Analysis of Reliability and Maintainability of Topologies of the System of Fixed Telephony

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Abstract

The work, presented under the heading "Analysis of Reliability and Maintainability of Topologies of the System of Fixed Telephony", has as objective to consider a practical model for the maintenance, based on the reliability and maintainability of components.
The data of this work, had been gotten through managemental reports of the Company of Telecommunications of São Paulo S/A, in the period of January / 97 to September / 98, for 3 telephonic centers of the South Zone of São Paulo: Santo Amaro (SA), Morumbi (MB) and Campo Limpo (CL). With these data, we use the algorithm of Weibull, whose probabilist model allows to correctly justify to all the types of experimental and operational results.
Of this form, we determine for the 3 studied telephone centers, the operational reliability, the average time of good functioning (MTTF), the maintainability and the average time of repair (MTTR) for the components of the External Network, General Distributor and Telephone Exchange, as well as, for the topologies of the system of fixed telephony.
Finally, was made an analysis of costs of the corrective and preventive maintenance for the 3 analyzed telephonic centers.
From the cited results above, the present work makes possible the following evaluations:

- Optimize the process, objectifying minimum failure rate.
- Planning and cost of necessary the human and financial features for operation, corrective and preventive maintenance, planning of the external network and growth of the conventional plant.

1. Introduction

The installation of the telephone network makes possible the communication between users and equipments, through the use of the telephone, modem, fax, Central Private of Commutation Telephone (CPCT) or other equipment.

The work objective to establish an effective methodology in the analysis of failures and the operation of the plans of corrective and preventive maintenance, with optimized costs.

The data were obtained through the attendance of the monthly operational indicators of the components of the External Network, General Distributor (DG) and Commutation. These data were registered in tables and analytical graphs, being used of the algorithm of Weibull for determination of the reliability of DG, of the Commutation and of each component of the External Network. Soon afterwards, the reliability of each topology of the External Network was discussed in each one of the 3 Telephones Centers (CT's) mentioned.

1. Topologies of the Telephone External Network

In this item, they will be described the Topologies that the Incumbent disposes for service of a subscriber, through metallic network.

We should define direct cable, because this will be one of the differentials in the Topologies of the Telephone External Network:

Direct cable: it customer's service without the use of the Closet of Distribution, could be Underground Cable or Aerial Cable.

In the Table 1, we will define the abbreviation of the components that will configure the Topologies of the Telephone External Network and that it will be used in the current text:

Table 1 - Abbreviation of the components of the Topologies of the External Network.

COMPONENTS	ABBREVIATION
Telephone Exchange	Central
General Distributor	DG
Underground Cable	CS
Closet of Distribution	ARD
Aerial Cable	CA
Internal Box	CxI
Aerial Box	CxA
External Wire	FE
Point of Termination of the Network	PTR

Below, we showed the existent topologies of the External Network for the customer's service:

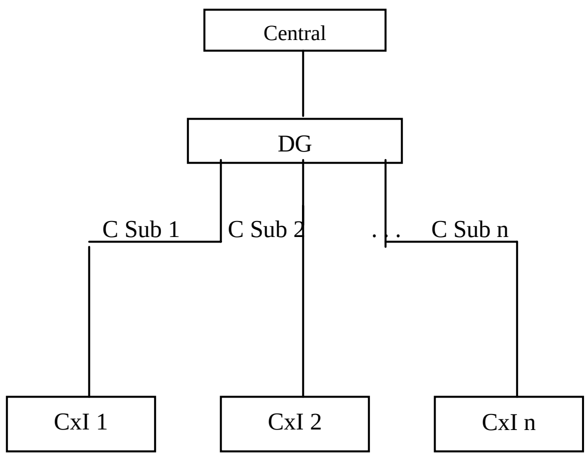

Figure 1 - Topology 1 - Underground Direct Cable.

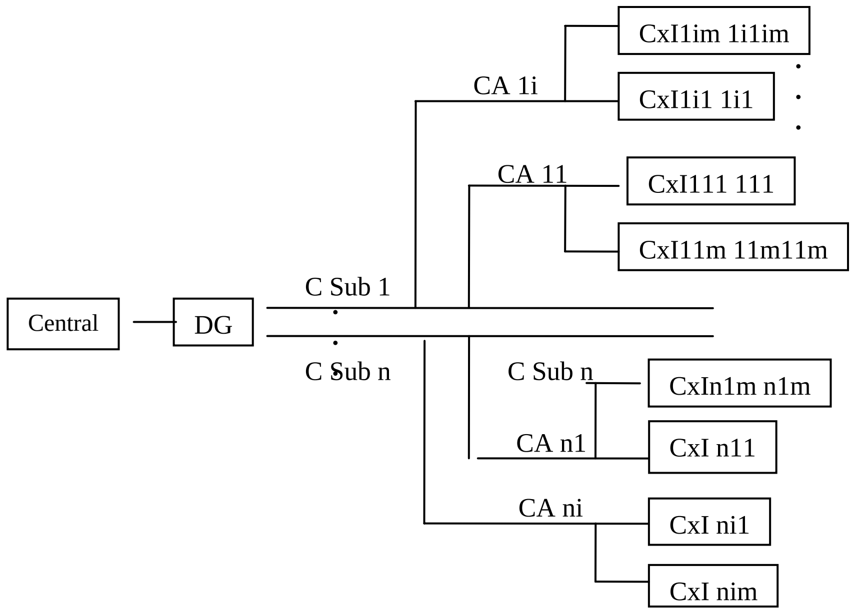

Figure 2 - Topology 2 – Aerial Direct Cable without the use of CxA.

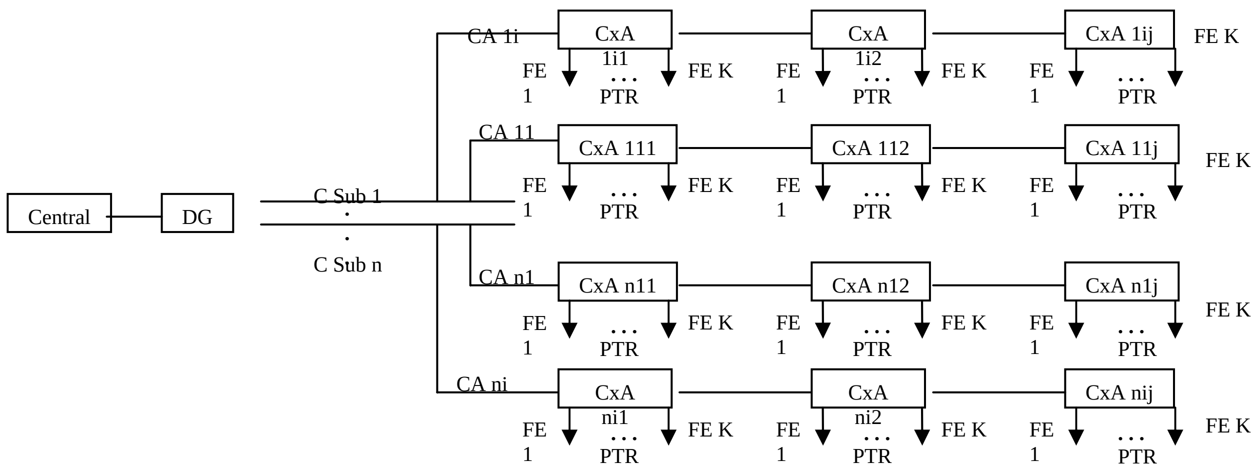

Figure 3 - Topology 3 - Aerial Direct Cable with the use of CxA.

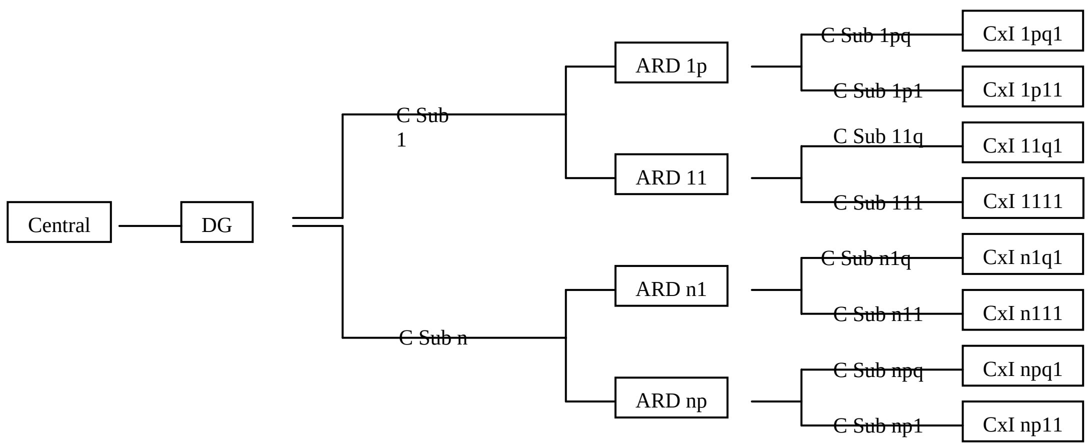

Figure 4 - Topology 4 - Cable No Direct Underground.

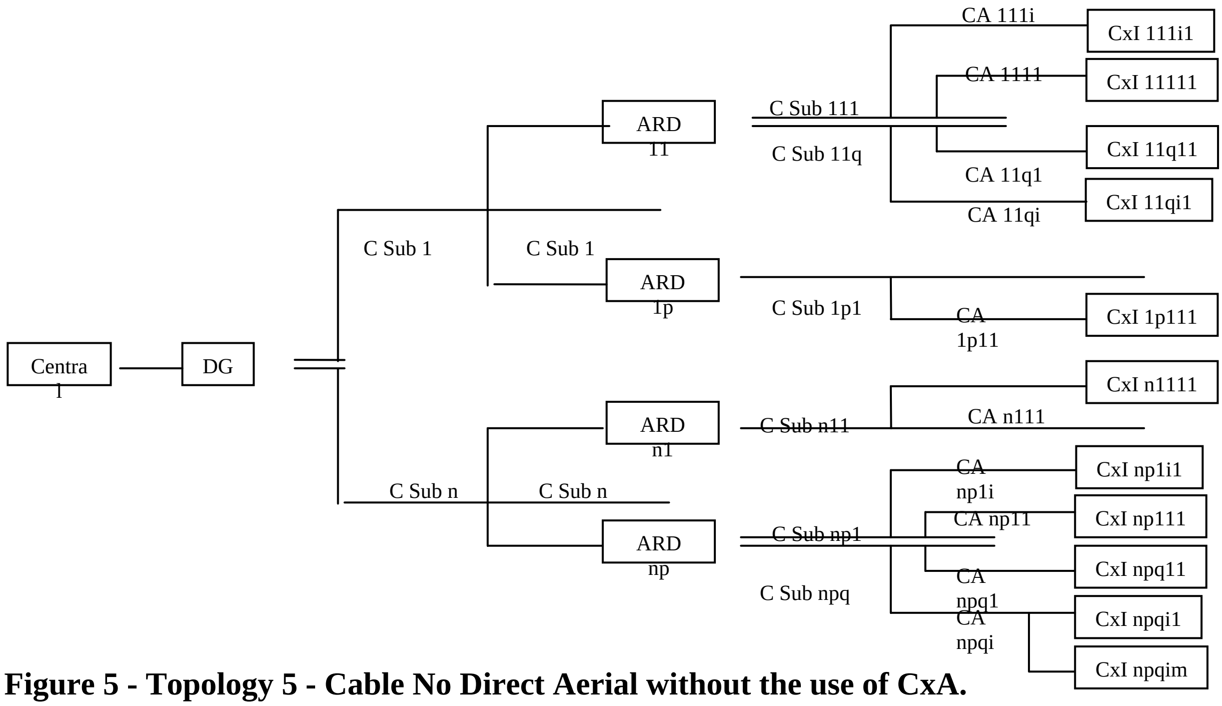

Figure 5 - Topology 5 - Cable No Direct Aerial without the use of CxA.

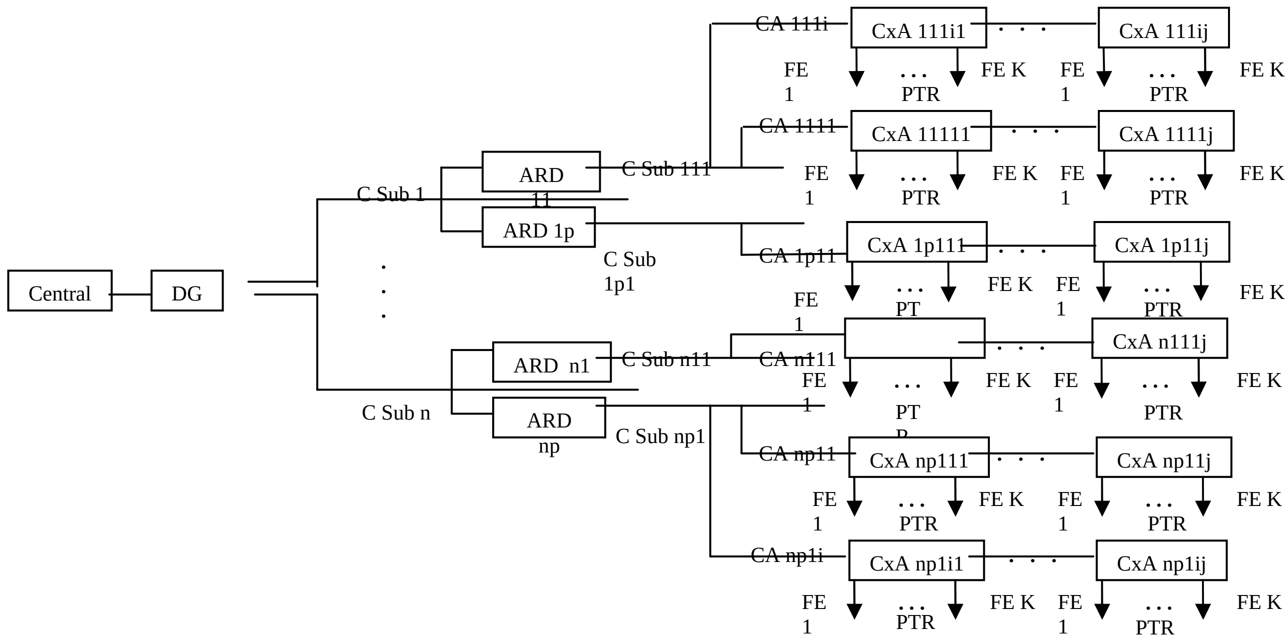

Figure 6 - Topology 6 - Cable No Direct Aerial with the use of CxA.

To proceed, the Table 2 shows the comparisons among the topologies presented in reliability terms, maintainability and investment costs for enlargement of the External Network.

Table 2 - Comparisons among the Topologies of the Telephone External Network.

Topology	Reliability	Maintainability		Enlargement	Customer's service
		Cost	Remove of Repair		
1	high	low	fast	high cost	great quantity and diversity of services
2	high	low	fast	high cost	minimum of 7 telephones lines
3	low	high	slow	low cost	maximum of 6 telephones lines
4	average	average	average	high cost	great quantity and diversity of services
5	average	average	average	high cost	minimum of 7 telephones lines
6	low	high	slow	low cost	maximum of 6 telephones lines

3. Reliability and Maintainability Operational of DG, Central and of the Components of the External Network

It took place a monthly collect data of the Times Between Failures and of the Times Technical of Repair of the components of the External Network, DG and Central.

3.1 - Determination of the operational reliability of the components of the external network, DG and central of 3 studied CT's

For the determination of this reliability, a historical collect data of the Times Between Failures was accomplished through the attendance of the monthly indicators of the External Network, in the period of Janeiro/97 to Setembro/98.
They were obtained for the components of the External Network, DG and Central of each CT, in subject, the quantity of conventional accesses and the quantity of the users' complaints. In the tables 3, 4 and 5, we verified the information mentioned for 3 CT's that they are being analyzed.
The distribution of Weibull is a model flexible probabilistic, because the law of the three parameters, allows to adjust all correctly of the types of experimental and operational results. Contrarily to the exponential model, this Law collects the cases where the failure rate λ is variable [2].

Table 3 - Monthly Attendance of the Quantity of Complaints and of Accesses of the Components of the External Network, DG and Central of Santo Amaro.

Month	Hour/ Month	Quantity of Complaints								Quantity of Accesses							
		ARD	CS	CA	CxA	CxI	FE	DG	COM	ARD	CS	CA	CxA	CxI	FE	DG	COM
Jan/97	744	110	79	213	39	55	370	110	165	49315	78754	56113	39279	39475	39279	78754	78754
Feb/97	672	87	126	173	71	31	283	134	79	49262	78669	56053	39237	39432	39237	78669	78669
Mar/97	744	86	424	118	55	39	220	181	173	49212	78589	55996	39197	39392	39197	78589	78589
Apr/97	720	126	47	110	87	24	229	166	316	49411	78907	56223	39356	39551	39356	78907	78907
May/97	744	110	431	117	55	16	196	149	399	49030	78299	55790	39053	39246	39053	78299	78299
Jun/97	720	117	149	117	63	31	297	219	344	49017	78278	55774	39042	39236	39042	78278	78278
Jul/97	744	161	77	169	46	23	284	246	914	48073	76770	54700	38290	38480	38290	76770	76770
Aug/97	744	158	90	143	30	30	301	188	504	47074	75174	53563	37494	37680	37494	75174	75174
Sep/97	720	248	45	120	38	38	406	241	1151	47102	75219	53594	37516	37703	37516	75219	75219
Oct/97	744	136	82	151	45	23	272	174	362	47269	75486	53786	37650	37836	37650	75486	75486
Nov/97	720	216	284	246	30	22	388	172	291	46722	74613	53163	37214	37399	37214	74613	74613
Dec/97	744	201	423	178	30	22	364	215	379	46519	74289	52933	37053	37236	37053	74289	74289
Jan/98	744	306	160	139	22	22	540	284	190	45657	72912	51951	36366	36546	36366	72912	72912
Feb/98	672	262	51	167	15	29	589	291	720	45554	72748	51834	36284	36464	36284	72748	72748
Mar/98	744	248	44	168	36	44	452	211	277	45637	72880	51929	36350	36530	36350	72880	72880
Apr/98	720	346	68	96	69	37	390	184	611	46112	73639	52469	36728	36911	36728	73639	73639
May/98	744	290	52	104	51	37	394	171	371	46510	74274	52921	37045	37229	37045	74274	74274
Jun/98	720	194	22	82	68	41	239	164	216	46715	74601	53154	37208	37393	37208	74601	74601
Jul/98	744	211	196	106	54	28	377	166	249	47206	75385	53713	37599	37786	37599	75385	75385
Aug/98	744	190	15	114	33	34	349	167	228	47511	75874	54061	37843	38031	37843	75874	75874
Sep/98	720	190	30	99	42	45	349	167	228	47511	75874	54061	37843	38031	37843	75874	75874

Table 4 - Monthly Attendance of the Quantity of Complaints and of Accesses of the Components of the External Network, DG and Central of Morumbi.

Month	Hour/ Month	Quantity of Complaints								Quantity of Accesses							
		ARD	CS	CA	CxA	CxI	FE	DG	COM	ARD	CS	CA	CxA	CxI	FE	DG	COM
Jan/97	744	78	62	29	25	8	132	29	37	31800	41153	30100	21070	20083	21070	41153	41153
Feb/97	672	103	58	54	29	12	144	16	62	31826	41186	30124	21087	20099	21087	41186	41186
Mar/97	744	66	25	37	33	25	79	17	463	31967	41369	30258	21181	20188	21181	41369	41369
Apr/97	720	67	12	37	29	29	100	37	32	32171	41633	30451	21316	20317	21316	41633	41633
May/97	744	73	44	17	21	17	103	26	146	33145	42894	31374	21962	20932	21962	42894	42894
Jun/97	720	102	217	44	27	22	98	22	195	34271	44351	32439	22707	21644	22707	44351	44351
Jul/97	744	129	74	53	40	27	80	36	76	34393	44509	32555	22788	21721	22788	44509	44509
Aug/97	744	80	18	67	27	27	125	31	98	34462	44598	32620	22834	21764	22834	44598	44598
Sep/97	720	112	22	76	40	22	126	36	49	34675	44874	32822	22975	21899	22975	44874	44874
Oct/97	744	79	33	52	26	17	127	57	118	33775	43709	31970	22379	21330	22379	43709	43709
Nov/97	720	90	54	18	23	9	95	27	266	34831	45076	32970	23079	21997	23079	45076	45076
Dec/97	744	72	27	59	23	5	104	41	153	34821	45063	32960	23072	21991	23072	45063	45063
Jan/98	744	122	72	194	32	18	122	77	262	34900	45165	33035	23124	22041	23124	45165	45165
Feb/98	672	145	81	23	14	14	195	41	394	35029	45331	33156	23209	22122	23209	45331	45331
Mar/98	744	123	209	50	9	9	236	23	105	35116	45444	33239	23267	22177	23267	45444	45444
Apr/98	720	122	17	50	5	18	132	23	213	35052	45361	33178	23225	22136	23225	45361	45361
May/98	744	142	338	27	27	27	114	27	580	35318	45706	33430	23401	22305	23401	45706	45706
Jun/98	720	105	28	23	14	9	96	37	46	35419	45836	33525	23468	22368	23468	45836	45836
Jul/98	744	64	198	28	14	9	78	41	41	35566	46026	33664	23565	22461	23565	46026	46026
Aug/98	744	65	79	92	28	37	102	69	818	35705	46207	33797	23658	22549	23658	46207	46207
Sep/98	720	70	14	33	9	28	117	47	751	36049	46652	34122	23886	22766	23886	46652	46652

Table 5 - Monthly Attendance of the Quantity of Complaints and of Accesses of the Components of the External Network, DG and Central of Clean Field.

Month	Hour/ Month	Quantity of Complaints								Quantity of Accesses							
		ARD	CS	CA	CxA	CxI	FE	DG	COM	ARD	CS	CA	CxA	CxI	FE	DG	COM
Jan/97	744	112	57	60	27	8	375	5	192	21151	27372	24550	17185	10187	17185	27372	27372
Feb/97	672	105	94	44	28	17	283	8	33	21258	27510	24747	17323	10238	17323	27510	27510
Mar/97	744	116	61	61	30	8	193	11	58	21295	27558	24816	17371	10256	17371	27558	27558
Apr/97	720	100	122	61	36	6	188	3	44	21360	27642	24936	17455	10287	17455	27642	27642
May/97	744	69	102	39	17	6	136	6	64	21424	27725	25050	17535	10318	17535	27725	27725
Jun/97	720	128	69	100	31	11	195	11	28	21476	27792	25150	17605	10343	17605	27792	27792
Jul/97	744	92	82	58	28	8	239	14	25	21500	27823	25194	17636	10355	17636	27823	27823
Aug/97	744	103	99	125	22	4	230	3	39	21438	27743	25080	17556	10325	17556	27743	27743
Sep/97	720	158	113	100	25	7	379	28	102	21381	27670	24976	17483	10298	17483	27670	27670
Oct/97	744	103	106	83	33	9	285	19	44	21410	27707	25029	17520	10311	17520	27707	27707
Nov/97	720	83	77	86	19	3	216	11	22	21432	27735	25069	17548	10322	17548	27735	27735
Dez/97	744	94	91	53	24	4	247	19	89	21412	27709	25031	17522	10312	17522	27709	27709
Jan/98	744	103	42	42	29	10	347	8	72	21446	27753	25094	17566	10329	17566	27753	27753
Feb/98	672	130	119	72	34	15	400	10	67	21453	27763	25109	17576	10332	17576	27763	27763
Mar/98	744	116	47	47	26	20	352	7	36	21434	27738	25073	17551	10323	17551	27738	27738
Apr/98	720	166	114	36	37	14	283	6	119	21404	27699	25017	17512	10308	17512	27699	27699
May/98	744	197	304	52	25	11	296	14	186	21398	27691	25006	17504	10305	17504	27691	27691
Jun/98	720	141	168	50	30	6	224	9	88	21342	27619	24903	17432	10279	17432	27619	27619
Jul/98	744	252	114	58	32	5	261	8	78	21425	27726	25056	17539	10318	17539	27726	27726
Aug/98	744	119	113	125	24	7	276	22	354	21354	27635	24926	17448	10285	17448	27635	27635
Sep/98	720	136	202	100	28	3	269	6	72	21452	27761	25106	17574	10332	17574	27761	27761

The three parameters of Weibull are:

γ = position parameter

η = scale parameter or reference

β = form parameter

The determination of these parameters is made according to the algorithm of the Law of Weibull, Appendix.

In the table 6, we determined the three parameters of Weibull for 3 studied CT's.

With the three parameters Weibull [1], [3], we have the following functions:

By definition we have:

Function Reliability

$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad (1)$$

We have that, the sum of the Reliability and of the Probability of Failure it is same to 1:

$$R(t) + F(t) = 1 \qquad (2)$$

Like this, of the equation (2):

Function Probability of Failure

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad (3)$$

We have by definition, the Density of Probability of Failure f(t):

$$f(t) = \frac{dF(t)}{dt} \qquad (4)$$

Like this of the equation (4):

Function of Density of Probability of Failure

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad (5)$$

In that way, we have that:

$$\lambda(t) = \frac{f(t)}{R(t)} \qquad (6)$$

Dividing the equation (5) for the equation (1), we obtain:

Function Rate Instantaneous of Failure

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \qquad (7)$$

Medium Time To Failure

$$\text{MTTF} = \eta.\left(\frac{1}{\beta}\right)! + \gamma \qquad (8)$$

The duration of nominal life of a component is associated to an operational reliability R(t) of 90%, being with a probability of failure F(t) of 10%. In this case, we established the notation L_{10} for the duration of nominal life.
In the table 7, we showed the values of MTTF, it associated reliability, the Rate Instantaneous of Failure and the period of nominal life.

3.2 - Determination of the Maintainability operational of the components of the External Network, DG and Central of 3 studied CT's

For the determination of this maintainability, it was accomplished a historical collect data of the Times Technical of Repair through the monthly attendance of the technicians' productivity of the External Network, DG and Central, in the period of Janeiro/97 to Setembro/98. This report is generated daily goes the administration of each technician's productivity at field, informing the time of remove of repair. The time is counted since the moment in that the technician is informed of the repair, until the moment in that the same assured the good operation of the telephone line.
The times technical of repair present very low values when compared at the times between failures, but even so we can model them through the distribution of Weibull for obtaining of Maintainability.
Like this, the determination of the three parameters of Weibull for Maintainability, it will be obtained in agreement with the algorithm of Weibull described appendix. In the table 8, we determined these 3 parameters.

Table 6 - The three parameters of Weibull for 3 studied CT's.

Component	Santo Amaro			Morumbi			Campo Limpo		
	γ	η	β	γ	η	β	γ	η	β
ARD	99589	156103	1,031	178813	148067	0,897	71920	72944	1,593
CA	177607	164178	1,223	237756	562765	1,051	140126	187447	1,134
CS	93251	933267	0,789	0	106108	1,092	-48846	299444	2,970
CxA	266311	511188	1,408	433680	571240	0,803	233756	259490	2,250
CxI	567923	558350	0,934	480632	918770	0,789	565919	902109	0,755
FE	54771	39018	1,031	-30394	191013	4,192	25461	27892	1,747
DG	202484	117162	1,246	256334	892159	1,781	385796	2747441	1,279
Central	87925	167458	0,807	39124	344824	0,807	111703	354444	0,972

Table 7 - MTTF, Reliability associated to MTTF, Rate Instantaneous of Failure and Period of Life Nominal of the components of the External Network, DG and Central of 3 analyzed CT's.

Component	Santo Amaro				Morumbi				Campo Limpo			
	MTTF (h)	R(MTTF) (%)	$\lambda(t)$ x 10^{-6}	Time of Life L_{10}	MTTF (h)	R(MTTF) (%)	$\lambda(t)$ x 10^{-6}	Time of Life L_{10}	MTTF (h)	R(MTTF) (%)	$\lambda(t)$ x 10^{-6}	Time of Life L_{10}
ARD	253772	37,26	6,60	450146	334890	35,05	7,64	554185	137344	43,13	20,47	195058
CA	331310	39,75	7,34	502324	789491	37,55	1,87	1482092	319269	38,68	6,02	531104
CS	1161375	32,88	0,82	2777803	1020535	38,12	1,03	2271876	218438	48,99	740,3	347675
CxA	731798	41,63	2,65	1190645	1079182	33,18	1,38	2047040	463586	46,72	7,45	609661
CxI	1144084	35,71	1,67	1931831	1532163	32,88	0,84	3123483	1634197	32,11	0,80	3288656
FE	93310	37,26	26,40	142394	143198	51,19	16,17	202665	50305	44,18	57,44	70425
DG	311679	40,01	10,45	431314	1050177	44,39	1,82	1681238	2746510	40,36	0,49	5276455
Central	276483	33,27	4,71	558755	427396	33,27	2,29	1008639	470578	36,34	2,74	947708

Table 8 - The three parameters of Weibull for 3 analyzed CT's.

Component	Santo Amaro			Morumbi			Campo Limpo		
	γ	η	β	γ	η	β	γ	η	β
ARD	45,87	82,68	0,991	21,85	59,21	0,731	21,78	70,55	1,317
CA	183,07	114,98	0,893	42,10	49,39	1,007	78,33	107,71	0,595
CS	65,80	261,24	0,639	13,83	148,84	1,109	121,69	240,32	0,991
CxA	28,43	51,10	1,283	7,67	35,38	1,246	32,91	17,21	1,134
CxI	8,85	12,46	1,134	4,70	10,73	0,698	1,51	3,73	0,672
FE	288,64	235,58	0,930	117,32	76,37	1,214	288,54	164,55	0,493
DG	30,49	68,19	1,456	4,59	13,64	1,795	1,05	5,96	1,187
Central	82,59	127,98	0,560	14,14	231,93	0,451	7,41	31,78	1,072

Table 9 - MTTR, Maintainability associated to MTTR, Rate Instantaneous of Repair of the components of the External Network, DG and Central of 3 analyzed CT's.

Component	Santo Amaro			Morumbi			Campo Limpo		
	MTTR (h)	M (MTTR) (%)	$\mu(t)$ x 10^{-2} repairs/h	MTTR (h)	M (MTTR) (%)	$\mu(t)$ x 10^{-2} repairs/h	MTTR (h)	M (MTTR) (%)	$\mu(t)$ x 10^{-2} repairs/h
ARD	128,88	63,35	1,20	93,90	68,47	1,20	86,77	59,24	1,80
CA	304,57	65,02	0,80	91,35	63,10	2,00	242,17	72,29	0,50
CS	429,68	70,95	0,20	157,07	61,65	0,70	362,95	63,35	0,40
CxA	75,75	59,59	2,50	40,65	59,99	3,50	49,37	61,32	6,60
CxI	20,75	61,32	9,10	18,32	69,31	6,10	6,42	70,00	16,40
FE	532,27	64,36	0,40	188,95	60,35	1,60	626,43	75,97	0,20
DG	92,28	57,95	2,00	16,72	55,52	1,20	6,67	60,67	19,70
Central	294,59	73,47	0,40	586,16	77,75	0,10	38,35	62,15	3,40

We have that the equations of Weibull related with Maintainability, are similar equations the Reliability:

By definition we have:

Function Maintainability

$$M(t) = 1 - e^{-\left(\frac{t - \gamma}{\eta}\right)^{\beta}} \qquad (9)$$

We have by definition, the Density of Probability of Repair g(t):

$$g(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \qquad (10)$$

We have that:

$$\mu(t) = \frac{g(t)}{1-M(t)} \qquad (11)$$

In that way, substituting the equation (9) and (10) in the equation (11), we obtain:

Function Rate Instantaneous of Repair

$$\mu(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \qquad (12)$$

Medium Time of Repair

$$MTTR = \eta.\left(\frac{1}{\beta}\right)! + \gamma \qquad (13)$$

In the table 9, we showed the values of MTTR, it associated maintainability and the rate instantaneous of repair.
After the analysis of the components of the system of fixed telephony, we will analyze the reliability and MTTF of the topologies in subject, for 3 analyzed CT's.
The equation of the reliability for the mentioned topologies, it will be obtained through the association series of their components [1], [3], according to the equation 14:

$$R_T(t) = \prod R_i(t) \qquad (14)$$

In the table 10, we showed MTTF and the reliability of the topologies analyzed for 3 CT's. We observed that the obtained results of this table, they are in agreement with the results of the table 2.

Table 10 - MTTF and the Reliability of the topologies analyzed for 3 studied CT's.

Topology	Santo Amaro		Morumbi		Campo Limpo	
	MTTF (h)	R (%)	MTTF (h)	R (%)	MTTF (h)	R (%)
1	233056	37,20	184613	38,12	46095	45,45
2	235770	36,88	184613	38,12	46095	45,45
3	99157	30,42	135386	26,04	51213	44,18
4	173068	35,45	204589	34,02	132677	44,70
5	173068	35,45	204589	34,02	132677	44,70
6	99115	30,42	144172	21,62	85398	30,29

4. Costs of Maintenance

In the analysis of the costs of the maintenance of the system of fixed telephony, we should consider the costs of the corrective and preventive maintenance [1]:

4.1 - Costs of the Corrective Maintenance

The costs regarding the corrective maintenance are composed by the following costs [4]:

$$C_{mc} = C_{op} + C_{mom} + C_R \qquad (15)$$

being:

$$C_{op} = \tau_{op} \,.\, TA \qquad (16)$$
$$C_{mom} = \tau_{mom} \,.\, H \,.\, TTR \qquad (17)$$
$$C_R = \tau_{sub} \,.\, N_{sub} + \tau_{rep} \,.\, N_{rep} \qquad (18)$$

where:

C_{mc} = cost of the corrective maintenance; C_{op} = cost operational of the maintenance corrective or preventive; τ_{op} = operational rate of the maintenance corrective or preventive; TA = time of interruption of a telephone line; C_{mom} = labor cost requested for maintenance; C_R = repairing cost; τ_{mom} = rate of requested labor; H = number of technicians for service; N_{sub} = number of substituted components; τ_{sub} = substitution rate; N_{rep} = number of repaired components; τ_{ep} = repairing rate.
The operational cost of a phone line for 3 studied CT's is shown in the table 11:

Table 11 - Cost Operational of 3 CT's studied.

CT	Cost Operational
Santo Amaro	0,13.TA
Morumbi	0,15.TA
Campo Limpo	0,09.TA

The determination of the time of interruption of a telephone line, it will be obtained through the time technical of repair (TTR). Like this, we will have TA = TTR.
The labor rate, the cost of repair and spare parts are shown in the table 12 in $ (monetary units).

Table 12 - Labor Rate, Costs of Repair and Spare Parts of the components of the system of fixed telephony.

Component	CT	τ_{mom} ($ / h)	$ Spare parts / unit	$ Repair / unit
ARD	Independent	17,55	127,85	0,03
CA	Independent	19,20	148,68	0,12
CS	Independent	19,20	602,25	0,03
CxA	Independent	17,55	77,00	0,01
CxI	Independent	17,55	5,65	0,03
FE	Independent	17,55	12,00	12,00
DG	Santo Amaro	10,14	1,20	1,20
	Morumbi		0,80	0,80
	Campo Limpo		0,40	0,40
Central	Independent	20,60	678,20	0,01

We have that the times technical of repair of the substituted components and repaired, they were appropriate exclusively in field, being independent of analyzed CT. For the service of a complaint, the Incumbent makes available a technician for accomplish the corrective maintenance in field.
In the table 13, we showed the total of substituted components and repaired for 3 CT's.

Like this, substituting these values in the equation 15, we obtain the cost of the corrective maintenance in the table 14, in the janeiro/97 period the setembro/98.

Table 13 - Total of Components Substituted and Repaired for 3 CT's.

Component	Substituted Components			Repaired Components		
	SA	MB	CL	SA	MB	CL
ARD	0	0	0	3993	2009	2623
CA	8	18	27	2230	542	1277
CS	53	26	26	1845	982	1946
CxA	0	0	0	979	495	585
CxI	0	0	0	671	389	182
FE	7289	2505	5674	0	0	0
DG	4000	760	228	0	0	0
Central	38	28	21	1516	4352	1696

Table 14 - Cost Total of the Corrective Maintenance of the components of each CT.

Component	Cost of Maintenance Corrective ($)			Cost Total ($)
	AS	MB	CL	
ARD	45762,48	23136,65	30726,43	99625,56
CA	119638,73	44031,28	62422,44	226092,45
CS	185836,57	101099,83	131678,72	418615,12
CxA	25815,52	13290,57	15742,50	54848,59
CxI	7337,88	4451,72	2070,22	13859,82
FE	278758,53	98861,67	219362,47	596982,67
DG	27081,80	4613,90	1295,27	32990,97
Central	129422,25	92434,17	34369,84	256226,26
C_{Tmc}	819653,76	381919,79	497667,89	1699241,44

4.2 - Costs of the Preventive Maintenance

The cost of the preventive maintenance can be obtained through the following equation:

$$C_{mp} = TA_{mp} \cdot (\tau_{op} + \tau_{mom} \cdot H) + C_R \qquad (19)$$

where:

C_{mp} = cost of the preventive maintenance; TA_{mp} = time of interruption of a telephone line attributed to the preventive maintenance.

In the case of that maintenance type, they won't be taken into account the repair costs, because these were already considered in the corrective interventions.
The program of preventive maintenance should contemplate the following components: external wire, underground cable, closet of distribution, aerial cable and aerial box. For execution of the preventive maintenance of the components mentioned above, the Incumbent is used two couples of technicians, exception done to the closet of distribution, because the

Incumbent is only used of a couple of technicians, due to the technical and economical viability.
In the table 15, we showed the time of interruption of a telephone line and the total of components substituted for 3 analyzed CT's, in the execution of the annual preventive maintenance.

Table 15: Time of Interruption and Total of Components Substituted in the execution of the annual Preventive Maintenance.

Component	Time of Interruption (h)			Substituted Components		
	SA	MB	CL	SA	MB	CL
ARD	3150	2250	1350	84	60	36
CA	480	144	240	120	36	60
CS	768	384	192	96	48	24
CxA	480	144	240	240	72	120
FE	720	360	1440	2400	1200	4800

Like this, substituting these values in the equation 19, we obtain the annual cost of the corrective maintenance in the table 16.

Table 16 - Cost total of the preventive maintenance of the components of each CT.

Component	Cost of Maintenance Preventive ($)			Cost Total ($)
	SA	MB	CL	
ARD	121713,90	86983,50	52109,10	260806,50
CA	48613,60	14586,48	24298,80	87498,88
CS	82433,60	41220,00	20605,20	144258,80
CxA	24106,40	7232,40	12051,60	43390,40
FE	79437,60	39726,00	158817,60	277981,20
C_{Tmp}	356305,10	189748,38	267882,30	813935,78

5. Conclusion

The evaluation of the reliability and operational maintainability of the components and of the topologies, it was accomplished through of the algorithm of Weibull. Based on the reliability and operational maintainability of the components and topologies of the telephone external network, it was determined the costs of spare, operational and of the maintenance.
With this points, can determine the following above:

- The operational reliability, the medium time to failure (MTTF), the maintainability and the medium time technical of repair (MTTR) for the components and topologies of the system of fixed telephony for 3 CT's analyzed in this work.
- The total and medium cost of the maintenance corrective, preventive and global for 3 studied CT's.

Starting from the foregoing results, the present work makes possible the following evaluations:

- Optimization of the process, objectifying minimum rate of failure.
- Cost of the necessary resources for operation and planning of the external network.
- Cost operational the relationship telephone line interrupted x availability of the maintenance team.

- Evaluation of the needs of resources, objectifying the growth of the conventional telephone plant in these 3 CT's, for the focus of the maintenance.
- Appropriate planning of the human resources / contracted teams of corrective and preventive maintenance, objectifying an optimization of the time of repair of a conventional telephone line and of the availability.
- Evaluation of the reliability and maintainability of the topologies analyzed with redundancy of the underground and aerial cable, proposing an occupation of high network and the same time of the remove of repair for the maintenance team.

Starting from the considerations above, we have an improvement in the quality of the services rendered the fixed telephony users of 3 analyzed CT's, could extend the model of reliability analysis and maintainability for other CT's of the country, always respecting, the particularities of each CT.

Appendix - Algorithm of Weibull

To proceed, the procedure is described for the assembly of the graph of Weibull for the determination of the parameters β, η and γ [1], [3], [4].

1) To set up table of attendance of the Times To Failure (TTF);

2) To establish order of growing classification of TTF;

3) To establish a column for accumulated frequency F(i), where:

$$F(i) = \frac{i}{N+1}$$

with sampling 20 <N <50;

4) In paper Di-log, to register the group of coordinated points (TTFi, F(i)), and to draw the graph;

- in case the adjustment of the group of points goes a straight line, the parameter $\gamma = 0$;
- in case the adjustment of the group of points goes a curve, the value of the displacement parameter γ will be determined by the linear technique of the curve.

Let us take three points on the graph of the figure 7; A_1, A_2 and A_3. It is advisable take spaced points, but not of the ends. On the axis t (TTF), we will read the values t1, t2 and t3.

The value of γ is obtained by the following expression:

$$\gamma = \frac{t_2^2 - t_1 \, x \, t_3}{2\,t_2 - t_1 - t_3},$$

where obtain the points:

$A'_1 = A_1 + \gamma$

$A'_2 = A_2 + \gamma$ e

$A'_3 = A_3 + \gamma$, showed in the figure 7.

5) Through the points A'_1, A'_2, A'_3, the straight line D_1 is drawn. We have that in the point the accumulated frequency F(i) = 63,21%.

$$\ln\left(\ln \frac{1}{1 - F(i)}\right) = 0;$$

In this point, we drew a parallel one to the axis t, determining the straight line η. In the point of intersection of the straight line D_1 with the straight line η, determined the parameter η, according to plan in the figure 7.

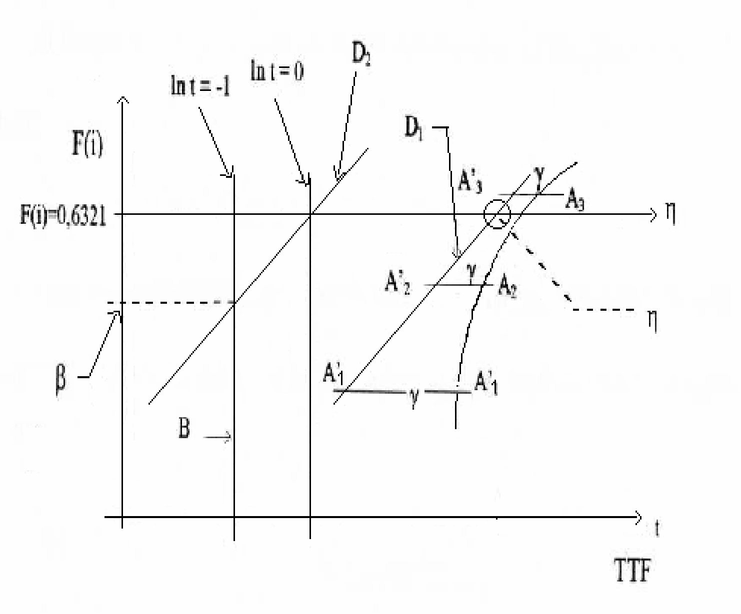

Figure 7 - Graph of Weibull for determination of the parameters.

6) For us to obtain the value of β should register on the straight line η a parallel straight line to the axis F(i) on the point ln t = 0, in other words, in t = 1. Soon afterwards, we registered a straight line parallel B to the axis F(i) on the point ln t = -1, in other words, in t=0,3679;

To draw a straight line parallel D_2 to the straight line D_1, going by the point 1n t = 0, cutting the straight line B, whose intersection indicates the value of F(i) corresponding to the parameter β. As the axis F(i) adopted is guided down, to the we obtain β, we should invert it sign when determined in the following equation:

$$\beta = \ln\left(\ln \frac{1}{1 - F(i)} \right)$$

Like this, we determined the three parameters of Weibull => β, η and γ.

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