

# **Integrated LTC-MPV Vehicle Dynamics Control**



## **Group**

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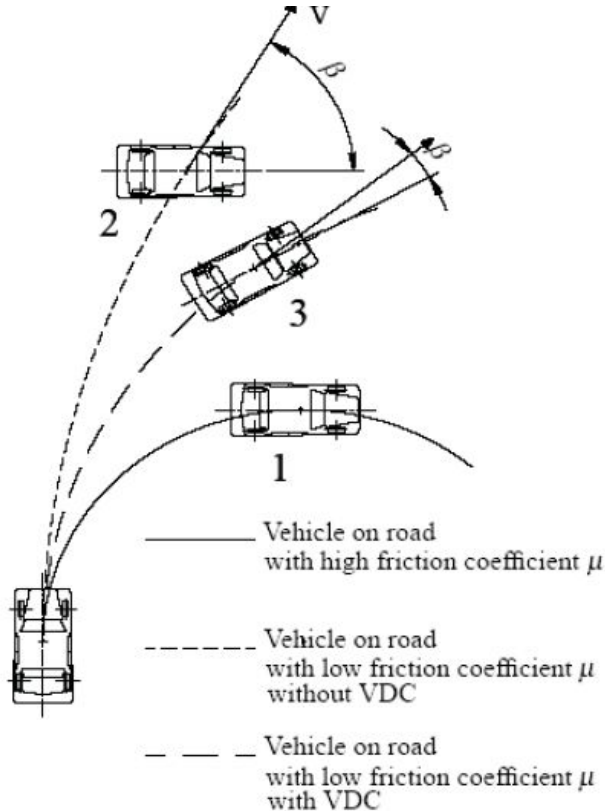
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# Introduction

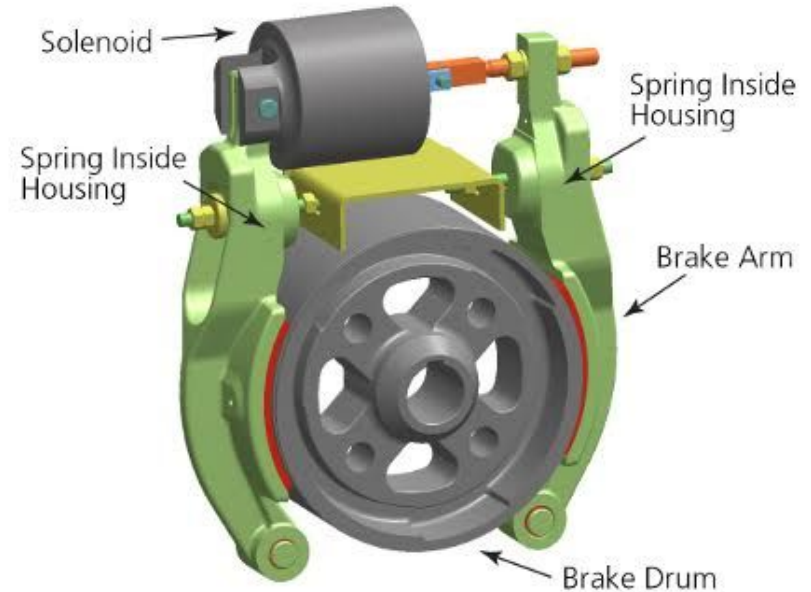
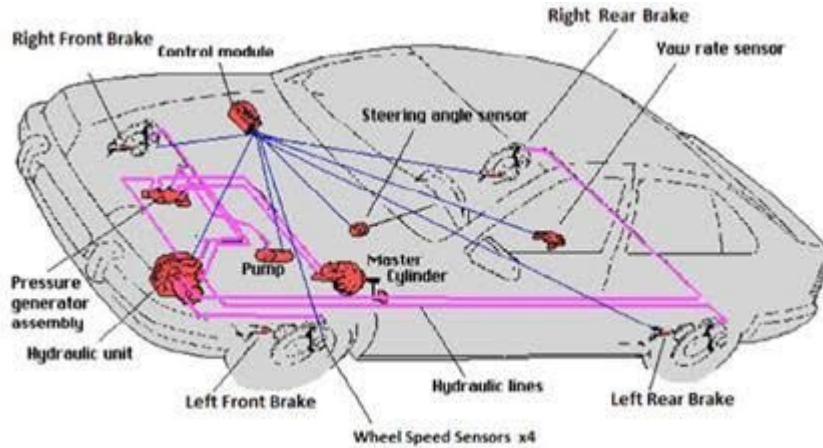
- Nowadays a great number of control systems are present in a car, each of them being designed to control a particular part of the vehicle: engine, clutch, gearbox, active and semi active suspension control, power steering, electronic differential, etc. One of them is LTC-MPV
- **LTC-MPV**: Integration of a **Linear-time-varying Model predictive-control** (LTV-MPC), designed to stabilize a vehicle during sudden lane change or excessive entry-speed in curve
- LTC MPV uses **slip controller** that converts the desired longitudinal tire force
- LTC MPV is used to manipulate **three groups of variables**: the front (and seldomly, rear) steering angle, the braking force (through the so called differential braking) and the engine torque.
- Goals of the lateral control system are to track the yaw velocity and steering angle of the vehicle as much as possible the nominal motion **expected by the driver**. It regulates other parameters accordingly.

# Motion with controller



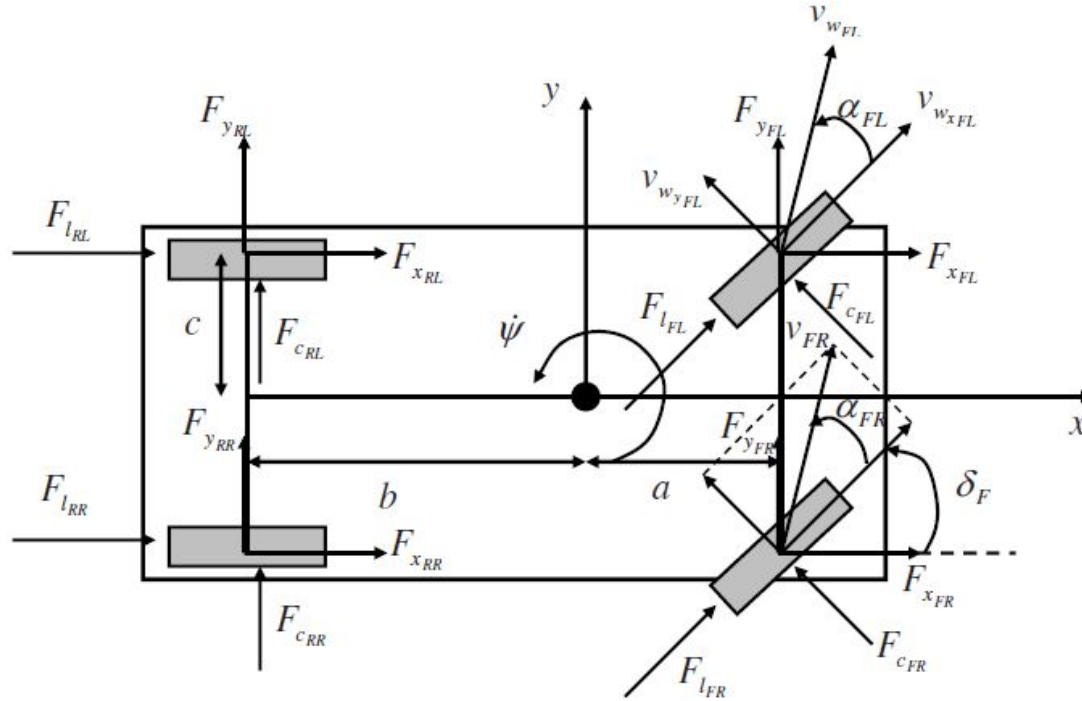
- The Lateral Controller regulates the yaw rate and the vehicle **side slip angle** by acting on the longitudinal force of tires. The slip controller regulates the **brake pressure** to achieve the desired longitudinal force of the tire.
- Advantage over simple PI controller: Since **wheel dynamics** are much faster than **vehicle body dynamics**, the design of lateral control neglects wheel dynamics. However the LTV-MPC controller enables a more precise design which takes into account both the things

# Differential braking:



- Differential braking is the **unequal application of braking** applied to different wheels
- differential braking would be used during the activation of any **anti-lock/anti-skid systems** on the vehicle
- Completely controlled by solenoid which works on the electrical signals provided by LTC-MPV control system.

# Full vehicle model



- The state variables are the side slip angle of vehicle  $\beta$ , the yaw rate  $\dot{\psi}$  and the rotational speed  $\omega_{ij}$  of each wheel.
- **Input:** the wheel turn angle  $\delta$  is a “disturbance input”, We are keeping it constant for the complete process.
- **Input:** the contribution of engine torque on each wheel  $T_{eng}$  and the braking torque  $T_B$  on each wheel, instead, are given by the controller.
- **Output:**  $\beta, \dot{\psi}, \omega_{ij}$

# Governing Equations

$$\begin{bmatrix} \dot{\beta} \\ \ddot{\psi} \\ \dot{\omega}_{ij} \end{bmatrix} = \begin{bmatrix} f_1(v, \beta, \psi, \delta, F_{Lij}, F_{Sij}) \\ f_2(v, \beta, \psi, \delta, F_{Lij}, F_{Sij}) \\ f_3(F_{Lij}, T_{engij}, T_{Bij}) \end{bmatrix}, \quad i = \{F, R\}, \quad j = \{L, R\} \quad (15.1a)$$

$$f_1(v, \beta, \psi, \delta, F_{Lij}) = \frac{1}{Mv} \{ (F_{L_{FL}} + F_{L_{FR}}) \sin(\beta + \delta) - (F_{S_{FL}} + F_{S_{FR}}) \cos(\beta - \delta) \\ + (F_{L_{RL}} + F_{L_{RR}}) \sin \beta - (F_{S_{FR}} + F_{L_{FL}}) \cos \beta \} - \ddot{\psi}, \quad (15.1b)$$

$$f_2(v, \beta, \psi, \delta, F_{Lij}) = \frac{1}{J_z} \{ l_a (F_{S_{FL}} - F_{S_{FR}}) \cos \delta - l_a (F_{L_{FL}} - F_{L_{FR}}) \sin \delta + l_b (F_{S_{RL}} + F_{S_{RR}}) \\ + l_c (F_{S_{FL}} - F_{S_{FR}}) \cos \delta + l_c (F_{L_{FL}} - F_{L_{FR}}) \sin \delta + l_c (F_{L_{RR}} - F_{L_{RL}}) \}, \quad (15.1c)$$

$$f_3(F_{Lij}, T_{engij}, T_{Bij}) = \frac{1}{J_w} (-r F_{Lij} - T_{Bij} + T_{engij}). \quad (15.1d)$$

By using '**ode45**' in Matlab with the initial conditions and constants (assuming **hatchback** car), we can find out the required output as stated earlier.

# Major equations

$$a_y = \frac{1}{m} \begin{bmatrix} F_{y11} \cos \delta_1 + F_{y12} \cos \delta_2 + \\ F_{x11} \sin \delta_1 + F_{x12} \sin \delta_2 + \\ F_{y21} + F_{y22} \end{bmatrix},$$

$$a_x = \frac{1}{m} \begin{bmatrix} -F_{y11} \sin \delta_1 - F_{y12} \sin \delta_2 + \\ F_{x11} \cos \delta_1 + F_{x12} \cos \delta_2 + \\ F_{x21} + F_{x22} \end{bmatrix},$$

Acceleration in x and y direction

$$F_{z11} = m_v g \frac{b}{2L} - m_v \frac{h}{2L} a_x - m_v \frac{hb}{EL} a_y$$

$$F_{z12} = m_v g \frac{b}{2L} - m_v \frac{h}{2L} a_x + m_v \frac{hb}{EL} a_y$$

$$F_{z21} = m_v g \frac{a}{2L} + m_v \frac{h}{2L} a_x - m_v \frac{ha}{EL} a_y$$

$$F_{z22} = m_v g \frac{a}{2L} + m_v \frac{h}{2L} a_x + m_v \frac{ha}{EL} a_y$$

Vertical loads on each wheel

# Major equations

$$s_{ij} = \frac{r_w w_{ij} - V_{wxij}}{r_w w_{ij}} \quad \text{accelerating}$$

Longitudinal slip ratio of each wheel

$$V_{wx11} = \left( V_x - \frac{\dot{\psi} E}{2} \right) \cos \delta_1 + \left( V_y + a \dot{\psi} \right) \sin \delta_2,$$

$$V_{wx12} = \left( V_x + \frac{\dot{\psi} E}{2} \right) \cos \delta_1 + \left( V_y + a \dot{\psi} \right) \sin \delta_2,$$

$$V_{wx21} = V_x - \frac{\dot{\psi} E}{2},$$

$$V_{wx22} = V_x + \frac{\dot{\psi} E}{2}.$$

Longitudinal velocity of each wheel

$$\alpha_{11} = \delta - \arctan \left[ \frac{V_y + a \dot{\psi}}{V_x - E \frac{\dot{\psi}}{2}} \right]$$

$$\alpha_{12} = \delta - \arctan \left[ \frac{V_y + a \dot{\psi}}{V_x + E \frac{\dot{\psi}}{2}} \right]$$

$$\alpha_{21} = - \arctan \left[ \frac{V_y - b \dot{\psi}}{V_x - E \frac{\dot{\psi}}{2}} \right],$$

$$\alpha_{22} = - \arctan \left[ \frac{V_y - b \dot{\psi}}{V_x + E \frac{\dot{\psi}}{2}} \right],$$

Tire side slip angle for each wheel



# Major equations

$$f(\lambda) = \begin{cases} (2 - \lambda)\lambda, & \text{if } \lambda < 1 \\ 1, & \text{if } \lambda \geq 1 \end{cases}$$

$$\lambda = \frac{\mu F_z (1 + s)}{2 [(C_s s)^2 + (C_\alpha \tan \alpha)^2]^{\frac{1}{2}}},$$

Parameter which considers effect of road conditions, longitudinal and cornering stiffness

$$F_{x|dugoff} = C_s \frac{s}{1 + s} f(\lambda),$$

$$F_{y|dugoff} = -C_\alpha \frac{\tan \alpha}{1 + s} f(\lambda),$$

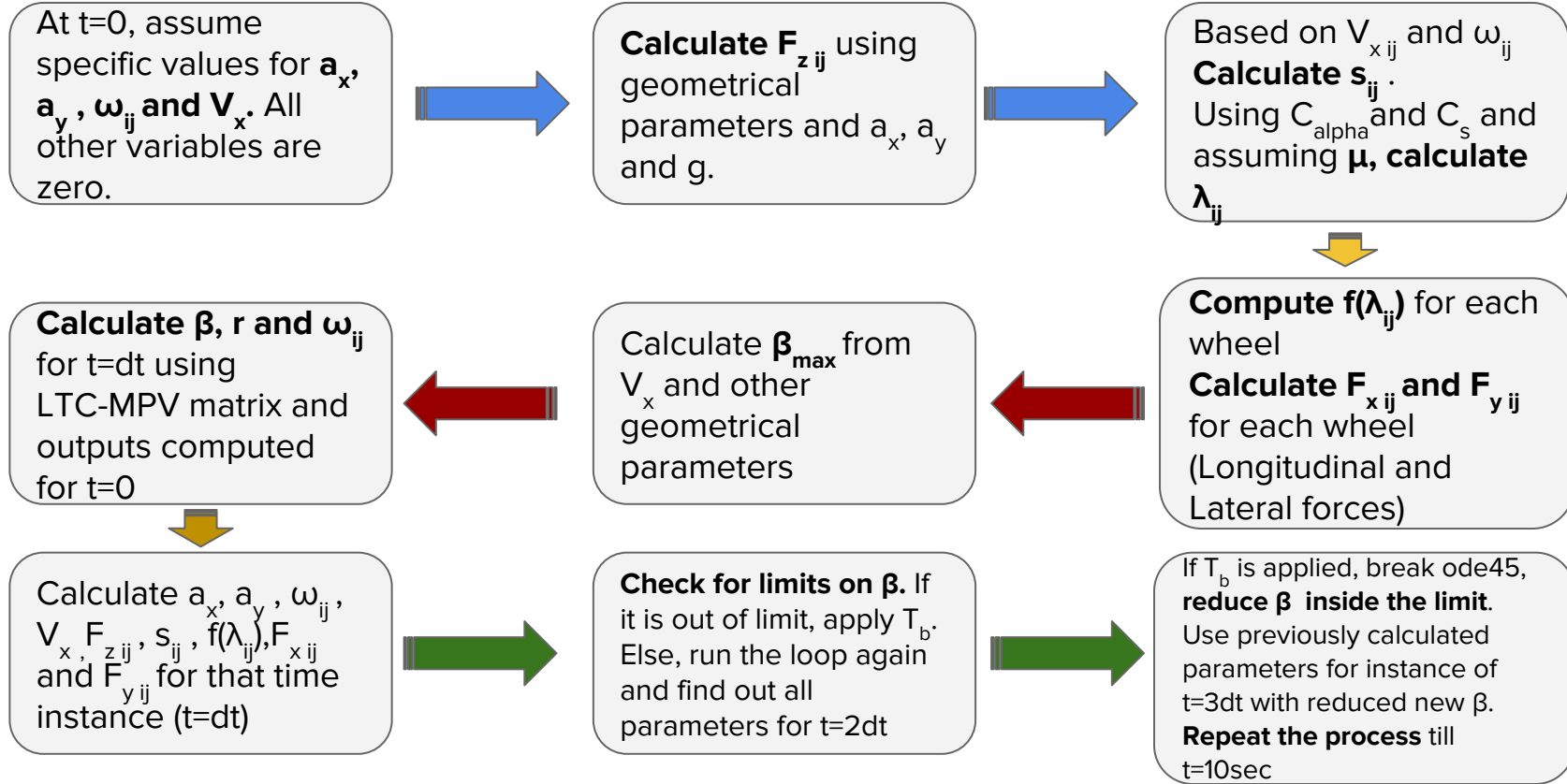
Longitudinal and Lateral forces on each wheel

# Vehicle under study

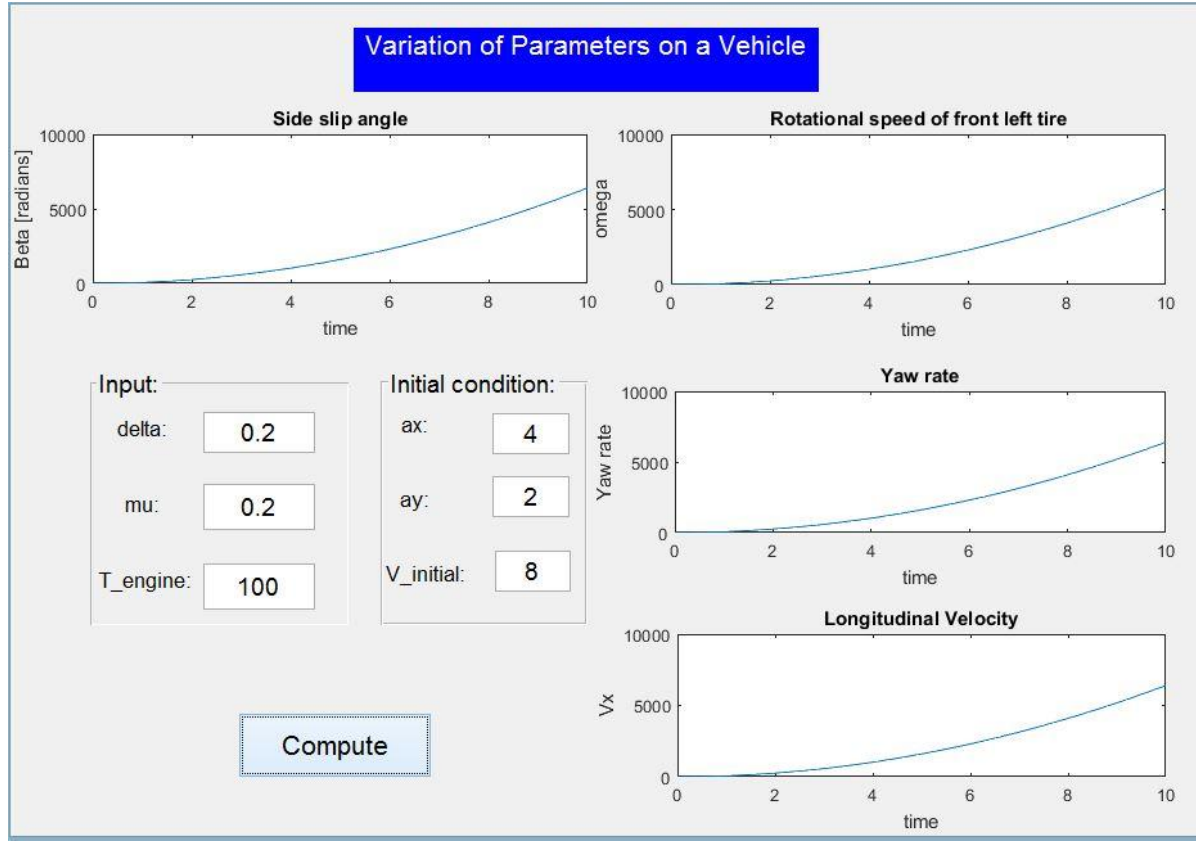


- Mass = 1000 Kgs
- $a$  (Distance of front tires from CG) = 1 m
- $b$  (Distance of rear tires from CG) = 2 m
- $L = a + b = 3$  m
- $E$  (width of vehicle) = 1 m
- $c = E/2 = 0.5$  m
- $C_s () = 500$  N/rad
- $C_{\alpha ()} = 400$  N/rad
- $H$  (Height of CG from ground) = 0.75 m
- $R_w$  (Wheel radius) = 0.3 m

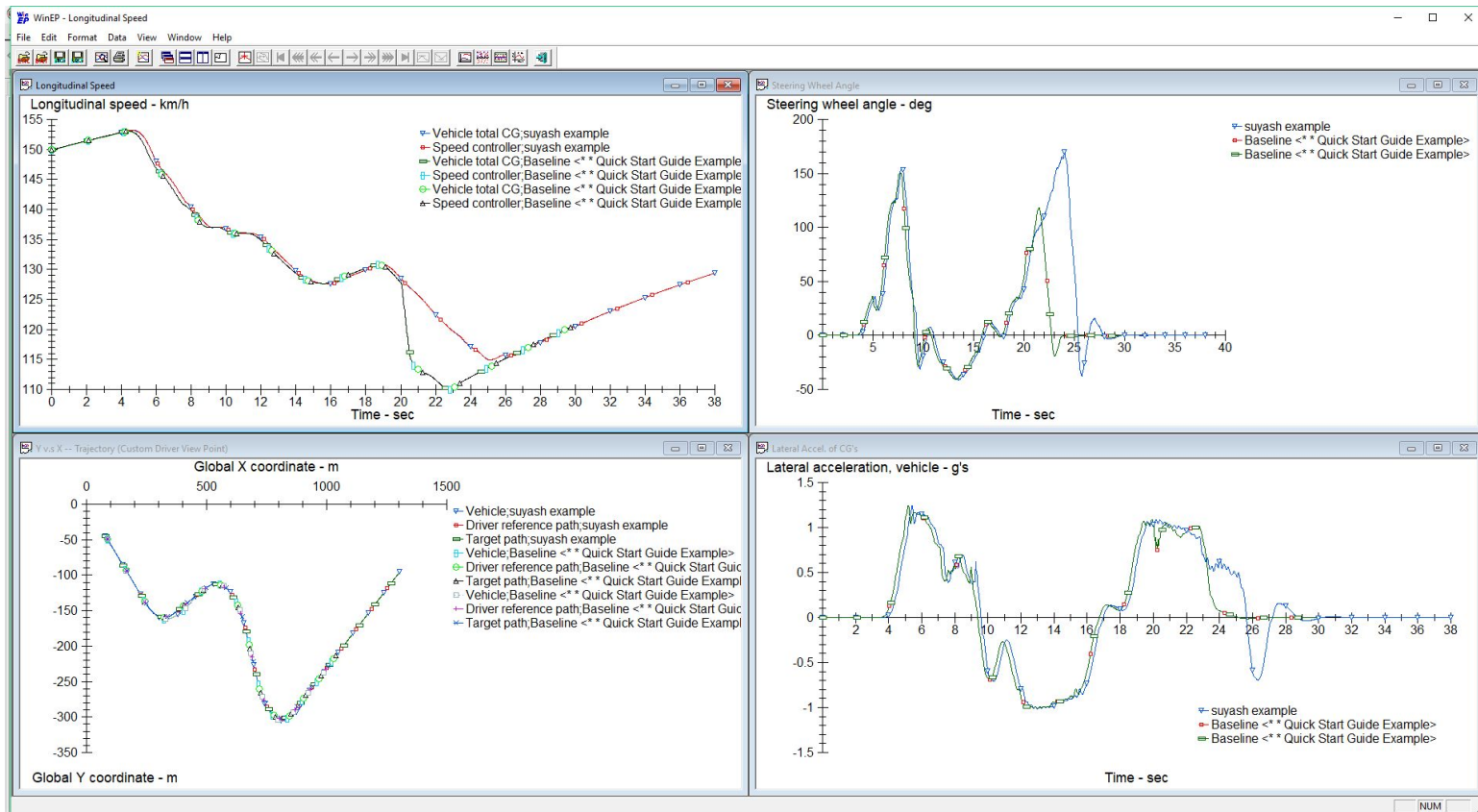
# Process flow



# Graphical User Interface



# Sample CARSIM results



# Challenges

- The research paper presented uses softwares such as **CARSIM** and **Elasis – Centro Ricerche Fiat** (CRF) proprietary software. Our simulations are done in MATLAB.
- Differential braking applies different braking torque on each wheel. As the equations in which how  $T_b$  affects  $a_x$ ,  $a_y$ , and  $V_x$  is not known, it is difficult to model in MATLAB. Hence, we are assuming constant values of braking torque on each wheel. (Braking force applied is a **nonlinear equation** in reality which is already embedded in CARSIM software)
- Running ode45 for 7 variables in continuous loops for each time instant while requesting output for each variable is proving to be difficult task as there are multiple interdependent variables in equations.
- Variation in  $T_{eng}$  and its effect on each wheel is unknown. In current scenario,  $T_{eng}$  on each wheel is assumed to be constant value for the whole period of time of 10 seconds. It does not reduce or increase at anytime. This is not always the case practically.
- As all the CARSIM formulations (algorithms with formulae) are unknown, it is difficult to match the results shown in the research paper.

# References

- Giovanni Palmieri, Osvaldo Barbarisi, Stefano Scala, and Luigi Glielmo: 'An Integrated LTV-MPC Lateral Vehicle Dynamics Control: Simulation Results'
- Carlos Reyes, Olmer García, Pablo Siqueira Meirelles, Janito Vaqueiro Ferreira 'Estimation of longitudinal and lateral tire forces in a commercial vehicle'
- Secondary data about vehicle collected from internet. CARSIM software available data.
- Class notes written for academic course: Vehicle Dynamics by Dr. Ashok Kumar Pandey, IIT Hyderabad.

**Thank You!**