isttt
international symposium transportation & traffic theory

ISTTT20
Noordwijk
the Netherlands
July 17-19, 2013

Modeling Dynamics of Dilemma Zones by Formulating Dynamical Contributing Factors with Video-observed Trajectory Data

Zhixia Li, Ph.D., Assistant Researcher, University of Wisconsin-Madison
Heng Wei, Ph.D., P.E., Associate Professor, University of Cincinnati

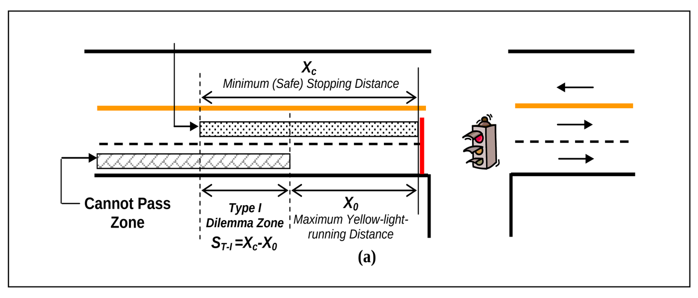
THE UNIVERSITY of WISCONSIN MADISON
UNIVERSITY OF Cincinnati

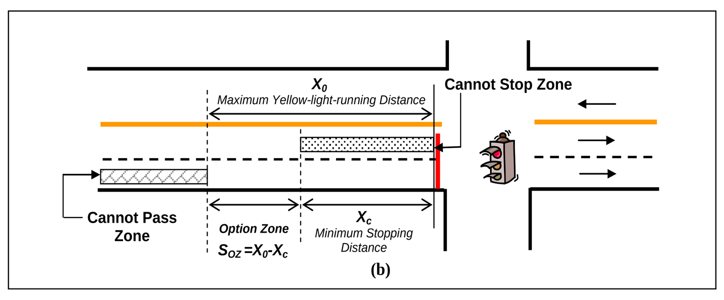
Introduction

Dynamics of Dilemma Zone

- Gazis et al. defined the dilemma zone (DZ) as the distance between the minimum safe stopping distance X_c and the maximum yellow-light-running distance X_0.

Type I DZ — **OZ**





- Type I DZ: $X_c > X_0$: hazardous; could be eliminated by a long enough yellow time.
- Option Zone (OZ): $X_0 > X_c$: drivers in OZ still experience indecisiveness, which contributes to crashes; longer when yellow time is longer.

$$X_c = V_0\delta_2 + \frac{V_0^2}{2a_2} \qquad X_0 = V_0\tau - W - L + \frac{1}{2}a_1(\tau-\delta_1)^2$$

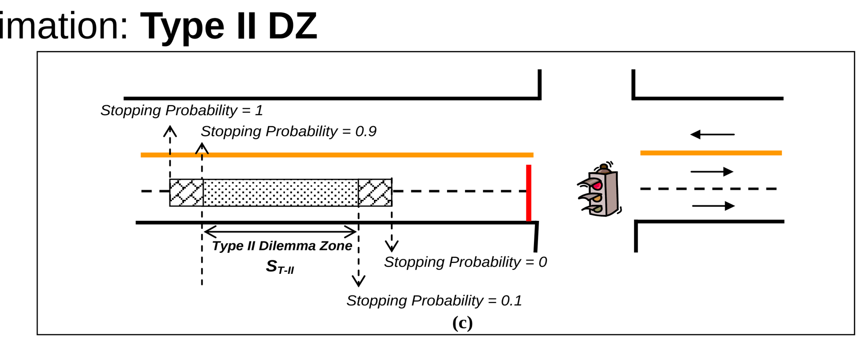
Where,

V_0 is vehicle's speed (ft/s); δ_1 is minimum perception-reaction time (PRT) for passing (s); δ_2 is minimum PRT for stop (s); a_1 is maximum acceleration rate for passing (ft/s²); a_2 is maximum deceleration rate for stop (ft/s²); τ is duration of yellow interval (s); W is intersection width (ft); and, L is vehicle length (ft).

- **Dynamics of dilemma zone**: reflected by ***the dynamical characteristics of the driver-vehicle complex***; the dynamics have not yet been fully revealed and modeled.

Compromised Alternatives to Estimating Dilemma Zone

- Factors that are associated with the ***dynamical characteristics of the driver-vehicle complex***: δ_1, δ_2, a_1, and a_2.
- In practice, there has been a lack of quantitative knowledge of the above four factors.
- Compromised way were used to estimate the dilemma zone:
  - **Assumed constant values** for δ_1, δ_2, a_1, and a_2. (FHWA, ITE)
    - Constant values are not dynamic per se.
  - Probabilistic definition to facilitate estimation: **Type II DZ**
    - Stopping probability [0.1, 0.9];
    - Simple computation;
    - Not reflecting true DZ dynamics.



Research Objective

- Model the dilemma zone dynamics by formulating the dynamical contributing factors δ_1, δ_2, a_1, and a_2;
- Update the exiting dilemma zone model to incorporate the dilemma zone dynamics;
- Validate and evaluate the accuracy of the dynamical dilemma zone model.

Tentative Dynamical Dilemma Zone Model

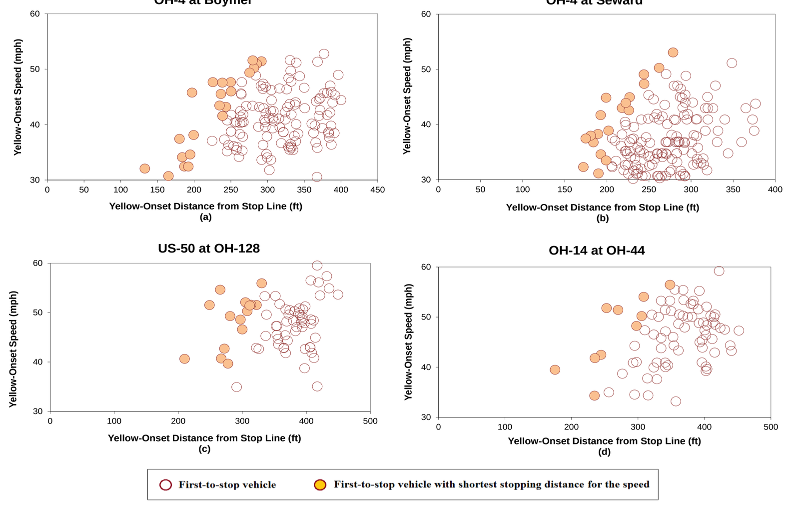
- The Dynamical model is based on the original GHM model, but assumes the dilemma zone to be **vehicle-specific** and **site-specific**. An individual vehicle has its own dilemma zone boundaries, which is determined by:
  - The individual vehicle's speed V_0;
  - The approach's 85th percentile speed V_{85th}; and potentially,
  - The duration of the yellow interval τ.
- The dilemma zone contributing factors, δ_1, δ_2, a_1, and a_2, are assumed to be dynamical as functions of V_0, V_{85th}, τ.

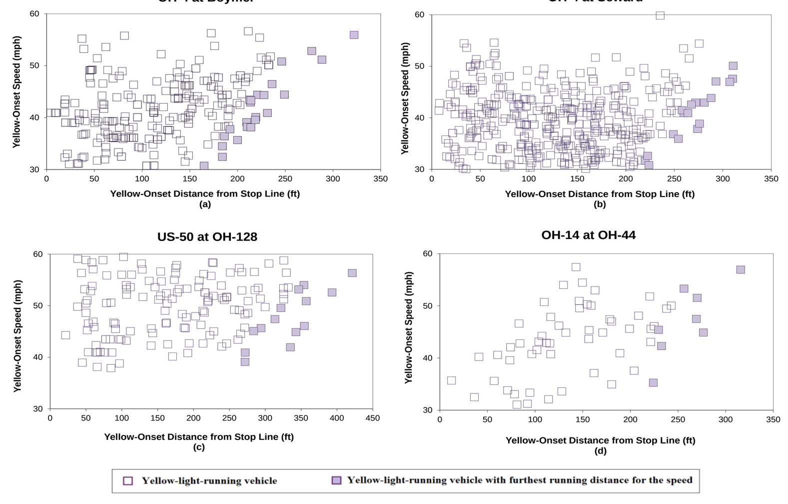
$$\delta_1 = f(V_0, V_{85th}, \tau) \qquad a_1 = f(V_0, V_{85th}, \tau)$$

$$X_c = V_0\delta_2 + \frac{V_0^2}{2a_2} \qquad X_0 = V_0\tau + \frac{1}{2}a_1(\tau-\delta_1)^2 \qquad \delta_2 = f(V_0, V_{85th}, \tau) \qquad a_2 = f(V_0, V_{85th}, \tau)$$

Data Collection and Analysis Dataset Preparation

- Conducted at 4 high speed signalized intersections in Ohio, US with various V_{85th} and τ.
- Software program VEVID used to extract vehicle's yellow-onset speed, acceleration rate for passing or deceleration rate for stopping, and driver's PRT for stopping.
- Collected trajectory data of 1445 vehicles (speed ≥ 30 mph (48 km/h)).





Preparing Datasets for Modeling δ_1, δ_2, a_1, and a_2

- **Solid circles** represent vehicles with the shortest stopping distance at different speeds; their deceleration rate and PRT correspond to a_2 and δ_2, respectively.
  - Number of samples in the dataset for modeling a_2 and δ_2 is 44 (from 3 study sites).
  - Dataset of 22 samples from the rest study site were reserved for validating the a_2 and δ_2 models.
- **Solid squares** represent vehicles with the furthest yellow passing distance at different speeds; their acceleration rate and PRT correspond to a_1 and δ_1, respectively.
  - As δ_1 is hard to be accurately collected, it is assumed that $\delta_1 = \delta_2$.
  - Number of samples in the dataset for modeling a_1 is 41 (from 3 study sites).
  - Dataset of 23 samples from the rest study site were reserved for validating the a_1 model.

Modeling the Dynamics

Modeling δ_2

Step 1: Identification of factors impacting δ_2

Based on results from the linear regression analyses, the yellow-onset speed (V_0) is the only statistically significant factor to impact δ_2.

Linear Regression Analysis [a, b]		B	Std. Error	t	Sig. (p-value)
Analysis 1	Constant	1.463	0.353	4.142	0.000
	V_0 (mph)	-0.017	0.007	-2.619	0.012
	V_{85th} (mph)	0.005	0.007	0.736	0.466
Analysis 2	Constant	1.610	0.524	3.072	0.004
	V_0 (mph)	-0.015	0.006	-2.548	0.015
	τ (s)	0.007	0.108	0.061	0.951

a. Dependent Variable: δ_2; b. Sample Size: 44.

Candidate Regression Models [a, b]	Model Summary				Parameter Estimates	
	R^2	F	Sample Size	Sig. (p-value)	Constant	Coefficient
Linear	0.138	6.745	44	0.013	1.637	-0.015
Logarithmic	0.154	7.642	44	0.008	3.554	-0.682
Inverse	0.170*	8.626	44	0.005	0.274	30.392
Power	0.126	6.049	44	0.018	14.952	-0.734
S	0.136	6.583	44	0.014	-0.816	32.263
Exponential	0.116	5.527	44	0.023	1.918	-0.016

a. Dependent Variable: δ_2; b. Independent Variable: V_0; * indicates the highest R^2

Step 2: Formulation of δ_2

Based on the results from the model-fit test, inverse model is identified as the best-fit model.

$$\delta_1 = \delta_2 = f(V_0) = 0.274 + \frac{30.392}{V_0}$$

Modeling a_2

Step 1: Identification of factors impacting a_2

V_0 and V_{85th} are the factors that significantly impact a_2, while τ is not.

Step 2: Formulation of a_2

$$a_2 \sim \exp(b_0 + \frac{b_1}{V_0}) \qquad a_2 \sim b_2 + \frac{b_3}{V_{85th}} \qquad a_2 = f(V_0, V_{85th}) = \exp(b_0 + \frac{b_1}{V_0}) + b_2 + \frac{b_3}{V_{85th}}$$

$$a_2 = f(V_0, V_{85th}) = \exp(3.572 + \frac{-25.013}{V_0}) - 17.855 + \frac{480.558}{V_{85th}}$$

$$R^2 = 0.637$$

Modeling a_1

Step 1: Identification of factors impacting a_1

V_0 ,V_{85th}, and τ are the factors that significantly impact a_2. Considering that V_{85th} and τ are highly correlated as in practice τ is usually determined by V_{85th}, V_{85th} was selected as the second variable in the model of a_1 in addition to V_0 .

Step 2: Formulation of a_1

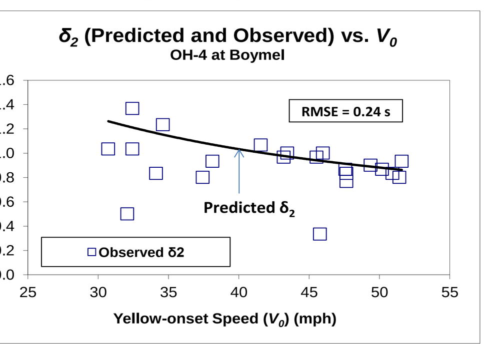
$$a_1 \sim b_0 + \frac{b_1}{V_0} \qquad a_1 \sim b_2 \cdot V_{85th} + b_3 \qquad a_1 = f(V_0, V_{85th}) = b_0 + \frac{b_1}{V_0} + b_2 \cdot V_{85th}$$

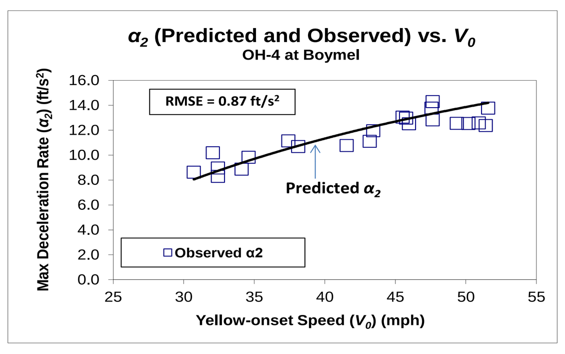
$$a_1(V_0, V_{85th}) = -23.513 + \frac{658.948}{V_0} + 0.223 \cdot V_{85th}$$

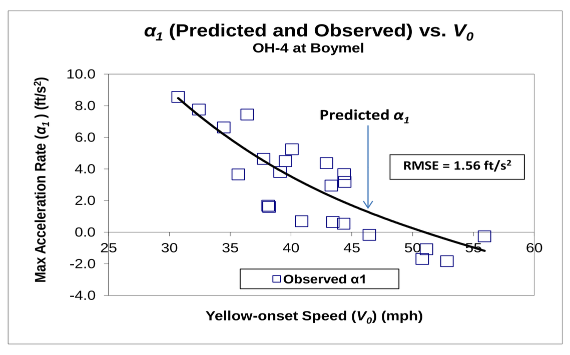
$$R^2 = 0.774$$

Validating the δ_2, a_1, and a_2 Models

- Independent datasets from the fourth study site were used in the validation.
- RMSEs between the predicted and observed values were computed as the performance measure indicating the prediction accuracy.







- **Result**: low to acceptable RMSEs were obtained, which validated the models.

Final Form of the Dynamical Dilemma Zone Model

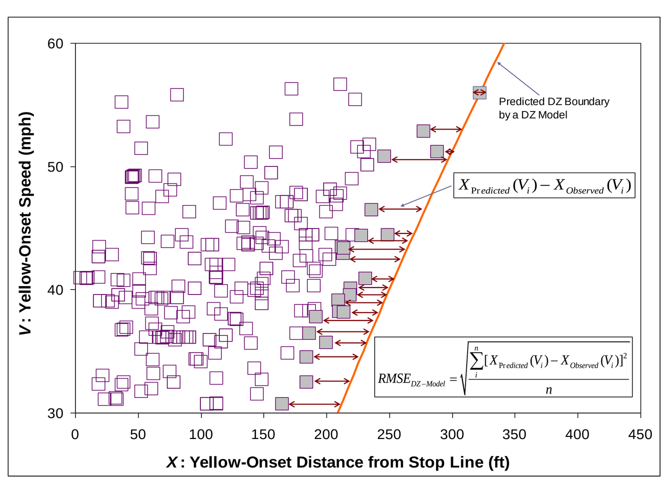
$$X_c = V_0\delta_2(V_0) + \frac{V_0^2}{2a_2(V_0, V_{85th})} \qquad \delta_1(V_0) = \delta_2(V_0) = f(V_0) = 0.274 + \frac{30.392}{V_0} \qquad a_2(V_0, V_{85th}) = f(V_0, V_{85th}) = \exp(3.572 + \frac{-25.013}{V_0}) - 17.855 + \frac{480.558}{V_{85th}}$$

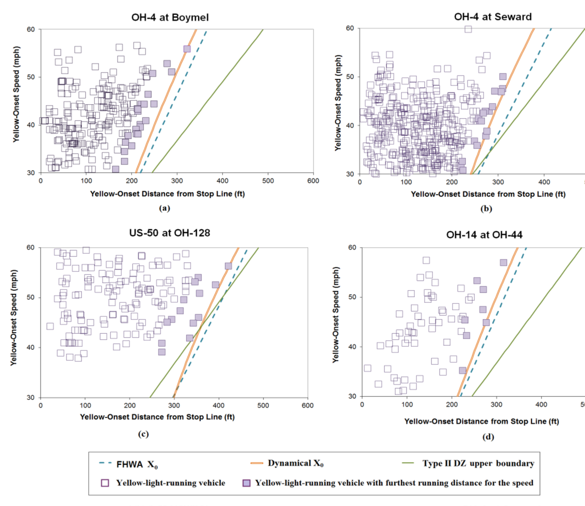
$$X_0 = V_0\tau + \frac{1}{2}a_1(V_0, V_{85th})[\tau - \delta_1(V_0)]^2 \qquad a_1(V_0, V_{85th}) = f(V_0, V_{85th}) = -23.513 + \frac{658.948}{V_0} + 0.223 \cdot V_{85th}$$

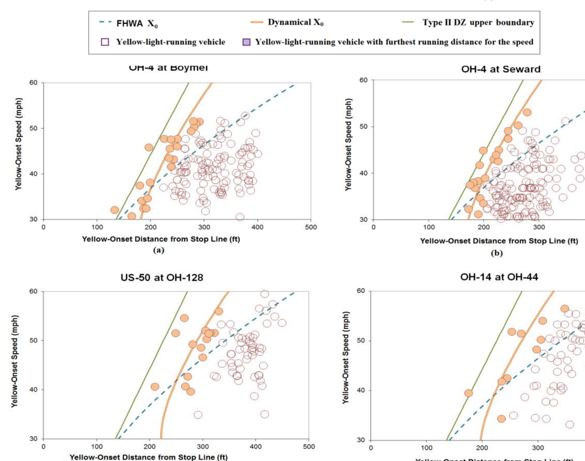
Evaluation of the Dynamical Dilemma Zone Model

- Compare the dynamical DZ model to the traditional DZ model (constant δ_1, δ_2, a_1, and a_2 values recommended by FHWA) and the Type II DZ Model (calibrated using the observed trajectory data).
- **Performance Indicator:** Root-mean-square error (RMSE) that measures the horizontal deviation between the predicted DZ boundary and the observed DZ boundaries represented by the observed minimum stopping distance and the maximum yellow-light-running distance.

$$RMSE_{DZModel} = \sqrt{\frac{\sum_i^n [X_{Predicted}(V_i) - X_{Observed}(V_i)]^2}{n}}$$







	Alternative Dilemma Zone Model	US-50 @ OH-128 (ft (m))	OH-4 @ Boymel (ft (m))	OH-4 @ Seward (ft (m))	OH-14 @ OH-44 (ft (m))
RMSE for Prediction of the Lower DZ Boundary (ft (m))	Dynamical X_c Model	26.6 (8.1)	20.3 (6.2)	12.4 (3.8)	28.9 (8.8)
	FHWA X_c Model	62.4 (19.0)	52.4 (16.0)	53.2 (16.2)	64.7 (19.7)
	Calibrated Type II DZ Model	72.7 (22.2)	38.7 (11.8)	28.1 (8.6)	61.9 (18.9)
RMSE for Prediction of the Upper DZ Boundary (ft (m))	Dynamical X_0 Model	57.0 (17.4)	38.7 (11.8)	18.7 (5.7)	33.2 (10.1)
	FHWA X_0 Model	73.8 (22.5)	56.4 (17.2)	45.3 (13.8)	48.4 (14.8)
	Calibrated Type II DZ Model	71.3 (21.7)	121.1 (36.9)	66.1 (20.1)	129.9 (39.6)

- **Result:** When compared to the traditional DZ model, the dynamical DZ model reduces the predicting error by 62% and 34% for the prediction of the lower and upper boundaries, respectively.
- **Result:** When compared to the calibrated Type II DZ model, the dynamical DZ model reduces the predicting error by 56% and 62% for the prediction of the lower and upper boundaries, respectively.

Conclusions

- The dynamics of DZ have been modeled; and, the resulting models have been verified.
- The dynamical DZ model outperforms other existing DZ models in terms of prediction accuracy.