



System Engineering Simulation Applied to Motorsport

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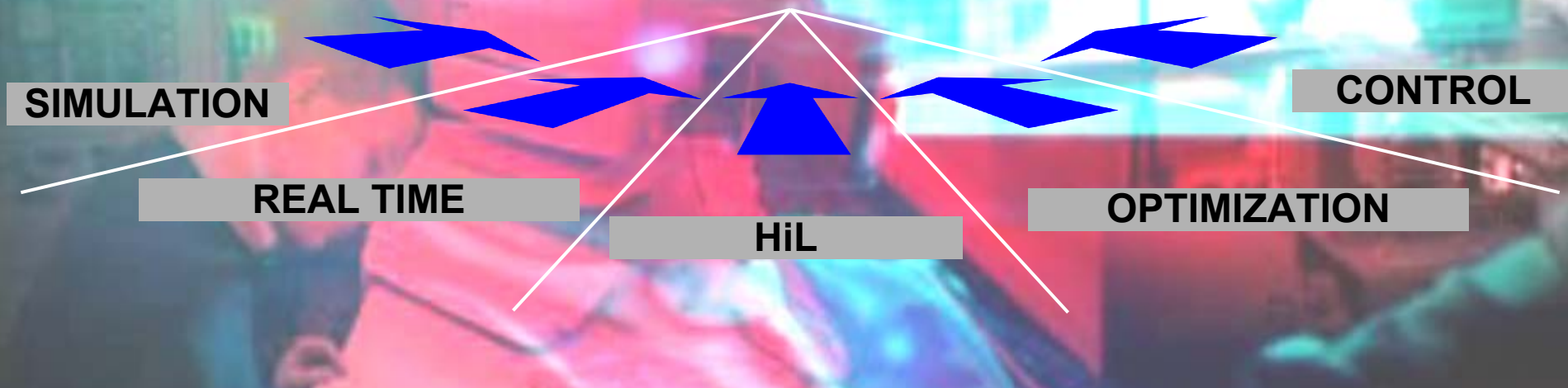
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The future of vehicle engineering lies in virtual evaluation and development of complete vehicle systems through high fidelity component and subsystem models operating in a co-simulation environment, enabling hardware-in-loop component evaluation & development linked to a highly responsive vehicle simulator that delivers human-in-loop interaction and evaluation



This allows for the optimization of each component within the operating range of the system it is part of.
The main advantages are:

- ☐ Allows for a complete trade-off analysis between each components performance
- ☐ Achieves an overall optimum for the system
- ☐ Allows for the testing and evaluation of each component before it is built
- ☐ Reduces the development cycle by using high fidelity simulation codes with fast run time and optimization
- ☐ Reduces the number of mule vehicles to be built and tested
- ☐ Using a simulator as early as the concept stage will provide a safe evaluation environment

Ricardo is championing the development of new methods and co-simulation strategies to achieve the optimization of increasingly complex system driven by new requirements [fuel economy, performance, emissions, etc...]

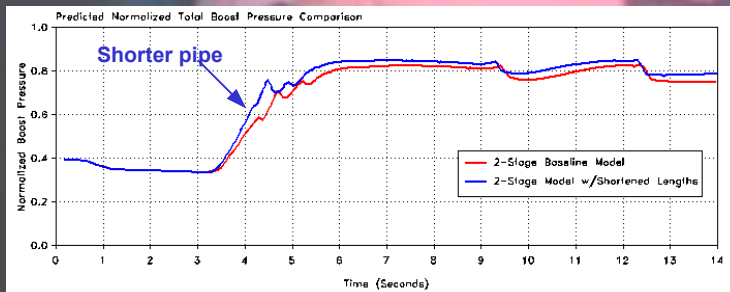
The transient behavior of an automotive system becomes very important in achieving these targets as simulation:

- ❑ Allows for a realistic assessment of component performance during real life operation
- ❑ Allows the development team to focus on the challenges early on and re-direct the program as necessary hence saving time and money

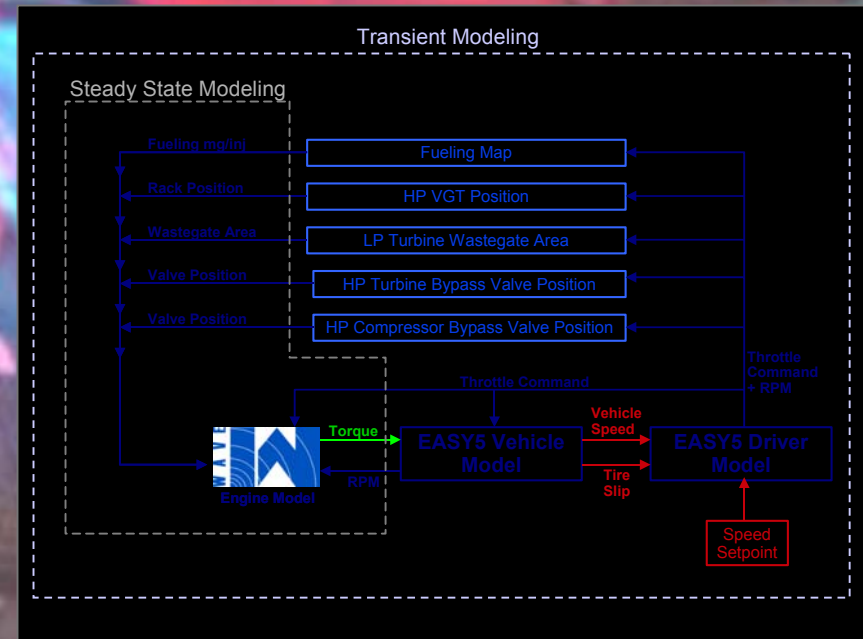
Example: WAVE - MATLAB - EASY5 co-simulation

In the development of a sequential turbo-charged LDD engine, MATLAB Simulink + WAVE was used to size the boosting system and develop control maps at steady state.

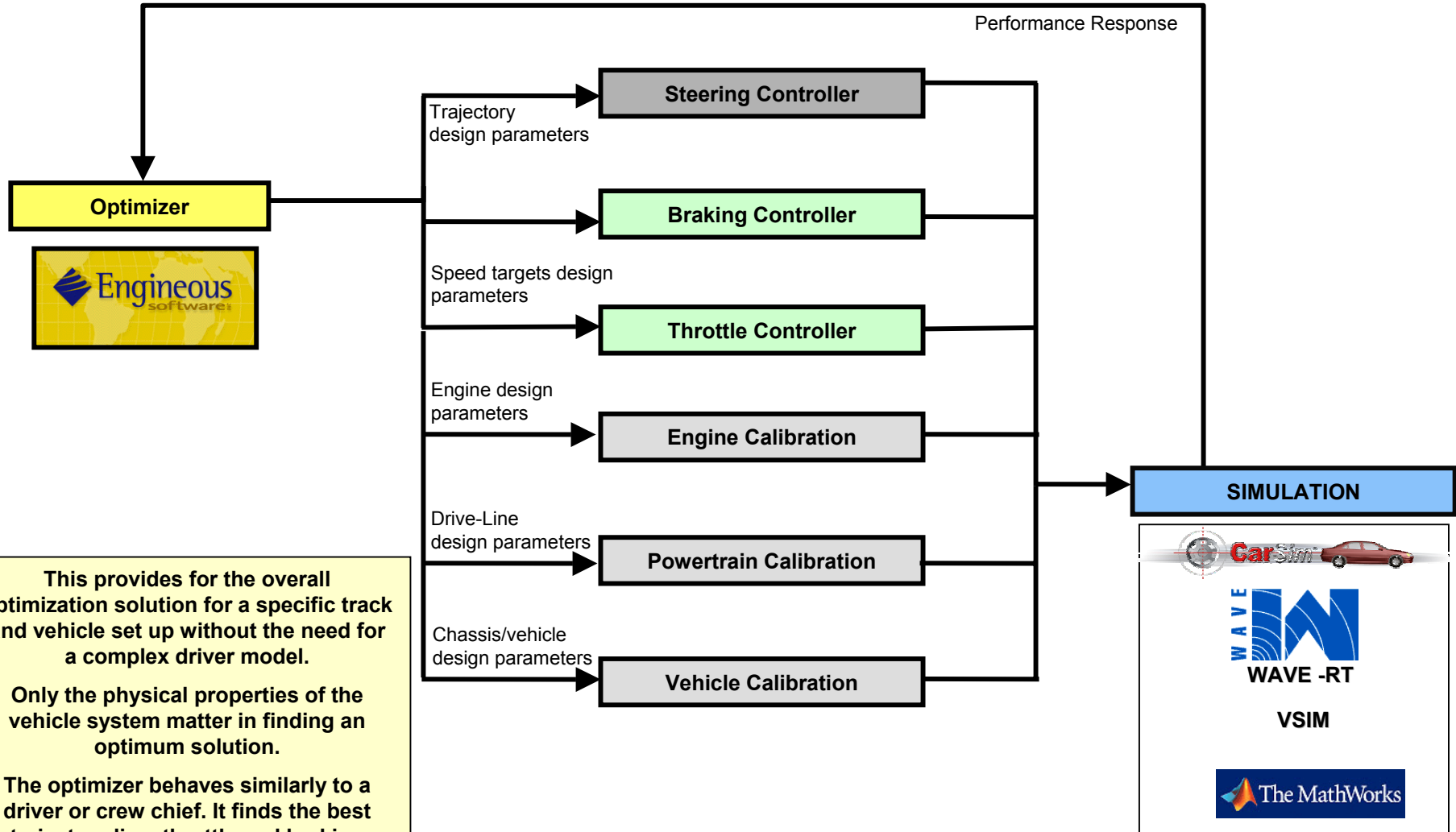
The Simulink + WAVE model was then linked to a vehicle model in EASY5 for transient performance simulation. Only then can the impact of the design decision pertaining to the location of the 2 turbo-chargers be achieved.



Normalized Boost Pressure Trace during Transient Acceleration



MOTORSPORT APPLICATION CONCEPT: LAPTIME

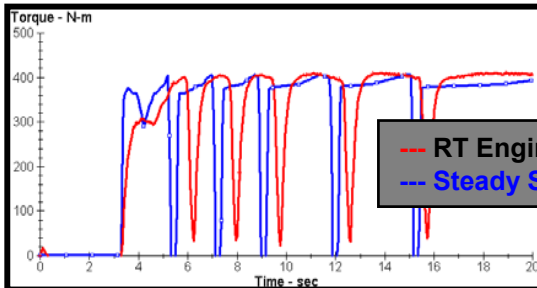
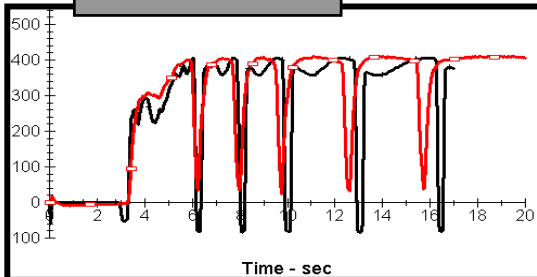


MOTORSPORT APPLICATION: TOOLS

WAVE-RT^{BETA} provides realistic transient engine response and allows for various technologies to be tested on the fly. Real Time capable when compiled.

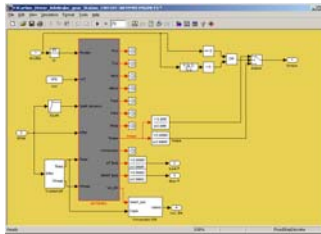


--- RT Engine Model
--- WAVE



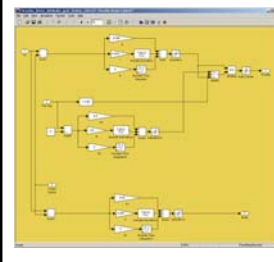
--- RT Engine Model
--- Steady State Blue

WAVE-RT^{BETA}

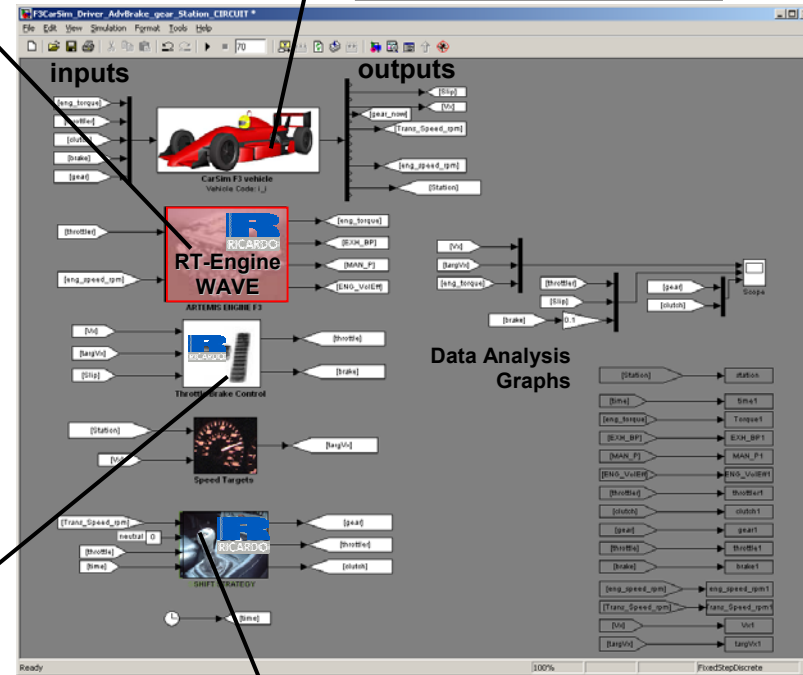


- ☐ Physical model
- ☐ Intake/exhaust dynamics
- ☐ Real-Time capable

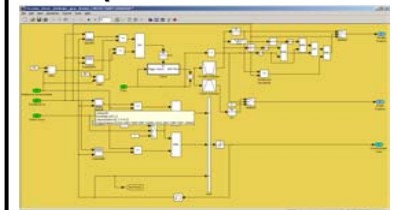
Throttle / Brake Controller



- CarSim S Function**
- ☐ Chassis model
 - ☐ Vehicle characteristics
 - ☐ Tire models
 - ☐ Race track data



- VSIM Powertrain Model**
- ☐ Transmission mode
 - ☐ Up/Down Shift Points

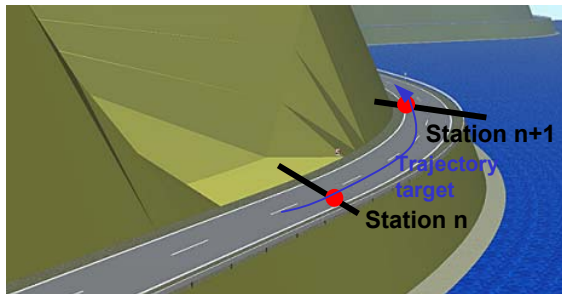


MOTORSPORT APPLICATION: OPTIMIZATION₁

Example 1: Constant Speed – S shape turn

Genetic Algorithm is used to optimize the section time on an S-shaped turn divided into 2 sections. 7 stations with variable longitudinal location on the track were set. For each station, a variable lateral target from the road centerline is used to generate a target trajectory input to the steering controller. Speed is maximized over the track.

The optimizer finds an optimum solution with the constraint being that the conditions at the end of turn 1 are identical to turn 2 starting conditions.



Design Parameters:

- Vehicle speed
- 7 stations positions
- Trajectory targets @ 7 stations

Output:

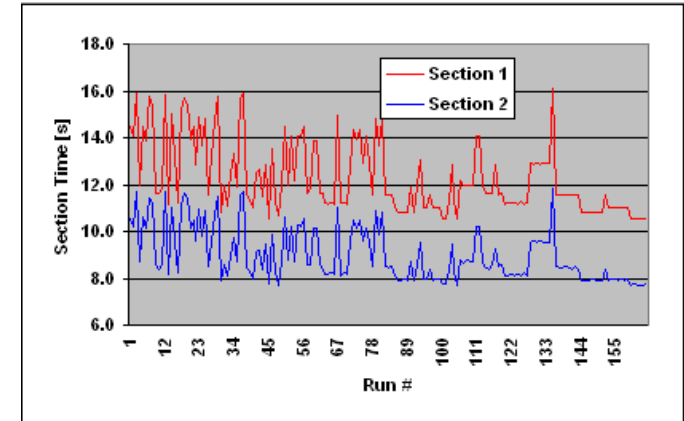
Turn 1 and 2 run time



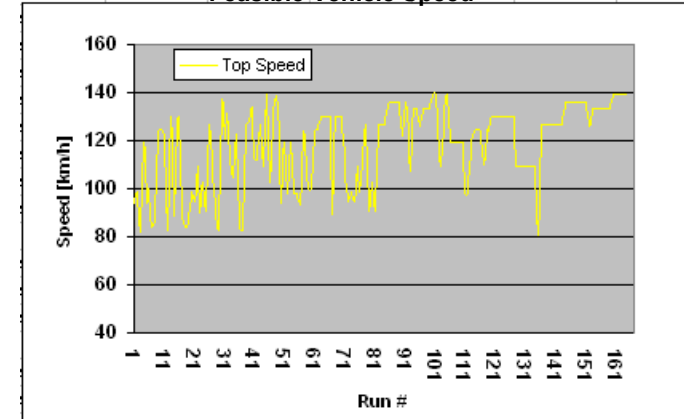
Red car: feasible run
Blue Car: Unfeasible
Black Car: Optimized

ANIMATION

Section Time Minimization



Feasible Vehicle Speed



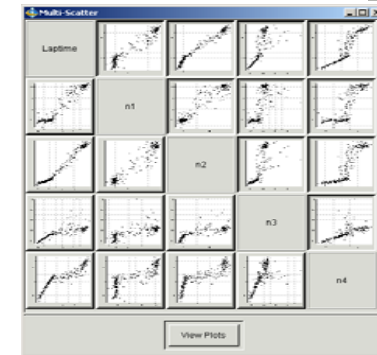
Run Time: 1h [with steady state torque curve]

MOTORSPORT APPLICATION: OPTIMIZATION₂

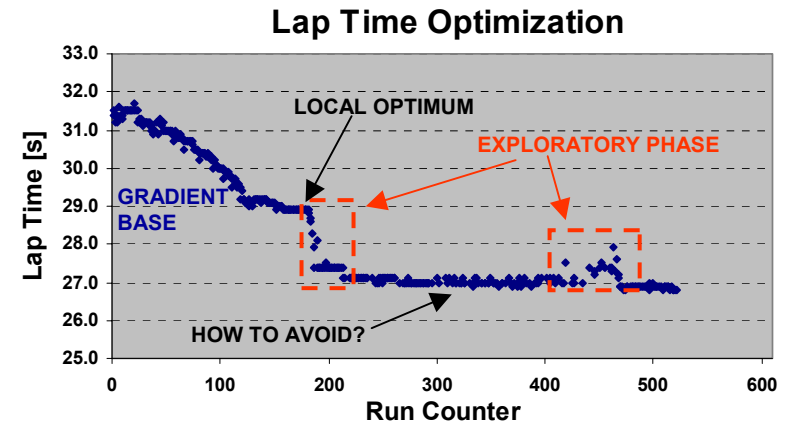
Example 2: Full Optimization – Simple Track

In this example, DoE and optimization are used to optimize vehicle speed and trajectory as well as powertrain design parameters, in this case related to engine performance using WAVE-RT.

The Data Mining Tool is used to choose a baseline vehicle set up with good overall performance from the DoE runs. The optimization method is a mix of exploratory and gradient base method in order to avoid a local minimum.

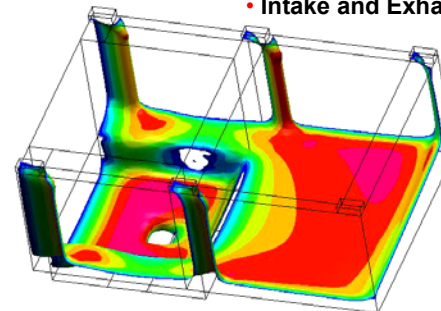


Data Mining



Run Time: 15h [with engine model not compiled]
• 30 trajectory and speed target parameters
• Intake and Exhaust cam timing

Optimized vehicle data is passed to CFD for dry sump oil motion during turn 2 operation



G-G Diagram Based Optimization – new development

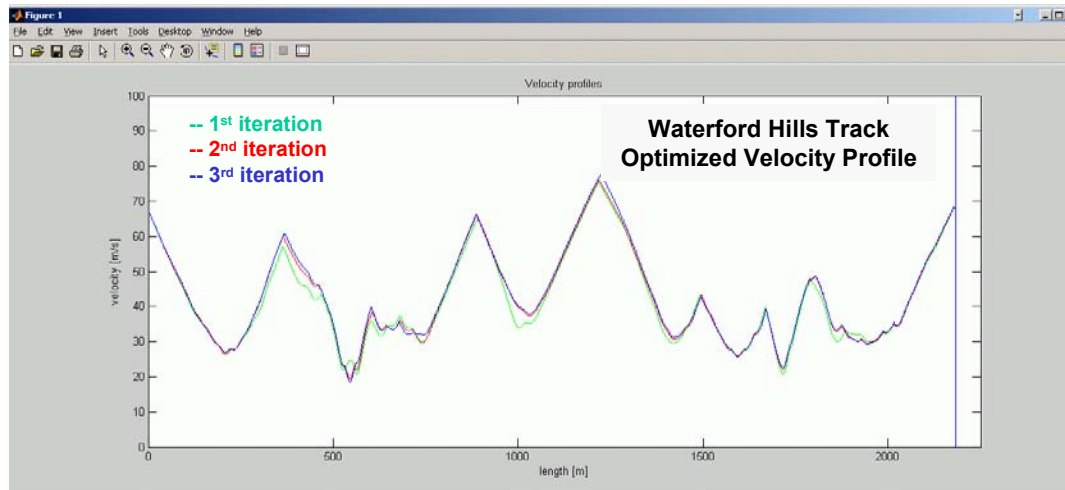
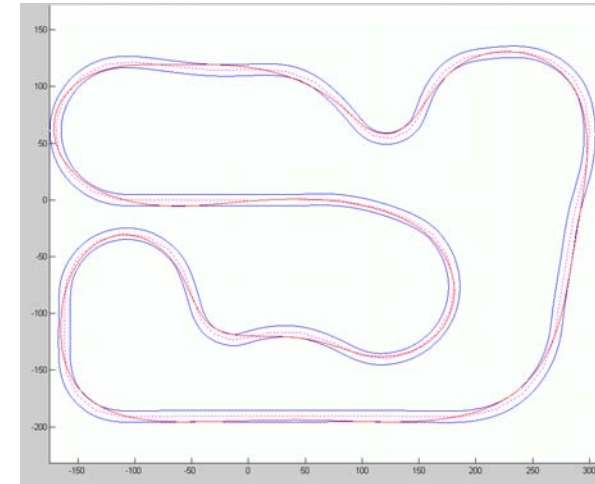
Example 3: Full Track

The track is divided into 9 sections and a piece-wise optimization is performed so as to match the end/start conditions of each segment. This is achieved by overlapping each segment during the optimization.

The optimization is performed using the vehicle maximum longitudinal and lateral acceleration capability. This can be achieved by running various maneuvers simulation with CarSim. It was approximated in this example. The vehicle trajectory is parameterized as in the previous examples and a MATLAB code computes the critical vehicle velocity at each apex [max. lateral acceleration] and fills in between based on the vehicle longitudinal acceleration capabilities for each trajectory iteration.

The results can be used as the baseline start point for the optimization using the full co-simulation tool and hence shorten run time. It can also be used for assessing the track characteristics and make quick decision on the vehicle set up.

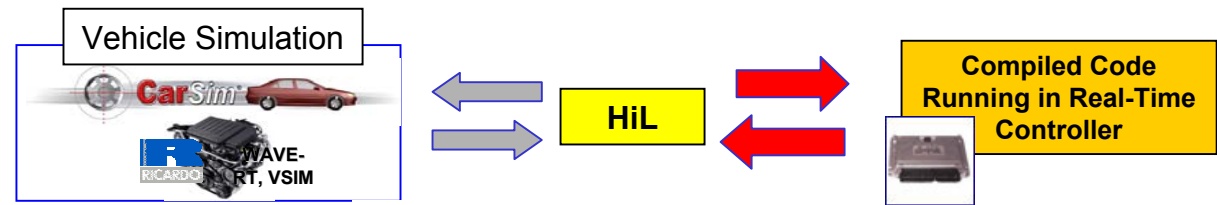
**Waterford Hills Track
Optimized trajectory**



Future Development

The laptime simulation tool was developed by Ricardo to demonstrate the maturity of the available codes and the possible connection between them. Analysis led design will become a standard in the industry in order to reach future vehicle requirements.

The Virtual Vehicle System goals are to provide:



- ❑ High-fidelity replication of vehicle performance and feel
- ❑ Reduced iterations of prototype hardware
- ❑ Reduced development time when hardware changes are virtual
- ❑ Reduced dependence on test tracks and environmental trips
- ❑ Improved test repeatability
- ❑ Vehicle equipped with an extensive array of virtual instrumentation (simulation state variables) which can be used in objective rating systems
- ❑ Simplified calibration or algorithm comparison
- ❑ Ability to do “what-if” testing and comparison when hardware does not exist

WAVE-RT^{BETA} and CarSim were run successfully real time on a 2 processor OPAL-RT system. For future simulator work, CarSim will handle the connectivity with the hardware and driver with WAVE-RT and VSIM replacing the CarSim engine and transmission blocks.

Emulation
Outputs

Driver Control
Inputs



Vehicle Simulators

The lap time tool provides a platform to implement new methods in system engineering:

- ❑ Integrates specialized codes into one robust environment that best fit the application
- ❑ Integrate in-house codes without sharing Intellectual Properties [use of ISIS]
- ❑ Access a large amount of interacting design variables to scan the full system design space
- ❑ Use advanced DoE, optimization and customized methods to optimize the full system and avoid:
 - local optimums
 - lengthy simulation time
- ❑ Use network resources in order to minimize run time [parallel processing, ISIS]
- ❑ Be accessible from remote locations [ISIS]
- ❑ Automatically share outputs to different engineering departments for secondary studies [CFD, FEA, etc...w/ ISIS]

In its actual set-up each software can be used for Real-Time simulation. This is a key asset as HiL and Man-in-the-Loop development activities are increasingly a major part of automotive development programs. The methodology used by the laptime simulation tool is applicable and being implemented in many automotive system development such as:

- ❑ Conventional vehicle development including after-treatment simulation
- ❑ Hybrid vehicle systems
- ❑ Advanced concepts [camless engines integration, 2 stroke/4 stroke switching “HULK” engine, etc...]

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