

Power for traction characterized by normal distributions

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Introduction

A driving cycle defines the speed profile as requirement for a propulsion systems or vehicles. As a single driving cycle can hardly be considered representative for all situations a vehicle will experience, attempts are made to classify driving cycles, using techniques as fuzzy logic, statistics and principal component analysis. The need for a definition of the required speed also explains the many driving cycles available in literature.

Objective of this study is to classify driving cycles not in terms of speed, but in terms of power, with a focus is on electric vehicles.

Observations

From simulations with driving cycles and vehicle models, and from measurements obtained from fuel cell hybrid vehicles, it was observed that the distribution of the power for traction tends to be bell-shaped, regardless the driving cycle. An example is presented in figure 1, representing a simulation of the JE05 driving cycle with a validated vehicle model of a delivery van. To falsify or confirm a bell-shaped power distribution, measurements were obtained from a fuel cell hybrid Fiat Doblo. As indicated in figure 2, these measurements confirm the assumed distribution.

Application

As sketched in figure 4, a normal distribution as generalized definition of the power for traction is derived from a representative driving cycle and a model of the vehicle. Assuming a fuel cell hybrid propulsion system, the energy management strategy defines the power split over primary source (fuel cell system) and storage (battery). Based on this power split, the individual power distributions for fuel cell stack and battery are estimated. These estimates provide a definition of the power demand for the separate components in the propulsion system, useful for sizing.

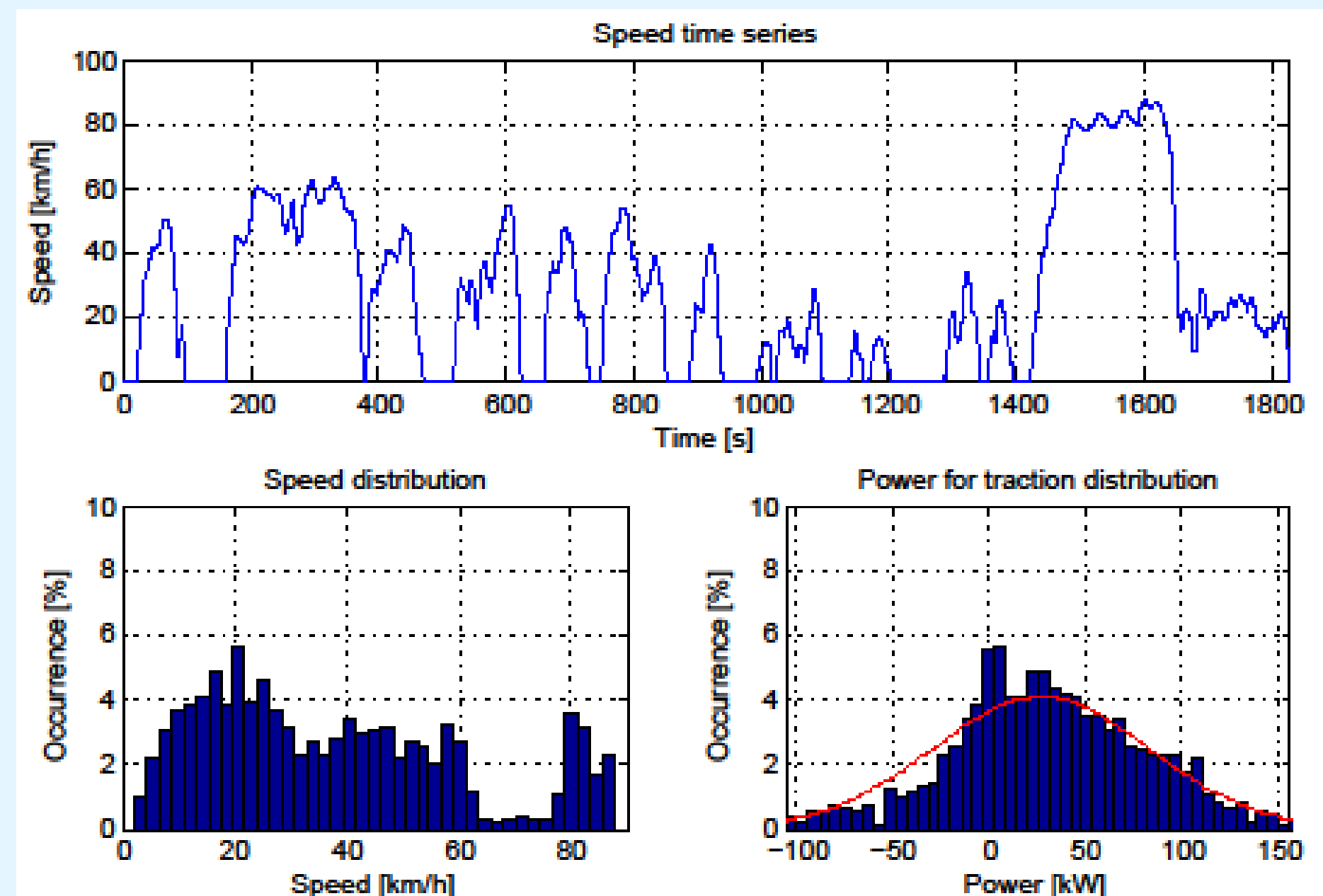


Figure 1 Simulated distributions.

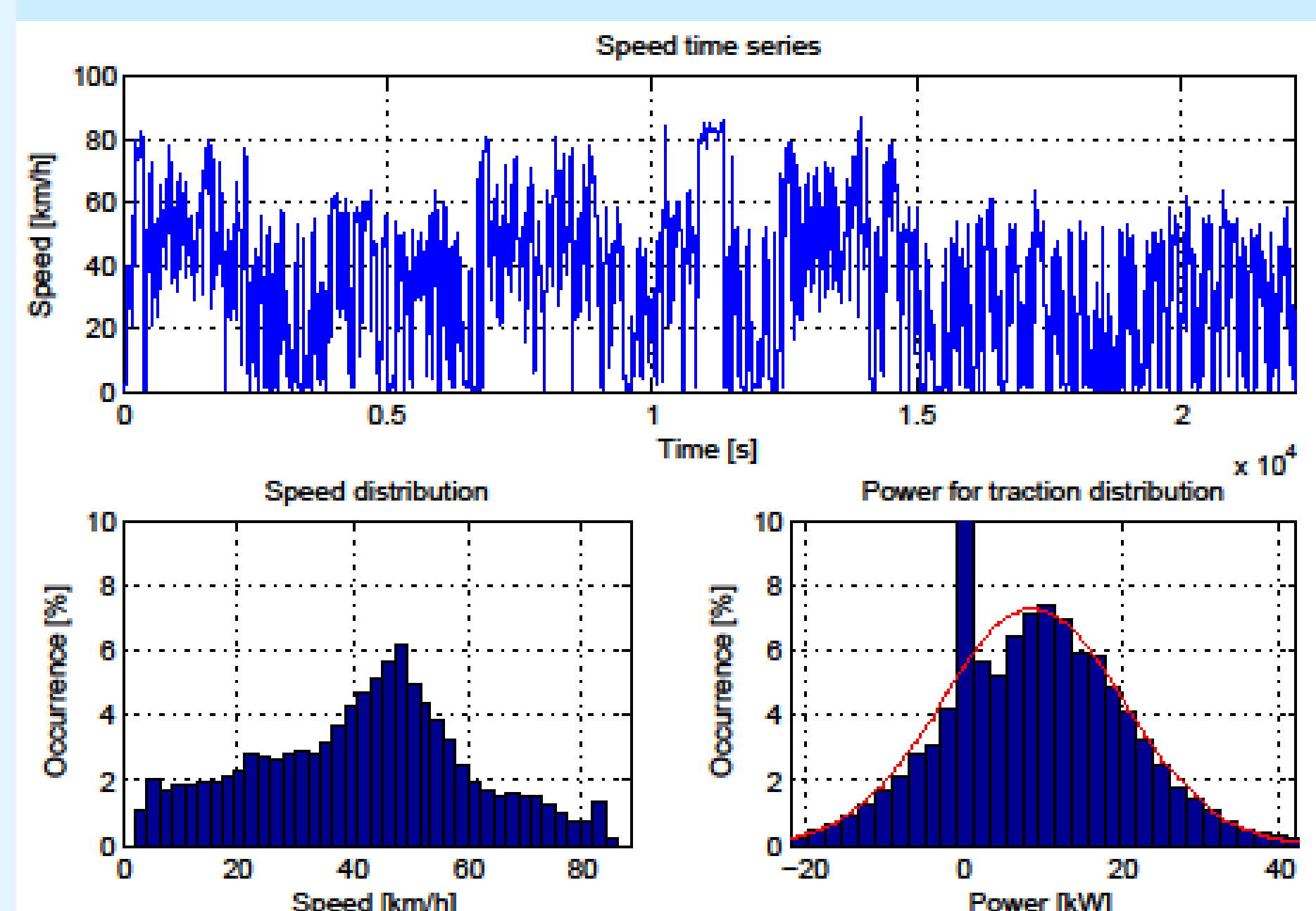


Figure 2 Measured distributions.

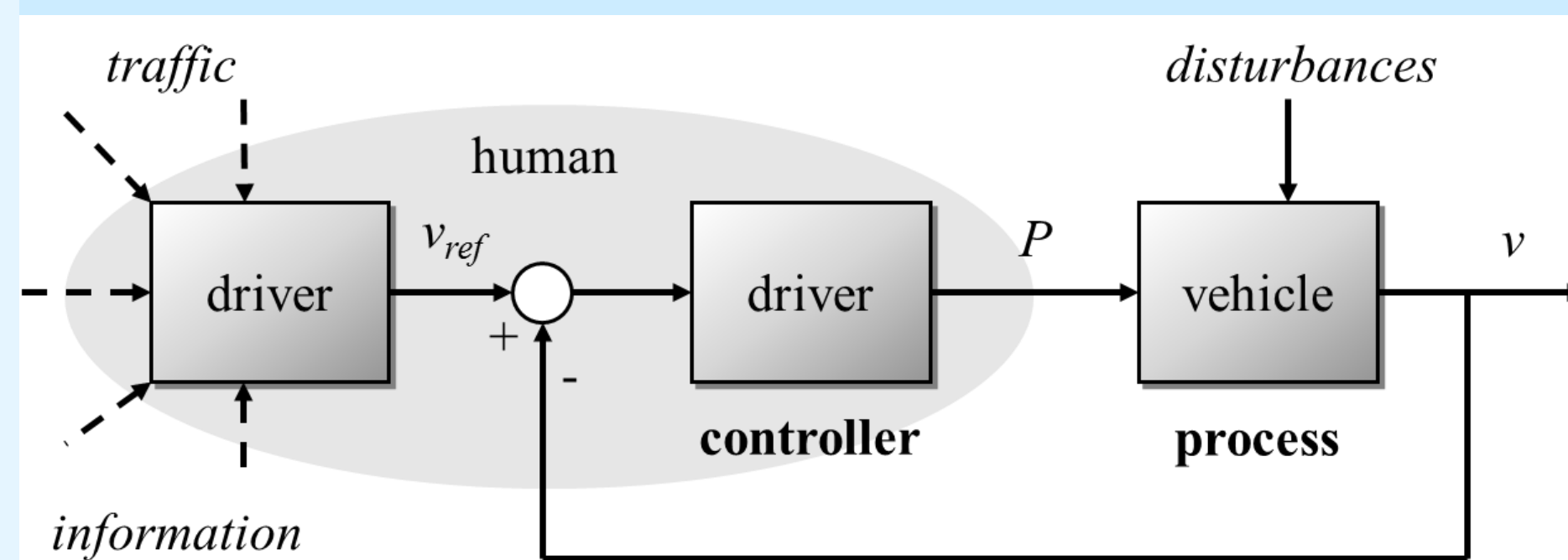


Figure 3 Driver and vehicle as control loop.

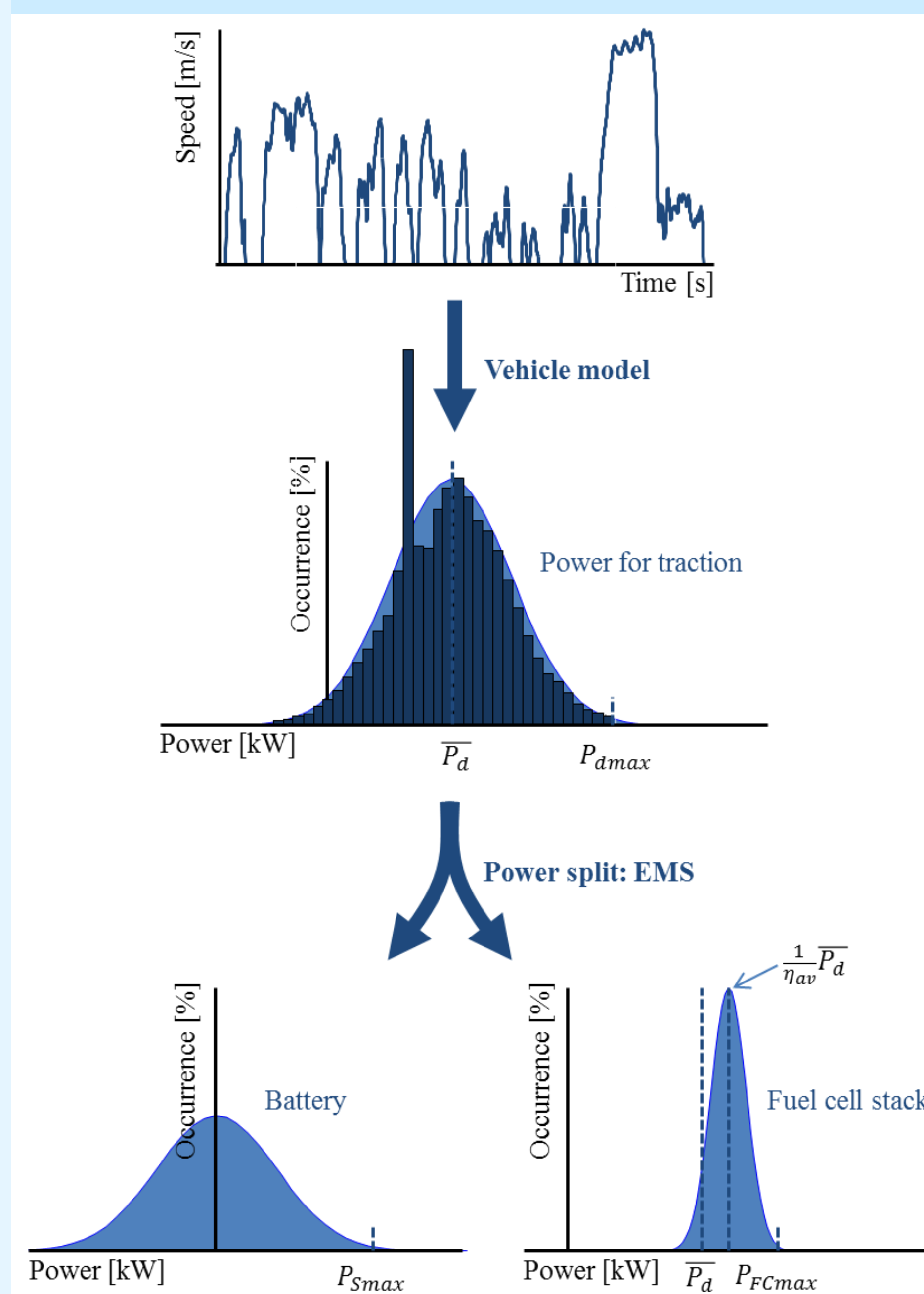


Figure 4 From cycle to component size.

Motivation

Based on the observations, it is stated that *over the lifetime of the vehicle, the distribution of the power for traction is reasonably approximated with a normal distribution.* The motivation for this hypothesis is based on the interaction between driver and vehicle. As indicated in figure 3, the driver continuously generates a speed set point v_{ref} using information of the surrounding traffic environment. As the vehicle shows a low pass behaviour between the power for traction P and the realized speed v , the driver as controller acts initially as differential action to speed up the response of the vehicle. Still, ultimately, the drivers' response is low pass. More precisely, literature proposes to approximate human control loops with a first order transfer function with delay. For such (linear) low pass transfer functions it can be proven that regardless the amplitude distribution of a random input, the output is normal (Gaussian) distributed. As at least part of the information of the surrounding traffic is random, the power for traction will evolve towards a normal distribution. Variables as wind speed and inclination are considered disturbances in the control loop. As these disturbances are also partly uncorrelated, over time, based on the central limit theorem, this further supports a normal distribution.

Conclusion

The study motivates that normal distributions are an acceptable approximation of the power for traction of an electric propelled vehicle. The resulting power distribution represents a traffic environment for which the considered driving cycle is an instance. Mean and variance of this normal distribution directly relate to vehicle parameters and key properties of the considered driving cycle. Based on the energy management strategy, the power distributions for the separate propulsion system components are estimated. This supports sizing these components.