This is an end-to-end, grey-box model for the vehicle dynamics. The model parameters are not measured directly, but optimized to best fit the vehicle behavior.

$$
\begin{aligned}
\boldsymbol{x} &= [p_x, p_y, \psi, v] \\
\boldsymbol{u} &= [f, \delta_{ref}, V]
\end{aligned}
$$

p_x	IPS x-position
p_y	IPS y-position
ψ	IPS yaw angle
v	Odometer Speed
f	Dimensionless motor command
δ_{ref}	Dimensionless steering command
V	Battery voltage

$$
\begin{aligned}
\dot{p}_x &= p_1 \cdot v \cdot (1 + p_2 \cdot (\delta_{ref} + p_9)^2) \cdot \cos(\psi + p_3 \cdot (\delta_{ref} + p_9) + p_{10}) \\
\dot{p}_y &= p_1 \cdot v \cdot (1 + p_2 \cdot (\delta_{ref} + p_9)^2) \cdot \sin(\psi + p_3 \cdot (\delta_{ref} + p_9) + p_{10}) \\
\dot{\psi} &= p_4 \cdot v \cdot (\delta_{ref} + p_9) \\
\dot{v} &= p_5 \cdot v + (p_6 + p_7 \cdot V) \cdot \mathrm{sign}(f) \cdot |f|^{p_8}
\end{aligned}
$$

This is a kinematic bicycle model with some added terms to account for various errors.

- p_1: Compensate calibration error between IPS speed and odometer speed.
- $(1 + p_2 \cdot \delta^2)$: Compensate for speed differences due to different reference points between the IPS and odometer. The formulation is simplified with a second-order Taylor approximation.
- p_3: Side slip angle (Schwimmwinkel) due to steering.
- p_{10}: IPS Yaw calibration error.
- p_4: Unit conversion for the steering state.

- p_5: Speed low pass (PT1).
- p_6, p_7: Motor strength depends on the battery voltage.
- p_8: Compensate non-linear steady-state speed.
- p_9: Steering misalignment correction.