#11-3181: Design of Intergreen Times Based on Safety Reliability

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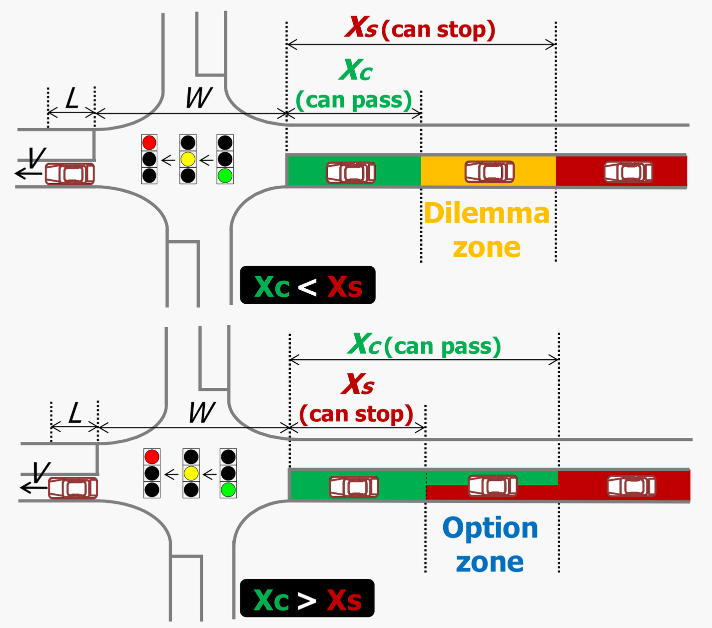
1. Background and Problem Statement

☐ Conventional intergreen time design (*Gazis, D., Herman, R., and Marududin, A., 1960*)



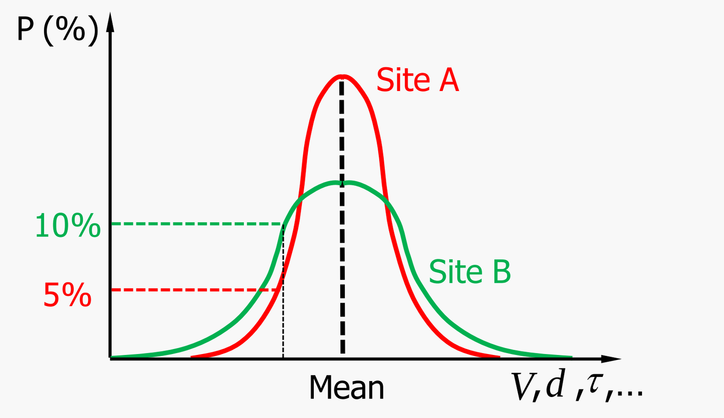
$$X_c = IV - (W + L)$$

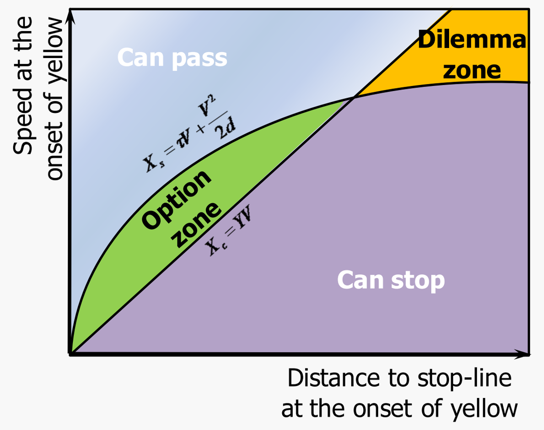
$$X_s = \tau V + \frac{V^2}{2d}$$

$$I = \tau + \frac{V}{2d} + \frac{W + L}{V}$$

Y   AR

- Insufficient consideration of traffic flow randomness
- Ignoring driver decision randomness at the onset of yellow





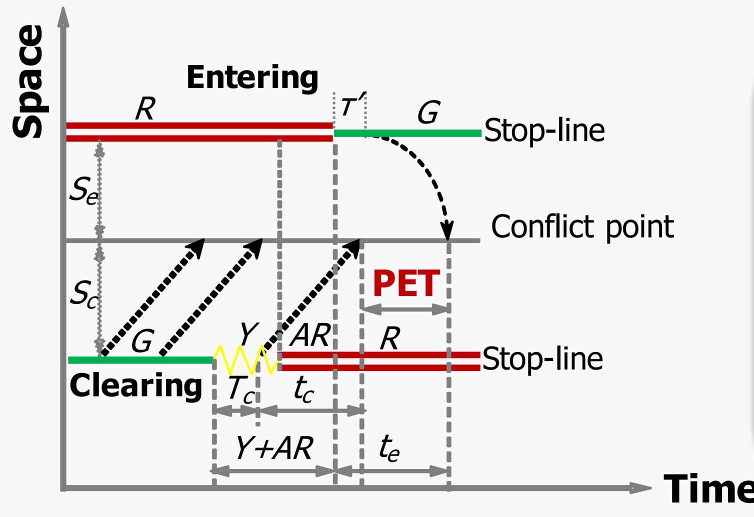
2. Objective

To develop a safety reliability based intergreen design method, enabling to account for the randomness of traffic and driver decision

3. Methodology

☐ Safety reliability = Occurring probability of risky behavior at the change of phases

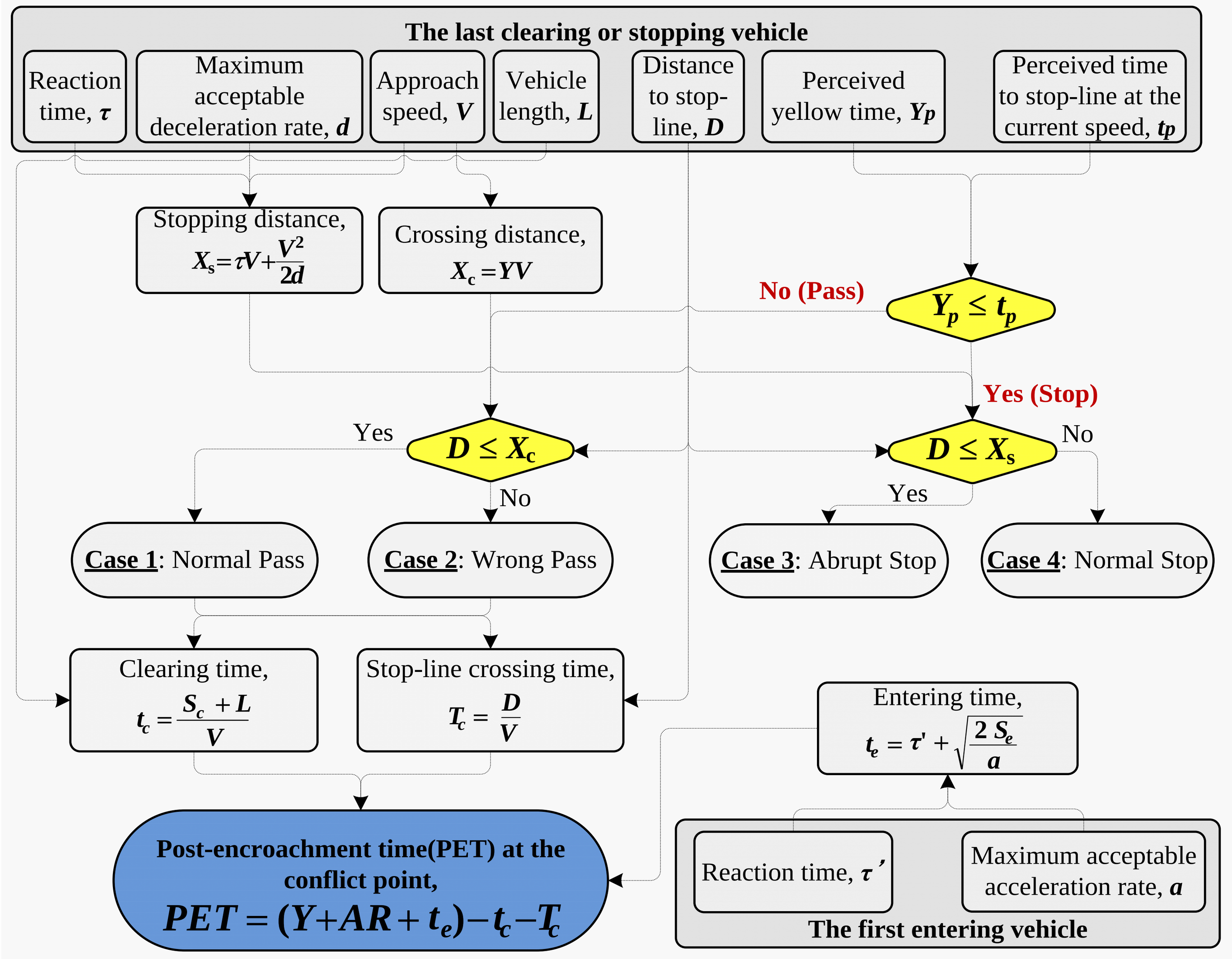
- Risky behavior related to yellow time design
  - ✓ Abrupt stop → rear-end collision, etc.
  - ✓ Red-light-running → right-angle collision, etc.
- Risky behavior related to all-red time design
  - ✓ Clearance failure (PET<1s) → right-angle collision, etc.



$$PET = (Y + AR + t_e) - t_c - T_c$$

Where,
PET=post-encroachment time;
Y=yellow time;
AR=all-red time;
t_e=entering time;
t_c=clearance time;
T_c=entry time of the last clearing vehicle.

☐ Estimation procedure of safety reliability



- Red-light-running (Case 2, P_2) occurs if
  - ✓ Perceived yellow time, $D >$ Perceived time to stop-line, X_c
  - ✓ Distance to stop-line, $Y_P >$ Crossing distance, t_P

$$P_2 = P(Y_P > t_P \cap D > X_C)$$

$$Y_P = Y + \delta \qquad t_P = \frac{D}{V} + \eta \qquad f(D; D_u) = \frac{\lambda^D e^{-D_u}}{D!} \qquad X_c = Y \times V$$

$$f(\delta) = \frac{1}{\sqrt{2\pi\sigma_\delta^2}} e^{-\frac{\delta^2}{2\sigma_\delta^2}} \qquad f(\eta) = \frac{1}{\sqrt{2\pi\sigma_\eta^2}} e^{-\frac{\eta^2}{2\sigma_\eta^2}} \qquad f(V) = \frac{1}{\sqrt{2\pi\sigma_V^2}} e^{-\frac{(V-\mu_V)^2}{2\sigma_V^2}}$$

$$P_2 = \iiint_{(Y+\delta > \frac{D}{V}+\eta)\cap(D > Y\times V)} f(\delta, \eta, D, V) d_\delta d_\eta d_D d_V$$

- Abrupt stop (Case 3 , P_3) occurs if
  - ✓ Perceived yellow time, $Y_P <$ Perceived time to stop-line, t_P
  - ✓ Distance to stop-line, $D <$ Stopping distance, X_s

$$P_3 = \iiint_{(Y+\delta \le \frac{D}{V}+\eta)\cap(D \le \tau V + \frac{V^2}{2d})} f(\delta, \eta, D, V, \tau, d) d_\delta d_\eta d_D d_V d_\tau d_d$$

- Clearance failure (P_{cf}) occurs if PET<1.0s

$$PET = (Y + AR + t_e) - t_c - T_c$$

$$t_e = \tau' + \sqrt{\frac{2S_e}{a}} \qquad t_c = \frac{S_c + L}{V} \qquad T_c = \frac{D}{V}$$

$$f(\tau') = \frac{1}{\sqrt{2\pi\sigma_{\tau'}^2}} e^{-\frac{(\tau'-\mu_{\tau'})^2}{2\sigma_{\tau'}^2}} \qquad f(a) = \frac{1}{\sqrt{2\pi\sigma_a^2}} e^{-\frac{(a-\mu_a)^2}{2\sigma_a^2}}$$

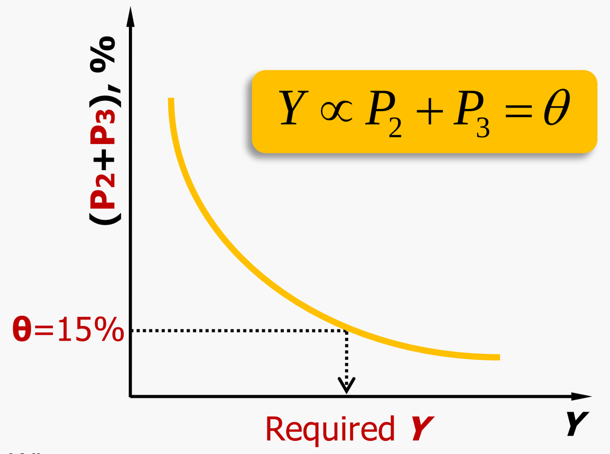
$$f(L) = \frac{1}{\sqrt{2\pi\sigma_L^2}} e^{-\frac{(L-\mu_L)^2}{2\sigma_L^2}} \qquad f(V) = \frac{1}{\sqrt{2\pi\sigma_V^2}} e^{-\frac{(V-\mu_V)^2}{2\sigma_V^2}}$$

$$f(D; D_u) = \frac{\lambda^D e^{-D_u}}{D!} \qquad f(V) = \frac{1}{\sqrt{2\pi\sigma_V^2}} e^{-\frac{(V-\mu_V)^2}{2\sigma_V^2}}$$

$$P_{cf} = \iiint (Y + AR + t_e - t_c - T_c) d_\tau d_a d_L d_V d_D$$

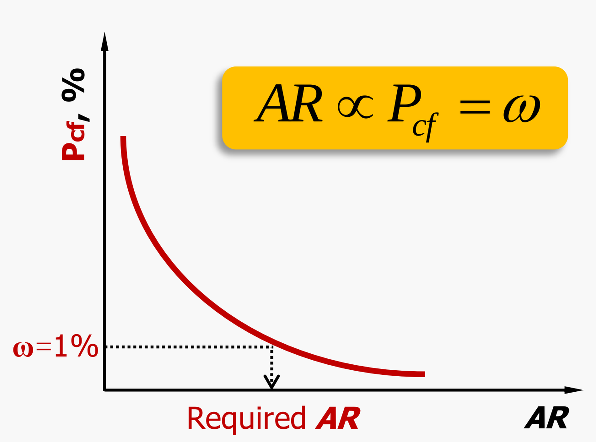
☐ Determination of intergreen times based on safety reliability

$$Y \propto P_2 + P_3 = \theta$$



Where,
P_2=Occurring probability of red-light-running;
P_3=Occurring probability of abrupt stop;
θ=Safety reliability index for the determination of yellow time, e.g., 15%.

$$AR \propto P_{cf} = \omega$$



Where,
P_{cf}=Occurring probability of clearance failure;
ω=Safety reliability index for the determination of yellow time, e.g., 1%.

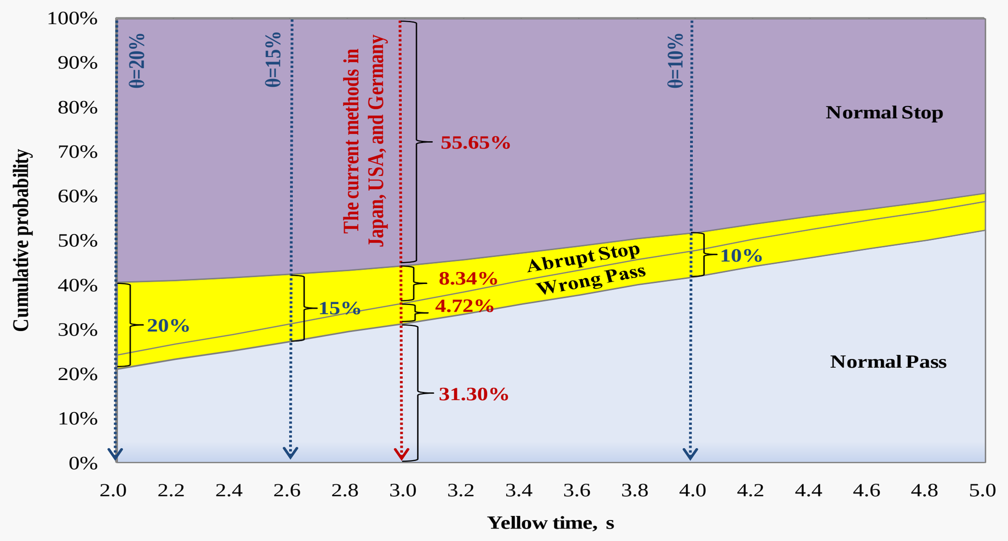
4. Validation of the Proposed Method

☐ Uncertainty analysis of input variables

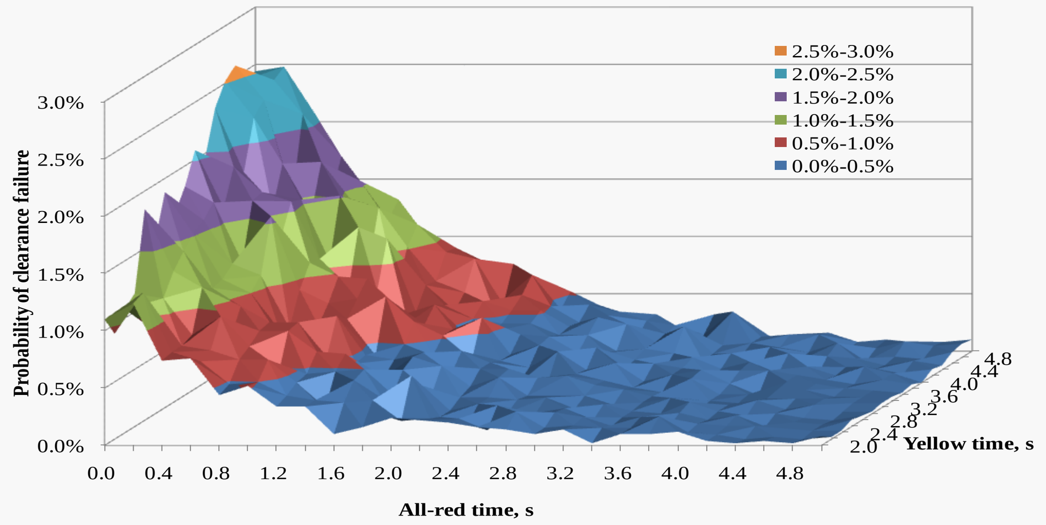
	Variables	Distribution	Mean	Std.dev
The last clearing or stopping vehicle	t, [s]	Normal	0.70	0.21
	V, [km/h]	Normal	50.00	15.00
	d, [m/s²]	Normal	3.00	0.90
	D, [m]	Poison	60.00	60.00
	S_c, [m]	Constant	40.00	/
	L, [m]	Normal	4.50	1.35
	δ, [s]	Normal	0.00	0.20×Y
	η, [m]	Normal	0.00	0.20×D/V
The first entering vehicle	t', [s]	Normal	1.76	0.53
	a, [m/s²]	Normal	2.27	0.68
	S_e, [m]	Constant	20.00	/

☐ Impacts of the yellow time on the occurring probability of risky behavior

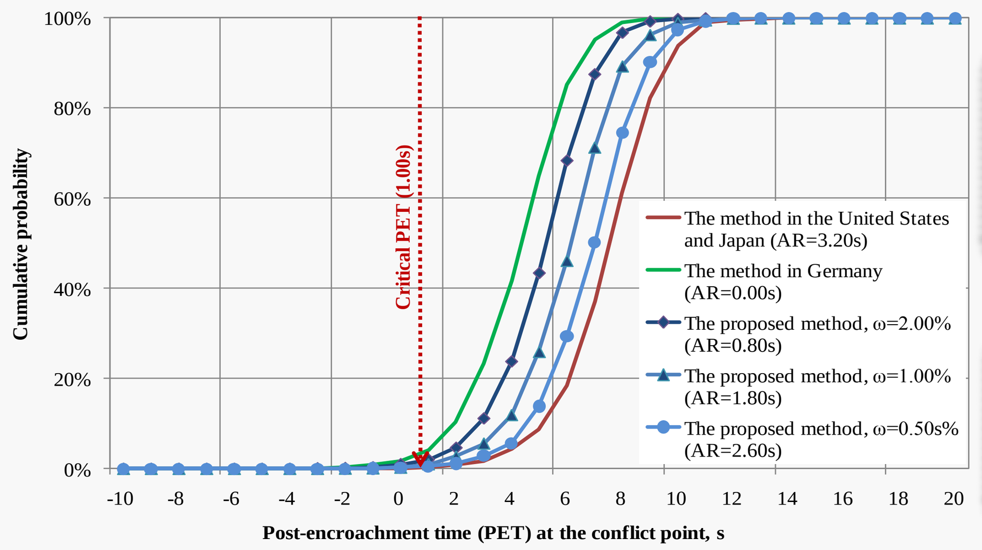
- The relationship between yellow time and the occurring probability of risky behavior



- The relationship between intergreen times and the clearance failure probability



- Comparison of the estimated PET distributions for the all-red times based on the proposed method and the current methods in the United States, and Germany



U.S.A

$$AR = \frac{W + L}{V}$$

W=intersection width;
L=vehicle length;
V=clearing speed.

Germany

$$AR = t_c - t_e$$

t_e=entering time;
t_c=clearance time;

8. Conclusions and Future Works

☐ Conclusions

- A safety reliability based intergreen time design method was proposed, which is able to account for not only traffic randomness but also driver decision error at the onset of yellow.
- Occurring probability of risky behavior and clearance failure was investigated for a set of ordinary conditions (V=50km/h) and compared with that of conventional dilemma zone.
  - ✓ θ=10%, Y=4.0s; θ=15%, Y=2.6s; θ=20%, Y=2.0s;
  - ✓ ω=0.5%, AR=2.6s; ω =1.0%, AR=1.8s; ω =2.0%, AR=0.8s;

☐ Future Works

- A closed-form solution for the proposed method
- Correlations of input variables → impacts of long intergreen times
- Extension of Monte Carlo Simulations → approach speed (15km/h~100km/h)