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Outline of Brilon Paper

"Recent Developments in Calculation Methods For Unsignalized Intersections in West Germany"

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Brilon paper

"Recent Developments in Calculation methods for Unsignalized Intersections in West Germany"

1. The simple queueing model

Problem is the crossing of a priority stream by a non-priority stream:

q_p = priority stream flow (veh/hr)

q_n = non-priority stream flow (veh/hr)

vehicles in priority stream (major street) cross intersection without delay

vehicles in non-priority stream (minor street) can enter intersection only if next major street vehicles is at least t_g seconds upstream, where t_g = critical gap

vehicles in non-priority stream (minor street) can enter the intersection t_f seconds after the departure of the previous minor street vehicle, where t_f = move-up time.

2. The 1972 German Guideline

a. Based on Harders formula for capacity of minor street:

$$G = q_p \frac{e^{-\beta}}{e^{\alpha} - 1}$$

G = capacity of minor street

q_p = priority stream flow

$\alpha = p t_f$

$\beta = p(t_g - t_f)$

$p = q_p / 3600$

Analysis of Harders Formula

(1) Oddly enough, as q_p increases, the minor street capacity increases. This increase will probably be ameteriorated by the other exponential factors.

(2) $e^{-\beta} = e^{-p(t_g - t_f)} = e^{-q_p(t_g - t_f)/3600}$

As the major stream flow increases, this factor decreases rapidly. So as major street flow increases, minor street capacity decreases. The term $(t_g - t_f)$ is the major street gap minus the move up time.

(3) $e^{\alpha} - 1 = e^{p t_f} - 1 = e^{q_p t_f/3600} - 1$

As the major street flow increases, this term increases exponentially, and the minor street capacity estimate will decrease.

$$G = q_p \cdot \frac{e^{-\beta}}{e^{\alpha} - 1} \quad \begin{array}{l} \rightarrow \text{decreases as } q_p \text{ increases} \\ \rightarrow \text{increases as } q_p \text{ increases} \end{array} \Bigg] \text{cumulative effect is to decrease } q_p$$

b. Assumptions in Harders formula:

(1) exponentially distributed major stream headways

(2) same critical gaps and move-up times for all drivers

c. Effect of different critical gaps and move up times (Harders). He assumed a statistical distribution for t_g and t_f and accounted for this with a factor f:

$$f = 1 - q_p^2 \cdot 10^{-7}$$

$$G = f \cdot q_p \frac{e^{-\beta}}{e^{\alpha} - 1}$$

This assumes that each driver keeps his t_g constant while in the queue.

d. It is assumed that there is a fixed relationship between the critical gap and movement time:

$$t_f = 0.6\, t_g$$

or: $t_g = 1.67\, t_f$

$$G = f \cdot q_p \frac{e^{-\beta}}{e^{\alpha} - 1}$$

$$= (1 - q_p^2 \cdot 10^{-7})(q_p) \frac{e^{-q_p(t_g - t_f)/3600}}{e^{q_p t_f/3600} - 1}$$

$$= (1 - q_p^2 \cdot 10^{-7})(q_p) \frac{e^{(-q_p/3600)(t_g - .6 t_g)}}{e^{(q_p/3600)(0.6 t_g)} - 1}$$

$$= [1 - q_p^2 \cdot 10^{-7}][q_p] \frac{e^{(-q_p/3600)(0.4 t_g)}}{e^{(q_p/3600)(0.6 t_g)} - 1}$$

e. Priorities of Traffic Streams (Impedance Effects)

Different levels of priority are assigned to different traffic streams by a set of fixed rules. A vehicle can cross or merge into the intersection only if there are no vehicles waiting that are of a higher priority. These are called impedance effects.

Priorities:

1st. major street through and right-turning vehicles.

2nd. major street left-turning vehicles and minor street right-turning vehicles

3rd. minor street through vehicles

4th. minor street left-turning vehicles

To account for these impedance effects, we must know the probability p_0 that no vehicle is waiting in the minor stream under consideration.

$$p_0 = \frac{G - q_n}{G - \gamma \cdot q_n}$$

where $\gamma = e^{-(q_p \cdot t_g + q_n \cdot t_f)/3600}$

(Note: Brilon asserts that this equation is founded on an inadmissable simplification)

F. Practical Capacity (Another idea of Harders which Brilon asserts is still practical today)

$N = G - C$ where

N = practical capacity

G = minor street capacity

C = constant reserve capacity

There is a definition in the relationship of C to minor street delay as a function of the major street (priority) flow.

9. Another fundamental approach of Harders that Brilon asserts is still valid is the shared-lane capacity formula.

$$\frac{1}{L} = \sum_{i=1}^{k} \frac{a_i}{L_i}$$

where L = max. capacity of lane shared by several minor streams

k = number of minor streams

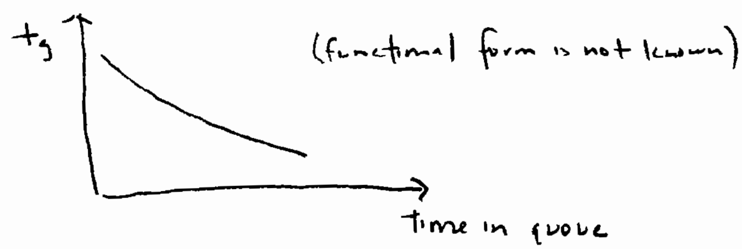
L_i = capacity of ith minor street, either directly for streams of 1st or 2nd priority, or, after a reduction due to p_0, for minor streams of 3rd or 4th level.

$$a_i = \frac{q_{ni}}{\sum_{j=k}^{K} q_{nj}}$$

3. Critical Gaps and Move-up Times

a. The original assumptions is Harders worked for capacity assumed that while t_F and t_g might be statiscally distributed (i.e. not the same for each driver), each driver would have a constant critical gap and move-up time value while waiting in the queue. Harder produced extensive measurements of t_f and t_g for different major street speeds (40 - 90 km/hr) and for different vehicle types.

b. But Harder and others later found that the value for t_g can change as a given driver is searching through the available gaps. And it is not unusual that the value of t_g will decrease, the longer that a vehicle waits for an acceptable gap.



c. This non-constant t_g means that the correction factor f considered earlier is no longer valid.

d. Brilon notes that a "comprehensive investigation of the influence of the distribution of t_g and t_f on capacity" emphasizing the non-constant nature of these parameters is still needed.

e. Brilon also notes ~~two other problems~~ that there is still disagreement on both the correct definition of t_g and its measurement.

4. Recent Formulae For Capacity Calculation

a. Besides other problems just mentioned, the capacity equation of Harders assumes a Poisson distribution for vehicle arrivals. Brilon notes that it is impossible to adapt these equations to realistic headway distributions.

b. Siegloch developed a generalized capacity calculation equation based on the above mentioned queueing model.

$$L = q_p \int_0^\infty f(t) \cdot g(t)\, dt$$

where L = capacity (maximum volume of departing minor stream)
$f(t)$ = statistical function of the headway distribution in the major stream
$g(t) = \sum_{n=0}^{\infty} n \cdot p_n(t)$

$p_n(t)$ = probability that n minor stream vehicles enter a gap in the major stream of length t.

All practical investigations show that $g(t)$ can be adequately approximated by a straight-line equation:

$$g(t) = \begin{cases} 0 & \text{for } t < t_0 \\ \frac{1}{t_f} \cdot t - \frac{t_0}{t_f} & \text{for } t > t_0 \end{cases}$$

where: t_0 = zero-gap (gap in major stream on average used by no driver to enter conflict area.
t = headway in major stream.

If the above relationship for $g(t)$ is assumed and if we assume that headways in major stream are exponentially distributed, we can now write the equation for capacity L:

$$L = \frac{3600}{t_f} e^{-p \cdot t_o}$$

where $p = \frac{q_p}{3600}$

The relationship to the Harders equation for capacity is established by:

$$t_o = t_g - t_f/2$$

Note:

[Harders eq.] $$G = q_p \cdot \frac{e^{-\beta}}{e^{\alpha} - 1} = \frac{q_p \, e^{q_p(t_g - t_f)/3600}}{e^{q_p t_f/3600} - 1}$$

[Siegloch] $$L = \frac{3600 \, e^{-q_p t_o/3600}}{t_f}$$

$$= 3600 \, e^{-q_p/3600 \, (t_g - t_f/2)}$$

$$= \frac{3600 \, e^{-q_p t_g/3600} + e^{q_p/3600 \, (t_f/2)}}{t_f}$$

[Brilon notes that while the relationships between G and L are not identical, the results of each are within 10 veh/hr.

Siegloch also showed an unexpected result : the simple Poisson condition [an exponential distribution of headways $f(t)$ in the major stream] leads to a reliable estimation of capacity under realistic traffic conditions.

~~The~~ A final consideration is the choice of minimum headways in the ~~main~~ major street. Jacobs used a shifted exponential distribution $f(t)$ for the headways in the major stream. He derived the following capacity formula:

$$L = \frac{1 - p \cdot t_m}{t_f} \cdot e^{-s(t_0 - t_m)} \cdot 3600$$

where $t_0 = t_g - \frac{1}{2} t_f$

t_f = move-up time

t_m = minimum major stream headway ($t_m = 1.8 - 2.0$ sec)

$$s = \frac{p \cdot b}{1 - p t_m}$$

b = portion of free-flow vehicles in major stream (headways > t_m)

$p = q_p / 3600$

L in veh/sec

$\Rightarrow b \simeq e^{-x \cdot p} \quad (6 \le x \le 9)$

Summary of key points

1. Harders basic capacity equation (for minor street) assumes poisson arrivals. Surprisingly, it compares favorably with more complex capacity expressions.
2. Siegloch developed a generalized capacity calculation equation where capacity is a function of the statistical distribution of the major stream headways, the gap acceptance characteristics of the minor street, and the flow rate on the major street.
3. Harders' equation and Siegloch's equation if Poisson arrivals are assumed, are nearly identical.
4. Important variables in determining minor street traffic capacity:
   a. major street flow rates, q_p
   b. critical gap, t_g
   c. move-up time, t_f
   d. zero gap, t_0

Harders

$$G = q_p \frac{e^{-p(t_g - t_f)}}{e^{pt_f} - 1}$$

Siegloch
(poisson assumed)

$$L = \frac{3600}{t_f} \cdot e^{(q_p/3600)\,t_0}$$

Brilon paper (p. 124-125)
calculations relating t_g, t_f, t_o.

t_g = 5.8 sec
t_f = 3.39 sec.
t_m = 2 sec

$t_o = t_g - 1/2\, t_f$
= 5.8 - 1.7
= 4.1 sec.

$$g(t) = \begin{cases} 0, & t < t_o \\ \frac{1}{t_f} \cdot t - \frac{t_o}{t_f}, & t > t_o \end{cases}$$

so: if $t > t_o$

$$g(t) = \frac{1}{3.4} \cdot t - \frac{4.1}{3.4}$$

$$= .3t - 1.2$$

$g(t) = 0.3t - 1.2$
$g(5) = 0.3(5) - 1.2$
$= 0.3$
$g(6) = 0.6$
$g(7) = 0.9$
$g(8) = 1.2$

5. DELAY AND CONGESTION

a. The delay of the minor stream vehicles and the length of the queues at the intersection are indicators of the quality of traffic flow.

b. For the simple queueing model assumed at the beginning, Kremser has developed the following equations: (assumes exponential dist. for both major and minor streets)

$$D = \frac{E(w_1)}{x} + \frac{n}{2} \cdot \frac{y \cdot E(w_1^2) + z \cdot E(w_2^2)}{x \cdot y}$$

D = average delay for minor street vehicles

$x = y + z$

$y = 1 - n \cdot E(w_2)$

$z = n \cdot E(w_1)$

[what are w_1 and w_2? waiting times or vehicles in queue?]

c. Siegloch proposed a more simplified delay formula:

$$D = \frac{1}{h} \cdot \left[\frac{e^{-h t_f} - 1}{1-a} \right]$$

$h = q_n/3600$

a = load factor $= q_n/L$

L = minor street capacity