

Experience Fastback analysis for Maintenance Optimization at the Stations and Drilling of AEP-Béjaïa's Network

Boussouira H., Chachoua L. et Aïssani D.

lamos_bejaia@hotmail.com

Résumé Les nombreux projets de densification du tissu urbain de la ville de Béjaïa conduiront dans les années à venir à des extensions du réseau d'AEP. Dans ce cas, les équipements de la compagnie des eaux EDEMIA pourront ils faire face à la continuité du processus de production ?

L'objectif de cette étude est l'analyse du retour d'expérience des équipements principaux des stations et des champs de captage du réseau d'AEP de la ville de Béjaïa, et ce, afin d'évaluer leurs fiabilités, leurs disponibilités et par suite, celles des différents modes de fonctionnement du réseau. Il s'agit de déterminer une politique optimale de maintenance, sur la base d'une étude économique.

Mots clés : Réseau Hydraulique, Analyse du Retour d'Expérience, Fiabilité, Maintenabilité, Disponibilité, Lois et Tests non Paramétriques.

Abstract

The numerous project of densification urban tissue of Bejaïa city will drive in the years to come to extensions of AEP's network. In that case, will the equipments of EDEMIA Water Company be able to face the continuance of the production process ?

The objective of this study is the experience fastback analysis of stations and fields harnessing main equipments of AEP's network, and this in order to estimate theirs reliabilities, theirs availability and as a consequence, those of the various modes network functioning. It is a question of determining an optimal policy of maintenance, on the base of an economic study.

Keywords : Hydraulic Network, Experience Fastback Analysis, Reliability, Maintainability, Availability, Laws and Tests non parametric.

3.1 INTRODUCTION

The water is a vital resource for the man. The sending of this water from the source until the faucet of each-one, in a continuous and sufficient way, represents a very high capital cost because the developer has to implant and administer a set of works and very complex equipments.

Modern technologies allow us to list and to exploit in the best way the few hydro resources that we have. Indeed, Algeria is in one of the poorest zones in hydraulic resources. Where resides the importance of a good exploitation and a good management of this indispensable resource. A good management suggests obviously an adequate plan of maintenance of the equipments, based on the concepts of reliability, of maintainability and availability.

Reliability is the characteristic of a device expressed by the probability that carries out a function required in given conditions, during a given time [1]. The historic of the breakdowns

of a system allows to have information about the laws of probability of various failings. The statistical analysis of these data makes so much integral part of reliability's theory.

Maintenance based on the reliability rests essentially on the treatment of the experience fast-back of the materials in exploitation.

The fast extension of the population of Bejaïa's city leads to difficulties in the drinkable water supply. Current availability is of 42000 m³/day. With this level of production, the EDEMIA water Company manages to assure certain degree of satisfaction of the population's necessities. It will become more difficult with the new extensions of the network. These extensions concern particularly Sidi-Ahmed zone and that of Ihaddaden, where projects of densifications of the urban tissue are in progress (two new stations, Tala Markha and Oussama, will be operational in 2003). In parallel, to be able to face this increase of demand, the EDEMIA envisages the mobilization of new resources, such as the realization of two new drillings of a debit 40 l/s each. Nevertheless, it can be insufficient, according to different abnormalities which knows the AEP network of Béjaïa's city (repeated cuts of water, considerable flights, ...). Where there is a necessity of a rigorous management allowing to reduce these abnormalities, by assuring a continuance in the process of production, by the introduction of procedures able of optimizing the equipments' exploitation of the network, to raise their availability.

The objective of this report goes with this context and concerns the implementation of a possible policy of preventive maintenance. It is for others to define the periodicity of material's maintenance. The optimization of policy of maintenance leads itself to a decision-making study. To make this study, we should know the true law of the materials' life expectancies. However, this is practically impossible. One is so forced to appeal on the experience fastback concerning the exploitation of the materials, which can be ambiguous and partial.

This work is illustrated with a functional modeling of the system, realized according to what someone knows of each of its constituents, their dependences, and statistical observations concerning them by the modeling of the reliability of the network's various variants. A main equipments data's statistical treatment of pump stations and fields of harnessing, allows to estimate reliability, maintainability and availability of these last ones, and by this even, the network.

3.2 DESCRIPTION OF AEP'S NETWORK OF BEJAIA'S CITY

The drinkable water supply of Bejaïa's city makes from the drillings of Oued Zitouna and Oued Agrioune, Oued Djemaa's wells, as well as from Kherrata's source. The produced water arrives at the central station situated to Oued Sghir. Of this last one, arise three chains of expulsion, allowing the food of it almost totality of the city. According to the topography (hilly landscape) of Bejaïa's city, food makes by floors :

- The first chain of expulsion has for role to feed the zone of Ancient City, by way of stations Fouka and Boussiron.
- The second chain of expulsion has for role to feed Sidi-Ahmed's zone, by way of stations Sidi-AhmedI, Sidi-AhmedII and Sidi-AhmedIII.
- The third chain of expulsion has for role to feed Ihaddaden's zone, by way of stations IhaddadenI and IhaddadenII.

3.3 MAINTENANCE WITHIN THE EDEMIA AND DATA COLLECTION

The public establishment of domestic distribution industrial water and purification of Bejaïa's Wilaya (E.D.E.M.I.A) was created by consideration of the APW in date 12.07.1987.

THE EDEMIA administers six sectors of Bejaïa's Wilaya, regrouping 13 municipalities. Until 31.12.01, it feeds more than 320.000 inhabitants.

The service maintenance of the EDEMIA assures preservation in state of functioning of 31 drillings and (05) wells equipped with groups electropumps immersed, and 46 stations of transfer equipped with groups electropumps horizontal. It includes a section organization, a preventive section and a curative section.

The data collection was made at the level of the department exploitation, within services of maintenance and production. Information contained in these data are ambiguous and present certain indistinctness.

To reconstitute our samples, we were forced to confront several sources : The cards of interventions, the checks of exit stock, the reports of production, and it, for period spreading for 01. 01. 1995 to 30. 09.2001.

3.4 MODELING AND APPRAISAL OF NETWORK'S RELIABILITY

During a study of reliability, it is advisable to consider any system as a joining of constituents of which actions and interactions are going to determine the behavior of the set.

AEP's network of Bejaïa's city includes (08) drillings, (04) wells and (08) main stations. These last ones put on the whole 40 groups electropumps.

Before proceeding to the model of the network, we made a classification of the groups electropumps according to their technical characteristics. So one made first one subdivision in two classes according to the disposal of the pump's axis, namely, the class of the groups electropumps immersed (GEPI) who characterize those of drillings and well, and the class of the groups electropumpes horizontal (GEPH) who characterize those of stations. These two classes are subdivided in their tour into sub-classes, according to the main characteristics of the engine and the group's pump, of a way presented in the following two tables :

The study of reliability is going to base itself on the main constituents of drillings, wells and network's stations, which are going to represent the diagram's blocks of the system's reliability. This last one consists in a representation of type

Classes of GEPH	Count of GEP by station	Pump			Engine	
		Mark	Debit $Q(m^3/h)$	Height $Hmt(m)$	Power $P(kw)$	Speed $N(tr/mn)$
GEPH1	3 GEP/ Centrale	KSB	800	80	250	1480
GEPH2	3 GEP/ Centrale	KSB	540	80	160	1475
GEPH3	4 GEP/ Fouka. 2 GEP/ IhaddadenI	KSB	350	67	110	1470
GEPH4	5 GEP/ Sidi-AhmedI. 2 GEP/ Sidi-AhmedII	SONACOM	482	55	102	1460
GEPH5	2 GEP/ Sidi-AhmedIII 3 GEP/ Boussiron	KSB	183	94	84	2915
GEPH6	2 GEP/ Boussiron	GUINARD	284	37	45	2900
GEPH7	4 GEP/ IhaddadenII	ENPMH	29	166	75	2900

TABLE 3.1. Classes of horizontal electropumps groups

Classes of GEPH	Count of GEP by drilling	Pump			Engine	
		Mark	Debit $Q(m^3/h)$	Height $Hmt(m)$	Power $P(kw)$	Speed $N(tr/mn)$
GEPH1	2 GEP/ Oued Agrioune 1 GEP/ Oued Djemaa	ATURIA	108	126	55	2900
GEPH2	2 GEP/ Oued Agrioune 4 GEP/ Oued Zitouna	RATEAUX	152	140	88	2900
GEPH3	2 GEP/ Oued Djemaa	ATURIA	218	116	103	2900

TABLE 3.2. Classes of immersed electropumps groups

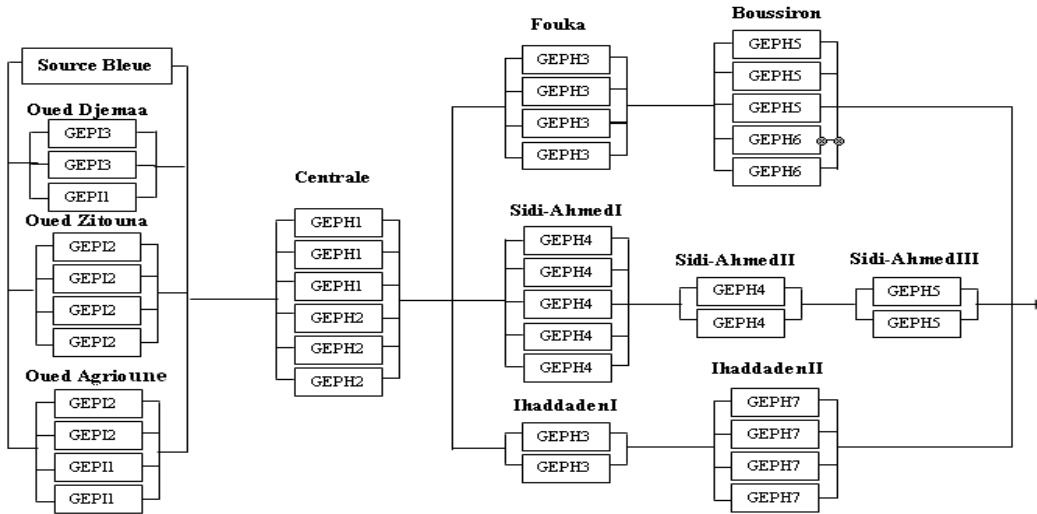


FIGURE 3.1. Reliability diagram of AEP's Network of Bejaïa's city.

functional plan, the constituents of the system are represented with blocks and connections between these blocks represent relations between elements [2]. The global structure of the system is represented as follows :

Where drillings, well and source forms, of the point of view reliability, a system 12/12, which is mass with the central station and under system representing distributive network. This last one constitutes a system 3/3 (three directions) of the point of view reliability.

According to the quantity of water produced with the fields of harnessing (drillings, well, source), the network works according to four modes for climatic reasons, such as the pluviometry, the temperature and the evaporation. These modes were determined from the registers of production for various periods of the year (summer, winter, ...).

From the global system, approach consists so in estimating the reliability of variants characterizing the various modes of it functioning.

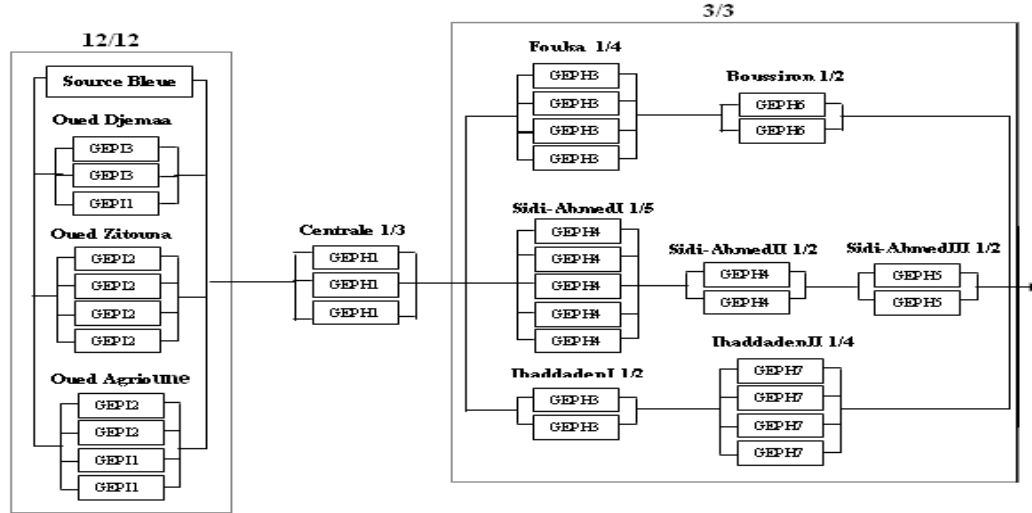


FIGURE 3.2. Variant 1 reliability diagram.

Model 1

$$R_{V_{ar1}}(t) = [(R_{GEPH1}(t))^3(R_{GEPH2}(t))^6(R_{GEPH3}(t))^2][1 - (1 - (R_{GEPH1}(t))^3)[1 - (1 - R_{GEPH3}(t))^4](1 - (1 - R_{GEPH6}(t))^2)[1 - (1 - R_{GEPH4}(t))^5](1 - (1 - R_{GEPH4}(t))^2)(1 - (1 - R_{GEPH5}(t))^2)][(1 - (1 - R_{GEPH3}(t))^2)(1 - (1 - R_{GEPH7}(t))^4)].$$

Variant 2 :

It is about the most frequent case of functioning of the system, With a debit varying between $1300m^3/hour$ and $1600m^3/hour$, the central station has to work with two pumps. The other stations remain functional with a single pump, except for the stations Boussiron and IhaddadenI, which have to work each with two pumps because of the weak debit supplied by these last ones.

Variant 3 :

Notations :

$R_{GEPH_i}(t)$: Reliability of a group electropumpe horizontal belonging to the class $N^\circ i$, $i = 1, \dots, 7$

$R_{GEPI_i}(t)$: Reliability of a group electropumpe immersed belonging to the class $N^\circ i$, $i = 1, \dots, 3$.

$R_{vari}(t)$: Reliability of the variant i , $i = 1, \dots, 4$.

Remark

$R_{source}(t) = 1$ because the sending of the water produced with the blue source is made by gravity. It does not require equipments for it extraction.

Variant 1 :

This variant represents the functioning of stations when it is a question of working with a debit varying between $800m^3/hour$ and $1000m^3/hour$. In this variant, all the stations work only with a single group electropumpe. This scenario is rather rare. It can happen towards the end of the dry season. The diagram as well as The final expression of the model of reliability of this variant are given this below :

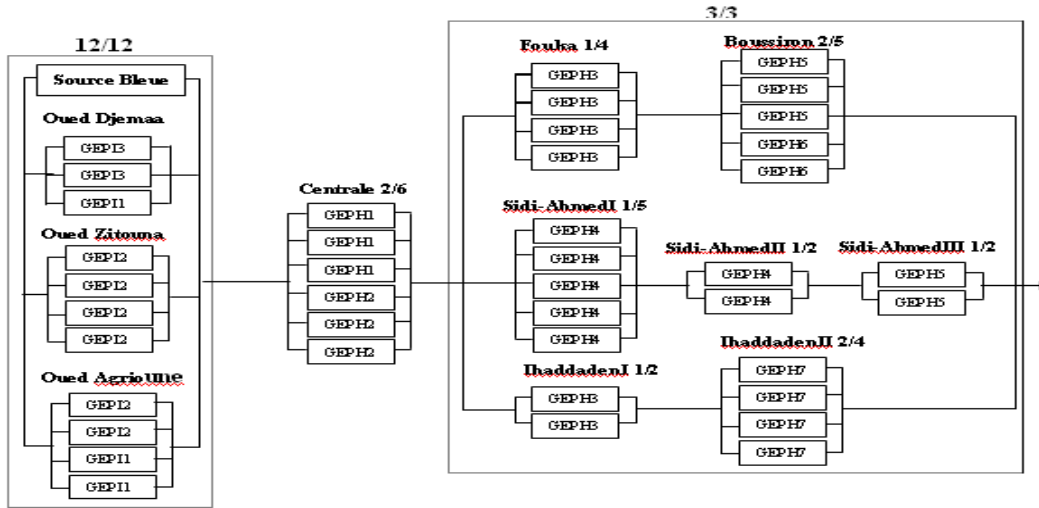


FIGURE 3.3. Variant 2 reliability diagram

In this variant, the central station has to work with three pumps to be able to evacuate debit supplied by the link production, the station Sidi-AhmedI has to work with two pumps and the other stations remain functional with the same number of pumps as in the previous variant.

Model 2 :

$$\begin{aligned}
 R_{Var2}(t) = & [(R_{GEPH1}(t))^3(R_{GEPH2}(t))^6(R_{GEPH3}(t))^2][9R_{GEPH1}(t)R_{GEPH2}(t)(1 - \\
 & R_{GEPH1}(t))^2(1 - R_{GEPH2}(t))^2 + 9R_{GEPH1}(t)(R_{GEPH2}(t))^2(1 - R_{GEPH1}(t))^2(1 - \\
 & R_{GEPH2}(t)) + 3R_{GEPH1}(t)(R_{GEPH2}(t))^3(1 - R_{GEPH1}(t))^2 + 3(R_{GEPH1}(t))^2(1 - \\
 & R_{GEPH1}(t))(1 - R_{GEPH2}(t))^3 + 9(R_{GEPH1}(t))^2R_{GEPH2}(t)(1 - R_{GEPH1}(t))(1 - R_{GEPH2}(t))^2 + \\
 & 9(R_{GEPH1}(t))^2(R_{GEPH2}(t))^2(1 - R_{GEPH1}(t))(1 - R_{GEPH2}(t)) + 3(R_{GEPH1}(t))^3R_{GEPH2}(t)(1 - \\
 & R_{GEPH2}(t))^2 + 3(R_{GEPH1}(t))^3(R_{GEPH2}(t))^2(1 - R_{GEPH2}(t)) + (R_{GEPH1}(t))^3(R_{GEPH2}(t))^3][(1 - \\
 & (1 - R_{GEPH3}(t))^4)(6R_{GEPH6}(t)R_{GEPH5}(t)(1 - R_{GEPH6}(t))(1 - R_{GEPH5}(t))^2 + \\
 & 6R_{GEPH6}(t)(R_{GEPH5}(t))^2(1 - R_{GEPH6}(t))(1 - R_{GEPH5}(t)) + 2R_{GEPH6}(t)(R_{GEPH5}(t))^3(1 - \\
 & R_{GEPH6}(t)) + 3(R_{GEPH6}(t))^2R_{GEPH5}(t)(1 - R_{GEPH5}(t))^2 + 3(R_{GEPH6}(t))^2(R_{GEPH5}(t))^2(1 - \\
 & R_{GEPH5}(t)) + 3(R_{GEPH5}(t))^2(1 - R_{GEPH6}(t))^2(1 - R_{GEPH5}(t)) + (R_{GEPH5}(t))^3(1 - \\
 & R_{GEPH6}(t))^2 + (R_{GEPH6}(t))^2(R_{GEPH5}(t))^3][(1 - (1 - R_{GEPH4}(t))^5)(1 - (1 - (R_{GEPH4}(t))^2)(1 - \\
 & (1 - R_{GEPH5}(t))^2)][(1 - (1 - R_{GEPH3}(t))^2)(6(R_{GEPH7}(t))^2(1 - R_{GEPH7}(t))_2 + 4(R_{GEPH7}(t))^3(1 - \\
 & R_{GEPH7}(t)) + (R_{GEPH7}(t))^4)]
 \end{aligned}$$

FIGURE 3.4. Variant 2 reliability diagram

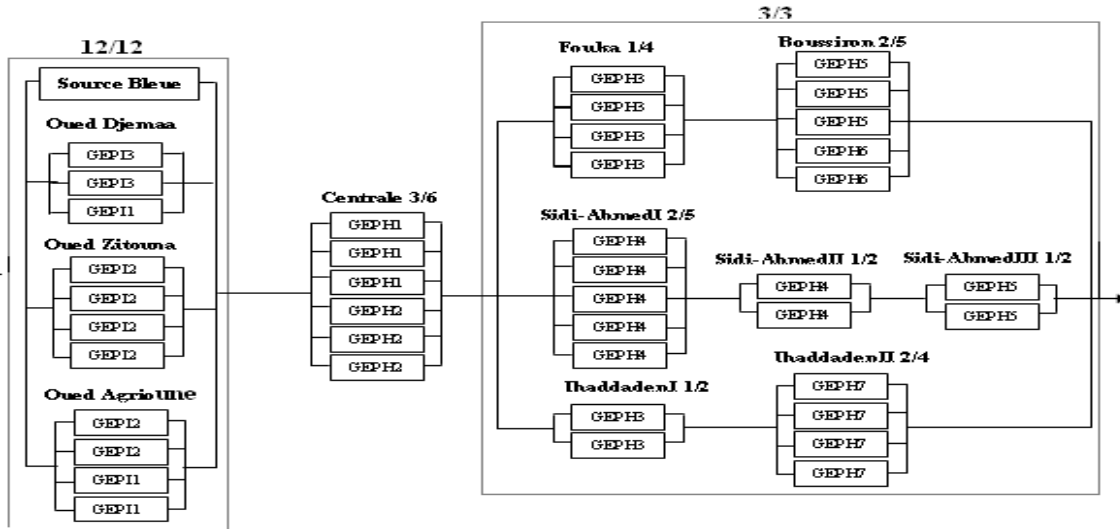


FIGURE 3.5. Variant 3 reliability diagram

Variant 4 :

This mode of functioning is not frequent. It occurs when total debit arrived at the central station exceeds $2300m^3/hour$. In that case, the central station has to work with four elements. The station Fouka has to work with two elements, what leads to put on three elements in the station Boussiron and the other stations remain functional with the same number of pumps as in the previous variant.

Model 3 :

$$\begin{aligned}
R_{Var3}(t) = & [(R_{GEPH1}(t))^3(R_{GEPH2}(t))^6(R_{GEPH3}(t))^2][9(R_{GEPH1}(t))^2R_{GEPH2}(t)(1 - \\
& R_{GEPH1}(t))(1 - R_{GEPH2}(t))^2 + 9(R_{GEPH1}(t))^2(R_{GEPH2}(t))^2(1 - R_{GEPH1}(t))(1 - \\
& R_{GEPH2}(t)) + 3(R_{GEPH1}(t))^2(R_{GEPH2}(t))^3(1 - R_{GEPH1}(t)) + 3(R_{GEPH1}(t))^3(R_{GEPH2}(t))(1 - \\
& R_{GEPH2}(t))^2 + 3(R_{GEPH1}(t))^3(R_{GEPH2}(t))^2(1 - R_{GEPH2}(t)) + 9R_{GEPH1}(t)(R_{GEPH2}(t))^2(1 - \\
& R_{GEPH1}(t))^2(1 - R_{GEPH2}(t)) + 3R_{GEPH1}(t)(R_{GEPH2}(t))^3(1 - R_{GEPH1}(t))^2 + \\
& (R_{GEPH1}(t))^3(R_{GEPH2}(t))^3][(1 - (1 - R_{GEPH3}(t))^4)(6R_{GEPH6}(t)R_{GEPH5}(t)(1 - \\
& R_{GEPH6}(t))(1 - R_{GEPH5}(t))^2 + 6R_{GEPH6}(t)(R_{GEPH5}(t))^2(1 - R_{GEPH6}(t))(1 - R_{GEPH5}(t)) + \\
& 2R_{GEPH6}(t)(R_{GEPH5}(t))^3(1 - R_{GEPH6}(t)) + 3(R_{GEPH6}(t))^2R_{GEPH5}(t)(1 - R_{GEPH5}(t))^2 + \\
& 3(R_{GEPH6}(t))^2(R_{GEPH5}(t))^2(1 - R_{GEPH5}(t)) + (R_{GEPH6}(t))^2(1 - R_{GEPH5}(t))^3 + \\
& (R_{GEPH6}(t))^2(R_{GEPH5}(t))^3][(10R_{GEPH4}(t))^2(1 - R_{GEPH4}(t))^3 + 10(R_{GEPH4}(t))^3(1 - \\
& R_{GEPH4}(t))^2 + 5(R_{GEPH4}(t))^4(1 - R_{GEPH4}(t)) + (R_{GEPH4}(t))^5(1 - (1 - (R_{GEPH4}(t))^2)(1 - (1 - \\
& R_{GEPH5}(t))^2))[(1 - (1 - R_{GEPH3}(t))^2)(6(R_{GEPH7}(t))^2(1 - R_{GEPH7}(t))^2 + 4(R_{GEPH7}(t))^3(1 - \\
& R_{GEPH7}(t)) + (R_{GEPH7}(t))^4)]
\end{aligned}$$

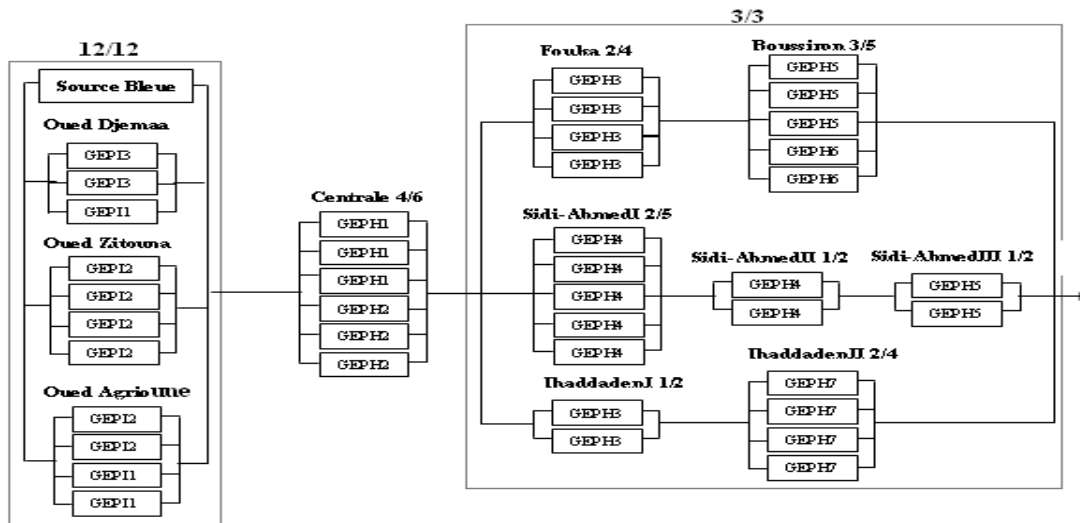


FIGURE 3.6. Variant 4 reliability diagram

Model 4 :

$$\begin{aligned}
R_{Var4}(t) = & [(R_{GEPH1}(t))^3(R_{GEPH2}(t))^6(R_{GEPH3}(t))^2][3(R_{GEPH1}(t))^2(R_{GEPH2}(t))^3(1 - \\
& R_{GEPH1}(t)) + 3R_{GEPH1}(t)(R_{GEPH2}(t))^3(1 - R_{GEPH1}(t))^2 + (R_{GEPH1}(t))^3(R_{GEPH2}(t))^3][(6(R_{GEPH3}(t))^2(1 - \\
& R_{GEPH3}(t))^2 + 4(R_{GEPH3}(t))^3(1 - R_{GEPH3}(t)) + (R_{GEPH3}(t))^4)(6R_{GEPH6}(t)(R_{GEPH5}(t))^2(1 - \\
& R_{GEPH6}(t))(1 - R_{GEPH5}(t)) + 2R_{GEPH6}(t)(R_{GEPH5}(t))^3(1 - R_{GEPH6}(t)) + \\
& 3(R_{GEPH6}(t))^2R_{GEPH5}(t)(1 - R_{GEPH5}(t))^2 + 3(R_{GEPH6}(t))^2(R_{GEPH5}(t))^2(1 - R_{GEPH5}(t)) + \\
& (R_{GEPH6}(t))^2(R_{GEPH5}(t))^3][(10R_{GEPH4}(t))^2(1 - R_{GEPH4}(t))^3 + 10(R_{GEPH4}(t))^3(1 - \\
& R_{GEPH4}(t))^2 + 5(R_{GEPH4}(t))^4(1 - R_{GEPH4}(t)) + (R_{GEPH4}(t))^5(1 - (1 - (R_{GEPH4}(t))^2)(1 - (1 - \\
& R_{GEPH5}(t))^2))[(1 - (1 - R_{GEPH3}(t))^2)(6(R_{GEPH7}(t))^2(1 - R_{GEPH7}(t))^2 + 4(R_{GEPH7}(t))^3(1 - \\
& R_{GEPH7}(t)) + (R_{GEPH7}(t))^4)]
\end{aligned}$$

3.5 ANALYSIS OF THE GROUPS ELECTROPUMPS' RELIABILITY

In this part of the study, we modeled the laws of survivals of the system's constituents, from the data of the times of good functioning, of the electropumps groups' classes raised from the experience fastback.

We made for that purpose, two types of modeling :

- A modeling by laws non parametric (IFR, DFR) confirmed by the test of Prochan-Pyke and by the graphic test.
- A modeling by Weibull's law in two parameters. Confirmed by the test of Khi-deux and by the test of Kolmogorov-Smirnov.

3.5.1 Non-parametric Modeling

Graphic Test [3]

This test is based on the properties of the TTT-graph. It consists in representing points $\frac{j}{n}, U_j = \frac{S(t_j)}{S(t_n)}, j = 1, \dots, n$ on the square unity.

Where :

$$S(t_j) = \sum_{k=1}^j S_k, \text{ for } j = 1, \dots, n, \quad (3.1)$$

whith $S_k = (n-k+1)(t_k - t_{k-1})$ for $k = 1, \dots, n, (t_0 = 0), t_1, t_2, \dots, t_n$ is an orderly stemming sample of variable unpredictable X "life length", of distribution function F . So, according to the distribution of these points, one can end with regard to the membership of the distribution studied in one of the classes non-parametric of age.

- If the obtained curve is concave : F is IFR (at increasing rate of failing).
- If the obtained curve is convex : F is DFR (at lessening rate of failing).

We present in this below the cloud of points obtained for the class GEPH1

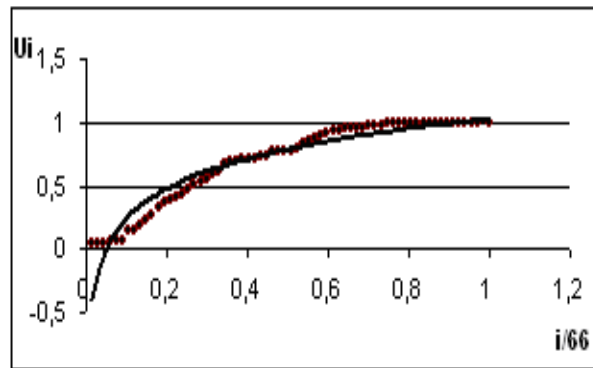


FIGURE 3.7. Graphic test for the class GEPH1.

Results obtained for the set of the classes are given in the following tables :

Proshan-Pyke's test [3]

It allows to made out a will : H_0 " $F(t) = 1 - e^{-\lambda t}$ ", against H_1 " F is IFR (DFR)". This test is based on the statistics $V_r = \sum_{i < j} V_{ij}$, with :

$$V_{ij} = \begin{cases} 1, & \text{if } S_i > S_j \\ 0 & \text{else.} \end{cases} \quad i, j = 1, \dots, r, \quad (3.2)$$

GEPH	n	Allure	Model
GEPH1	66	Concave	IFR
GEPH2	78	Concave	IFR
GEPH3	94	Concave	IFR
GEPH4	102	Concave	IFR
GEPH5	80	Concave	IFR
GEPH6	51	Concave	IFR
GEPH7	63	Straight	Exponential

TABLE 3.3. Graphic test results for the classes of GEPH

GEPI	n	Allure	Model
GEPI1	73	Straight	Exponential
GEPI2	29	convex	DFR
GEPI3	45	Straight	Exponential

TABLE 3.4. Graphic test results for the classes of GEPI

With a significant threshold equals to 0.05, one accepts H_0 when the value of the statistics V_r is included between 1.96 and -1.96 and rejected should the opposite occur. Obtained results are presented in the following tables :

GEPH	Vr	Observation
GEPH1	-6.1	IFR
GEPH2	-5.43	IFR
GEPH3	-7.5	IFR
GEPH4	-4.88	IFR
GEPH5	-3.18	IFR
GEPH6	-6.23	IFR
GEPH7	0.97	Exponential

TABLE 3.5. Results of the test of Pyke Proschan Pyke for the GEPH's classes.

GEPI	Vr	Observation
GEPI1	-1.75	Exponential
GEPI2	1.84	Exponential
GEPI3	-0.02	Exponential

TABLE 3.6. Results of the test of Pyke Proschan Pyke for the GEPI's classes.

3.5.2 Parametric modeling

The data collected are of type right multiple censored. We did not take into account censored times because we have a sufficient number of complete data.

We chose Weibull's model in two parameters because of the equivalence for mechanical systems on one hand and for the capacity to cover a big number of laws.

Estimation of parameters by the graphic method [5]

Having classified the TBF (mean up time) in order increasing and calculated the function of empirical distribution by the method of the median ranks, one put back results on Weibull's paper. The parameters' values of Weibull's law, determined so for every class, are given in the following tables :

GEPH	n	β	$\eta(Hours)$
GEPH1	66	1.4	1400
GEPH2	78	1.3	1500
GEPH3	94	1.2	1100
GEPH4	102	1.5	900
GEPH5	80	1.6	900
GEPH6	51	1.6	1750
GEPH7	63	1.1	1650

TABLE 3.7. Results of the graphic method for the GEPH's classes

GEPI	n	β	$\eta(Days)$
GEPI1	73	1.2	125
GEPI2	29	0.8	180
GEPI3	45	0.9	200

TABLE 3.8. Results of the graphic method for the GEPI's classes

Estimation of parameters by the least square procedure

The estimation of parameters by the least squares procedure brings in at the same moment the TBF and the function of empirical survival. This last one estimated by Kaplan-Meier's method for complete data. The validation of obtained models is realized by the test of Kolmogorov-Smirnov and the one of Khi-deux.

The test of Kolmogorov-Smirnov is based on the statistics [5] :

$$D_n = \max_{x \in \mathbb{R}} |F_n(x) - F_0(x)|. \quad (3.3)$$

Where $F_0(x)$: theoretical law.

$F_n(x)$: the function of empirical distribution. The test of Khi-deux is based on the statistics [5] :

$$K_n^2 = \sum_{i=1}^r \left(\frac{n_i - np_i}{np_i} \right)^2. \quad (3.4)$$

Where :

n_i : the actual of the class C_i .

P_i : Probability to be in the class C_i .

np_i : Effectif théorique of the class C_i .

The results of the adjustment obtained using the Stat-graph software are represented in the following tables :

GEPH	Adjusted laws	Parameters		MUT (hours)
GEPH1	Weibull	$\beta = 1.70$	$\eta = 1927$	1719.26
GEPH2	Weibull	$\beta = 1.54$	$\eta = 2027$	1823.08
GEPH3	Weibull	$\beta = 2.04$	$\eta = 1452$	1286.70
GEPH4	Weibull	$\beta = 2.42$	$\eta = 1314$	1164.96
GEPH5	Weibull	$\beta = 1.97$	$\eta = 1330$	1179.31
GEPH6	Weibull	$\beta = 1.45$	$\eta = 1737$	1574.94
GEPH7	Exponential	$\lambda = 0.00056536$		1768.78

TABLE 3.9. Adjustment results of lows for the GEPH's classes.

GEPI	Adjusted laws	Parameters		MUT (hours)
GEPI1	Weibull	$\beta = 1.32$	$\eta = 3664$	3356.16
GEPI2	Exponentielle	$\lambda = 0.000270738$		3693.60
GEPI3	Exponentielle	$\lambda = 0.000223773$		4468.80

TABLE 3.10. Adjustment results of lows for the GEPI's classes.

MUT represents the mean up time. It is equal to the mathematical of the life expectancy length w [10] :

$$MUT = E(W) = \int_0^{\infty} t f(t) dt = \int_0^{\infty} R(t) dt. \quad (3.5)$$

In the case of Weibull's law, it costs : $MUT = \gamma + \eta \Gamma(1 + \frac{1}{\beta})$. Where γ , η , β are the parameters of Weibull' law, and $\Gamma(\cdot)$ is the Gamma function define by : $\Gamma(a) = \int_0^{\infty} x^{a-1} e^{-x} dx$.

3.5.3 Comparison and interpretation of results

The results of the graphic test show that the clouds of points for the majority of the horizontal electropumps groups' classes are concave, so in this case, exponential model is rejected to the profile of the law IFR. On the other hand the clouds of points for the majority of the immersed electropumps groups' classes are aligned approximately according to right-hand sides, what drives to retain exponential model in that case. These results suit well those of the parametric modeling, which shows that the estimated value of the parameter of shape is sharply superior to 1 for the most part of the horizontal electropumps groups' classes, and close to 1 for the immersed electropumps groups' classes.

So one was able to arrange the groups electropumps, following their behavior, in two categories :

- The groups electropumps which present a parameter of shape sharply superior to 1, which corresponds to the case of the majority of the GEPH's classes. They are of this fact characterized by an increasing rate of failing according to time. This means that their breakdowns

are due to ageing. This explains itself by the fact that the starting of the majority of these groups dates years eighty. Preventive maintenance is recommended in that case.

- The groups electropumps which present a parameter of shape close to 1, which corresponds to the case of the GEPI's classes. They are so characterized by a constant rate of failing. This explains itself by the fact that this type of groups are characterized by failings catalectic. In that case, it is difficult to observe degradation. Consequently, they do not require a preventive maintenance.

The curves of reliability of the groups electropumps' classes show that the GEPI's classes reaches a reliability of 0.5 after a time of good functioning varying between 150 and 200 days. On the other part, for the classes GEPH, they reach a reliability of 0.5 after a time of good functioning included between 50 and 80 days.

The curves of the rate of failing of the GEPH's classes are increasing according to time, what corresponds to the third phase of the curve in bathtub representing the period of old age. On the other hand, the rate's curves of failing of the classes of immersed electropumps groups' classes are approximately aligned according to right-hand sides.

The figure N°6 shows that variant 2, most frequent case of the functioning of the system, reaches a reliability of 0.5 after a time of good functioning equal at 2550 Hours. This last one represents a half for variant 4 and it is equal in 1500 and 3500 for variants 3 and 1 respectively.

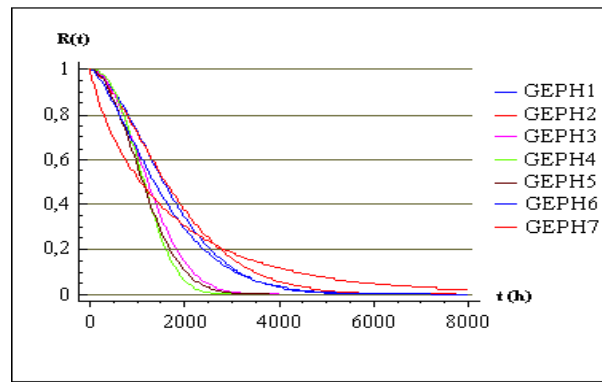


FIGURE 3.8. Reliability function of GEPH s class.

3.6 ECONOMICAL RENEWAL STUDY

The purpose of this part of study is the choice of the most advantageous renewal among the curative and the preventive. It is for the GEP which present an increasing rate of failing, determined by the previous study, namely the GEPH. However the application of maintenance requires a decomposition of the GEPH in elements maintainable. A statistical study for all the elements of the group for every class would show itself long. We made for that purpose an analysis ABC by containing the constituents of GEPH's all classes. The elements of information necessary

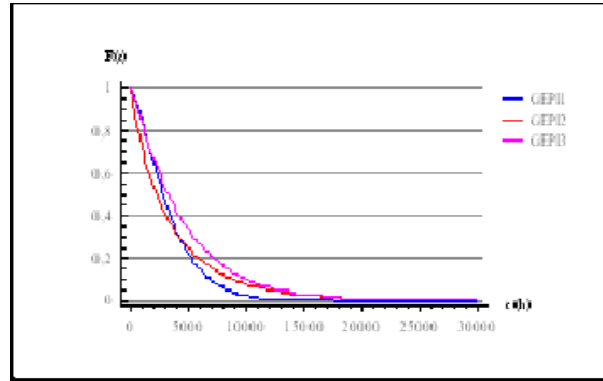


FIGURE 3.9. Reliability function of GEPI's class.

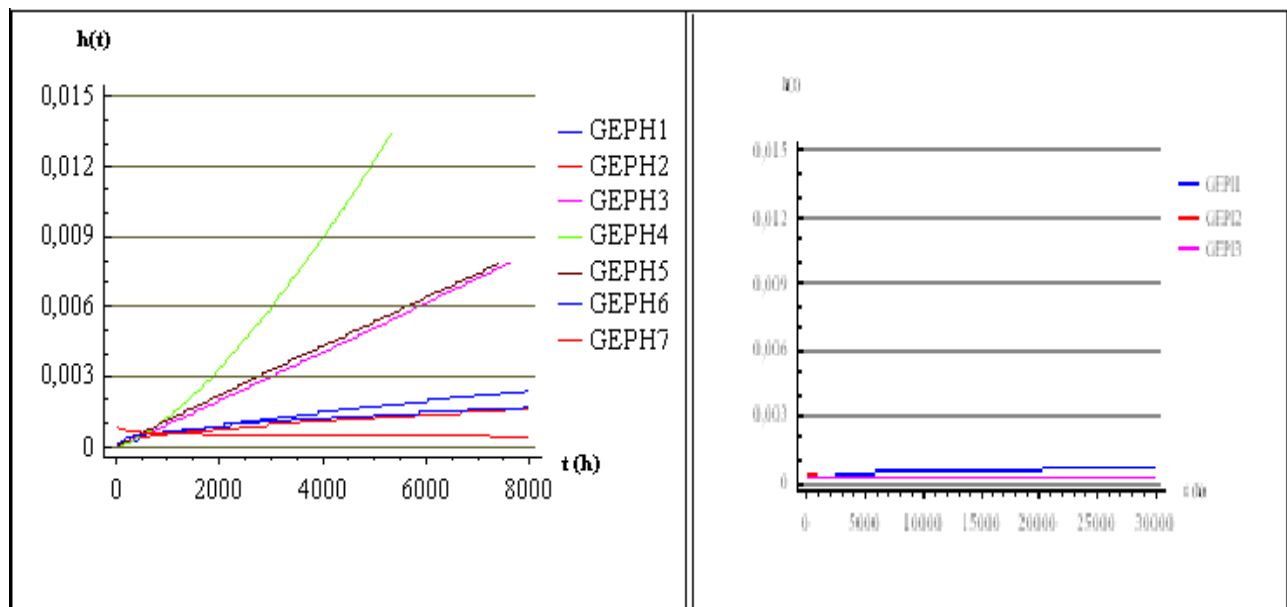


FIGURE 3.10. Failure rate of GEPH' & GEPI's class.

for Pareto's analysis, namely, costs of intervention as well as number of breakdowns relative to every element, were obtained by the confrontation of several sources (the cards of intervention, checks of exits), for period going from 1995 till 2001. Having classified breakdowns in order decreasing of cost, every breakdown reports in an element. The results of Pareto's analysis are put back on the table (11) and the graph (7). They reveal that 61.89 % of costs incurred during studied period are engendered by 14.54 % of breakdowns. This analysis allowed us to conclude that rumblings NU314, 6412 and 6411, as well as engines of power 250 kw, 160 kw, 110 kw and 90 kw are the most expensive in maintenance for the horizontal groups élektropompes.

Cost evaluation [5]

- ✓ The cost of failing C_d is estimated by basing on the following considerations :
 - Loss in raw material P_m null.
 - Loss of amortization P_a null.

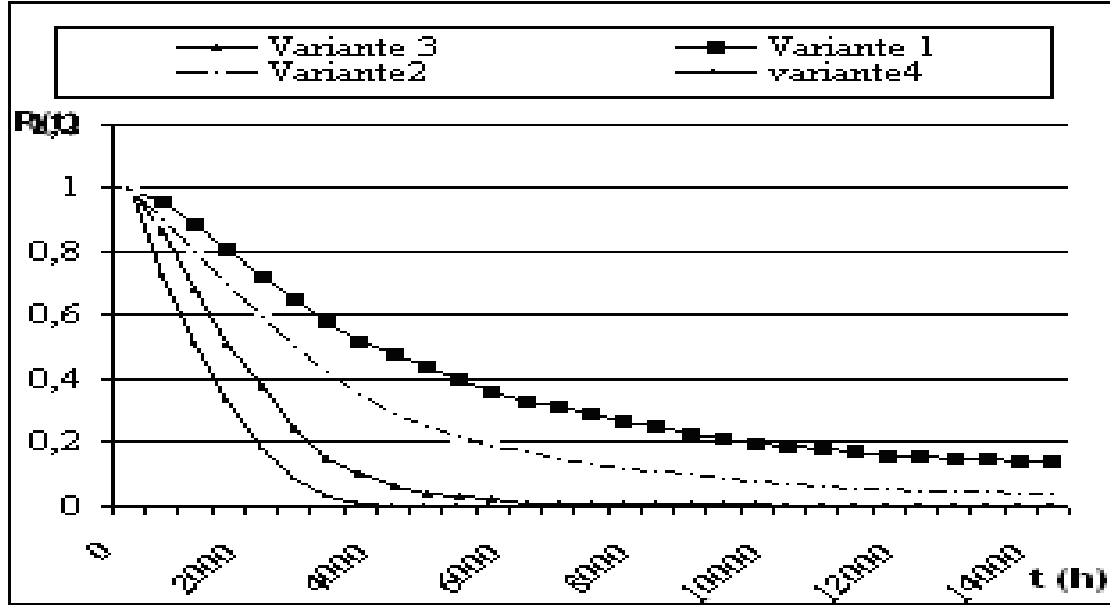


FIGURE 3.11. System variants reliability

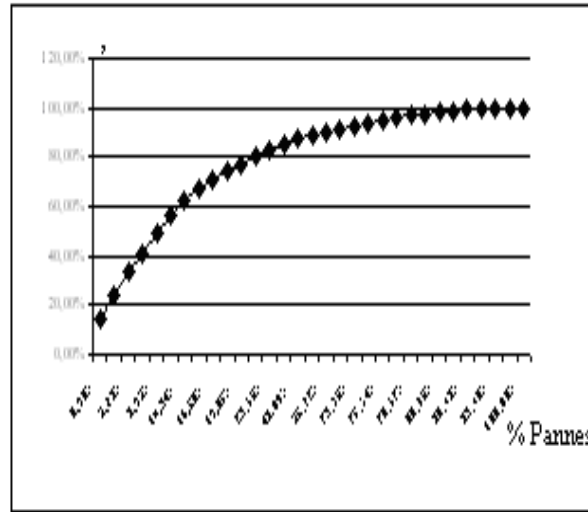


FIGURE 3.12. Pareto diagram

- Consumed energy unimportant P_e .

Consequently, the cost of failing will be likened to the loss of production P_p , and will be so equal to the production cost schedule Ch multiplied by pause T : $C_d = T \times Ch$.

- ✓ The average cost of the curative maintenance (C_∞) is reckoned from the following formula :

$$C_\infty = \frac{C_d + C_p}{\int_0^\infty R(t)dt} = \frac{C_d + C_p}{MUT}. \quad (3.6)$$

Where $C_p = C_m + C_s$.

With : C_m = cost of the replacement part. C_s = cost of the hand of work which contains the direct salaries and the loads. C_p = cost of the renewal.

- ✓ The average cost of the preventive maintenance ($C(T)$) is obtained by the following expression :

Elements	Costs (DA)	% Costs	Nbr breakdowns	% breakdowns
Moteur 250 KW	800000	0,1401	4	0,0030
Moteur 160 KW	551070	0,2366	3	0,0052
Roulement 6412	540960	0,3314	69	0,0572
Roulement NU314	450840	0,4103	51	0,0957
Moteur 90 KW	450000	0,4891	5	0,0994
Moteur 110 KW	420000	0,5627	3	0,1017
Roulement 6411	320740	0,6189	58	0,1454
Moteur 75 KW	280000	0,6679	4	0,1484
Roulement 6320	211680	0,7050	18	0,1620
Roulement 6315	209560	0,7417	31	0,1853
Accouplement Ø133	172944	0,7720	15	0,1966
Roulement 6210	157780	0,7996	49	0,2336
Moteur 30 KW	140000	0,8242	4	0,2366
Plots	136890	0,8481	175	0,3685
Goujons	131894	0,8712	172	0,4981
Accouplement Ø93	99161	0,8884	17	0,5109
Roulement 6313	80400	0,9027	15	0,5222
Joint Ø100	74798	0,9158	298	0,7467
Roulement 6214	71610	0,9283	9	0,7535
Bague d'usure	65691	0,9399	12	0,7626
Roulement 6213	64039	0,9511	17	0,7754
Roulement 6312	47880	0,9595	3	0,7776
Roulement 3308	47229	0,9677	12	0,7867
Roulement 6414	34980	0,9739	6	0,7912
Joint Ø70	33120	0,9797	92	0,8605
Roulement 6307	31848	0,9852	15	0,8718
Tresse Ø 14	27468	0,9900	43	0,9042
Roulement 6317	18800	0,9933	16	0,9163
Joint Ø250	15300	0,9960	51	0,9547
Tresse Ø10	13057	0,9983	31	0,9781
Tresse Ø8	9386	1	29	1

TABLE 3.11. Pareto's analysis results

$$C(T) = \frac{C_d(1 - R(t)) + C_p}{\int_0^T R(t)dt}. \quad (3.7)$$

In the case of a preventive renewal, optimal time T_0 for the replacement is obtained by minimizing this expression. However, for the choice among the preventive and the curative, one can base on the comparison between the cost of the replacement of the element C_p and that of the failing C_d of the same element. So, preventive renewal is recommended only for the elements whose cost of the preventive is superior to the cost of the curative [8]. Results are recorded in the following table :

Elements	$C_d(DA)$	$C_s(DA/h)$	$C_m(DA)$	$r = C_d/C_p$	Maintenance type
Roulement NU314	756	1040	7800	0.085	Curative
Roulement 6412	756	1040	6800	0.096	Curative
Roulement 6411	756	1040	4750	0.130	Curative

TABLE 3.12. Choice of maintenance's type

3.6.1 Interpretation of results

The results of the table (12) show that the report of the cost of failing C_d on the cost of the renewal is sharply lower than 1. What drives to conclude that preventive renewal is not profitable

for all the studied elements. These results are confirmed with the curves' plans of the two renewals' costs, which appear that whatever is periodicity T , the cost of the preventive renewal $C(T)$ for all the elements is sharply superior to the cost of the curative renewal C_∞ . These results explain themselves by the fact that the cost of the cubic meter of water is very weak in front of the replacement's cost of the failing element.

3.7 AVAILABILITY STUDY

This part of the study is devoted to the study of the groups electropumps' availability, and consequently, that of the network. The objective is to know the factors that influence this availability, among the reliability, the maintainability and the logistics of maintenance. To do it, we have first to estimate the laws of maintainability and the pauses of the various classes of groups electropumps.

In the case of repairable system (as in our study), the probability of good functioning of a system stabilizes towards a constant value during time. This value characterizes the availability of the system [6].

According to the renewal limit theorem, availability D of a material is given by :

$$\lim_{t \rightarrow \infty} D(t) = D = \frac{MUT}{MUT + MDT}. \quad (3.8)$$

If $MDT \approx MTTR$ et $MUT \approx MTBF$, one will have :

$$D = \frac{MTBF}{MTBF + MTTR}.$$

With

MUT : Mean Up Time.

MDT : Mean Down Time.

MTTR : Mean Time To repair.

MTBF : Mean Time Between Failure.

Having adjusted the times of good functioning, the times of repair and the pauses of the GEP, one estimated the availability of these last ones. In the first place by taking into account times annex in the repair, noted D_1 . Secondly, one let us consider only the times of repair, noted D_2 . So, one was able to estimate unavailability pulled by times annex in the repair ($D_2 - D_1$). Obtained results are put back in the following table : The network works on average in one year :

GEP	MUT	MTTR	MDT	D_1	D_2	$D_2 - D_1$
GEPH1	1719.26	17.55	75.18	0.958	0.990	0.032
GEPH2	1823.08	17.72	75.94	0.960	0.990	0.030
GEPH3	1286.70	16.49	117.98	0.916	0.987	0.071
GEPH4	1164.86	17.99	135.57	0.895	0.985	0.090
GEPH5	1179.31	16.47	151.94	0.886	0.986	0.100
GEPH6	1574.94	17.46	170.80	0.902	0.989	0.087
GEPH7	1768.78	15.40	189.90	0.903	0.991	0.088
GEPH1	3355.20	35.07	103.77	0.970	0.990	0.020
GEPH2	3693.60	30.62	114.23	0.970	0.992	0.022
GEPH3	4468.80	31.91	186.20	0.960	0.993	0.033

TABLE 3.13. Availability of the network's GEP

- 85 % according to the variant 2, which corresponds at 7446 o'clock.
- 12 % according to the variant 3, which corresponds at 1051 o'clock.
- 2 % according to the variant 1, which corresponds at 175 o'clock.
- 1 % according to the variant 4, which corresponds at 87 o'clock.

The availability of every variant is obtained by combining the availability of the elements of the network with the same procedure as for the calculation of the reliability. The following table summarizes the rate of availability for every variant, as well as corresponding availability in the time of system's functioning with this variant.

	Variant 1	Variant 2	Variant 3	Variant 4
Availability rate	0.905	0.894	0.792	0.775
Availability (hours)	158.4	6656.7	832.5	67.42

TABLE 3.14. Availability for system's variants

3.7.1 Results interpretation

One notices according to the obtained results that the groups electropumps of drillings and central station present unavailability's rate caused by times annex to the repair, relatively weak with regard to those groups electropumps of the other network's stations. This explains itself by the importance of the impact over the return on the network in case of breakdown at the level of drillings or of central station, what drives service maintenance to take care of them first and foremost.

3.8 CONCLUSION

The objective of this study was the analysis of the experiences fastback of stations' main equipments and harnessing' fields of AEP's network of Bejaïa's city, so as to estimate their reliabilities, their availability and then, those of the various modes of the network's functioning.

In a first stage, we made a functional analysis of the network, so we were able to model, from the point of view reliability, the various variants of the system's functioning.

The second stage, evolved around the modeling of the main equipments' behavior of the network's infrastructures.

It revealed, on one part that the majority of the groups electropumps pump stations are subject to failings wear. On the other part, it revealed that the groups electropumps fields of harnessings are subject to unpredictable failings.

The economic study of the renewal showed that preventive renewal is not economically advisable.

Besides, The calculation of the groups electropumps' availability revealed that the availability of the fields of harnessing and the central station is more high than that of the other of the network's stations.

This study will allow the EDEMIA to estimate reliability and availability of the network by envisaging other modes of functioning, notably in the case of increase of the network's exploitation. It will also allow a help in making decision to raise the network's availability by the practice of redundancy on the least reliable infrastructures, or by setting up a better management of repairs.

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