Sustainable energy production systems: deterioration modeling and predictive maintenance

Mitra Fouladirad
Institut Charles Delaunay
Université de Technologie de Troyes

1/04/20

1 Subject

Motivation

An important issue that the engineering and technology are facing is the maintenance optimisation of multi-component systems, such as solar panel, solar farm, wind turbine or wind farm. In absence of interaction between components, the reliability and optimal maintenance policies of multi-component systems can be obtained by applying similar approaches as the single unit systems. However, such assumption is often unrealistic because of the internal complex structures of the systems, the set up costs, the common cause failures to the components, etc. There are several types of interaction between components of the multi-component systems such as the economic interaction when the system maintenance cost is related to the components, structural dependence when to repair the failed component one has to remove or even to replace the non-failed components, stochastic dependence when the failure or deterioration of components can affect the state (the deterioration level, the failure rate, etc.) of other components [11–13].

An accurate deterioration and interaction modeling requires health monitoring data. Even though, the majority of deterioration phenomenon have physical or mechanical meanings due to the large number of unknown environmental factors influencing this latter, it is nearly impossible to base the prediction on pure deterministic models. Hence, the deterioration phenomenon can be considered as random with a gradual time-continuous trajectory. With respect to the system under study, the degradation model can take values in discrete or continuous space. For instance, the corrosion indicator can take infinite possible values as soon as it begins but the cumulative number of rejected products in a production day which can be considered as a deterioration indicator is finite and can be enumerated, for more examples refer to [1–3]. Complex models are able to take into account all available information and describe precisely the dynamics of degradation but they are not always tractable with large difficulties for inference and calibration in the presence of data. Very simple and tractable models which can be easily calibrated can lead to wrong evaluation of the uncertainty around the lifetime prediction. This wrong evaluation can cause additional costs and desastruous consequences. A fair and satisfactory degradation model should make a balance between accuracy and tractability, [4, 5].

For a complex multi-component system under consideration, the main challenge is to model the deterioration and the interaction between the components, to calibrate the model in presence of field data and to plan efficient maintenance operations.

General layout of the thesis

One considers a multi-component system. The components are deteriorating and the failure, maintenance action and duration of one component impact the degradation level of the other components since the whole system should continue to fulfill its mission and produce the expected result. To propose an efficient maintenance policy, first, it is essential to focus on the degradation interaction modeling and afterward consider the maintenance efficiency modeling. The optimisation problem should take into account all the maintenance constraints.

The different steps of this thesis can be resumed as follows:

1. Degradation and interaction modeling
2. Maintenance modeling
3. Maintenance policy optimisation

The key knowledge and required skills to implement the previous steps are as follows:

1. Reliability analysis
2. Probability and stochastic models
3. Statistical Inference
4. Function optimisation
5. Simulation and programming software: Matlab, R, Scilab,...

Main collaboration on the subject

The candidate will organise and/or participate to meetings or seminars with the major industrial partners of the UTT on this subject.

2 Research team

Mitra Fouladirad research interests focus on maintenance modelling and joint maintenance/monitoring policies by using stochastic models to optimise maintenance and/or inspections policies (see references [6–10, 14, 15]). Contacts: **mitra.fouladirad@utt.fr** (refer to www.researchgate.net for more details)

Laboratory

The Systems Modeling and Dependability Laboratory (webpage: http://lm2s.utt.fr/en/index.html) is part of the Charles Delaunay Institute. This institute coordinates all the research activities in the university. The Systems Modeling and Dependability is organized into two main research projects: decision and diagnostic in non-stationary environment and stochastic models for reliability and maintenance. The applicant will be involved in the last team.

National collaborations

B. Castanier, Angers university, (Angers, France), A. Barros, Centrale-Supelec (Saclay, France), P. Do Van, Lorraine University (Nancy, France), C. Bérenguer Alpes Grenoble University (Grenoble, France), Vlad Barbu University of Rouen (Rouen, France)

International collaborations

What is more The candidate will be able to work with the usual international partners of the supervisors on the subject that is the research teams of:

- M. Giorgio from University of Naples Federico II Italy (https://www.docenti.unina.it/massimiliano.giorgio)
- B. Lindqvist from Norwegian University of Science and Technology, Trondheim, Norway, (http://www.math.ntnu.no/ bo/)

- M. Xie from Hong Kong University, China (minxie@cityu.edu.hk)
- P. Scarf from Salford University, U.K. (https://www.salford.ac.uk/business-school/our-staff/business-academics/philip-scarf)
- J. Vatn from Norwegian University of Science and Technology (https://www.ntnu.edu/employees/jorn.vatn)

If necessary, a research stay in one of these universities can be organised. Moreover, if the quality of the work is correct, any Ph.D student of the team attends international conferences during the thesis.

References

[1] Nikulin, M.S. and Limnios, N. and Balakrishnan, N. and Kahle, W. and Huber-Carol, C., Advances in Degradation Modeling: Applications to Reliability, Survival Analysis, and Finance, Birkhauser Boston, 2010

[2] Ye,Zhi-Sheng and Xie,Min,Stochastic modelling and analysis of degradation for highly reliable products Appl. Stochastic Models Bus. Ind., 31,16–32, January,2015

[3] Zhou, R. R. and Serban, N. and Gebraeel, N.,Degradation modeling applied to residual lifetime prediction using functional data analysis The Annals of Applied Statistics, 5 2B, 1586-1610,2011

[4] Liao, C. M. and Tseng, S. T.,Optimal design for step-stress accelerated degradation tests IEEE Transactions on Reliability,1, 55 59-66,2006

[5] Xu, Z. and Ji, Y. and Zhou, D., Real-time reliability prediction for a dynamic system based on the hidden degradation process identification IEEE Transactions on Reliability, 2, 230–242,57, 2008

[6] N. Zhang, M. Fouladirad, A. Barros, Maintenance analysis of a two-component load-sharing system *Reliability Engineering and System Safety* Volume 167, November 2017, Pages 67-74

[7] N. Zhang, M. Fouladirad, A. Barros, Optimal imperfect maintenance cost analysis of a two-component system with failure interactions *Reliability Engineering and System Safety* 177, 24-34, 2018

[8] N. Zhang, M. Fouladirad, A. Barros, Evaluation of the warranty cost of a product with type III stochastic dependence between components *Applied Mathematical Modelling* 59, 39-53 .

[9] Lorton, A., Fouladirad, M. and Grall, A. Computation of remaining useful life on a physic-based model and impact of a prognosis on the maintenance process. *Journal of Risk and Reliability*,227(4), 434-449 ,2013.

[10] Lorton, A., Fouladirad, M. and Grall, A. A methodology for probabilistic model-based prognosis. *European Journal of Operational Research*, 225(3):443-454, 2013.

[11] Budai, G. et al. Scheduling preventive railway maintenance activities, *Journal of the Operational Research Society*, 57(9),1035–1044,2006.

[12] Levitin, G. and Xie, M., Performance distribution of a fault-tolerant system in the presence of failure correlation, *IIE Transactions*,38 (6),pp 499–509,2006.

[13] Murthy, D.N.P. and Nguyen, D.G Study of two-component system with failure interaction, *Naval Research Logistics Quarterly*,32,2 pp 239-247,1985.

[14] Nguyen, K.T.P., Fouladirad, M. and Grall A. New methodology for improving the inspection policies for degradation model selection according to prognostic measures, *IEEE Transactions on Reliability 2018*

[15] Ma, J., Fouladirad, M. and Grall A. Flexible wind speed generation model: Markov chain with an embedded diffusion process *Energy 2018* Volume 164, Pages 316-328