



**HAL**  
open science

## System performance prognostic: context, issues and requirements

Pierre Cocheteux, Alexandre Voisin, Eric Levrat, Benoît Iung

### ► To cite this version:

Pierre Cocheteux, Alexandre Voisin, Eric Levrat, Benoît Iung. System performance prognostic: context, issues and requirements. 1st IFAC Workshop on Advanced Maintenance Engineering, Services and Technology, A-MEST'10, Jul 2010, Lisbon, Portugal. pp.CDROM. hal-00497674

**HAL Id: hal-00497674**

**<https://hal.science/hal-00497674>**

Submitted on 6 Jul 2010

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# System performance prognostic: context, issues and requirements

Pierre Cochetoux, Alexandre Voisin, Eric Levrat, Benoît Iung

*Centre de Recherche en Automatique de Nancy (CRAN), Nancy-Université, CNRS,  
Boulevard des Aiguillettes B.P. 70239, 54506 Vandœuvre-lès-Nancy, France  
(e-mail: {pierre.cochetoux,alexandre.voisin,eric.levrat,benoit.iung}@cran.uhp-nancy.fr)*

---

**Abstract:** Maintenance plays now a critical role in manufacturing for achieving important cost savings and competitive advantage while preserving product and process conditions. Such a role suggests moving from conventional maintenance practices to predictive strategy. However industrial systems are complex and need to have a global view of the system health and its performance. Indeed a maintenance action has to be done at the right time according to the system performance and the component Remaining Useful Life (RUL) given by a prognostic process. Nevertheless system performance prognostic are lacking in generic methodology and support tools for assessing system performance vs. component degradations. In that way, generic concepts in relation with dysfunctional causality of the system performance are introduced. These concepts are traditionally modelled separately although they interact with each others. Thus this paper aims at giving issues and requirements on models representative of each concept and for information to share between them in order to reach a global system performance prognostic model.

**Keywords:** maintenance, prognostic, system performance assessment.

---

## 1. INTRODUCTION AND PROBLEM STATEMENT

Evolutions of the business world and new constraints on industrial systems have led to increase the role of the maintenance function. This new role impacts not only in the operation phase but also all along the product life cycle (Takata et al., 2004), in particular during the design phase through the concept of Integrated Logistic Support. To support this role in operation, the maintenance concept undergone through several major developments to lead to proactive considerations about system performances which require changes in transforming traditional “fail and fix components” maintenance practices to “condition-based vs. predict system performances” strategies.

The predictive vs. proactive maintenance could be supported by an integrated system of proactive maintenance (Muller et al., 2008) whose goal is to assess if the future system finality is guaranteed, and if not, to adjust maintenance schedule by adding, deleting, changing or rescheduling maintenance actions. In this objective, prognostic business process is considered as the key process of the proactive maintenance since it supports proactive ability.

A complete prognostic definition is given in (Voisin et al., 2010): the prognostic business process has, first, to predict the future performance of the system. Then it has to calculate in consistence with (ISO, 2004), the different RULs (Remaining Useful Life of the system, sub-system or component) by taking into account the

functional and dysfunctional knowledge on the system, background information, current information on the health and future information (scenario with manufacturing and maintenance data). The need of different kinds of RULs (component or functional) is due to maintenance purpose which deals with two different levels: (1) the performance level because the maintenance business process aims at maintaining and guaranteeing the global system performances, (2) and the component degradation level because maintenance actions impact on the component degradation levels and/or dynamics. Therefore both levels have to be considered and justify system approach to tackle prognostic modelling.

Most of existing scientific contributions about prognostic are mainly focused on the projection of a physical state perception (either a simple variable or a refined indicator which results from several sources). In accordance with (Lee et al., 2006), some prognostic issues still remain as follow:

- most of prognostic approaches are component oriented. A generic and scalable prognostic methodology or toolbox does not exist,
- methods are generally focused on the failure prediction problem, without taking account of performance degradation.

In order to face the previous issues, this work presents several generic concepts in relation with system performance prognostic. These concepts are modelled by models which have therefore to interact

with each others in order to reach a global system prognostic model. This paper aims only at describing the system performance prognostic's context by establishing the issues of these multi-models interoperation and the induced generic requirements on models and shared information in a generic way.

The generic concepts of system performance prognostic model are developed in section 2. Section 3 highlights issues from a global prognostic model and gives requirements on models. The modelling tool and the constraints for tackling the system performance are detailed in section 4. Section 5 describes works and requirements on component degradation prognostic. Then section 6 tackles the need to integrate the use conditions and section 7 the need to represent the impact of maintenance actions. Finally conclusion and prospective are proposed in section 8.

## 2. GENERIC PROGNOSTIC MODEL WITHIN SYSTEM APPROACH

System prognostic model deals with generic concepts influencing system performances. These concepts define different domains of the dysfunctional causality (DDC). The dysfunctional causality explains the causal relationships between primary causes and final effect (figure 1).



Fig. 1. Relationships and concepts representing domains of dysfunctional causality (DDC)

DDC (ellipse) represent system performance, components degradation, use conditions (operational and environmental conditions) and maintenance of the system. They affect each others by causality links (spears).

System performances' DDC materializes the set of performances of the system, sub-systems and finally components. Their losses are due to the component degradations. The performance DDC aims at aggregating their impact on performances. In spite this link is the main one, system performances is also in relation with operational conditions. The operational conditions defined the expected performances given by the user. The difference between both represents the

observable impact of the degradation/failure of all components on system performances.

Components degradation's DDC addresses the component health degradation. These degradations are caused by physical evolution (degradation modes) which evolves with their own dynamic. This dynamic depends on time and use conditions. In return the degradation level can lead to modify use conditions, e.g. for ending the actual system mission without failure.

Use conditions' DDC deals with the description of operational and environmental conditions. The operational conditions stand for the control variables of the physical system. For a production system, they may contain the type of product to be processed, the number to output, the production speed... The environmental condition enables to consider the system's environment.

Maintenance's DDC includes: (1) the maintenance decision support process which needs system performances for using it as decision criterion and (2) the maintenance operational process for acting directly on the component degradation. When the real performance loss reach a predefined threshold, a maintenance action is (re-) scheduled and performed on one or more components. Maintenance action leads to decrease, or even reset, the degradation of the component and therefore restores system performances.

Thus the global prognostic model has to be:

- generic,
- system performance-centred (it aims at assessing system performance),
- component degradation-based,
- integrated by taking into account the operational and environmental conditions and maintenance action impact.

These required properties induce a set of issues detailed in the next section.

## 3. ISSUES FROM DDC INTERACTIONS FOR MODEL REQUIREMENTS

The previous DDCs tackle concepts defined on different level. Primary causes (degradation) described at component (local) level affect the performance, defined at system (global) level. Such as difference of level needs to be tackled each part separately, i.e. each DDC has to be modelled separately and linked together to obtain the global prognostic model. It underlines two main issues: (1) the complexity enclosed within the global prognostic model and (2) the need of interoperability between models.

Complexity is inherent within each DDC and the interactions between them: interactions between components (brought by multi-components systems) and interactions between local/global/environmental points of view. Moreover degradation view is supported

by information of different natures (probabilistic, physical...) and their results are given in different formats (reliability, physical dimension, vibration...). This complexity prevents to choose an analytical way of solving. Simulation seems the right solution to evaluate such a global model.

The interactions between the different DDCs need interoperability between their specific models. Each DDC has received lots of attention by research community but separately. In the prognostic field, most works on prognostic concern the components degradation including or not the use conditions. Based on this observation, a generic methodology has to be proposed to make models work together.

Thus semantic interoperability between models has to be defined. Two ways are considered: either all models are expressed in the same formalism, e.g. (Muller et al., 2008) use Bayesian networks, or a “common semantic” is defined to share information between models. The first way is constrained by the chosen formalism and doesn’t consider different natures of degradation view. Thus the latter way performed by several models which share a common semantic seems more appropriate. The common semantic could be represented by physical and measurable features or defined with specific tool already used for semantic interoperability like ontology (Doerr, 2003).

To describe the global prognostic model, the models related to each DDC are detailed within sections 4, 5, 6, and 7 by establishing invariant concepts and requirements.

#### 4. MODEL FOR PERFORMANCE ASSESSMENT

The system modelling has to be performed in a generic way. Therefore the functional and dysfunctional system knowledge has to be structured using a generic methodology.

##### 4.1 Functional point of view

The formalization of the functional knowledge has to be supported by a generic functional description methodology well-adapted for multi-components systems. The methodology needs to define the following invariant concepts:

- *System performance*: the system performance (which has to be prognosticated) is the ability of the system or process to perform its finality (goal) (Shin et al., 2009). The finality (goal) is represented by the process output flows (e.g., on figure 2, the “accumulation strip”) (Cocheteux et al., 2009). Thereby we consider that performance indicators are connected with properties of these flows (e.g. average strip flow rate, pressure of an oil flow or rotation speed of a rotation movement). The performance has only a sense by considering (a) the use conditions which provide the

expected finality level and (b) input flows such as control flows, the energies flows or main flows (flows processed by the function).

- *System decomposition*: the global function is broken up into sub-functions supported by sub-systems which compose the global system. These sub-functions may be broken up into sub-sub-functions until an adequate level (elementary level) is obtained. A function has input flows and output flows (function finality). Elementary functions are supported by components. Relationships between two functions are performed by linking input and output flows of both functions (Leger and Morel, 2001; Muller et al., 2008).

- *Component performance*: every elementary function has a finality materialised by the function’s output flows and component performances are defined on properties of these output flow’s functions (e.g. rotation speed is the property about the performance of “to produce rotation” (“Motor rotation”).

An example performed by a process approach is showed on figure 2. The process approach breaks down the whole system into processes or functions. It identifies the components supporting the processes and the flows consumed and produced by the processes.

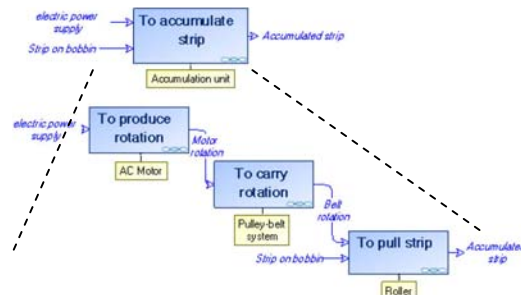


Fig. 2. Functional description of a multi-levels system

##### 4.2 Dysfunctional point of view

The system dysfunctional causality knowledge needs generic methods and tools as well. This causality describes the impact of the components degradation or failure on the previously defined performances. Performances decrease with time since flow properties evolve and deviate from a nominal value. This performance loss results from two possible causes:

- the degradation of support (system or component which supports the process)
- the deviation of input flows.

As previously highlighted, the functional decomposition breaks up the system function until elementary/component level. These elementary functions (supported by components) are like a functions chain linked by flows. The output flows of the last functions (last down-stream functions) are also the output flows of the system function (e.g. “accumulated strip” on figure 2). Thus the component performance

models can be linked in the same way and allow to obtain the system performances deviations (losses) on the output flows of the last functions.

This causality can be formalized by generic causal relationships as proposed by (Leger and Morel, 2001). These generic relations need to be particularized for every system. Thereby complementary knowledge at the component level has to be extracted and formalized. Method such as FMECA (Failure Mode, Effects, and Criticality Analysis) and HAZOP (HAZard and OPERability) studies provide information about causes and consequences of failure modes and flow deviations. A specific analysis can be performed at the component level (component performance model) and can be linked in order to reach the system level (system performance model). An example of this generic system performance approach can be found in (Cocheteux et al., 2009) which details the methodology and applies it on a practical case.

## 5. COMPONENT DEGRADATION PROGNOSTIC MODELS

The system performance's model gathers all components degradation levels on system performances but doesn't project them into the future. In order to prognostic system performance, this model just needs the future components degradation levels as inputs. Therefore the projection has to be performed by component degradation prognostic models which thus have to include proactive capabilities.

### 5.1 Statement about prognostic contributions classifications

Scientific contributions about the degradation DDC are numerous and use several approaches. Thus surveys propose classification of the prognostic community works. The most famous one is the "pyramidal" classification of (Byington et al., 2002). It proposes a typology of the different prognostic tools according to the nature of the projection models. (Heng et al., 2009) and (Jardine et al., 2006) also proposed classifications by using others criterions (respectively nature of the used information and form of the expected result). But in order to propose a further refinement, they used a second criterion allowing to obtain the same category as (Byington et al., 2002). Thus it is possible to make the correspondence between the three classifications in order to highlight the focus of works on degradation model without interest for system performance.

We consider that it is important to base our prognostic proposition on the community knowledge and to integrate the already proposed works into our model as COTS (Components Off The Shelf). However to obtain interoperability with performance model, we introduce requirements to be satisfied.

### 5.2 Requirements for component degradation model

In order to define a generic formalization of the prognostic process, (Voisin et al., 2010) have proposed generic prognostic sub-processes (figure 3): (1) "To initialize state and performances", (2) "To project" and (3) "To compute RUL". The last sub-process "To pilot prognostic" coordinates the sequence within time and the models used to perform the three first sub-processes. We consider that these processes represent invariant task for each prognostic models at the component level.

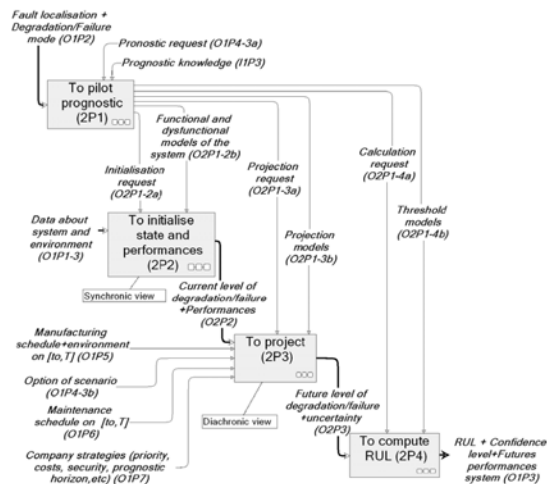


Fig. 3. Prognostic process decomposition (Voisin et al., 2010)

For a system prognostic model, the performance assessment model needs information about degradation level (about physical features). They are provided by the output flow of second sub-processes "Future level of degradation/failure+ uncertainty" because this flow contains information about future component health. Therefore the accessibility of these results is needed to plug component degradation prognostic model with performance model. The process "To compute RUL" could be also performed but its result (the RULs) is sent directly to the decision-making support process.

A second requirement about the choice of degradation prognostic model is its ability to be initialized. Indeed when a prognostic calculation has to be performed, the degradation level of the different components has to be initialized (in relation with the process "To initialize state and performances"). This ability allows to use on-line the maintenance system by updating the model with the current observations made on the real system. Thus models without initializing way have not to be used in a generic prognostic model.

## 6. USE CONDITIONS' INFLUENCE

The use conditions enable to support two kinds of information: the operational conditions and the environmental conditions. The operational conditions are described by operational modes which define what the user expects from the system. The environmental conditions represent the environment in which the system is functioning. They are composed of atmospheric variables (temperature, pressure...) and all variables impacting the degradation. The main difference is related to the property of controllability: the operational conditions are controllable whereas the environmental conditions are not.

The impact of the use conditions on the degradation is a well-known issue within the prognostic field. More exactly use conditions impact on the degradation dynamics. It is the key-point of the prognostic sub-process "To project". Thus use conditions require to be integrated in degradation models by considering these data as input data. Thereby this information is presented on figure 3 as input flow ("Manufacturing schedule+environment on  $[t_0, T]$ ") of process "To project".

Some works have proposed to integrate these conditions as input of the degradation prognostic model through different modelling ways. (Jardine et al., 2006) propose to use a Cox's model to influence the failure rate by environmental variables. (Lung et al., 2008) have also proposed degradation model based on a discrete event model of the degradation where transitions are fired according to time and use conditions.

## 7. MAINTENANCE ACTIONS IMPACT

Maintenance actions by means of their impacts on component degradation level or on its dynamics have to be modelled. It allows to consider pre-established maintenance policies or the decision support process to investigate different maintenance options (represented on figure 3 by flows "Maintenance schedule on  $[t_0, T]$ " and "Option of scenario"). Two ways may be used to represent the impact: (1) the new degradation level is directly obtained (absolute way) or (2) the increment (derivative) is calculated and added/subtracted to the previous level (relative way).

Thus a model has to be built in order to compute to what extent the component is repaired. Some works deal already with the maintenance impact e.g. (Doyen and Gaudoin, 2004). The stochastic nature of the maintenance action impact induces the use of stochastic tool in relation to reliability concepts (hazard rate). The impact is classically modelled between two bound which represent the perfect maintenance called AGAN (As Good As New) where the degradation level is reset, and the no-impact maintenance called ABAO (As Bald As Old) where the degradation level remain unchanged.

Nevertheless the frame used concerns conventional or condition-based maintenance without proactive ability.

The development of a prognostic process creates a special context in which future could be assessed and options could be tested before they are performed. But few works have tackled this issue in the prognostic field. (Muller et al., 2008) adjust directly (absolute way) the new degradation state after a maintenance action. Degradation new state is obtained by a probability distribution. Thus evolutions of future system performances contain supplementary uncertainty due to uncertainty from maintenance action impact.

The maintenance action aims at modifying the components degradation and thus maintenance action model has to directly impact the degradation level as use conditions. But the main issue is due to the difference between the continuous nature of the degradation (degradation dynamic) and the discrete nature of the maintenance (event). Maintenance action impact has to modify the component degradation level in a discrete way as an update of the difference between simulated and actual degradation level.

The required property made on the component degradation prognostic model carried out the "to initialize the degradation level" process (figure 3). This direct access to the degradation level allows to reset it (perfect maintenance action like replacement) or to decrease the level (imperfect action) at a fixed level or by an added/subtracted increment.

As conclusion, it is observed that the stochastic nature of the maintenance impact led these works towards reliability concepts as reliability function or hazard rate in order to represent the degradation but didn't propose model of the maintenance action in term of physical impact. This lack reduces the use of data-driven or physic-based models for evaluating future maintenance options and seems a future challenge for the scientific community.

## 8. CONCLUSION

In this paper, we have showed that the system performance prognostic is mandatory for supporting proactive maintenance strategies applied to industrial system. It leads to propose definitions for prognostic on system (multi-technology and multi-components) within a global model without focusing on system technology. Therefore the generic modelling methodology enable to highlight invariant concepts based on functional and dysfunctional system approach. Then issues and requirements have been explained at the global level (interoperability between models) and also at the local level (requirements on performance models, degradation models...). Existing surveys highlighted too important considerations about components degradation and a lack of topics such as

performance assessment and maintenance impact modelling. On the first one, a proposition based on ANFIS model has been made in (Cocheteux et al., 2009) and shows a practical case.

This initial contribution about performance has now to be improved at least on (1) the dysfunctional causality modelling and on (2) the component degradation model. First the causality modelling is supported by the causal relationships. But the relation between these causes and the output flows are modelled by simple logical relations (Leger and Morel, 2001). This basic model needs to be refined. For example, scientific contributions on functional models can be considered.

Secondly component degradation models have to be improved in order to enlarge the set of models which can be included into the global prognostic model. Therefore a better consideration of the use conditions impact (in order to increase genericity by proposing a model which can be adjusted according to the environment) is required. The maintenance impact modelling for physic-based and data-driven models has also to be tackled by the scientific community.

These models which need to include component degradation connected to system performance and environment can be interesting for other research context than prognostic as maintenance strategies optimisation and evaluation, e.g. (Zille et al., 2009). Thus the studies led in different frameworks with different goals can bring reusable models in several contexts in order to save their development costs (just one development and not several) and then decreased the life cycle cost of the product maintenance.

## REFERENCES

- Byington, C.S., Roemer, M.J., and Galie, T. (2002). Prognostic enhancements to diagnostic systems for improved condition-based maintenance, in *Proceedings of 2002 IEEE Aerospace Conference*, Big Sky, MT, USA.
- Cocheteux, P., Voisin, A., Levrat, E., and Iung, B. (2009). Methodology for assessing system performance loss within a proactive maintenance framework, in *Proceedings of 13th IFAC Symposium on Information Control Problems in Manufacturing, INCOM'2009*, Moscow, Russia.
- Doerr, M. (2003). The CIDOC Conceptual Reference Module: an ontological approach to semantic interoperability of metadata, *AI Magazine*, vol. 24 (3), pp 75-92.
- Doyen, L., and Gaudoin, O. (2004). Classes of imperfect repair models based on reduction of failure intensity or virtual age, *Reliability Engineering and System Safety*, vol. 84 (1), pp. 45-56.
- Heng, A., Zhang, S., Tan, A.C.C., and Mathew, J. (2009). Rotating machinery prognostics: State of the art, challenges and opportunities, *Mechanical Systems and Signal Processing*, vol. 23 (3), pp. 724-739.
- ISO (2004). Condition Monitoring and Diagnostics of Machines - Prognostics part 1: General Guidelines, in *ISO13381-1:2004(e)*.
- Iung, B., Monnin, M., Voisin, A., Cocheteux, P., and Levrat, E. (2008). Degradation state model-based prognosis for proactively maintaining product performance, *CIRP Annals - Manufacturing Technology*, vol. 57 (1), pp. 49-52.
- Jardine, A.K.S., Lin, D., and Banjevic, D. (2006). A review on machinery diagnostics and prognostics implementing condition-based maintenance, *Mechanical Systems and Signal Processing*, vol. 20 (7), pp. 1483-1510.
- Lee, J., Ni, J., Djurdjanovic, D., Qiu, H., and Liao, H. (2006). Intelligent prognostics tools and e-maintenance, *Computers in Industry*, vol. 57 (6), pp. 476-489.
- Léger, J.B., and Morel, G. (2001). Integration of maintenance in the enterprise: Towards an enterprise modeling-based framework compliant with proactive maintenance strategy, *Production Planning and Control*, vol. 12(2), pp. 176-187.
- Muller, A., Suhner, M.C., and Iung, B. (2008). Formalisation of a new prognosis model for supporting proactive maintenance implementation on industrial system, *Reliability Engineering & System Safety*, vol. 93, pp. 234-253.
- Shin, J.H., Jun, H.B., Kiritsis, D., and Xirouchakis P. (2009). Function performance evaluation and its application for design modification based on product usage data, *International Journal of Product Lifecycle Management*, vol. 4 (1-3), pp. 84-113.
- Takata, S., Kimura, F., Van Houten, F.J.A.M., Westkämper, E., Shpitalni, M., Ceglarek, D., and Lee, J. (2004). Maintenance: Changing Role in Life Cycle Management, *CIRP Annals - Manufacturing Technology*, vol. 53/2, pp. 643-656.
- Voisin, A., Levrat, E., Cocheteux, P., and Iung B. (2010). Generic prognosis model for proactive maintenance decision support: application to pre-industrial e-maintenance test bed, *Journal of Intelligent Manufacturing*, vol. 21, pp. 177-193.
- Zille, V., Bérenguer, C., Gall, A., Despujols, A., and Lonchamp, J. (2009). Modelling and simulation of complex maintenance strategies for multi-component systems. In Cigolini, R.D., Deshmukh, A.V., Fedele, L., McComb, S.A (ed.), *Recent Advances in Maintenance and Infrastructure Management*, Springer.