Table 1: Physics-based predicate set Φ used to validate candidate causal edges. "Scope" indicates whether the predicate is evaluated within a single domain (intra) or across domains (cross). All constants ($a_{\max}$, $\theta_{\max}$, etc.) are platform-specific and drawn from OEM specs.

ID	Predicate Formula / Rule	Primary DOF(s)	Scope	Explanation
ϕ_1	$\lvert a\rvert \le a_{\max}$	Longitudinal	Intra	Longitudinal acceleration must stay within feasible limits.
ϕ_2	$\lvert \dot{a}\rvert \le j_{\max}$	Longitudinal	Intra	Jerk (rate of change of a) bounded for ride comfort.
ϕ_3	$v \ge 0$	Longitudinal	Intra	Vehicle speed cannot be negative.
ϕ_4	$\lvert \theta\rvert \le \theta_{\max}$	Lateral	Intra	Steering angle within mechanical limits.
ϕ_5	$\lvert \dot{\theta}\rvert \le \dot{\theta}_{\max}$	Lateral	Intra	Steering-rate bounded by EPS motor capability.
ϕ_6	$P \le P_{\max}$	Power-train	Intra	Instantaneous propulsion power capped by inverter capacity.
ϕ_7	$I_{\text{bat}} \le I_{\max}$	Energy	Intra	HV-battery current below safety limit.
ϕ_8	$T_{\text{brake}} \le T_{\max}$	Longitudinal	Intra	Brake torque must not exceed system rating.
ϕ_9	$d_{\text{brake}} \ge \frac{v^2}{2\mu g}$	Longitudinal	Intra	Stopping distance obeys physics, given road friction μ.
ϕ_{10}	CAN brake cmd $\rightarrow$ torque drop $\le 150\,\text{ms}$	Long.+Power	Cross	Electronic brake command must manifest in power-train quickly.
ϕ_{11}	Steering change $> 15^\circ \Rightarrow$ torque cut $\le 150\,\text{ms}$	Lat.+Power	Cross	Ensures lateral manoeuvres are reflected in propulsion load.
ϕ_{12}	OTA start (Eth) $\Rightarrow$ Host flash log $\le 2\,\text{s}$	Energy	Cross	Firmware flashing must be logged promptly on host.
ϕ_{13}	Host diag fault $\Rightarrow$ CAN DTC within $1\,\text{s}$	Long./Lat.	Cross	Host-detected fault must propagate to CAN diagnostics quickly.
ϕ_{14}	Eth throttle pkt $\Rightarrow$ CAN rpm rise $\le 500\,\text{ms}$	Power	Cross	Throttle over Ethernet must appear in CAN engine-RPM frames.