# Torque Vectoring System of PER22

Diagram

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*Figure 1: The Model*

# Introduction

This document seeks to describe the Torque Vectoring (TV) project developed in 2021. This model seeks to improve vehicle performance for current and future vehicle designs that Purdue Electric Racing (PER) produces. This goal is essentially described at determining the power distribution among the four in-hub motors in the current vehicle design (2022).

The model is generally divided into two parts: the vehicle and the controller. These two components communicate in a closed loop. As a result, the only time series input needed for this simulation are disturbances-both driver and environmental. This means the accuracy of the closed loop variables are as accurate as the systems being modeled.

The model produces a large quantity of information during every simulation. A wise engineer will learn to know what pieces of information are useful, and which usually are not. A great deal of time can be spent while accomplishing very little if one is not intentional in their analysis of simulation output data. In addition, the ability to work within the MATLAB/Simulink software is invaluable and cannot be understated.

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# Overview

This project is based on research conducted by A. Stoop [1], who developed a model to optimize torque distribution on driving wheels. The model is redesigned and optimized for all wheel drive (AWD) vehicles and deployed in the latest racing car of PER.

Figure 2 is an overview of the model. The environmental conditions and manipulation are imported to the model as data input. The controller takes the responses from vehicle body and driver input to calculate the optimal torque distribution. Finally, the optimal distribution is materialized by motors and sent to vehicle body.

TV Controller

Vehicle Body

Dynamics Information

Controller Output

Control

Signal

Torque

Data Input

Motors and Battery

*Figure 2:TV System Diagram*

## Data Input

Excel spreadsheets are used to input disturbance data into the model. Appendix A shows an example. The first row is always the same, and the first column is always time. All other number can be changed to simulate many different conditions. It is important to note that these are the only time series data that can be modified, but there are various parameters, called ‘tunable parameters’ that can also be changed.

To input data, the following procedure can be used:

1. In the top panel, ensure the radio button ‘signal name’ is selected
2. When the simulation is open, select the simulation tab in the top left
3. Find the button called ‘connect inputs. This can be found in the ‘prepare’ subheading\
4. Select ‘from spreadsheet’ in the top left, the browse
5. Select the desired spreadsheet, click ok
6. Select ‘Map to model’
7. Select the dataset in the left-hand panel; click ‘mark for simulation in the top right’
8. The data is now correctly connected to the model

Useful information:

1. It is possible to import several datasets. ‘Mark for simulation’ button is used to select which dataset to use.
2. The box that pops up when you click ‘connect inputs’ is best left open during simulation use.

## Simulating

To simulate a selected dataset, select the stop time, then click run.

# Vehicle

The vehicle consists of 5 different blocks: The motor, battery, tires, body, and steering.

Figure 3: The Vehicle

## Steering

The real vehicle uses Ackermann steering. This is a mechanism that ensures that the front 2 tires share the same turning radii.

[Kinematic steering for Ackerman, rack-and-pinion, and parallel steering mechanisms - Simulink (mathworks.com)](https://www.mathworks.com/help/vdynblks/ref/kinematicsteering.html)

## Tires

The real tires are LC0 compound. The modeled tire only models longitudinal behavior of the tires. Most of the parameters for the tire are incorrect. A better, nonlinear tire model that implements lateral behavior is desired.

[Tire with longitudinal behavior given by Magic Formula coefficients - MATLAB (mathworks.com)](https://www.mathworks.com/help/physmod/sdl/ref/tiremagicformula.html)

## Vehicle Body

The vehicle body is a 3DOF model that has 3 different modes: external longitudinal forces, external forces, and external longitudinal velocity. The first option is used because we do not have a tire model that does both lateral and longitudinal computation. For this selection, the vehicle body models lateral tire dynamics for us.

The vehicle body is unable to simulate downforce on the vehicle because the lift coefficient must be greater than 0. As such, an external function is used to approximate the downforce that acts on the vehicles CoG (center of gravity). The downforce should at the CoP (center of pressure). Will need to figure that out.

[3DOF rigid vehicle body to calculate longitudinal, lateral, and yaw motion - Simulink (mathworks.com)](https://www.mathworks.com/help/vdynblks/ref/vehiclebody3dof.html)

## Motor

Currently, the motor is modeled manually using curves that approximate the actual motor behavior.

## Battery

The battery is a combination of cells in parallel and in series. The model uses empirical data to characterize the battery. Right now, the parameters are set to be a random, but realistic battery. If the battery subteam want, they can give us specific information regarding the real battery.

[Lithium-ion, lithium-polymer, or lead-acid battery - Simulink (mathworks.com)](https://www.mathworks.com/help/autoblks/ref/datasheetbattery.html)

# Controller

The controller takes as input the relevant vehicle variables, and outputs 4 torque values, corresponding to each of the four motors. In the simulation, the disturbances are time series data inports, but in application all variable information that the controller uses will come from sensors on the vehicle. The controller uses MATLAB function block the execute the code.

[Include MATLAB code in models that generate embeddable C code - Simulink (mathworks.com)](https://www.mathworks.com/help/simulink/slref/matlabfunction.html)

## Optimization Statement & fmincon

The goal of the optimization is to find the largest total driving force that the motors can produce, subject to a litany of constraints. fmincon is the MATLAB function that does the optimization. It finds the minimum of an objective function, subject to given constraints. It is currently set to use the sqp algorithm to determine the optimal values of torque.

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## Boundaries

The boundaries defined the maximum and minimum torque that each individual motor can output. As such, the upper and lower boundaries are both vectors, length 4.

A picture containing watch, gauge

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The boundaries consist of several different potential boundaries. The actual boundary is the torque that is closest/furthest to 0, corresponding to lb/ub.

1. Slip Limit
2. Power Limit
3. Motor Limit

)

)

## Power

The vehicle is limited by the battery. There exists a maximum that the battery can output from the battery. There also exists a minimum that the motor can input to the battery - this is regenerative braking.

## Driver Input

Driver input is the main source of disturbances to the vehicle. This includes steering, braking and acceleration. Each of these needs to be considered when determining the optimal torque distribution.

## Yaw Acceleration

The PID output is equivalent to the yaw acceleration of the vehicle. The yaw acceleration is set to control the yaw of the vehicle. The yaw acceleration is a function of the lateral and longitudinal forces acting on the tires, in the tire coordinate system (See appendix B).

# Variables, Constants, Parameters

## Tunable Parameters

Tunable parameters are defined as variables within the model that can be changed, for the purposes of changing the controller performance.

*Table 1: Tunable Parameters*

## Vehicle Constants

Vehicle constants are values that are directly describe the vehicle.

*Table 2: Vehicle Constants*

## Initial Conditions

Initial conditions set the start point for various vehicle blocks.

*Table 3: Initial Conditions*

## Controller Variables

Controller variables are variables are computed within the controller.

*Table 4: Controller Variables*

## General Constants

General constants are any other constants that do not fit any of the above categories.

*Table 5: General Constants*

## Appendix A: Data Input

## Appendix B: Coordinate Systems