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# Impact of Improving Machines' Availability Using Stochastic Petri Nets on the Overall Equipment Effectiveness

*Aman Zineb, Latifa Ezzine and Haj El Moussami*

## Abstract

The objective of this chapter is to demonstrate the robustness of stochastic petri nets in the field of maintenance for the improvement of machine availability. We aim to present the modeling of the maintenance function in a production site with stochastic Petri nets by using two performance indicators: the mean time between failures (MTBF: the time between two successive failures) and the mean time to repair (MTTR: average time to repair) to improve the equipment performance. The determination of the distribution law is essential for each statistical study and provides a powerful and reliable model for the evaluation of the equipment performance. After determining these laws we switched to modeling Petri nets, we proposed the establishment of an effective preventive maintenance plan which aims at increasing the reliability, thus reducing the probability of failures. Consequently, we increase the machines' availability and then the overall equipment effectiveness.

**Keywords:** maintenance, modeling, stochastic petri nets, performance indicators, availability, overall equipment effectiveness

## 1. Introduction

Nowadays, companies are in total competition aiming the development of new industry strategies especially concerning the maintenance and the production planning. In fact, general customer non satisfaction is noted to be a consequence either of random demand or sudden equipment failure. Therefore, it becomes a necessity to develop new maintenance and production strategies.

The maintenance function is largely considered as a non productive one since it does not afford us with currency directly. In fact, each company should produce goods of a certain quality and quantity required by the customer who needs to receive the product at the right time. To achieve this objective, production systems should operate efficiently and accurately by using an effective maintenance plan helping companies maximizing availability by minimizing machine downtime. Our work is the continuity of the previous one that manifested the obligation of improving availability [1, 2]. The machine suffered several failures. That's why we want to find a law that will helps us anticipate future failures and when these

failures will occur. The aim of this paper is to propose a modeling and performance evaluation method for a production site using stochastic Petri nets as a very powerful modeling tool that contributes to the improvement of the availability.

In order to exhibit the role played by the maintenance function within the company, it seems important to focus first on the huge difference between planned downtime and unplanned downtime. Unplanned downtime should be minimized. It is function of the number of breakdowns within a specified time period and related measures such as mean time between failures (MTBF) and mean time to repair (MTTR) [3]. MTBF and MTTR are claimed to be measures of equipment achievement and are related to objectives such as functional performance and process capability [4]. Thorough analysis of these two elements enables the maintenance function to improve equipment's availability by either increasing the MTBF or reducing the MTTR.

In this chapter, we show the interest of stochastic Petri nets for modeling, evaluation and performance analysis. Therefore, we will present two applications of SPNs to generate the model after having conducted a statistical study to determine transitions laws. Based on the model and after its simulation, we calculated the availability of machines after having developed a high-quality preventive maintenance plan allowing us to notice the impact of the increase value of availability on OEE.

## **2. Literature review**

Petri net models have been studied extensively over the last decade [5–8]. These models have been applied to many types of systems [9–16]. A lot of analysis has been made on different states a system may occupy. These analyses had not take into consideration any study of timing. Recently, timing is integrated in some attempts [14, 17]. Merlin and Farber [18] discussed timed Petri nets. In fact, they assigned a time threshold and maximum delay to a transition. This was done to allow the incorporation of timeouts into a protocol model.

In his work, Zuberek [17] presents a fixed time for each transition to model the performance of a computer system at the register level. In another case, probability was introduced to allow a random switching of flow through the graph [19]. Shapiro limits the model to discrete time and a maximum of one token in each place. In this paper, Petri nets are extended by assigning an exponentially distributed firing rate to each transition for continuous time systems or a geometrically distributed firing rate to each transition for discrete time systems. These new stochastic Petri nets (SPNs) are isomorphic to homogeneous Markov processes [20]. In this work, SPN's are used to model the maintenance field in order to increase availability, productivity and efficiency of the production line.

Many stochastic Petri Nets classes are proposed for performance analysis of production systems. The characteristics of the different classes are essentially in the nature of transitions used, where laws other than exponential are associated [20–22].

To model our system we have used the stochastic Petri Nets with predicates because they consist of both, the immediate transitions, the deterministic transitions and the transitions with stochastic timings distributed with any law. In addition, they use variables to include two other properties:

- “Guards”: variables or Boolean expressions that make the transitions uncontrollable until they are verified.

- “Assignments”: assignments that modify the values of variables when crossing transitions.

To define a maintenance policy, prioritize the interventions or establish the budget, the maintenance manager must be able to choose the means and modes of intervention most suited to his machines. Similarly, a working group aimed at making machines, a line, a cell or a workshop more reliable, requires a structured method of attacking the site. Here are some simple indicators to help with the decision.

### 2.1 Reliability index: mean time between failures (MTBF)

Mean time between failure (MTBF) indicator measures the time elapsed between failures. It is therefore beneficial for reliability and a fortiori for availability. Mathematically, the criterion of reliability is thus defined by the inverse of its indicator. MTBF is the mean time between consecutive failures. For a repairable system, the MTBF is the average time between completion of the repair and the next failure and is calculated using (1).

$$\text{Mean time between failures} = \frac{\text{total up time}}{\text{number of breakdowns}} \quad (1)$$

Total up time includes stopping time off failure and micro stops time.

### 2.2 Maintainability index: mean time to repair (MTTR)

Maintainability means, for an entity used under given conditions, the likelihood that a given maintenance operation can be performed over a given time interval, maintenance is provided under given conditions, and use procedures and means. MTTR is calculated using (2).

$$\text{Mean time To repair} = \frac{\text{total down time}}{\text{number of breakdowns}} \quad (2)$$

### 2.3 Rate of availability

The notion of availability expresses the probability that an entity is in a state of “availability” under given conditions at a given time, assuming that the provision of external means is assured. This rate is calculated using (3).

$$\text{availability} = \frac{\text{MTBF}}{(\text{MTBF} + \text{MTTR})} \quad (3)$$

## 3. Applications

In this section, we present two applications in automotive and food sector where stochastic Petri Nets proves its strength in order to increase equipment’s availability.

### 3.1 Electrical test table (automotive sector)

In this first application, we present a study to improve availability of equipment that guarantees the good quality of the wiring harnesses. It is the electrical test table

whose role is to check the flow of the electric current and therefore it ensures the main technical function of the wiring harnesses produced.

To achieve this result, we present the electrical test table and its components. Then, availability is calculated based on the history provided by the company. After this, we find the law that will help us anticipate future failures and when these failures will occur. This law enables us to develop a high-quality preventive maintenance plan in order to increase the availability of the equipment.

3.1.1 Description and decomposition of electrical test table

It is a matter of clearly identifying the elements of the machines to be studied in order to analyze, for each element, the risks of dysfunction. We proceed with a general analysis followed by operational analysis. It is first of all necessary to formulate the need in the form of simple functions that the equipment must fulfill by answering three basic questions shown on the standardized tool called the horned beast diagram illustrated in **Figure 1**.

Operational analysis is the analysis of the decomposition of the electric test table; this analysis will be made by a simple decomposition into blocks of element presented in **Figure 2**.

3.1.2 Determination of the transition laws

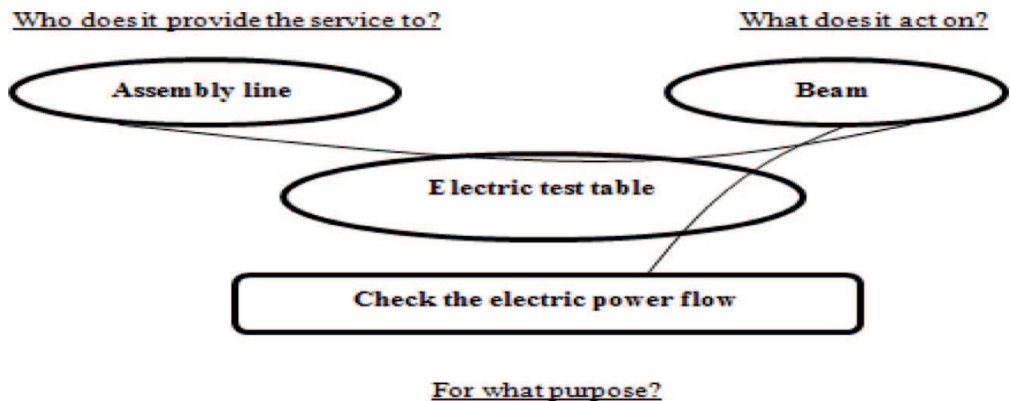
After describing the electric test table to be studied, we are confronted with the problem of determining the failure and repair function of this equipment.

In order to model the breakdown/repair process of a repairable system we have used the history of the operating time of this equipment. The failure history of the electric test table machine enabled us to analyze the data and calculate the availability of this machine along the past period. After any calculation made, the availability of the machine is found to be of the order of 62.73%.

The choice of a particular model is statistically tested to select the model best suited to the observed failure and repair times. The protocol to be used for the study of repairable equipment has been developed by Ascher and Feingold [23].

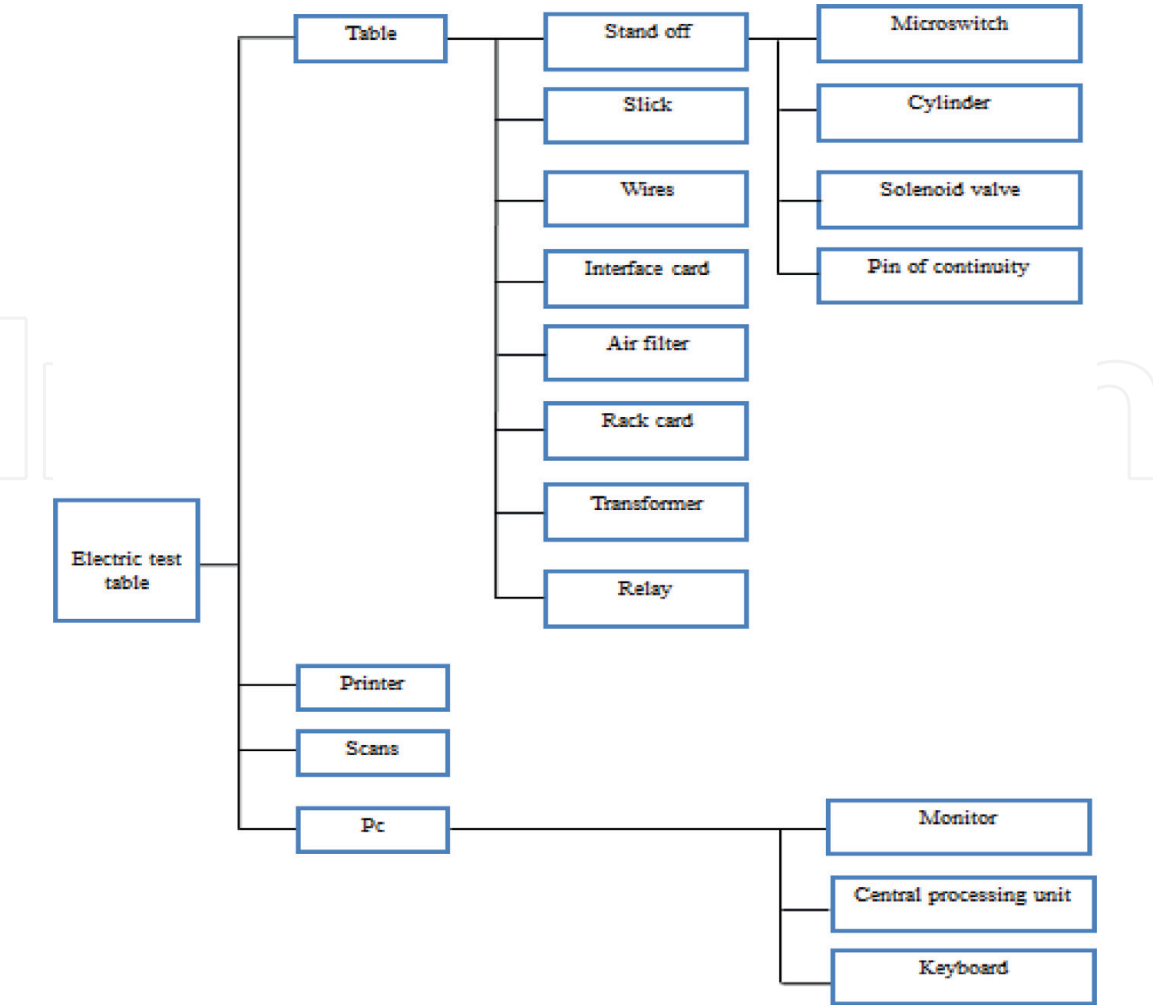
Using the Anderson-Darling statistic and its p-value, we make the decision that the model, the exponential, the Weibull or Log normal, is the one that best adjusts the data. The Anderson-Darling test [24] is used to check if a sample of the data comes from a population with a specific distribution.

Minitab computes the Anderson-Darling statistic using the weighted quadratic distance between the fit line of the probability diagram (based on the chosen law and using the maximum likelihood estimation method or estimates of the least



**Figure 1.**  
*Horned beast for the electric test table.*





**Figure 2.**  
*Decomposition of electric test table.*

squares) and the non-parametric staircase function. The calculation is weighted more extensively at the ends of the distribution.

The hypothesis test is defined as:

- $H_0$ : the data come from a specific distribution.
- $H_1$ : the data does not come from a specific distribution.

The decision to accept or reject the null hypothesis concerns the value  $p$ . If the value  $p$  is greater than 0.05, the null hypothesis is accepted, and if the value  $p$  is less than 0.05, the hypothesis is rejected.

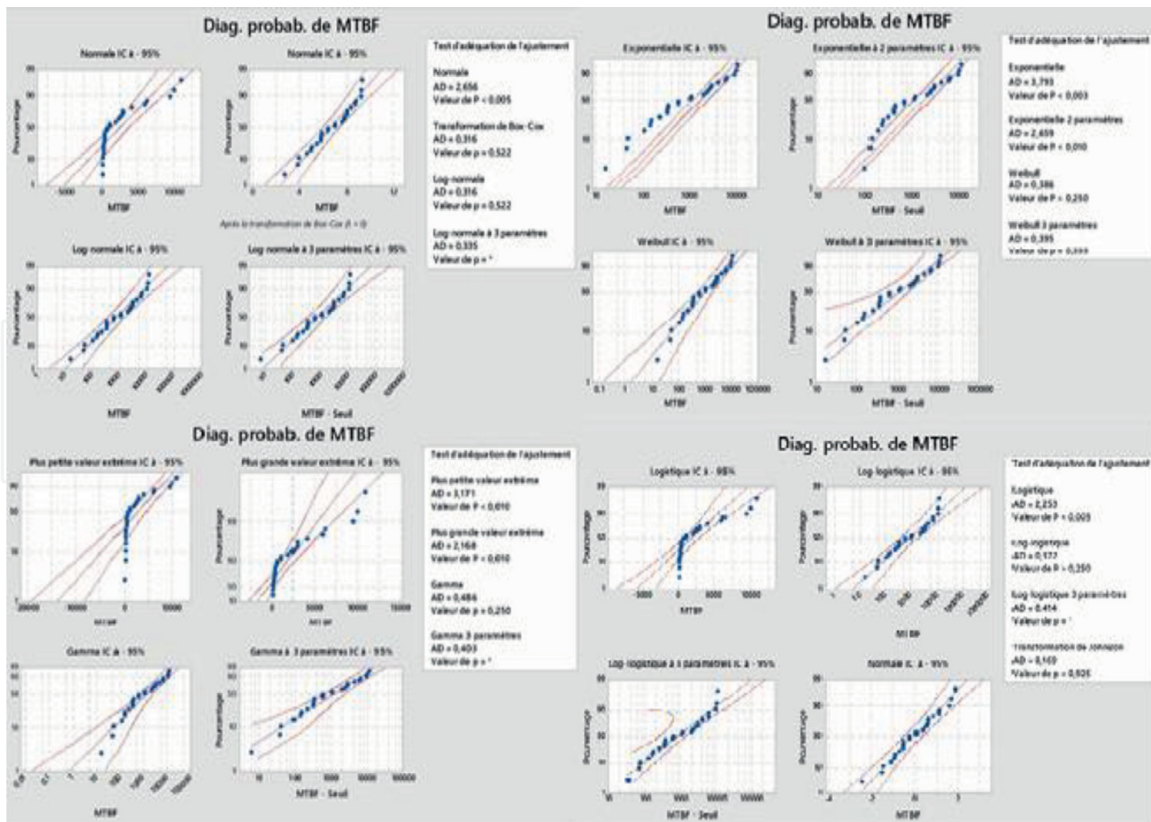
### 3.1.3 Mean time between failure modeling

On the basis of the history of operating times, we used the data processing software MINITAB17 [25] in order to obtain the results mentioned in **Figure 3**.

According to the results obtained and by comparing the different values of  $P$ , we note that the largest values of  $p$  are:

0.522: This corresponds to the law: normal distribution with BOX-Cox transformation.

The Box-Cox transformation is a power transformation,  $W = Y^\lambda$ , in which Minitab determines the best value for  $\lambda$ .



**Figure 3.**  
Distribution laws for MTBF.

0.925: This corresponds to the law: normal distribution with Johnson transformation.

After the application of a Johnson transformation, the data closely follow a normal distribution; indeed, the value of  $p$  is high and virtually all data points lie within the confidence limits of the Henry line.

Box-Cox transformation:  $\lambda = 0$

Johnson transformation:  $1.15528 + 0.453754 \times \ln((X - 10.5919)/(13309.4 - X))$

### 3.1.4 Mean time to repair modeling

Based on the history of the same equipment for the same time period, and using the MINITAB17 data processing software in order to obtain the results mentioned in **Figure 4**.

We note that the largest values of  $P$  are:

0.55: This corresponds to the law: normal law with transformation of BOX-Cox.

The Box-Cox transformation is a power transformation,  $W = Y \times \lambda$ , in which Minitab determines the best value for  $\lambda$ .

0.145: This corresponds to the law: normal law with Johnson transformation.

After the application of a Johnson transformation, the data closely follow a normal distribution; indeed, the value of  $p$  is high and virtually all data points lie within the confidence limits of the Henry line.

Box-Cox transformation:  $\lambda = 1$

Johnson transformation:  $-6.98629E-16 + 0.898955 \times \ln((X - 1.44460)/(11.5554 - X))$

### 3.1.5 Stochastic Petri Net modeling for preventive maintenance plan

After the analysis and calculations, the following stochastic Petri net was realized in **Figure 5**.

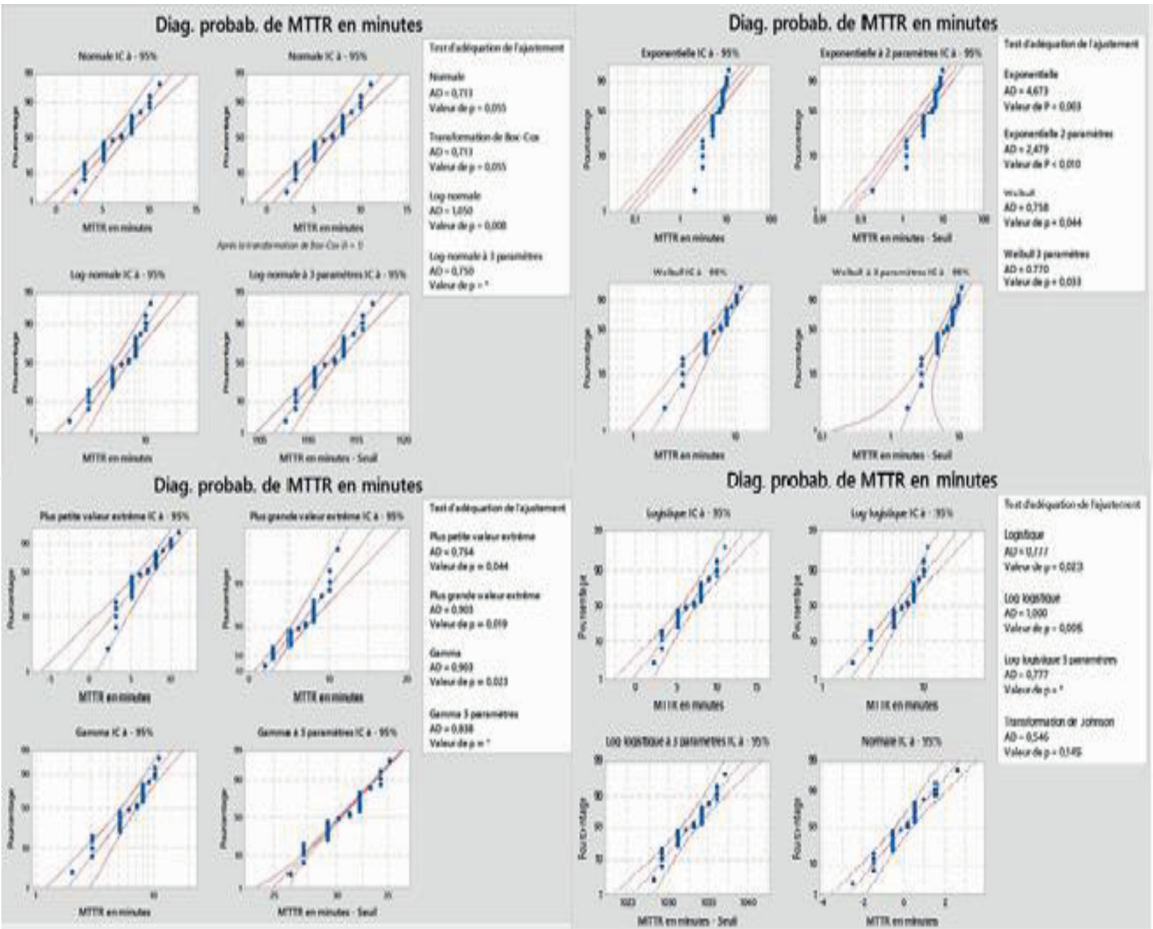


Figure 4.  
Distribution laws for MTTR.

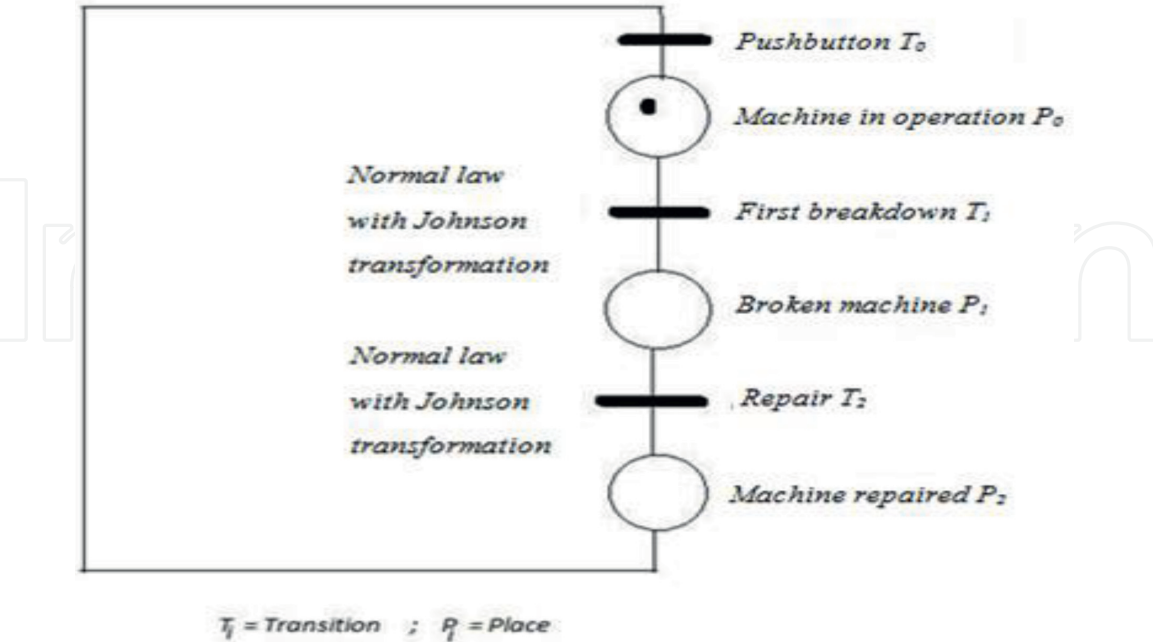


Figure 5.  
Stochastic petri net modeling.

After modeling the maintenance function of the electric test table, it became easy to predict the next breakdown and when it will occur. So, we developed a high-quality preventive maintenance plan based on the modeling realized.



The application of this preventive maintenance plan will have an important impact on the availability of the equipment which is best manifested in the progress of the availability which reached the value of 97.05%.

Thus, the strength of the stochastic petri nets was demonstrated as a tool of modeling allowing the availability of the machine studied to be improved.

3.2 Sieve machine (food sector)

In this second application, we present our study to improve the efficiency of a production line in a food company. We are interested in improving availability. To achieve this result, we find laws that will help us anticipate future failures and when these failures will occur. We model then and simulate the machine maintenance. The laws found enable us to develop a high-quality preventive maintenance plan in order to increase the availability of the equipment using stochastic Petri Nets.

3.2.1 The normality test

This test shown in **Figure 6** is considered as the first step of the statistical mastery which makes it possible to analyze the normality of the data by using the probability plot (p-value\*) that is to say the probability that two samples are identical by using a test hypothesis.

The hypothesis test is defined as:

- $H_0$ : the data follow the normal law;
- $H_1$ : the data do not follow the normal law.

The decision to accept or reject the null hypothesis concerns the value p. If the value p is greater than 0.05, we accept the null hypothesis, and if the value p is less than 0.05, we reject the hypothesis.

For the TTR we found p-value = 0.335 > 0.05. So we will accept the hypothesis  $H_0$  and we can say that the data of the TTR follow the normal law.

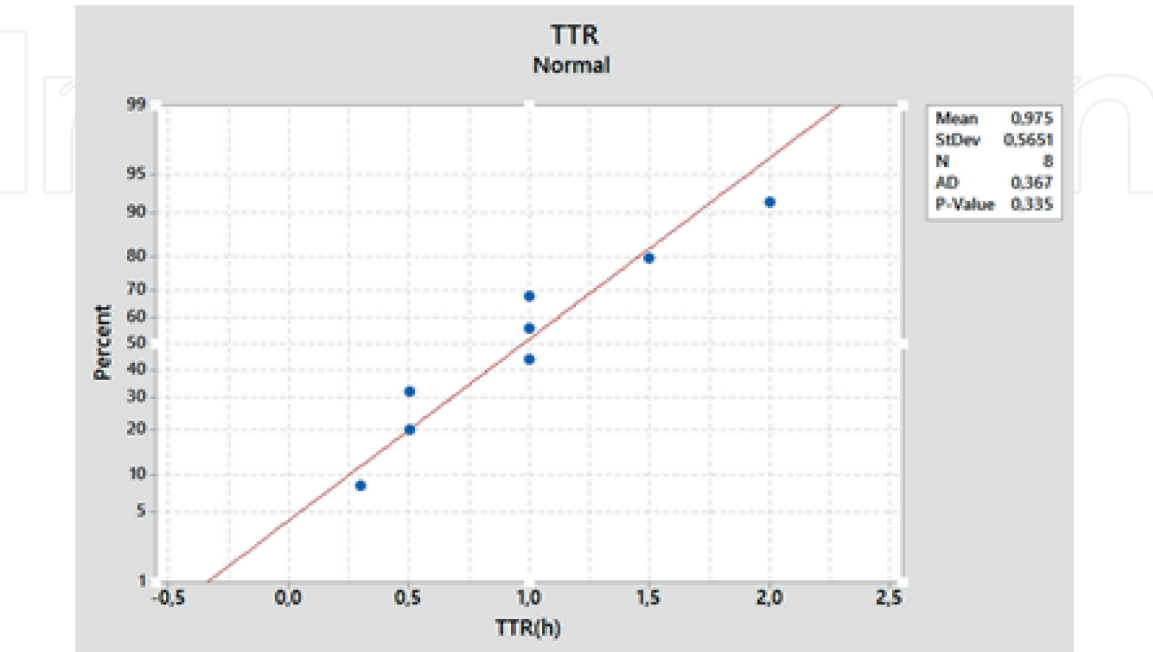


Figure 6.  
Normality test for TTR.

3.2.1.1 The tests of the laws on Minitab 17

Minitab proposes Anderson-Darling Statistics and its p-value to make the decision on which model the data is distributed in. The Anderson-Darling test [24] is used to test whether a sample of the data comes from a population with a specific distribution.

The hypothesis test is defined as:

- $H_0$ : the data come from a specific distribution;
- $H_1$ : The data does not come from a specific distribution.

The decision to accept or reject the null hypothesis concerns the value p. If the value p is greater than 0.05, we accept the null hypothesis, and if the value p is less than 0.05, we reject the hypothesis.

On the basis of the history of operating times, we used the data processing software MINITAB17 [25] in order to obtain the results mentioned in **Figure 7** for TTR.

From the results obtained we notice that the value of p-value of the TTR for all distributions is greater than 0.05. This last value allows us to accept the hypotheses  $H_0$ .

3.2.1.2 Adjustment tests on XL-Stat

Using this software, we performed a law fit with a risk of 5% and we adopted the method of estimation of maximum likelihood.

The different laws tested and their value of P can be summarized in **Table 1**.

The distribution that best fits the data for the fit test is the Weibull distribution (2).

Its estimated parameters are grouped in **Table 2**.

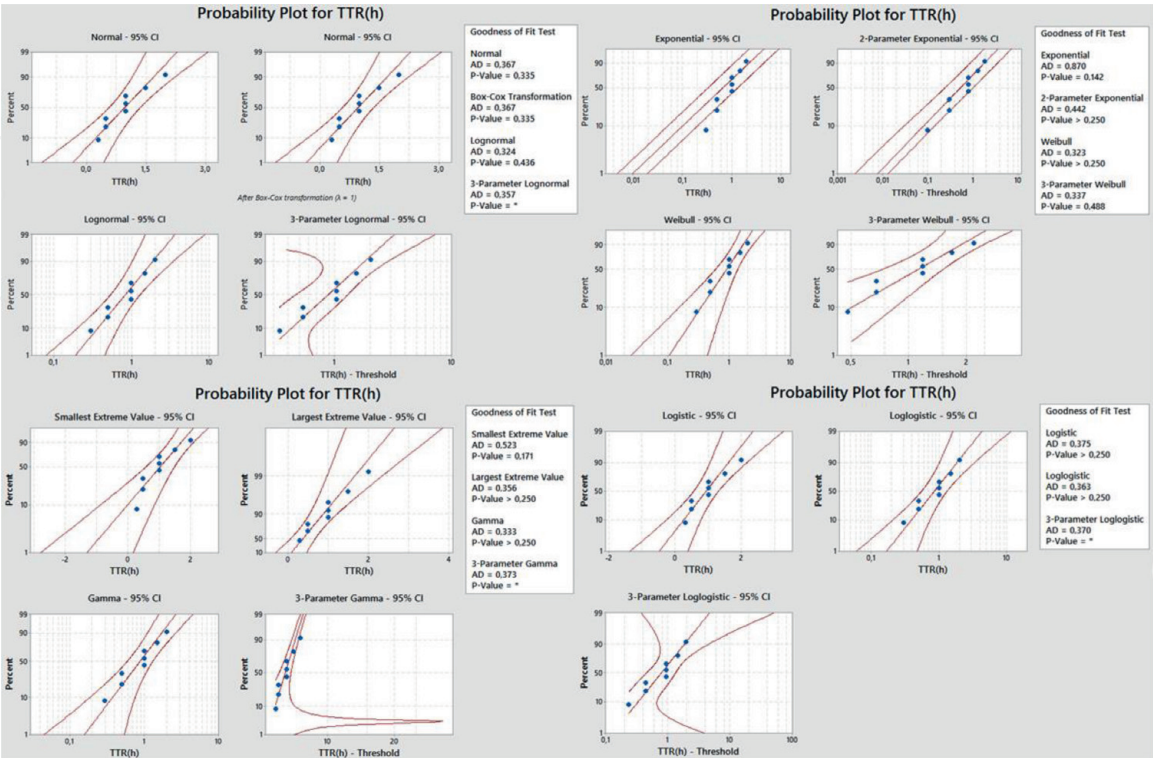


Figure 7.  
Anderson-Darling analysis of the TTR.

| Distribution       | p-Value |
|--------------------|---------|
| Normal standard    | 0.010   |
| Student            | 0.010   |
| Fisher-Tippett (1) | 0.064   |
| Gumbel             | 0.089   |
| Gamma (1)          | 0.191   |
| Erlang             | 0.200   |
| Khi <sup>2</sup>   | 0.516   |
| Weibull (1)        | 0.560   |
| Exponential        | 0.638   |
| Log-normal         | 0.774   |
| Gamma (2)          | 0.901   |
| Normal             | 0.929   |
| Logistic           | 0.964   |
| GEV                | 0.966   |
| Weibull (2)        | 0.969   |

**Table 1.**  
*The TTR distributions and their p-value.*

| Parameters | Value | Standard error |
|------------|-------|----------------|
| Beta       | 1.919 | 0.659          |
| Gamma      | 1.187 | 0.267          |

**Table 2.**  
*The estimated parameters of Weibull distribution (2).*

The XL-stat software offers several tests to ensure this distribution: Kolmogorov–Smirnov test and chi-square test.

Following the same steps, after having conducted the normality test for TBF, we found  $p\text{-value} = 0.020 < 0.05$ . So we will accept the hypothesis  $H_1$  and we can say that the data of the TBF do not follow the normal law.

The Anderson-Darling analysis showed that, for TBF, the value of  $p$  for some distributions is less than 0.05. As a result, we can conclude that none of the distributions is the one that best fits the data. Hence, the need to make further adjustment tests on the XL-Stat software that will be most appropriate.

3.2.2 Determination of transition laws

All tests that are already done do not give an exact distribution for our database. To solve this problem we compare the risk  $\alpha$  (the risk of rejecting the null hypothesis  $H_0$  when it is true) for the distributions whose value of  $p$ -value is greater than 0.5. ( $H_0$ : data comes from a specific distribution) (Tables 3 and 4).

After several adjustment tests on the two performance indicators TTR and TBF and using the comparison between the risk values  $\alpha$ , we find that the good distribution for the TTR is the Exponential distribution and for the TBF is a normal Log distribution.

| Distribution | p-Value | $\alpha$ (%) |
|--------------|---------|--------------|
| Weibull (1)  | 0.560   | 32.43        |
| Exponential  | 0.638   | 10.65        |
| Log-normal   | 0.774   | 21.40        |
| Gamma (2)    | 0.901   | 28.72        |
| Normal       | 0.929   | 27.37        |
| Logistic     | 0.964   | 22.06        |
| GEV          | 0.966   | 20.60        |
| Weibull (2)  | 0.969   | 32.43        |

**Table 3.**  
*The TTR distributions and their risk  $\alpha$ .*

| Distribution       | p-Value | $\alpha$ (%) |
|--------------------|---------|--------------|
| Exponential        | 0.382   | 80.4         |
| Fisher-Tippett (2) | 0.593   | 1.13         |
| Normal             | 0.642   | 0.37         |
| Logistic           | 0.759   | 0.25         |
| Log-normal         | 0.800   | 0.5          |
| Gamma (2)          | 0.882   | 7.31         |
| Weibull (2)        | 0.906   | 4.40         |

**Table 4.**  
*The TBF distributions and their risk  $\alpha$ .*

| Performance indicator | Distribution law | Parameters  | Value |
|-----------------------|------------------|-------------|-------|
| TTR                   | Exponential      | $\lambda_1$ | 0.952 |
| TBF                   | Normal Log       | $\mu$       | 2.097 |
|                       |                  | $\sigma$    | 1.726 |

**Table 5.**  
*Parameters estimated for each law.*

According to the method of maximum likelihood, we estimate the value of the parameter of each law (**Table 5**).

### 3.3 Petri net modeling for preventive maintenance

For our case, we worked on modeling a single machine (Sieve) using stochastic Petri nets because we can use this type of model to take into account probabilistic events such as the failure of a machine moreover it allows to model tasks with non deterministic execution times and to evaluate the performances of the system.

The Petri Net modeling in **Figure 8** represents the behavior of a sieve.

This network has two places:

- Pl1: Running
- Pl2: Out of order



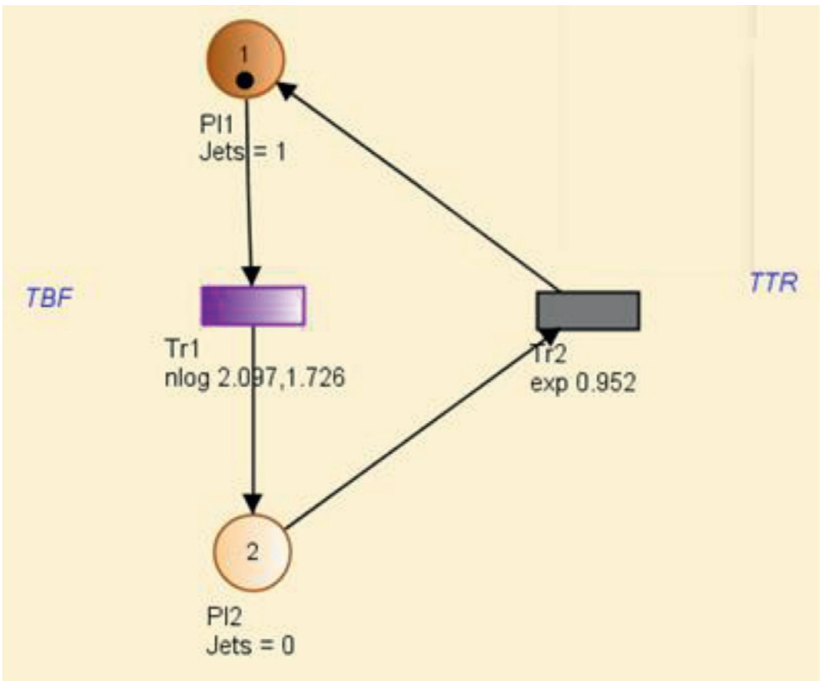
And two transitions:

- Tr1: Equipment failure
- Tr2: Equipment repaired

The simulation results are presented in **Tables 6** and 7.

From the results of the simulation, it can be seen that the residence time of the sieve in working order is equal to 24.13 times the residence time in the state of failure. For the crossing frequencies of the two transitions, they are approximately equal in view of the nature of our operating process, that is to say a loop sequence.

After modeling the maintenance function of the sieve, it became easy to predict the next breakdown and when it will occur. So, we developed a high-quality preventive maintenance plan based on the modeling realized.



**Figure 8.**  
*Modeling with Petri nets.*

| Name  | Number | Residence time | Standard deviation ( $\sigma$ ) | Number of jets | Mean standard deviation | Number of jets | Final standard deviation |
|-------|--------|----------------|---------------------------------|----------------|-------------------------|----------------|--------------------------|
| PI1:1 | 1      | 7.1439E2       | 7.3264                          | 0.9602         | 9.8473E-3               | 0.9            | 0.3162                   |
| PI2:2 | 2      | 2.9612E1       | 7.3264                          | 3.9801E-2      | 9.8473E-3               | 0.1            | 0.3162                   |

**Table 6.**  
*Simulation result by GRIF-residence time of places.*

| Name   | ID | Frequency of sorting period transitions |
|--------|----|-----------------------------------------|
| Tr1: 1 | 1  | 3.07E1                                  |
| Tr2: 2 | 2  | 3.06E1                                  |

**Table 7.**  
*Simulation result by GRIF-Frequency of sorting period transitions.*

The modeling allowed us to conclude that our machine has a good availability as the time of breakdowns is negligible compared to the time of stay in operation.

The application of this preventive maintenance plan will have an important impact on the availability of the equipment which is best manifested in the simulation conducted. According to the calculation of the performance using this modeling, we find an average availability of the sieve which equals:

$$D = \frac{714.39}{714.39 + 29.612} = 96\% \quad (4)$$

Thus, the strength of the stochastic petri nets was demonstrated as a tool of modeling allowing the availability of the machine studied to be improved.

### 3.4 Synthesis

In these applications, we have demonstrated the robustness of stochastic petri nets in the field of maintenance in two different sectors for the improvement of machines' availability.

Our study is based on the values of the two indicators (MTBF and MTTR) calculated within a company working in automotive sector and another one operating in food sector. The determination of the distribution law is essential for each statistical study and provides a powerful and reliable model for the evaluation of the equipment performance by incorporating preventive maintenance. After that, we developed a preventive maintenance plan that improves availability of machines.

For each sector, we obtained an increase in availability rate thanks to SPNs methodology.

## 4. Conclusion

The objective of this chapter is to demonstrate the robustness of stochastic petri nets in the field of maintenance for the improvement of machine availability. We presented the modeling of the maintenance function in a production site with stochastic Petri nets by using two performance indicators: the mean time between failures and the mean time to repair to improve the equipment performance.

The determination of the distribution law is essential for each statistical study and provides a powerful and reliable model for the evaluation of the equipment performance in the automotive sector and the food sector. After determining these laws we switched to modeling Petri nets, we proposed the establishment of an effective preventive maintenance plan which aims at increasing the reliability, thus reducing the probability of failures. Consequently, we increase the machines' availability and then the overall equipment effectiveness.

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