Design of Experiments (DoE) Approach to Driver Modeling

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Agenda

- **Introduction**
- DoE Approach to Driver Modeling
- Results
- Applications
- Summary

Introduction

- *Motivation*
  - The need to increase fidelity in simulation models in order to rely less on physical testing such that
    - Costs are reduced
    - Number of tested solutions are dramatically increased
    - Development and testing time are minimized
    - Results are made repeatable
    - Vehicle performance is separated from “outside noise” and driver performance
    - Safety of testing is increased
- *Objective*
  - Improve current common practice driver modeling techniques by approaching the problem through a different philosophy
    - Eliminate driver model & analyst influence on results through DoE/RSM
    - Provide a knowledge discovery toolkit to the engineer

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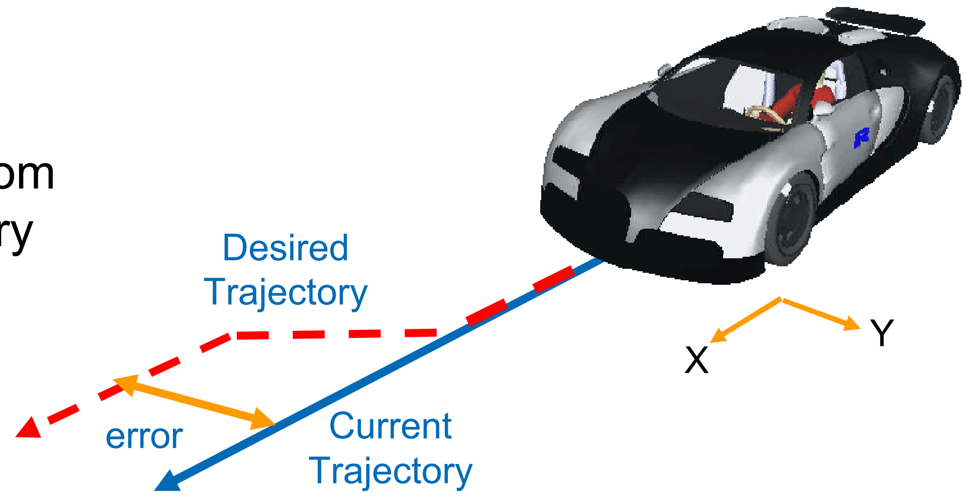
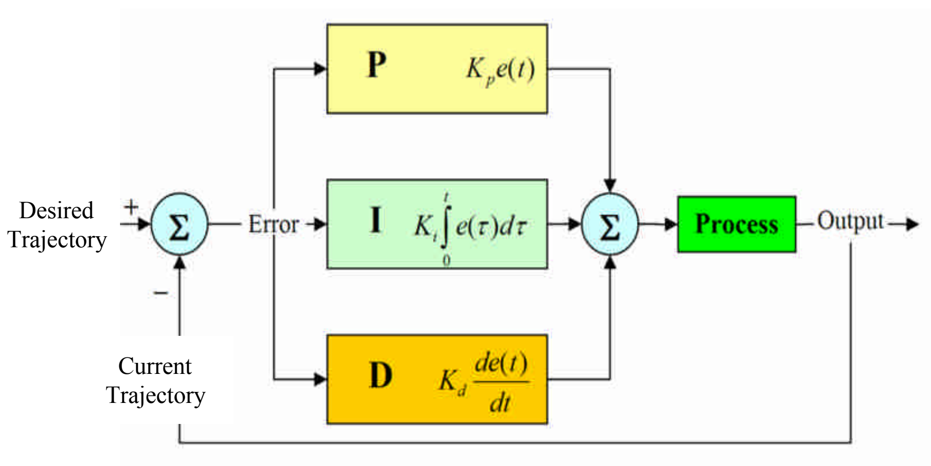
Path Follower Driver Model

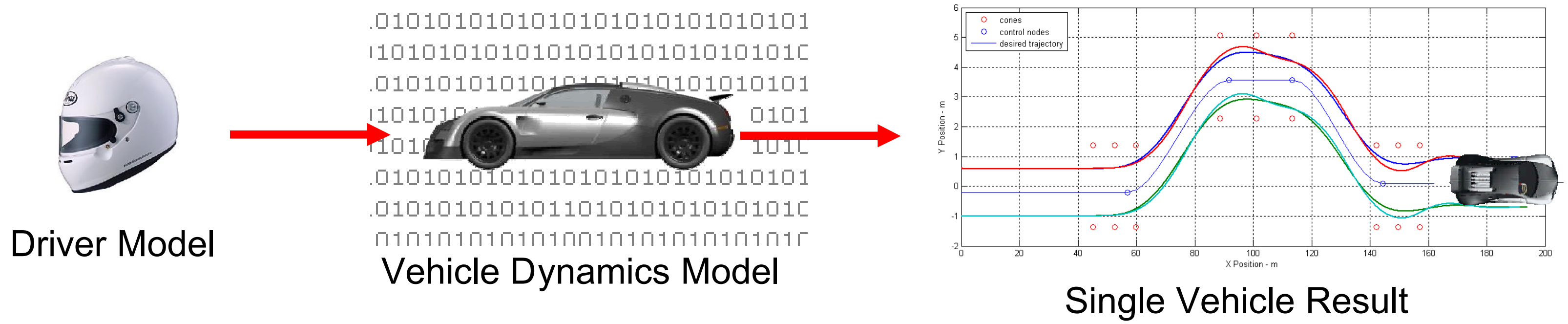
- Common ‘closed-loop’ model
- PID Control
  - Acts on lateral deviation error from user prescribed desired trajectory
  - Few tuning parameters
- Challenges
  - Desired trajectory is dependent on road and vehicle
  - Trial & error
    - Slow, inaccurate and subjective
  - Optimization
    - Not a mathematical optimum
    - Returns a single answer which may or may not be optimum



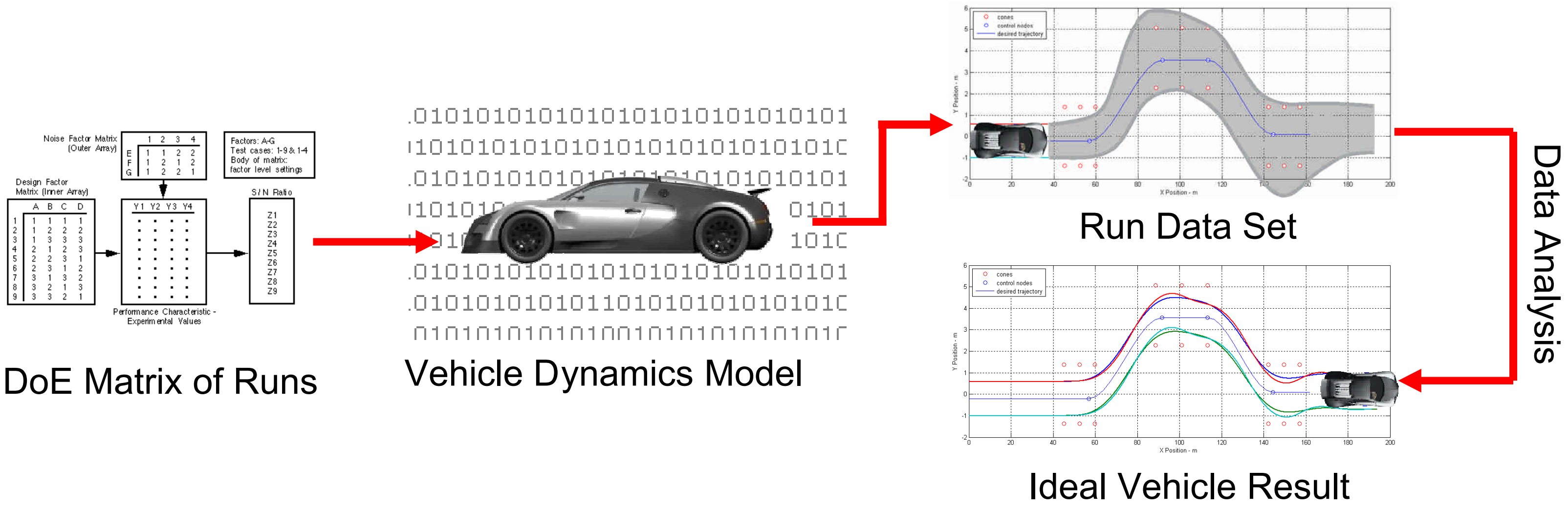


DoE – Driver Model Problem Philosophy

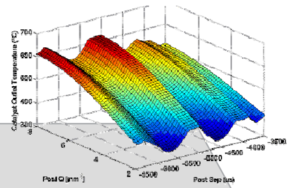
Convention



Design of Experiments Approach

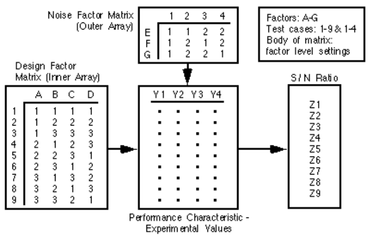


DoE Driver Model Process Flow

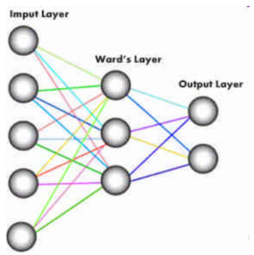


Execution of DoE Runs → **Neural Network Fitting** → **Data Analysis**

- 10,000 runs are executed
  - 3.8 hours of computing time
    - Intel Cored Duo 2.16 GHz
- Lumped parameter vehicle dynamics simulation used
  - SWA rate < 400 °/sec
  - Non linear tires
  - Constant vehicle speed

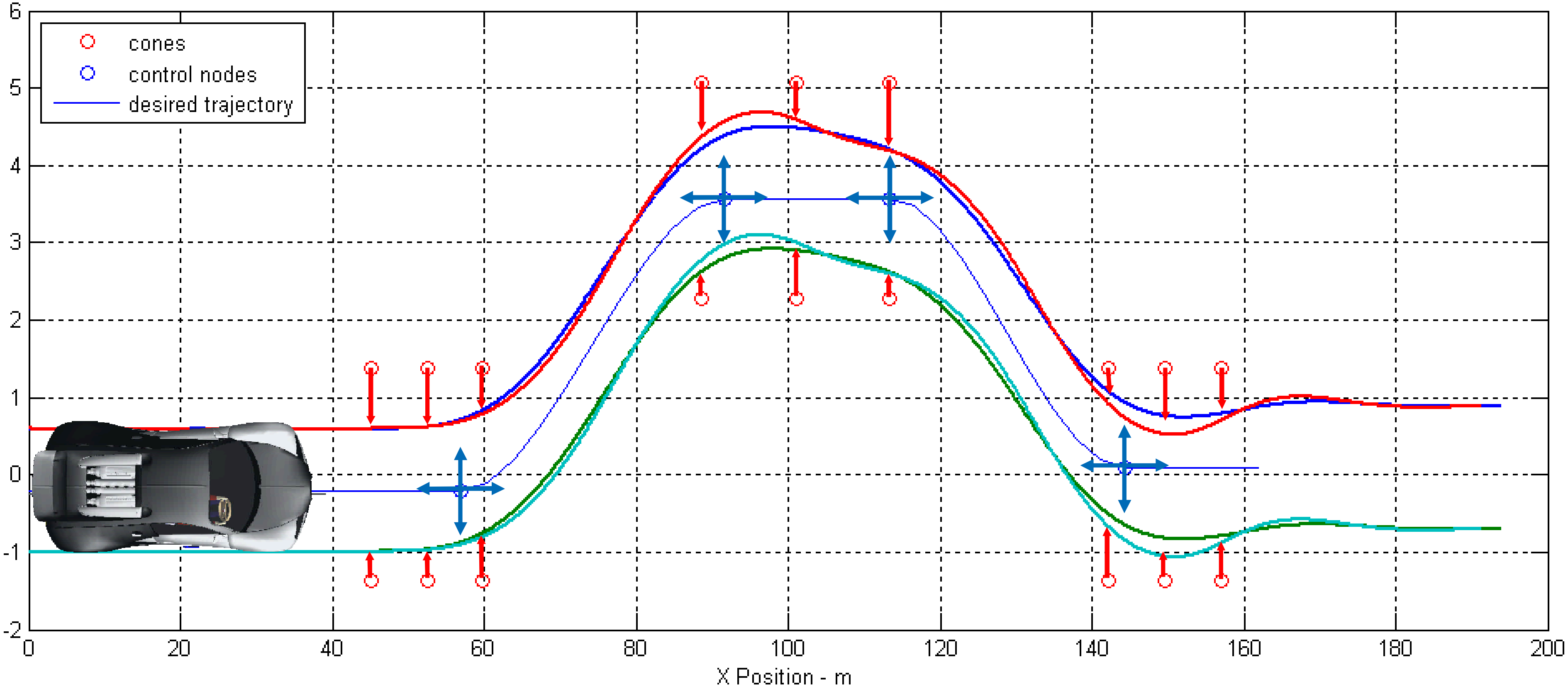


- Neural Network equations are fit to result data
  - Fitting shows very small error
  - Unlimited amout of data can be generated from approximation model
  - Vehicle Dynamics model is replaced allowing engineer to get results instantly as design evolves



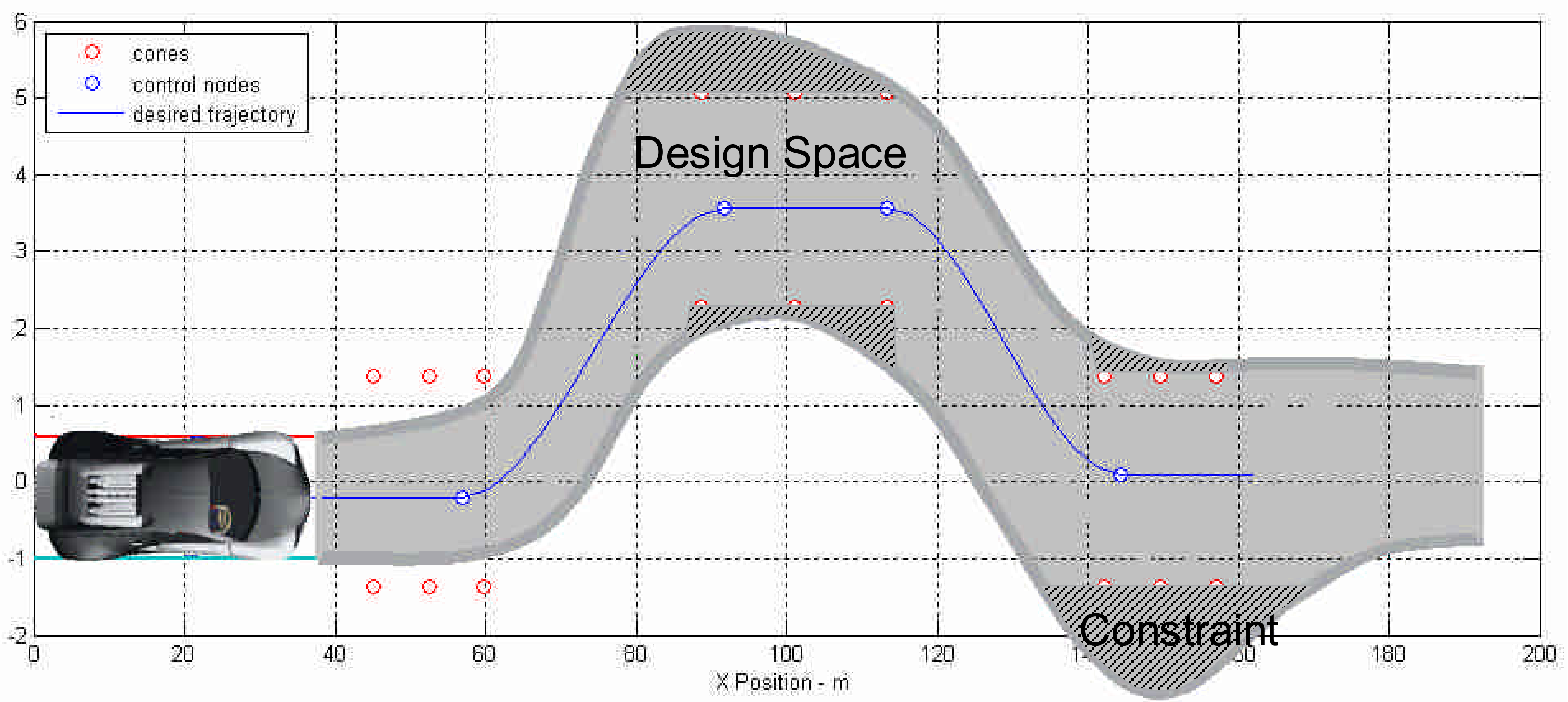
- Explore Design Space
  - Perform trade-off analysis, sensitivity studies, anomoly identification to characterize design space
- Fine Tuning
  - A confident initial position is made for the optimization to fine tune
  - Neural networks are quizzed virtually instantaneously (optimization performed in matter of minutes)

DoE Example - Double Lane Change Maneuver



- Factors: 4 control nodes [ea with 2 degrees of freedom (dof)] define a cubic spline
- Responses: 18 lateral cone distances to nearest tire trace (negative value = cone hit)

DoE Example - Double Lane Change Maneuver



- Large design space to cover wide range of vehicle trajectories
- The sampling resolution choice is a trade off between neural network accuracy and DoE run time

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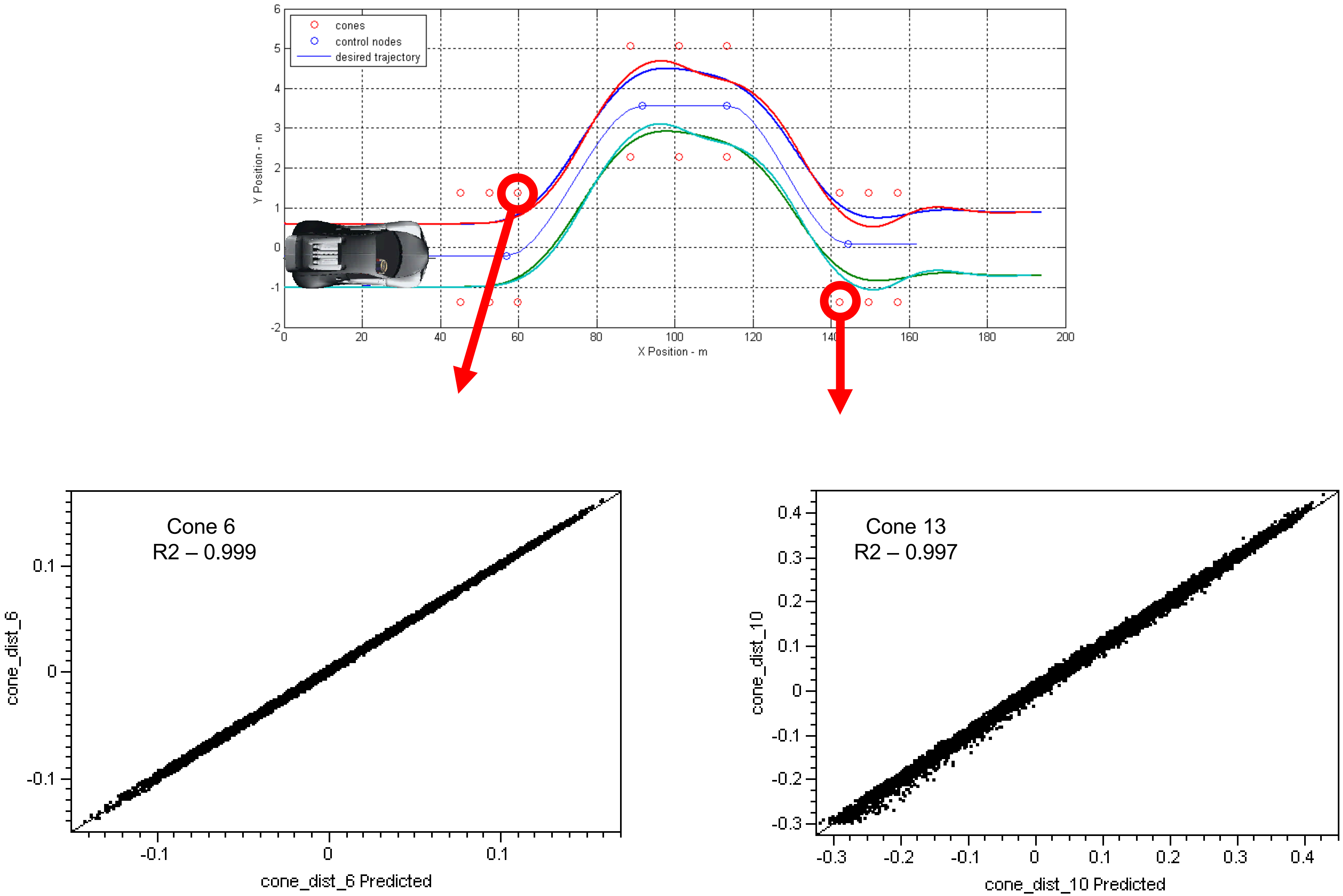
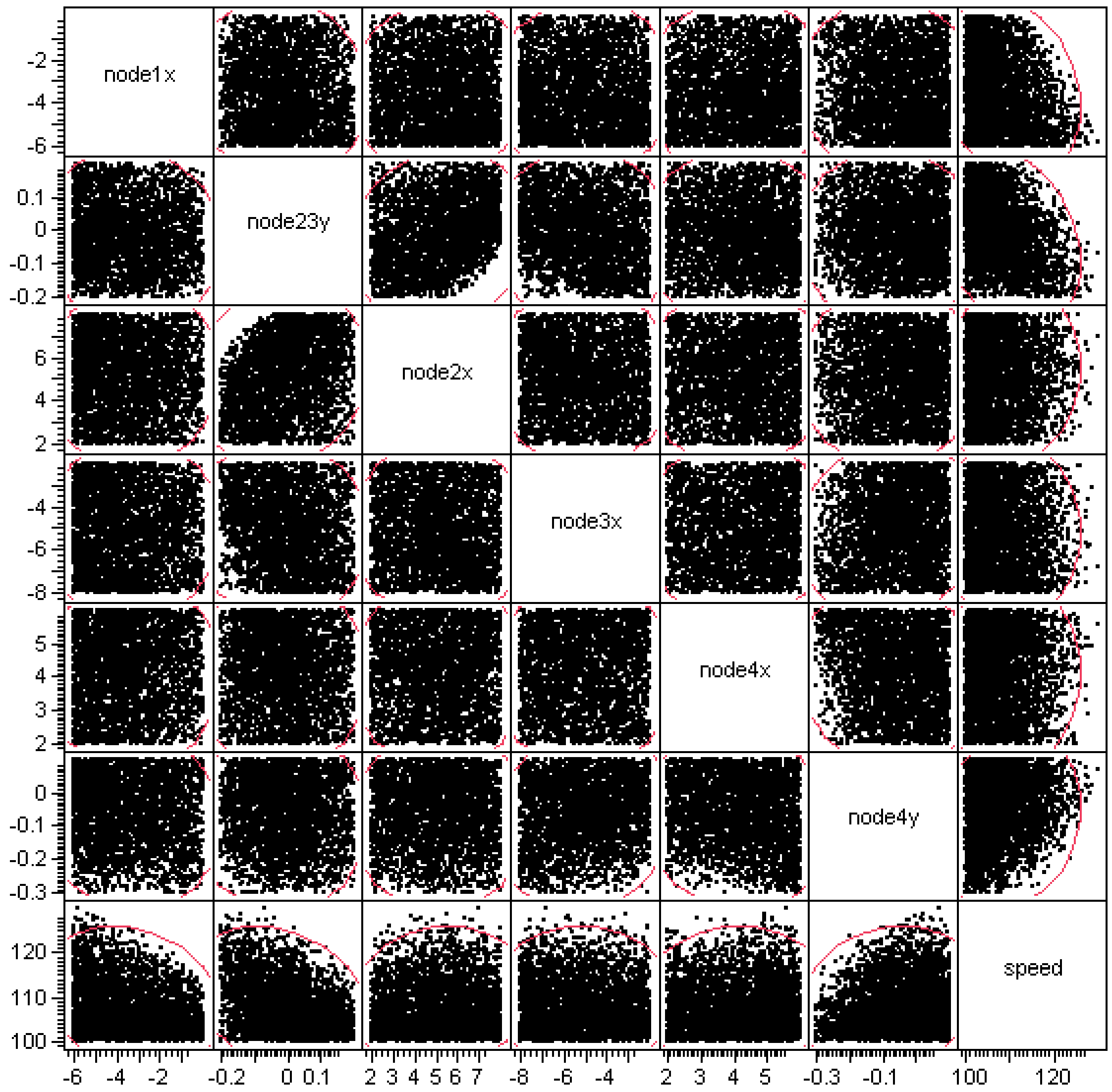
Neural Network Fitting – Actual vs. Predicted Values

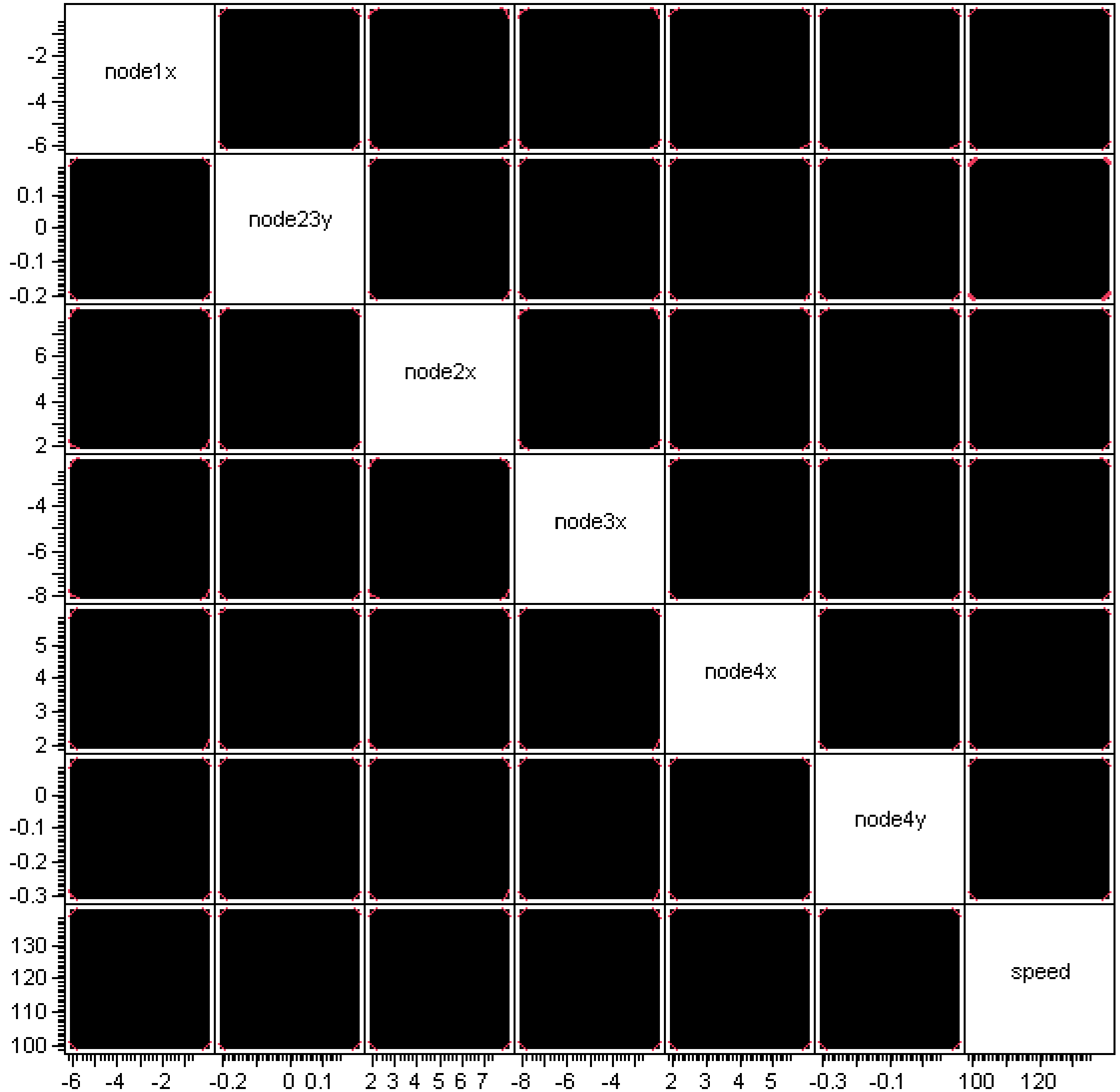


Data Analysis – Multivariate Matrix



- Approximation model used to generate extremely large data set (5e5 points)
- Green points are successful lane change completions
- An understanding of the design space allows for a confident design point to used as an initial optimization point

Data Analysis – Multivariate Matrix



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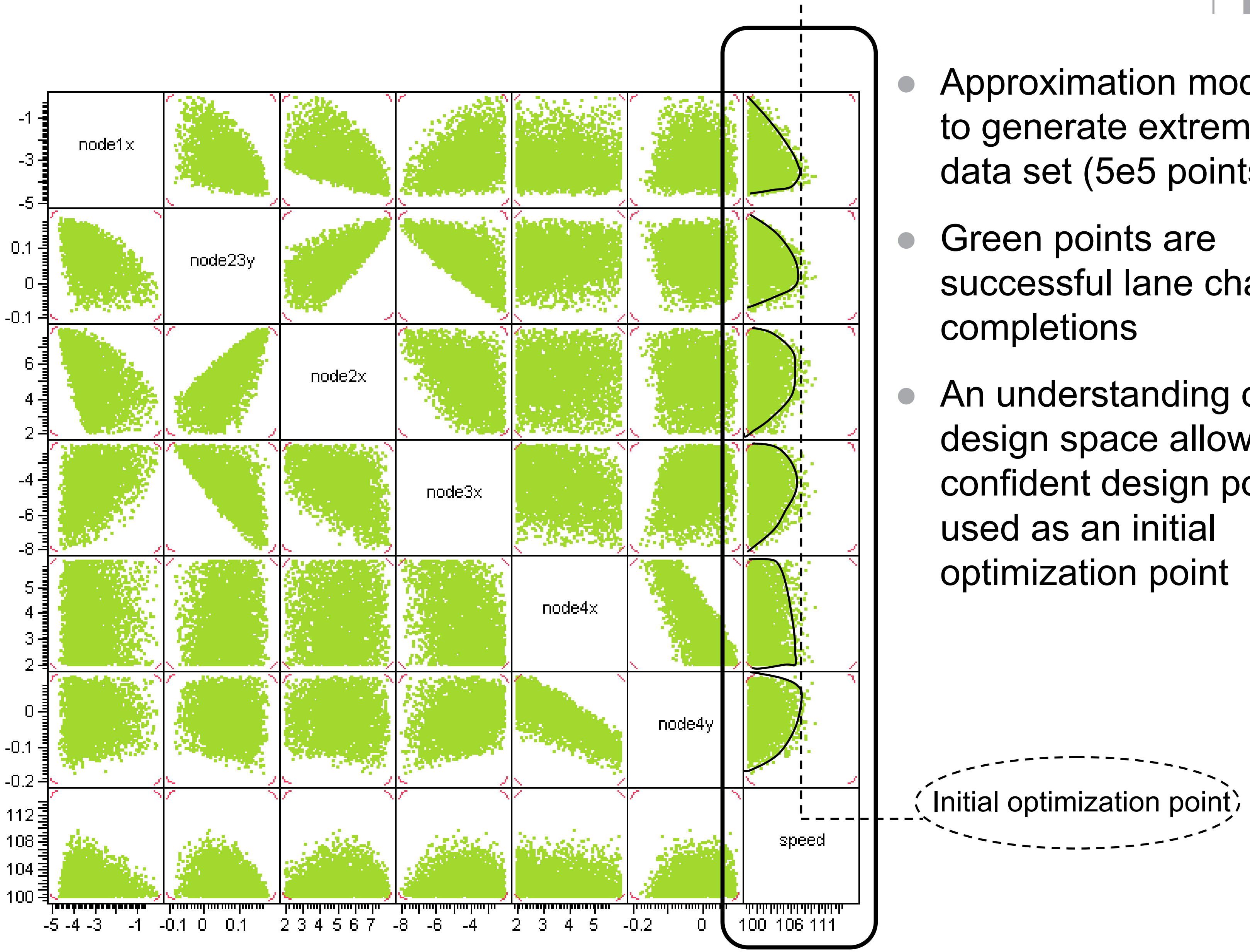

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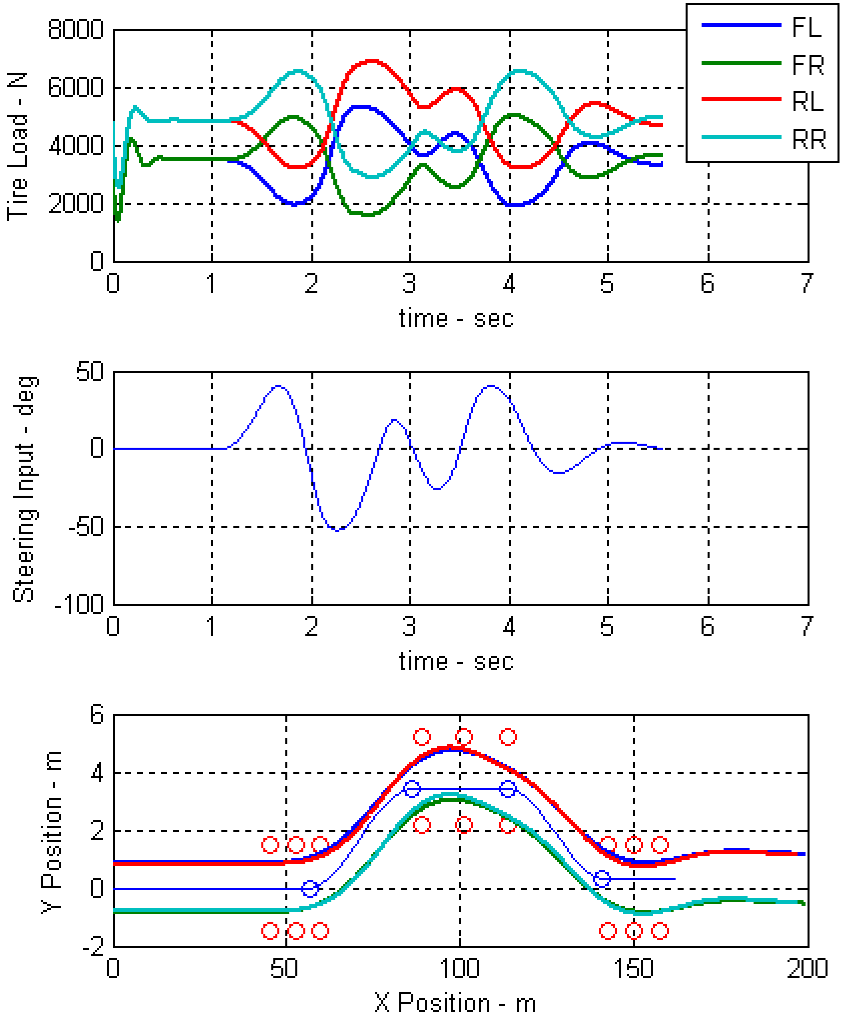
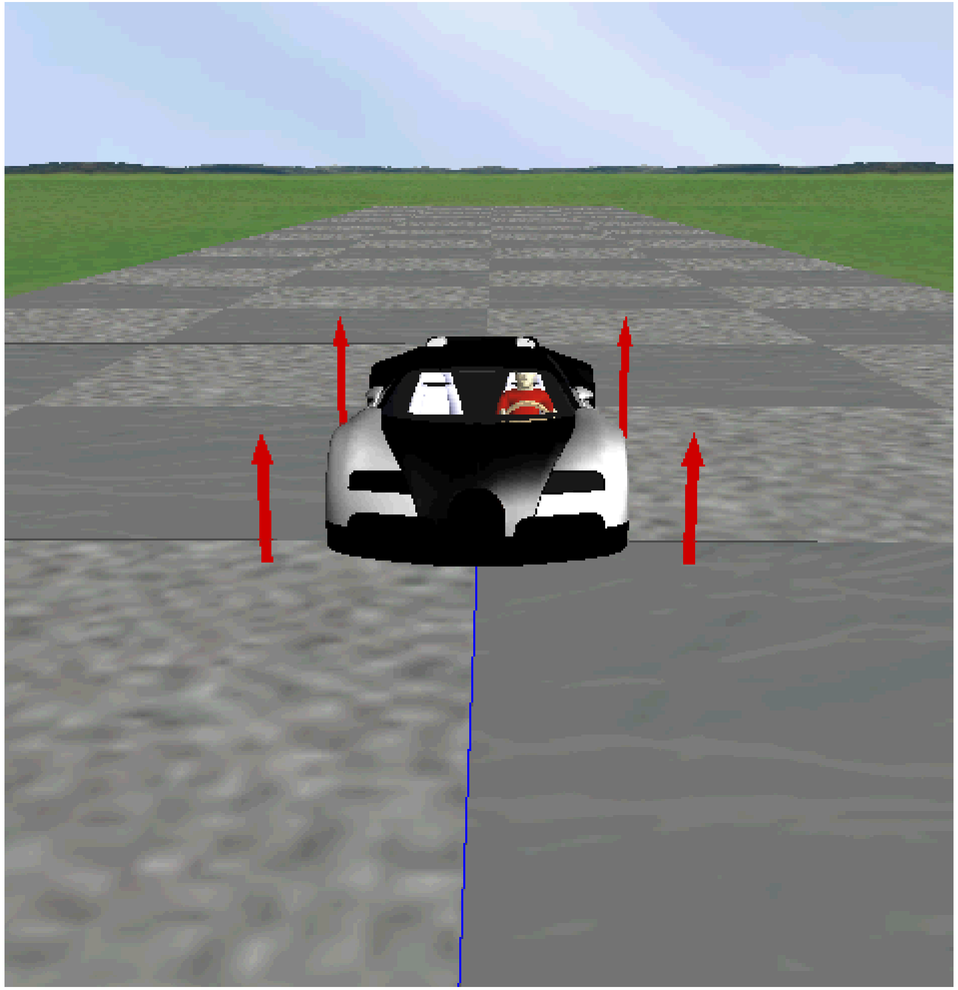
Optimized Double Lane Change Animation





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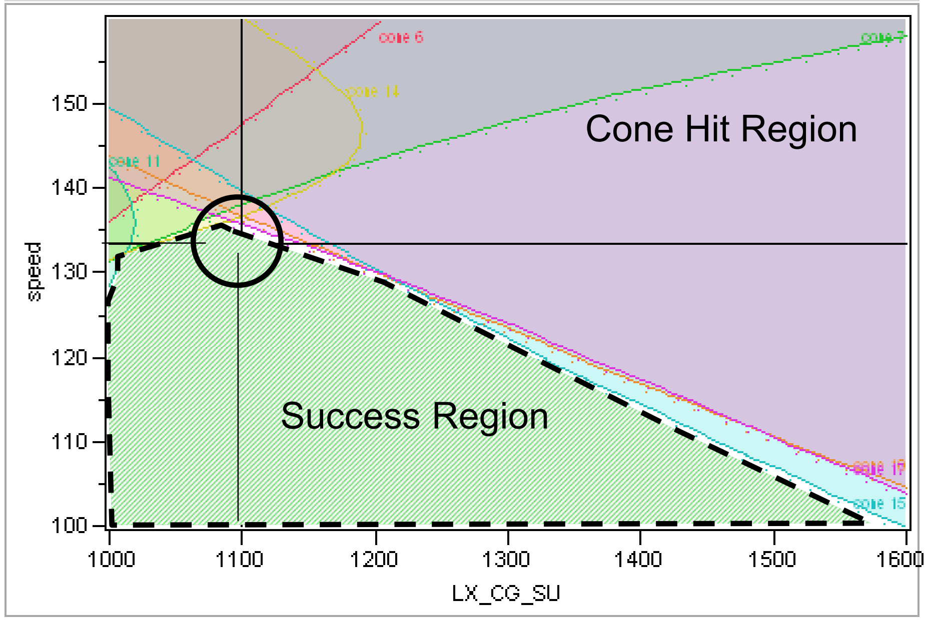
Applications

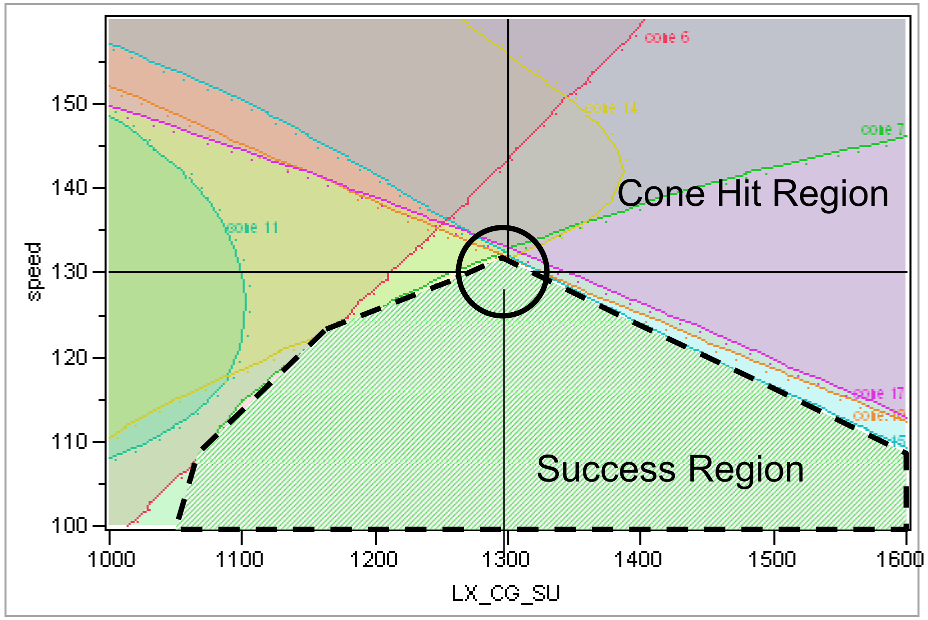
- DoE process can be used not only as a driver model but as a full vehicle design tool
  - By adding vehicle parameters as factors to the DoE matrix the influence of vehicle parameters (CG position, vehicle mass, damper rates, spring stiffness, anti-roll bar stiffness, etc…) can be studied
  - Adding the complexity of several vehicle parameters to the DoE makes the design space large but through DoE sampling and approximation techniques it is made time efficient and practical
  - Neural networks allow for the vehicle simulation model to be replaced by mathematical equations which provide the engineer with answers on the fly as design changes are executed
- As an example, a DoE was performed using longitudinal CG position as an additional vehicle design factor

Example – Long. CG 1100 mm
Constraint Visualization



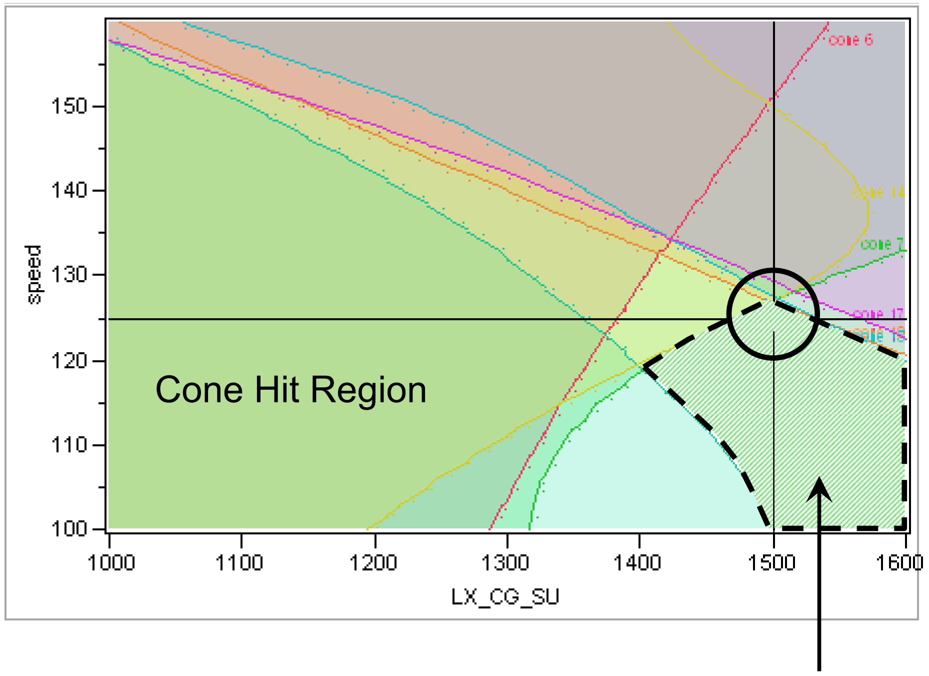
- Dashed green region shows successful lane change completion (no cone hit)
- Other colored areas define constraints (cone hits)
- Success region is greater for longitudinal CG of 1100mm
- Local CG sensitivity is visualized – when changing CG by large values driver inputs will need to be re optimized
- 4 cones are near hits

Example – Long. CG 1300 mm
Constraint Visualization



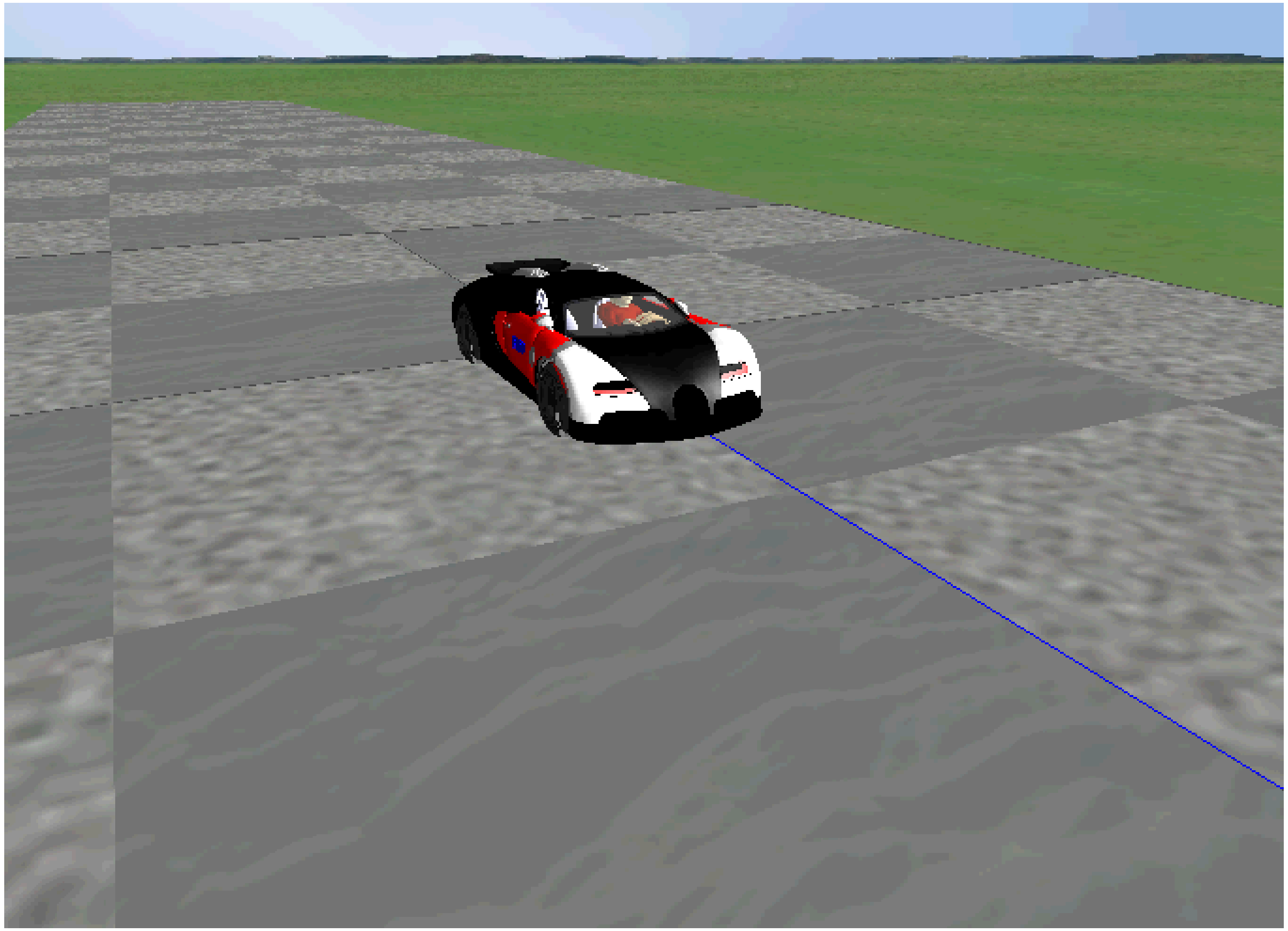
- Driver inputs have been tweaked for CG of 1300mm
- Success region is about same size as before
- Local CG sensitivity is more pronounced
- 5 cones are near hits showing a greater degree of difficulty in driving

Example – Long. CG 1500 mm
Constraint Visualization



- For a CG of 1500mm, the success region is dramatically smaller
- Lane change speed is decreased
- 5 cones are near hits
- As CG is moved rearward, lane change performance is degraded and greater driver skill are required

Example – Optimized Double Lane Change Animation



White – CG @1100 mm

Gray – CG @ 1300 mm

Red – CG @ 1500 mm

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Summary

- This concept study shows that the DoE approach to driver modeling
  - Provides a method for objective answers
  - Ensures robustness of the design choice
  - Allows sensitivity studies to be performed on driver inputs as well as vehicle design parameters
  - Allows flexibility in the design objective choice without the need to re-run computer intensive simulations

Questions