AVL: Battery lifetime prediction

Survival analysis and Hidden Markov Model

Tom Davis, Marco Murtinu, Kari Heine, Mark Opmeer

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Overview

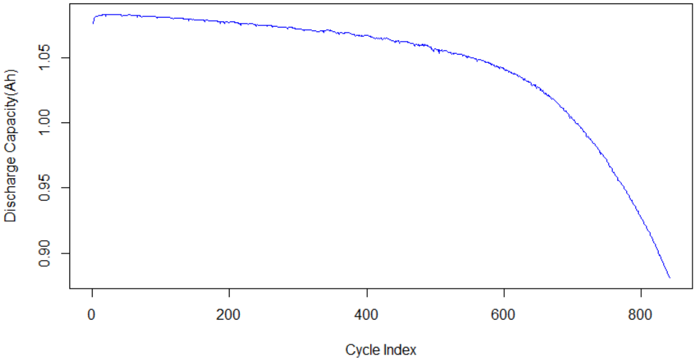
Problem: predicting remaining lifetime of a battery. Battery degradation may have several causes such as

- Capacity degradation
- Resistance degradation

We are only interested in the time to failure, not in the cause of failure. Specifically we are interested in understanding when the capacity falls below 80 %.

Data

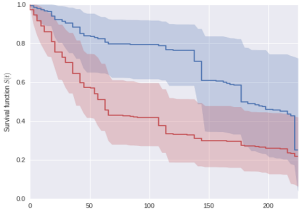
The dataset consists of 124 batteries cycled to failure. It contains physical information such as discharge capacity, internal resistance, voltage and others.
Goal: forecast when the discharge capacity will fall below 80 %.



Approaches

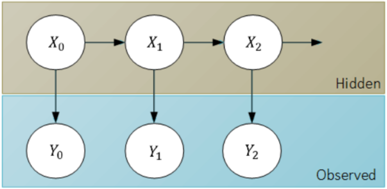
Survival analysis

- It studies the expected duration of time until one or more events happen
- Used to model failure rates of components in engineering



Hidden Markov model

- The system is a Markov process with unobservable states
- The output, dependent on the state, is observable



Survival Analysis: Toy Model

Aim: to estimate $S(t)$, the probability of a new battery surviving to time $t > 0$.
We do this by estimating the "failure rate" for battery i as follows:

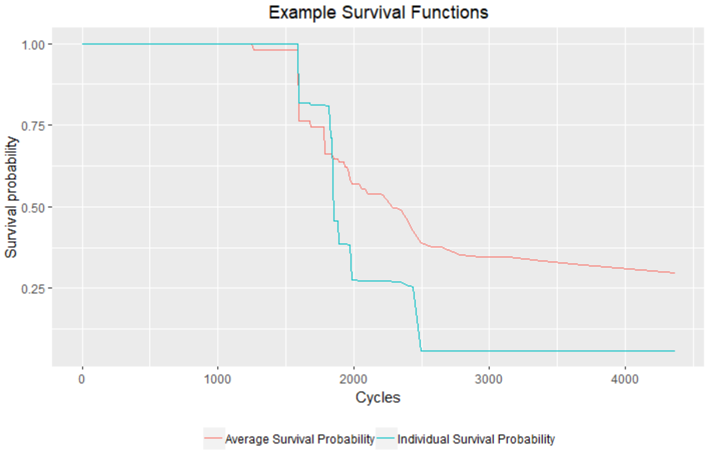
$$\lambda_i(t) = \lambda_0(t) \exp(\beta^T x_i(t)),$$

for some baseline hazard $\lambda_0(t)$ and independent variables x_i (which vary in time)
Given λ_i, the survival probability is then:

$$S_i(t) = \exp\left\{ - \int_0^t \lambda_i(s) \mathrm{d}s \right\}$$

Example Results

Example plots using battery voltage/temperature as covariates:



Data-Bank Hidden Markov model

Hidden Markov model: Conclusions and next steps

The DBHMM deserves further investigation.

- The proposed model is purely statistical and it does not require any physical knowledge
- We expect it to be fairly fast
- It uses little data.

Next steps:

- Understand whether we can construct a sufficiently representative data-bank
- Incorporate other data sources.

Conclusion and Further Ideas

Conclusions:

- Basic survival analysis gives sensible ideas
- Difficult to estimate precisely with limited data

Ideas for further development:

- Try a similar approach using real-world data, more independent variables
- Introduce covariates to capture historical effects, e.g. n-day moving average of temperature
- Competing risks models: incorporate multiple causes of failure and model time to the first one