Thank you, …, for the introduction.

Good afternoon, Ladies and Gentlemen,

At FEV, GT-DRIVE is applied for multiple purposes such as simulation of fuel consumption, vehicle performance prediction or gear box layout. These are typical and rather serious engineering tasks in engine and vehicle development.

But besides those activities, the simulation of a race car is not only an exiting but also a very sophisticated modeling task that supports the work of FEV Racing.

Our presentation today is intended to inform you about the challenges of modeling a Lap on the Nurburgring. You will see later, why that famous race track is also called “The Green Hell” 🌿
My presentation today will be structured as follows:

After talking about the motivation for doing lap time simulation of a race car I will show you some necessary features of the GT-DRIVE model followed by simulation results.

At the end of the presentation the above will be summarized and I will give you a prospect on how GT-DRIVE will support further development work at FEV Racing.
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Among reasons like marketing or demonstrating excellence, there are other, just emotional reasons to be engaged in motor sports. Those are hard to explain to people who do not share this enthusiasm. Such a group of racing maniacs came together at FEV and decided to spend their free time in a cold test cell building at a noise level of 140 dB.

The FEV racing team was born.

FEV Motorentechnik however, provides the material resources to support these activities.

With major engagement together with team Scheid Motorsport in the BFGoodrich endurance championship, but not limited to that, the FEV Racing Team activities cover the subjects listed here.
Success in motor sport – and in particular for endurance races – is mainly influenced by:

- aggressive, but also careful drivers
- a vehicle, which is perfectly prepared
- well tuned strategy for pit stops
- and a powerful engine, simultaneously with good fuel economy

And at last but not least you need a lot of luck
Now I want give a short overview about important items of the BFGoodrich endurance championship:

- All races take place at the Nurburgring Nordschleife in combination with the (short version) Grand Prix Course.

- The race track has a very challenging profile with altitudes between 620 m at the start and 320 m at Breitscheid.
The BFGoodrich Endurance Championship (VLN)
Race Track and Championship Regulations

- Only one race track, the Nurburgring Nordschleife
  1 Lap = 24.433 km
- Engine based on production engine of same manufacturer
- No restrictions for gas exchange of naturally aspirated engines, except noise regulation
- Fuel tank capacity max. 120 l
- Refueling with gasoline-station equipment
- Up to 3 drivers for each vehicle

Further information: http://www.vln.de

- In the vehicle class “24 hour specials”, in which the BMW M3 with FEV’s 4.0l V8 engine is classified, you can use any production engine from the manufacturer of the vehicle as baseline for deep modifications.
- For naturally aspirated engines there are no special restrictions for tuning the gas exchange, except a noise regulation for the running vehicle.
- The capacity of the gasoline tank of the race car depends on the vehicle type, for the investigated car a maximum capacity of 120l is allowed.
- Refueling of gasoline – typically after approximately 10 laps (which is equivalent to 244 km) – must be carried out with gasoline station equipment. Due to this, an engine with high efficiency is needed to reduce overall pit stop time.
- Most cars are driven by more than one driver.
Now let me show you a few features of the GT-DRIVE model 🤝
GT-DRIVE Model Approach
Level 2 Vehicle Model with ‘VehDriver’ Object

Here you can see a typical GT-DRIVE ‘Level 2’ model with detailed driveline with e.g. a tire object, which contains maps for rolling resistance or tire traction. The engine is described by maps like friction vs. engine speed or BMEP and fuel rate vs. speed and load.

Also a driver object is included, but … 😊
The driver operation mode within GT-DRIVE allows constant values for e.g. accelerator pedal position or use of ‘ProfileTransient’ reference objects. For lap time simulation, all driver events depend on the vehicle position at the race track.

Driver Object of GT Drive not useful for lap time prediction because of time based action.

...the driver operation mode within GT-DRIVE can only be used together with time based ‘ProfileTransient’ reference objects. For the lap time prediction, the driver object of GT-DRIVE is not useful, because all necessary driver action – like braking or gear shifting – depends on the current vehicle position on the race track.
GT-DRIVE Model Approach
Simulation Philosophy and Simplifications

- Only consideration of longitudinal dynamic effects
- Transversal dynamic vehicle behavior (side forces) covered by specification of maximum cornering speed (taken from data logging) for each corner of the race track
- For max. acceleration, target speed set to unachievable high value
- Anticipatory brake algorithm depends on distance to next corner
- No influence of vehicle parameter (e.g. weight or drag coefficient) on lap time investigated, yet

As you know, GT-DRIVE is mainly a software tool for simulation of longitudinal dynamic effects of a vehicle. But for lap time simulation you also have to consider transversal effects. To cover this for the simulation work at FEV Racing, all transversal effects are integrated by specification of a maximum cornering speed for each corner of the race track. These values are taken from the data logging of the vehicle. Between two corners the vehicle can accelerate as much as possible. Therefore, the target speed is set to an unachievable high value.

To fit the maximum corner speed, an anticipatory brake algorithm depending on the distance to the next corner and the road grade is calculating the latest possible brake point.

These simplifications can be made because the simulation tool is only used to improve the engine, not the vehicle. This includes that the different vehicle parameter (e.g. weight or tire specifications) were not varied during our simulation work.
As we had to replace the driver, we rebuilt strategies for all necessary functions using GT-SUITE control elements. This includes also the calculation and the output of the appropriate gear number.

Different functions were required for the actuation of clutch and gear number for up and down shift, as the sequential gear box was power-shift enabled. This means, up shifts are done under load, whereas the driver has to step on the clutch pedal for downshifts.
The handling of the so-called power shift is shown here. Down shifts on the left are done opening the clutch. But under up shift the clutch remains closed.

The engine management system will retard spark timing briefly, to unload the gears for shifting.
Now I want to present the comparison of measured vehicle data with the results from the GT-DRIVE simulation.
Results

I have selected the track section between Pflanzgarten and the beginning of Döttinger Höhe as you can see on the on-board video (7:48 - 8:20) out of the BMW M3 of Scheid Motorsport, equipped with FEV’s 4.0l V8 engine.

The first diagram shows the throttle position (red curve = simulation result, black curve = data logging). The second graph compares brake pressure of the vehicle with brake actuator position simulated by GT-DRIVE model. 100% brake actuator is a realistic value for a race car with anti-lock brake system. The measured brake pressure differs from the maximum value because of the ABS action. Here you can see a very good correlation between simulation and measurement. The last plot includes the vehicle speed and indicates again the realistic results of the simulation work.
Results

<table>
<thead>
<tr>
<th>Track Position [km]</th>
<th>Throttle</th>
<th>Brake</th>
<th>Vehicle Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Schwalbenschwanz</td>
</tr>
</tbody>
</table>

As last results, I want to show you the overall lap time and the vehicle fuel consumption in comparison to the measured data. The difference is approximately 1%.

Optional: [Average vehicle speed is about 170 kph or 105 mph and the fuel mileage about 5 miles per gallon.]

This shows that it is possible to use GT-DRIVE for such a simulation work. The model, however, is quite a bit more sophisticated than conventional drive cycle simulation models 🤗
At last, I want to summarize the presentation and give a prospect to further race car simulation activities. 🏁
Summary

Lap time prediction with GT-DRIVE

- Simulation of race car lap time is possible with GT-DRIVE
- Conventional simulation model with VehDriver object has to be modified
  - Time based VehDriver object is not useful
  - All driver action depend on vehicle position on the track
  - Algorithm for calculation of brake points is necessary
  - Gear shifting has to consider ‘Power-Shift’
- Simulation result for lap time and fuel consumption deviates approximately by 1 % from measured data

We have seen, that the simulation of race car lap time using GT-DRIVE is possible. However, some measured data is still required to handle to bypass the problem of handling side forces.

The vehicle driver model had to be rebuilt with modified functionality, as it has to determine brake points and match corner speed.

The simulation results match measured data quite closely.
Prospect

Further planned extensions of FEV’s simulation model

- Influence of vehicle parameters such as drag coefficient on cornering speed via ‘Lookup1D’ out of further measured data
- Consideration of vehicle track position on gear shift events
  - A human driver will not shift in higher gear immediately before braking
- Handling more detailed track information such as
  - Corner radii
  - Variations of tarmac
  - Track temperature

- These extensions will require further validation with measured data

Further activities of the race car model will deal with including the influence of for example down force and drag force on cornering speed. In a first step this could be handled by interpolating between corner speeds of laps with a steep and a flat rear wing.

Furthermore, our driver model currently shifts only dependant on engine speed. But a human driver will just continue driving in the speed limiter when he is about to brake for the next corner.

Further extensions may deal with capturing the influence of tarmac characteristics and of track temperature on traction. The modeling of true side force would require models of each single wheel instead of axes and thus extensive support from Gamma Technologies.

All these extensions for sure have to be validated again with track measurements.
Thank you for your attention and feel free to ask everything.