Estimation of Passenger Car Equivalent for Heavy Vehicles Considering Geometric Elements of Roundabout

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Roundabout entry capacity is one of the most important indices for evaluating roundabout's performance. Three gap parameters are necessary to estimate the roundabout entry capacity, which are affected by geometric design and vehicle type compositions. Passenger car equivalent (PCE) is used for evaluating the impact of heavy vehicles on roundabout entry capacity. However, in Japan there is still a low number of roundabouts and it is very difficult to get the sufficient number of heavy vehicle samples. This paper proposes an alternative method to estimate and supplement the missing gap parameters for vehicle compositions and estimates the impact of heavy vehicles on entry capacity depending on roundabout geometric design.

Key Words: *Roundabout, Passenger car equivalent, Heavy vehicle, Geometric elements, Entry capacity*

1. INTRODUCTION

Implementing roundabouts in Japan has been promoted in recent years and the number of roundabouts is increasing due to their safe and effective performance at low to medium traffic demand levels. For evaluating the operational performance, roundabout entry capacity is one of the most important indices. In order to improve accuracy of roundabout capacity estimation, influencing factors on entry capacity should be reasonably taken into account. The impact of heavy vehicles is one of the significant factors because of their larger size and slower driving performance. Compared to the passenger cars only cases, entry capacity would be decreased with increase in the heavy vehicle percentage. Furthermore, the roundabout geometric design impacts heavy vehicles' driving behavior.

Passenger car equivalent (PCE) for heavy vehicles, which represents the number of passenger cars displaced by each heavy vehicle in the traffic stream, is one method to consider the impact of heavy vehicles in roundabout entry capacity estimation.

In Highway Capacity Manual (HCM) 6th edition[1)] and Japan Roundabout Manual (JRM)[2)], PCE for heavy vehicles at entry of roundabouts is assumed as a constant value of 2.0. However, this value can fluctuate under various vehicle compositions and should also have a range for different geometric elements. However, it is very difficult to get a sufficient number of heavy vehicle samples in Japan where examples of roundabouts are still limited.

Therefore, the main objectives of this paper are to propose an alternative method to estimate and supplement the missing gap parameters for vehicle compositions and to estimate the PCE range for heavy vehicles depending on roundabout geometric design.

2. LITERATURE REVIEW

There are two methods to estimate roundabout entry capacity, one is based on regression of empirical data and the other is the gap acceptance theory. For heavy vehicle's impact on entry capacity, one method is to adjust traffic flow by using PCE for heavy vehicles.

Chris et al.[3] obtained PCE based on empirical data at roundabouts in the United States. However, it is anticipated that the PCE value is different depending on the maximum size of heavy vehicle and performance.

Kang and Nakamura[4] and Goto et al.[5] estimated PCE for heavy vehicles based on empirical observations in Japan as well as simulated data. They concluded that PCE values range between 1.4 to 3.0 on the entry approach and 1.3 to1.5 on the circulatory roadway. However, the impact of roundabout geometry was not considered.

Kimber[6] determined six geometric factors that have significant influence on the entry capacity and used them to propose a function named Kimber's capacity model to estimate roundabout entry capacity.

Kanbe and Nakamura[7] empirically investigated the impact of geometric elements based on Kimber's geometric parameters using the data collected at 4 roundabouts in Japan. In their empirical models, no heavy vehicles were assumed in the entry and circulating flows.

Zhao et al.[8] investigated both the influence of vehicle types and geometric elements on entry capacity. It was concluded that the driving behavior of heavy vehicle is significantly affected by roundabout geometric design. However, due to the limitation of empirical data, PCEs could not be estimated.

Therefore, this paper proposes a method to estimate and supplement the missing gap data for heavy vehicles, then calculates PCE range based on roundabout geometric design by using the supplemented data.

3. METHODOLOGY

(1) Geometric elements and operational variables

This paper defined six geometric factors which may have influence on entry capacity. Five of them are based on the geometric elements proposed by Kimber[6] and one of them is proposed by Kanbe and Nakamura[7]. As shown in **Fig. 1**, they are: Entry width W_e(m), the width of the entry approach from the splitter island vertical to the curve; Approach half width W(m), the width of lane of entry approach; Inscribed circle diameter D(m); Entry radius R(m), the radius of the curve of entry approach; Entry angle φ_e (deg), the angle between vertical to the entry width

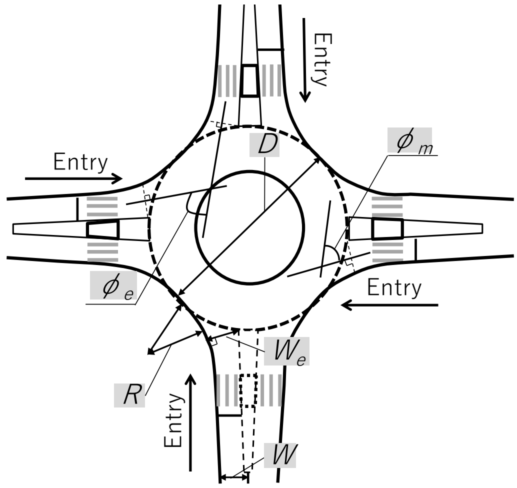


Fig.1 Roundabout geometric elements

of entry approach and vertical to the outflow width of the next downstream approach and Merging angle φ_m (deg), the angle between vertical to the entry width of entry approach and the tangent line of the center circle of the circulating roadway. The impact of these parameters are investigated in this study by using empirical data. All of the geometric elements are measured using curbs and splitter islands of entry approaches as references. If there is no splitter island, then the distance is measured from zebra marking to curb.

In order to analyze the relationship between geometric elements and gap parameters, video surveys were carried out at six roundabouts in Japan. All of them are single lane roundabouts. The gap data was observed from videos by using the image processing system *TrafficAnalyzer*[8]. Since some of the videos were recorded right after the roundabouts were newly in operation, in order to represent this impact, a dummy variable D_{op} is defined as 1 for the first three months and 0 otherwise. A dummy variable D_{sp} is assumed 1 for the approach constructed with splitter island and 0 for no splitter island. A dummy variable D_{st} reflects the control type of roundabout. 1 represents for stop control and 0 represents for yield control.

The detailed geometric design elements and dummy variables measured in each site are summarized in **Table 1**.

(2) Gap parameters

The entry capacity is the maximum number of vehicles that are expected to enter roundabout from one approach during a certain period. The JRM[2] estimates the entry capacity by Equation (1) which is based on the gap acceptance theory by defining three gap parameters in circulating and entry flows.

$$c_i = \frac{3600}{t_f}\left(1 - \tau\frac{Q_r}{3600}\right) \times exp[-\frac{Q_r}{3600}\left(t_c - \frac{t_f}{2} - \tau\right)] \quad (1)$$

Where, c_i: entry capacity of entry i in the unit of pcu/h, Q_r: circulating flow at the entry i in the unit of pcu/h. The three gap parameters are: t_f: follow-up time of entry vehicle (sec), τ: minimum headway of circulating flow (sec), t_c: critical headway (sec).

Some examples of three gap parameters and their measurement methods are illustrated in **Fig. 2**.

a) Follow-up time t_f and minimum headway on circulatory roadway τ

Follow-up time t_f and minimum headway on circulatory roadway τ are headways between leading vehicle and follow-up vehicle of entry approach and circulatory roadway, respectively. Only the gaps below 5 sec were collected and then the 50 percentile value of the cumulative distributions of follow-up time for one approach is defined as t_f of this approach. The 50 percentile value is approximately around 3.0 sec and it can be considered as the headway between leading and following vehicles. This method also applies to the minimum headway on circulatory roadway τ.

b) Critical headway t_c

Critical headway is defined as the minimum acceptable headway between two circulating vehicles where the gap is judged by entering vehicle to accept or reject. In the case of t_c, only the gaps under 10 sec were collected. Raff's method[9] is utilized to estimate the value of t_c for each approach, which defined critical gap is the intersecting point of the cumulative distributions of accepted and rejected gaps.

(3) Vehicle compositions

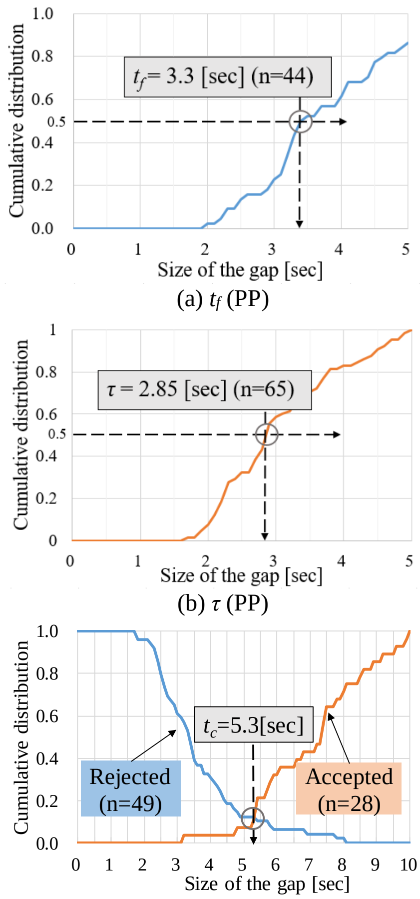
Considering the positions of heavy vehicle in the gap acceptance behavior, there are four compositions for t_f, four compositions for τ and eight compositions for t_c as shown in **Table 2** where H and P represent heavy vehicle and passenger car, respectively. e_1, e_2, c_1, c_2 represent leading entering vehicle, following entering vehicle, leading circulating vehicle and following circulating vehicle, respectively.

(4) Sample size

The obtained gap parameters after processing the video data are shown in **Tables 3(a)** and **(b)** with their numbers of samples. Due to the limited sample size of t_c, we could not have sufficient data for

Table 1 Geometric elements and dummy variables

RAB	Approach	W_e	W	D	R	φ_e	φ_m	D_{op}	D_{sp}	D_{st}
Itoman yield	N	3.12	3.15	39.0	9.36	15.0	38.0	1	1	0
	E	2.94	4.00	39.0	9.36	74.0	36.0	1	1	0
	SE	3.21	3.00	39.0	6.78	53.0	44.0	1	0	0
	S	2.94	2.95	39.0	9.36	45.0	35.0	1	1	0
	W	2.94	3.50	39.0	15.4	54.0	27.0	1	1	0
Hitachitaga yield	E	4.65	4.15	28.0	11.9	32.0	30.0	0	0	0
	W	3.48	3.16	28.0	10.5	22.0	42.0	0	0	0
	N	5.26	5.53	28.0	10.4	26.0	22.0	0	0	0
Towacho stop	N	6.78	4.48	30.0	13.0	58.0	21.0	0	1	1
	NW	5.45	3.25	30.0	16.0	94.0	38.0	0	0	1
	W	4.95	3.20	30.0	13.0	47.0	45.0	0	1	1
	S	4.17	4.64	30.0	13.0	56.0	32.0	0	0	1
	E	4.60	3.24	30.0	13.0	51.0	43.0	0	1	1
Towacho yield	N	6.78	4.48	30.0	13.0	58.0	21.0	0	1	0
	NW	5.45	3.25	30.0	16.0	94.0	38.0	0	0	0
	W	4.95	3.20	30.0	13.0	47.0	45.0	0	1	0
	S	4.17	4.64	30.0	13.0	56.0	32.0	0	0	0
	E	4.60	3.24	30.0	13.0	51.0	43.0	0	1	0
Azuma yield	N	6.02	3.56	39.0	15.6	68.0	48.0	0	1	0
	E	4.74	4.34	39.0	10.3	65.0	41.0	0	0	0
	S	5.79	3.59	39.0	7.76	77.0	51.0	0	1	0
	SW	7.73	3.84	39.0	5.35	63.0	48.0	0	0	0
	W	4.77	4.40	39.0	7.84	50.0	36.0	0	0	0
Kakudahama yield	N	5.68	4.10	30.0	29.2	19.0	38.0	0	1	0
	S	6.23	4.10	30.0	29.7	11.0	30.0	0	1	0
	W	6.12	4.25	30.0	30.0	37.0	39.0	0	1	0
Yahata yield	E	3.83	4.01	44.0	10.3	35.5	56.7	1	1	0
	S	3.77	3.52	44.0	10.3	62.6	56.1	1	1	0
	W	3.75	4.04	44.0	10.3	65.4	53.2	1	1	0
	N	3.76	3.77	44.0	10.3	71.4	62.9	1	1	0



(a) t_f (PP)

(b) τ (PP)

(c) t_c (PP-P)

Fig.2 Gap parameters (i.e. Hitachitaga Entry E)

Table 2 Vehicle combinations

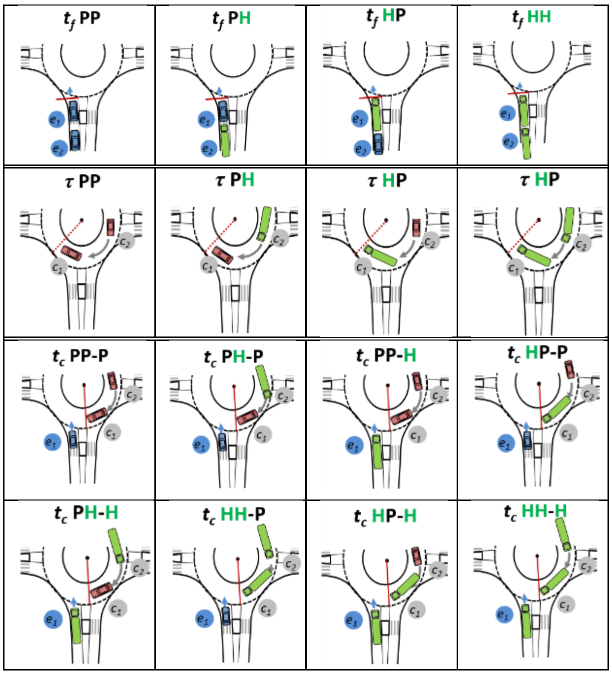


Table 3 Sample size of critical gap

(a) Sample size of t_f and τ

RAB		Approach	Follow-up Time			Minimum Headway		
			PP	PH	HP	PP	PH	HP
Itoman yield		N	2.80	3.17	4.15	2.75	3.45	4.00
		E	2.90	3.65	4.80	2.65	3.35	3.50
		SE	3.50	-	-	2.70	3.90	3.58
		S	2.85	3.50	4.02	2.75	3.12	3.92
		W	2.90	-	3.95	2.60	3.10	4.02
Hitachitaga yield		E	3.30	3.25	4.00	2.85	3.65	3.70
		W	3.15	2.91	3.60	2.90	3.30	4.17
		N	3.00	3.35	3.90	2.85	2.95	3.35
Towacho	stop	N	3.85	4.15	4.00	3.45	3.75	3.80
		NW	3.65	3.90	4.00	2.97	3.10	3.70
		W	3.61	3.91	4.00	2.91	3.20	3.50
		S	3.45	3.85	4.05	3.02	3.30	3.70
		E	3.80	-	-	3.25	3.40	3.80
	yield	N	2.60	-	2.90	2.68	3.15	2.97
		NW	2.66	-	-	2.77	2.75	3.03
		W	2.80	3.73	3.48	2.63	2.67	3.19
		S	2.90	3.85	4.00	2.65	2.70	3.50
		E	2.65	3.85	3.40	2.68	3.05	3.30
Azuma yield		N	2.81	3.37	3.35	2.70	3.25	3.18
		E	2.93	2.35	3.65	2.63	3.10	3.45
		S	2.78	3.35	3.88	2.65	2.42	3.02
		SW	2.72	2.95	3.90	2.65	2.35	2.95
		W	2.85	-	2.95	2.53	2.85	3.10
Kakudahama yield		N	3.00	3.20	3.65	2.97	2.60	3.18
		S	2.62	-	3.25	2.98	2.95	3.23
		W	2.65	3.58	-	2.50	2.95	3.35
Yahata yield		E	2.47	3.25	3.05	2.60	3.35	3.38
		S	2.65	-	-	2.63	-	3.68
		W	2.66	-	3.82	2.40	2.48	3.95
		N	2.57	-	-	2.48	3.95	3.75

*Legend of sample size

n≥50	30≤n<50	20≤n <30	10≤n<20	n<10

(b) Sample size of t_c

RAB		Approach	Critical Gap							
			PP-P	n(a,r)	PH-P	n(a,r)	PP-H	n(a,r)	HP-P	n(a,r)
Itoman yield		N	5.50	63,61	6.20	8,2	6.80	13,5	6.40	7,10
		E	5.00	60,58	5.30	10,16	5.80	16,58	7.20	7,28
		SE	5.10	65,68	-	4,8	5.70	10,17	7.50	6,24
		S	6.00	62,181	-	5,10	6.40	3,13	6.10	6,25
		W	4.60	58,88	-	3,9	6.10	14,66	6.60	4,19
Hitachitaga yield		E	5.30	28,49	4.10	9,3	4.00	1,4	6.20	11,13
		W	4.50	26,31	5.10	14,11	5.50	6,11	5.50	16,30
		N	4.50	43,92	5.30	5,20	5.50	11,35	5.30	9,31
Towacho	stop	N	5.25	73,75	-	4,3	6.30	6,11	6.45	5,6
		NW	5.00	73,76	4.60	4,5	6.40	2,5	7.00	5,5
		W	4.75	64,75	-	3,5	-	0,1	7.30	3,5
		S	5.45	62,56	-	4,2	6.30	3,4	-	1,1
		E	5.65	71,66	-	4,1	-	1,0	-	1,3
	yield	N	5.40	60,60	5.30	7,1	-	2,4	7.80	1,4
		NW	4.60	54,63	7.00	5,5	5.70	6,8	-	1,6
		W	4.70	60,70	6.20	4,5	-	2,6	-	0,5
		S	4.80	64,77	-	1,1	-	2,3	5.90	5,9
		E	5.00	60,63	4.50	3,6	4.80	4,10	6.30	5,15
Azuma yield		N	4.90	44,64	-	0,2	-	0,0	-	2,3
		E	5.00	52,61	-	1,0	4.60	4,6	-	2,2
		S	4.90	62,65	-	1,2	-	1,8	-	4,3
		SW	4.80	32,60	-	1,1	-	2,5	-	3,0
		W	4.30	60,72	-	0,1	-	1,0	-	4,3
Kakudahama yield		N	-	2,6	-	0,1	-	0,1	-	0,0
		S	5.46	21,77	-	1,1	-	1,3	-	1,5
		W	4.72	8,23	-	0,1	-	0,1	-	1,0
Yahata yield		E	4.86	7,9	-	0,0	-	0,0	-	0,0
		S	4.55	26,38	-	1,0	-	1,2	-	1,7
		W	4.1	38,48	-	0,0	-	1,4	-	0,1
		N	4.26	12,40	-	0,0	5.73	7,14	-	0,0

both a & r ≥ 50
20<n<50
either of a or r < 20
either of a or r < 10
both of a and r ≤ 10

n = sample size
a = sample size of accepted gap
r = sample size of rejected gap
\- = sample size too small to calculate critical gap

analyzing all the compositions of gap parameters, thus the most challenging problem is that except most of the PP-P cases, the other compositions of critical gap performs not reliable enough. However, the sample size of most of t_f and τ are exceeding or close to 50, which can be regarded as reliable. Therefore, one objective of this paper is to predict the value of gap parameters for all vehicle compositions.

(5) Alternative method for vehicle compositions

a) Follow-up time t_f and minimum headway τ

In order to predict the gap parameters for all the compositions, the influence of heavy vehicles' driving behavior should first be considered. The relationship between each composition with heavy vehicles and the case composed of passenger cars only are calculated. Then this paper proposes a multiplier *r* by using the following four procedures to calculate it for each composition based on the empirical results. All the multipliers are estimated by the gap parameters with heavy vehicle (HV) cases divided by passenger car (PC) cases only. It means that the multiplier for the case of passenger car only is 1.0.

1) Calculate mean values of all the available multipliers of each approach.
2) Calculate mean value of all the available multipliers of each approach except the negative values. Considering the influence of heavy vehicle on critical gap, the multipliers which are smaller than 1 are unrealistic and this is mainly due to too small sample size to get a reliable

value.

3) Calculate mean value of all the available multipliers of each approach except the maximum and minimum values which are considered as outliers.
4) Mean values of the results which are calculated by three procedures above are assumed as estimated multipliers r.

For t_f, if vehicle e_1 is HV, the main cause of larger t_f is HV's longer length, and r is assumed as 1.30. When e_2 is HV, its size and driving behavior don't affect the follow-up time directly, but since e_2 would like to keep a larger safe distance with the leading vehicle, the t_f may increase. Then r is assumed as 1.20.

In the case of τ, the impact of HV on τ are the same as t_f since both of them are follow-up times. If c_1 is HV, r is assumed as 1.30. When c_2 is HV, r is assumed as 1.15. These two assumed multipliers are the same as HV's multipliers of t_c.

By applying estimated r to all the compositions, t_f and τ can be estimated based on empirical data. For the HH case, the size of gaps are close to 5 sec, which is defined as the upper bound of estimation of t_f and τ, in **Fig.2** and it can be considered reasonable.

b) Critical headway t_c

Due to heavy vehicle's large size and slow driving behavior, the compositions which include heavy vehicles would affect the gap acceptance a lot. Furthermore, the position of the heavy vehicle influences the value of t_c.

If c_1 is HV, the main cause of larger t_c is HV's longer length, which increases headway. The slower speed of c_1 and worse view for e_1 while selecting the gap may also increase the t_c. When c_2 is HV, although its size and driving behavior don't affect the headway directly, e_1 would like to accept a larger safe distance for entering in front of a HV, thereby increasing the critical headway. When e_1 is a HV, due to its own large size and slow driving behavior, the gap it can accept should be larger than that of a PC.

Therefore, comparing the influence of these three situations, t_c is largest when the HV is in position c_1, then e_1, and smallest with HV in position c_2. For this reason, the order of t_c for each composition is assumed to be PP-P < PH-P < PP-H < HP-P < PH-H < HH-P < HP-H < HH-H.

To predict the unavailable t_c, the same method of multiplier as t_c and τ are also applied to PH-P, PP-H and HP-P cases which include only one HV. The comparison of averaged values are shown in **Table 4**. Compared to the PP-P case, the PH-P case has a feature that the heavy vehicle is at the position c_2. In this case, we assign a multiplier of 1.15 to this feature. Compared to the PP-P case, the PP-H case and HP-P case also have the features of HV in positions e_1 and c_1, respectively. Therefore, we assign r as 1.2 and 1.3, respectively.

Table 4 Estimated multipliers r for every composition

t_f	PP	PH	HP	HH
Estimated multiplier r	1.00	1.20	1.30	1.50
T	PP	PH	HP	HH
Estimated multiplier r	1.00	1.15	1.30	1.45
t_c	PP-P	PH-P	PP-H	HP-P
Estimated multiplier r	1.00	1.15	1.20	1.30
t_c	PH-H	HH-P	HP-H	HH-H
Estimated multiplier r	1.35	1.45	1.50	1.65

With these values for different positions of heavy vehicles, we combine these features together to predict r for the other four compositions. For example, the PH-H case has HVs as c_2 and e_1. Considering both the impact of these two factors, for PH-H r = 1+0.15+0.2 = 1.35. The assumed multiplier for the other compositions are shown in **Table 4**.

After applying these estimated r to all the compositions, for HH-H, the t_c values ranged up to close to 10 sec, which is the upper bound of analyzed gaps.

c) Prediction of $t_{c\_pp\text{-}p}$

Among all the PP-P cases, only t_c of Kakudahama roundabout N approach (Kakudahama-N) could not be estimated due to insufficient gap data. However, for predicting all the combinations with HV, $t_{c\_PP\text{-}P}$ is necessary. For predicting it, the geometry of N approach is very similar to the other two approaches as shown in **Table 1**. In addition, t_c is strongly related with τ because that both of them measure the headway time on circulatory road. For this reason, the $t_{c\_PP\text{-}P}$ of N approach can be set as same as S approach based on their similar values of τ in **Table 3(a).**

d) Adjustment for geometric design

The estimated multipliers which calculated based on four procedures for each vehicle composition of three gap parameters are shown in **Table 4**.

By using the estimated multipliers r for every composition in **Table 4**, the vehicle compositions which have insufficient samples were supplemented. However, the method explained above relies too much on the critical headway of PP-P but neglect the impact of geometric design over other vehicle combinations. Therefore, a adjustment calculation considering the empirical data of heavy vehicle is applied to eliminate this limitation. For the cases of PH-P, PP-H, HP-P, their t_c values are calculated by the estimated multipliers r in **Table 4**. For the P-HH, HH-P, HP-H and HH-H, they are calculated by Equation (2).

$$t_c i = \left[\left(\frac{t_c i}{t_c\, HP-P}\right)\times D_{c1} + \left(\frac{t_c i}{t_c\, PH-P}\right)\times D_{c2} + \left(\frac{t_c i}{t_c\, PP-H}\right)\times D_{e1}\right] \times t_c\, PP-P \,/\, (D_{c1}+D_{c2}+D_{e1}) \quad (2)$$

Where, i : $D_{c1}D_{c2}-D_{e1}$ and $D_{c1,}D_{c2,}D_{e1} are$ dummy variables, if c_1, c_2 and e_1 are H then D = 1, otherwise = 0.

4. MODELING GAP PARAMETERS

After supplementing the data, the relationship between the three gap parameters and geometric elements is further analyzed and then the gap parameters are modeled by using linear regression as functions of geometric layout parameters and defined dummy variables.

As shown in **Table 5**, all the three gap parameters are influenced by D_{st}, which reveals that the capacity of the stop control roundabout is lower than the yield control one. For the t_f, PP case is affected by the D_{sp} because the presence of splitter island limits driving behaviors of passenger cars. Whereas, D_{sp} is not significant to the cases with HV because no matter there is splitter island or not, HV will be careful and run slowly.

The smaller the τ value is, the higher the circulating speed is. Regarding the results of τ in **Table 5(b)**, W_e has a negative influence on the τ of PH, HP, and HH. It is because the heavy vehicles pay more attention to the roadside impact due to their large size. If W_e becomes larger, the distance from circulating vehicles to the vehicle waiting in the entry approach or the approach curve is shorter and the roadside impact becomes smaller. It is also found that D is significant to the τ of the PP case. Larger D provides passenger cars with a more comfortable turning angle and passenger cars will have a smoother trajectory.

In **Table 5(c)**, the result indicates that φ_e has a negative relationship with t_c of PP-P, PH-P. It is difficult for a vehicle entering the roundabout with a large entry angle.

5. SENSITIVITY ANALYSIS

A hypothetical four-leg roundabout with a common geometric layout (W_e=4.5m, W=3.5m, D=35m, R=13m, φ_e=50deg, φ_m=40deg, D_{op}=1, and D_{st}=1) is designed for sensitivity analysis. The percentage of heavy vehicles in the circulatory roadway and in the entering approach is HV_c and HV_e, respectively.. HV_c is set as 20% while circulating flow q_c and HV_e are changed for various scenarios. Probability of composition is calculated by Equation (3).

Table 5 Estimation results of models for t_c, t_f and τ

(a) Models for t_f

t_f model	PP	PH	HP	HH
	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)
Intercept	2.95 (44.9**)	3.34 (47.1**)	3.69 (41.1**)	4.22 (53.0**)
D_{sp}	-0.188 (-2.37*)	-	-	-
D_{st}	0.836 (8.16**)	0.730 (4.20**)	0.508 (2.31*)	0.750 (3.84**)
R^2	0.731	0.386	0.160	0.345
N	30	30	30	30

(b) Models for τ

τ model	PP	PH	HP	HH
	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)
Inter-cept	3.22 (19.6**)	3.68 (14.0**)	4.39 (27.5**)	4.78 (23.3**)
W_e	-	-0.134 (-2.48*)	-0.200 (-6.08**)	-0.196 (-4.65**)
D	-0.0113 (-2.30*)	-	-	-
φ_e	-0.0.0259 (-2.03*)	-	-	-
D_{st}	0.398 (5.46**)	0.364 (2.00*)	0.347 (3.14**)	0.423 (2.98**)
R^2	0.702	0.246	0.608	0.499
N	30	30	30	30

(c) Models for t_c

t_c model	PP-P	PH-P	PP-H	HP-P
	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)
Intercept	5.27 (25.8**)	6.09 (27.2**)	5.68 (47.9**)	6.30 (51.1**)
φ_e	-7.63×10^{-3} (-2.04*)	-1.03×10^{-2} (-2.53*)	-	-
D_{st}	0.413 (2.00*)	0.544 (2.41*)	0.612 (2.11*)	0.740 (2.45*)
R^2	0.201	0.274	0.137	0.177
N	30	30	30	30
t_c model	PH-H	HH-P	HP-H	HH-H
	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)	Coef. (t-value)
Intercept	6.47 (62.8**)	7.04 (64.4**)	7.17 (57.6**)	7.94 (66.2**)
φ_e	-	-	-	-
D_{st}	0.597 (2.36*)	0.685 (2.56*)	0.808 (2.65**)	0.799 (2.72**)
R^2	0.166	0.190	0.200	0.209
N	30	30	30	30

*: Significant Level < 5%, **: Significant Level < 1%

$$P_{Dc1Dc2\text{-}De1} = P_{Dc1} \times P_{Dc2} \times P_{De1} \quad (3)$$

if $\quad D_i = HV,\ P_i = HV_i$;

otherwise $\ D_i = PC,\ P_i = 1 - HV_i$

In this sensitivity analysis, the entry capacity of proposed model is calculated by Equations (1) and (3). Significant decreasing trends of entry capacity can be observed with the increasing circulating flow q_c and HV_e in **Fig. 3(a)**. In **Fig. 3(b),** comparing the entry capacity of D_{sp} = 1 and 0 when HV_e = 50%, it is found that roundabouts with splitter islands have larger entry capacity than those without splitter islands. It means that splitter island can effectively guide the entering vehicles.

The comparison of proposed model and JRM model are based on the basic setting of the common geometric layout and HV_c is set as 20%. The entry capacities of the proposed models and those estimated by JRM[2)] have similar slopes but it of the proposed model is larger than JRM's, as shown in **Fig. 4**. The entry capacity of JRM model is calculated with the recommended parameter values (t_c=4.1sec, t_f =2.9sec, τ=2.1sec and PCE_e = 2.0).

Then the PCE for entering heavy vehicle PCE_e can be calculated by Equation (4).

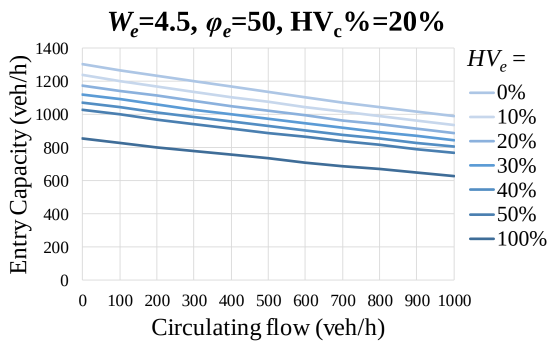
$$PCE_e = \frac{1}{HV_e}\left(\frac{c_{e\,(0,q_c)}}{c_{e\,(HV_e,q_c)}} - 1\right) + 1 \quad (4)$$

Where, $c_{e(0,\,qc)}$ and $c_{e(HVe,\,qc)}$ are the entry capacity for circulating flow q_c when heavy vehicle percentage at the entry approach is 0 and HV_e, respectively.

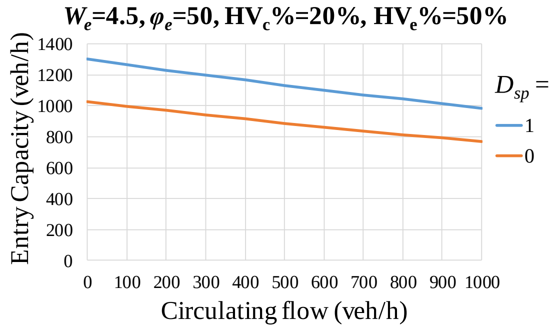
Fig.5 shows that the value of PCE is not constant but ranges between 1.52 and 1.58, which is smaller than the 2.0 in JRM. With the increasing of HV_e, the increasing tread becomes larger.

6. CONCLUSION AND FUTURE WORK

This paper proposed an alternative method to estimate and supplement the missing gap parameters for vehicle compositions and estimate the impact of heavy vehicle on roundabout entry capacity based on geometric elements. The potential impacts of geometric layout and heavy vehicle percentage on the entry capacity of roundabouts was investigated through empirical observations. It is concluded that the gap parameters (critical headway, follow-up time and minimum headway of circulatory roadway) are strongly influenced by the geometric layout and vehicle composition. The most significant influencing factors are dummy variable of stop control, entry angle and entry width. It is proved that



(a) Entry capacity of standard roundabout



(b) Entry capacity of different D_{sp}

Fig.3 Sensitivity of geometric elements to entry capacity

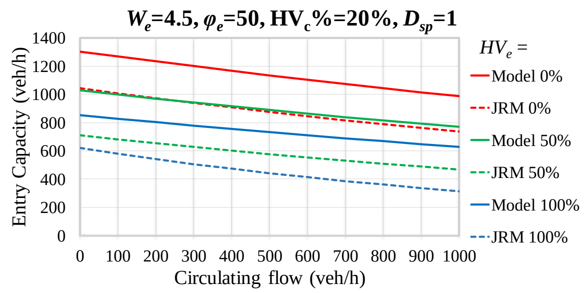


Fig.4 Comparison between JRM and proposed model

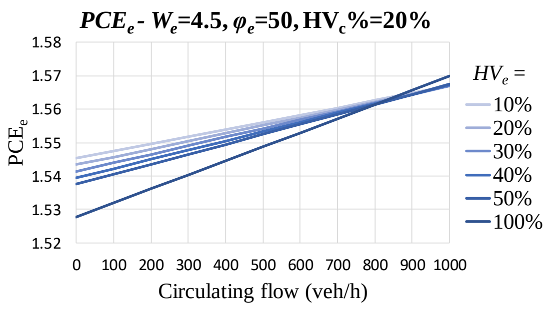


Fig.5 PCE for proposed model

stop-control perform worse than yield-control due to its negative influence on capacity.

Furthermore, the differences of the proposed models and JRM[2)] are compared. It indicates that the trend of two models are similar but entry capacity of

JRM is lower than proposed model when heavy vehicle percentage increases. It was suggested that PCE ranges from 1.52 to 1.58 depending on heavy vehicle percentage HV_e.

In the future work, more empirical data should be collected for validating whether the procedure of predicted data can reflect the real situation of roundabout in Japan. Moreover, it is also recommended to conduct a simulation study to verify the impact of geometry parameters on entry capacity.

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