Predictive maintenance for deteriorating systems with dynamic environmental conditions: application in energy production

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1 Subject

Motivation

In many industrial problems it is an important issue to deal with systems which gradually deteriorate. For example, in electric power industry the degradation phenomena that appear on components of nuclear power plants is a very important subject, the stress corrosion cracking that appears in pressurized water reactors can cause very serious damage.

The evolution of the system's deterioration can be influenced by the environmental conditions in which the system is evolving. Hence, it is important to take into account the environmental conditions in the deterioration modeling.

A high level of deterioration of a system can lead to a failure. A failure can be costly and dangerous. For example if the system represents a large structure such as a bridge, a dike or a pipeline, its failure would have catastrophic consequences not only on humans but also on the environment. The failure of such a system should be avoided and that is why the system must be maintained. Two maintenance actions can be considered the corrective maintenance action and preventive maintenance action. The corrective action is applied on a failed system and the corrective action is performed before the failure on a highly deteriorated system.

The aim of this thesis is to propose an adequate maintenance model for a considered deteriorating system which takes into account the influence of the environmental conditions. For example if a crack growth is considered it is very useful in the reliability and durability to schedule inspection and repair/replacement maintenance.

Previous work and general layout of the thesis

One considers a system which is gradually deteriorating. Usually, the deterioration is modelled by a stochastic process. Several stochastic process are well known for the modeling of the evolution of a system's deterioration. For example, in the case of a monotone deterioration [18] proposes to model the degradation by a gamma process. Authors in [3,8,19] approximate the stationary gamma process with a discrete-time stochastic process having independent, identically and exponentially distributed increments. In the case of a non-monotone deterioration with increasing tendency [2] models the degradation by a Brownian motion. In [24] authors model the non-monotone deterioration with increasing tendency by a special process obtained by the difference of exponentially distributed random variables. More complex models have been used during the last decades, [9,25].

It might happen that the environmental conditions in which the system is evolving influence the deterioration rate of the system. The environmental conditions can be resumed by a variable called ”covariate” which can be random. In the life science and engineering experiments, the covariates describe the dynamical environment and they are often expressed by the proportional hazards model (see [4, 13, 17]). It is of great importance to incorporate these explanatory variables in the structure of the deteriorating system and to deal with degradation models including covariates. The state of the environment (the value of covariates) can be completely unknown and not be revealed by inspections. In this case an estimation method should be used to estimate the real sate of the environment. It can also happen the impact of the environmental conditions on the deterioration rate to be completely unknown, therefore, statistical tools should be used to deal with this lack of information via estimation methods.

If the deterioration level of the system, collected through inspections, exceeds a safety level, known as the failure threshold, the system is said to be failed and as the system is not repaired instantaneously after a failure, it is unavailable until the corrective replacement. In order to avoid failures and to stay in an operating state, the system should be preventively maintained.

At each inspection time the mean residual life time (mean delay before failure) can be calculated. A preventive maintenance policy based on the mean residual life time of the system at each inspection time can be proposed. Fo example one can replace preventively the system as soon as the the mean residual life time is lower than a fixed threshold called preventive threshold.

The inter-inspection interval times and the value of the preventive threshold are two factors which influence the global maintenance cost. For example, in the case of costly inspections it is not worthwhile to inspect often the system. But if the system is scarcely inspected, the risk of missing a failure occurrence increases. In some cases the maintenance cost depends only on one variable: the inter inspection interval or the replacement threshold. Authors in [12] considered the cost as a function of inspection interval while the preventive maintenance level is fixed. In [10] the maintenance cost is considered as the combination of the preventive maintenance level and inspection interval. In [7] authors propose condition-based inspection/replacement and continuous monitoring replacement policies for a deteriorating system. In those previous works, a maintenance cost model is proposed which quantifies the costs of the maintenance strategy and propose a method to find the optimal strategy leading to a balance between monitoring and maintenance efficiency.

It is of great importance to incorporate the information on covariates (environnemental conditions) in the structure of the maintenance policy. In [1] and [11] an optimal replacement model for a system with stochastic deterioration which depends on the value of covariates is considered. In [5, 6, 16, 22–25] an inspection/replacement policy for a non-monotone deteriorating system which takes into account the environmental conditions (covariates) is proposed.

There are preliminary results on each of the points highlighted above, for instance refer to [16]. These results can be considered as a starting point to enhance the models and their performances.

The different steps of this thesis can be resumed as follows

1. Degradation modelling considering environmental conditions as covariates
2. Statistical inference in presence of covariates
3. Proposition of maintenance decision rules considering covariates
4. Sensitivity analysis
5. Application to an energy production data

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

1. Probability and statistics
2. Mathematical modeling
3. Optimisation
4. Simulation and programming software: R, Python, Matlab, Scilab, etc..

Main collaboration on the subject

The candidate will organize and/or participate to meetings or seminars with the major industrial partners of the UTT on this subject. He or she will be also able to participate to a french and European working groups, ESRA (`http://www.esrahomepage.eu/`),
S3 (`http://gt-s3.cran.univ-lorraine.fr/`),
PHM Europe (`https://phm-europe.org/`), SFDS (`SFDS https://www.sfds.asso.fr/`).

2 Research team

This thesis is supervised by two researchers of the Systems Modeling and Dependability Laboratory, Mitra Fouladirad and Estelle Deloux who are respectively professor and associate professor at the Troyes University of Technology (France). They worked both during the three last years on maintenance modeling for gradually deteriorating systems and are qualified persons in the laboratory for the subject. They already supervised previous theses ([16, 23–25]) which motivate the present proposal. Their research interests focus on maintenance modeling and joint maintenance/monitoring policies by using stochastic models to optimize maintenance and/or inspections policies (see references [14, 15, 20, 21, 26]). Contacts: **mitra.fouladirad@utt.fr, estelle.deloux@utt.fr**
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Laboratory

The Team of Systems Modelling and Dependability (M2S, web page: https://recherche.utt.fr/computer-laboratory-and-digital-society-list3n/system-modelling-dependability-m2s) is part of the Computer Laboratory and Digital Society (LIST3N). The Team of Systems Modelling 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

The candidate will participate to national collaborations with researchers from many french universities (Ecole centrale Supelec, University of Grenoble Alpes, University of Angers,...).

International collaborations

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

- Professor Balakrishnan McMaster university Canada
- Professor Jorn Vatn NTU Norway
- Professor David Coit Rutgers University USA
- Professor Min Xie Hong Kong University China
- Professor Kharoufeh Clemson University USA
- Professor Gorgio university of naples Federico II
- Professor Singpurwalla Hong Kong University China

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

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