STOCHASTIC OPTIMIZATION OF INDUSTRIAL MAINTENANCE STRATEGIES

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Abstract

The dynamics of business requires industries to produce more and more at the lowest cost, highest quality and a high level of reliability (availability and reliability of their equipment) to meet the stringent technical, economical and legal requirements, and to remain efficiently and competitively in the market.

The aim of this research is the development of a mathematical simulation model for the optimization of maintenance policy in a complex industrial production system, in which maintenance practices and production are integrated into a single procedure, in which control variables are the maintenance policies. This was done using a combination of maintenance management techniques and stochastic processes.

This work combines an efficient methodology for maintenance management, such as RCM, with mathematical modeling, to be able to optimize the availability of a complex system.

To be able to compare different maintenance strategies and the corresponding reliability, availability and economics, the model's output variables are the system and parts availability in a given time.

Two different simulation strategies were used, on one hand being the modeling of the complex system using an Excel database and the interaction of variables through constraints and likelyhood behavior, and on the other hand Matlab's Simulink / SimEvents, feeded by equipment characteristics, behavior, the companies' environment, needs and maintenance strategy actions.

Keywords: *reliability, maintenance, stochastic processes, simulation*

1. Introduction

Since even industrial equipment of the same type tends to behave in a different way, maintenance techniques consider equipment as independent items, which mean that maintenance decisions are made for individual equipment. The common practice is that decisions are made regarding the most problematic equipment and afterwards these decisions are generalized to other equipment of the same type. This causes maintenance to be effective, although usually with very high costs and unnecessary in some equipment.

Industrial equipment computers have a feature that generally is not taken into account in the determination of its reliability: the equipment may have failures that do not limit their production capacity, but increase the proportion of defective products, operation or preparation time, etc.

This paper discusses a computer application designed as a decision support tool for selection of maintenance activities taking into account the risks and costs associated with choosing different maintenance strategies. Rather than searching for a solution to a problem: "what maintenance strategy would lead to the best reliability and dependability parameters of system operation", in this approach different maintenance scenarios can be examined in "what-if" studies and their reliability and economic effects can be estimated.

The proposed model represents the reality of the machines and can be successfully implemented as a maintenance management system as for example Reliability Centered Maintenance (RCM). The model makes use of stochastic process theory, specifically semi-Markov chains in continuous time (SMC). The first difficulty to model the problem is its mixed discrete/continuous condition. On one hand, the equipments degree of damage is considered to be continuous in time; on the other hand the maintenance inspection system which detects the state of the team and take actions for it, is discrete in time. This makes the mathematical system to predict the total system state at time *t* a hybrid stochastic system (HSP) and thus quite complex. To overcome this problem, simulation will be used to optimize the system. The second difficulty with respect to the modeling of the system is that the behavior of a real maintenance system is usually unknown: due to its nature, accurate data is difficult to obtain as in case of actual failure, inspection and reparations are carried out, so future state of the equipment without maintenance cannot be known. To overcome this limitation, subjective information from maintainers is taken into account in the model data.

1.1 Other research

The simulation of maintenance models generally do not represent a complete the reality of the machines by focusing on very specific aspects of individual machines. In the aging model proposed by Jaroslaw Sugie refers to a maintenance model which does not depend on changes in the maintenance, rather focuses on the deterioration of the machine, so it does not propose changes to improve efficiency the machine, its life or reduce costs.

This system proposes a new approach, the machine as part of a system which responds to the decisions arising from the maintenance management and selection policies. This model shows costs of each policy, use of the machine and economic performance in the system.

2. Modeling System

The deterioration process of the equipment will, to a large extent, depend on the adopted inspection and maintenance policy. However, it is often difficult to determine with reasonable confidence just what the best frequency of equipment inspection is, or what should be inspected. As a result, some maintenance procedures may cost more money than they should or essential equipment may be unnecessarily taken out of service for prolonged periods of time.

Preventive maintenance policies are either aimed at detecting deterioration of the equipment before it fails or simply are adopted on the a priori assumption that the equipment has deteriorated and requires replacement. In either case, there is a need to select the maintenance frequency and extent so that the desired objectives are achieved. As well, the operators want to maximize benefits (which would results in reduced equipment deterioration and reduced cost of equipment replacement and repairs) and to minimize the costs of the maintenance activities.

2.1 Life cicles

The simulation model will determine the maintenance strategy that maximizes the availability of equipment; the availability is linked to the equipment's aging and corresponding life cycle, which in turn is also linked with the maintenance activities. These life curves represent the relationship between the equipment's technical or financial condition, and time. Since there are many uncertainties in predicting equipment life, the probabilistic analysis of failure rates should be done carefully to construct and evaluate the life curves properly. Figure 1 shows an example of a life curve and its modeled equipment status over time with different maintenance policies. The simulation results are similar to the presented ones.

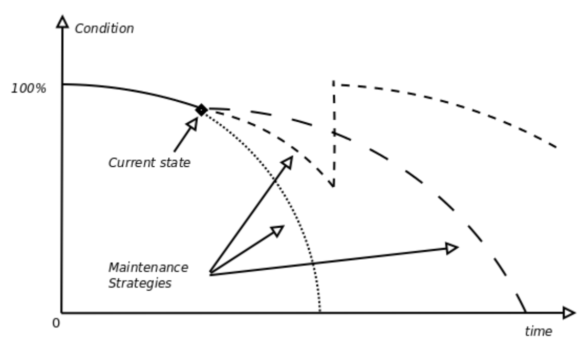

Figure 1: Typical life cycle of industrial equipment.

The three examples of maintenance policies are:

1) Stop all maintenance actions.
2) Continue current maintenance policies.
3) Reduce partially existing maintenance policies after some time.

2.2 Application Scenarios

Optimization of maintenance policy using the proposed tool is applicable to any company that meets the following initial conditions:

- Being a medium sized manufacturing industrial
- Have a maintenance department or maintenance operations
- The machinery must be analyzed and removable reparable

All variables in the model must be analyzed for each case study, the values that will in many cases are subjective information by the maintenance technicians.

2.3 Model Explanation

The simulation model consists of a machine that has a number of stages during his life. Each stage is represented as D1 to *D4*, each has different levels of productivity, efficiency and quality of product produced. For example, *D1* represents brand new machine with 0 defects and 100% efficiency, *D4* represents the machine in the last stage of their productive life with low efficiency and many defective products.

The transitions between states are represented by *Dn* a Markov chain with a continuously variable λ which determines the values of the exponential distribution for the state changes represented as *PDij*. When the team arrives at *D4* and changes state again becomes F means failure of the equipment.

During his lifetime the machine have a system to prevent this reaches *F*, this is maintenance. Each determined time inspections are performed (*In*) to the machine to determine the degree of wear and take decisions about whether to be left like this, send it to light maintain (*Mn1*)

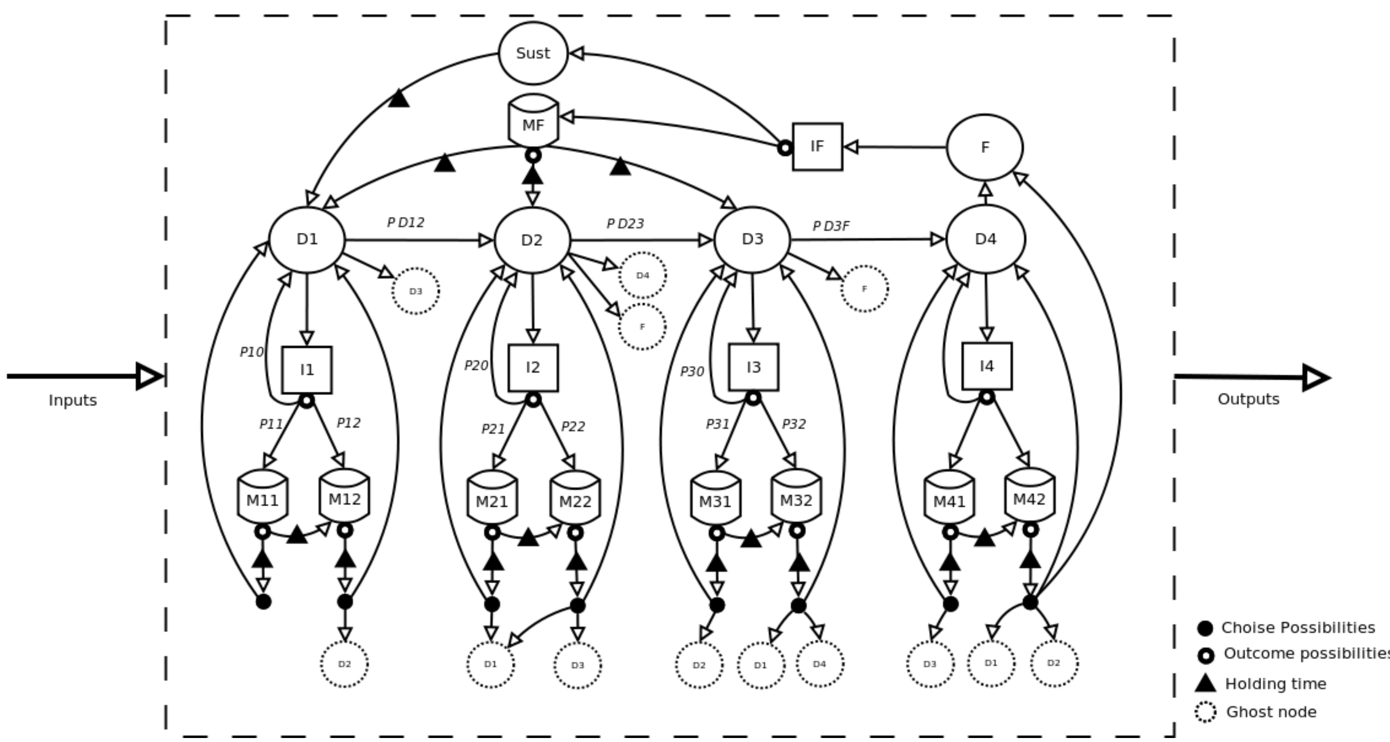

Figure 2. Graphical representation of the proposed Markov model.

or intensive maintenance (*Mn2*). These decisions will be taken by the analysis and experience of the inspector. This value should be studied for each simulated case and will likely *Pn0, Pn1* and *Pn2*. The inspection system is represented by a discrete markov chain imbued. The maintenance system is represented by a semi-markov chain.

If the machine was sent to maintenance, it going to be out from production system, this will cause delays also maintenance generates costs and a timeout to return to activities. Waiting times and maintenance costs are normally distributed with μ and σ, which are greater in *Mn2* case.

At the end of the holding time before maintenance, the machine will return to production at some stage *Dn* which will be simulated by a binomial distribution. Depending on the situation the machine and maintenance process, as result may have a minor, higher or same wear state after maintenance.

When the machine reaches state *F* has a special status of the inspection (*IF*) which determines the conditions of the machine and if it can be repaired through an exhaustive maintenance (*MF*) or must be replaced completely (*Sust*). In *MF* has high waiting times and high costs, the machine could return to any of the first 3 states of deterioration, depending on the skill of workers; in *Sust* have a high cost for the acquisition of new machinery. If the system reaches the final state of *Sust*, the simulation stops because it would be the life of a second machine. The graphic model system shows in Figure 2.

The model input variables are divided into 2 types: variables and variables of computer maintenance. Parameters of the equipment are all variables that are intrinsic to the equipment, facilities, the external environment as demand and costs. Maintenance variables are variables that can simulate different maintenance strategies, these variables are: time between inspections, experience levels of inspectors and inspection fidelity.

These variables fed the model and responds with results, also varying levels to design the best strategy. The model results are divided into 3 categories, each of which will have a different priority in each case: financial, time available and maintainability.

The machinery is in a industrial system of production inputs and outputs. This system is designed so that each time *t* (representing 1 day) has outputs useful for decision-making as downtime, number of parts produced, defects,

		Replica	Time available	Garanty cost	Maintenance Cost	Total Cost	Number of maintenance	Time until failure
1	default maintenance policy	1	81%	$450.00	$6,300.00	$6,750.00	21	1173
		2	85%	$512.00	$6,900.00	$7,412.00	23	1150
		3	83%	$571.00	$6,900.00	$7,471.00	23	1144
2	Inspections each 10 days	1	92%	$270.00	$9,600.00	$9,870.00	32	1250
		2	93%	$356.00	$8,700.00	$9,056.00	29	1310
		3	89%	$381.00	$8,400.00	$8,781.00	28	1330
3	Inspections each 20 days	1	95%	$255.00	$8,400.00	$8,655.00	28	1850
		2	93%	$456.00	$9,300.00	$9,756.00	31	1890
		3	94%	$421.00	$9,600.00	$10,021.00	32	1880
4	Inspections each 40 days	1	92%	$295.00	$7,500.00	$7,795.00	25	1173
		2	89%	$396.00	$9,300.00	$9,696.00	31	1150
		3	72%	$378.00	$8,400.00	$8,778.00	28	1189
5	No inspections	1	100%	$15,145.22	$0.00	$15,145.22	0	986
		2	100%	$14,416.24	$0.00	$14,416.24	0	1009
		3	100%	$13,825.46	$0.00	$13,825.46	0	992

Table 1: Main model results

delays, etc. Those are transformed into costs for the analysis of the financial part of the model. It takes into account each day that the machine is under maintenance or inspection to assess the percentage of the working life of machinery. The model collected how often the machine has been sent to light or intensive maintenance to determine the maintainability of the equipment.

2.4 Setting the model

The proposed model has great flexibility in representing various types of maintenance systems and situations, which may range from corrective maintenance, preventive and situational analysis of the team.

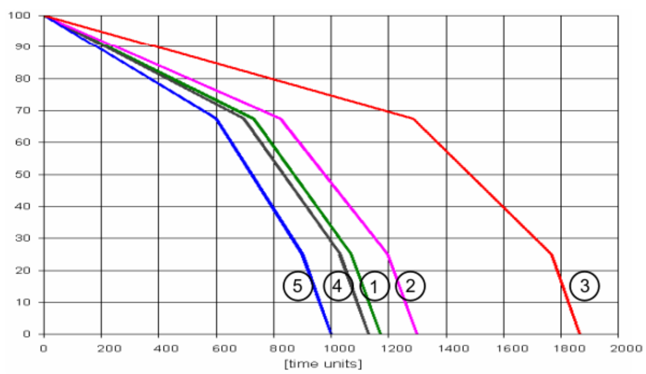

Figure 3: Results of life curve of equipment for default and generated maintenance policy from markov model.

As input variables are the specific qualities of the maintenance system, the main ones: the set time between inspections, the rigor of the inspection, maintenance time and costs and the length of time between the various states of impairment, as well the company variables such as demand, production costs, sales costs, compliance costs and rework costs.

3. Application example

Model was used to simulate production machinery within a company dedicated to selling radiator cooling tubes. The system was tested in 5 different conditions: default policy, inspections of 10, 20 and 40 days, without inspections. There were 3 replicates of each type and the results were as follows, Figure 3 shows the curves of life of different models to the point of wear.

As noted on table 1, you have different factors to select the most appropriate policy. If you search the availability of the machine would select the alternative 5, if you want to reduce costs is due to select Alternative 1 and to extend the life of machine to the maximum recommended Scenario 3.

4. Conclusions

The optimization of maintenance activities through the implementation of techniques such as simulation, situational analysis and maintenance management techniques play a key role in industries which increase their competitiveness by achieving better results with high quality at lower cost possible.

The paper presents a markov model adaptation method that allows adjustment of the basic model to user-expected changes in maintenance policy. The model has the ability to adjust to working environments commonly found in industries and can be extended to represent more complex systems, confirming the effectiveness of a system or proposing a new one with a tuning of policies.

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BIOGRAPHICAL NOTES

Francisco Castellanos obtained his bachelor degree in Industrial Engineering (Tecnológico de Monterrey, México). Currently is studying a master's degree on System engineering at UNAM.

Ann Wellens is a chemical engineer with postgraduate studies in Industrial Administration (KUL, Belgium) and a master degree in Environmental Engineering (UNAM, Mexico). At the moment she is a full-time lecturer in the Systems Department of the Industrial and Mechanical Engineering Division of the National University of Mexico (UNAM). She has been working in air pollution issues for the last 15 years, dictating courses, collaborating in research projects and participating in conferences related with mathematical modeling of air pollution dispersion and statistics.