1-1-2014

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Abstract

Bothheavy goods vehicles (HGV) and exiting vehicles can significantly affect the entry capacity of a roundabout. However, their effects have not been taken into account in HCM 2000 model.Recently two studies have been carried out to address this issue: 1) Dahl and Lee (2012) proposed an expectation theory based approachto incorporate the effect of HGVs [1]; and2)Qu et al. (2013) deriveda new roundabout capacity model by assuming that each exiting vehicle could provide one entry opportunity for waiting vehicles [2]. In this paper, the two models are integrated using a scenario-based approachtoanalyse the effects of not only exiting vehicles but also HGVs. A comparative study indicates that HCM 2000 model performs well under low to mid traffic conditions while it underestimates the capacities under high traffic conditions in combination with high proportions of exiting vehicles.

Keywords

entry, capacities, investigation, single, roundabouts, lane

Disciplines

Engineering | Science and Technology Studies

Publication Details

Ren, L., Qu, X., Wang, S. & Guan, H. (2014). Investigation on entry capacities of single-lane roundabouts. Applied Mechanics and Materials, 505-506 497-500.

Investigation On Entry Capacities of Single-lane Roundabouts

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Keywords: Roundabout; Entry Capacity; Gap Acceptance Theory; Heavy Goods Vehicles

Abstract
The heavy good vehicles (HGV) and exiting vehicles can significantly affect the entry capacity of a roundabout. However, their effects have not been taken into account in HCM 2000 model. Recently two studies have been carried out to address this issue: 1) Dahl and Lee (2012) propose an expectation theory based approach to incorporate the effect of HGVs [1]; and 2) Qu et al. (2013) derive a new roundabout capacity model by assuming that each exiting vehicle could provide one entry opportunity for waiting vehicles [2]. In this paper, the two models are integrated using a scenario based approach to analyse the effects of not only exiting vehicles but also HGVs. A comparative study indicates that HCM 2000 model performs well under low to mid traffic conditions while it underestimates the capacities under high traffic conditions in combination with high proportions of exiting vehicles.

Introduction
Along with increase of traffic demand, transport infrastructures are designed and established to satisfy higher requirements of safety, capacity and fluidity [3-6]. A roundabout is a type of circular intersection with one or more marked lanes in which road traffic is slowed and flows are almost continuously in one direction around a central island to several exits onto the various intersecting roads [7-9]. Its detailed operations are usually not formulated in transportation network modelling studies [10-15]. In reality, roundabouts could substantially reduce queue and delay under low volume conditions as vehicles are not required to perform a complete stop. Roundabouts allow U-turn within the normal flow of traffic, which often are not possible at other forms of junction [16]. Further, roundabouts provide higher safety than signal controlled junctions in terms of not only frequency but also severity of accidents. Fortuijn (2009) asserted that as the vehicles in a roundabout could drive along the same direction, the probability of crashes could be reduced thanks to the decrease of conflicting points [17]. Accordingly, roundabouts have been an increasingly popular intersection type, especially in less populous suburbs [18,19]. Along with the wider use of roundabouts, the entry capacity is of more importance to transport agencies [20-22].

Various models have been developed to estimate the entry capacities of roundabouts [23-25]. Highway Capacity Manual (HCM) 2000 model is the most widely-used analytical model based on the gap acceptance theory [25], mathematically,

$$C_{2000} = v_c \times \frac{\exp(-v_c \tau_c / 3600)}{1-\exp(-v_c \tau_f / 3600)} \quad (0)$$

where C_{2000} is the entry capacity of an arm (veh/hr); v_c is the conflicting circulating flow (veh/hr); τ_c and τ_f are critical gap and follow-up time (s), respectively.

In the above-mentioned model, the entry capacity is calculated as a function of circulating traffic, critical gap, and follow-up time, without taking into account the flow interactions and vehicle types [26]. In reality, as pointed out by Barry [27] and Dahl and Lee [1], the exiting flows and heavy goods vehicle (HGV) have significant impacts on the entry capacities. HCM 2000 model treat the exiting vehicles as non-existent, which are not counted as circulating traffic. Based on survey of 19 single-lane modern roundabouts in Queensland, Australia, Qu et al. (2014) indicated that waiting vehicles will immediately (in an average of 1.4 seconds) enter the roundabout after exiting vehicles turn their indicators on (usually more than 1 second before the actual turning movements) [2]. In other words, a waiting vehicle might not necessarily wait for a critical gap if an exiting vehicle shows up. Accordingly, by assuming that each exiting vehicle could provide one entry opportunity for waiting vehicles, a new roundabout capacity model (referred to as *NRC model I* hereafter) is proposed by Qu et al. by considering influence of exiting vehicles [2], mathematically expressed by

$$C_{exit} = v_{c'} \times \left[\rho + \frac{\exp(-v_{c'}\tau_c / 3600)}{1 - \exp(-v_{c'}\tau_f / 3600)} \right] \quad (2)$$

where C_{exit} is the entry capacity considering exiting vehicles (veh/hr); $v_{c'}$ is circulating flow including exiting vehicles (veh/hr); ρ is proportion of exiting vehicles.

In addition, Dahl and Lee [1] analysed the effect of heavy good vehicles by adjusting critical gap and follow up time. If the entry flow consists of cars and HGVs only, the critical gap should consider the effect from both car and truck, mathematically,

$$\tau'_c = \tau_{c,1} q_1 + \tau_{c,2} q_2 \quad (3)$$

where τ'_c is the adjusted critical gap (s); $\tau_{c,1}$ and $\tau_{c,2}$ are the critical gap for cars and trucks, respectively (s); q_1 and q_2 denote the proportion of cars and trucks within the entry flow, respectively. Similarly, the follow-up times are influenced by various proportions in cars and trucks at entry flow. Dahl and Lee [1] pointed out that the follow-up time varies depending on the type of two entering vehicles in a queue - the lead vehicle and the following vehicle within the entry flow. Four cases of vehicle-following conditions were assumed as follow:

1) Car followed by car (car/car)
2) Car followed by truck (car/truck)
3) Truck followed by car (truck/car)
4) Truck followed by truck (truck/truck)

The adjusted follow-up time is described as follow:

$$\tau'_f = \tau_{f,cc} q_1^2 + \tau_{f,ct} q_1 q_2 + \tau_{f,tc} q_1 q_2 + \tau_{f,tt} q_2^2 \quad (4)$$

This equation can be rewritten as follow:

$$\tau'_f = \tau_{f,cc} q_1^2 + (\tau_{f,ct} + \tau_{f,tc}) q_1 q_2 + \tau_{f,tt} q_2^2 \quad (5)$$

where τ'_f is the adjusted follow-up time (s); $\tau_{f,cc}$, $\tau_{f,ct}$, $\tau_{f,tc}$ and $\tau_{f,tt}$ are follow-up times for a car following a car (car/car), a truck following a car (car/truck), a car following a truck (truck/car) and a truck following a truck (truck/truck), respectively (s).

In this paper, a gap acceptance based analytical model is proposed to incorporate the effects of both exiting vehicles and HGVs. A comparative study is further carried out to analyse the results calculated by the HCM 2000 model and the proposed models. According to the analyses, although the HCM 2000 model is good approximations under low percentage of exiting flows or low circulating flow conditions, their performances for other conditions are questionable.

Proposed models

Based on the pioneering work by Dahl and Lee [1], we incorporate this difference in the gap acceptance process. Table 1 presents two scenarios of gap acceptance based on a simple classification. Scenarios 1 and 2 refer to the cases that the lead vehicles in a queue are car and truck, respectively. The probabilities of Scenario 1 and 2 could be estimated by the proportions of cars and trucks. Table 1 shows the critical gaps, follow up times, and capacities under each scenario. Note that the adjusted follow-up time is still adopted in this model. The capacity under each scenario could be estimated by either HCM 2000 model or the NRC model I.

Table 1 Scenarios

Scenario (k)	Lead vehicles (probability)	Critical gap	Follow up time	Capacity of scenarios
1	Car (q_1)	$\tau_{c,1}$	τ'_f	$C(\tau_{c,1}, \tau'_f)$
2	Truck (q_2)	$\tau_{c,2}$	τ'_f	$C(\tau_{c,2}, \tau'_f)$

Notes: $C_k(\tau_{c,j}, \tau'_f)$ denotes the capacity under Scenario *k*.

Having had the probabilities and capacities for each scenario, the new model to estimate the roundabout capacity (referred to as *NRC model II* hereafter) presented as

$$C^{HGV} = E\left(C\left(\tau_{c,i}, \tau'_f\right)\right) = \sum_{i=1}^{2}\left(q_i C\left(\tau_{c,i}, \tau'_f\right)\right) \quad (6)$$

where $C\left(\tau_{c,1}, \tau'_f\right)$ and $C\left(\tau_{c,2}, \tau'_f\right)$ are the roundabout capacity under Scenarios 1 and 2, respectively. C^{HGV} thus represents the expectation of the capacity under a combined scenario. $C\left(\tau_{c,i}, \tau'_f\right)$ can be estimated by either HCM 2000 model or NRC model I. Accordingly, we then establish two proposed models as follows:

$$C_{2000}^{HGV} = \sum_{i=1}^{2}\left[q_i\left(v_c \times \frac{\exp(-v_c \tau_{c,i}/3600)}{1-\exp(-v_c \tau'_f/3600)}\right)\right] \quad (7)$$

where C_{2000}^{HGV} is the entry capacity (veh/hr) when only heavy good vehicles are considered based on HCM 2000 model. This model is named as *NRC model II* hereafter.

$$C_{exit}^{HGV} = \sum_{j=1}^{2}\left[q_j\left(v_{c'}\rho + \frac{v_{c'}\exp(-v_{c'}\tau_{c,j}/3600)}{1-\exp(-v_{c'}\tau'_f/3600)}\right)\right] \quad (8)$$

where C_{exit}^{HGV} is entry capacity (veh/hr) of considering both exiting vehicles and HGVs; $v_{c'}$ is circulating flow considering exiting vehicles; ρ is the proportion of exiting vehicles. This model is named as *NRC model III*.

A comparative study

To analyse the impact of combined effect, the field survey data collected by Dahl and Lee [1] from an approach of the Brattleboro roundabout are used in this study (see Table 2). This study assumes the proportion of driver using indicator is 60%. The proportion of exiting vehicles is assumed to be 0.25.

Table 2 Observed roundabout data from Brattleboro

Roundabout	Critical Gap (s)		Follow up Time (s)				Proportion of Truck
	Car	Truck	$t_{f,cc}$	$t_{f,ct}$	$t_{f,tc}$	$t_{f,tt}$	
Brattleboro	3.9	5.3	2.1	4.2	5.3	8.5	0.11

Source: Dahl and Lee [1]

We compare the performances of four models: adjusted HCM 2000 (Dahl and Lee's model in combination with HCM 2000), NRC model II, and NRC model III. As can be seen in Figure 1, the first two models have a very similar estimation for the capacity of this roundabout. However, the capacity might be significantly underestimated under high traffic conditions if the effects of exiting vehicles are ignored.

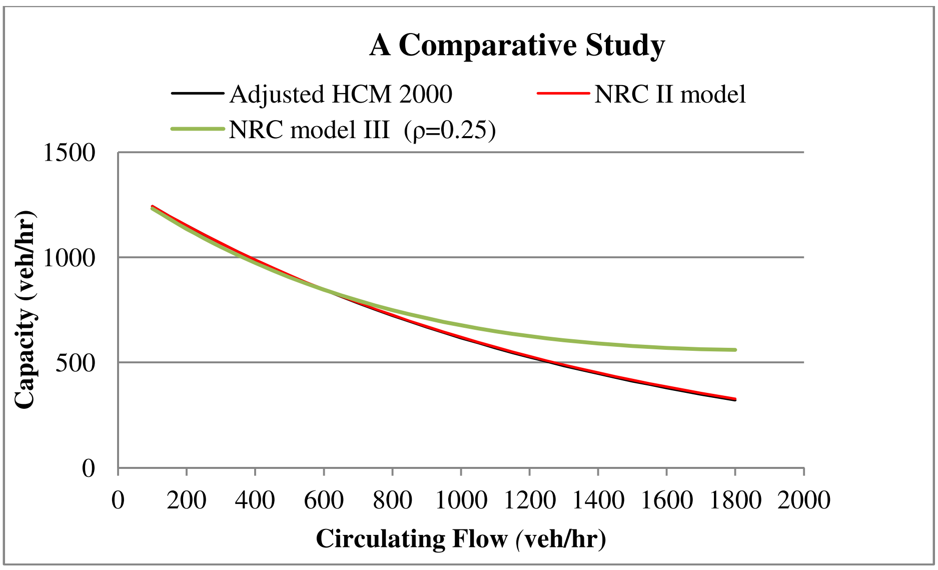

Fig. 1 Capacity comparison between NRC models and HCM model

Conclusions

The heavy good vehicles (HGV) and exiting vehicles can significantly affect the entry capacity of a roundabout. However, their effects have not been taken into account in HCM 2000 model. To incorporate the effect of HGVs, Dahl and Lee (2012) propose an expectation theory based approach [1]. To analyse the effect of exiting vehicles, Qu et al. (2013) derive a new roundabout capacity model by assuming that each exiting vehicle could provide one entry opportunity for waiting vehicles [2]. In this paper, the two models are integrated in order to take into account not only exiting vehicles but also HGVs. A comparative study indicates that 1) HCM 2000 model performs well under low to mid traffic conditions; 2) HCM 2000 model underestimates the capacities under high traffic conditions in combination with high proportions of exiting vehicles; and 3) the proposed model outperforms other models.

It should be pointed out that all three models give similar results under low to mid traffic conditions (circulating flow < 700 veh/hour). Accordingly, as a future work of this research, the at-capacity field data should be collected to verify the performances of proposed models under high traffic volume conditions (circulating flow > 700/hour).

Acknowledgements

This research is financially supported by Griffith NRG scheme.

References

[1] J. Dahl, and C. Lee: Transportation Research Record Vol. 2312 (2012), p. 34.
[2] X. Qu, L. Ren, S. Wang, and E. Oh: Submitted to Journal of Transportation Engineering, (2013).
[3] X. Qu, Y. Kuang, E. Oh, and J. Sheng: Traffic Injury and Prevention Vol. 15 (2014), p. 80.
[4] Q. Meng, and X. Qu: IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews Vol. 42 (2012), p. 1454
[5] X. Qu, Q. Meng, Y.H. Wong, and Y. Vivi: Expert Systems with Applications Vol. 38 (2011), p. 13827.
[6] Q. Meng, X. Qu, K.T. Yong, and Y.H. Wong: Risk Analysis Vol. 31 (2011), p. 1872.
[7] B. Hellinga, and A. Sindi: Transportation Research Record Vol. 2912 (2012), p. 56.
[8] F Xu, and Z.Z. Tian, Transportation Research Record Vol. 2071, (2008), p. 117.
[9] T.Z. Qiu, and D. Yin: Transportation Research Record Vol. 2265 (2011), p. 244.
[10] S. Wang: Transportation Research Part C Vol. 32 (2013), p. 61.
[11] S. Wang, Q. Meng, and Z. Liu: Transportation Research Part B Vol. 47 (2013), p. 77.
[12] S. Wang, Q. Meng, and H. Yang: Transportation Research Part B Vol. 50 (2013), p. 42.
[13] Z. Liu, Q. Meng, and S. Wang: Transportation Research Part C Vol. 31 (2013), p. 83.
[14] Z. Liu, and Q. Meng: Journal of Advanced Transportation Vol. 47 (2013), p. 553.
[15] Z. Liu, Y. Yan, X. Qu, and Y. Zhang: Transportation Research Part C Vol. 35 (2013), p. 46.
[16] A. Flannery: Transportation Research Record Vol. 1751 (2001), p. 76.
[17] L.G. Fortuijn: Transportation Research Record Vol. 2130 (2009), p. 83-92.
[18] S. Jin, X. Qu, D. Wang: Physica A Vol. 392 (2013), p. 3881.
[19] Y. Bie, D. Wang, and X. Qu: IET Intelligent Transport Systems Vol. 7 (2013), p. 28.
[20] T. Wei, J.L. Grenard., and H.R. Shah: Transportation Research Record Vol. (2011), p. 1.
[21] S. Jin, D. Wang, C. Xu, Z. Huang: Physics Letters A, Vol. 376 (2012), p. 153.
[22] J. Bie, H.K. Lo, and S.C. Wong: Journal of Advanced Transportation, Vol.44 (2012), p. 245.
[23] S.C. Wong: Transportation Research Part B Vol. 30 (1996), p. 441.
[24] J.M. Diah, M.Y.A. Rahman., M.A. Adnan, and H.L. Khoo: ASCE Journal of Transportation Engineering Vol.137 (2011), p. 980.
[25] Transportation Research Board (TRB). Highway Capacity Manual 2000.
[26] T. Wei, and J.L. Grenard: Transportation Research Record Vol. 2257 (2012), p. 150.
[27] C.D. Barry: Calibration of the HCM 2010 Roundabout Capacity Equations for Georgia conditions. Master thesis. Georgia Institute of Technology, 2012.