Multi-component systems, interaction modelling and maintenance planning

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1 Subject

Motivation

In the framework of high technology and advanced monitoring, the reliability and lifetime extension of complex systems is one of the major challenges in industrial engineering. To avoid failure and induced losses the systems must be maintained. Maintenance operations can be corrective or preventive. The corrective action is applied on a failed system and the preventive action is performed before the failure on a highly deteriorated system. A general survey of maintenance policies is given in [8]. The maintenance actions can be perfect or imperfect. After a perfect maintenance action the system is as good as new. For example the maintenance of electronic devices corresponds to replacements of components and therefore after the maintenance the system is as good as new after maintenance. After an imperfect maintenance action the system is not as good as new. There exists many possibilities to consider imperfect maintenance in the literature. For example steel structures are protected by an organic coating which is also deteriorating. Maintenance actions are then done in order to improve the condition of the organic coating. Typical maintenance actions performed on the coating are local and lead to an imperfect maintenance.

Nowadays, maintenance optimisation of multi-component systems is an important issue and has attracted a lot of attention. 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 of components can affect the state (the deterioration level, the failure rate, etc.) of some working components [9–11].

The proposed research subject focuses on multi-component systems with complex physical interactions between components which makes their respective degradations dependent. It means for example that the degradation rate of one component may depend on the degradation level of other components when it is replaced. The main challenge is to model the interaction between the degra-

dation process of components and to take advantage of this model to plan efficient maintenance operations.

General layout of the thesis

One considers multi-component systems which may be of a highly mixed nature, such as a gearbox or a wind farm. Some components are subject to wear with different kind of physical interactions. The failure, maintenance action and duration of one component impact the degradation level or rate of the other components since the whole system should continue to fulfill its mission and produce the expected result. The aim is to propose a modeling framework which can be very general. To propose an efficient maintenance policy, first, it is essential to focus on the possible degradation interaction modeling and afterward consider the maintenance efficiency modeling. The final relevant decision rule should decide which components to replace and when in a condition-based predictive framework. 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 : the general framework of stochastic processes should be considered including in a privileged manner gamma processes, Wiener processes or IG processes;
2. Maintenance effect modeling : from the interaction between components the effect of the maintenance of one specific composant on the others should be characterized;
3. Condition-based or predictive maintenance decision rule : the decision about maintenance and possibly about inspection times should include information based on the actual degradation level and remaining useful life of components. Parametric decision rules should be developped first ;
4. Maintenance policy assessment and optimisation : analytical calculations and Monte Carlo simulation can be considered for cost calculation

The key knowledge and required skills to implement the previous steps includes:

1. Reliability analysis

2. Probability and stochastic models
3. Maintenance assessment and optimisation
4. 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

Antoine Grall and 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 [1–7, 12–14]).
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Laboratory

The Systems Modelling 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 Modelling and Dependability is organised 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

P. Do Van Lorraine University (Nancy, France), C. Bérenguer Alpes Grenoble University (Grenoble, 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:

- 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)
- A. Barros from Norwegian University of Science and Technology (https://www.ntnu.edu/employees/anne.barros)

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] 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

[2] 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

[3] 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 .

[4] 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.

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

[6] Ponchet, A., Fouladirad, M. and Grall, A. Assessment of a maintenance model for a multi-deteriorating mode system. *Reliability engineering and systems safety*, 95:1244-1254, 2010.

[7] Ponchet, A., Fouladirad, M. and Grall, A. Maintenance policy on a finite time span for a gradually deteriorating system with imperfect improvements. *Journal of Risk and Reliability*, 225:105-116, 2011.

[8] Dekker, R. et al., A review of multi-component maintenance models with economic dependence,*Mathematical Methods of Operations Research*,45(3),pp411–435,1997.

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

[10] 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.

[11] 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.

[12] Ghamlouch, H., Fouladirad, M. and Grall A. The use of real option in condition-based maintenance scheduling for wind turbines with production and deterioration uncertainties The use of real option in condition-based maintenance scheduling for wind turbines with production and deterioration uncertainties *Reliability Engineering and System Safety 2017.*

[13] 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*

[14] Kim Anh Nguyen, Phuc Do, and Antoine Grall. Joint predictive maintenance and inventory strategy for multi-component systems using Birnbaum's structural importance. *Reliability Engineering & System Safety*, 168(Supplement C):249–261, December 2017.