

DELAY MODEL FOR UNCONTROLLED INTERSECTIONS IN MIXED TRAFFIC CONDITIONS

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Abstract

Intersections are the critical zones where vehicles make different manoeuvres and want to occupy the same space at the same time. As the vehicle reaches the intersection the driver of the subject vehicle has to take quick decision considering the intersection geometry, speed and vehicles present near the intersection. In developed countries like India, heterogeneous traffic exists, consisting of varied sizes of vehicles and lack of lane discipline. Due to absence of lane discipline, the small sized vehicles try to accept the available gaps, causing delay to the major stream flow which in turn affects the intersection capacity. In this study, capacity of the intersection is estimated by gap acceptance method, and data was collected from three uncontrolled three-legged intersections covering various regions of India. The parameters extracted from the video include critical gap, follow-up time, stopped delay and total time to cross the intersection for each vehicle type. Gap Acceptance Method is used for mixed traffic condition because it is based on the critical gap and follow-up time, which depends on the type of vehicle and traffic conditions. This study tries to develop a Multiple linear regression (MLR) model for delay and compares the capacities of Uncontrolled intersection (UCI) with different gap acceptance model like Drew's model, Harder Model, Modified Sieglösch model, Lutinen's model and Highway capacity manual (HCM) 2010. It was observed that critical gap is influenced by the size of the vehicle and traffic volume. There is also an increase in delay as the size of vehicle increases.

Keywords: Gap Acceptance, Capacity, Critical Gap, Follow-up Time, Delay, Uncontrolled intersection

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Introduction

At an uncontrolled intersection, the vehicular interactions are very complex. Most of the vehicles move without following the rules of priority. The critical gap estimation and capacity estimation are very complex at uncontrolled intersection in heterogeneous traffic scenario because the performance of the vehicles varies widely. The static and dynamic characteristics of each vehicle are different from the other. In the absence of lane discipline and with wide variation in size of vehicles, a side by side queuing of vehicles is usually observed in minor approach of an intersection. Further, small sized vehicles accept least possible gap in dangerous manner causing the major stream vehicles to forcefully stop resulting in larger delays for traffic in major stream. Generally, all the vehicles accept the gap in a zig-zag manner making the critical gap determination very difficult. Gap estimation is an integral part of capacity estimation at uncontrolled intersection. Even a micro-second difference in gap calculations leads to error in capacity estimation.

Literature review

Most of the studies reported on critical gap estimation are for homogenous traffic conditions and are applicable where the rules of priority are truly followed (Raff and Hart, 1950; Solberg and Oppenlander, 1966). Several researchers carried out studies on the delay and also estimated the capacity at uncontrolled intersection using different methods and different parameters were used for estimating the capacity of the intersection. The first study tried to use queuing concept for estimating the delay at two-way stop controlled intersections (Tanner, 1953; Tanner, 1962). A theoretical model was derived based on the gap acceptance behavior for determining the average service time (Surti, 1970). A relationship between delay and traffic intensity was proposed for minor roads at un-signalized intersections (Kimber *et al.*, 1977). Also, studies were done for calculating queue length and delay at road junctions, which considers the stochastic nature of traffic and the capacity (Kimber and Hollis, 1979). Researchers also tried to analyze the influence of stopped delay on the gap acceptance. However, such studies mainly focused on the left turning minor traffic and limited to the conditions where there was less or no queue (Adebis and Sama, 1989). For a stop-controlled intersection, a probabilistic delay model reflecting the driver gap acceptance behavior was developed that was applicable only to right-turning traffic at T-intersection (Madanat *et al.*, 1994). Few of the

studies evaluated the influence of driver behavior on delay at un-signalized intersections (Kaysi and Alam, 2000). A relationship between delay and traffic flow on the minor roads was developed (Luttinen, 2004), however a study was carried out for the capacity models and parameters taken for un-signalized urban intersections (Chodur, 2005). A service delay model based on the microscopic approach was developed and concluded that the proportion of heavy vehicles in the conflicting traffic stream is mainly affected by the service delay (Chandra *et al.*, 2009). Also, the service delay was studied under different priority movements by considering two wheelers, three wheelers, passenger cars and heavy vehicles at un-signalized intersections (Ashalatha and Chandra, 2011). For estimating the delay, a detailed procedure is presented in the Highway capacity manual 2010 (Transportation Research Board, 2010). Based on the existing capacity and delay models, the results were tested with the data collected in Croatia, also the delay model based on queuing theory was studied. Finally, capacity and delay values of uncontrolled intersection with normal traffic and road condition yielded good results according to Highway Capacity Manual 2000 procedure (Cvitanic *et al.*, 2007). A study conducted in Indonesia mainly focused on the differences with their intersections compared to those in developed countries and proposed a new method based on the conflict technique for determining the capacity of the un-signalized intersection under mixed traffic conditions (Prasetijo *et al.*, 2011). Further, the capacity of un-signalized intersection is reduced by 11.26% in slightly snow weather condition when compared with sunny weather condition by using gap acceptance procedure (Xu and Cheng, 2012). Further, capacity models of the vehicular movements can also be assessed under mixed traffic condition for both AWSC and TWSC intersections (Brilon and Miltner, 2005; Li and Deng, 2008). Also, using the conflict technique method, the influence of non-motorized (pedestrian and bicycle) movements on the capacity of Two-way stop controlled TWSC and All-way stop controlled AWSC intersections was analyzed and reported that influence of the non-motorized vehicles cannot be ignored (Shi and Li, 2008). From the literature, it can be observed that the capacity of uncontrolled intersections is estimated using three methods. The methods developed to find the capacity of uncontrolled intersections are mainly based on the calculation of critical gap and follow up time of minor stream vehicles. Gap-Acceptance method

(GAP) was developed in Germany (Harders, 1968) and is widely used in United States and several European countries. This method is based on critical gap acceptance and follow up times of vehicles from the minor road. Hence, comparing the three methods, GAP is more suitable for mixed traffic conditions because it can be used for different composition of vehicles. The main objective of this study is to develop a delay model and to analyze the capacity of right turning vehicles at uncontrolled intersections under mixed traffic condition.

Study area and data collection

Three uncontrolled three-legged intersections (New Delhi, Kozhikode and Karimnagar) located at different regions of India were selected as shown in Figures 1, 2 and 3, respectively. New Delhi is the capital city of India and is located in the Northern region. Karimnagar is a medium-sized city and is located in the South Central region. Kozhikode is a medium sized city and is located in the Southern region. The dimensions of all the three intersections are tabulated in Table 1. The traffic volume is higher at intersections located in Kozhikode and Karimnagar when compared to the intersection located at New Delhi. The intersections are AWSC having four-lane divided carriageway with two lanes in each direction on major road as well as minor road for intersections located at New Delhi and Karimnagar whereas the intersection located at Kozhikode consists of four-lane divided carriageway on major road and minor road having two-lane undivided carriageway. During the survey, the weather was sunny and data was collected for duration of four h during the peak period on a weekday from 8 to 10 a.m. and 4 to 6 p.m. The extracted data contains traffic volume, types of vehicle, total time to cross the intersection, critical gap, follow-up time, and stopped delay.

Methodology

For this study, the total traffic is classified into several categories including two-wheelers (2w), three-wheelers (3w) consisting of the passenger auto-rickshaw, four-wheelers (4w) consisting of mainly cars and jeeps, Light Commercial

Vehicles (LCV), Heavy Commercial Vehicles (HCV), Buses and Bicycles. All the vehicles taking right turn at an intersection were observed in this study and critical gap of those vehicles is determined using Raff's method which is one of the simple critical gap determination methods (Raff, and Hart, 1950). The modal share of each vehicle type for each intersection is shown in Table 2. By using Raff's method, the critical gap of each right turning vehicles from both major road and minor road are calculated (Abhigna *et al.*, 2016) and compared with each other. A delay model is developed using multiple linear regression, and compared the capacity obtained by various existing gap acceptance model and by Highway Capacity Manual (HCM) method.

For all the three intersections, the critical gap for each vehicle type was computed and it was observed that two-wheelers and three wheelers are more forced to accept the gap than other vehicle types. Hence, the critical value of two-wheelers and



Figure 1. New Delhi Intersection.



Figure 2. Kozhikode Intersection.



Figure 3. Karimnagar Intersection.

Table 1. Dimensions of all three intersections.

Location	Major road		Minor road		Total volume (veh/h)
	Number of lanes	Lane width (meters)	Number of lanes	Lane width (meters)	
New Delhi	2	3.5	2	3	6744
Kozhikode	2	3.5	1	3.5	15818
Karimnagar	2	3.5	2	3.5	19153

three wheelers is lower than other types of vehicle. The critical gap for HCVs and buses are high because of their larger size. The critical gap for four-wheelers and LCVs are moderate compared to other vehicles because they tend to take no-risk when compared to two-wheelers and three-wheelers as shown in Figure 4, 5 and 6.

Table 2. Mode share for all the intersections in percentage (%).

Vehicle Type	New Delhi	Kozhikode	Karimnagar
Bicycle	6	0.3	0.4
2W	33	62.8	53
3W	4.7	9.2	19.7
4W	48	22.8	18.2
LCV	2.5	2.3	3.2
BUS	2.5	1.3	2.5
HCV	3.3	1.3	3

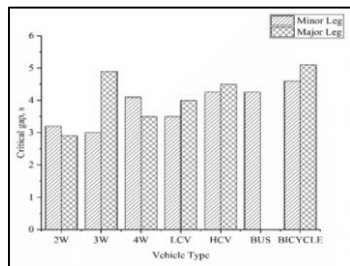


Figure 4. Critical gaps for all vehicle types at New Delhi Intersection.

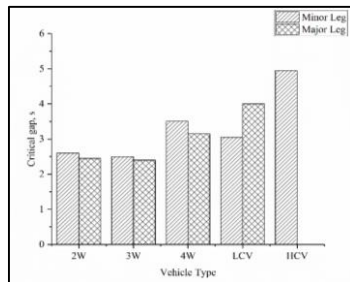


Figure 5. Critical gaps for all vehicle types at Kozhikode Intersection.

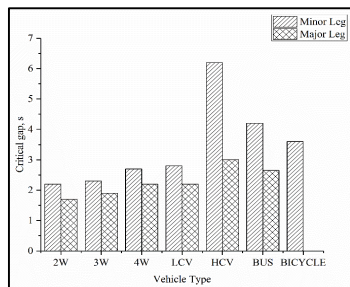


Figure 6. Critical gaps for all vehicle types at Karimnagar Intersection.

While observing the approach-wise critical gap values as shown in Table 3, it is observed that critical gap value depends on the traffic volume of the intersection. Thus, it can be concluded that, as traffic volume increases, critical gap of intersection decreases. Further, the vehicle size also can significantly affect the acceptance of critical gaps as shown in Table 4. The follow-up times of each approach of an intersection is shown in Table 3.

Table 3. Critical gap and follow-up time for all the different intersections.

Intersection		Critical Gap (s)	Follow-up time (s)
New Delhi	Major Leg	4.5	3.564
	Minor Leg	3.8	3.984
Kozhikode	Major Leg	2.6	2.713
	Minor Leg	2.9	3.049
Karimnagar	Major Leg	2.0	3.185
	Minor Leg	2.1	2.773

Table 4. Critical gap for all the different intersections.

Intersection	Critical Gap (s)
New Delhi	3.9
Kozhikode	2.8
Karimnagar	2.1

Estimation of total delay and service delay at the intersection

For each type of vehicle, the service delay or stopped delay and total delay for all the intersections are calculated. Service delay is the time for which a subject vehicle will stop at the intersection entrance while passing through the intersection for appropriate gap. The delay value is noted when the vehicle is fully stopped and ends when the vehicle begins to accelerate. Total delay is the time taken by the subject vehicle to cross the intersection. From the three intersections as shown in Figure 7, 8 and 9, it is observed that two-wheelers and three-wheelers have less total delay as well as stopped delay because two-wheelers and three-wheelers are more forced to accept the available gap and also tend to accept shorter gaps. HCVs and buses will have large delay because of their enormous size, and hence need more time to cross the intersection. LCVs and four-wheelers have medium delay compared to other vehicles because of their equivalent size. Finally, it is concluded that as traffic volume increases, there is an increase in the vehicular delay. Hence, vehicle size significantly affects the delay and as size of the vehicle increases, delay also increases. In the past it was observed that the proportion of the heavy vehicles in the conflicting traffic stream was significantly affected by the service delay (Chandra *et al.*, 2009). In a similar study, it was

observed that with increase in the conflicting flow rate, the service delay increased significantly and average service delay was found to be more for heavy vehicles irrespective of the movement type (Praveen *et al.*, 2016). The findings of this study agree with the previous two research studies where an increase vehicle size significantly contributes towards the delay.

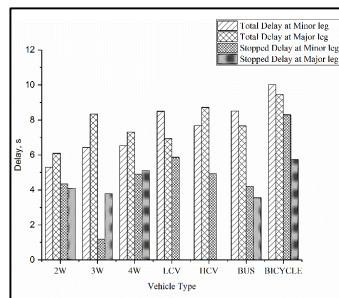


Figure 7. Delay in seconds for all vehicle types at New Delhi Intersection.

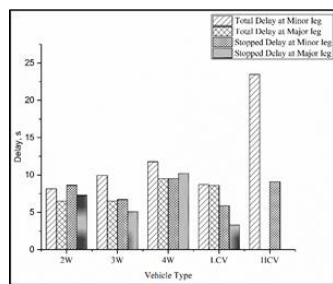


Figure 8. Delay in seconds for all vehicle types at Kozhikode Intersection.

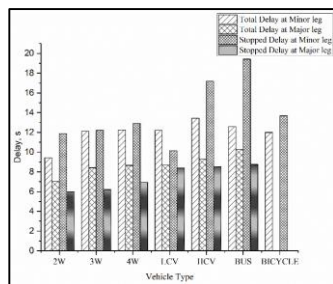


Figure 9. Delay in seconds for all vehicle types at Karimnagar Intersection.

Modelling of delay

For all the intersections considered in this study, a delay model was developed by using multiple linear regression (MLR) model using Statistical Package for Social Sciences (SPSS), (version 20.0) as depicted in Table 5. For developing a delay model, the parameters such as vehicle composition, critical gap and follow-up times are considered. However, in the past service delay model was developed by considering the vehicle proportions and conflicting traffic (Chandra *et al.*, 2009). For vehicular composition, only two-wheeler, three-wheeler and four-wheeler compositions were considered because, out of the total volume, 90 to 95% data consists of these three vehicle types and rest 5% consists of LCVs, HCVs, Buses and Bicycles as shown in Table 1. However, for developing a delay model, two intersections data was used for calibration and one intersection data was used for validation.

Based on the results, the model can be presented as,

$$D = 40.854 + 0.023 \times P_{2W} - 0.116 \times P_{4W} + 10.450 \times t_c - 4.168 \times t_f \quad (1)$$

Where, D is delay at intersection; P_{2W} is percentage of two-wheelers; P_{4W} is percentage of four-wheelers; t_c is critical gap; t_f is follow-up time.

As shown in Equation (1), critical gap and follow-up time are in seconds and two-wheelers and four wheelers proportion is in percentage. The R-square value is obtained as 0.945 at 95% confidence interval. For developing delay model, three-wheeler is not included because it does not have good correlation among the three vehicle types considered in this study. For checking the model performance, cross validation of the model is carried out between observed delay and calculated delay and observed R-square value to be 0.674.

From the MLR equation it is observed that, delay is directly dependent on critical gap value as tabulated in Table 6. Due to higher volume at Karimnagar intersection, a lower critical gap can be seen and exactly opposite scenario is being observed for New Delhi intersection. As a result,

Table 5. MLR Model for Delay details obtained from SPSS for Intersection.

Model	Unstandardized Coefficients B	Std. Error	Standardized Coefficients	t-stat	Sig.
Constant	40.854	2.896		14.108	0
Percentage of Two-Wheeler	0.023	0.009	0.064	2.637	0.009
Percentage of Four-Wheeler	-0.116	0.009	-0.328	-13.322	0
Critical Gap	10.45	0.524	1.144	19.947	0
Follow-up Time	-4.168	1.25	-0.19	-3.334	0.001

Table 6. Delay at all the Intersections with Different Delay Models.

Delay Model	Intersection		
	New Delhi	Kozhikode	Karimnagar
Field Delay (s)	53.728	46.593	68.178
HCM 2010 (s)	47.683	59.700	71.552
MLR Model (s)	61.021	56.911	49.486

delay obtained from MLR model is lower than the field delay for Karimnagar intersection but delay obtained from MLR model is higher than the field delay in case of New Delhi intersection. For Kozhikode intersection, the proportion of two wheelers is much more compared to the proportion of the other vehicles which leads to the higher delay obtained from MLR model as compared to the field delay. As per HCM 2010 model, delay at Karimnagar intersection is very high compared with MLR model due to the higher heavy vehicle composition.

Capacity Estimation by Gap Acceptance Model

The theory of gap-acceptance is a major concept for uncontrolled intersection analysis. This method is based on critical gap acceptance and follow-up times of the right turning vehicles. The existing Tanner's, Drew's, Modified Sieglöch, Luttinen's, and HCM-2010 models are used for determining capacity because the intersections selected are satisfying the underlying conditions for the chosen models. Estimated critical gap and follow-up times are common for all the models except for HCM 2010. In Tanner's and Luttinen's model, minimum headway in the major stream and major stream volumes are used to determine the capacity while in Drew's Model only major flow rate is used. In modified Sieglöch model, conflicting traffic is used while Sieglöch model is applied only for saturated conditions, which is very difficult to find in many practical cases. In HCM model, percentage of heavy vehicle is considered.

From Table 7 and Table 8, it is observed that capacities estimated by the Drew's method and modified Sieglöch methods are nearly equal. Drew's model and modified Sieglöch model shows comparatively higher capacity values when compared with Tanner's model and Luttinen's model. Because the minimum headway of major stream traffic is greatly influencing the capacity for Tanner's and Luttinen's model. In modified Sieglöch method, conflicting volume is inversely affecting the capacity of the road. In HCM 2010, the capacity values are different because it is dependent on heavy vehicle composition and total traffic flow.

Table 7. Capacities (Veh/h) for Minor Road for all the Intersections.

Parameters	Intersection		
	New Delhi	Kozhikode	Karimnagar
Tanner's Model	599	568	754
Drew's Model	609	695	822
Modified	638	659	804
Sieglöch Model	630	587	691
Luttinen's Model	499	413	405

Table 8. Capacities (veh/h) for Major Road for all the Intersections.

Parameters	Intersection		
	New Delhi	Kozhikode	Karimnagar
Tanner's Model	624	788	761
Drew's Model	627	826	817
Modified	599	790	890
Sieglöch Model	595	716	717
Luttinen's Model	515	1363	1796

Conclusions

The following conclusions are drawn from the present study:

From the critical gap values it is observed that, for the critical gap at an intersection, Two-wheelers and Three-wheelers are more forceful to accept the gap than other types of vehicles. Two-wheelers and Three-wheelers are accepting shorter gap, whereas Four-wheelers and LCVs are having moderate gap and HCVs and Buses having larger critical gap.

It is also observed that, as the critical gap decreases, the traffic volume increases. Furthermore, as the size of vehicle increases, there is an increase in the critical gap. Although the gap acceptance concept is difficult, methods developed based on this are simpler and requires less parameters.

Delay is significantly influenced by the size of the vehicle because large sized vehicle take more time to maneuver. It is observed that, total time taken to cross the intersection is found to be higher for the traffic from minor road when compared to the traffic from the major road.

Total delay for LCV, Bus and Bicycle are high while, total delay for Two-wheeler, Three-wheeler, and four-wheeler is observed to less.

From the MLR model it is observed that the delay is directly dependent on the critical gap. For New Delhi and Kozhikode intersections, delay calculated from the MLR model have shown higher values when compared with field delay, whereas

for Karimnagar intersection, less delay is observed when compared to field delay.

As per HCM 2010, delay depends on the percentage of heavy vehicle composition and total traffic flow. Thus, higher delays are observed at Karimnagar intersection when compared with MLR model due to the large heavy vehicle composition.

As per HCM 2010, Capacity depends on the heavy vehicle percentage. Capacity of the intersections is almost equal in Drew's Model and modified Sieglösch Model. Tanner's model and Luttinen's model is showing less capacity because of the influence of minimum headway of major stream traffic.

The effect of pedestrians is not taken into account in the present study while calculating the capacity and delays at urban uncontrolled intersections. Thus, inclusion of pedestrians is expected to be more realistic as delays caused to the vehicles at urban uncontrolled intersections depend on the characteristics of the pedestrians. Further, the findings of the current study are limited to three-legged uncontrolled urban intersections. Thus, intersections with more than three legs and varied intersection geometrics with varied control conditions and presence of pedestrians can lead to more realistic delays models.

References

- Abhigna, D., Kondreddy, S., and Ravishankar, K.V.R. (2016). Effect of vehicle composition and delay on roundabout capacity under mixed traffic conditions. *Arch. Transp.*, 40(4):79-86.
- Adebisi, O. and Sama, G.N. (1989). Influence of stopped delay on driver gap acceptance behaviour. *J. Transp. Eng.*, 115(3):305-315.
- Ashalatha, R. and Chandra, S. (2011). Service delay analysis at TWSC intersections through simulation. *KSCE J. Civil Eng.*, 15(2):413-425.
- Brilon, W. and Miltner, T. (2005). Capacity at intersections without traffic signals. *J. Transp. Res. Bd.*, 1920(1):32-40.
- Chandra, S., Agarwal, A., and Rajamma, A. (2009). Microscopic analysis of service delay at uncontrolled intersections in mixed traffic conditions. *J. Transp. Eng.*, 135(6):323-329.
- Chodur, J. (2005). Capacity models and parameters for unsignalized urban intersection in Poland. *J. Transp. Eng.*, 131(12):924-930.
- Cvitanic, D.D., Breski, D.M., and Vidak, B. (2007). Review, testing and validation of capacity and delay models at unsignalized intersections. *Pap. Sci. Trf. and Transp.*, 19(2):71-82.
- Harders, J. (1968). Capacity of unsignalized urban intersections. In: *Strassenbau und Strassenverkehrstechnik*, Heft 76 Bundesminister für Verkehr. Abt. Strassenwesen, BONN, Federal Republic of Germany.
- Kaysi, I. and Alam, G. (2000). Driver behaviour and traffic stream interactions at unsignalized intersections. *J. Transp. Eng.*, 126(6):498-505.
- Kimber, R.M. and Hollis, E.M. (1979). Traffic queues and delays at road junctions. *Transp. Rd. Res. Lab.*, Report Nr. LR909, England.
- Kimber, R.M., Marlow, M., and Hollis, E.M. (1977). Flow/delay relationships for major/minor priority junctions. *Trf. Eng. Ctrl.*, 18(11):516-519.
- Li, H. and Deng, W. (2008). Capacities and delays at All-Way Stop-Controlled intersections. In: *Transp. Res. Bd.*, National Research Council, Washington, D.C., USA, p. 8-29.
- Luttinen, R.T. (2004). Capacity and level of service at finish unsignalized intersections. In: *Finnish Road Administration*, Helsinki, Finland.
- Madanat, S.M., Cassidy, M.J., and Wang, M.H. (1994). Probabilistic delay model at stop-controlled intersection. *J. Transp. Eng.*, 120(1):21-36.
- Prasetijo, J., Pour, M.H., and Ghadiri, S.M.R. (2011). Capacity of unsignalized intersections under mixed traffic conditions. *Procedia-Soc. Behav. Sci.*, 16:676-685.
- Praveen, D., Saibaba, A.N., and Rao, M.K. (2016). Delay modelling at urban uncontrolled intersection. *Int. J. Adv. Eng. Res. Dev.*, 3(2):112-118.
- Raff, M.S. and Hart, J.W. (1950). A volume warrant for urban stop signs. In: *Eno Foundation for Highway Traffic Control*, Saugatuck, Connecticut.
- Shi, F. and Li, H. (2008). The influence of non-motorized streams on capacities of vehicular streams at unsignalized intersections. *Proc. IEEE.*, 978(1):2004-2008.
- Solberg, P. and Oppenlander, J.C. (1966). Lag and gap acceptances at stop controlled intersections. In: *Highway Research Record 118*, Highway Research Board, National Research Council, Washington D.C., USA, p. 48-67.
- Surti, V.H. (1970). Operational efficiency evaluation of selected at-grade intersections. In: *Highway Research Record 321*, Highway Research Board, National Research Council, Washington, D.C., USA, p. 60-73.
- Tanner, J.C. (1953). A problem of interference between two queues. *Biom.*, 40: 58-69.
- Tanner, J.C. (1962). A theoretical analysis of delays at an uncontrolled intersection. *Biom.*, 49(1-2):163.170.
- Transportation Research Board. (2010). Highway capacity manual. In: *Transportation Research Board of the National Academies*, Washington, D.C., USA.
- Xu, L. and Cheng, G. (2012). Analysis on capacity of unsignalized intersection on urban arterial road in slight snowy weather. *Appl. Mech. Mat.*, 209-211:833-836.