SAFE-FOLLOWING DISTANCES BASED ON THE CAR-FOLLOWING MODEL

Department of Highways
Thailand

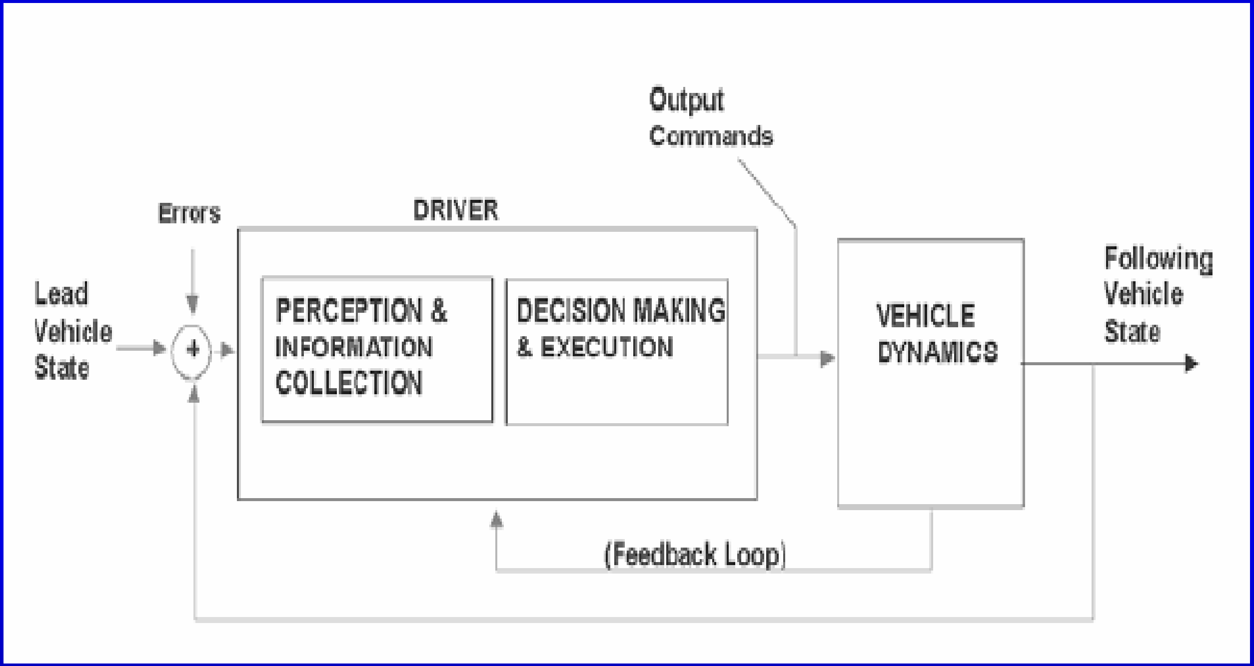
Overview

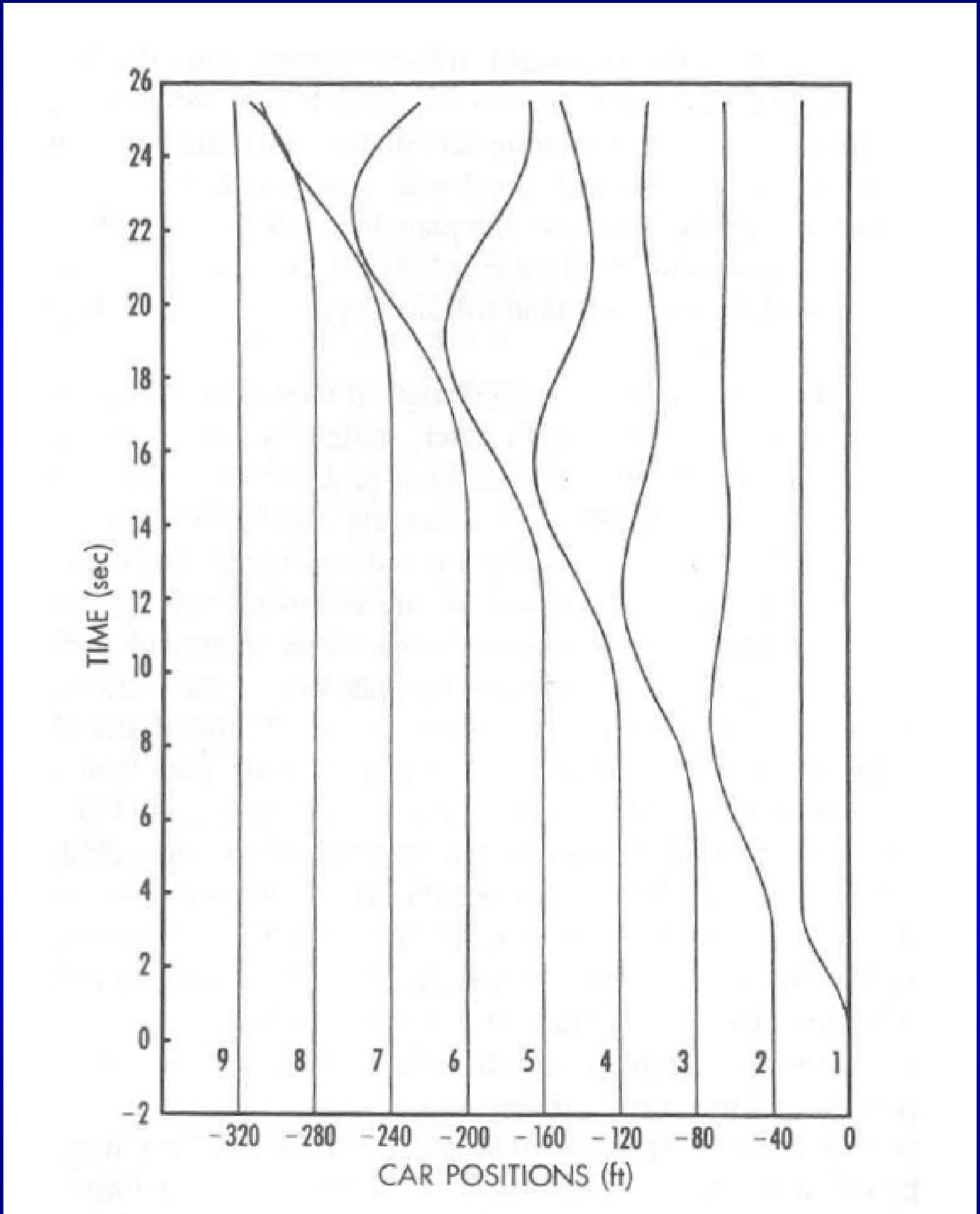
- Introduction
- Methodology
- Data Collection
- Results
- Conclusions

Introduction

- More than 100,000 traffic accidents per year (12,000 deaths).
- Rear-end collisions ~ most common
- Aim of this research ~ reduce the severity and the number of road accidents.
- Derive safe following distance.
- Assist drivers with treatment marking.

Driving Task



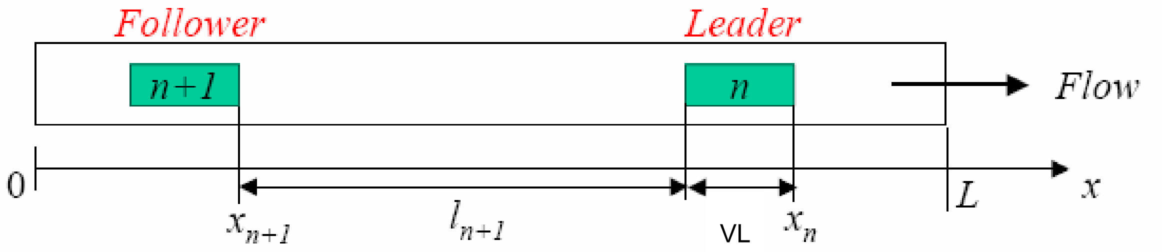


Traffic Stability

- 1st decelerates.
- Others react.
- 7th and 8th collide.

Car-Following

- Notation:



- $x_n(t) - x_{n+1}(t)$ = spacing (space headway) $= l_{n+1}(t) +$ VL
- speed of vehicle n : $\dfrac{dx_n(t)}{dt} = \dot{x}_n(t)$
- acceleration (decceleration) of vehicle n : $\dfrac{d\dot{x}_n(t)}{dt} = \dfrac{d^2 x_n(t)}{dt} = \ddot{x}_n(t)$
- $\dot{x}_n(t) - \dot{x}_{n+1}(t) = \dot{l}_{n+1}(t)$

GM 5th Car-Following

$$\ddot{x}_{n+1}(t+T) = \frac{\alpha[\dot{x}_{n+1}(t+T)]^m}{[x_n(t) - x_{n+1}(t)]^l}\{\dot{x}_n(t) - \dot{x}_{n+1}(t)\}$$

where $\ddot{x}_{n+1}(t+T)$ is the acceleration of the n + 1 th car at time t + T
$\dot{x}_{n+1}(t+T)$ is the velocity of the n + 1 th car at time t + T
$x_n(t)$ is the distance of the n th car at time t
$x_{n+1}(t)$ is the distance of the n + 1 th car at time t
$\dot{x}_n(t)$ is the velocity of the n th car at time t
$\dot{x}_{n+1}(t)$ is the velocity of the n + 1 th car at time t
α is the sensitivit y factor
m, l are constant

Methodology

- Calibrate the car-following model
- Analyze stability condition
- Derive safe following distance

Methodology

- Convert GM5th => Traffic Stream Model

$$v = v_f \cdot \left[1 - \left(\frac{k}{k_j} \right)^{\gamma - 1} \right]^{\frac{1}{1-\beta}}$$

Methodology

- Introduce error terms

$$v_i = v_f \cdot \left[1 - \left(\frac{k_i}{k_j}\right)^{\gamma-1}\right]^{\frac{1}{1-\beta}} + \varepsilon_i$$

$$\varepsilon_i \sim N[0, \sigma^2]$$

$$f(\varepsilon_i) = \frac{1}{\sqrt{2\pi\sigma^2}} \cdot e^{-\frac{1}{2\sigma^2}\varepsilon_i^2}$$

- Log-likelihood

$$\ln L(\beta, \gamma, v_f, k_j, \sigma^2) = -\frac{N}{2}\ln(2\pi\sigma^2) - \frac{1}{2\sigma^2} \cdot \sum_{i=1}^{N}\left[v_i - v_f\left[1 - \left(\frac{k_i}{k_j}\right)^{\gamma-1}\right]^{\frac{1}{1-\beta}}\right]^2$$

Stability Condition

- The Governing Equation of the car following model

$$\ddot{x}_{n+1}(t+T) = \frac{\alpha[\dot{x}_{n+1}(t+T)]^m}{[x_n(t) - x_{n+1}(t)]^l}\{\dot{x}_n(t) - \dot{x}_{n+1}(t)\}$$

- Perturb the equilibrium solution with a small deviation term

$$X_n(t) = b \cdot n + v \cdot t + \varepsilon(n,t)$$ where $$\varepsilon(n,t) = f_n \cdot e^{i\omega t}$$

Stability Condition

$$\frac{\alpha \cdot [v]^{\beta}}{b^{\gamma}} \cdot T \leq \frac{1}{2}$$

Where v = prevailing speed

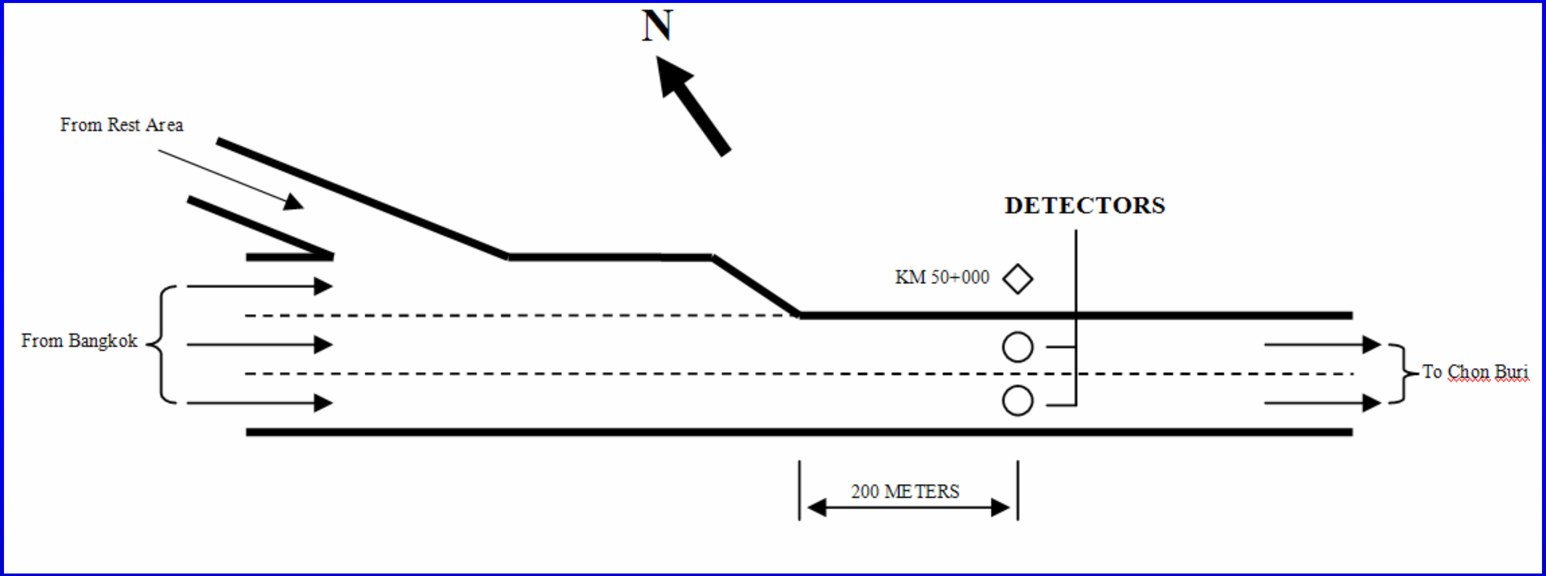
T = reaction time

b = distance headway

Case Study

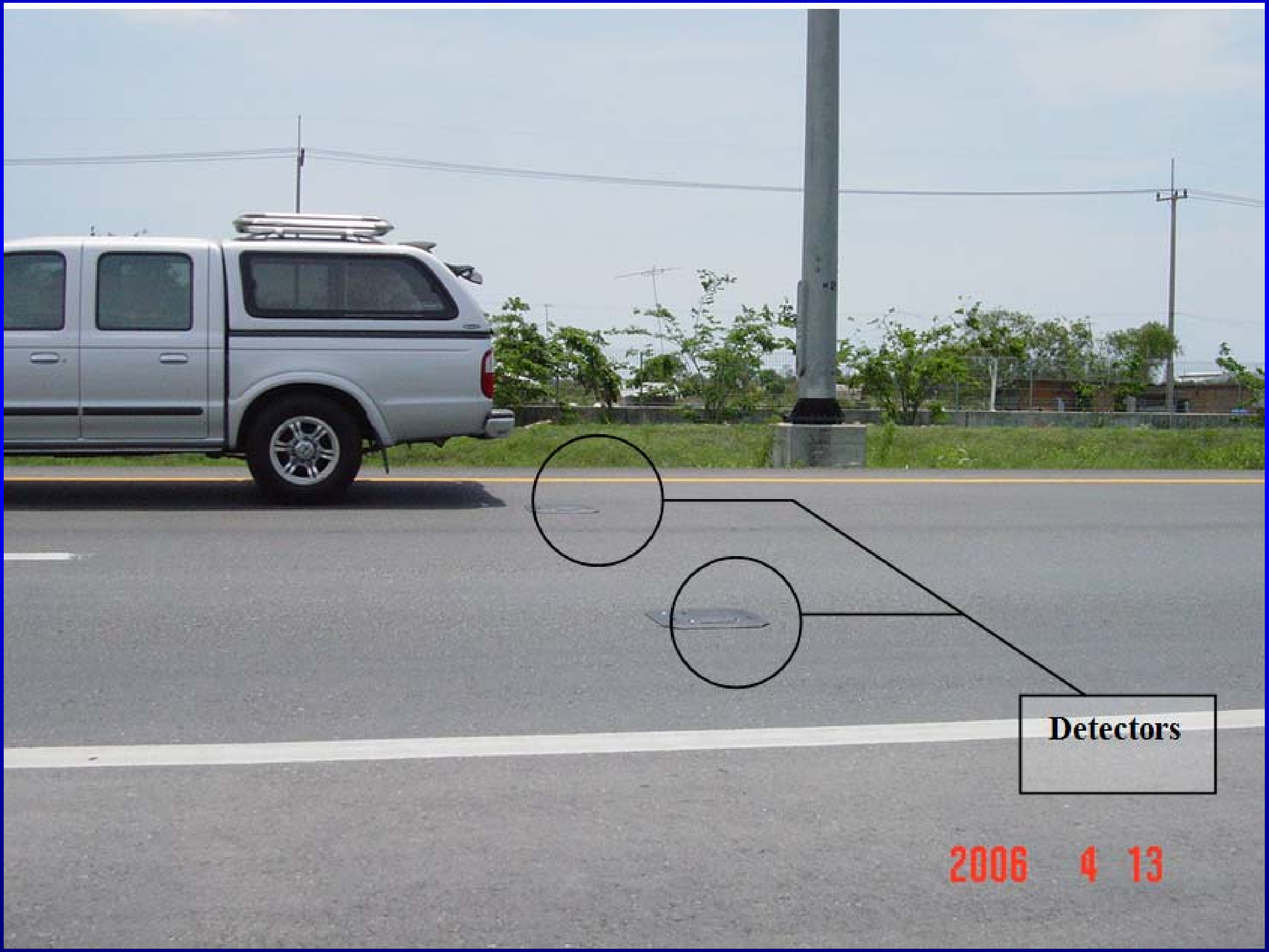
- National Highway 7 (Chon Buri Motorway)
- Located at km 50+000 toward Chon Buri
- Traffic volumes ~heavy during weekend morning and afternoon peak periods (ADT ~ 60,000)

Study Site


N
From Rest Area
DETECTORS
KM 50+000
From Bangkok
To Chon Buri
200 METERS

Study Site

Detector Placement



Calibration Result

Parameter	Mean	Standard Error	t-ratio
σ^2	33.646	2.238	15.034
v_f	95.716	0.080	1,196.450
k_j	116.067	1.482	78.318
γ	4.510	0.042	107.143
β	0.990	0.00002	49500.000

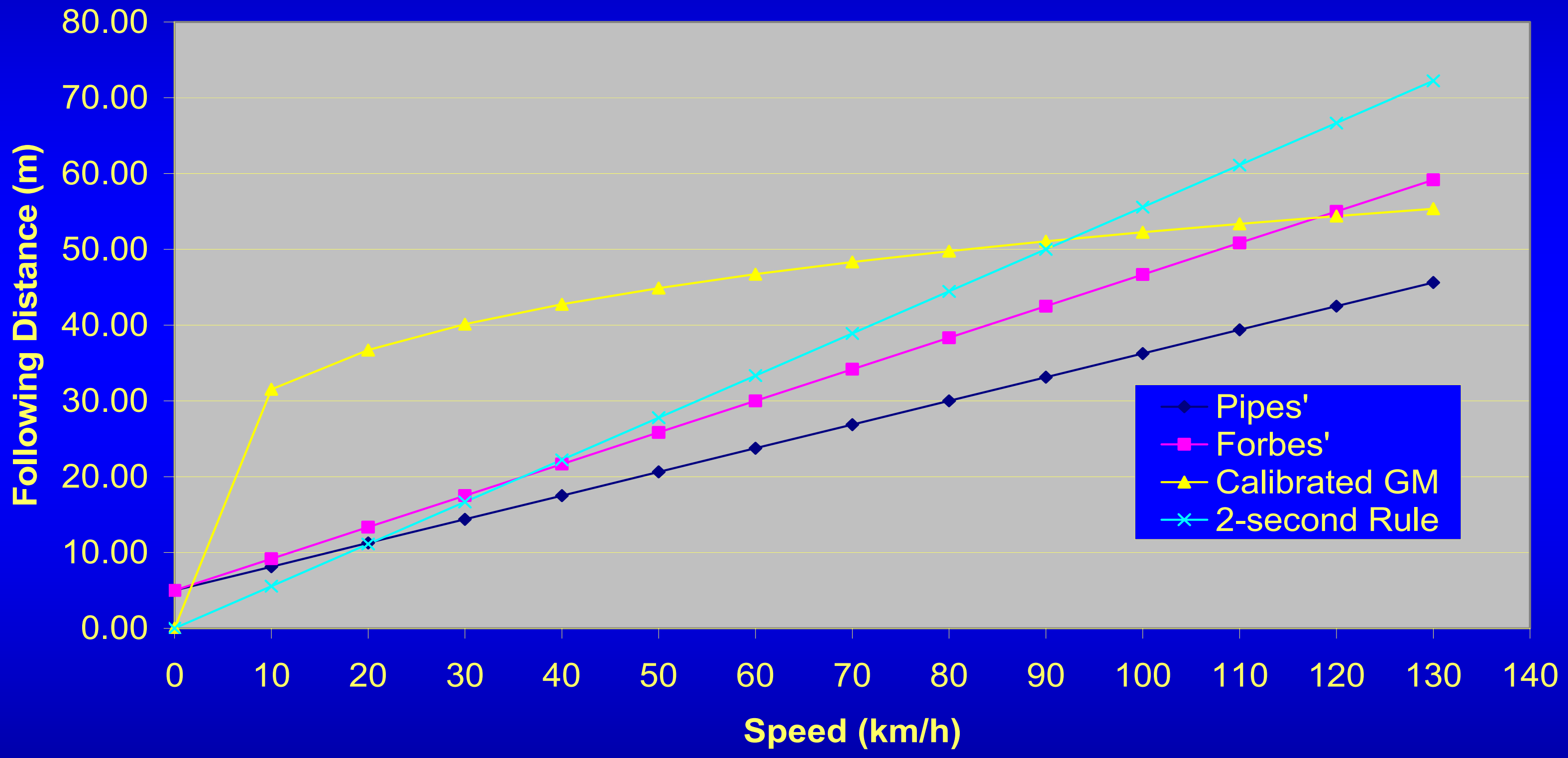
Comparison of Recommended Following Distances

Speed (km/h)	Safe Following Distance (m)			
	Pipes'*	Forbes'*	Calibrated GM	2-second Rule
80	30.00	38.33	***49.76***	44.44
90	33.13	42.50	***51.06***	50.00
100	36.25	46.67	***52.26***	55.56
110	39.38	50.83	***53.36***	61.11
120	42.50	55.00	***54.39***	66.67
130	45.63	59.17	55.35	72.22

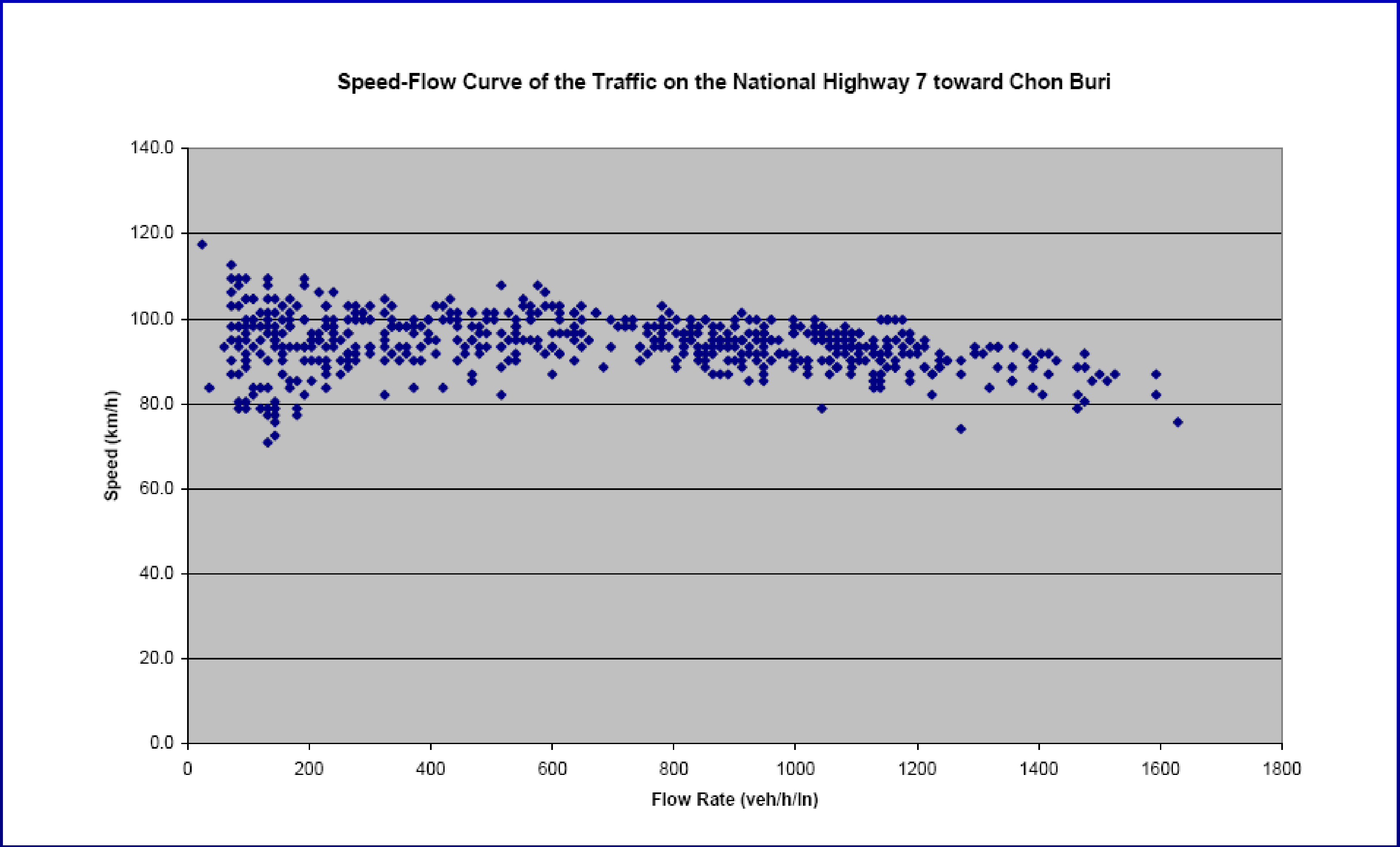
* Assume average vehicle length of 5 meters.

Recommended following distances (highlighted)

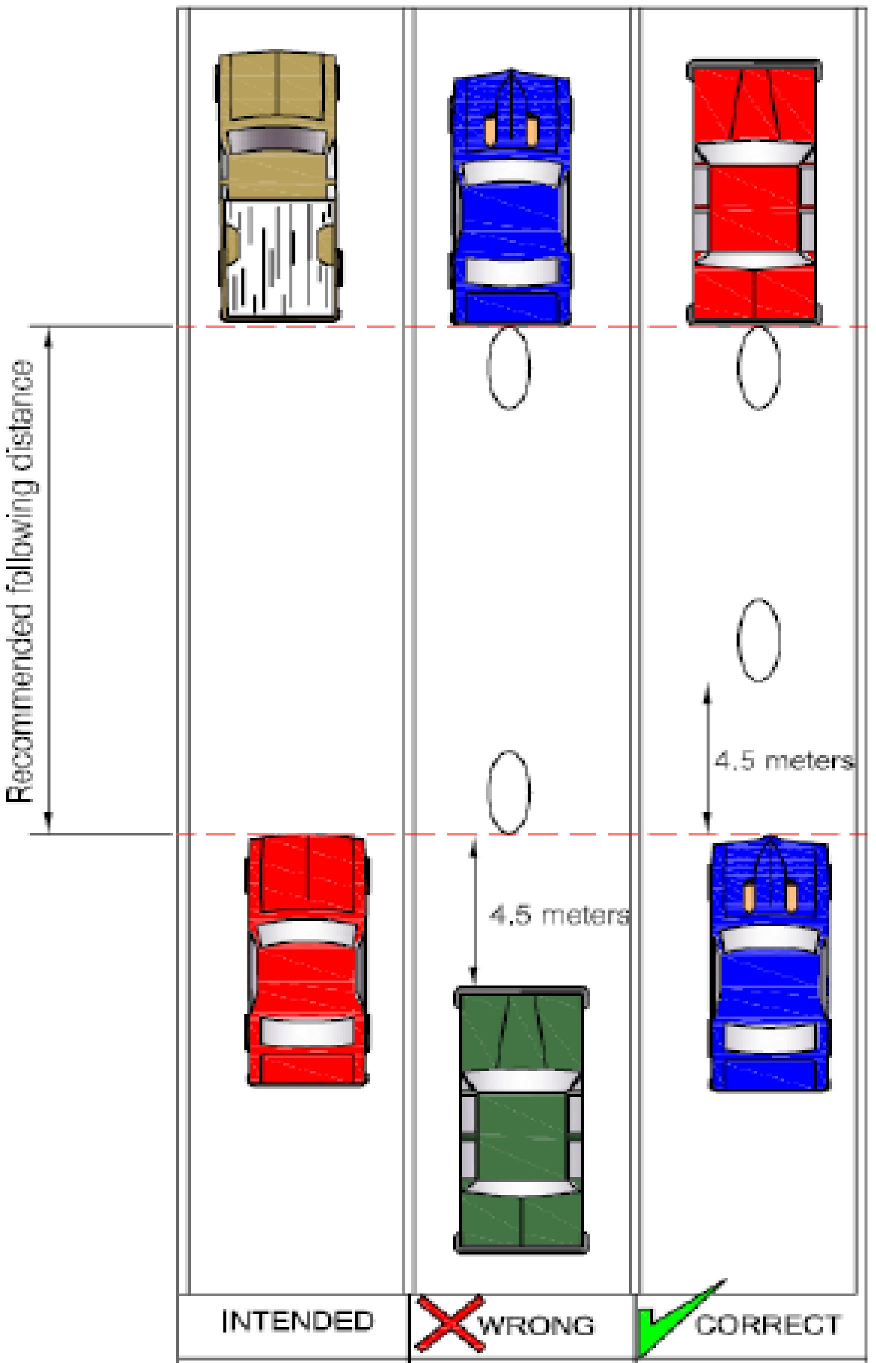
Following Distances Based on Different Car-Following Models



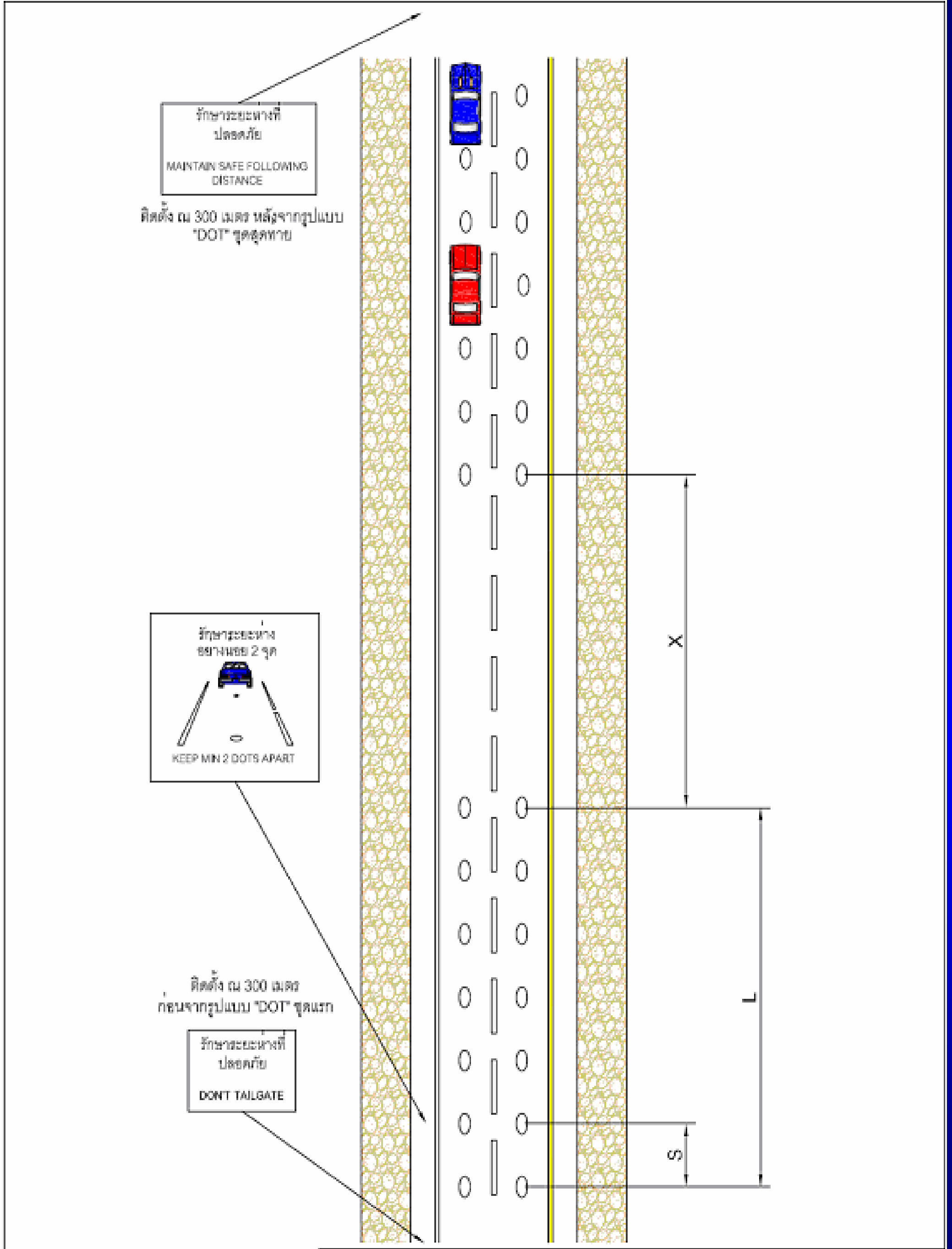
Speed-Flow Curve



"DOT" Tailgating Treatment

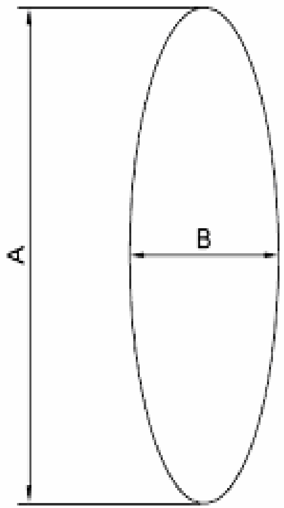


Sign and Pattern Layout



Typical "DOT" Marking

"DOT" Tailgating Treatment



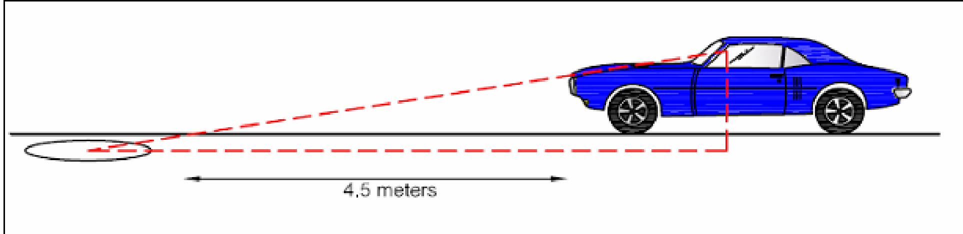
Width:Length = 1:3 ratio*

Typical Marking

Alternative	A (m)	B(m)	Area (sq m)
Motorway	2.25	0.75	1.33

*Based on standard oblong pavement markings referenced in the MUTCD

VEHICLE GEOMETRY INVOLVED



When vehicles approach the "DOT" and the driver perceives his vehicle as touching the first marking the front of the vehicle is actually 4.5 meters away from it as show here.

Comprehension Time	:	5	sec
P/R Time	:	2.5	sec
Adjustment Time	:	20	sec
Effective Time	:	60	sec
Vehicle Correction	:	4.5	meters
Vehicle Legth	:	5.0	meters

Posted Speed (km/h)	Recommended Following Distance (meters)	S Marking Spacing (meters)	Minimum Marking in Pattern	L Min Pattern Length (meters)	X Pattern Spacing (meters)	Capacity (pc/ln/hr)
80	50	41	15	574	1300	1440
90	52	43	16	645	1500	1560
100	53	44	18	748	1600	1700
110	54	45	19	810	1800	1830
120	55	46	20	874	2000	1960

* Remark

1. If the observed volume exceeds the capacity provided in this table, the "DOT" tailgating treatment should not installed.
2. The "DOT" tailgating treatment should only be installed to the location where rear-end collisions due to aggressive driving behaviors are frequent.

CONCLUSIONS

- MLE => calibrate => GM 5th car-following model
- Assist drivers => Following distance for speed range 80 - 120 km/h

FUTURE RESEARCH

- More Data Collection
- Reaction Time => determination
- More Field Applications => validation

THANK YOU