

## Energy Analysis of Power Steering Systems During a Newly Developed Driving Cycle

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### ABSTRACT

Developments in power steering systems have been concentrated on the energy consumption as the environmental issues intensified in recent years. After the widely used hydraulic power steering system, the introduction of electric and electro-hydraulic power steering systems has shed light on the energy saving of the power steering system.

In order to evaluate the energy consumption of the systems, firstly a new driving cycle was developed taking into account of both longitudinal and lateral driving behaviour. By comparing the vehicle response to the customer driving behaviour, the most similar sections on different traffic conditions were chosen therefore form the new driving cycle.

Steering models of these three different types, hydraulic, electro-hydraulic and electric power steering systems, were developed and the new driving cycle was used as the inputs to the models so that the energy consumption of the three steering systems can be calculated and compared under the same condition. Typically one of the inputs to the steering models is

the lateral acceleration instead of steering angle because different vehicle setup can be simulated and compared using the same lateral acceleration and velocity profile.

The steering models are modelled in a way that a mechanical module and a power assistance module interact with each other. The mechanical module provides steering velocity and rack velocity to the power assistance module while the power assistance module feeds back the assisting force and the friction caused by the power assistance module such as the sealing friction caused by the pressure in hydraulic powered system (HPS). The models predict accurate energy consumption of the steering systems with the new driving cycle.

Accurate power consumption of the systems was predicted due to the inclusion of the lateral dynamics in the new driving cycle. The power consumption of steering systems increases up to 48% compared to the conventional driving cycle. The steering models under the new driving cycle provide very useful information about the energy consumption of the three steering systems. This information can be an essential criterion for future optimisation of new steering systems.

## INTRODUCTION

Increased environmental concern coupled with ever reducing emission targets has led to increased pressure on car manufacturers to reduce vehicle fuel consumption. The New European Driving Cycle (NEDC) is seen as an important bench mark for European car manufacturers, as EU fuel consumption tests are based on it. The cycle consists of four low speed segments, representing urban driving, followed by an extra-urban driving cycle (EUDC), to account for high speed driving modes. Various other standard cycles have been developed by motoring authorities across the world, such as the Federal Test Procedure (FTP) cycles in North America or the 10 / 10-15 Mode cycles in Japan, however the cycle duration and general structure always conform to that of the NEDC. It should be noted that currently none of these standard driving cycles include lateral driving manoeuvres.

As a major energy consumer within the vehicle, the power steering system has been identified by many manufacturers as an area in which energy savings could be made. One development within this field is the introduction of electric (EPS) and electro-hydraulic (EHPS) power steering systems. The energy consumption of these systems, which have been shown to improve vehicle comfort, handling and safety [3], is strongly dependent on lateral dynamics. It is therefore no longer adequate to simply predict energy consumption with the standard cycle mentioned above. A new driving cycle needs to be developed predicting the energy consumption of the steering system so that both longitudinal and lateral driving behaviour are covered.

## MEASUREMENT

The vehicle measurements, which are carried out in a sports car with electro-hydraulic steering, can be split into two phases. Firstly as much data as possible is collected during normal driving situations. The amount of data collected is limited only by time constraints and vehicle availability. Secondly three pre-defined public road routes, as described below, are driven. The data from these routes, which have been selected to represent a full range of driving situations, will be used for the final driving cycle development.

- Motorway Lap - a 25km stretch of motorway between Stuttgart Airport and Aichelberg has been selected. There no speed limit for the majority of this road, therefore speeds in excess of 200 km/h can be reached.
- Country Lap - the 20km route consists mostly of winding country roads with some dual carriageway sections.

- Town Lap -represents a typical urban driving experience. The 5 km route includes both small residential roads and larger single and double lane carriageways.

## DEVELOPMENT OF THE NEW DRIVING CYCLE

In order to convert the driving cycle measurements into a concise driving cycle a unique cycle development process is defined as part of this work. A step-by-step description of this process is given below in [Figure 1](#). Four 2D-Histograms are created to represent a simple summary of driving behaviour in terms of vehicle speed and lateral acceleration. The histograms are described as follows-

Histogram 1 - contains all information for data collected during the first phase of measurements, i.e. during normal driving situations. Approximately 16 hours of driving data was collected for this phase of the measurements. This histogram is also referred to as the customer driving profile (KFP).

Histogram 2 - contains all information for data collected on the Stuttgart Town Lap. In order to avoid any anomalous driving results, the lap was driven 4 times.

Histogram 3 - contains all information for the data collected on the Weissach-Zuffenhausen Country Lap. This lap was driven 5 times.

Histogram 4 - contains all information for the data collected on the A8 Autobahn Lap. This lap was driven twice.

Histograms 2, 3 and 4 are merged at 1% intervals to find the weighting combination, which conforms best to the customer driving profile. This is determined by calculating the root mean square of the differences between the customer driving profile and merged histograms. After the total duration of the cycle is decided, the individual section durations, i.e. for town, country and motorway, is determined. The particular test trip, and section of that trip, is selected which best conforms to the corresponding lap histogram. This is determined using a similar process to that described in Step 2. That is histograms are formed to represent the sections of the individual test trips; the root mean square of the differences between these histograms and corresponding lap histogram is then calculated. The selected sections are joined together to form the final driving cycle. Using the above-described development process, the new driving cycle (KBP) was created, as shown in [Figure 2](#).

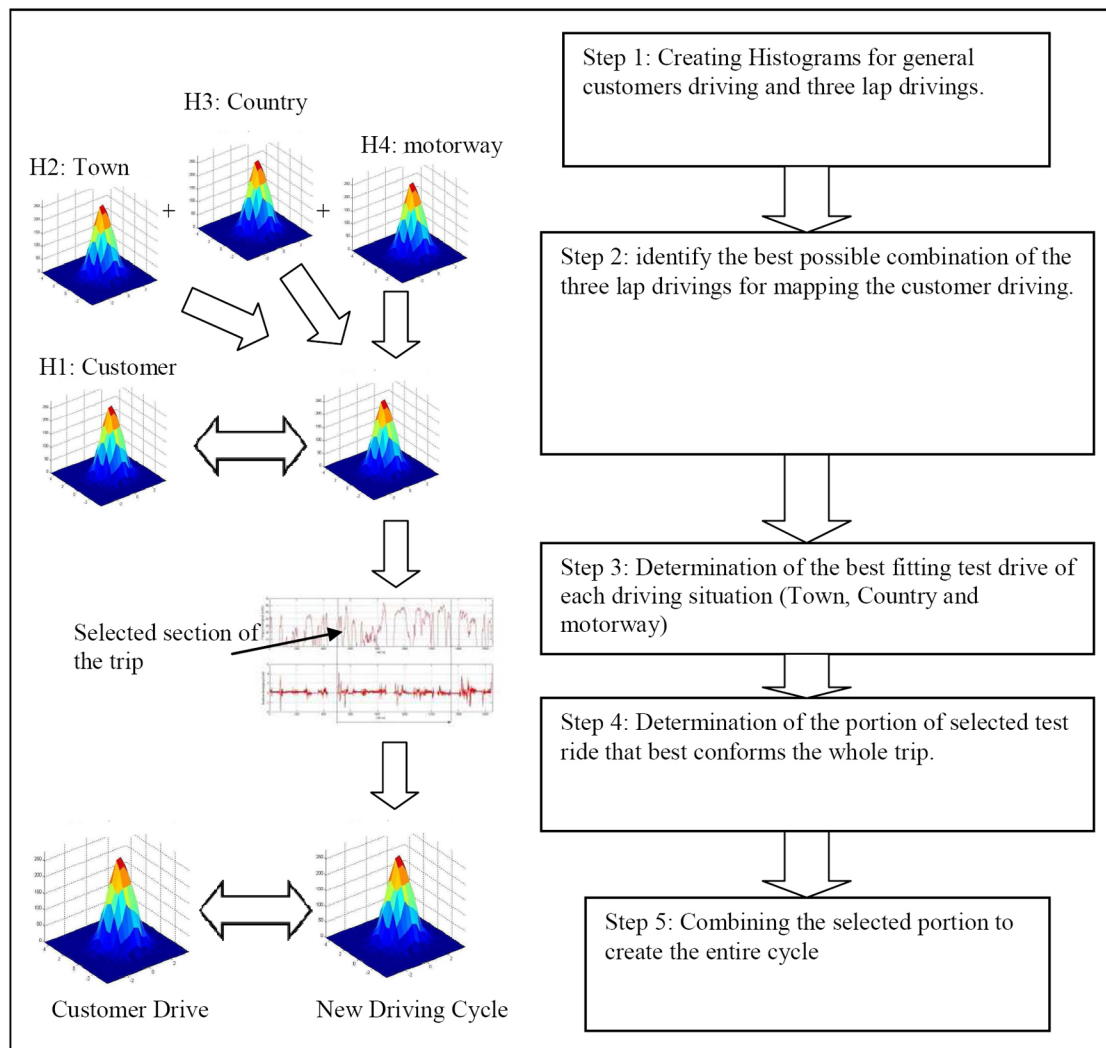


Figure 1. Process of the new cycle development KBP

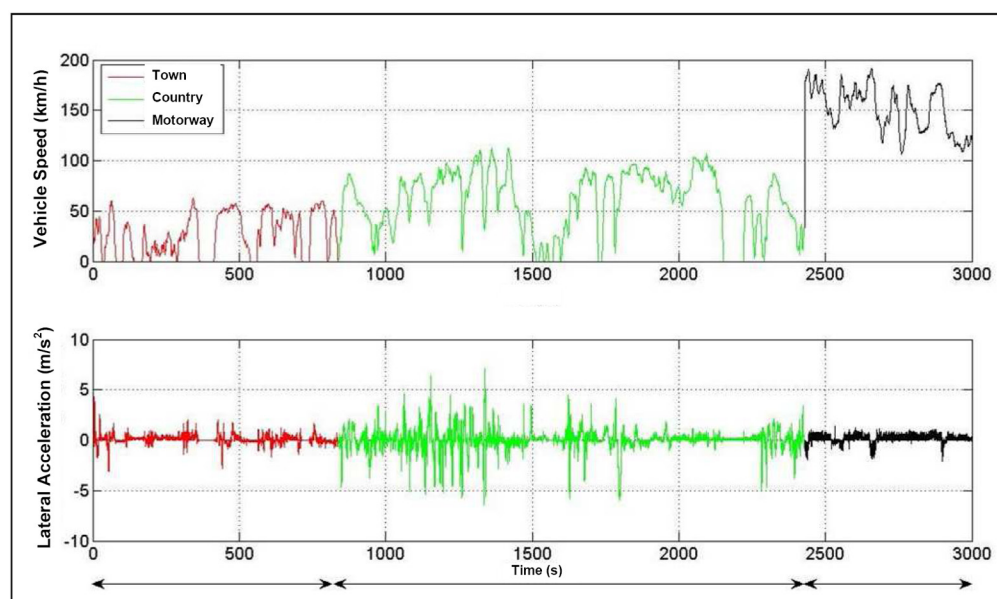


Figure 2. New Driving Cycle KBP