A COMPARISON OF REAL WORLD AND ACCELERATED POWERTRAIN ENDURANCE CYCLES FOR LIGHT DUTY VEHICLES

Pradeep Attibele, Sandeep Makam
Powertrain Virtual Analysis
Yung–Li Lee
Stress Lab and Durability Development
Chrysler Group LLC

ABSTRACT

Accelerated powertrain endurance cycles have been historically used to ensure that various transmission and driveline components meet the reliability requirements of the 95th percentile customer. These accelerated tests may be carried out, either in vehicle at the proving grounds, or on a dynamometer test stand. These accelerated tests rely on heavy throttle operation to achieve a reduction in test durations. As a consequence, they tend to force the transmission to operate primarily in lower gears. While this was acceptable in transmissions with fewer ratios, the accelerated test schedules may not always address the needs of the newer multi-speed automatics.

Here we first present a simple driveline model that is capable of simulating the accelerated endurance cycles as they are run on the proving grounds or on the dynamometer. We then compare these results with results of simulations of several real world drive cycles for the same vehicle category. We compare metrics such as the time at torque in gear and percentage of time spent at different throttle levels.

INTRODUCTION

Competitive pressures have led to ever decreasing development times for automotive systems, and in particular for automotive powertrains. This paper addresses two related needs: first, the need to quickly evaluate the impact of various driveline configuration changes on component durability, and second, the need to make the durability test cycles more representative of real world driving. The use of a validated simulation model can assist us in meeting both these needs.

Performing accelerated durability tests before the hardware becomes available is not possible, and performing complete durability tests to evaluate the impact of 'minor' changes in vehicle/powertrain can be time consuming. Simulations can be used as a complement to testing in such cases to provide timely durability assessments. This paper describes a simple driveline model that was developed to allow engineers to quickly generate time at torque data for various accelerated test schedules that are employed at Chrysler. The model is a second generation of models that have been developed at Chrysler. The first generation model was limited in scope and was developed to handle a specific accelerated test schedule [1]. The second generation model is more general in scope, and is capable of

assessing durability for any arbitrary test schedule, although it was specifically developed to simulate Chrysler Powertrain endurance schedules. The primary use of this model is to evaluate the impact of changes in vehicle/driveline configuration on the durability of rotating components, when a baseline already exists. As an example, the following types of changes could be investigated for their impact on, say, axle hypoid gear durability:

- Increasing vehicle payload
- Changing tire size
- Changing transmission
- Changing the torque converter
- Increasing engine displacement

Another aspect of durability tests is the need to capture the driving behavior of real world customers. The purpose of accelerated tests is to catch potential failure modes early, and they perform that task admirably. However, accelerated tests typically utilize high torque loads and high throttle, and high throttle generally implies increased time spent in lower gears. It would be desirable to supplement these tests with more time spent in high gears, so as to represent real world customer driving more appropriately. This has been achieved through various means in the past, and this paper presents a new option to do the same by using public domain driving data.

The following sections lay out the development of the simulation model, and the use of the real world data to generate various metrics of interest.

DRIVELINE SIMULATION MODEL

In this section, the development of the driveline simulation model (called VirtualPT, for Virtual PowerTrain), along with some examples of its use, is described. VirtualPT has been used extensively within Chrysler to evaluate the impact of changes to the driveline on the durability of rotating components. Figure 1 below shows an outline of the entire process:
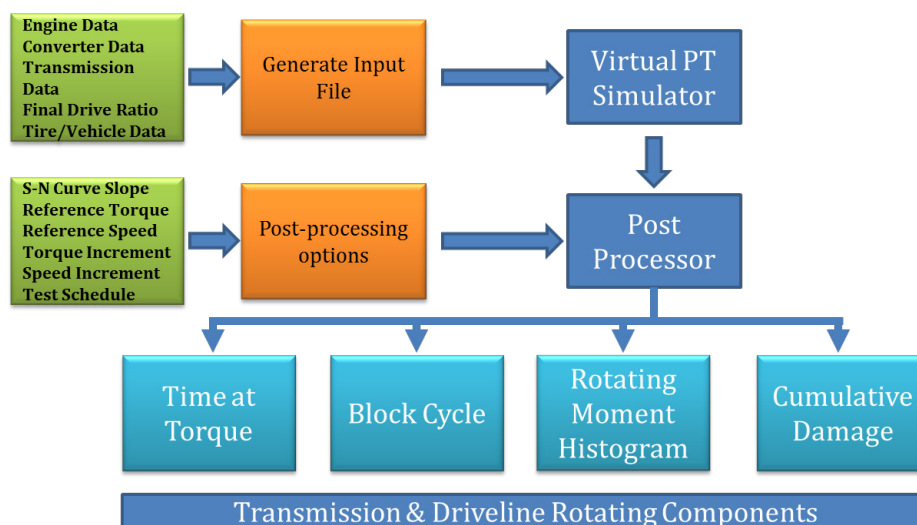

Figure 1 – Outline of the Simulation Process

The various input data are used to create an input file, which is fed into the simulator. The outputs of the simulator are torques and speeds at various points in the driveline. These are post-processed based on the desired format of the results. One point to note is that, even though VirtualPT can be used to predict the cumulative damage*, it is most useful for comparative analyses, when a baseline already exists.

VirtualPT has several major components which include the engine, torque converter, transmission (gearbox), vehicle, transmission control module, driver module, durability test schedules, and finally the topography of the proving grounds. Figure 2 below shows the layout of the simulation tool.
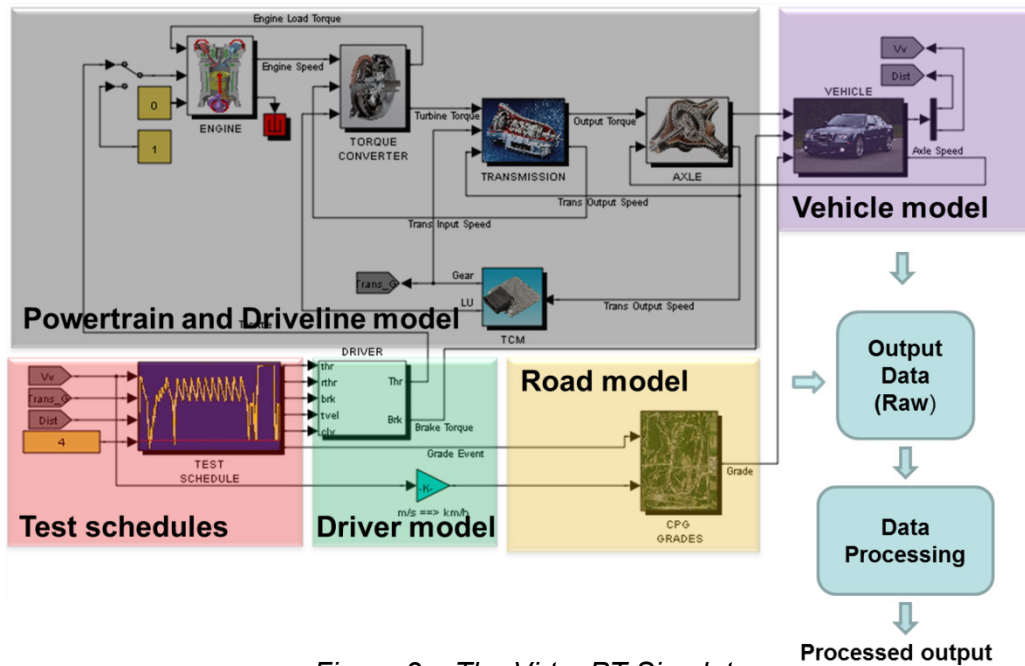

Figure 2 – The VirtuaPT Simulator

The model outputs have been compared with measured data from the Chrysler proving grounds, and in general, the simulation results indicate higher cumulative damage than measured data. There are a variety of reasons for this, among which driver variability in the measured data ranks at the top. Figure 3 compares the cumulative damage results from VirtualPT to calculations based on measured data from the proving grounds for a range of ballast conditions:
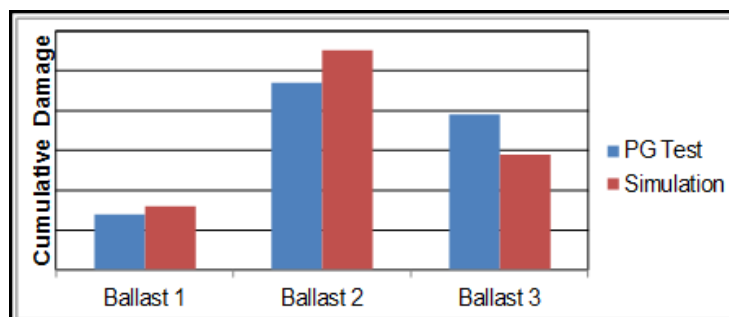

Figure 3 – Comparison of VirtualPT Simulation Data with Proving Ground Data

*Cumulative Damage is a term that reflects the natural degradation that occurs as a result of repeated cyclic loading. Mechanical damage can be observed *any* time a structural component undergoes repeated cyclic loading. Cumulative damage does not refer to a defect in the component or system.

Two examples of the application of this simulation tool are described below. In the first example, a control strategy for proportioning torque between the front and rear axles of an AWD vehicle was investigated. The intent was to balance the durability of the Rear Drive Unit (RDU) and the Front Drive Unit (FDU) for the given powertrain endurance cycle. The strategy called for automatically adjusting the torque split between the FDU and the RDU above a threshold throttle level in order to manage the loads on each unit. Figure 4 below shows how the analysis results offered a solution where both the RDU and FDU could operate with balanced safety factors.
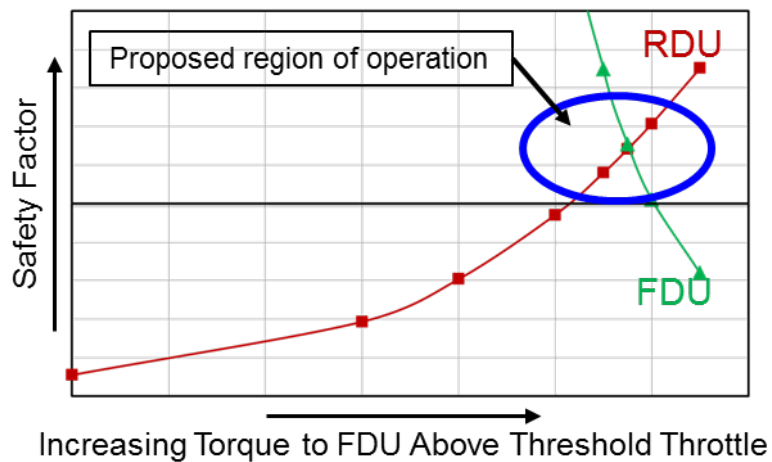

Figure 4 – VirtualPT Application (1)

In the second example, durability data was available for a transmission that was mated to a gasoline engine in a passenger car application. It was necessary to evaluate the feasibility of using the transmission in the same vehicle application behind a diesel engine. Since the baseline data were available, it was possible to use the simulation tool to evaluate the cumulative damage of the various rotating components in the transmission to see whether they were within target. The cumulative damage was calculated for both non-shot peened gears and shot peened gears, and as Figure 5 below indicates, it was determined that the transmission could not be used behind a diesel engine.
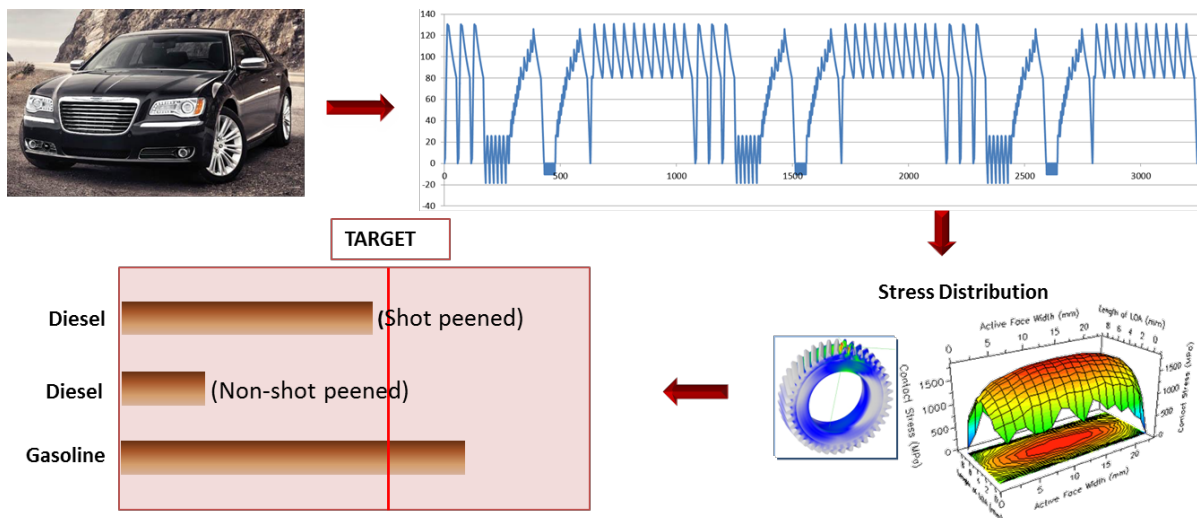

Figure 5 – VirtualPT Application (2)

REAL WORLD DRIVE CYCLES

The previous section showed a simple driveline model that could be used to simulate the accelerated powertrain endurance cycles. This approach has been used within Chrysler on several occasions to quickly evaluate the impact of design changes. However, as it has been pointed out earlier, these simulations may not always represent real world driving. Obtaining time at torque data that is truly representative of real world customers is very desirable, but obtaining real world drive cycle data can be expensive. Real world drive cycle data could also provide us information on the duty cycles of other components such as clutches, stop-start systems, etc.

In this analysis, drive cycle data collected from real customers that is available in public domain is used to generate time at torque and other information for a Chrysler FWD vehicle. These data have been collected by various government agencies in the United States, and were primarily meant for transportation planning at the local community level. The data sets are maintained and made available to the public by NREL (National Renewable Energy Laboratory). Different data sets have different types of information. In some cases only vehicle speed traces are available, while in other cases, vehicle speed and elevation traces are both available. These data were acquired using GPS data loggers installed in the vehicles. More information about these data sets can be obtained at the NREL TSDC (Transportation Secure Data Center) website [2]. In this study, only data sets which have both speed and elevation traces, along with vehicle make and model, have been used for the simulations. These data are available for a few thousand vehicles. However, for the purpose of these analyses only a small subset of vehicles, which included 66 FWD vehicles from two different cities (Austin, TX and San Antonio, TX) were used. The analyzed data represented 75 hours and 4090 kilometers of driving. The results shown here have been scaled to 150,000 miles of driving. Because of the nature of the data, there were missing/incomplete information, and assumptions had to be made regarding payload, driving style, etc. in order to proceed with the computations. Some of the assumptions include:

- No reverse gear operation was considered (GPS data could not indicate whether the vehicle was using reverse gear)
- Constant payload was assumed over the drive cycle.
- Single passenger usage vs. fully loaded vehicle usage was assumed to be in 1:3 ratio.
- No towing was considered.
- Constant shift-schedule, independent of grade or load.

These real world driving data were used as inputs to the simulation, essentially running a 'backward' simulation to generate speeds and torques at various points in the driveline, along with the gear, lock up state and throttle position. The results of the simulations are compared to the results from the accelerated powertrain endurance cycle below, and some interesting differences can be seen.

Figure 6 shows the time at torque in gear for roller bearings. The real world results show a steady decrease in time at torque with increasing gear. This could partly be the result of the large city driving component in the data sets. More highway driving would have resulted in moderate throttle, higher gear operations. The Psuedo-damage shown in the figure is essentially the equivalent time at torque calculated at a reference torque and

reference speed. Figure 7 shows the percentage of time spent in a particular operating torque range of the transmission, across all gears. The real world duty cycles indicate reduced time spent at higher input torque levels. In general, the higher the torque band, the lower the time spent. This could also be a result of the fact that the older vehicles for which the data are available had lower output engines than engines that are currently used.
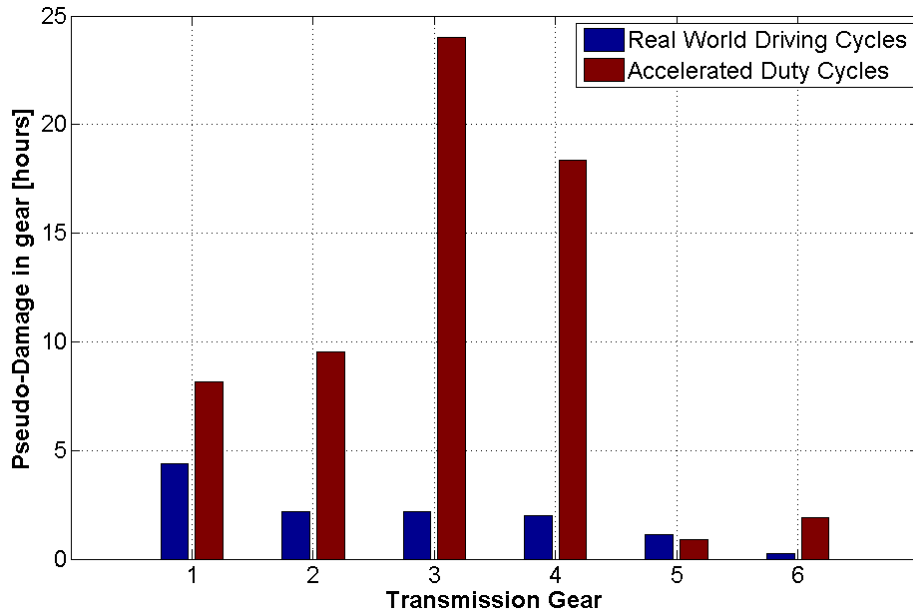

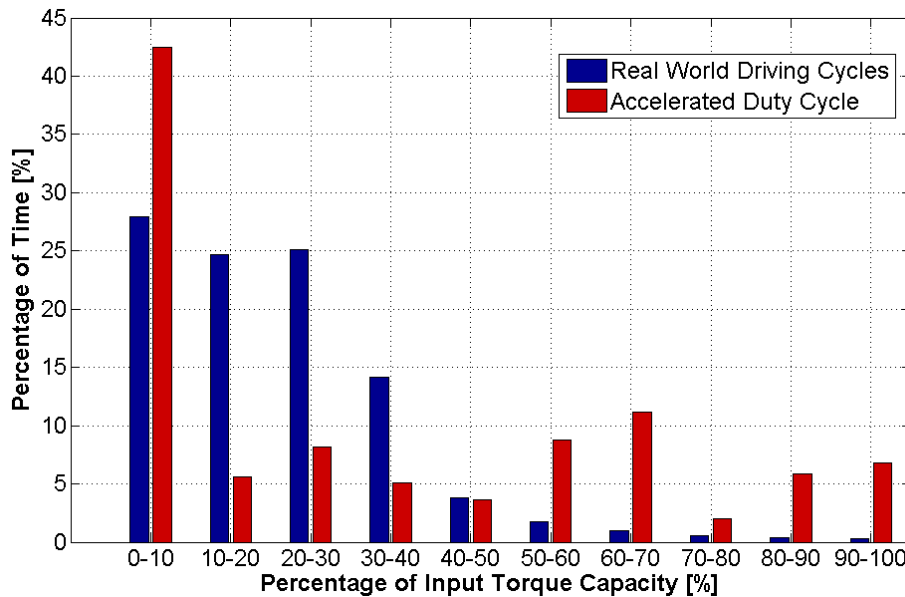Figure 6 – Comparison of Time at Torque in Gear

Figure 7 – Percentage of Time at Input Torque Level

In contrast, the accelerated duty cycle data in Figure 6 show that the time at torque is highest in 3rd and 4th gear, reflecting high throttle operation at moderate to high vehicle speeds. The overall time at torque in each gear is higher than the corresponding real world data as well. In Figure 7, the accelerated test data indicate significant amounts of time spend in the higher torque bins, reflecting the high throttle, high torque nature of the accelerated

test. The interesting aspect though, is that the maximum amount of time by far is spent in the lowest torque bin, and this is due to the significant amount of coasting that is involved in the accelerated test.

Figure 8 shows a rotating moment histogram for the real world driving cycles. The curves are quite smooth, reflecting real world operation spanning a wide range of torques and speeds. The mean for each gear's rotating moment histogram sees a monotonic reduction in torque value (moves downward in the graph) and an increase in revolutions (moves towards the right in the graph).
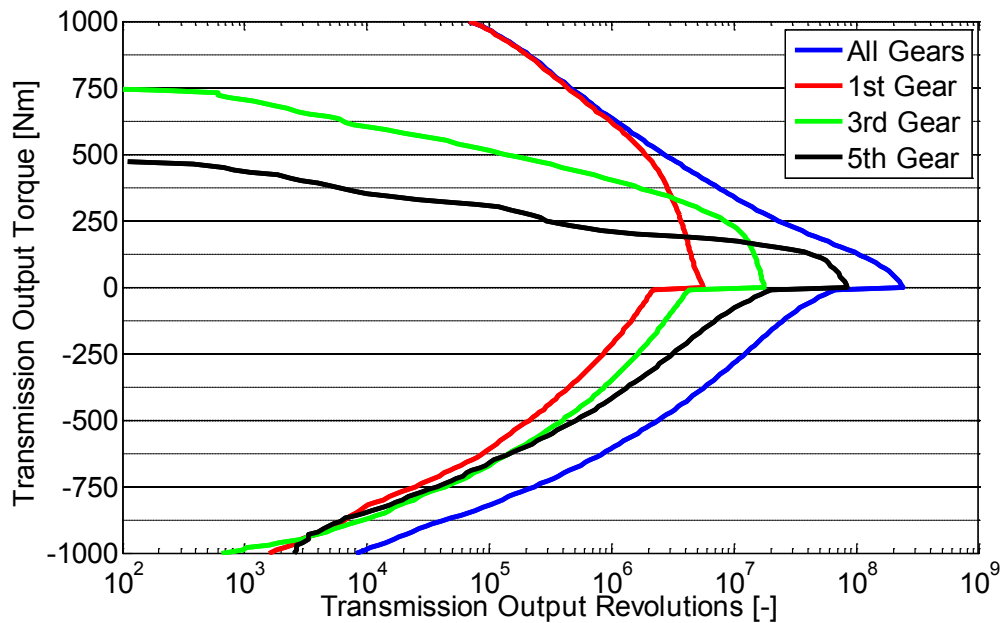

Figure 8 – Cumulative Output Shaft Revolutions vs. Output Shaft Torque

In Figure 9 below, the output from the real world data was processed to calculate the number of applications of the various clutches in the transmission. In conjunction with the torque levels at which these engagements occurred, a picture of the cumulative clutch energy dissipation could be obtained as well.
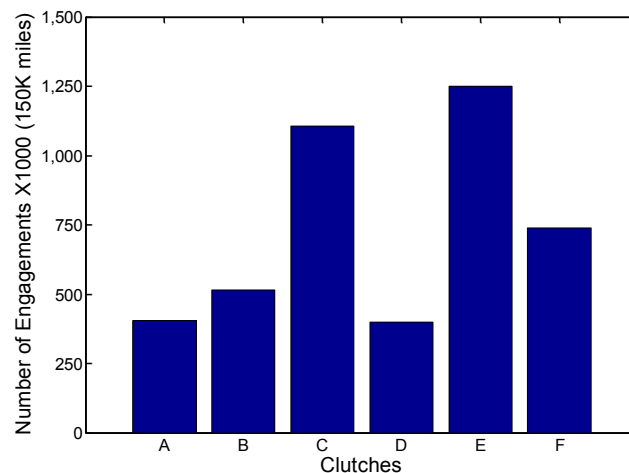

Figure 9 – Clutch Applications in Rear World Driving

CONCLUSIONS AND FUTURE WORK

In the preceding sections, first a simple driveline model that was used to generate time at torque data for accelerated powertrain endurance cycles was described along with some examples of its application, and second, public domain real world drive cycle data was used with this model to obtain time at torque and other data for a front wheel drive vehicle.

Comparing the two sets of outputs shows the complementary nature of the two data sets. Accelerated test cycles are essential for identifying potential issues in the powertrain system or component early in the design cycle, and they are also very effective in capturing the driving style of 'enthusiastic' drivers. The average, more moderate driver, subjects the drivetrain to a different kind of duty cycle which is characterized by more moderate throttle operation in higher gears. While it is normally difficult to capture this type of driving behavior for a large customer pool, the drive cycle data made available by NREL offers opportunity to do just that. As they say in economics, there is no such thing as a free meal, and the price for the 'free meal' in this case is the lack of information regarding payload and other vehicle information, as well as the low time resolution of the data. However, with some reasonable assumptions regarding these, the data could still be put to good use provide a way to complement the accelerated duty cycles and help achieve coverage of all driver types. This is all the more important for transmissions with large number of ratios.

The real world data sets can also be used for several other applications as well. One obvious application is to use it get more realistic estimates of fuel consumption in city driving. The data could be especially useful for evaluating the efficacy of stop-start strategy, and the benefit that can be had from employing different stop-start technology. With a more detailed model, it may also be possible to utilize real world temperature data in the simulations to estimate transmission operating temperatures. In fact the more uses that can be found for these types of data, the more reasons there are to maintain and add to these data sets.

ACKNOWLEDGEMENTS

REFERENCES

[1]   Basil Joseph, Pradeep Attibele, Yung-Li Lee, A PG Based Powertrain Model to Generate Component Loads for Fatigue Reliability Testing, *SAE 2003-01-1222*

[2]   http://www.nrel.gov/vehiclesandfuels/secure_transportation_data.html