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Driving Cycle, Load and Fatigue Life Predictions based on measured Route Data

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ABSTRACT

In order to shorten the length of time it takes to develop a vehicle, a system has been designed which combines actual measurements and simulation. Firstly, the route data is measured by a simple to use system. Based on this, a computer-simulation of a vehicle is carried out. It was found, that fuel consumption and driving characteristics can be predicted correctly.

Fatigue life estimation is much more complex, but in the hand of an experienced user a reliable comparison of different components is successful.

INTRODUCTION

When designing a vehicle, the aim is to achieve the best possible combination of the factors expected (safety when driving, best possible weight, durability). Extensive tests are carried out on various types of road and with various drivers.

The aim of the measuring and simulation system described here, is to reduce the number of these tests and replace them with computer simulations.

The system has the following functions:

> A system for recording measured data: (Measuring Case), which is not electrically linked to the vehicle and which can therefore be installed quickly. It ascertains route data (coordinates), the driving speed, transverse acceleration, yaw rate and gradient of the road and plots these on the computer.
>
> A system for simulating driver, vehicle and environment: Based on the data recorded in this way, a computer simulation can be carried out in which a driver-vehicle model drives along the measured route. By altering the vehicle and/or driver data, it is possible to go through extensive variations on the computer.
>
> A system for calculating fatigue life: A combination of multibody dynamics, finite element system and fatigue life calculation.

Comparisons between simulation and actual measurements have proved that simulation results can be achieved which correspond to actual results and that in particular, the driver model is able to portray very many different types of driver.

In this way it is possible to carry out variant calculations based on realistic route data very quickly providing information on car performance, fuel consumption and fatigue life.

COMBINED EFFECT OF DRIVER, VEHICLE AND ENVIRONMENT WITHIN THE SYSTEM

The driving cycles and the vehicle loadings and the stress and strain which result from this and the fatigue life depend mainly on:

-the route used,
- the vehicle characteristics,
- the traffic,
- the driver
- environmental factors (vision, friction, legal limits)

A large spectrum of very different countries driven in and types of driver makes it difficult to say which conditions are typical. It is therefore even more important to be able to predict the conditions and the resulting loadings in a simple way in order to estimate data for dimensioning and optimising a vehicle and in particular for estimating the limits.

RECORDING THE MEASUREMENTS

Over a period of several years Steinbeis Transfer Center has driven test routes on normal roads and made measurements so that data can be recorded on how a vehicle is used and what the route is like. WinADAM, a system to record measurements, was developed for this purpose. This system is built into a measuring case and – apart from the magnetic aerial for the GPS system - is installed without being wired to the vehicle in any way. (Diagram 1). The following values can be recorded:

- Route coordinates with the aid of GPS,
- Yaw rate,
- Speed with the aid of GPS,
- Height above sea level calculated from environmental pressure,
- Distance to the vehicle in front (optional, with an additional infra-red laser on the roof)

In addition,

- the permitted speed limit,
- characteristics of the route (place names)

can be typed in and recorded as required. Usually the whole measured journey is recorded by a video camera and documented with additional comments. From this it is possible to calculate the following values:

- Topography (height profile)
- Angle and radius of the route
- Speed
- Transverse acceleration

This data can be used for different criteria and queries and it provides a detailed picture of the conditions for use.

The route is shown as a map (Diagram 2) and the various values are marked in different colours. It is therefore possible to ascertain immediately the link between any of these values and any position on the route.

In the diagram the speed is shown using 5 different colours. Diagram 3 shows a typical measuring result for height profile, speed, transverse acceleration and curvature of the road.

Diagram 4 shows the comparison of the two drivers – one of them with several years of experience driving cars with diesel engines and the other a beginner with diesel cars. Speed, gear and transverse acceleration are shown for part of the course around the Lone Valley.

The frequency proportion of a speed (diagram 5) and the speed and transverse acceleration (diagram 6) show typical characteristics of drivers which have an effect on the loading on the vehicle.

Despite the limited number of measured values, they are nevertheless sufficient to characterise the driver, vehicle and route.

By combining the measured data with a simulation model, it is possible to obtain additional information on, for example, the drive line and the chassis which is very useful.

A SIMULATION MODEL FOR DRIVER, VEHICLE AND ENVIRONMENT

The data recorded as a result of measuring the route (topography, angle and curvature) and also the route information added manually (legal speed limit) are (on the whole) permanent and therefore valid for other vehicles and drivers. These can be used as described below with the help of the simulation system, winEVA. Diagram 7 shows the elements of the system and how they work together.

The simulation system consists of:

- a vehicle model which takes into account in detail the physical characteristics of the drive line (diagram 9). As well as the classic drive line, you also have access to ideas currently being developed for automatic engines, hybrid propulsion and E-power. Depending on what is required, it is possible to use models ranging from a simple one for predicting car performance and fuel consumption through to one capable of analysing torsional vibration.

- a driver model which analyses and evaluates the information regarding the route (permitted speed, curve radius, friction, forseeable length of the route). Using this information the driver model works out a driving strategy taking into account the vehicle´s engine performance and the type of driver (fast, economical, slow). This is shown in diagram 8. There is also a switch which selects the gear for engines with manual gears.

- a model for describing the route. This contains not only the information recorded using winADAM (a system for analysing measured values which has already been described) but also records additional detailed route information (bus stops for town buses, rolling resistance coefficients for cross country driving etc.).

- a traffic flow model for motorways.

The simplest simulation exercise is to take the values measured in the test i.e. speed and - in the case of vehicles with manual gears – the gear and use these for a simulation. The simulation model car should be (almost) identical to the real vehicle used for the actual measuring. All the drive line and chassis values which are of interest can then be calculated.

A simulation such as that described above was carried out for the Lone Valley Circular Route. The resulting engine torque and RPM distribution can be seen for both drivers in diagram 10. It can be seen clearly that driver IA (the diesel beginner) drives with a comparatively high RMP, which means that, although he drives more slowly, his fuel consumption is much higher than that of the other driver, GW (an experienced diesel driver).

If you also wish to simulate the behaviour of the driver, it is no longer necessary to state the speed and gear. The model only uses the route information (speed limit, curvature, friction, vision) to work out a desired speed.

Using the speed history of an unhindered vehicle (no traffic), you can take various possible traffic conditions into account by manually adding, for example, stops at road crossings or special incidents such as overtaking manoeuvres.

By analysing the measurements taken on test drives it is also possible to record and automate traffic conditions and transfer these to the desired speed history.

The detailed driver model enables you to simulate entirely different types of driver. He can be anything from extremely economical to a racing driver.

The driver model (diagram 7) also takes into account the characteristics of your own vehicle. By selecting various motivation factors the drivers can also be made to drive in very different ways. All types can be modelled from a learner to a racing driver.

In this example, driver behaviour was measured and sets of data were created. The simulation results were then compared with the real test results.

Diagram 11 shows the results for a simulation of driver IA. The speed and gear can be seen. Diagram 12 shows the simulated driving force at the wheels engine torque and gear. A comparison of the calculation and actual measured values for the time proportion at a certain speed can be seen in diagram 13.

Diagram 14 shows the time proportion in the engine characteristic curves.

A traffic flow model (diagram 15) was developed for routes which have neither crossroads nor oncoming traffic (motorways). It models a finite road length with a finite number of representative vehicles and drivers. The vehicles are simplified (mass, road resistance, installed performance, location of centre of gravity, dimensions) and the driver model describes, in particular, the distance kept and how the driver overtakes.

The model is sufficient to create speed cycles under traffic influence. These can then be used as a basis for the simulation of individual vehicles. There is a source at the start of the route from which the cars are dispersed with realistic starting conditions. At the end of the stretch they disappear into a hollow. The route characteristics (topography) is dealt with continually and it is therefore possible to model a finite number of vehicles for routes which are as long as required.

The results of extensive test drives in actual traffic are available to us and enable us to make realistic statements regarding driver characteristics.

FATIGUE LIFE PREDICTIONS

To dimension vehicle components we use these simulations in two various ways. These can be shown using an articulated shaft and a double wishbone axle as examples.

In the case of an articulated shaft, the transmitted torque is of importance because this leads to torsional stress within the component.

For this reason we used the simulation of the Lone Valley circular route to calculate the peripheral force at the wheels (diagram 16). From this the torsional nominal stress could be determined. The rainflow grading of the nominal stress (diagram 17) counts the occurrences relevant to the damage and is a suitable basis for a fatigue life calculation.

With the help of groove factors, stress gradient and quality of the component surface it is possible to determine a component S-N curve locally for the critical point of the articulated joint (diagram 18) and then using the damage accumulation, to determine the route until failure. occurs.

Components where one particular type of load dominates and where the principal stress direction of the time variable stresses do not alter are relatively simple to calculate using the method described above.

It is more difficult to predict the fatigue life if there is more than one loading and if you cannot presume that the principal stress directions will remain constant (non-proportional loading). The fatigue life calculation of a double wishbone axle is described to show an example of this type of case.

The peripheral, side and vertical forces which were obtained from the simulation are used as a loading. These can be calculated from the simulated data for the

Lone Valley circular route under the presumption that the road surface is smooth and even.

With the help of the multi-body dynamic program MSC.VisualNastranDesktop (diagram 19) an axle including the proportional vehicle mass can be modelled and put into the system by actuators with the help of the forces obtained from the simulation (peripheral forces, side forces and dynamic axle loads). The tyre is described in a relatively simple way with a non-linear suspension, shock absorber and a contact element. Unevenness in the road surface can also be taken into consideration as a vertical displacement of the tyre contact point with the aid of the actuator.

The forces in the axle joints are determined using the MKS-System. The fatigue life is then calculated from this information with the FE-Program MSC.Nastran and the fatigue life calculation program winLIFE.

The following cases must be differentiated (Diagram 20):

In case A it is presumed that the road surface is even. Geometrical alterations due to tyre deflection are not taken into consideraton. But it is still posible to make useful relative fatigue life predictions for individual components and driver and route influence can be clearly recognised (eg. braking frequency and brake wear).

Case B also takes into account the unevenness of the road surface and the dynamic stress which results from this. This is of particular importance for bad roads. For many body components the unevenness of the road surface is a deciding factor. Case B does not, however, record any mass inertia or any geometrical alterations from compression.

Case C represents the most exact analysis possibility The axle with proportional, vertical vehicle mass moves at the speed taken from the simulation. along a route with obstacles described by height over length h(s) therefore causing a vertical displacement of the tyre contact patch.

The inertia forces from this are superimposed on the forces within the tyre contact patch taken from the simulation. In this way you can get an almost realistic result and which basically remains valid even when there are extreme obstacles. How exact this is depends then, however, on the correct modelling of individual components in the extreme areas (tyres, shock absorber).

The video shows a simulation of diving over an extreme obstacle The duration of the simulation is decidedly longer that the actual time. Fatigue life calculations are therefore seldom carried out based on this.

Conclusion

With only route data and/or easily ascertained additional data, it is possible to achieve detailed knowledge by combining this with the simulation.

Fuel consumption and car performance can be predicted fairly exactly, a fatigue life calculation, however, only permits relative statements and when these are used for parts relevant to safety they must always be backed up with tests.

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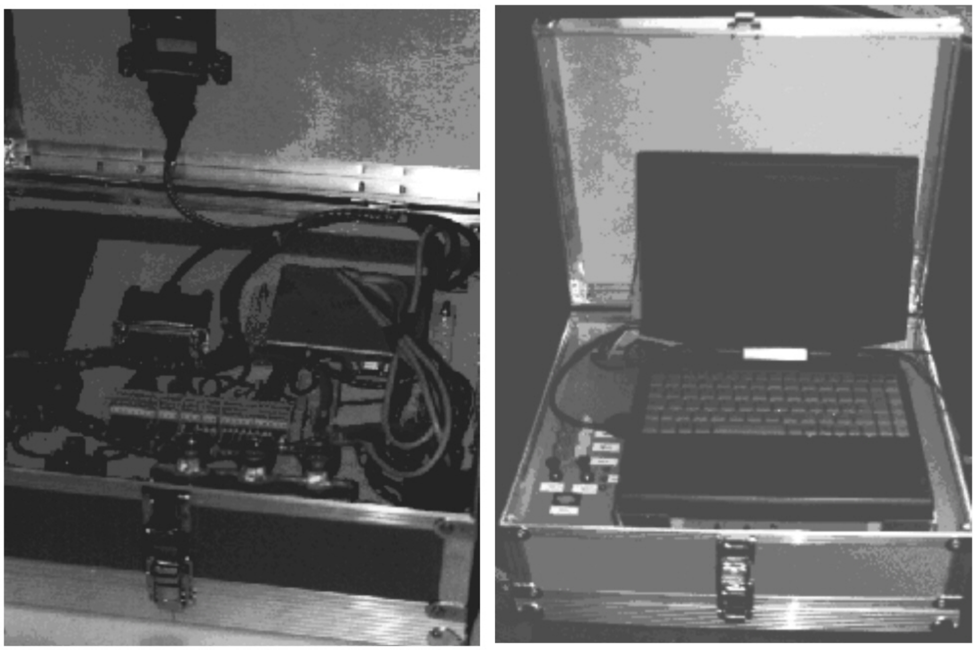


Diagram 1: Measuring system winADAM viewed from above and below.

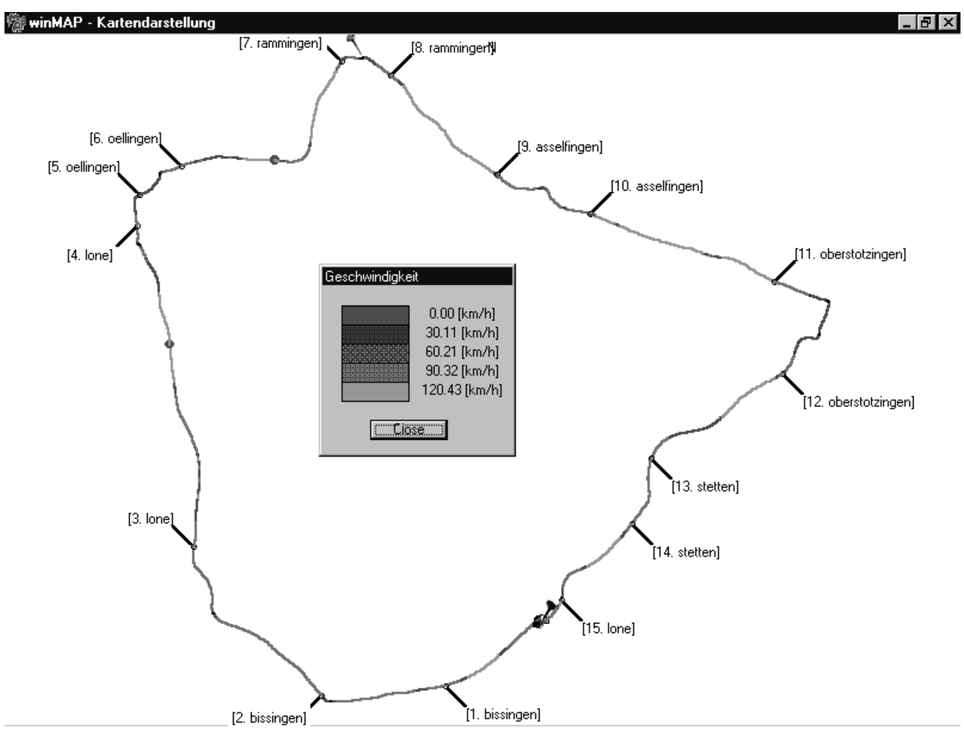


Diagram 2:Representation of a measured trip around the Lone Valley circular route

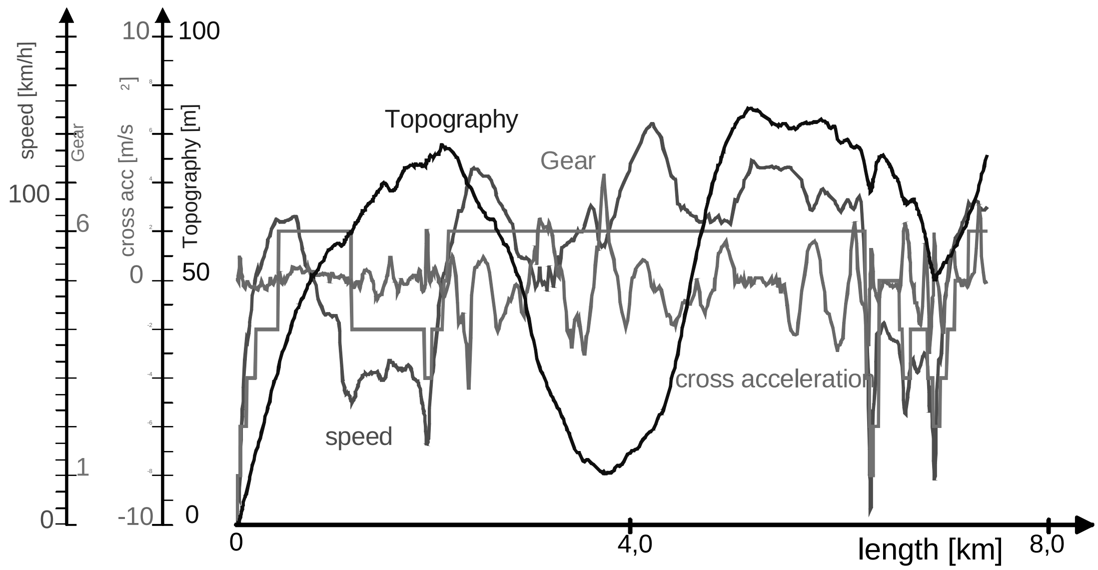
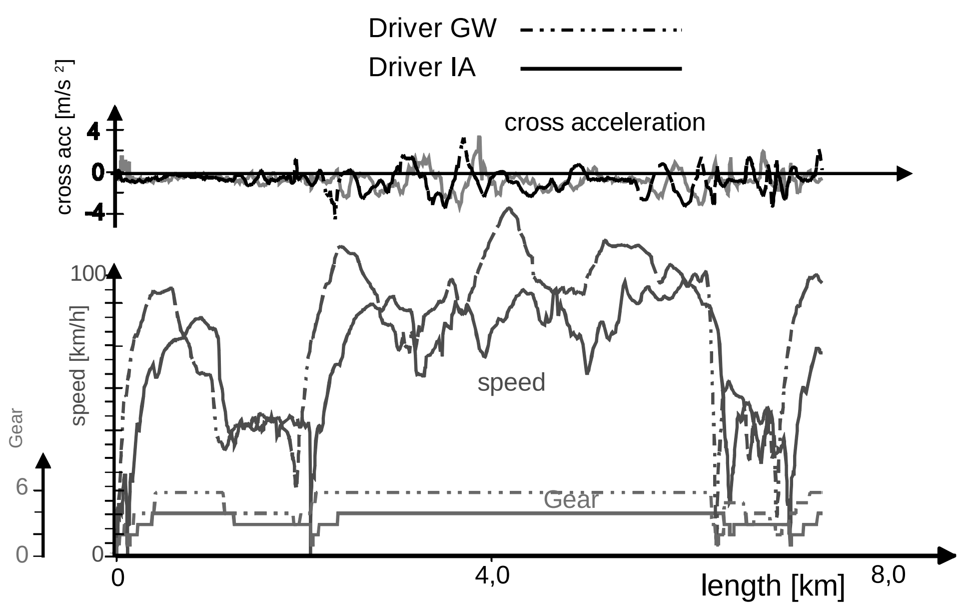


Diagram 3: Representation of a measured trip along the stretch of road on the Lone Valley circular route



Diygram 4: Comparison of 2 different drivers on the Lone Valley circular route

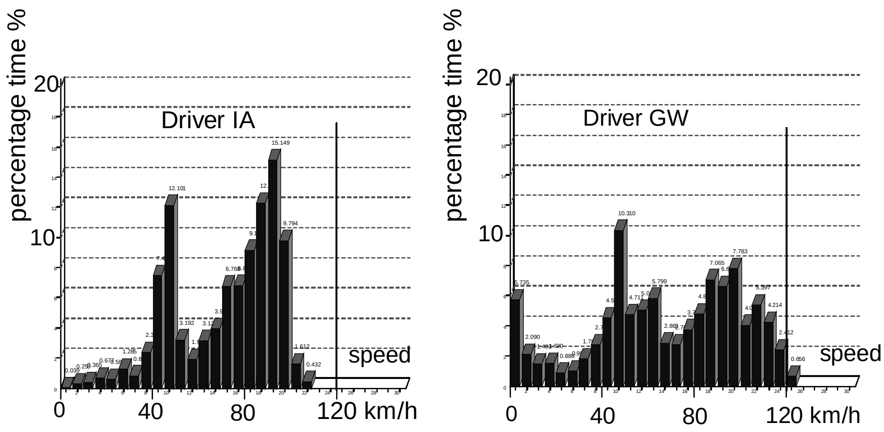


Diagram 5: Proportion of time driven at a certain speed by the 2 drivers along the Lone Valley circular route

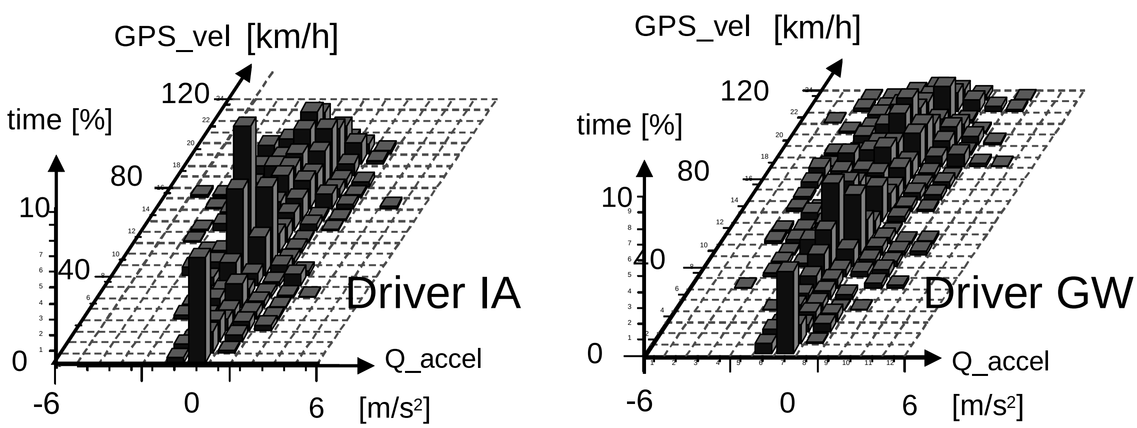


Diagram 6: Proportion of time driven at a certain speed and the transverse acceleration by the 2 drivers along the Lone Valley circular route

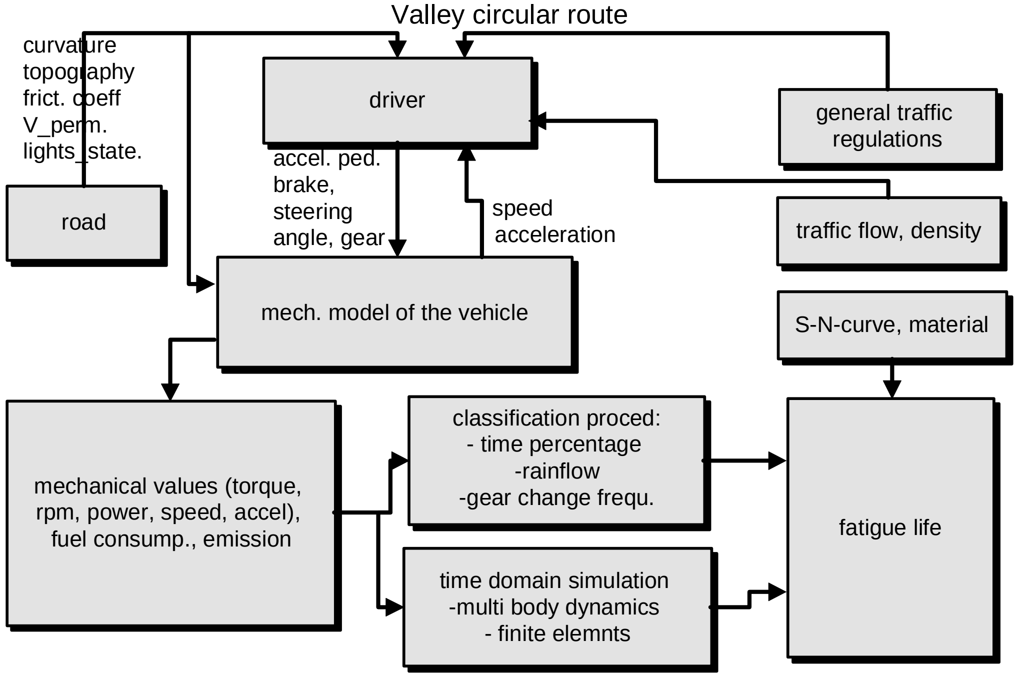


Diagram 7: Integration of the simulation system elements for driver, vehicle and environment

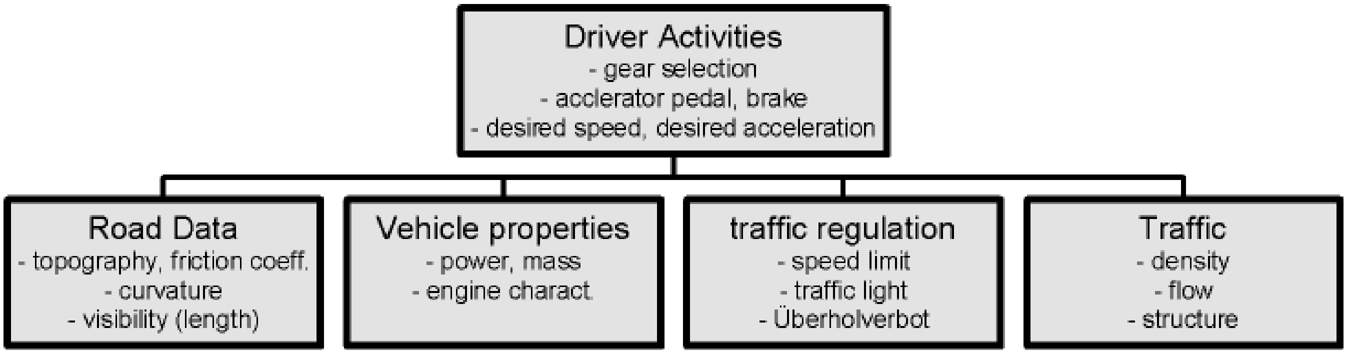


Diagram 8: Influencing variables on the driver model

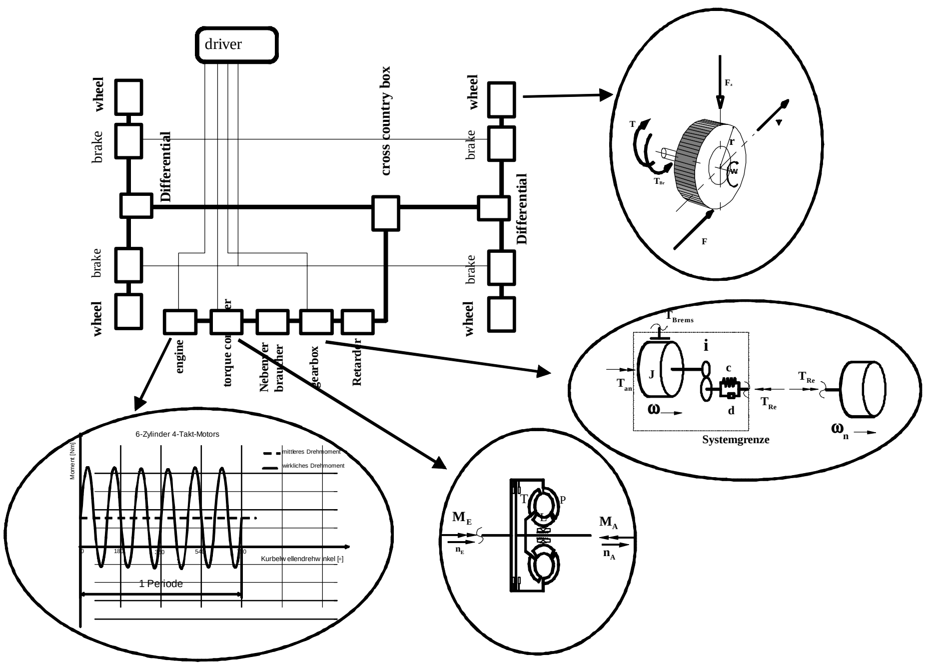


Diagram 9: Schematic representation of the vehicle model

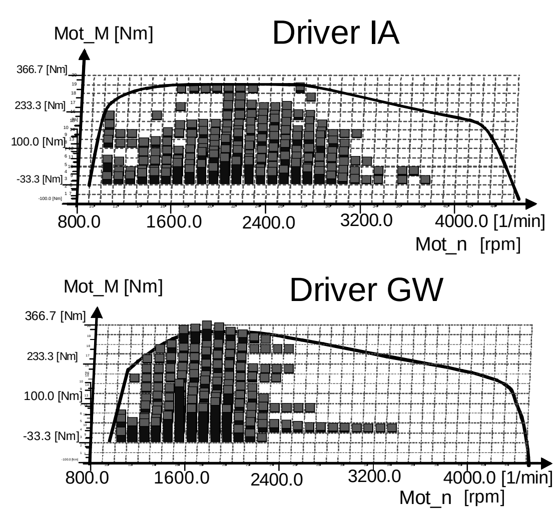


Diagram 10: Dwell duration of torque and RPM of the engines for both drivers IA and GW

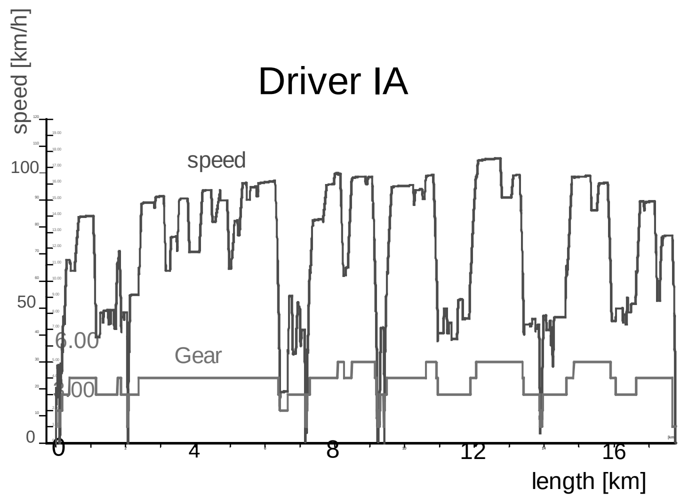


Diagram 11: Speed and gear of the simulated driver IA along the stretch of road on the Lone Valley circular route

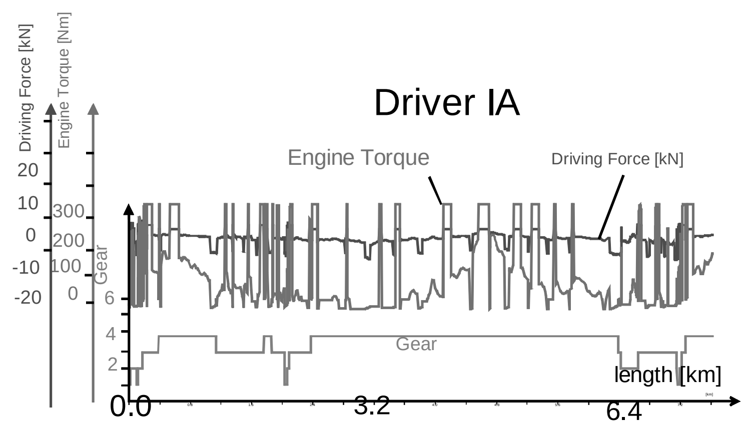


Diagram 12: Simulated engine torque, gear and driving force at the wheels along the stretch of road on the Lone Valley circular route

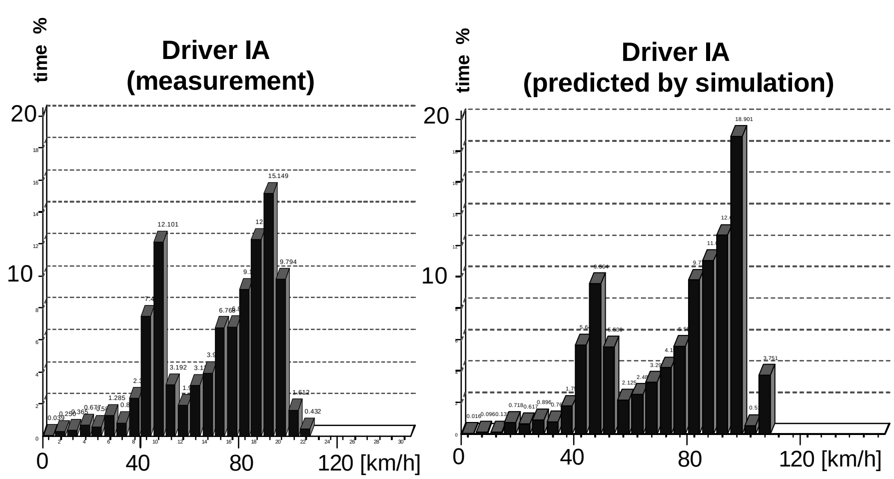


Diagram 13: Comparison between the calculation and the simulation for the proportion of time driven at a certain speed by driver IA

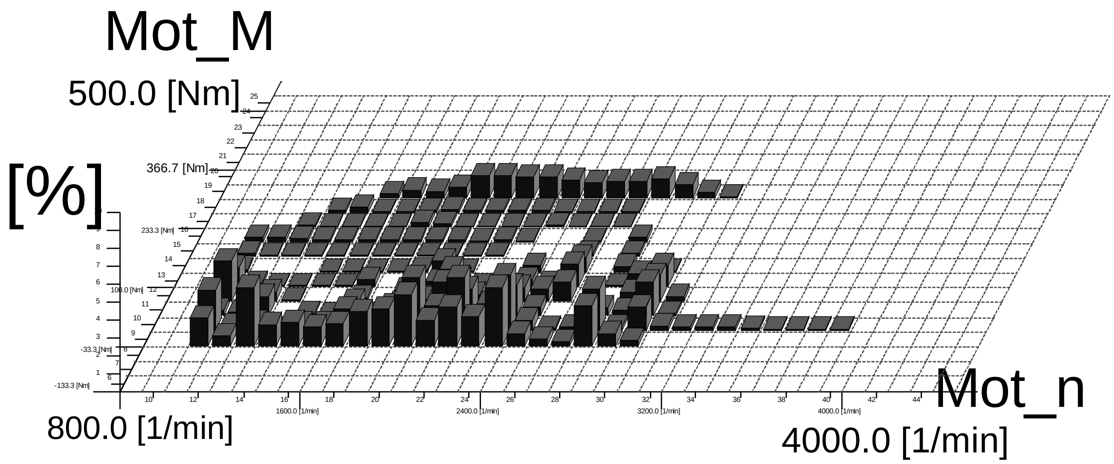


Diagram 14: Dwell duration of the engine torque and RPM as a result of the simulation for driver IA

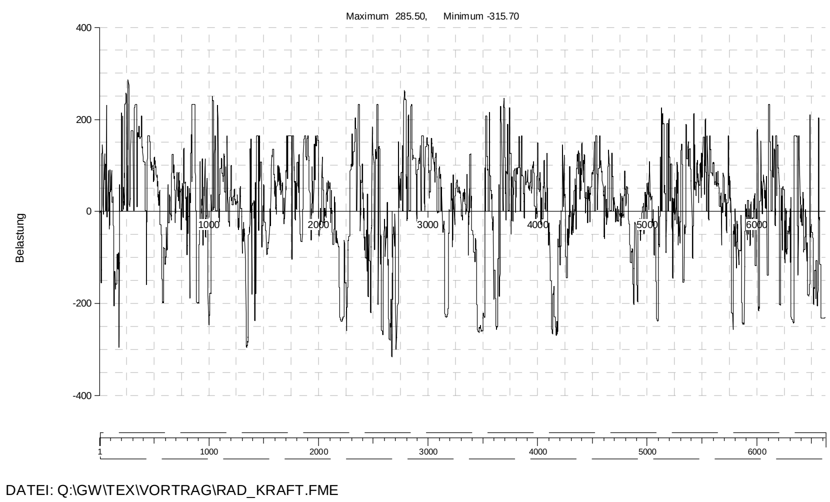


Diagram 15: History of the simulation nominal stress at a cardan shaft as the result of the torsional loading by the driving force

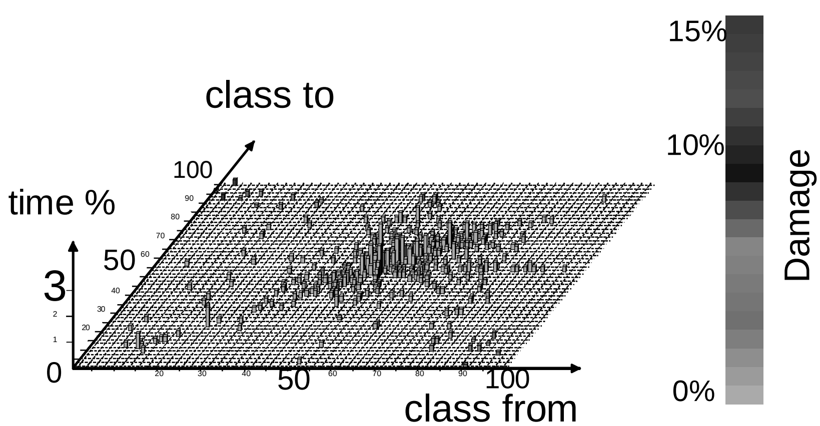


Diagram 16: Rainflow matrix of the nominal stress from diagram 15 and the damage proportion

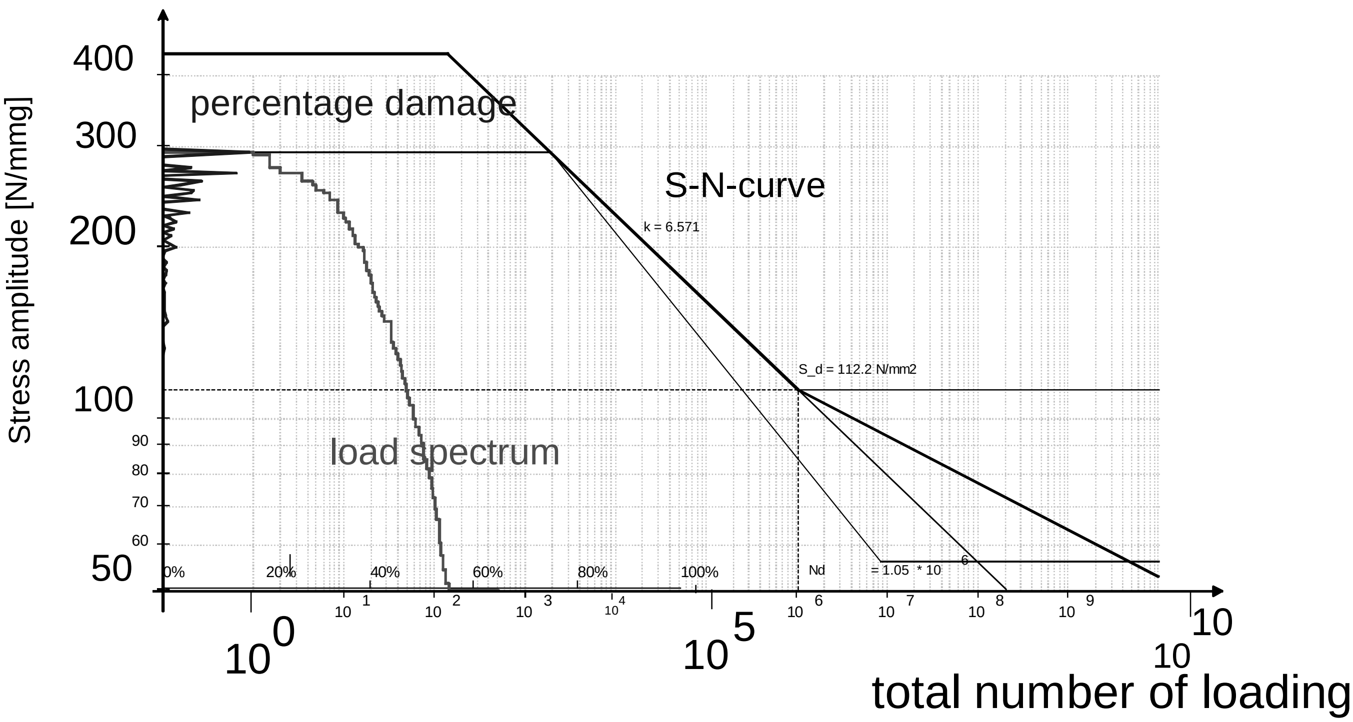


Diagram 17: Load spectrum of the torsional stress, damage percentage and component S-N curve

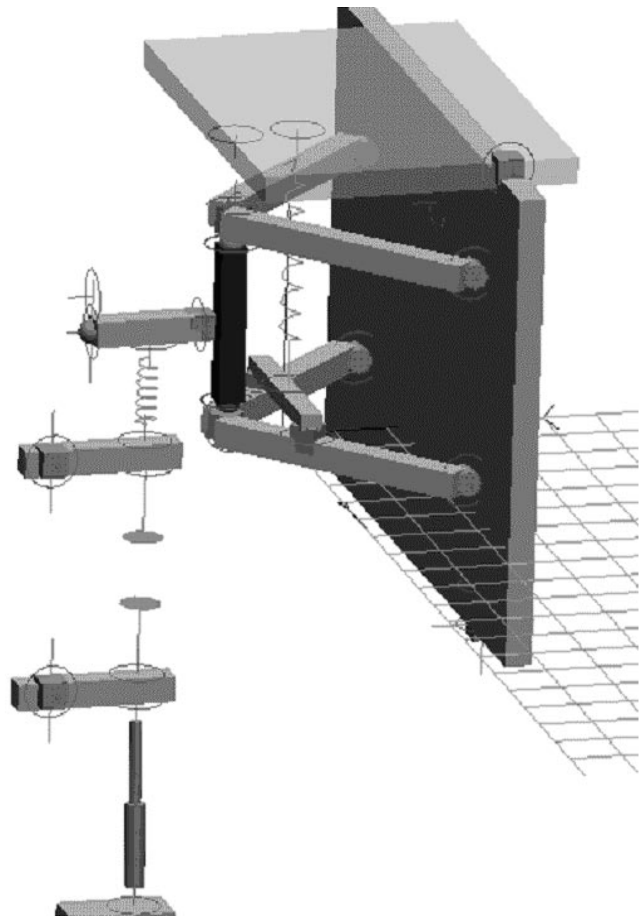


Diagram 18: Multibody dynamic model of a double wishbone axle

<table>
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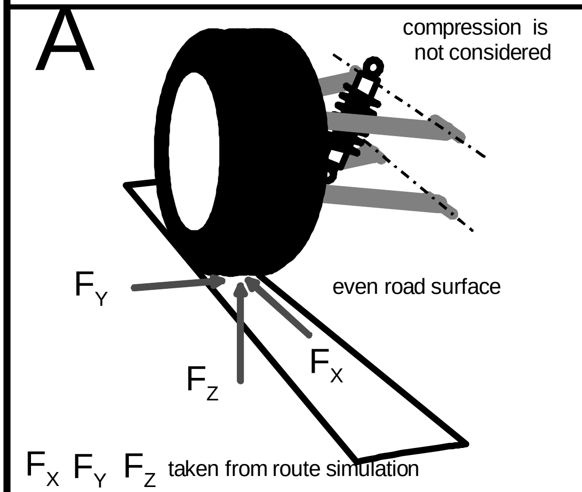

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- static FE- analysis for unit loads in the direction of the forces F_x,F_y, F_z
- calculation of the stresses for each time step and location by combining the static FE results and the load-time histories
- fatigue life calculation for each time step and node

Result: fatigue life on an even road surface without taking into account the compression of the axle
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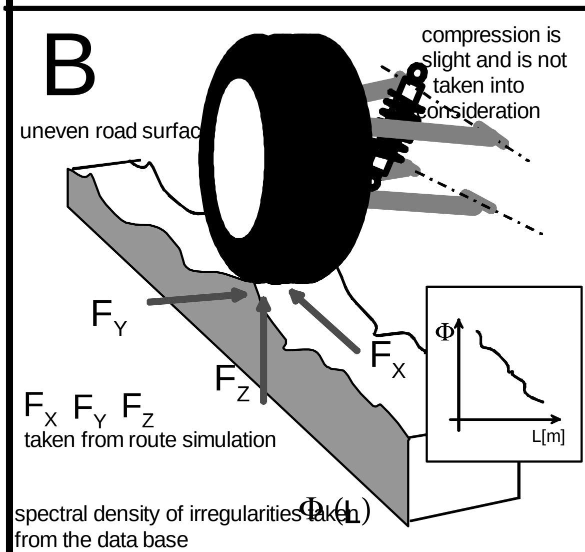

</td><td>
Step 1: Calculating the fatigue life according to forces F_x,F_y, F_z as in case A

Step 2: fatigue life according to irregularities in the road surface
- ascertaining the spectral density of irregularities in the road surface
- defining the lineal transmission behaviour of the axle
- calculating the spectral density of the stresses for the speed driven v(s) for each node
- calculating the fatigue life based on the spectral density of the stresses

Step 3:
Add together the damage sums from 1 + 2

Result: fatigue life on an uneven road surface without taking into consideration the geometrical alterations which occur with the compression of the axle
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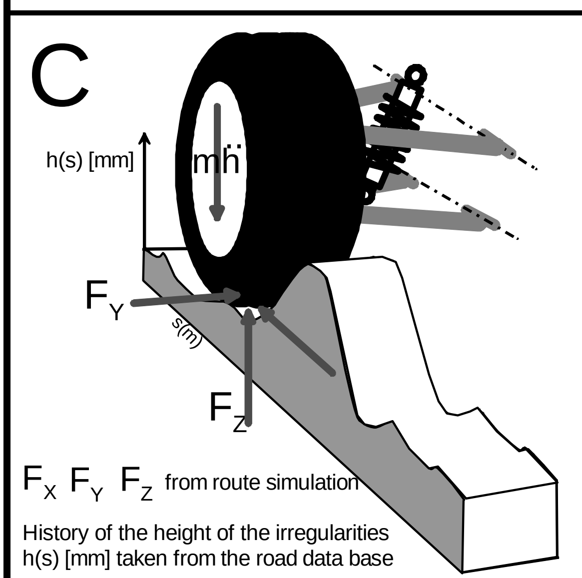

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Step 1:: simulation with a multibody dynamic model of the axle
calculating the cutting forces in individual components as a result of driving over irregularities in the road surface, taking into account the large spring deflection for each time step

Step 2: static FE calculations with various spring deflections under unit loads

Step 3: calculation of the stresses by combining the results from 1 and 2 for each time step and node

Step 4: multiaxial fatigue life calculation for each time step and node

Result: fatigue life on uneven road surface, taking into account the geometrical alterations which occur with the compression of the axle and all the inertia forces
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Diagram 19: Schematic representation of the calculation process for estimating the fatigue life of an axle