The Repair Process of Five Colombian Power Distribution Systems

C. J. Zapata, *Member IEEE*, J. Díaz, M. L. Ocampo, J. D. Marriaga, J. U. Patiño and A. F. Gallego

***Abstract*—This paper presents a study of the repair process performed in five Colombian power distribution systems using queuing theory concepts. It represents the input and service processes of the queuing system by means of stochastic point process models and assesses the repair process performance indexes applying a procedure of sequential Monte Carlo simulation. Results shows: *i.* The power law stochastic point process model is recommended as the first choice for representing the input and service processes because it fits even in those cases of samples with low tendency for which the fit to renewal process models failed. *ii.* Although the traffic intensity parameter gives at a glance the tendency of the repair process performance, to know when an index is higher o lower than a given value, it is necessary to apply the assessment procedure.**

***Index Terms*—Maintenance, Poisson processes, power distribution reliability, queuing analysis, reliability modeling.**

I. Introduction

THE repair process of a power distribution system is the sequence of repairs performed by crews in accordance with the work orders sent by a service center that receives customer calls regarding problems in the service or by substation/control-center operators requiring the intervention of repair personnel.

As shown in Fig. 1 this process is a queuing system: its input is the sequence of failures that cause service problems and its output is the sequence of repairs performed by crews. Although this fact, it has not been traditionally studied using queuing theory concepts but indirectly by means of statistical analysis of load point outage times, e.g. [1]-[2], or as part of component reliability models, e.g. [3]. In 2008, Zapata et al. [4] presented a methodology based in queuing theory concepts that was applied to three power distribution systems.

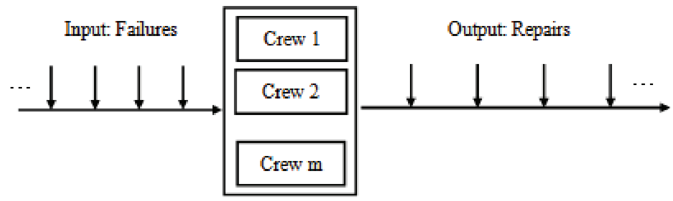

Fig. 1. Queuing model of a repair process

It represents the input and service processes by means of stochastic point process (SPP) models and assesses the process performance using a procedure of sequential Monte Carlo simulation (MCS). This approach explicitly evaluates the performance of the repair process and gives an analytical base for programming the repair resources in accordance with the pattern of failure arrivals and the targets for reliability indices.

This paper presents the application of that methodology to other five systems and gives a more detailed description of the steps for obtaining the input and service models.

II. Stochastic Point Processes

A SPP is a representation for a phenomenon in which events occur randomly in time. This concept is shown in Fig. 2; x_i denotes an inter-arrival interval and t_i an arrival time.

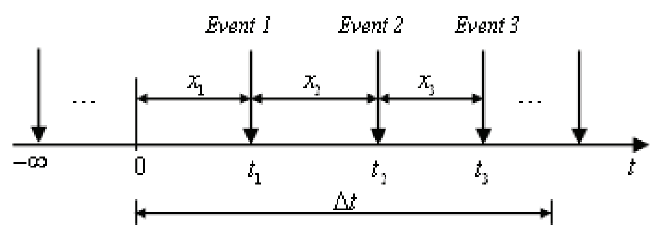

Fig. 2. The concept of SPP

Tendency of a SPP is positive if the pattern of event arrivals increase with time, negative if it decreases with time and zero if it does not increase or decrease.

The intensity function (1) controls the tendency of the SPP; it is the rate of change of the expected number of events N occurring in a given period Δt.

$$\lambda(t) = dE[N(\Delta t)]/dt \quad (1)$$

A classification of SPP models is shown in Fig. 3; λ, β, a, b and ω are parameters. A RP is named after the distribution of the $x's$. The most famous RP is the exponential one called Homogeneous Poisson Process (HPP).

C. J. Zapata is with Universidad Tecnológica de Pereira, Pereira, Colombia. (e-mail: cjzapata@utp.edu.co).
J. Díaz is with Electrificadora de Santander, Bucaramanga, Colombia, (e-mail: jimmy.diaz@essa.com.co).
M. L. Ocampo is with Central Hidroeléctrica de Caldas, Manizales,Colombia. (e-mail: mocampol@chec.com.co).
J. D. Marriaga is with Ingeniería de Redes Linci, Barranquilla, Colombia, (e-mail: jmarriaga1@hotmail.com).
J. U. Patiño is with Empresas Municipales de Cartago, Cartago, Colombia. (e-mail: subtecnica@emcartago.com).
A. F. Gallego is with Sypelc Ltda, Manizales, Colombia. (e-mail: anfegabe@hotmail.com).

978-1-4577-0487-1/10/$26.00 ©2010 IEEE

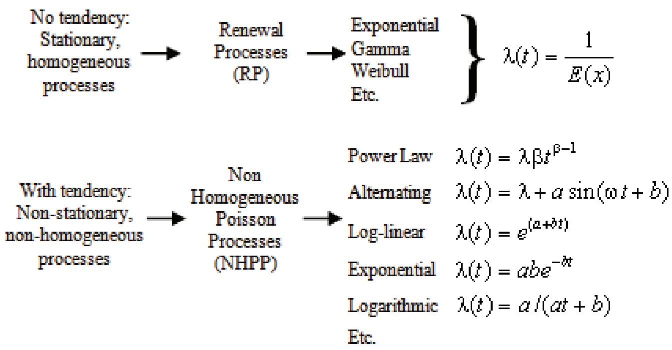

Fig. 3. A classification of SPP models

III. Procedure for Fitting a SPP Model

Fig. 4 shows the procedure that was applied for fitting a SPP model to a sample of size n. It is based on procedures presented in [5], [6] and [7].

Tendency is checked by means of (2) and (3), the Laplace and Lewis-Robinson statistics which are normally distributed. Other trend tests are described in [8].

$$U_L = [(\frac{1}{n-1}\sum_{i=1}^{k} t_i) - \frac{1}{2}t_n]/[t_n\sqrt{\frac{1}{12(n-1)}}] \quad (2)$$

$$U_{LR} = U_L * s_x / \bar{x} \quad (3)$$

s_x and $\bar{x}$ are, respectively, the inter-arrival times standard deviation and mean.

U_L and U_{LR} are compared to $z_{\alpha/2}$, the value in the standard normal distribution for a critical probability α, in order to hold or reject the null hypothesis of no tendency.

Independency of the inter-arrival times sample is checked by means of the scatter diagram described in [9].

Goodness-of-fit to the PLP model is checked by means the TTT-plot method described in [10]; other goodness-of-fit tests developed specifically for this model are presented in [11], [12], [13]. Goodness-of-fit to HPP, Weibull RP, Gamma RP and the Lognormal RP is checked by means of the Kolmogorov-Smirnov (KS) test; however, any goodness-of-fit method for probability distributions can also be applied.

The parameter of RP models is estimated before the application of the KS test using (4).

$$\hat{\lambda}(t) = n/t_n = 1/\bar{x} \quad (4)$$

The PLP parameters are estimated after the application of the TTT-plot test using (5) and (6).

$$\hat{\beta} = (n-2)/\sum_{i=1}^{n} Ln(t_n/t_i) \quad (5)$$

$$\hat{\lambda} = n/t_n^{\hat{\beta}} \quad (6)$$

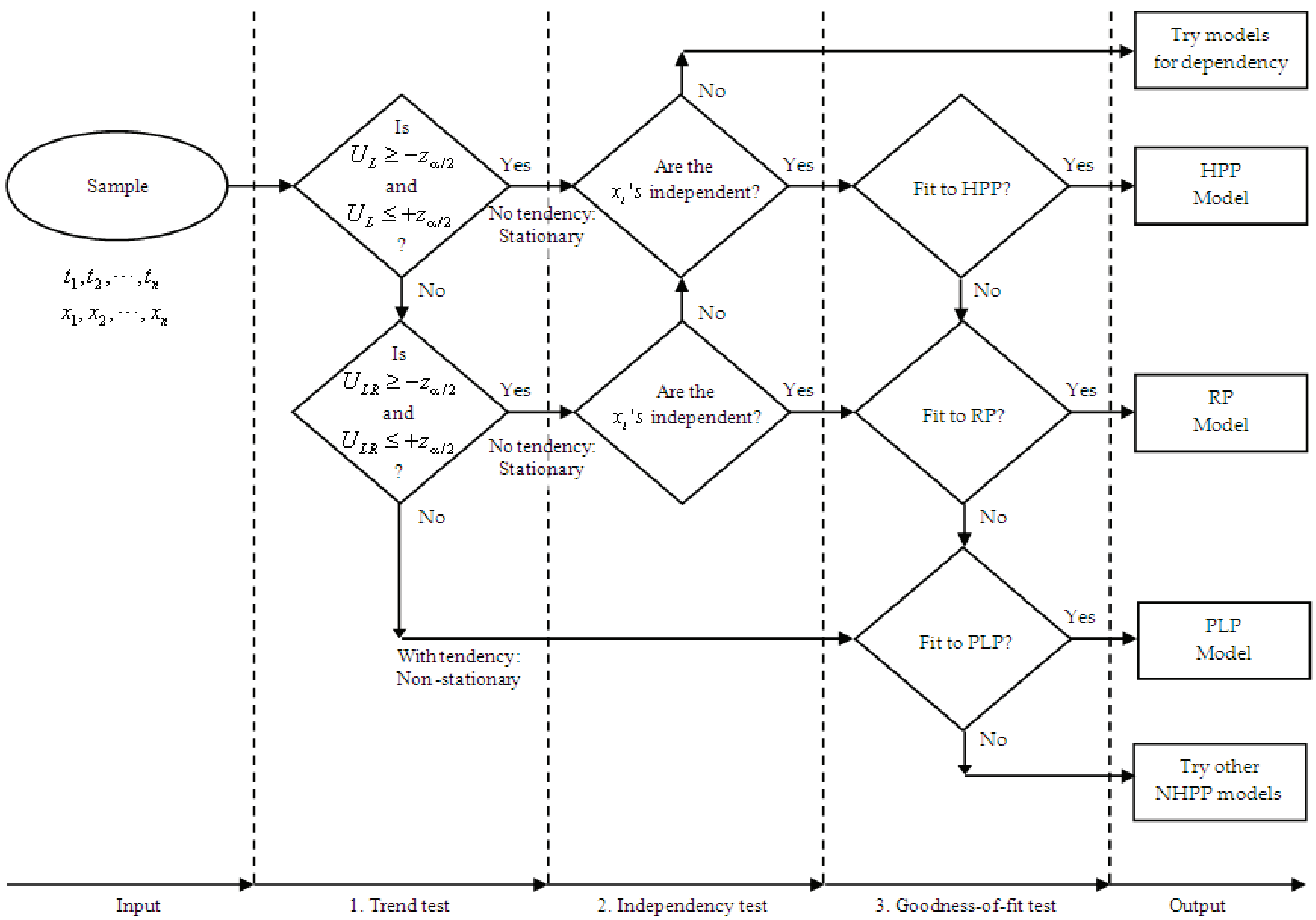

Fig. 4. Procedure for fitting a SPP model

IV. Queuing Modeling

A. Input Process

It is the SPP that represents the arrival of failures causing those service problems that have to be repaired by crews; its intensity function is denoted $\lambda_F(t)$.

Problems in the service can be classified into:

- Continuity: Service interruptions.
- Safety: Situations originated in the power system that are hazardous for human beings, Nature, customer equipment/installations or power system components.
- Power quality: High/low voltage, sags, swells, flicker, etc.

However, service interruptions have traditionally received most attention because:

1. They represent most of the service problems. For example, a survey in a Colombian power distribution system found that, in a five year period, service interruptions represented 84% of all repairs while power quality and safety problems only represented 9% and 7%, respectively [14].
2. The repair or inspection of a safety or power quality problem generally requires a service interruption.

The input process also includes those events where no problem in the service was found; these intentional or unintentional false requests occupy unnecessarily the crews and represent economic losses for the utility. A survey in a Colombian power distribution system found that, in a three year period, 2342 (9.3%) of 25249 repair orders were of this type [15]; this means an average of 65 false events per month!

Service problems can arise in all voltage levels of the power distribution system.

B. Service Process

It is the SPP that represents the pattern of the repair service rendered by crews. Its intensity function is denoted $\lambda_R(t)$.

The inter-arrival time of this model is the time to repair (ttr). It is the period a crew dedicates to inspect/repair a given problem and includes the time to go to the place where the problem was reported, the time to disconnect some parts of the system, the time to identify the cause of the problem, the time to fix the failed components, the reconnection time and the time to record what happened and what was done.

C. Output Process

It is the sequence of repairs performed by crews.

D. Kendall's Notation

This queuing system is described as follows:

$$G / G / m / \infty / FCFS$$

The first and second "G" indicate that both the input and service processes are general SPP (RP or NHPP).

m, ∞, and $FCFS$ indicate, respectively, the number of crews, the system capacity and the queuing discipline (First Come – First Served).

Capacity of this queuing system is infinite because all failures have to be rendered.

E. The Traffic Intensity Parameter

The traffic intensity index $a(t)$ defined by (7) is measured in Erlangs.

$$a(t) = \lambda_F(t) / \lambda_R(t) \quad (7)$$

Traffic intensity of 1.0 Erlang means one failure occupies the repair resources 100% of the time. Traffic intensity higher than 1.0 means failures arrives faster than repairs can be performed. Thus, it has to be less or equal to 1.0 in order to have a stable queuing system.

For the case where the input and service processes are represented by means of a PLP models:

$$a(t) = \lambda_a t^{\beta_a} \quad (8)$$

Where:

$$\lambda_a = \lambda_F \beta_F / (\lambda_R \beta_R) \quad (9)$$

$$\beta_a = \beta_F - \beta_R \quad (10)$$

Thus, the repair process performance will be constant if $\beta_a = 0$, deteriorating if $\beta_a > 0$ and improving if $\beta_a < 0$. t_{100} denotes the instant for which $a(t) = 100\%$.

V. How to Obtain the Samples for the Input and Service Processes

The procedure for obtaining the samples for the input and service processes shall be explained by means of an example.

Let us consider the set of work orders shown in Fig. 5 and its representation as point processes; f_i and r_i denote failure and repair i, respectively.

Maintenance Zone 1 – Work Orders of Year 2006							
#	Start			End			Crew
	Month	Day	Hour	Month	Day	Hour	
1	1	1	1	1	1	4	1
2	1	1	2	1	1	5	2
3	1	1	3	1	1	6	1
4	1	1	5	1	1	8	2
5	1	1	7	1	1	10	1
6	1	1	9	1	1	11	2
⋮	⋮	⋮	⋮	⋮	⋮	⋮	

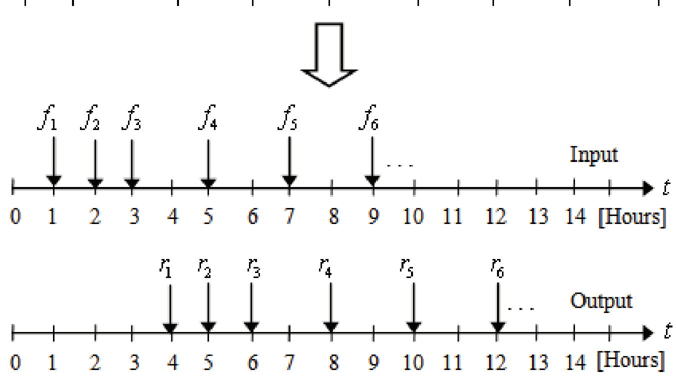

Fig. 5. Operating data example

A. Sample for input process

It is very easy to obtain the sample for the input process: from operating records take the magnitudes of arrival times or the corresponding inter-arrival intervals referenced to a common origin.

Fig. 6 shows the samples of times to failure (ttf) and times between failures (tbf) for the input process of operating data in example of Fig. 5.

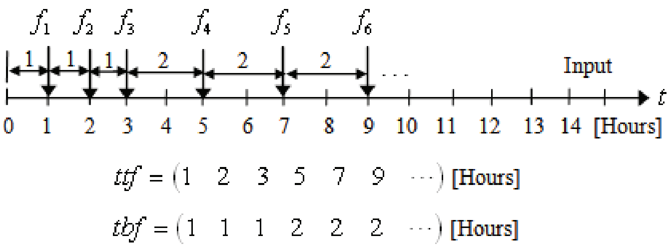

Fig. 6. Example of sample for the input process

The sample of failure inter-arrival times allows detecting two main types of errors or outliers:

1. Null values: SPP process modeling does not allow more than one event per instant, and, in real life, is difficult to prove that two failures have exactly the same arrival instant. This kind of error is due to rounding up of arrival times or poor recording practices. The recommendation for solving it is to displace one of the failures a small time, for example, 1 minute.
2. Very high values: In general intervals higher than 1 day are not logical in real power distribution systems; however, these authors have found values in the order of months! This error is due to poor recording practices: all work orders are not recorded. The recommendation for solving it is: *i.* To search for the missing work orders. *ii.* To replace the outliers by logical values. This concept is illustrated in Fig. 7. The first approach is the best one because the second alters the tendency.

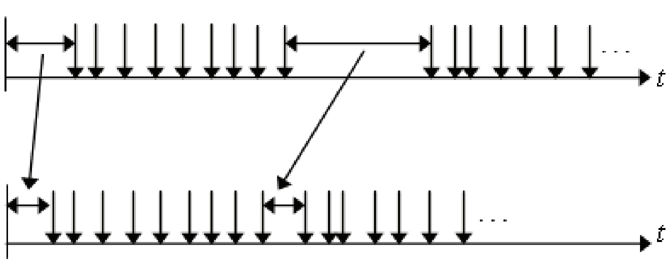

Fig. 7. Reduction of very high inter-arrival failure intervals

B. Sample for service process

The sample for service process of a given crew is the collection of durations of the repairs that were performed by it. Fig 8 and 9 show the samples for service for the two crews of the example of Fig. 5.

The sample of ttr allows detecting two main types of errors or outliers:

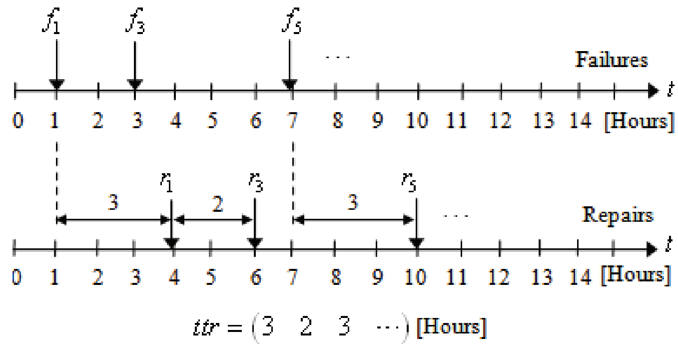

Fig. 8. Crew 1 sample for service

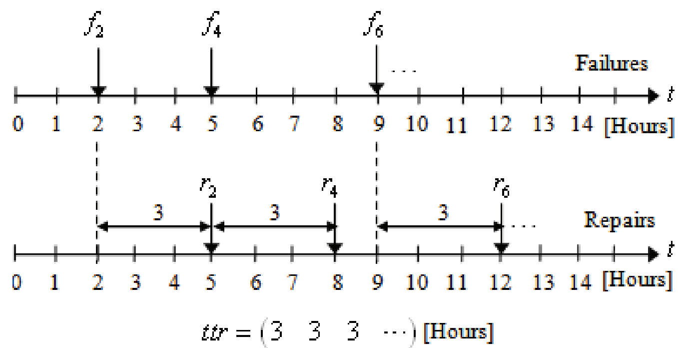

Fig. 9. Crew 2 sample for service

1. Null or very low values: Null values or values in the order of a few minutes are not logical in real power distribution systems; this error is due to poor recording practices. The recommendation for solving it is to replace the outliers by logical values.
2. Very high values: Repairs lasting more than 24 hours are in general not logical in real power distribution systems; however, extreme events like severe weather, earthquakes, etc. can be the cause of these long durations. If extreme events are not rare for the system under study the recommendation is to keep them in the sample; on the contrary they can be neglected.

   If it is desired to merge the service regarded by several crews in a single service model, the recommendation is to keep the chronological order of the repair times as they started or finished. Omission of this recommendation could lead to wrong modeling because independency and tendency are altered.

C. General Recommendations

A "logical value" to reduce a very high interval can be obtained from:

- A credible value taken from experience.
- The mean of inter-arrival times without considering the outliers.
- A SPP model fitted without considering the outliers; use this model to generate values that replace outliers.

The sample of repair orders should cover at least a year of system operation in order to be representative of the different operating conditions as weather changes.

VI. Computation of Performance Indexes

As shown in Fig. 10, a simulation consists of N realizations or artificial observations of the repair process during a period T of one or more years. This period can be split into k sub-periods S_i (week, month, semester, etc.).

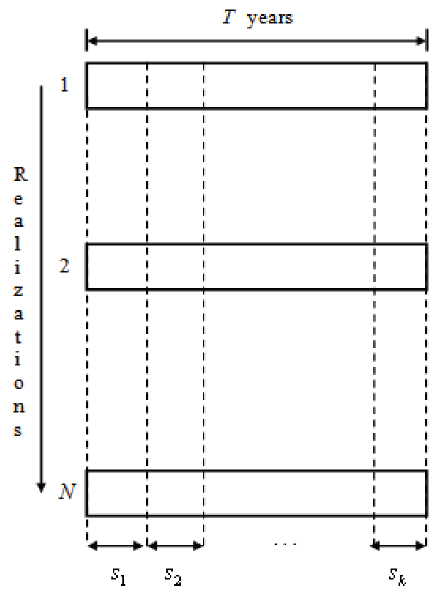

Fig. 10. General procedure of the simulation

As shown in Fig. 11, a realization produces a sequence of failures, repairs, times to repair (ttr), waiting times (tw) and outage durations (tod). See [4] for a detailed description of the MCS procedure.

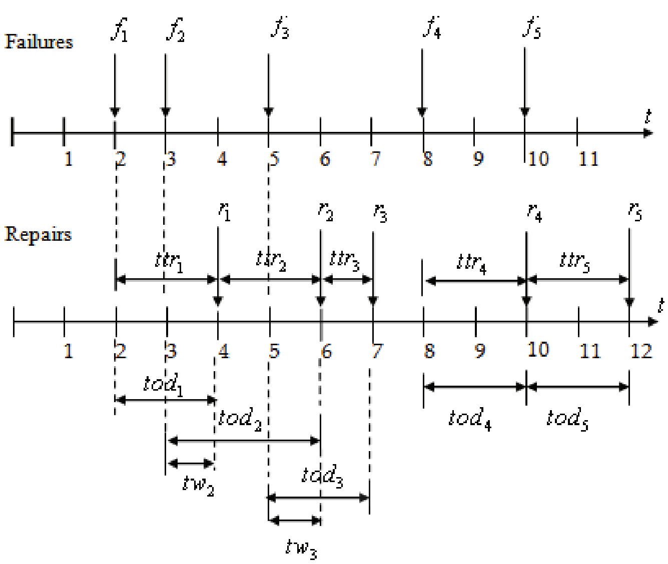

Fig. 11. Example of a sequence of failures and repairs in an realization

After N realizations, the mean waiting time ($\overline{tw}$), the mean outage duration ($\overline{tod}$) and the congestion (11) are computed.

$$C = \overline{tw} / \overline{tod} * 100\% \quad (11)$$

If the repair process performance is constant, it is not necessary to compute these indexes by sub-period.

VII. Description of The Systems under Study

Table I shows a general description of the five power distribution systems that were studied.

Barranquilla system is operated by Electrificadora del Caribe S. A. (ELECTRICARIBE). It includes the power distribution system that serves the municipalities of Barranquilla, Soledad, Puerto Colombia, Galapa and Malambo in the Department of Atlántico.

Manizales system is operated by Central Hidroeléctrica de Caldas S. A. (CHEC). It includes the power distribution system that serves the municipalities of Manizales and Villamaría in the Department of Caldas. Zone one of this system includes the feeders associated to Marmato, Chipre, Manizales and Villamaría substations. Zone two includes the feeders associated to Alta Suiza, Peralonso and La Enea substations.

Cartago system is operated by Empresas Municipales de Cartago S. A. (EMCARTAGO). It includes the power distribution system that serves the municipality of Cartago in the Department of Valle del Cauca, the Puerto Caldas neighborhood of the municipality of Pereira and the northern rural zone of the municipality of Obando.

Guanenta Province system is operated by Electrificadora de Santander S. A. (ESSA). It includes the power distribution system that serves the municipalities of San Gil, Aratoca, Barichara, Cabrera, Charala, Coromoro, Curiti, Encino, Jordan, Mogotes, Ocamonte, Onzaga, Paramo, Pinchote, San Joaquín, Valle de San José and Villanueva in the Department of Santander.

East Caldas system is operated by CHEC. It includes the power distribution system that serves the municipalities of La Dorada, Manzanares, Marulanda, Marquetalia, Norcasia, Pensilvania, Samaná y Victoria. Zone one of this system includes the feeders associated to Dorada, Dorada Norte, Norcasia, Florencia, Guarinocito, Bello Horizonte and El Llamo substations. Zone two includes the feeders associated to Manzanares, Bolivia and Pensilvania substations. Zone three includes the feeders associated to Victoria, Samaná and Marquetalia substations.

VIII. Failure and Service Models

Table II shows the input and service models for a confidence level of 95% ($\alpha = 5\%$).

An interesting result is that although U_L for some processes is lower than the critical value $z_{\alpha/2} = \pm 1.96$, RP models did not fit but the PLP did; this shows the great flexibility of the PLP model.

In all cases but East Caldas Zone 3, the repair process performance is constant because β_a is almost zero; by this reason, t_{100} is very high for those zones with $\beta_a > 0$ and zero for those ones with $\beta_a < 0$. East Caldas Zone 3 is the only zone with a deteriorating repair process; however, its rate of deterioration is very low because $a(t)$ requires 142 years to be 100%.

TABLE I
GENERAL DATA OF STUDIED SYSTEMS

	Barranquilla	Manizales	Cartago	Guanenta Province	East Caldas
Utility	ELECTRICARIBE	CHEC	EMCARTAGO	ESSA	CHEC
Area [km^2]	532	969	279	146	3262
Urban Population	1705711	342620	119063	36748	99180
Rural population	20560	25813	2678	6240	63180
Maintenance zones	1	2	1	1	3
Crews per zone	6	4	5	4	2

Notes:

1. Population in given in inhabitants.
2. Source for population data: Colombian census of year 2005 (www.dane.gov.co)

TABLE II
INPUT AND SERVICE PLP MODELS

System	Zone	Work orders	Years of data	Input process		Service process		Traffic intensity	
				U_L	Parameters	U_L	Parameters	Parameters	t_{100} [years]
Barranquilla	1	2336	1	-1.9479	$\lambda_F = 6.0110$ $\beta_F = 1.0107$	-2.4439	$\lambda_R = 22.2435$ $\beta_R = 0.9495$	$\lambda_a = 28.7654$ $\beta_a = 0.0612$	$1.9041e+6$
Manizales	1	5023	1	+1.3338	$\lambda_F = 11.6980$ $\beta_F = 1.0277$	+0.7711	$\lambda_R = 30.1405$ $\beta_R = 1.0101$	$\lambda_a = 39.4878$ $\beta_a = 0.0176$	$2.3224e+20$
	2	4307		-1.2095	$\lambda_F = 11.5106$ $\beta_F = 1.0043$	+0.8772	$\lambda_F = 27.9217$ $\beta_F = 1.0103$	$\lambda_a = 40.9797$ $\beta_a = -0.0060$	$7.3436e-68$
Cartago	1	4256	1	+0.0953	$\lambda_F = 12.5181$ $\beta_F = 0.9899$	-1.4484	$\lambda_R = 33.7417$ $\beta_R = 0.9904$	$\lambda_a = 37.0811$ $\beta_a = -0.0005$	0
Guanenta Province	1	4633	1	-8.8433	$\lambda_F = 19.608$ $\beta_F = 0.9521$	-9.0820	$\lambda_R = 39.665$ $\beta_R = 0.9359$	$\lambda_a = 50.2897$ $\beta_a = 0.0162$	$7.3271e+15$
East Caldas	1	5222	3	+1.2730	$\lambda_F = 4.6949$ $\beta_F = 1.0343$	-5.5271	$\lambda_R = 20.6393$ $\beta_R = 0.9383$	$\lambda_a = 25.0747$ $\beta_a = 0.0960$	$4.9621e+3$
	2	2423		+4.4825	$\lambda_F = 2.2344$ $\beta_F = 1.0817$	+5.3637	$\lambda_F = 4.5933$ $\beta_F = 1.1203$	$\lambda_a = 46.9678$ $\beta_a = -0.0386$	$8.6167e-12$
	3	2710		+3.9233	$\lambda_F = 2.0429$ $\beta_F = 1.1213$	-1.4799	$\lambda_F = 12.3665$ $\beta_F = 0.9689$	$\lambda_a = 19.1180$ $\beta_a = 0.1524$	142.1173

Notes:

1. Units of the input and service processes are, [Failures/day] and [Repairs/day], respectively.
2. Data for Barranquilla, Manizales and Guanenta Province systems corresponds to year 2007
3. Data for Cartago system corresponds to year 2009.
4. Data for East Caldas system corresponds to years 2007, 2008 and 2009.
5. Operating data for Barranquilla system only includes repairs in the 13.8 kV feeders. For other systems, it includes repairs in medium voltage distribution circuits and secondary networks.

IX. REPAIR PROCESS PERFORMANCE INDEXES

Table III shows the repair process performance indexes for $T = 1.0$ year. Table IV show the assessment by trimester for East Caldas Zone. More detailed results are presented in [16]-[20].

Results in Table IV shows that by the fourth trimester $\overline{tw}$, $\overline{tod}$ and C have increased 180%, 31.3% and 36.4%. Thus, although β_α shows a low rate of deterioration, the indexes have increased a lot in a year.

TABLE III
REPAIR PROCESS PERFORMANCE INDEXES FOR $T = 1.0$ YEAR

System	Zone	$\overline{ttr}$ [Hours]	$\overline{tod}$ [Hours]	$\overline{tw}$ [Hours]	$\overline{C}$ [%]
Barranquilla	1	1.38	2.20	0.82	36.90
Manizales	1	0.76	1.34	0.58	43.57
	2	0.82	1.37	0.55	40.19
Cartago	1	0.75	1.18	0.43	36.68
Guanenta Province	1	0.85	1.80	0.95	52.65
East Caldas	1	1.58	2.55	0.97	38.16
	2	2.84	4.98	2.14	42.93
	3	2.27	3.81	1.54	40.49

TABLE IV
REPAIR PROCESS PERFORMANCE INDEXES FOR EAST CALDAS ZONE 3

Trimester	Work orders	$\overline{ttr}$ [Hours]	$\overline{tod}$ [Hours]	$\overline{tw}$ [Hours]	$\overline{C}$ [%]
1	3228	2.2	3.2	1.0	32.7
2	3793	2.3	3.7	1.4	39.0
3	4050	2.3	4.0	1.7	42.3
4	4216	2.3	4.2	1.8	44.6

X. CONCLUSIONS

1. The PLP model is recommended as the first choice for representing the input and service processes because it fits even in those cases of process with low tendency for which the fit to renewal process models failed.
2. Although the traffic intensity parameter gives at a glance a good indication of the tendency of the repair process performance, to know when an index is higher o lower than a given value, it is necessary to apply the assessment procedure.

XI. ACKNOWLEDGMENT

The authors gratefully acknowledge the contribution of Rafael Oñoro, Johan Urrea and Jorge Sagre from ELECTRICARIBE for supplying the information for Barranquilla system.

XII. REFERENCES

[1] Chow M. Y, Taylor L. S, Chow M. S, “Time of outage restoration analysis in distribution systems”, *IEEE Transactions on Power Delivery*, Vol. 11, No. 3, 1996.
[2] Balijepalli N, Subrahmanyan S. Venkata, Christie R. D, “Modeling and analysis of distribution reliability indices”, *IEEE Transactions on Power Delivery*, Vol. 19, No. 4, October 2004.
[3] C. J. Zapata, S. C. Silva, O. L. Burbano, “Repair models of power distribution components”, *IEEE Transmission & Distribution Latin America*, 2008.
[4] C. J. Zapata, S. C. Silva, H. I. Gonzales, O. L. Burbano, J. A. Hernández, “Modeling the repair process of a power distribution system”, *IEEE Transmission & Distribution Latin America Conference & Exhibition*, 2008.
[5] C. J. Zapata, A. Torres, D. S. Kirschen, M. Rios, “Some misconceptions about the modeling of repairable components”, *IEEE PES General Meeting,* 2009.
[6] Ascher H. E, Hansen C. K, “Spurious exponentially observed when incorrectly fitting a distribution to nonstationary data”, *IEEE Transactions on Reliability*, Vol. 47, No. 4, December 1998.
[7] Ascher H, Feingold H, *Repairable systems reliability: Modeling, inference, misconceptions and their causes*, Marcel Dekker, 1984.
[8] Wang P, Coit D. W, “Repairable systems reliability trend test and evaluation”, *IEEE Annual Reliability and Maintainability Symposium*, 2005.
[9] Law A. M, Kelton D. W, *Simulation Modeling and Analysis*, Mc-Graw Hill, 2000.
[10] Klefsjo B, Kumar U, “Goodness-of-fit tests for the power law process based on the TTT plot”, *IEEE Transactions on Reliability*, Vol. 41, No. 4, December 1992.
[11] *IEC Power law model – Goodness-of-fit test and estimation methods*, IEC Standard 61710, 2000.
[12] Park W. J, Kim Y. G, “Goodness-of-fit tests for the power law process”, *IEEE Transactions on Reliability*, Vol. 41, No. 1, March 1992.
[13] Park W. J, Kim Y. G, “More goodness-of-fit tests for the power law process”, *IEEE Transactions on Reliability*, Vol. 43, No. 2, June 1994.
[14] C. J. Zapata, P. A. Montealegre, “Technical problems on the quality of electricity service”, *Mundo Eléctrico*, No. 68, 2007. (In Spanish).
[15] C. J. Zapata, P. A. Montealegre, A. Cardona, “In Pereira customers of the power distribution system reports quality service problems”, *Mundo Eléctrico*, No. 58, 2005. (In Spanish).
[16] J. Díaz, “Study of the repair process of the power distribution system of the Guanenta Province in Santander”, Universidad de los Andes, 2008. (In Spanish).
[17] J. D. Marriaga, “Study of the repair process of the power distribution system of the city of Barranquilla”, Universidad de los Andes, 2008. (In Spanish).
[18] M. L. Ocampo, “Study of the repair process of the power distribution system of the municipalities of Manizales and Villamaría”, Universidad de los Andes, 2008. (In Spanish).
[19] A. F. Gallego, “Study of the repair process of the power distribution system of the northern zone of the Department of Caldas”, Universidad de los Andes, 2010. (In Spanish).
[20] J. U. Patiño, “Study of the repair process of the power distribution system of the city of Cartago”, Universidad de los Andes, 2010. (In Spanish).

XIII. BIOGRAPHIES

Carlos J. Zapata obtained in 1991 his BScEE from the Universidad Tecnológica de Pereira, Pereira, Colombia, and his MSc and PhD from the Universidad de Los Andes, Bogotá, Colombia, in 1996 and 2010. From 1991 to 2001 he worked for Concol S. A, Bogotá, Colombia, where he participated in projects of power system studies, electrical designs and software development. Since 2001, he has worked for the Universidad Tecnológica de Pereira.

Jimmy Díaz obtained his BScEE from the Universidad Industrial de Santander, Bucaramanga, Colombia, in 1998 and the degree of specialist in transmission and distribution power systems from the Universidad de los Andes, Bogota, Colombia, in 2008. Since 1998 to 2002 he worked in several projects in the oil sector and for utilities. Since 2003 he works for ESSA and currently he is chief of maintenance of the Guanenta Province.

Miguel L. Ocampo obtained his BScEE from the Universidad Nacional de Colombia, Manizales, Colombia, in 2006 and the degree of specialist in transmission and distribution power systems from the Universidad de los Andes, Bogotá, Colombia, in 2008. Since 2006 he has worked for CHEC.

Jesús D. Marriaga obtained his BScEE from the Universidad del Norte, Barranquilla, Colombia, in 2000 and the diploma of specialist in transmission and distribution power systems from the Universidad de los Andes, Bogota, Colombia, in 2008. Since year 2000 he has worked as an independent consultant for several utilities and engineering firms in Barranquilla, Colombia. Currently he is working for Ingeniería de Redes Linci, Barranquilla, Colombia.

José U. Patiño obtained his BScEE from the Universidad Nacional de Colombia, Manizales, Colombia, in 2005 and the degree of specialist in transmission and distribution power systems from the Universidad de los Andes, Bogotá, Colombia, in 2010. During 2005 he worked in a project of technical losses reduction for Central Hidroeléctrica of Caldas. During 2006 and 2007 he worked in maintenance of traffic lights for the Municipality of Santiago de Cali, Cali, Colombia. Since 2008 he has worked for EMCARTAGO and currently he holds the position of Technical Manager.

Andres F. Gallego obtained his BScEE from the Universidad Nacional de Colombia, Manizales, Colombia, in 2006 and the degree of specialist in transmission and distribution power systems from the Universidad de los Andes, Bogota, Colombia, in 2010. Since year 2006 he has worked for Sypelc Ltda, in contracts for performing maintenance to the CHEC power distribution systems in the East and North-West regions of the Department of Caldas.