Traffic Sequence Charts (TSCs) and Criticality Metrics

Eric Yeats

Thomas Peikenkamp | Yang Gao

Criticality Metrics

- Established measures of danger for traffic situations
- Can be used to make inferences or decisions regarding a situation
- Criticality Metric applicability is situation-specific
- Criticality Metric formulas are model- and situation-specific

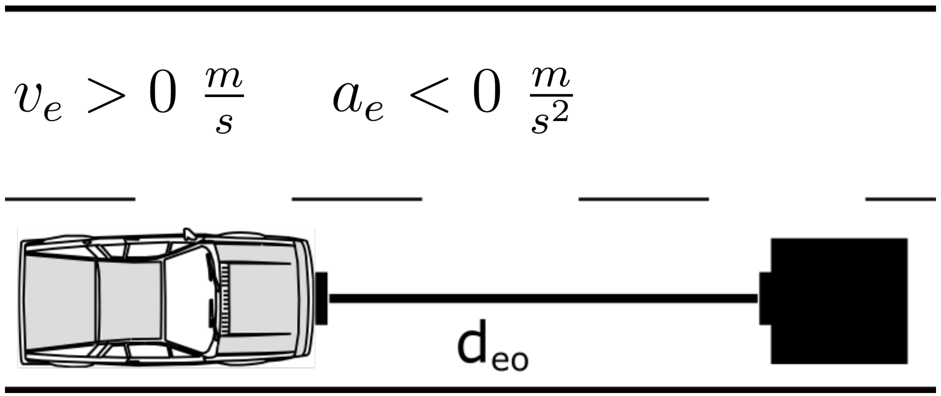
$$\mathrm{TTC}_i = \frac{X_{i-1}(t) - X_i(t) - l_i}{\dot{X}_i(t) - \dot{X}_{i-1}(t)}$$

$$\mathrm{PET} = t_2 - t_1$$

$$\mathrm{CI} = \frac{v^2}{\mathrm{TTC}}$$

Critical Metrics Applied to TSCs

- TSCs depict an abstract traffic scenario that can represent an infinite number of concrete evolutions
- Can pair a TSC with criticality metric equations for *ego*
- Infinite number of potential criticality outcomes for one TSC

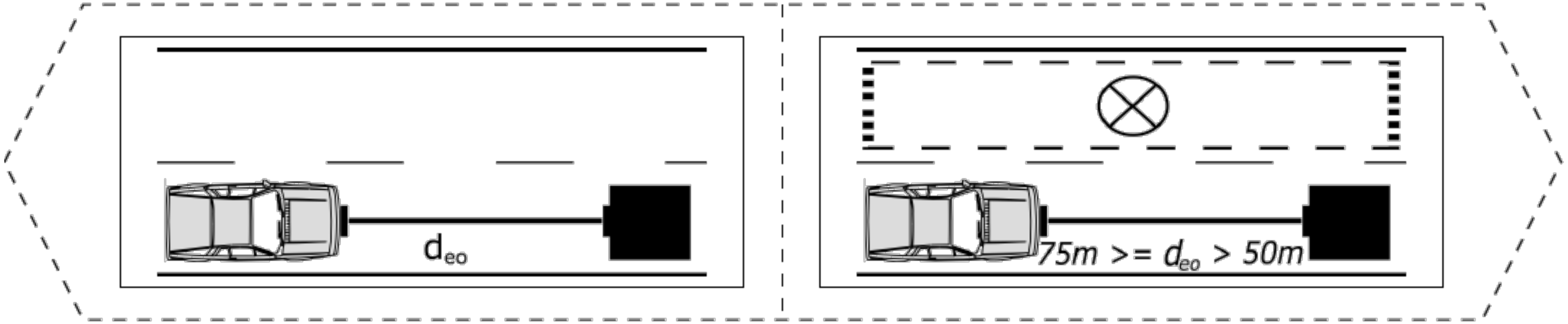


$$\mathrm{TTC} = \frac{-v_e \pm \sqrt{v_e^2 - 2 a_e d_{eo}}}{a_e}$$

$$\mathrm{CI} = \frac{v_e^2}{TTC}$$

[2]

Criticality Metrics applied to WM-Bounded TSCs



Characteristic	Assumed Value	Unit
Comfy Brake a_e	6	$\frac{m}{s^2}$
Emergency Brake a_e	9	$\frac{m}{s^2}$
Cruise Speed v_e	30	$\frac{m}{s}$
Dry Road μ	0.8	N/A
ego Width w_e	1.8	m
Object Width w_o	1.8	m
Gravity Accel. g	9.8	$\frac{m}{s^2}$

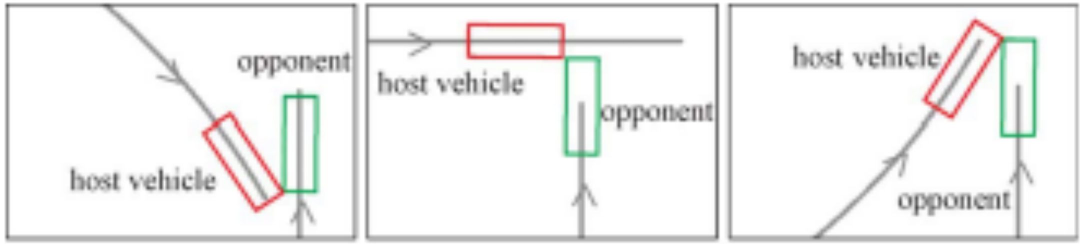
1.67s < TTC ≤ 2.5s

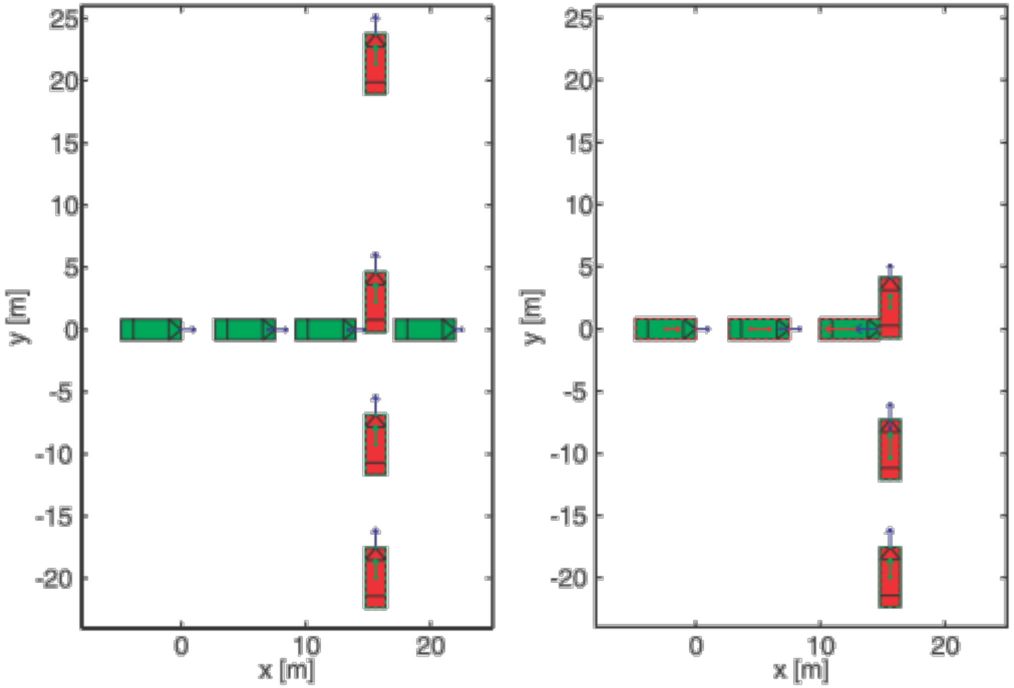
360 < CI ≤ 540

Criticality Metric Limitations

- Criticality Metric applicability is situation-specific
- Criticality Metric formulas are model- and situation-specific

$$TTC_i = \frac{X_{i-1}(t) - X_i(t) - l_i}{\dot{X}_i(t) - \dot{X}_{i-1}(t)}$$





[1] [5]

Criticality Metric Limitations (contd.)

- Hillenbrand *et al* 2006 required deceleration (a_{req}) & Time To Touch (TTT) example for an intersection collision

Case 4: The object neither comes to standstill nor disappears from the ego vehicle's driving corridor until the collision avoiding touch (TTT). This corresponds to the regular case.

$$a_{req} = a_{obj} - \frac{(v_{obj} - v_{ego})^2}{2x_{obj}} \qquad (24)$$

$$\mathrm{TTT} = -\frac{2x_{obj}}{v_{obj} - v_{ego}} \qquad (25)$$

[4]

Criticality Metric Abstraction

- Based on actor trajectories
- Collision relation identifies collisions between two trajectories at collision time t_c

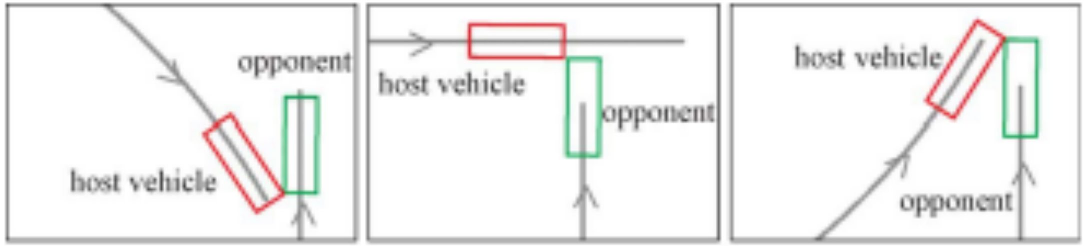
$$T_{act} : \text{Time} \Rightarrow \text{Position}$$

$$c(T_a, T_b) : T_a \times T_b \times \text{Time} \Rightarrow \text{Boolean},\ t_c$$

$$\exists t_c\ t_c \in [t_0, t_1)\ |T_a(t_c) - T_b(t_c)| \leq \varepsilon$$

Criticality Metric Abstraction (contd.)

- Define additional operations for trajectories in order to build expressions
- Can specify model- and situation-independent formulas for Criticality Metrics



$$\frac{|T_e'(t)|^2}{t_c - t}$$

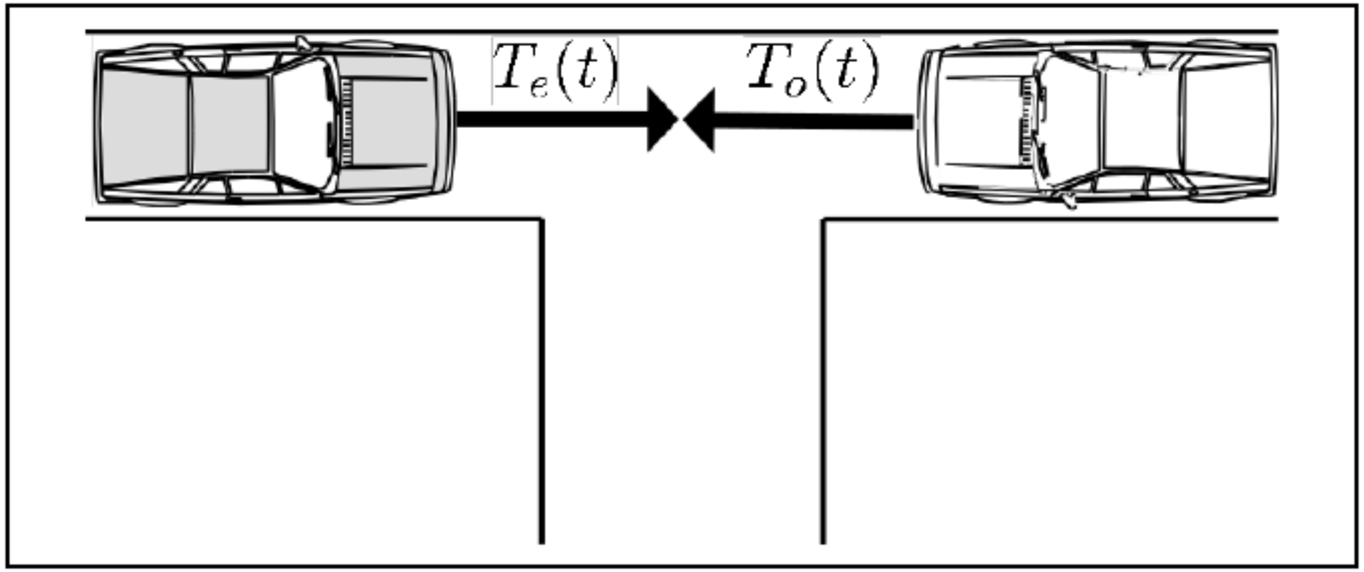
$$\mathrm{CI}(t) = \frac{|T_e'(t)|^2}{t_c - t} \leftrightarrow c(T_e, T_o) \; t \in [t_0, t_1)$$

[1]

Criticality Metric Abstraction (contd.)

$c(T_a, T_b)$	$true$	$\leftrightarrow \exists t_c \; t_c \in [t_0, t_1) \; \lvert T_a(t_c) - T_b(t_c)\rvert \leq \varepsilon$
	$false$	else
t_c	$argmin(\text{set of } t_c)$	$\leftrightarrow \exists t_c \; t_c \in [t_0, t_1) \; c(T_a, T_b)$
$\delta(t)$	1	$\leftrightarrow c(T_a, T_b)$, $\text{TTC}(t) \leq \text{TTC}^* \; t \in [t_0, t_1)$
	0	else
$\text{TTC}(t)$	$t_c - t$	$\leftrightarrow c(T_a, T_b) \; t \in [t_0, t_1)$
	∞	else
$\text{DH}(t)$	$\int_t^{t_c} \lvert T_a'(\tau)\rvert d\tau$	$\leftrightarrow \exists t_c \; c(T_a, T_b(t)) \; t \in [t_0, t_1)$
	∞	else
$\text{PET}(t)$	$t_c - t$	$\leftrightarrow c(T_a, T_b(t)) \; t \in [t_0, t_1)$
	∞	else
$\text{TET}(t)$	$\int_{t_0}^{t} \delta(\tau) d\tau$	$\leftrightarrow c(T_a, T_b) \; t \in [t_0, t_1)$
	0	else
$\text{TIT}(t)$	$\int_{t_0}^{t} \delta(\tau)(\text{TTC}^* - (t_c - \tau)) d\tau$	$\leftrightarrow c(T_a, T_b) \; t \in [t_0, t_1)$
	0	else
$\text{CI}(t)$	$\frac{\lvert T_a'(t)\rvert^2}{t_c - t}$	$\leftrightarrow c(T_a, T_b) \; t \in [t_0, t_1)$
	0	else

Abstract Critical Metrics Applied to TSCs



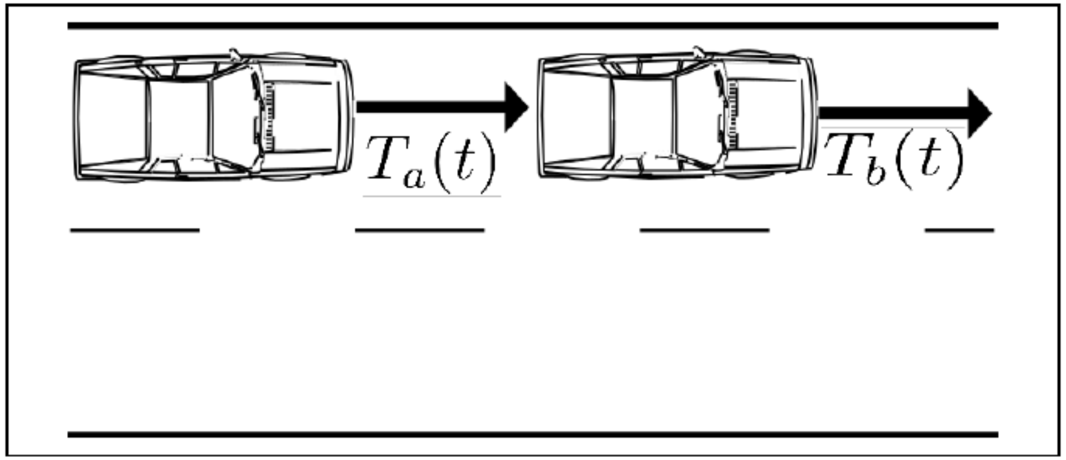
$$c(T_e, T_o)$$

$$\mathrm{TTC}(t) = t_c - t$$

$$\mathrm{CI}(t) = \frac{|T_e'(t)|^2}{t_c - t}$$

Abstract Critical Metrics Applied to TSCs (contd.)

- Applicability of a critical metric is inherent in the output of its formula
- Details/Realized motion model can be specified later

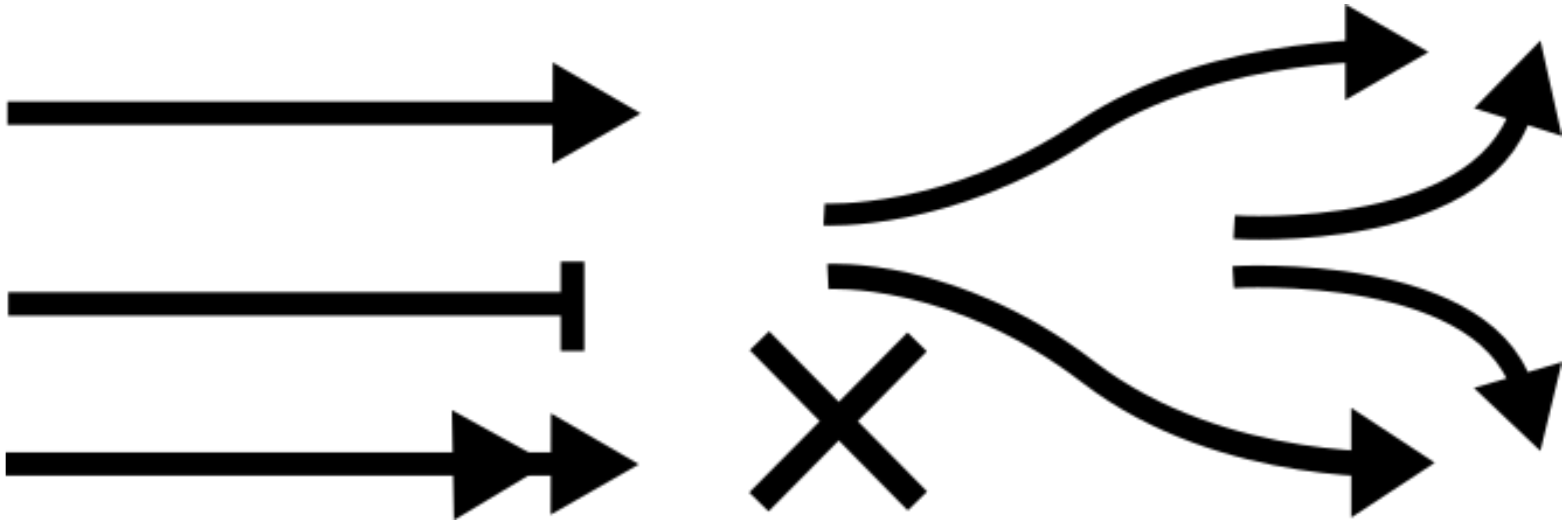


$$\mathrm{TTC}(t) = t_c - t \leftrightarrow c(T_a, T_b)\ t \in [t_0, t_1)$$
$$\infty \qquad \text{else}$$

$$\mathrm{PET}(t) = t_c - t \leftrightarrow c(T_a, T_b(t))\ t \in [t_0, t_1)$$
$$\infty \qquad \text{else}$$

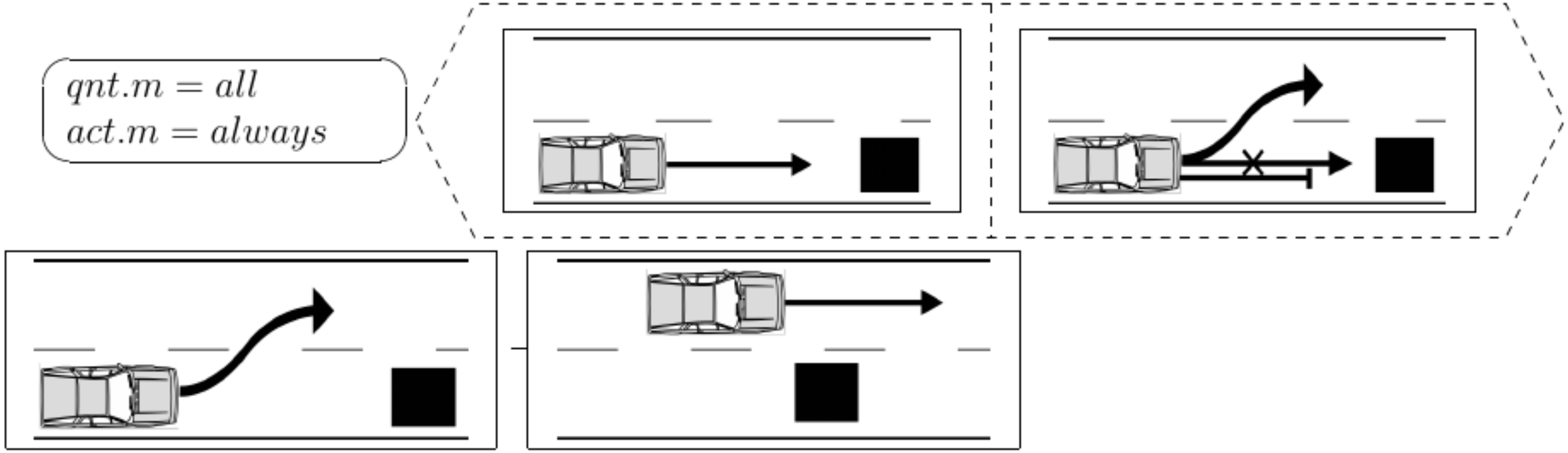
Abstract Maneuver Classes for TSCs

- Represent any ‘possible’ instance of a trajectory of a particular class
- If used in TSCs, could calculate minima, maxima of criticality of trajectories of a particular class



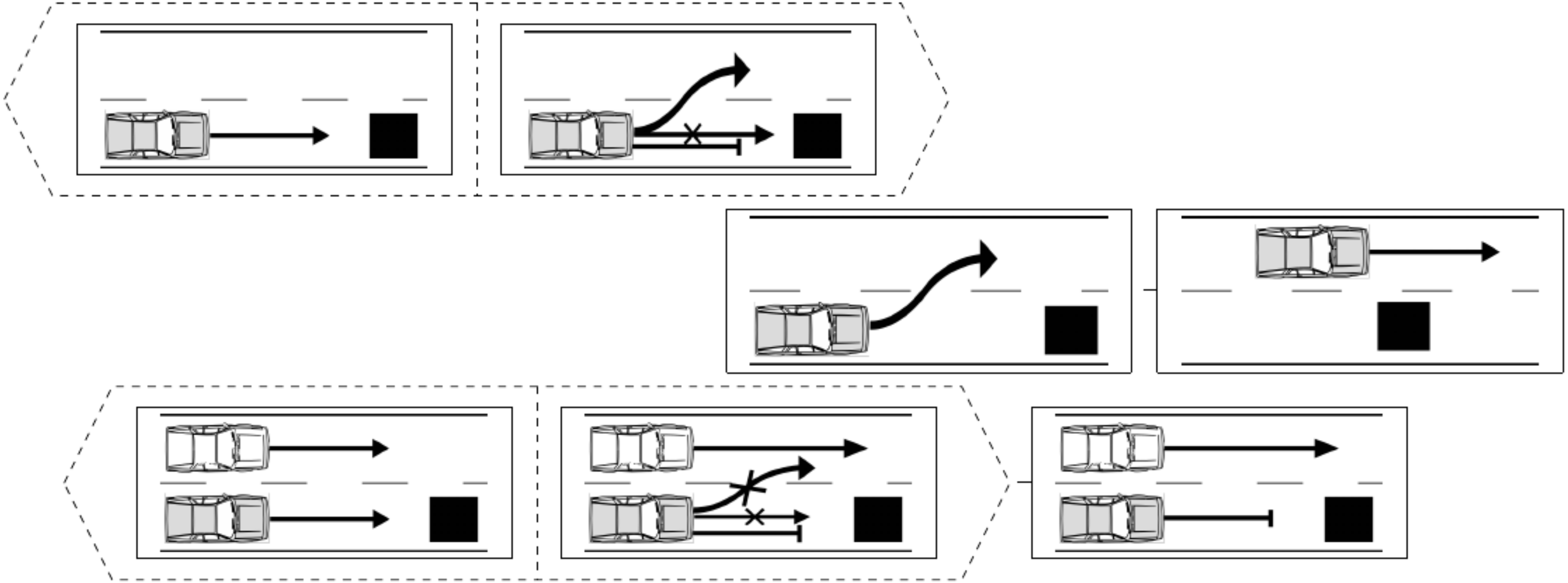
Graphical Use of Abstract Maneuver Classes in TSCs

- Can explicitly specify the intentions of actors
- Can use in predicates to specify possible responses to a situation and the associated criticality



Graphical Use of Abstract Maneuver Classes in TSCs (contd.)

- Can use existence of additional possible move classes as a basis for comparing the criticality of different traffic scenarios



References

[1] Kaempchen, N., Schiele, B., Dietmayer, K. "Situation Assessment of an Autonomous Emergency Brake for Arbitrary Vehicle-to-Vehicle Collision Scenarios" *IEEE Transactions on Intelligent Transportation Systems* vol. 10, no. 4, 2009, pp. 678-687

[2] Damm, W., Kemper, S. Möhlmann, E., Peikenkamp, T., Rakow, A. "Using Traffic Sequence Charts at the Development of HAVs" report.

[3] Hillenbrand, J., Kroschel, K. "A study on the performance of uncooperative collision mitigation systems at intersection-like traffic situations." *IEEE* 2006

[4] Hillenbrand, J., Spieker, A.M., Kroschel, K. "A multilevel collision mitigation approach – Its situation assessment, decision making, and performance tradeoffs." *IEEE Transactions on Intelligent Transportation Systems* vol. 7, no. 4, 2006, pp. 528-540

[5] Chan, C.Y. "Defining safety performance measures of driver-assistance systems for intersection left-turn conflicts." *IEEE* 2006