Overview of VERT Project: prediction of full vehicle behaviour in dangerous situations

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ABSTRACT

Transport system safety is clearly one of the most important social problems and involves a lot of items, such as road, tyre and vehicle design. VERT Consortium (EC funded Project BRPR-CT97-0461), including ten partners from six different European countries, has faced this problem in the last three years implementing in ADAMS Environment a full vehicle model focused on tyre/road interaction in presence of water, snow and ice. A strong experimental activity has been of course included (taking advantage of the hardware available in the Consortium and also developing new devices), but always targeted to modelling the main subsystems involved (i.e. the tyre, the road, the vehicle and also the driver). Such a model has been finally exploited to detect the most dangerous situations and to define guidelines for the optimised design of new products.

This paper presents a general overview of VERT activities and achievements, where the key-point has been clearly represented by the implementation and validation in ADAMS environment of the Tyre model, the Vehicle model and also the “Human” Driver model (with special procedures for identifying ADAMS/Driver “Human” parameters).

INTRODUCTION

VERT Consortium included 10 partners from 6 different European Countries:

- Pirelli Pneumatici (I)
- Nokian Tyres (FIN)
- Florence University (I)
- VTI (SE)
- TRL (GB)
- FIAT Research Center – CRF (I)
- Darmstadt University (D)
- Porsche (D)
- Helsinki University of Technology (FIN)
- CETE de Lyon (F)

The project started in November 1997 and lasted as planned exactly three years: following the original programme, the activities were developed in four main directions:

1. Development and validation of a new road-tyre-vehicle simulation **model**. This activity included the development of sub-models concerning:

- **friction prediction** models in presence of water, ice, snow and slush on the pavement
- development of **tyre-pavement interaction models** in presence of water, ice, snow and slush
- development of a **vehicle simulation model** using the previous submodels to asses the vehicle stability under adverse weather conditions.

2. Implementation of a real-time version of the road/tyre/vehicle model for driving simulators applications

3. Improvement of simulation capabilities of the existing **driving simulators** adding the behaviour in critical conditions

4. Development of specifications in order to improve friction measuring equipment in low (especially snow and ice) adherence conditions; construction of a **new generation test devices**

As herewith reported, other practical results of VERT have been:

- Identification of **dangerous physical situation** and driving environments
- Development of **guide lines** to improve each of the system components (road, tire, vehicle) to enhance road safety

As detailed in Fig.1, VERT activities were divided into 7 tasks:

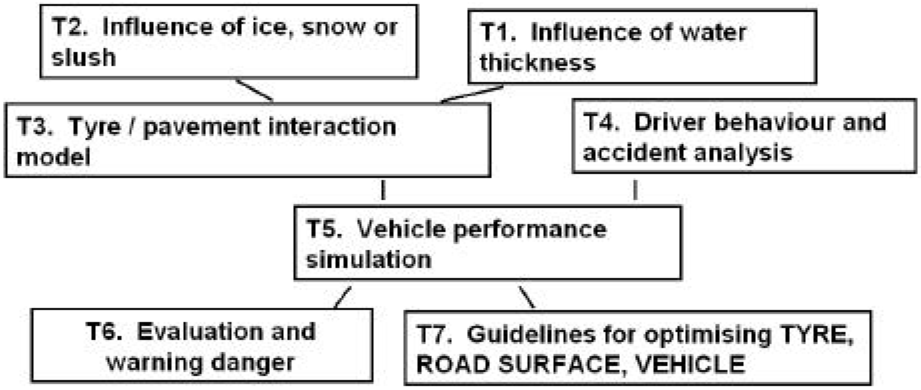


Fig.1 VERT Project Flow-Chart

DEVELOPMENT OF NEW TESTING DEVICES

The concept of VERT Project was to take advantage of the testing hardware available in the Consortium in order to perform a strong experimental activity always focused on the modelling objectives (i.e. the representation of tyre, road, vehicle and also driver).

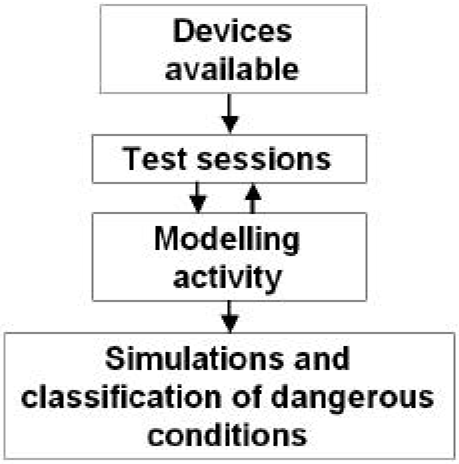


Fig.2 VERT Concept

The experimental activities have included, for instance, an intensive session of tests on wet and snowy road developing, thereby making necessary the development of **two new measuring vehicles** and a **special snow characterisation device**.

Nokian Tyres built a new second-generation friction measurement vehicle in order to be able to measure the lateral and longitudinal friction properties of tyres under the actual ice, snow and slush conditions (Fig.3).

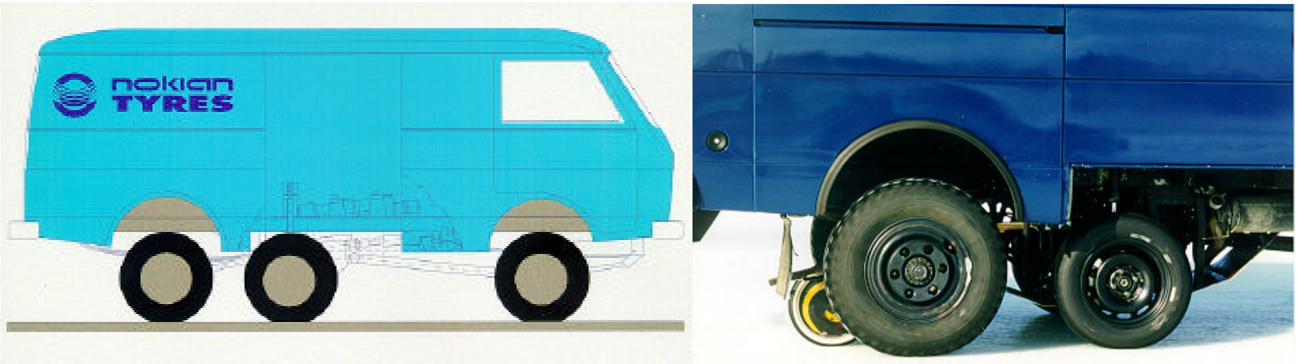


Fig 3. Nokian Tyres' second-generation friction measurement vehicle

The vehicle has two test wheels between the front and rear axles. The slip angle of both the wheels can be adjusted both dynamically and statically. The test wheel on the right side of the vehicle is driven by a hydraulic motor, which can either accelerate or brake the wheel. This wheel can be used either for plain longitudinal slip measurements or for combined longitudinal and lateral slip measurements. The test wheel on the left side is equipped with a disc brake for locked wheel braking measurements. The left side wheel can also be used for zero longitudinal slip lateral force measurements. The load for both the test wheels is applied with hydraulic cylinders. The cushioning is realised with hydraulic accumulator combined with load cylinders. The rotation speed of the test wheels is measured with pulse-type sensors. The suspension of the test wheels is shown in Figure 4.

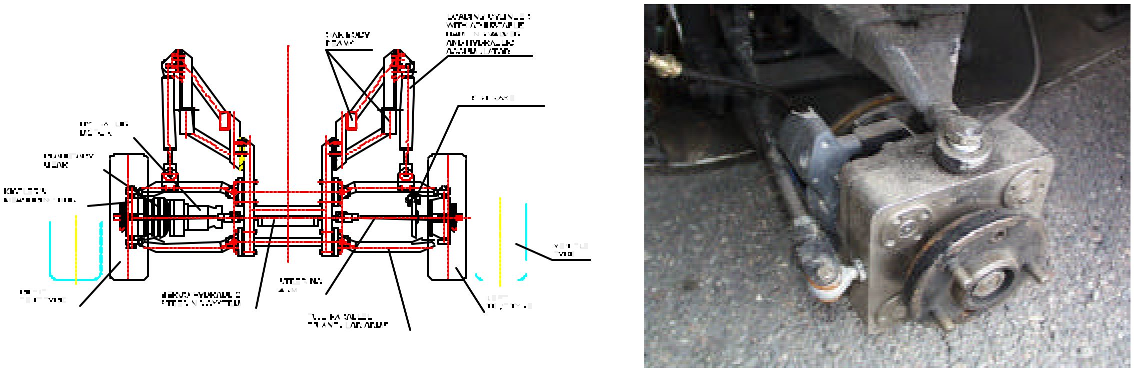


Fig 4. Suspension of the test wheels

The vehicle is capable of performing all the above-mentioned measurements at speeds up to 100 km/h.

The standard use of this equipment includes measuring longitudinal friction of a tyre under braking or acceleration and measuring lateral friction of a tyre with constant or varying slip angle. The analysis of the results is performed by comparing the tyres' friction coefficients at desired slip rates or slip angles to each other. An example of results is represented as shown in Figures 5.

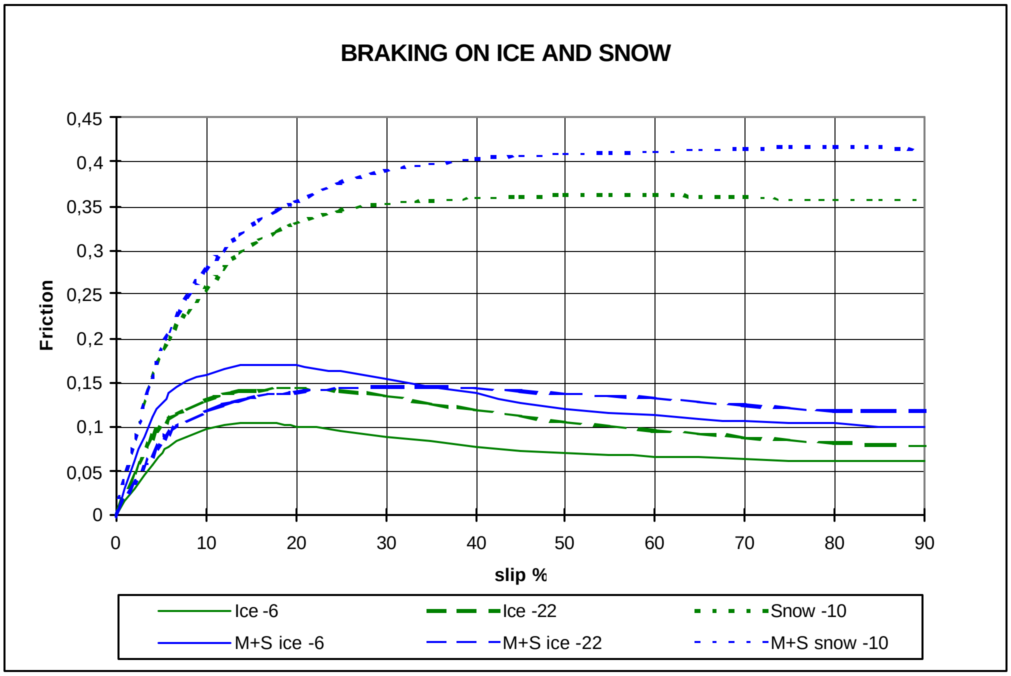


Fig 5. Example of lateral force measurement

In order to be able to measure combined braking and steering forces under aquaplaning conditions VTI existing device BV12 has been upgraded in the period May-October 1998. The upgrading is based on an existing test rig mounted on an obsolete test vehicle.

On this rig the vertical force was obtained by dead weights over a steel spring and hydraulic damper suspension and there was no vertical force transducer. The steering motion and the test wheel lift were performed by hydraulic cylinders. The longitudinal slip was varied by a variable belt transmission via a chain drive from the original test wheel hub between the axles to the rear mounted steerable test wheel. In the modified version BV12 B shown in figure 6 the arrangement is similar but with a number of substantial improvements.

Figure 6. Test vehicle BV12 right side view

The system is however due to the elasticity in the chain drive not suited for several relatively fast braking slip sweep measurements in sequence during one run over a reasonably short test track. Therefore a second disc brake system was added at the rear end of the chain drive.

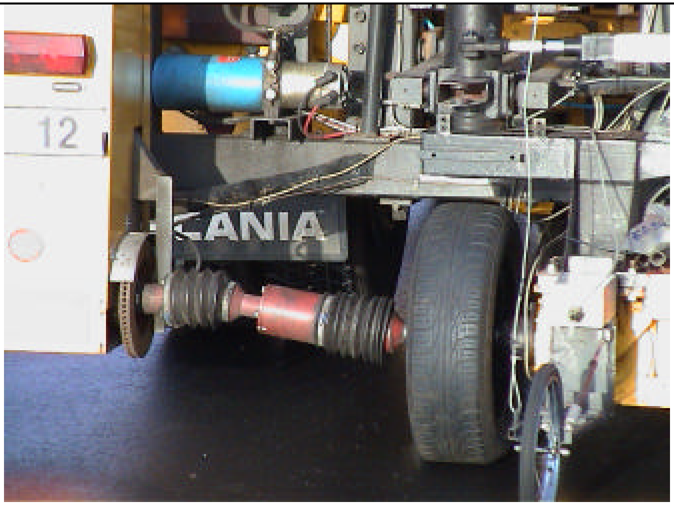


Figure 7. Disk brake and transmission shaft with axial movement ball spline unit

Figure 8. Water supply performance

A new on board vehicle water supply system was developed. It consists of a pump driven by a 120 HP petrol engine taking water from the original 3 m^3 water tank and letting the water out through a long tapered nozzle with an opening 200 mm wide and a variable height up to 10 mm. The maximum performance is a nominal water film height of 8 mm at 100 km/h outflow speed which was the maximum obtainable speed of BV12 B on the test site.

Finally, in VERT project, a new Shear Box device has been developed to measure shear and compression properties of snow. The device was also used to measure rubber-ice friction in cold chamber.

Test device is shown in Fig.9, and operation principle in Fig.10. Step motor starts rotating, and revolution is transformed into a linear movement by the ball screw. Displacement data is received from step motor control, and equivalent force is measured. In this test, 1 kN transducer has been used, because of high friction level in -10°C temperature.

Each rubber-ice couple has been pushed so many times, that friction did not change any more. Usually this meant 5-10 pushes, depending on how long ice had been in rest before the test. Last three pushes were taken in analysis.

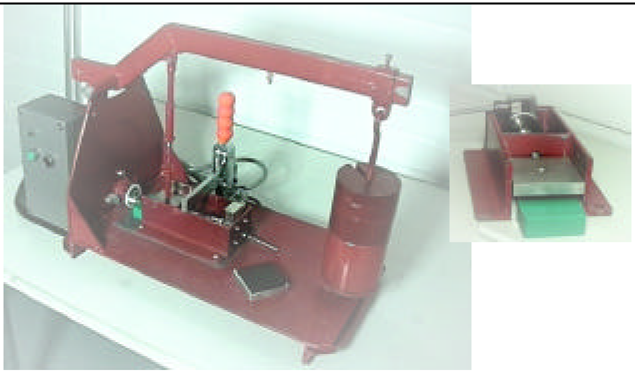


Figure 9. HUT Shear Box Device

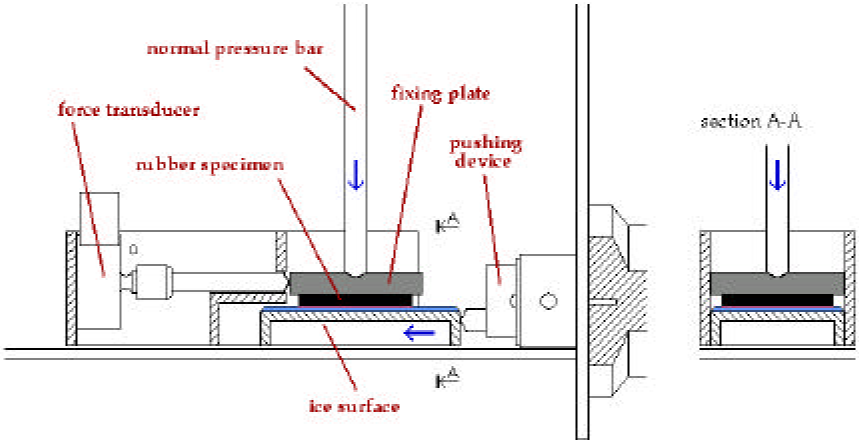


Figure 10. Operating principle in rubber specimen tests

In post processing, two values have been evaluated as described in Fig.11. Peak detection algorithm was used to define a peak that is considered as a static friction and an average sliding force is used to calculate kinetic friction value.

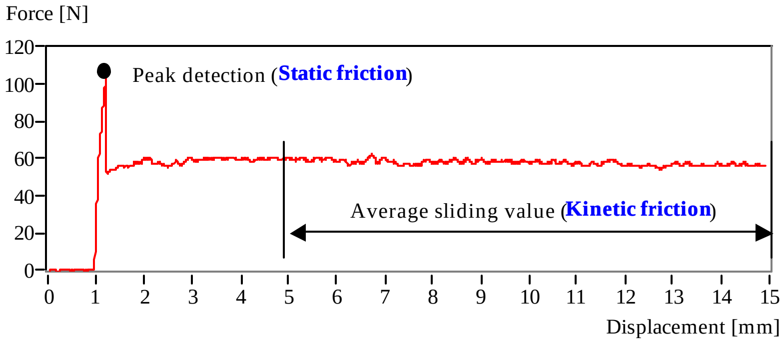


Figure 11. Readings from the curve

There are two major problems in measurements on ice surface. First one is the trouble of making homogenous surfaces and second one is that surface changes all the time. Especially after long rest, ice friction changes when pushes are repeated and then settles to some level.

This kind of testing method can be considered suitable for development and especially for research purposes in area of tyre technology. There are open questions in environmental variables and their effects with ice surface and interaction with different types of rubber. Shear box device shows promising capabilities to separate out rubber types, even if there is a lot of work to be done to understand all features of rubber-ice interaction.

FLOW AND FRICTION PREDICTION MODELS

The study of the very-small-scale (1-2 m) interaction between precipitation and impervious surfaces is crucial to understand the dynamics of water films and runoff during intense rainfall events. The influence that precipitation time-variability and road pavement geometry has on the water film dynamics was investigated using an experimental monitoring station installed on a mountain road prone to heavy storms. The monitoring system is composed by a camcorder, automatically activated during intense rainfall events through a weight switch, and a recording rain gauge. The investigation is based on the digital analysis of the recorded images between summer 1999 and autumn 2000. An indirect measurement technique has been set up for water film depth. The water film surface irregularities, due to the raindrop impact with the surface and to the presence of roll waves, are studied on the video records. From the images sequences the kinematics parameters of the roll waves, as they are prevalent in terms of visible effects during the periods of intense rainfall, are quantified. The digital analysis allows the estimation of direction and speed of the waves propagation with variable precision due to different light conditions. From specific laboratory experiments on the dynamics of laminar roll waves, empirical relationships between waves velocity and water depth are extracted and applied to the field data set. Using the empirical relationships and a high-resolution Digital Terrain Model of the road surface, depth and discharge of the water film in the maximum local slope direction are investigated.

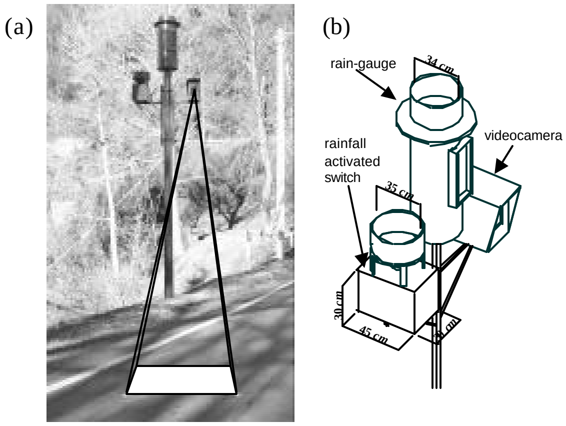


Figure 12 - The experimental monitoring station

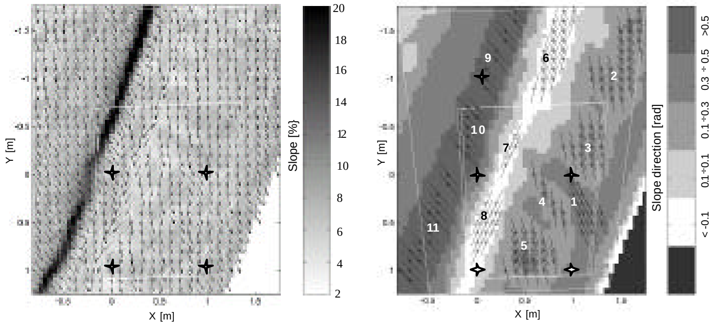


Figure 13 - Slope intensity/directions on a 5×5 cm grid and Slope direction classification/identification of 11 regions

The results obtained from the experimental apparatus here described suggest that the indirect, image processing based approach is potentially suitable for obtaining detailed information on the water film dynamics on a road surface during intense rainfall events. Moreover, this information appears to contain a detailed description at short scales both in time and in space.

The implementation of a vehicle handling simulation model, capable of predicting the response of a vehicle on any given surface under different operating conditions, requires also an accurate definition of the road surface properties. These are usually defined by means of conventional tests such as macrotexture measurements and friction measurements carried out with reference tyres (with a given thread depth), at a given speed and with a predefined nominal water depth between the tyre and the surface.

To face this problem in the VERT Project a specific model has been developed to predict the locked wheel and the peak friction values referred to any given speed, to any water depth and for different tyre thread depths for any surface. A friction measurement and a macrotexture measurement are required to run the model which provides the *"friction variation coefficient"* (FVC) which relates the measured value to the actual value in the given operating conditions.

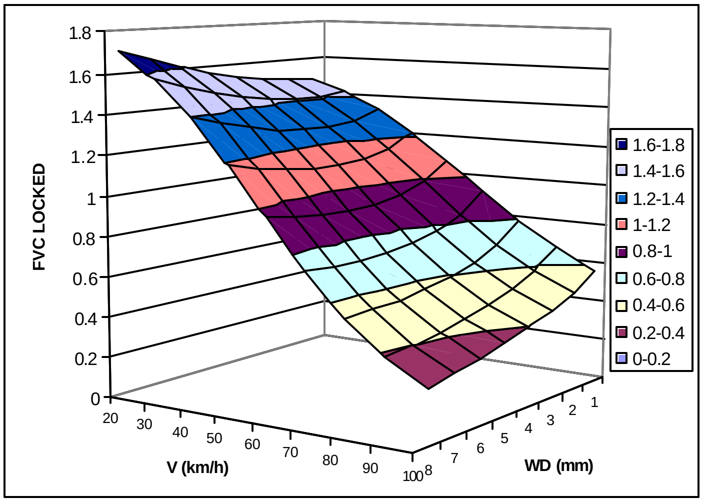


Figure 14: example of locked wheel FVC Vs. speed (V) and Water Depth (WD) curves for a given surface, tyre and tyre thread depth

The procedure proposed in the VERT Project allows to estimate the actual peak (longitudinal and transversal) and locked friction available at the interface between tyre and the road in any given operating condition and on any given surface on which a friction and a macrotexture measurements have been carried out.

The Friction Variation Coefficient (FVC) has been introduced in the VERT project and two different prediction models have been developed for the peak and for the locked wheel values.

A specific "s-shaped" function has been defined as a modified logistic function capable to account for all the different factors identified as relevant to the friction variations.

The two prediction models have been calibrated by using a randomly selected subset of 80% of the available data leaving the remaining for the evaluation of the prediction capabilities of the models.

The results are extremely interesting being the R^2 of 0.81 for the locked wheel model and 0.69 for the peak model over more than one thousand of runs.

TYRE-PAVEMENT INTERACTION MODELS

The objective of VERT Tyre modelling activity was to create one or more models capable to describe the interaction between the road surface and the tyre in presence of water. Therefore several influencing parameters have to be considered, especially water thickness and speed. The final models should be suitable

both for a full vehicle simulation and for a real-time application. All the activities described were coordinated by Pirelli Tyres and performed together with TRL, PORSCHE, Darmstadt Un., CETE, University of Florence.
First of all a very intensive test session on dry, wet, showy and icy roads was performed by Pirelli, TRL, VTI, Darmstadt Un., Nokian and Helsinki Un. with several testing devices in order to gain a good experimental bais for the development and validation of the models. In the meantime, a practical way suitable for facing the problem at different levels of complexity and technical risk was pointed out:

a) Use of Magic Formula formulation (Tyre characteristics in dry conditions and reference surface)
b) Introducing some λ-scaling factors (depending on surface conditions), in order to adjust continuously the reference tyre behaviour while running on the road (modifying the Pacejka curves shapes)

This approach features the following requirements:

a) To obtain the reference tyre characteristics:
- standard braking/cornering test in reference predefined surface

b) To obtain scaling factors (i.e. the actual tyre behaviour) referring to a certain conditions (surface / dry /wet/ice/snow /…):
- 1st chance (**IDEMO**): performing directly new measurements (physically or virtually) in that condition in order to **IDE**ntify the scaling factors and find general correlations and trends. This makes possible detailed handling simulations of dangerous situations (focused on sudden changes of road conditions, etc.).
- 2nd chance (**PREMO**): computing the scaling factors with a **PRE**dictive **MO**del gained from a preliminary special-purpose activity, suitable in particular for tyre design optimisation. Such a **PRE**dictive **MO**del can be gained in two different ways (with different levels of technical risk):

Chance 2a) (**PREMO-SE**) with a pure statistical analysis of a suitable amount of experimental data, with special attention paid to the choice of tyre/road characterizing parameters (**S**emi-**E**mpirical approach, giving directly the scaling factors)

Chance 2b) (**PREMO-PH**) with a **PH**ysical approach (e.g. lumped parameters model), able to predict directly the behaviour of the tyre in different conditions and (after post-processing) also the scaling factors

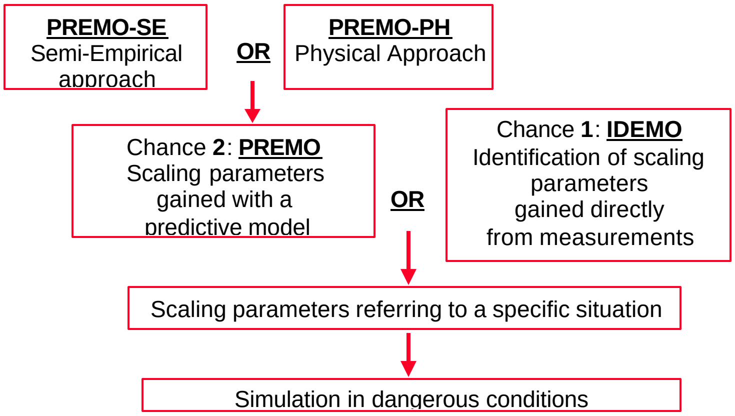


Figure 15: Concept of VERT Modelling approach

In this way, VERT modelling activities were developed in three different directions:

IDEMO (IDEntification **MO**del): identification of the Scaling-Factors l of Braking/Cornering/Combined characteristics in different working conditions (Water depth, etc.), by Pirelli

PREMO SE (Semi-**E**mpirical **PRE**dictive **MO**del): identification of l factors and investigation about their correlations with physical parameters (by Pirelli).

PREMO PH (PHysical **PRE**dictive **MO**del): extension of TOMS Model, Interface model, physical braking model, 2-D semi-physical tyre model for braking/driving torque

These activities are presented with more detail as follows:

a) IDEMO: identification of l factors and their correlations

The whole activity concerning semi-empirical model has been defined as follows:

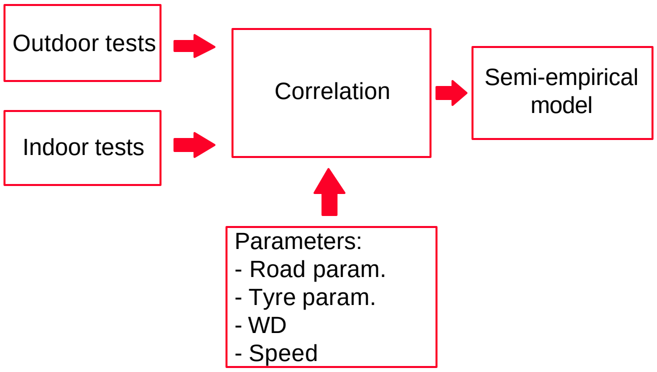


Figure 16: Concept of IDEMO Approach

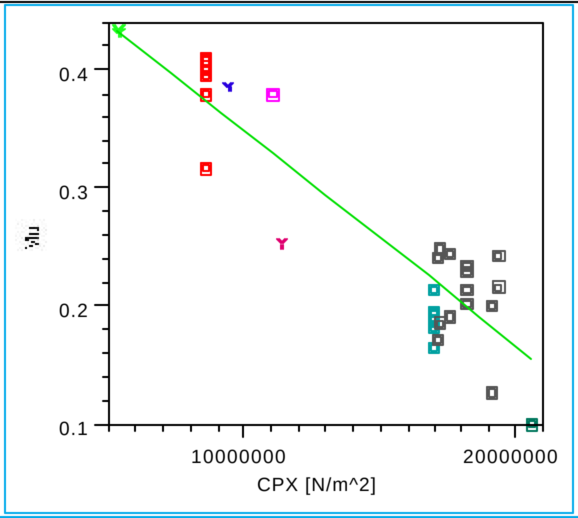
After a detailed investigation, the following characterising parameters were pointed out:

- **Tread stiffness: Ckx**
- **Torsional stiffness: Cb**q
- **Footprint area (just rubber, not the grooves)**
- **Height/Width ratio of Footprint area**
- **Drainage capacity**
- **Compound: G’’, tan** d

All these parameters will be identified by **standard indoor tests** or also by **virtual tests** with FEA simulations. Once fitted all the data and once chosen a reference condition, one other tool computes the scaling factors with respect to the reference test; the scaling factors selected for this investigation are:

- λμ Peak value
- λC Shape factor (peak value/slide value)
- λK Stiffness of the F-slip curve in the origin
- λE Curvature factor

Florence Un. performed the statistical investigation concerning the identified scaling factors (**PREMO-SE**), with valuable results: also Pirelli performed some brief statistical investigations directly on the fitted results (not on the scaling factors), with valuable considerations as well.



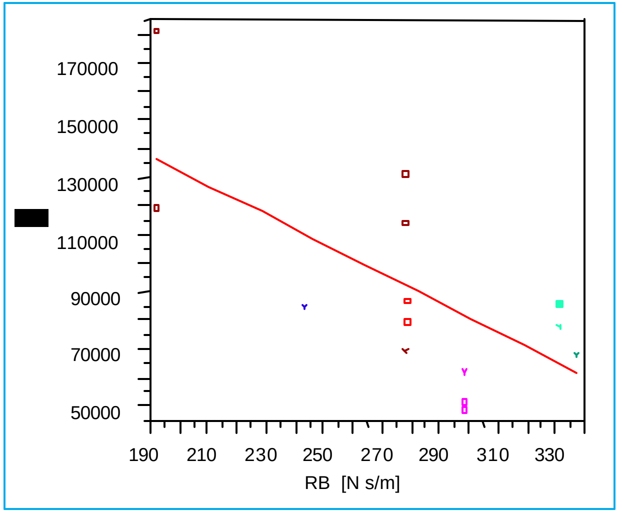


Figure 17: Example of statistical approach

PREMO-PH: Extension of TOMS Model

TOMS is a physical model for tyre combined braking/cornering: in order to obtain a high degree of accuracy the model needs some measurements as input is indispensable. On dry roads for example TOMS needs the basic curves (that means side force vs. slip angle / long. force vs. long. slip and self aligning torque vs. slip angle) without any combined measurements. The tyre forces and moments during combined slip angle and long. slip are calculated using a physical model and the parameters of this physical model are derived directly from the above mentioned measurements. So this model leads to a very good agreement between measurements and simulation (also for combined conditions which are not required as an input for the model).

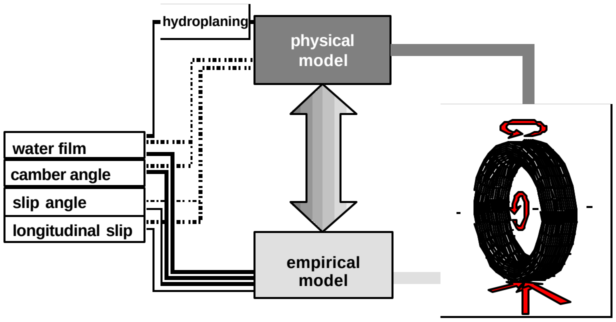


Figure 18: Concept of TOMS Model on wet roads

To extend the validity of TOMS model an additional hydrodynamic module has been developed by Porsche and Darmstadt University. This model calculates also a hydroplaning length using a simple analytical description of the flow processes in the contact patch. This model is applicable also for different values of profile depth and road roughness. The linkage of this hydrodynamic model with TOMS should lead to good results.

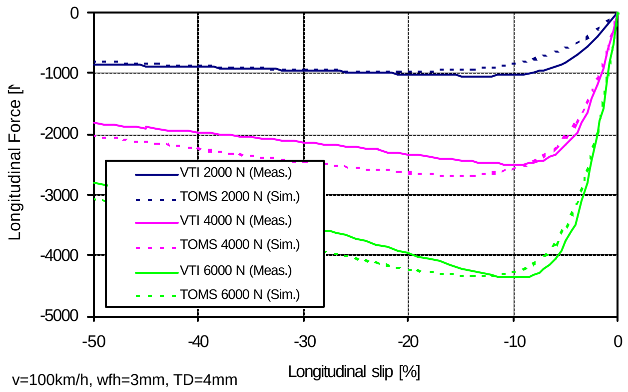


Figure 19: Simulation results TOMS

PREMO-PH: Physical 3D Model

As an evolution Pirelli Comfort Model, Pirelli developed also a full 3D lumped-parameters model (P3DT), with a special 3D Contact Model. As a lumped-parameters model, it is suitable for an ADAMS implementation and a linkage with a Friction prediction model, as the other ones developed within VERT.

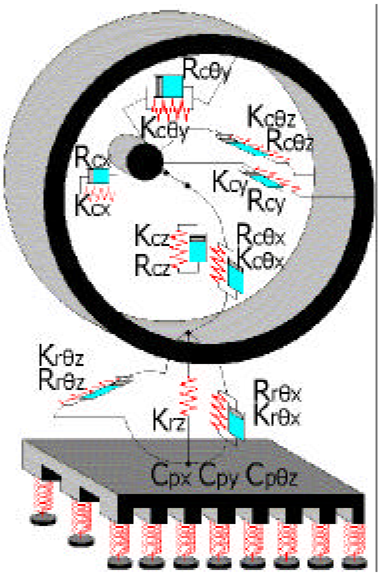


Figure 20: P3DT Model

The most outstanding features of this **Virtual Tyre Combined Slip Model** are the following:
- suitable for representing 3-D transient behaviour of the tyre under generic conditions of motion/torque/contact irregularities
- simple (only 3 rigid bodies and reduced number of DOF) for short CPU times
- clear relationship between physical parameters and structural properties
- this model is full predictive, since it doesn't require any experimental test on the tyre: the characterisation of its parameters comes only from FEA dynamical analysis:

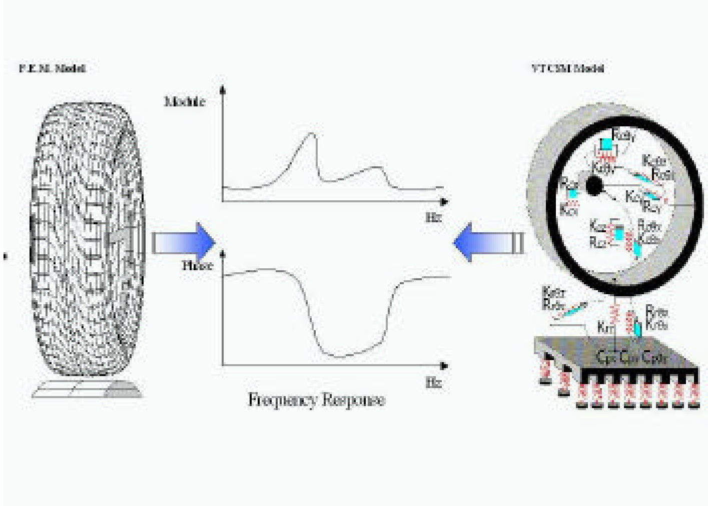


Figure 21: Response of P3DT Model

Moreover, the physical meaning of its parameters can actually give guidelines to tyre designers for a complete optimisation of several aspects of behaviour (Handling-Braking-Comfort).
Once connected to a vehicle model, such a model is clearly suitable for a reciprocal optimisation of tyre-suspension-vehicle system, since the physical parameters of the tyre can act also as physical parameters of the full vehicle system.

DEVELOPMENT OF FULL VEHICLE MODEL AND CHARACTERISATION OF DRIVER BEHAVIOUR

In order to represent in a realistic way vehicle dynamics under different road conditions, a complete vehicle model was implemented, with a special tyre representation.

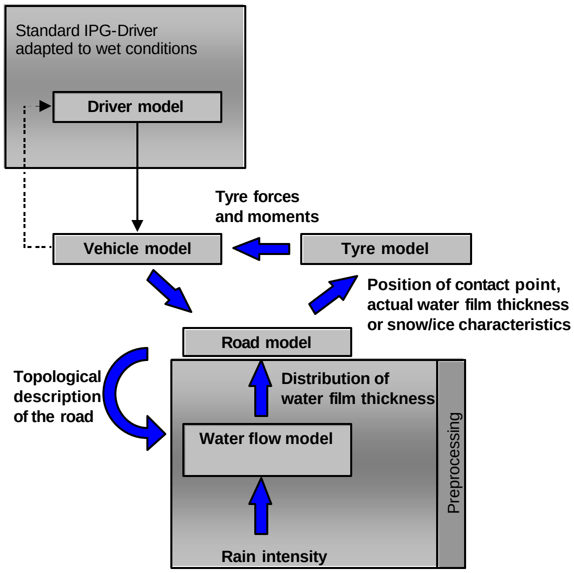


Figure 22: Structure of the complete model and interaction between submodels

The vehicle model is driven on a virtual roadway. The road model contains both the topological description and information about the local surface condition, e.g. water film thickness or condition of the snow layer. This information is delivered to the tyre model and processed within this model. With the help of different approaches the reduction of the transmissible forces due to the additional fluid between tyre and road is calculated. The generation of the information (e.g. water film height on the road) is executed with the help of a Preprocessor before the actual vehicle dynamics simulation is done.

The investigated vehicle is a front driven car with a front-mounted engine. The common approach to model a complete vehicle in a MBS program is also used within the VERT project. The vehicle model consists of rigid parts connected by joints and/or linear and nonlinear bushing elements. Damper forces and spring stiffnesses are modelled by means of nonlinear force descriptions. The tyres are implemented using the Standard Tyre Interface. In the model a simple drivetrain is modelled, which represents the characteristics relevant for vehicle dynamics. Figure 23 shows the MBS model including the rigid bodies of the axles and the vehicle body.

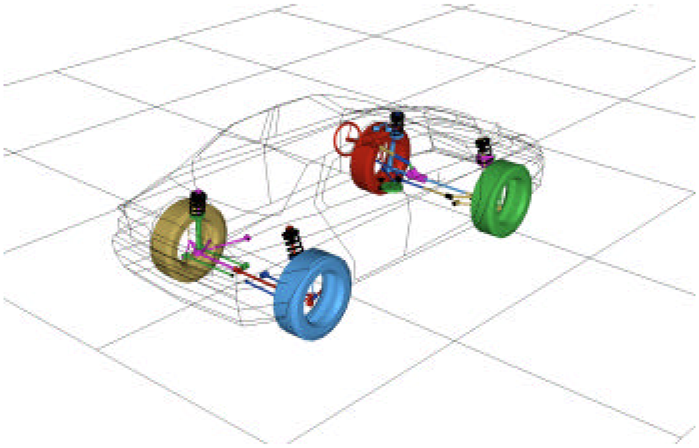


Figure 23: Full MBS vehicle model

In order to check the kinematics and elasto-kinematics of the axles, simulations on a virtual test rig were compared with those on real test rigs.

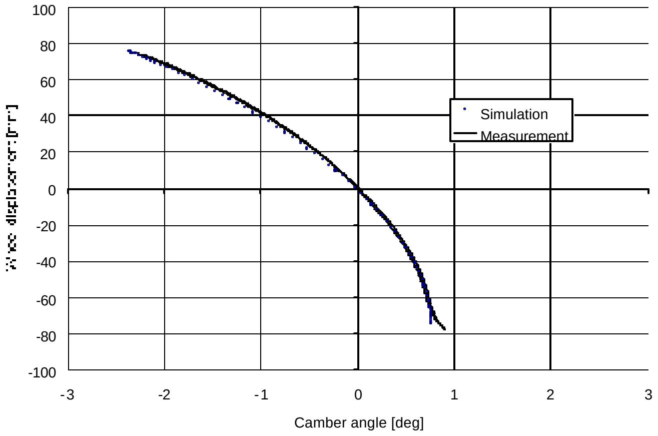


Figure 24: Wheel displacement vs. camber angle at the front axle

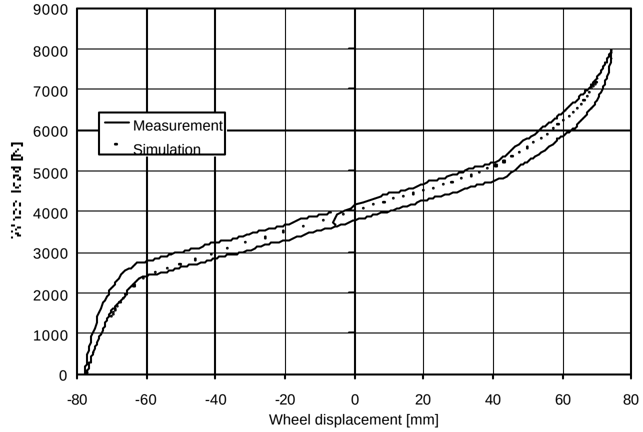


Figure 25: Wheel load vs. displacement at the front axle (symmetrical displacement with stabilizer bar)

A key element for the vehicle dynamics simulation in potentially dangerous situations is the tyre or its interaction with the road. The implementation of the calculation algorithms should be the same for both wet roads and snow-covered or frozen roads. The basis for the calculation of the tyre behaviour for the simulations in this project is the widespread tyre model “DELFT-TYRE” which is based on the so-called “Magic-Formula”. This essentially is a mathematical equation which calculates the tyre forces and moments when given the actual operating condition and tyre parameters as an input. In the actual version of this tyre model additional scaling factors are implemented which can be used to modify the tyre characteristics resulting from the original parameters. These values change of course during the manoeuvre caused by the driver’s input and by topographical data. Figure 6 shows the general operational sequence of the tyre calculation considering the road characteristics. If the vehicle dynamics simulation is executed on dry roads then the calculation of the tyre forces can be done directly using the tyre data set. However if the vehicle is either on wet, snow-covered or frozen roads then the left branch of the flow chart must be considered. For the wet road situation there is a special model called “Lambda model” in the following. This model calculates the scaling factors necessary to adapt the tyre characteristics to the current operating condition with specification of some additional input values, such as road condition etc. for varying water film height and variable speeds.

In case of snow covered or icy road no such module has been integrated in the model so far. In these cases, discrete measured values of the scaling factors with different speeds are required, for example. Values at intermediate speeds are calculated with the help of linear interpolation. The calculated scaling factors are then incorporated in the tyre model and used for the calculation of the tyre forces and moments.

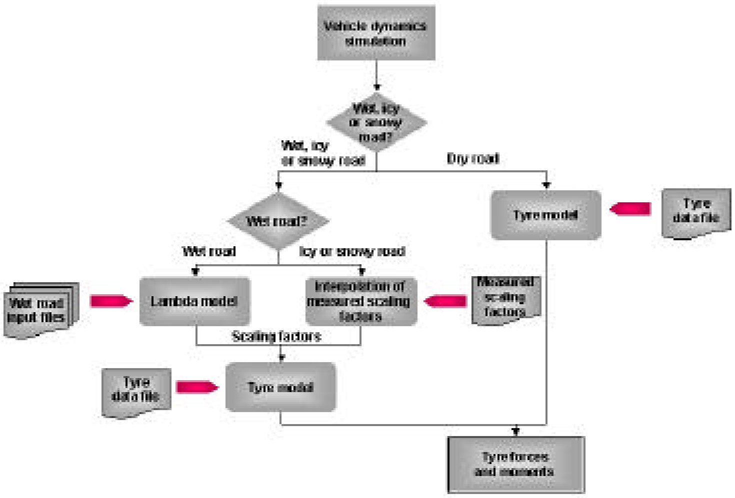


Figure 26: Flow chart of the tyre calculation in vehicle dynamics simulation on varying road surfaces

To validate the handling behaviour of the complete model the measured and simulated dry-road driving manoeuvres were compared with each other. Since the validation was to be limited to the vehicle model no wet-road mode was included. The driving manoeuvres were carried out in accordance with the ISO standards and the correlation between the measured and simulated values was excellent.

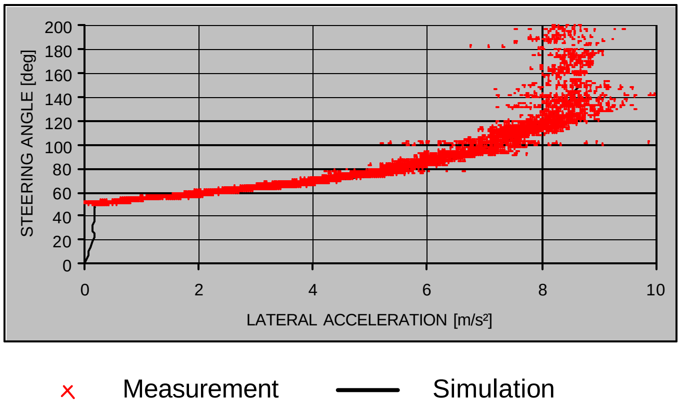


Figure 27: Steering wheel angle vs. lateral acceleration for steady state cornering (radius: 40 m)

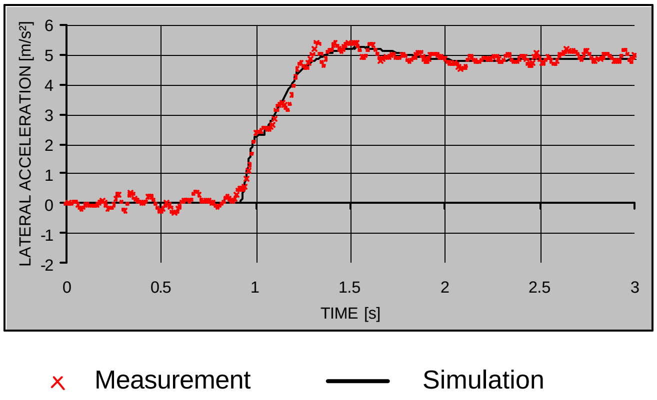


Figure 28: Lateral acceleration vs. time for a steering wheel step input at t=0.9 s

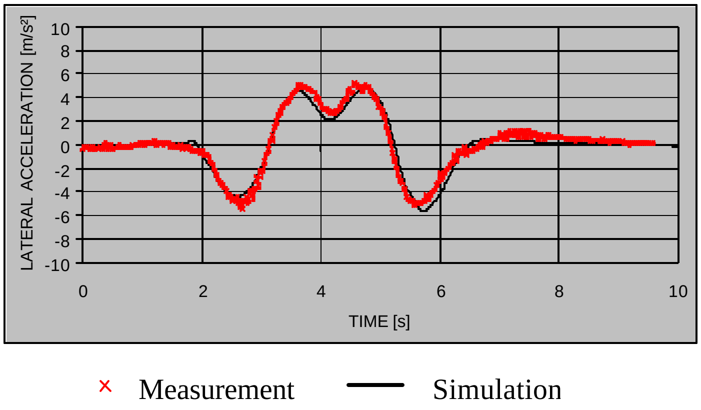


Figure 29: Steering wheel angle vs. time for a ISO-Lane change manoeuvre (initial velocity: 90 km/h)

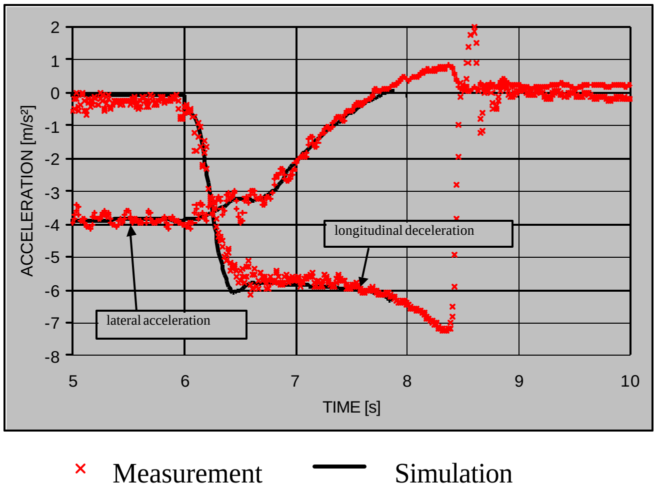


Figure 30: Time history of longitudinal deceleration and lateral acceleration for the “Braking in a turn” manoeuvre

Such a detailed vehicle model needs of course also a detailed Driver Model to actually reproduce in a realistic way closed-loop manoeuvres (e.g. ISO Double Lane Change, etc.). For this purpose, IPG Driver model was used with an extensive investigation on the correlation between the Driver model parameters and the actual driving style.

The following driver model parameters were chosen as variables for the analysis:

– t.l.d. = tolerated lateral deviation from the static path
– r.t. = lateral reaction time
– c.c. = corner cutting coefficient

On the other side**,** a parameter, which could represent people ability to control their vehicle has been defined, called *Driver Input Activity Effect* (DIAE):

$$\mathrm{DIAE} = \sum \left(\frac{d^2 y}{dt^2} \right)$$

A previous screening of a group of several drivers led to the following correlation DIAE-driving styles:

- Skilled drivers: high lateral acceleration values, low DIAE values
- Prudent drivers: low lateral acceleration values, low DIAE values
- Low experienced drivers: low lateral acceleration values, high DIAE values
- "Reckless" drivers: high lateral acceleration values, high DIAE values.

Simulating the same manoeuvres (bending and ISO Double lane change) even including the learning effect led to the following conclusions:

– An increasing t.l.d. reproduces the behaviour of a driver who is not able to correctly follow the trajectory. In fact a deviation of static path generates an irregular real path. So corresponding lateral acceleration and steering angle time histories are characterised by a great number of peaks.
– Reaction time amplifies the effect described above. The model corrects its trajectory when it realises that tolerated limit is exceeded. If reaction time increases, it takes a longer time for the model to do something about this situation. So the behaviour reproduced corresponds to a slowly reacting driver.
– A high corner cutting coefficient value makes the static path smoother. So the corresponding driver reaches lower lateral acceleration values being equal the other parameters. It does not necessarily correspond to the

behaviour of a skilled driver, who is able to drive very close to the imposed path, reaching high lateral accelerations, but with low DIAE, it reproduces a prudent driver.

- Sometimes one effect can balance another one.

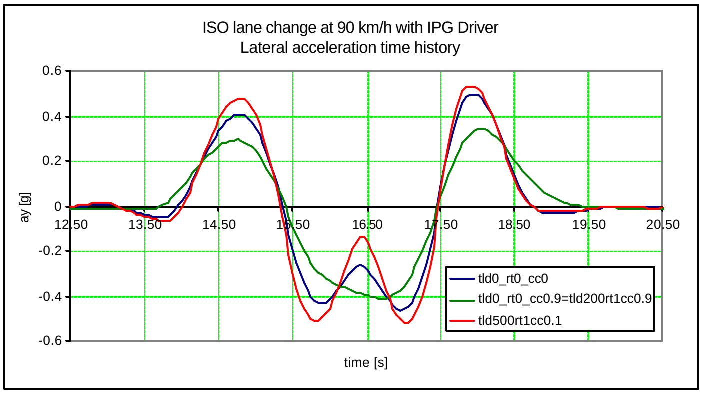


Fig.31 Effect of varying Driver model parameters (i.e. switching between different driving styles) on an ISO Double Lane Change

Finally, an existing Driving Simulator (belonging to VTI) has been updated in order to reproduce exactly the reference vehicle, thereby making possible to perform a subjective comparison between simulator and real car:

Fig. 32 Overview of VTI driving simulator

The validation process was done in several steps. First the vehicle model was checked in an open-loop manner to standard manoeuvres performed in field tests. In general the correspondence between simulations and field experiments was good, which shows that it is possible to use rather simple models for basic handling manoeuvres. The validation process also proved that all input data must be correct both for tires and vehicle, or otherwise the results will be seriously in error. Some data are necessary for computer models in driving simulators but are normally not measured by the automotive industry. Damping properties of the steering system are extremely important to quantify, since the driver immediately feels them and they play an important role for the on-center handling as well as high speed stability of the steering system.

The second step in the validation process is to compare results of real drivers performing the same manoeuvres in the simulator as on the test track. In this case a slalom manoeuvre between cones was chosen. No significant differences between the driving behaviour appear in the objective measures but the subjective evaluations show a more mixed scenario.

IDENTIFICATION OF POTENTIAL DANGEROUS SITUATIONS

Two simulations loops were performed within VERT. The first one included 380 different situations that all are based on a basic one: negotiating a bend with a constant radius and a constant road surface characteristic, but with different friction values due to different water depths along the bend or different parameters depending on the presence of ice or snow on the pavement.

The second loop was based on changing friction conditions through the bend and a braking manoeuvre in the bend, thereby including 184 simulations. After a first analysis of the first loop results, it has been decided to focus on one type of curve, on which few value of parameters are varying.

Three different criteria for the evaluation of the results were defined:

- Way out of the lane: car going out or not of the lane
- Danger of the situation given by the slip angle of the car: value of the actual maximum slip angle value
- Difficulty for the driver to follow the trajectory: behaviour of the square root of the difference between the actual and theoretical lateral acceleration.

The relative influence of microtexture, macrotexture, cross slope on the a.m. criteria (in particular the third one) was very complex and strongly depending on the longitudinal slope, speed and rainfall intensity: this seems to make not possible to draw immediately very general considerations.

GUIDE LINES FOR TYRE/ROAD/CAR DESIGN

a) Tyres All the aspects of Tyre Specification (Structure, Shape, Tread Pattern, Compound) strongly influence the braking/cornering tyre performance. The results gained within VERT show the complexity of the subject, since clear but often counter-acting tendencies can be detected. In particular, it seems very difficult to optimise all the performances with the same tyre specification.

b) Road surfaces Accident statistics have shown modern road geometry standards to be relatively safe. These layouts could be used as part of the validation stage of the VERT vehicle-handling model before it is applied to the development of road surface guidelines. VERT project has given idea of how some of the important properties of road surfaces could be considered during the selection of materials. The potential application of the vehicle-handling model to maintenance prioritisation has been better discussed. Its principal strength is that it can be used on a site-specific basis to help in engineering investigations. The results of simulations could also be used as part of accident analysis. Simulations could be used to help determine the length over which it is appropriate to average friction values during monitoring.

c) Vehicle design It has been defined general information about vehicle dynamics design and defined a set of manoeuvres and objective parameters in order to evaluate how design parameters change vehicle behaviour in lateral and longitudinal performance, stability, steerability, directional stability and roll-over. Some design parameters modify only one vehicle behaviour and in this case the choice is clear. On the other side there are other design parameters, like asymmetric stiffness distribution, that work in opposite directions in two different vehicle behaviour, stability and steerability. In this case it's necessary to find a compromise but it's even possible to use design parameters to have a particular vehicle behaviour.

CONCLUSIONS

VERT Project has represented a common effort of a strong team to introduce modelling approach as a key-point for vehicle active safety evaluation. Such a complex subject demanded for a lot of activities in an impressive deal of different fields (waterfall evaluation, snow/ice characterisation, tyre testing, human reactions representation, etc.). In spite of the complexity of the subject, the final representation of vehicle – driver behaviour was very realistic and the results very promising.

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