

Automated Model Initialization Using Test Data

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ABSTRACT

Building a vehicle model with sufficient accuracy for fuel economy analysis is a time-consuming process, even with the modern-day simulation tools. Obtaining the right kind of data for modeling a vehicle can itself be challenging, given that while OEMs advertise the power and torque capability of their engines, the efficiency data for the components or the control algorithms are not usually made available for independent verification. The U.S. Department of Energy (DOE) funds the testing of vehicles at Argonne National Laboratory, and the test data are publicly available. Argonne is also the premier DOE laboratory for the modeling and simulation of vehicles. By combining the resources and expertise with available data, a process has been created to automatically develop a model for any conventional vehicle that is tested at Argonne. This paper explains the process of analyzing the publicly available test data and computing the parameters of various components from the analysis. It includes the development of engine fuel maps, gear shift maps, and other vehicle specifications necessary to build a model. The paper also includes a case study in which this process is applied on test data from a conventional vehicle, and compares the results from the actual test to the outputs from the automatically generated vehicle model. This analysis shows the advantages and limitations of the process.

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INTRODUCTION

By using a properly developed simulation model, researchers can estimate fuel economy and performance, use the simulation results as a benchmark, or analyze the future performance of a vehicle when the technology is evolved [1,2]. However, building a reliable vehicle model is a time-consuming process, even with the modern-day simulation tools. Obtaining appropriate test data for modeling a vehicle can be a challenge. While OEMs advertise the power and torque capability of their engines, the efficiency data for the components or the control algorithms are not usually made available for independent verification. The U.S. Department of Energy (DOE) has funded the testing of vehicles at Argonne National Laboratory, and the test data are publicly available [3]. Even though the proper test data are available, it is a time-consuming job to build a vehicle model and to validate it with the test data. Argonne is also the premier DOE laboratory for the modeling and simulation of vehicles. Many types of vehicle models, such as conventional, hybrid electric, battery electric, light-duty or heavy-duty, have been developed over the years [4, 5, 6]. By combining the resources and expertise with available data, a process has been created to automatically develop a model for any conventional (non-hybrid) vehicle with multi-speed automatic transmission tested at Argonne's Advanced Powertrain

Because not every signal that is needed to build a model is publicly available, calculations and estimations of the operating status for the components with assumptions are needed. The calculation and estimation of missing signals are done in Autonomie. Autonomie is a high-fidelity simulation tool developed by Argonne for modeling automotive powertrains, in particular aspects of the energy and longitudinal dynamic performance of the vehicle. It uses forward-looking simulation tool where flows (e.g., speed or voltage) are the result of efforts (e.g., force and current). The vehicle components such as engine, motor and battery are developed independently and connected by the flows and efforts which makes the tool flexible and reusable. The flows of each components are calculated based on the vehicle dynamics using parameters and look-up tables verified by test data. More than 50 turn-key vehicles and 120 powertrains are currently available in Autonomie [7]. Every process to import the test data, to calculate missing signals for model building, and to analyze the results is developed through automatic methods. In this way, a validated vehicle model can be obtained by simply inputting a few vehicle specifications and test data into the automatic process. The paper describes the application of a case study to a conventional vehicle and compares the results from the actual test to the output from the automatically generated vehicle model. The process makes a reliable vehicle model and using it for future research easy.

Research Facility (APRF). This paper explains the process of analyzing the publicly available test data and computing the parameters of various components. The process includes the development of engine fuel maps, gear shifting maps, torque converter lockup, and other vehicle specifications to build a model.

TEST DATA IMPORT

To utilize raw test data, the test data must be imported to Autonomie. There are important signals to achieve sufficient accuracy in terms of fuel economy and performance, such as engine output torque, torque/

converter (TC) input and output speeds, gearbox input and output speeds, vehicle (dynamometer) speed and force, and the driver's acceleration demand signals. Some of the signals required can be achieved directly from the test data; however, many of the signals need to be calculated with assumptions. In a conventional vehicle (see Figure 1), there is only one power source to drive the vehicle; the engine. It is possible to calculate the estimated output torque of every component by using only one force or torque, like dynamometer force, and applying relevant assumptions. Table 1 shows the list of minimum required parameters and test signals for the process. The complete process to calculate the missing signals of each component is described below.

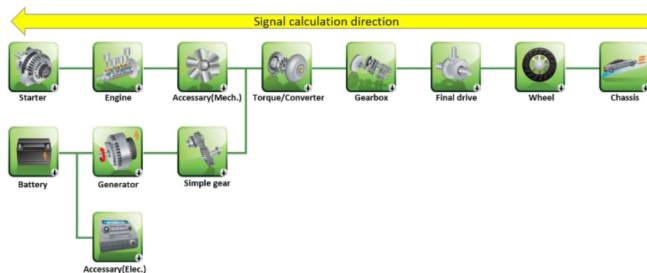


Figure 1. Configuration of conventional vehicle in Autonomie [7].

Table 1. The minimum required parameters and test signals for the process.

Name	Unit
Parameters	
Vehicle total mass	kg
Coast down coefficients	N, N/(m/s), N/(m/s) ²
Wheel radius	m
Final drive gear ratio	-
Gearbox gear ratios	-
Accessory load	W
Test signals	
Vehicle speed	m/s
Engine speed	rad/s
Engine fuel consumption rate	kg/s

Step 1: Wheel Signals Calculation

In the first step, wheel speed and torque need to be calculated. Wheel speed is easy to find because it can be simply calculated by using vehicle speed and tire radius. The tire radius can be found in publicly available resources, but the real tire radius and the official value in the specifications can be different. To obtain the appropriate wheel speed, the tire radius should be checked by comparing it with engine speed and gearbox input speed after acquiring the TC operating status signal. Wheel input torque also can be estimated by using dynamometer force and wheel rolling resistance. To determine proper rolling resistance, the correct coefficient numbers of rolling resistance should be known. Knowing the proper number of coefficients is difficult, however. In that case, the target value of the vehicle load for the dynamometer in testing, not the dynamometer force and rolling resistance, is used to obtain wheel input torque.

Step 2: Gearbox Signals Calculation

Gear number signal is important for estimating gear-shifting control. In some test data, the gear number signal is already measured, but if there are no gear number signals, it should be estimated. The gearbox

output speed can be calculated from vehicle speed as in (1), and the gear ratio can be calculated by dividing engine speed by gearbox output speed as in (2).

$$\omega_{gb.out} = \frac{V_{chas}}{R_{whl}} \cdot \gamma_{fd} \quad (1)$$

$$\gamma_{gb} = \frac{\omega_{eng}}{\omega_{gb.out}} \quad (2)$$

where $\omega_{gb.out}$, ω_{eng} and V_{chas} are the gearbox output, the engine and the vehicle speeds. R_{whl} , γ_{fd} and γ_{gb} are the wheel radius, the final drive ratio and the gear ratio. The calculated gear ratio can be checked if the official gear ratio can be found in publicly available resources. Both engine and gearbox output speed can be unmatched when the TC is not fully locked. In this case, the gear ratio should be abandoned, and the gear status is set neutral.

Step 3: Torque/Converter Signals Calculation

The condition of TC lockup is another important signal needed to build a reliable vehicle model. Because there are two speeds from engine and gearbox input (calculated from vehicle), the status of the TC lockup is determined by comparing both speeds of engine output and gearbox input. When both speeds from the engine and gearbox are the same or are within a set value of discrepancy, the TC is considered to be locked.

Step 4: Engine Signals Calculation

The speed and torque of the engine are the most important signals to build into a model with sufficient accuracy (especially in terms of fuel economy) because the engine map mostly affects fuel economy. The engine speed and fuel rate must be obtained from test data. If there are no signals for engine speed or fuel rate, the process developed in this research cannot be applied. The most favorable case is where the engine torque is also in the test data. However, in many cases (including some of the test data from the APRF), it is very difficult, expensive, and time-consuming work to obtain the engine torque from testing. Yet, because engine torque is the most important signal, it should be estimated. The engine output torque is calculated from the wheel input torque (or dynamometer force with rolling resistance) and accessory load power. Wheel output torque can be used to calculate engine torque according to gear ratio and on the basis of some assumptions, like the efficiency of gearbox as in (3). When the TC is not locked, the engine torque should not be estimated from the wheel input torque or the vehicle force at dynamometer. The estimated engine torque signal when the TC is not locked should be abandoned for the calculation of engine fuel rate map.

$$T_{eng} = T_{whl.in} \frac{1}{\gamma_{fd} \cdot \eta_{fd}} \frac{1}{\gamma_{gb} \cdot \eta_{gb}} + \frac{P_{acc}}{\omega_{eng}} \quad (3)$$

where T_{eng} and $T_{whl.in}$ are the engine and the wheel input torques. η_{fd} and η_{gb} are the final drive and gearbox efficiencies. P_{acc} is the accessory load power.