# Preliminary Results of a Vehicle Model for Simulation in Motorsport

**by**

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## Abstract

This paper presents a research program undertaken at the Industrial Research Institute Swinburne (IRIS), in collaboration with MoTeC Australia Pty Ltd, a company specialising in electronics products for motorsport applications. Commencing in February 2000, the program is expected to conclude in 2003. The purpose of this research is to investigate the use of vehicle modelling and simulation in motorsport applications. The current iteration of the developed vehicle model is outlined, and a summary of its key features and potential applications are given. Preliminary results of the current stage of development are presented, in a graphical comparison with the performance of an actual vehicle.

## 1. Introduction

Purnell (1998) notes that most professional racing teams utilise elaborate data acquisition systems to measure the performance of virtually any and every vehicle component. The objective is to determine an improved vehicle configuration by analysing the performance which results from the current state of vehicle specification.

Further, he believes "the single thing that most engineers would like to know … is simply what is the best combination of chassis, power train, aerodynamic settings for the track in question. This alone would be a great step forward". Despite the measurement sophistication currently employed, the choice of such vehicle settings is generally dependent on the skill and experience of the race engineer.

This research program is an attempt to contribute to such developments, by creating analysis techniques that better utilise the vast data recorded on a vehicle's performance. If a sufficiently accurate vehicle model is developed and validated by comparing the simulation results with measured data, the model parameters may then be varied to study and predict what effect these changes may have on the actual vehicle. The research work described herein focuses on summarising the current level of development of the model at the time of writing.

## 2. Potential Applications

The simulation model under development, as a primary outcome of this research program, allows the flexibility to potentially accommodate a wide range of vehicle configurations and characteristics. The scope exists to simulate front, rear or four wheel drive vehicle configurations, and any vehicle component can be tailored to suit such as engine, brakes, gearbox and transmission, tyres, suspension and aerodynamic characteristics.

As such, the possibilities for potential future applications may include:

- Evaluating the effects of parameter changes on the resulting whole vehicle performance, such as trying a different final drive or gearbox ratio, or a different spring and damper combination, thereby supplementing traditional testing and development
- Lap time simulation/prediction
- Implementing optimisation techniques to determine parameters that improve the model's performance, which may in turn result in improved performance of the vehicle being modelled
- Driver line investigation and optimisation.

In the time constrained motorsport environment, where testing and development on actual circuits is expensive, time consuming, and limited in numerous classes, this research may result in time and financial benefits.

## 3. Vehicle Representation

The dynamic behaviour of a vehicle may be studied by mathematically modelling the system in question. The set of equations of motion were derived and represented in SIMULINK and MATLAB. These packages were used to solve the equations of motion numerically, allowing the directional motion of the modelled vehicle to be analysed.

The model in its current state of implementation utilises a vehicle representation first proposed by Segel (1956), in what may be considered the pioneering work of vehicle dynamics studies. In this paper, Segel considered the vehicle to consist of two masses; a rolling mass constrained to rotate about a fixed "roll axis" relative to the non-rolling mass.

The rolling (or sprung) mass may be thought of as consisting of all parts of the vehicle supported by the suspension system (including a portion of the suspension system itself). The non-rolling (or unsprung) mass may be regarded as all other mass not carried by the suspension system, but which is supported directly by the tyre/wheel, and is considered to move with it. A useful visualisation of the vehicle representation employed is shown in Figure 1, including key terms, directions and orientations.

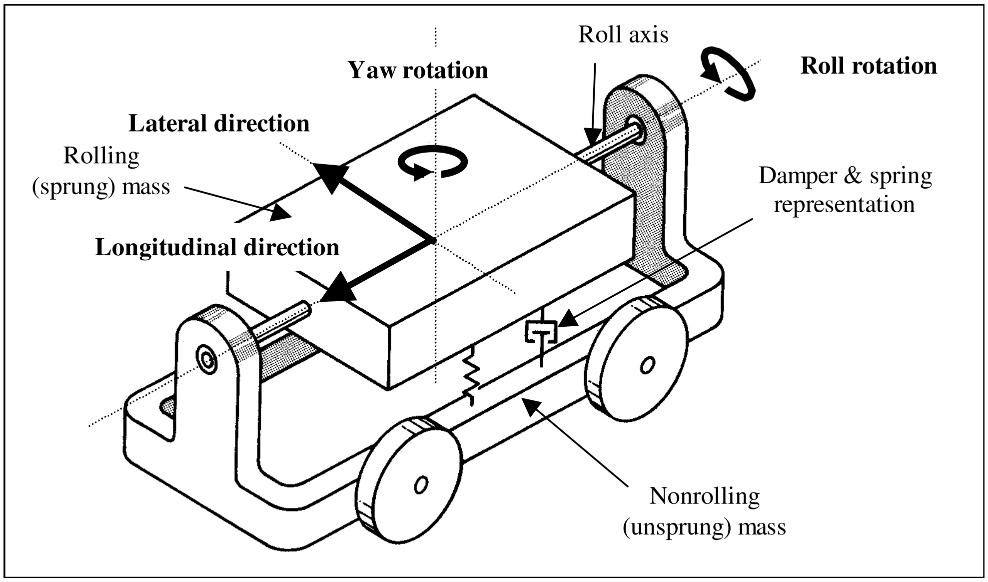


***Figure 1 – Two Mass Model of Vehicle with Roll Axis (Doebelin 1980)***

## 4. Model Features

Conceptually similar to the operation of an actual vehicle, the developed vehicle model responds to the inputs of braking, steering and throttle. In its current state of development, these may take the form of typical control waveforms (such as a ramp steering input, step throttle input), or as time sequenced data (for instance measured steering input trace from an actual vehicle).

A level of vehicle representation to include in the model was specifically chosen in order to satisfy the compromise between the complexity required for accurate results, and the simplicity required for meaningful understanding, analysis and use of those results by the end user. Over 50 parameters or characteristics are required to represent the vehicle to be simulated. Figure 2 gives an overview of the vehicle subsystems which are accounted for. This gives an indication of the level of vehicle representation included, and a selection of the parameters required.

Some of the key outputs available for analysis may include:

- Vehicle velocity
- Longitudinal and lateral acceleration
- Yaw and roll angle and velocity
- Engine RPM and torque produced
- Gear number selected
- Tyre slip angles, and normal, lateral and longitudinal forces produced
- Vehicle trajectory.

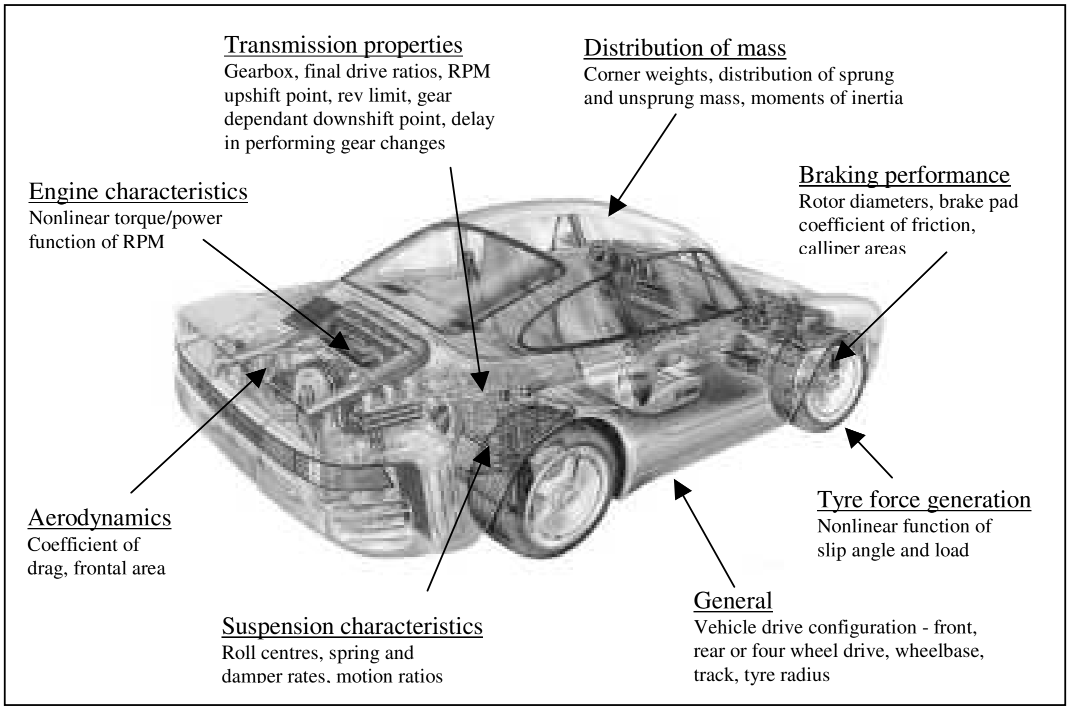


***Figure 2 – Represented Vehicle Subsystems, including Various Required Parameters***

## 5. Results

This section presents a graphical comparison of simulation outputs from the vehicle model in its current state of implementation, to those of an actual vehicle.

The vehicle in question was from Australia's so-called "premiere V8 Supercar" motorsport category. This class was based on Australian manufactured and mass produced, right hand drive, four door sedans, fitted with five litre pushrod two-valve V8 engines (V8 Supercars Operations Manual, 2000). These large rear wheel drive production cars have an approximate mass of 1400kg, with engines outputting around 480kW (620bhp).

An onboard data acquisition system was used to log the vehicle's performance around a lap of Willowbank Raceway, Queensland (shown in Figure 3). The vehicle's measured steering, throttle, and front and rear hydraulic brake pressure traces were fed into the simulation model as inputs, along with approximate vehicle parameters. Figures 4 to 7 show selected resulting outputs, compared to those measured from the data acquisition system.

As an indication of the computational efficiency of the model, an actual lap of 69.88 seconds took approximately 60 million floating point calculations and 15.39 seconds to simulate.

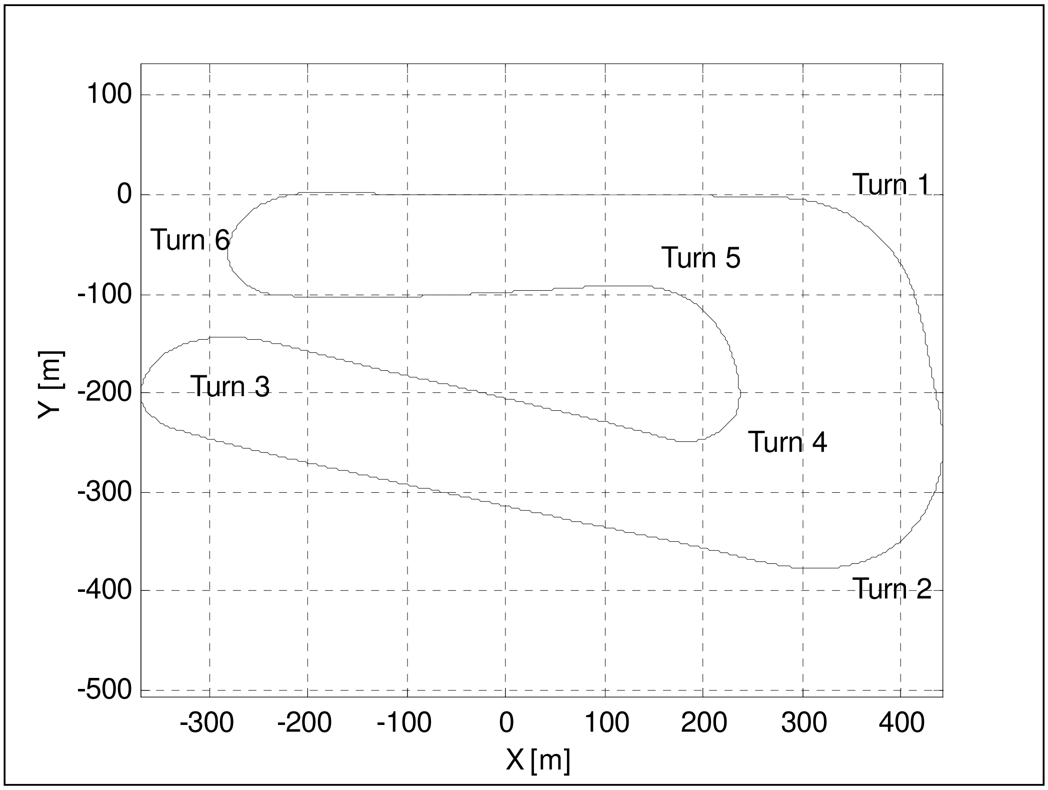


***Figure 3 – Circuit Layout: Willowbank Raceway, Queensland***

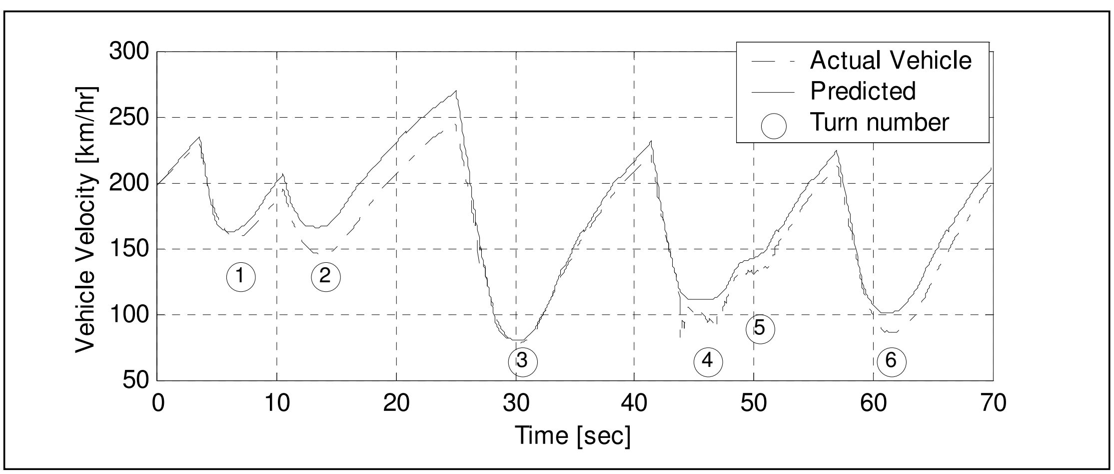


***Figure 4 – Predicted versus Actual Vehicle Velocity***

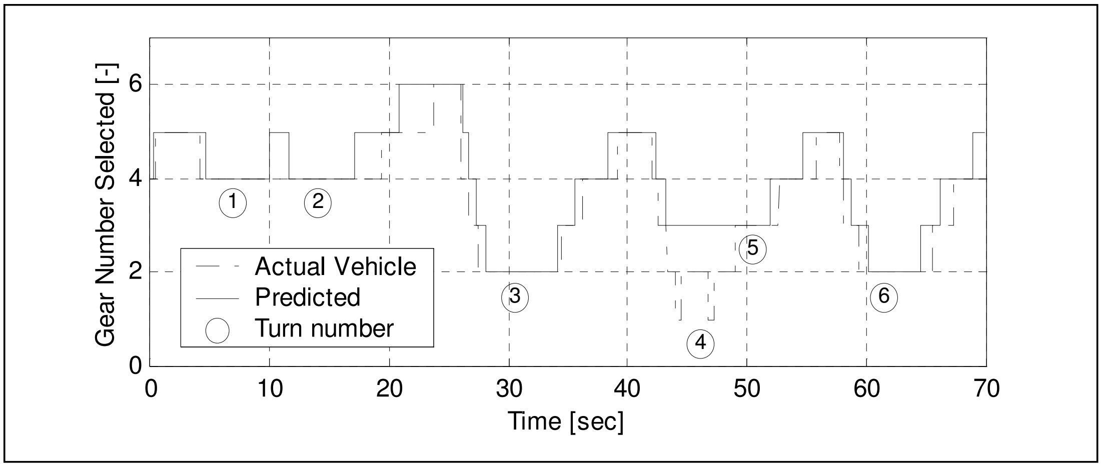


***Figure 5 – Predicted versus Actual Gear Selection***

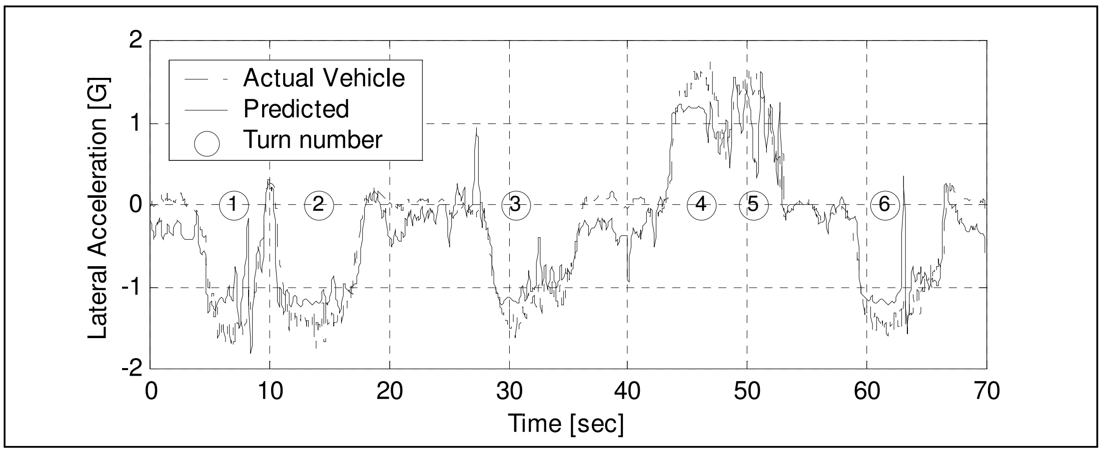


***Figure 6 – Predicted versus Actual Lateral Acceleration Generated***

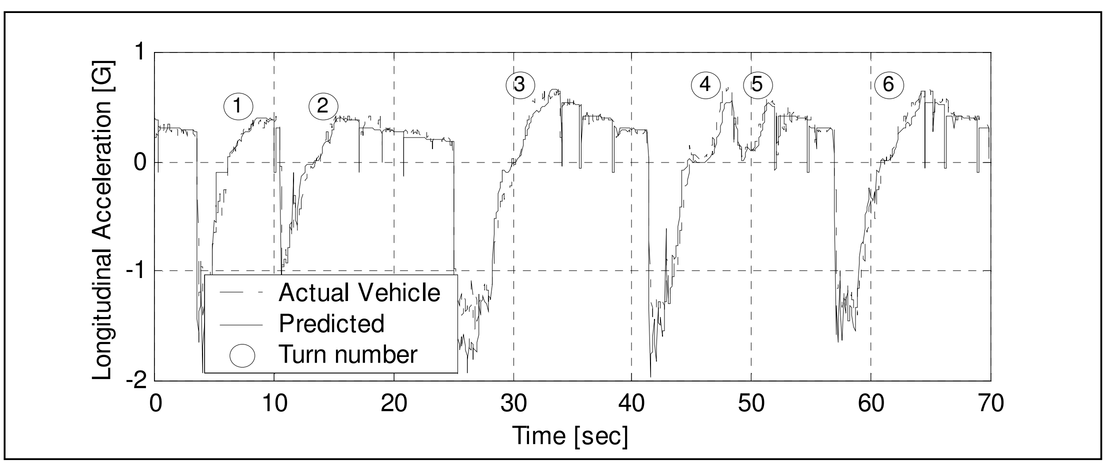


***Figure 7 – Predicted versus Actual Longitudinal Acceleration Generated***

## 6. Further Work

A detailed discussion of the preliminary results presented is beyond the scope of this paper. However, from Figures 4 to 7, it can be seen that the model in its current stage of development generally predicts the overall trend of the actual vehicle's performance.

As such, these results are encouraging, given that many of the vehicle parameters used were based on educated approximations, and therefore may not be particularly indicative of the exact vehicle specification used during the test. An illustrative example is in the area of tyres. The implemented nonlinear tyre model found in the literature (Radt 1994), represented a tyre of a similar size and vehicle application (ie relatively powerful and large rear wheel drive production car). However, it is unlikely that the modelled tyre, based on data measured in a laboratory and developed for a different motorsport category, exhibits the same force generating behaviour as those which were used on the tested vehicle under actual racing conditions.

Furthermore, the actual vehicle was driven with its inputs suitably modulated by the driver to follow a given path or trajectory. Operating in an open loop manner, the model was subjected to these data logged inputs in order to observe the resulting outputs, without reference to location on the circuit. Evidence of this can be seen in Figure 6, where the model predicted lateral accelerations to be non-zero along the straights, due to a slight error in the measured steering angle trace.

As such, further work involves the determination of a more complete and accurate vehicle parameter set, and the development of a "driver" model to generate the inputs required for the vehicle model to follow a given path in a closed loop manner. This would allow fully independent simulation of a vehicle to be performed, with the results directly comparable to those measured from the vehicle being modelled.

## 7. Conclusion

The simulation model under development as a primary outcome of this research program allows the flexibility to potentially accommodate a wide range of vehicle configurations and characteristics. The scope exists to simulate front, rear or four wheel drive vehicle configurations, and any vehicle component can be tailored to suit such as engine, brakes, gearbox and transmission, tyres, suspension and aerodynamic characteristics. Through the use of simulation and modelling, it is envisaged this research program will result in analysis tools which will aid in the choice of vehicle settings which achieve improved vehicle performance. The presented preliminary results indicate that the current model iteration generally predicts the overall trend of the actual vehicle's performance.

## 8. Acknowledgments

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