), when the traffic flows are working at the same traffic density.
- *Approaches of distances/spacing* (time interval of lagging), is one of the most-present methods. This method has been developped in 1947, by Greenshields, and it is known in a literature as basic method for determining the lagging interval. Concept of this method is far by simple and based on a relation

$$PCE_i = \frac{H_i}{H_{PC}}, \quad (1)$$

where:

PCE_i – Passenger Car Equivalent of i vehicle category

H_i – Average value of lagging interval of i category of the vehicle

H_{PC} – Average value of lagging interval for passenger car.

Based upon the unified information system of the Association of technical screening of Republic of Srpska data base, it has been determined that the figure of representation of passenger vehicles is 76.9%, which shows us the real influence in the structure of the vehicle fleet in Republic of Srpska, in figure of 23.1%. That is a significant movement of passenger vehicles in the traffic flow. Respectivelly to that, if we are observing the mixed lane of the signal crossroads, with the permission for movement only for the light duty vehcies and Public Ttransport Vehicles, the study related to the influence of delivery vehicles at the capacity of traffic lane. Furthermore, the calculation of PCE values for mixed lanes is also justified, since there is large influence of commercial vehicles.

Determining the values of equivalent for transformation of light duty vehicles in the passenger vehicles units, is performed with the pattern, which is based on the time intervals of vehicles lagging, which is related to the lagging of light duty vehicles [2]. The pattern is as it follows:

(2) $$PAE_i = \frac{\delta_i + \Delta y_i}{y_p}$$, where

PCE_i –Value of Passenger Car Equivalent, for i vehicle

δ_i –average time of lagging interval or i light duty vehicle

γ_p –average interval for passenger vehicle lagging another passenger vehicle

$\Delta\gamma_i$ –Average additional delay, caused by light duty vehicle, lagging another passenger vehicle.

This method is known under the name *"method of spacing"*. [2] Practically applied procedures are used for different types of vehicles, which are included in the category of light duty vehicles (delivery vehicles). When PCE is calculated, additional time is also taken in consideration, which is necessary for passenger vehicle to cross the crossroads, in the situation when the latter is lagged by the delivery vehicle. This methodology of determining the PCE equivalents is used as a part of this research, upon which were given the representative values of PCE equivalents. The adopted value of additional time as a part of this work is 0.2 sec and it is considered necessary and sufficient time loss for passing of the vehicle, across the four-sided signal crossroads in the mixed lane.

DESCRIPTION OF THE LOCATION OF RESEARCH

This location is situated at the downtown zone of town of Doboj, in Bosnia and Herzegovina. It is well-known for the occasional congestions in the morning and afternoon hours, within the increased frequency of work movements and delivery of material and goods. Mixed lanes for straight and right directions is occupying the corridor in a length of 900 m, with total number of 6 crossings, out of which, one has been taken for the analysis. The traffic in the lane, which is increased in the periods of rush hour, which is consisted mainly from the drivers which are driving on everyday basis. The traffic has been recorded with the handy camera, from the side perspective, in a proximity of the crossroads. Positioning the camera eliminates the influence to the potential delay of the vehicles, by the light duty vehicles, which is the result of the measures of time intervals of lagging at the video recordings. The frame percentage of light duty vehcles at the given location is about 15% during the morning hours (09:30-10:00), and afternoon hours (14:00-15:30).

Table 1

Date	Time	Number of observations	PCE	Weather Conditions
December 10, 2010	09:30-11:00	16	1,53	dry
	14:00-15:30	17	1,56	dry
December 13, 2010	09:30-11:00	17	1,55	dry
	14:00-15:30	15	1,64	dry
December 14, 2010	09:30-11:00	13	1,64	dry
	14:00-15:30	16	1,70	snow-rain
December 15, 2010	09:30-11:00	22	1,60	snow-rain
	14:00-15:30	14	1,52	dry
December 21, 2010	09:30-11:00	16	1,73	snow-rain
	14:00-15:30	16	1,69	dry
December 23, 2010	09:30-11:00	14	1,44	dry
	14:00-15:30	18	1,61	dry
December 24, 2010	09:30-11:00	16	1,54	dry
	14:00-15:30	12	1,64	dry
December 27, 2010	09:30-11:00	17	1,79	snow-rain
	14:00-15:30	19	1,67	snow-rain

It is planned to have the measure for different lengths of vehicle queue waiting on discharge, in accordance to the plan and program of the implemented research. Since the measured cycle of work at the four-sided signalcrossroads is C=60 seconds, the number of measured time intervals of lagging were easy to determine; that is represented as n-1, since the first vehicle is not taken into the consideration, and hte maximum number of vehicles whic are leaving mixed lane 7, which gave us 6 measuring results, and we did not go below four vehicles during the measure, which resulted with 3

given values of measurement. Given results gave different inter-dependency for the length of vehicle queue, which are awaiting the discharge and PCE values. Therefore, the curve that represents such interdependency will be approximated with the polynomial of adequate degree. As a reason that determins the practical application of pattern, forming polynomial larger than 3 will be abjured, and the approximation will be done with 3rd degreee polynomial, which enables sufficient correctness of the approximation.

Based on the analysis, we will boot the mathematical shape of vehicle queue length dependency,from PCE factors:

$$S = 95{,}5 \cdot PAE^3 - 1023{,}9 \cdot PAE^2 + 2649{,}2 \cdot PAE - 1978{,}3 \quad (3)$$

Maximum determined PCE value at the mixed lane is 1.79, which points us that the right half of the curve is not competent for determining the given crossroads equivalent (for PCE values approximatelly larger than 1.7). The data processing of data gained through the experimental way, will be done on a computer, through the program set MATLAB 2010.

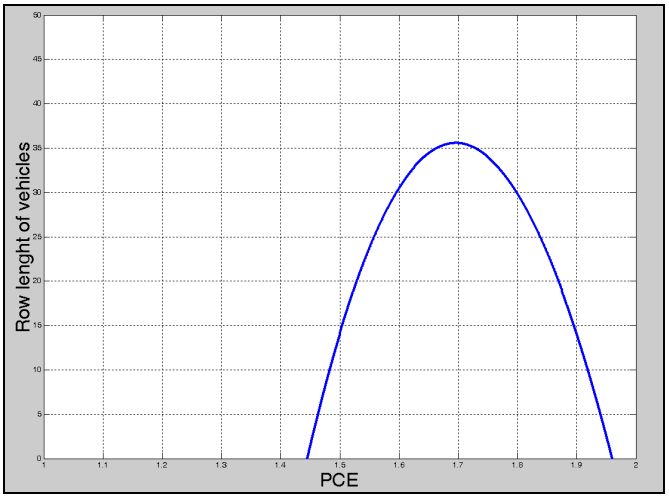

Fig. 2: *Mathematic model of PCE dependecy from the vehicle queue*

It is evident tha tthe PCE value for real queue length is in a diameter form 1.5 to 1.79. However, reconsidering the weather conditions, it has been determined that snow and rain have a significant influence of PCE euqivalents. The medium PCE value on rain, that is 1.7225 can be presented as an evidence, while the medium PCE value on dry weather conditions is 1.58. The difference in the deviation PCE on rainy condition and PCE in dry weater cconditions with value of 0.1425 can be considered as justifiable, since hte weather conditions are significantly influencing the mobility of vehicles, reduce of the vehicle movement, increase of the lagging space, etc. The pointer of equivalents for dry weather conditions does not deviate much from the HCM-2000, but the difference of deviation of PCE on rainy weather conditions is evident. Although, there are no major differences in PCE for the morning and afternoon hours. They are almost identical, and one can not reconsider that the PCE values are increased or decreased in the morning hours, related to the afternoon hours. The PCE are 1.615 in the morning hours, 1.616 in the afternoon hours. These values are almost identical.

DISCUSSION AND CONCLUSIONS

Mathematic (graphic and analytic) model of interdependency of PCE factors and vehicle queue length is forrmed as a basic goal of this work. As a part of such model, it has been concluded that the value of equivalents, in depencency from the vehicle queue length is in diameter from 1.50 to 1.79. Besides that, PCE values in worse weather conditions are progresivelly increasing, due to reducition of technical-exploitational properties of vehicles, that are represented in the fleet at the mixed lane. Also, the claim of many mentioned researchers that the drivers are maintaining the larger distances when they are lagging the light duty vehicle is evident, than when they are laggig the passenger vehicle. Light duty vehicles has an significant influence in the conditions of saturated flow, where PCE equivalent of given crossroads is 1.6155, which is over HCM-2000 values, which is 1.50, in the conditions of stabile flow.

The refferences for the future researches are related to the possibility of monitoring the PCE equivalents along the corridor, which goal would be forming the model of traffic management along the corridor, based on the PCE equivalents. It would be understandible to suppose that the drivers of light duty vehicles are basing their choice of maintaining the distance in accordance to the vehicle weight.

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ИЗСЛЕДВАНЕ ЕКВИВАЛЕНТИТЕ НА ЛЕКОТОВАРНИ ПРЕВОЗНИ СРЕДСТВА ПРИ СМЕСЕНИ УЛИЧНИ ПЛАТНА НА СИГНАЛИЗИРАНИ КРЪСТОВИЩА В ЦЕНТРАЛНА ГРАДСКА ЗОНА

Marko Subotić, Vladan Tubić, Dejan Anđelković

MSc, Faculty of Transport and Traffic Engineering, University of East Sarajevo, Vojvode Mišića 52 Doboj
BOSNIA & HERCEGOVINA
Ph.D., Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305 Belgrade
MSc, Faculty of Technical Science, University of Kosovska Mitrovica, Knez Miloša 7, Kosovska Mitrovica
SERBIA

Ключови думи: *PCE, лекотоварни автомобили, сигнализирани кръстовища с четири улици,, наситен поток.*

Резюме: *В този доклад се анализира влиянието на лекотоварни превозни средства върху капацитета на смесени платна за движение при сигнализирани кръстовища. Влиянието на лекотоварни превозни средства се посочва в еквиваленти на леки автомобили (PCE). Събирането на информация е проведено в Република Сръбска (Босна и Херцеговина) на територията на град Добой, където е направено наблюдение представителни кръстовища с четири улици. Факторите на PCE са били поставени Като цел и са анализирани чрез определяне на интервали от време на изоставане и тяхното влияние върху капацитет на кръстовищата. Измерената обща стойност на фактора PCE на смесено платно на кръстовищата е 1.6155, докато стойността в съответствие с HCM-2000 е 1.50. С това се целеше разработване на детерминантен математически модел на зависимостта за определяне на PCE на основата на определяне времевата разлика на изоставане, което е в зависимост от дължината на превозни средства на смесени улични платна, в очакване на освобождаване на платното. Обработването на резултата от научните изследвания е направено със софтуер MATLAB 2010.*