Development of Capacity Guidelines for Road Links and Intersections for Henan and Hebei Provinces, PRC

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ABSTRACT

A comprehensive highway capacity study and guideline development (HCS) was undertaken in the Hebei and Henan provinces 1995–1999. Field data collection was conducted at 144 road links and at 19 major intersections outside of urban areas. Aggregated data from all road link sites was analyzed to obtain passenger car equivalents, free-flow speed, and speed-flow-density relationships for all road and terrain types. Significant influencing factors included cross section characteristics, road class, side friction, and terrain type. The intersection analysis showed that traffic flow, split between major and minor road traffic, level of side friction, and road width were the main variables influencing traffic performance. Driver behavior studies showed that only 40% of the vehicles waited for a gap in the major road flow making it impossible to use gap acceptance models. A further development of the capacity guidelines based on data from five more major provinces in China is under way lead by the Highway Research Institute, Beijing

1. BACKGROUND

The vehicle fleet on interurban and township roads in PRC includes a large proportion of farm tractors and man- or animal-powered vehicles. Passenger cars are still few and activities along the side of the road create considerable "side friction" slowing down the traffic. In spite of generally high road standard and moderate traffic demand the average speed is very low. The intersections are often blocked by drivers trying to "cut the corners" making it difficult to apply capacity manuals from developed countries. A large-scale Highway Capacity Study (HCS) was therefore carried out in 1995–1999 with the purpose to develop draft capacity guidelines for roads and major intersections outside of urban areas. HCS was part of Technical Assistance under the China National Highway Project for which the World Bank had extended a loan. The project area only included the Hebei and Henan provinces situated around and south of Beijing with a total population around 200 million, but the project was intended to support central efforts towards the development of a complete Chinese Highway Capacity Manual. The traffic analysis and modeling for motorways and highways has been documented by Bang et al. (1998), and for intersections by Bang and Hai-Long (1999). This paper summarizes the capacity guidelines that were consequently developed for local use and possible inclusion in the planned National Chinese Highway Capacity Manual.

2. TRAFFIC ANALYSIS FOR ROAD LINKS

Field data collection of vehicle type, identity, speed, and passage time was conducted at 132 interurban and 12 township road segments in 1996–1997. Automatic short-base data collection stations were used for flat, homogenous road segments and long-base stations with license plate matching for segments in other terrain types and within built-up areas (Bang et al. 1995). For township roads mobile travel time monitoring with recording of opposing flow, overtaking movements, and side friction events was also used in parallel with travel time recording based on registration of license plate numbers. The field data were used for determination of flow, spot-speed, headways, and passenger car equivalents for seven vehicle types.

The field data were also used to calibrate and validate the VTI highway simulation model for Chinese conditions (Bang et al. 1998). This model was used for determination of passenger car equivalents (pce) and speed-flow relationships for different terrain types in parallel with multiple regression analysis of empirical speed-flow data. The results showed that the Chinese free-flow speeds were very low, and that the capacity generally was lower than on Western roads with the same geometry. Side-friction and the abundance of very slow vehicles with unpredictable behavior on Chinese roads may partly explain these results.

3. TRAFFIC ANALYSIS FOR UNSIGNALIZED INTERSECTIONS

Although given a lower priority the HCS project also included major intersections on interurban and township roads outside of urban areas. The purpose was to obtain rough estimates of intersection capacity as a basis for development of draft capacity guidelines. Field data collection of traffic flow and journey times was conducted in 5 signalized, 9 unsignalized intersections, and 5 roundabouts. Furthermore, studies of driver behavior and accepted gaps in conflicts between crossing traffic movements were performed in selected intersections as described below.

3.1 Traffic Flow and Travel Time Surveys

The long-base data collection method was used to register vehicle identity (license plate number), vehicle type, and passage time in both directions of travel on all intersection arms in undisturbed sections around 200 m away from the intersection. These data were then processed to obtain the actual travel time between the upstream and the downstream survey station for each traffic movement in the intersection. The intersection conflict area was also observed using continuous video recording.

Regression analysis was used to explore relationships between intersection geometry, traffic flow, type of control, and delay. The observed delay-flow data showed a considerable scatter resulting in rather weak models for prediction of delay (Bang and Hai-Long 1999). Comparison with studies from Indonesia (Bergh and Dardak 1994), where similar driver behavior exists, showed that the delays in China were normally higher in spite of the considerable width of the studied intersection approaches. Poor lane discipline including a tendency of the drivers to “cut corners” while making left turns which caused blockage to other traffic movements is a partial explanation. Only one of the studied intersections had a traffic demand that made it possible to observe conditions close to capacity. Delay-flow relationships were analyzed using multiple regression with power, exponential, and linear models. Intersection delay was found to primarily be a function of 1) total intersection traffic flow, 2) split between major and minor road flow, 3) level of side friction, and 4) width of the intersecting roads.

3.2 Driver Behavior Studies

Driver behavior in conflict points between crossing vehicle movements in unsignalized intersections was studied using video recordings from elevated positions. The data obtained from these surveys included:

- time headway at stop line passage;
- behavior in crossing conflicts (e.g., waiting for gaps, pushing, etc);
- accepted and rejected time gaps for minor road vehicles observing the right-of-way of the major traffic movements.

The driver behavior studies showed that only 40% of the vehicles that had a choice between “gapping” or “pushing” actually waited for a gap in the major road flow, i.e., gap acceptance models could not be used to predict intersection performance for unsignalized intersections and roundabouts. Critical gaps were nevertheless calculated for yielding vehicles and were found to be 3.2–4 seconds for light and 5.3–7.8 seconds for heavy vehicles.

4. CAPACITY GUIDELINES FOR ROAD LINKS

4.1 Introduction

The HCS Capacity Guideline for road links (Bang et al. 1999) covers two-lane two-way/undivided roads (2/2 UD) and divided and undivided multi-lane two-way roads (4/2 D, 4/2 UD, 6/2 D) and Motorways (MW). The guideline covers operational analysis for any given road segment including determination of capacity, degree of saturation, operational speed, and degree of bunching. An overview of the calculation procedure is shown below.

STEP A: INPUT DATA (Geometry, Environment, Traffic)

STEP B: CALCULATION OF FREE-FLOW SPEED
B-1: Base free-flow speed
B-2: Adjustment for carriageway width
B-3: Adjustment for road function and road class
B-4: Adjustment factor for land use and side friction conditions
B-5: Free-flow speed for actual conditions

STEP C: CALCULATION OF CAPACITY
C-1: Base capacity
C-2: Adjustment factor for carriageway width
C-3: Adjustment factor for directional split
C-4: Adjustment factor for side friction conditions
C-5: Capacity for actual conditions

STEP D: CALCULATION OF TRAFFIC PERFORMANCE
D-1: Degree of saturation
D-2: Actual speed and travel time
D-3: Bunching (platooning)

4.2 Traffic Flow and Passenger Car Equivalents

The following average traffic composition was recorded on the surveyed sites:

MC2	Two-axle motorcycles 4%	MV	Mini-vehicles (3 and 4 axles) 10%
LV	Light vehicles (cars, vans, etc) 27%	MHV	Medium heavy vehicles 25%
LHV	Large heavy vehicles 21%	TC	Truck combinations 8%
TRA	Farm tractors 5%		

In the guidelines traffic flow is converted into hourly flows in passenger car units (pcu) using the developed passenger car equivalents (pce) as exemplified in Table 1 below.

4.3 Free-Flow Speed

The capacity analysis for *undivided road segments* is always carried out for both directions of travel combined. *Divided road segments* with different geometric and traffic conditions in the two directions are analyzed separately for each direction of travel, as though each direction was a separate one-way road. Free-flow speed for light vehicles is a main parameter in the guideline procedure for calculation of actual (operational) speed. Free-flow speeds for other vehicle classes can also be calculated, e.g., for use in road user cost analysis.

TABLE 1 Passenger Car Equivalents for Road Links

Road type/ Carriageway width CW (total both directions)	Align-ment type	Traffic flow (two-way) (veh/h)	Passenger car equivalent (pce) (pce for LV = 1.0)					
			MV	MHV	LHV	TC	TRA	MC2
2/2 UD (CW < 13 m)	Flat	0	1.4	1.4	1.8	2.3	3.6	0.6
		1400	1.5	1.6	2.0	2.5	4.0	0.7
		2800	1.3	1.3	1.5	2.0	3.0	0.3
	Rolling	0	1.8	1.9	2.8	3.5	4.3	0.5
		1200	2.0	2.1	2.8	3.5	4.8	0.6
		2400	1.5	1.5	2.0	2.5	3.9	0.3
	Hilly	0	1.8	1.9	3.4	4.4	4.3	0.5
		1000	2.5	2.4	3.4	4.4	5.6	0.5
		2000	1.7	1.6	2.4	3.2	4.0	0.3
4/2 UD+D (CW = 13–16 m)	Flat	0	1.3	1.4	1.6	2.2	3.2	0.5
		2500	1.4	1.5	1.8	2.4	3.5	0.5
		5000	1.2	1.2	1.4	2.0	2.5	0.3
	Rolling	0	1.7	1.8	2.5	3.4	3.8	0.5
		2100	1.9	2.0	2.5	3.4	4.2	0.5
		4200	1.8	1.5	1.8	2.4	3.4	0.3
	Hilly	0	1.8	2.0	3.1	4.2	4.4	0.3
		1750	2.0	2.3	3.1	4.2	4.9	0.4
		3500	1.9	1.7	2.4	3.4	3.9	0.3

$$FV = (FV_0 + FV_{CW} + FV_{CLASS}) \times FFV_{LU} \quad (1)$$

where: FV = free-flow speed for light vehicles at actual conditions (km/h);
FV_0 = base free-flow speed for light vehicles (km/h);
FV_{CW} = adjustment for carriageway width (km/h);
FV_{CLASS} = adjustment for road function and road class (km/h);
FFV_{LU} = adjustment factor for land use and side friction.

The reason why multiplication factors were not used for all parameters was that the chosen shape gave a closer fit to measured values as well as a better consistency between road classes. The different factors are shown in Tables 2–4 below.

TABLE 2 Base Free-Flow Speed FV_0 for Interurban and Township Roads

Road type/CW total both directions	Terrain type	Base free-flow speed (km/h) FV_0						
		LV	MV	MHV	LHV	TC	TRA	MC2
Motorway	- flat	90	70	70	65	60	-	-
	- rolling/hilly	80	60	60	52	50	-	-
Multi-lane road CW > 13 m	- flat	70	55	62	62	54	25	41
	- rolling	65	50	57	55	47	23	39
	- hilly	60	45	51	48	39	20	37
Two-lane undivided CW = 6–13 m	- flat	60	50	55	57	54	22	40
	- rolling	56	46	51	52	49	21	39
	- hilly	52	42	46	45	43	20	37

TABLE 3 Adjustment Factors FV_{CW} and FV_{CLASS} for Free-Flow Speed

Road type/ CW	Carriageway width CW (m)	Adjustment FV_{CW} (km/h)
Motorway	Per lane 3.00	-3.0
	3.25	-1.0
	3.50	0.0
	3.75	2.0
Multi-lane CW > 13 m	Total CW 14	-2.0
	15	0.0
	16	1.0
	>16	2.0
Two-lane undivided CW = 6-13 m	Total CW 6	-12.0
	7	-7.0
	8	-3.0
	9	0.0
	10	2.0
	11	3.0
	12	4.0
	13	4.5

Road function	Road class	Free-flow speed adjustment FV_{CLASS} (km/h)
Arterial	Class II mvo	8
	Class II mix	0
Collector	Class II mix	-5
	Class III mix	-9
Local	Class III mix	-12

Class II is a high-standard interurban highway with wide shoulders.

Class III is a local highway with narrow shoulders.

mvo for motor vehicles only.

mix for mixed traffic.

TABLE 4 Adjustment Factors FFV_{LU} for Free-Flow Speed

Road type	Side friction class	Adjustment factor FFV_{LU} for the influence of land use				Adjustment factor FFV_{LU} (only for township roads)			
		Roadside development (%)				SEP = degree of separation of bicycles	MI = approaches in minor intersections/km		
		0-24	25-49	50-74	75-100		<1	1-2	>2
Multi-lane CW >13m	Very low	1.00	0.97	0.94	0.91	0=no sep.	0.75	0.73	0.72
	Low	0.93	0.91	0.88	0.85	1=one side	0.86	0.84	0.83
	Medium	0.87	0.85	0.82	0.80	2=two sides	0.95	0.93	0.92
	High	0.81	0.79	0.77	0.80				
	Very high	0.80	0.79	0.71	0.75				
Two-lane undivided CW = 6–13m	Very low	1.00	0.95	0.90	0.85	0=no sep.	0.60	0.58	0.56
	Low	0.92	0.87	0.82	0.78	1=one side	0.73	0.71	0.69
	Medium	0.83	0.79	0.75	0.72	2=two sides	0.84	0.82	0.80
	High	0.74	0.71	0.68	0.66				
	Very high	0.65	0.63	0.61	0.60				

Since the guideline does not cover urban traffic conditions the flows of bicycles and pedestrians are only considered in terms of side friction adjustment factors for free-flow speed and capacity as shown in the equations and tables.

4.4 Capacity

The capacity of a road segment is determined as follows:

$$C = C_0 \times FC_{CW} \times FC_{SP} \times FC_{SF} \text{ (pcu/h)} \quad (2)$$

where:

C = capacity (pcu/h)
C_0 = base capacity (pcu/h)
FC_{CW} = adjustment factor for carriageway width
FC_{SP} = adjustment factor for directional split
FC_{SF} = adjustment factor for side friction.

TABLE 5 Input for Calculation of Road Link Capacity

Road type/ Alignment type	Base capacity C_0 (pcu/h/lane)		Road type/ Effective carrriage-width CW (m)	Adjustment factor for effective carriageway width FC_{CW}
Motorway (MW D):			MW, 4/2 D ,6/2 D Per lane (m):	
- Flat	1900			
- Rolling	1800		3.0	0.91
Divided interurban road (4/2 D or 6/2 D):			3.25	0.96
			3.50	1.00
- Flat	1600		3.75	1.03
- Rolling	1500		2/2 UD 4/2 UD Total both dir. (m)	
- Hilly	1400		5	0.69
Two-lane undivided 2/2 UD	Base capacity C_0 (pcu/h total)		6	0.91
			7	1.00
- Flat	2500		8	1.08
- Rolling	2400		9	1.15
- Hilly	2300		10	1.20
			11	1.24
			12	1.26

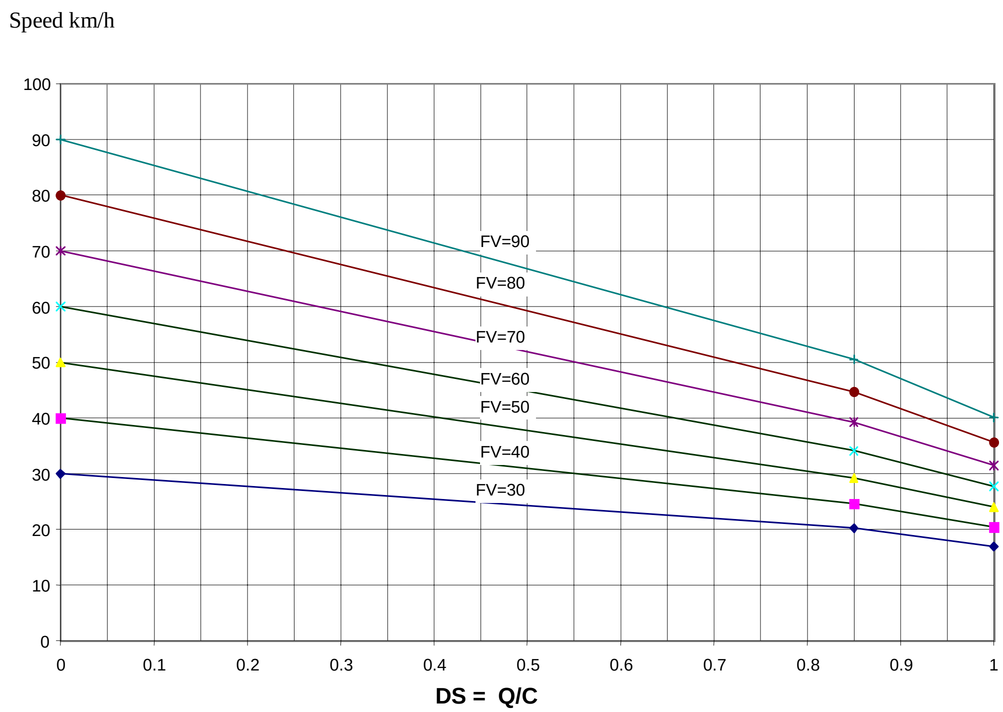
Directional split SP %-%	50-50	55-45	60-40	65-35	70-30
FC_{SP} (only applicable for UD roads)	1.00	0.97	0.94	0.91	0.88

TABLE 6 Input for Calculation of Road Link Capacity (continued)

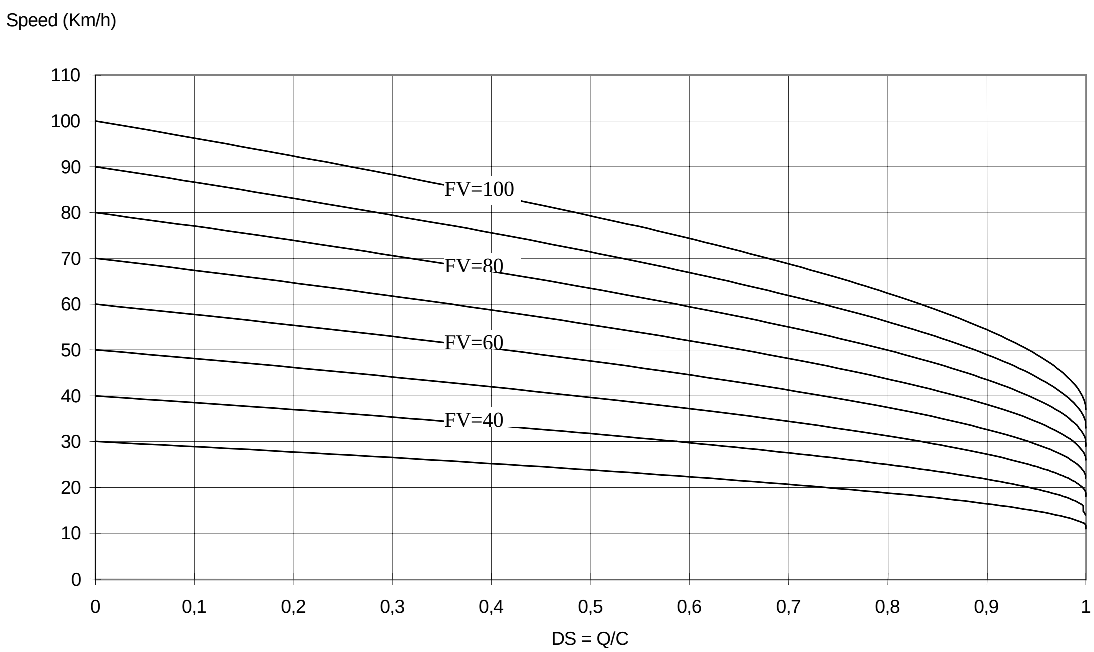
Road type	Side friction Class	Adjustment factor for side friction FC_{SF} Effective shoulder with SW (m)				Degree of separation (SEP)	Adj.factor for side friction FC_{SF} (only for township roads) Effective shoulder with SW m			
		≤ 0.5	1.0	1.5	≥ 2.0		≤ 0.5	1.0	1.5	≥ 2.0
Four-lane	VL	0.99	1.00	1.01	1.03	0=no sep.	0.90	0.92	0.94	0.96
Roads	L	0.97	0.98	0.99	1.01	1=one side	0.93	0.94	0.96	0.98
	M	0.95	0.96	0.97	0.99	2=two sides	0.96	0.97	0.98	1.00
	H	0.92	0.93	0.95	0.97					
	VH	0.90	0.92	0.94	0.96					
Two-lane	VL	0.98	0.99	1.00	1.01	0=no sep.	0.85	0.87	0.91	0.93
Roads	L	0.95	0.96	0.98	1.00	1=one side	0.89	0.92	0.95	0.97
	M	0.92	0.94	0.96	0.98	2=two sides	0.93	0.96	0.98	1.00
	H	0.89	0.91	0.93	0.95					
	VH	0.85	0.87	0.91	0.93					

4.5 Speed-Flow Relationship

Operational speed (speed at actual traffic conditions) is obtained with the help of Figure 1 using free-flow speed and degree of saturation (DS = Q/C) as inputs.



Upper diagram: Two-lane two-way undivided roads



Lower diagram: Divided roads (four-lane or six-lane)

FIGURE 1 Operational speed determined as a function of free-flow speed and degree of saturation (DS = Q/C).

5. CAPACITY GUIDELINES FOR UNSIGNALIZED INTERSECTIONS

The HCS Intersection Guidelines (Bang et al. 1999) contain preliminary procedures for the calculation of capacity, degree of saturation, and delay for the following types of intersections on interurban and township roads outside if urban areas:

- unsignalized intersections with 3 and 4 arms (these intersections do not have any form of right-of-way control such as yield or stop-signs);
- roundabouts;
- signalized intersections (two-phase fixed time control).

An overview over the calculation procedure is shown in Figure 2. The procedure for unsignalized intersections is shown below.

5.1 Intersection Capacity

The total actual capacity (C pcu/h) for all arms of the intersection is calculated as the product between a base capacity (C_0) for a set of pre-determined (ideal) conditions and a number of adjustment factors (F) taking account of the influence on capacity of the actual site conditions.

The format of the capacity model and its input variables for unsignalized intersections is as follows:

$$C = C_0 \times F_{LT} \times F_{RT} \times F_{MI} \times F_{SF} \quad (3)$$

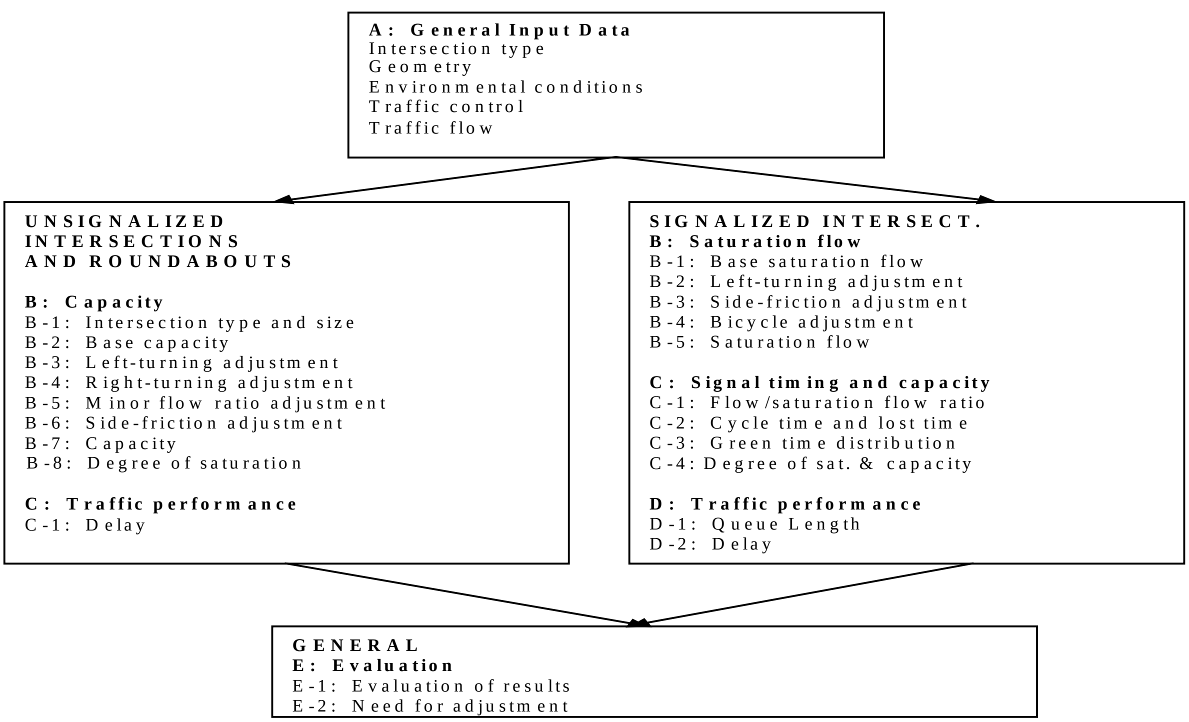


FIGURE 2 Flow chart for analysis of major intersections on interurban roads.

Tables 8, 9, and 10 below document parameter values and adjustment factors used in Equation (3).

Adjustment factors for left- and right-turning traffic:

$$F_{LT} = 1.14 - 0.92 \times p_{LT}$$
$$F_{RT} = 0.76 + 1.61 \times p_{RT}$$

As can be seen from the latter equation the capacity of an unsignalized intersection increases with ratio of right-turning traffic, which is logical since this movement can avoid conflict with the major traffic streams provided that the shoulders are wide enough.

In the field data the range of minor road flow ratio was between 0.21–0.60. Since there is no clear designation of major or minor road in China the table covers the whole interval from 0.1 to 1.0.

TABLE 7 Overview of Capacity Model Input Variables

Variable type	Variable description and input name		Model factor
Geometry	Intersection size (No. of arms/No. of lanes major road/Dito minor road)	INTSIZE	C_0
Traffic	Left-turning ratio Right-turning ratio Minor road flow ratio	p_{LT} p_{RT} Q_{MI}/Q_{TOT}	F_{LT} F_{RT} F_{MI}
Environment	Side friction class	SF	F_{SF}

TABLE 8 Intersection Base Capacity Values

Intersection size code no. of arms/ no of lanes major road/ no. of lanes minor road	**Intersection Base Capacity C_0** (total for the intersection, pcu/h)			
	Unsignalized intersection	Roundabout, center island diameter (m)		For reference: Signalized intersection
		10	25	
322	1600			
342	2200			
324	1800			
344	2300			
422	2100	2300	2400	(1800)
424, 442	2200	2900	3100	(2500)
444	2300	3300	3500	(3200)

TABLE 9 Adjustment Factor for Side Friction F_{SF}

Side friction class	Corresponding area type	Adjustment factor F_{SF}
Low	Rural, e.g.some roadside buildings & activities	1.00
Medium	Residential, e.g. village	0.96
High	Commercial: e.g. township: some market activities	0.92

TABLE 10 Adjustment Factor for Minor Road Flow Ratio F_{MI}

Intersection Size (INTSIZE)	Minor road flow adjustment factor F_{MI}								
	Minor Road Flow Ratio (p_{MI})								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
322	1.08	1.00	0.94	0.91	0.89	0.88	0.86	0.84	0.80
342	1.08	1.00	0.94	0.91	0.89	0.92	0.99	1.11	1.30
324	1.30	1.00	0.88	0.84	0.83	0.82	0.81	0.78	0.74
344	1.30	1.00	0.88	0.84	0.83	0.82	0.81	0.78	0.74
422	1.08	1.00	0.94	0.91	0.89	0.91	0.94	1.00	1.08
424	1.30	1.00	0.88	0.84	0.83	0.84	0.88	0.91	1.01
442	1.30	1.00	0.88	0.84	0.83	0.84	0.88	0.91	1.01
444	1.30	1.00	0.88	0.84	0.83	0.84	0.88	0.91	1.01

5.2 Intersection Delay

Intersection traffic delay DT_I (sec/pcu) is the average traffic delay for all motor vehicles entering the intersection. DT_I is estimated from empirically derived relationships between DT_I and the degree of saturation DS as shown in Figure 3. One of the two graphs in this figure applies to unsignalized intersections, and the other to roundabouts.

The guidelines also contain methods for separate determination of major and minor road delay as well as methods for calculation of geometric delay. Signalized intersections are also included in the guidelines but have been omitted from this paper due to lack of space.

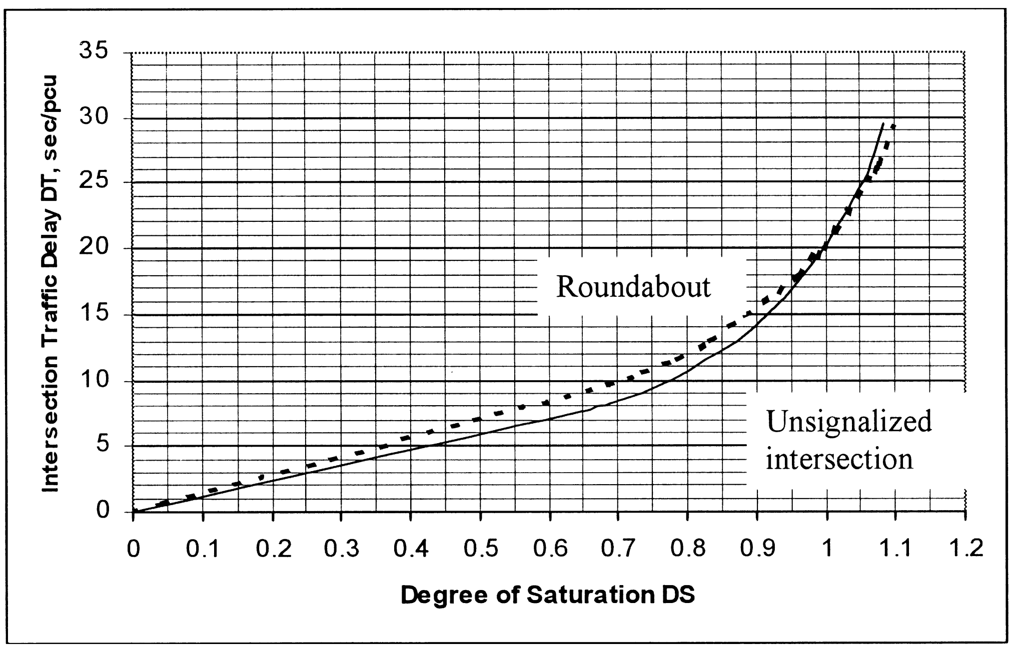


FIGURE 3 Intersection traffic delay DT_I versus DS = Q_{pcu}/C.

6. RECOMMENDATIONS TO THE USERS

The Hebei and Henan HCS Capacity guidelines have been primarily designed to estimate consequences regarding capacity and traffic performance of a set of given conditions regarding geometric design, traffic, and environment. Since the outcome of the analysis rarely can be predicted beforehand, it is quite likely that the user will need to revise some of the input assumptions which are within the engineer's control, particularly the geometric conditions, in order to get a desired traffic performance regarding capacity and delay, etc.

The quickest way to evaluate the results is to look at the degree of saturation (DS) for the studied case, and to compare it with the annual traffic growth and the desired functional “life” of the intersection in question. If the obtained DS value is high (e.g., 0.75), the user might want to revise his assumptions regarding approach width, etc., and make a new set of calculations. Local validation of the guidelines, e.g., by surveys of free-flow speed, speed, and flow at peak traffic conditions, saturation flow and delay are highly recommended.

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