

Uso de Bases de Datos de Falla en Estudios de Confiabilidad

Techgnosis®

APPLITechgnosis



2022



**CONGRESO INTERNACIONAL DE
MANTENIMIENTO PREDICTIVO, CONFIABILIDAD
Y LUBRICACION DE CLASE MUNDIAL**

- SUMMIT PRECONLUB

LEÓN, GTO. 9 Y 10 DE JUNIO 2022

Ponentes



**CEO de
Predictiva21**

Ingeniero en Confiabilidad

Data management y
desarrollo de software
(Capacitación y confiabilidad)



**Fundador de
Predictiva21**

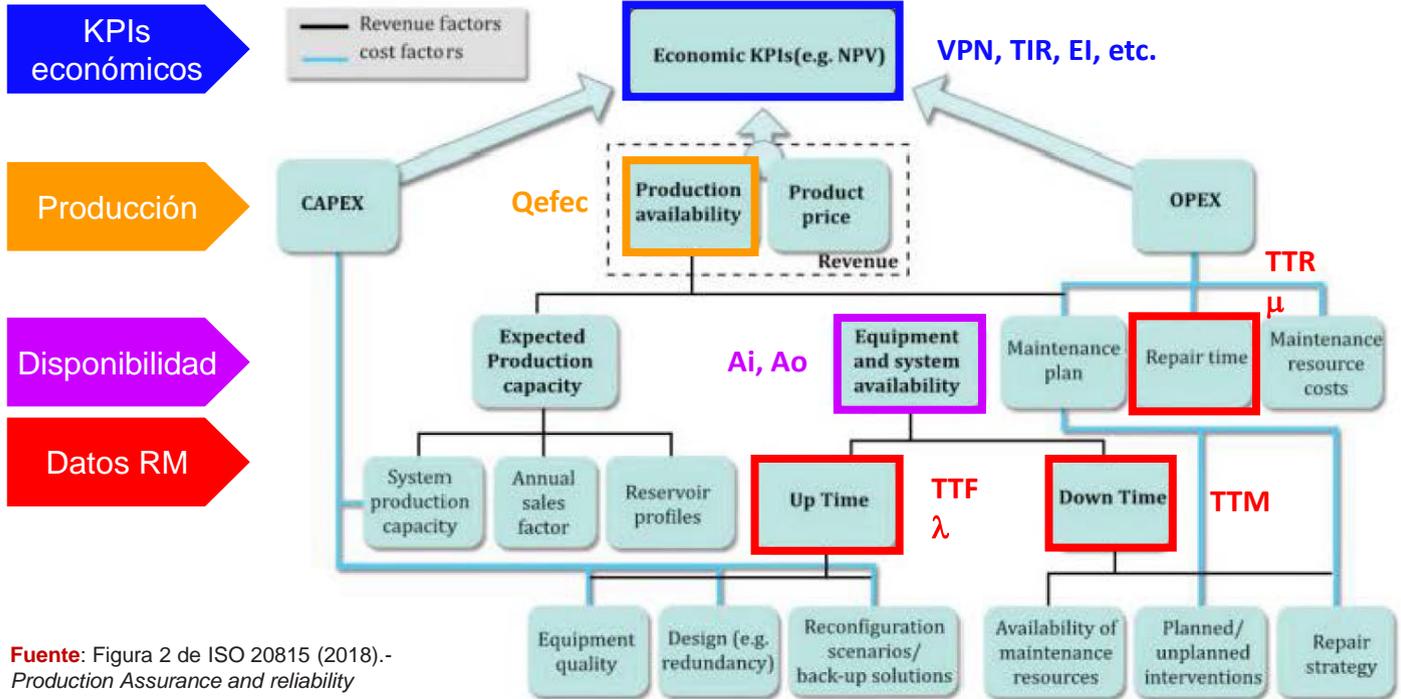
Especialista en Confiabilidad

Máquinaria rotativa
(compresores, turbinas,
bombas, etc.).

PREDICTIVA21



Los datos y su relación con la gestión de los activos



Fuente: Figura 2 de ISO 20815 (2018).-
Production Assurance and reliability
management.

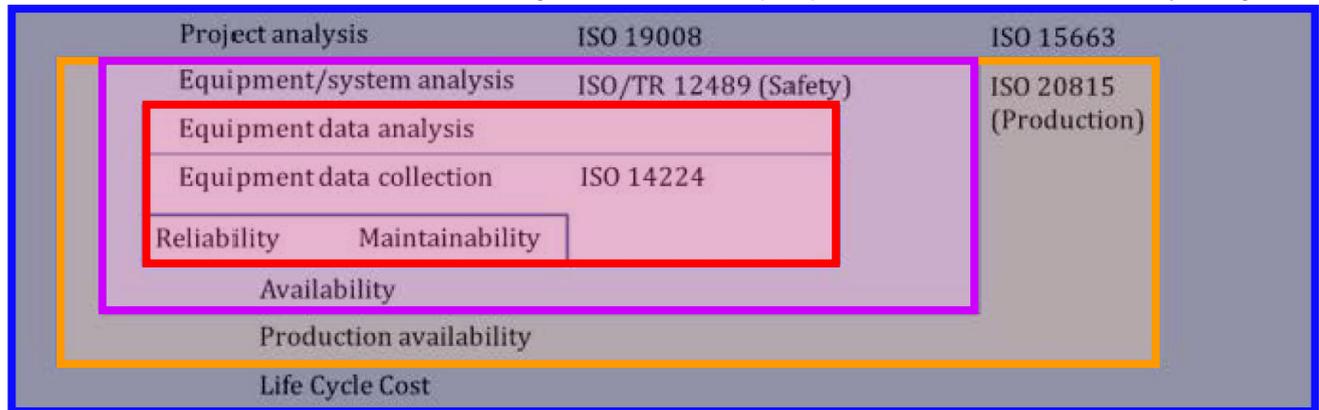
Influencia de los datos RM de aseguramiento de producción en la economía de los proyectos (ISO 20815)

Los datos y su relación con la gestión de los activos – marco normativo

La colección, procesamiento y análisis de **datos e indicadores de confiabilidad y mantenibilidad** (ISO 14224 “Collection and exchange of reliability and maintenance data for equipment”) es un insumo fundamental para:

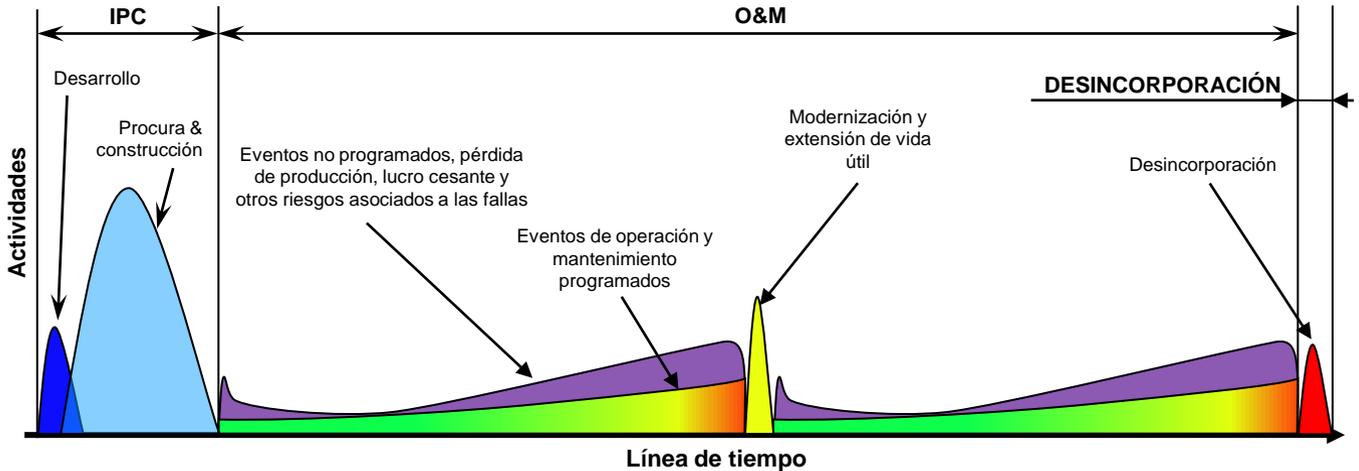
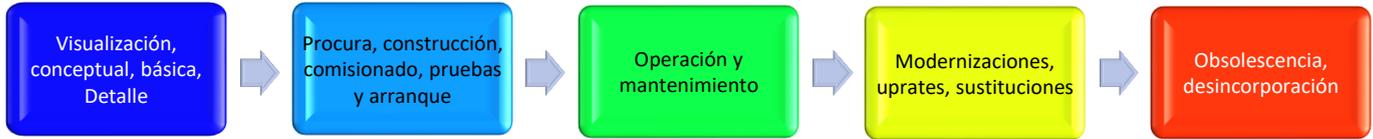
- El análisis de la **disponibilidad de equipos y sistemas** (ISO/TR 12489 Reliability Model and Calculation of Safety Systems).
- **Producción** o capacidad efectiva (ISO 20815.- Production assurance and reliability management).
- **Costos en ciclo de vida** (ISO 15663 Life cycle costing)

Fuente: Figura D2 de ISO 20815 (2018).- *Production Assurance and reliability management.*



Relación de los tipos de análisis en sus marcos normativos

Los datos y su relación con la gestión de los activos – el ciclo de vida



Confiabilidad desde el Diseño

- RAM / Mantenibilidad
- SIL/SIS
- IBR
- FMEA / FMECA / MCC
- Repuestos
- LCC

Confiabilidad durante la operación y mantenimiento

- RAM
- IBR
- MCC
- Repuestos
- LCC
- Benchmarking / KPI
- Vida útil y obsolescencia
- LCC
- Análisis de riesgo al ambiente y terceros



Historia



MANUAL MARTIN TITAN BOOK

PRIMERA GENERACIÓN

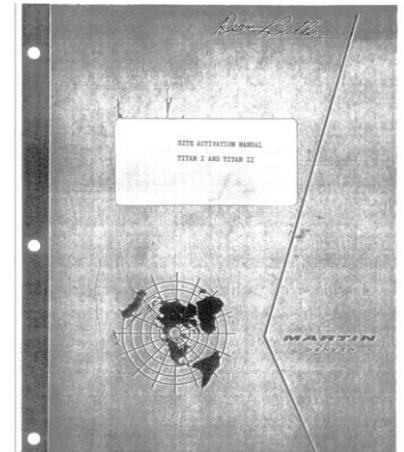
La primera fuente de datos de confiabilidad.

Tasas de falla genéricas en componentes:

Eléctricos
Electrónicos
Electromecánicos
Mecánicos.

Estandarización de la presentación de las tasas de falla en términos de fallas por **10⁶** horas

1 millón de horas – 144 años



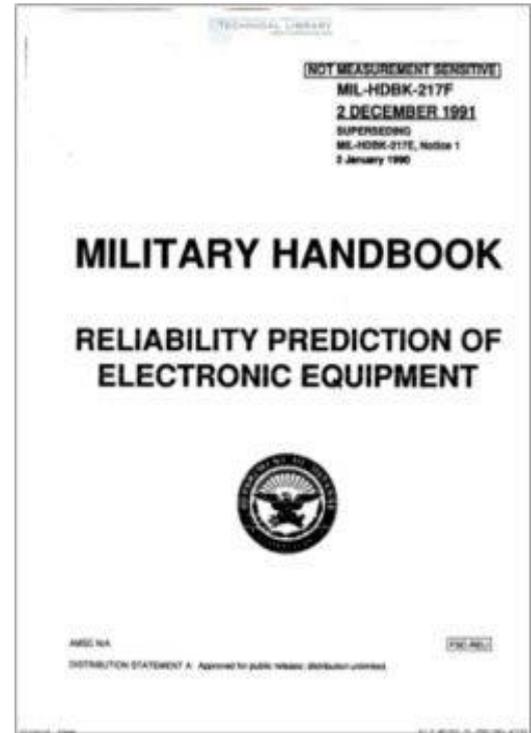
(Martin Titan Handbook, Procedure and Data for Estimating Reliability and Maintainability).

SEGUNDA GENERACIÓN

Los ejemplos más brillantes de estos esfuerzos son:

- 1) Manual **MIL-217**
- 2) Banco de Datos de Tasa de Fallas (**FARADA**)
- 3) Cuaderno de confiabilidad no electrónica **RADC**

- Utilizan del modelo exponencial.
- Tasas de falla por cada 10^6 .



TERCERA GENERACIÓN

La principal deficiencia de la 2da gen era:

- Las tasas de falla constantes
- Falta de adecuación del modelo de riesgo a todo el espectro de condiciones ambientales y posibles razones de falla.

Estimaciones de rango para solventar el problema de las subpoblaciones heterogéneas.

Incertidumbre real de la mezcla a través de percentiles,

Separación en categorías (tiempo y demanda).

Modos de falla se dividieron en **catastrófica**, **degradada** e **incipiente**;

- **Industria nuclear comercial.**
- **Industria petrolera.**
- **Industria química.**

IEEE Std. 500-1984, IEEE Guide To The Collection and Presentation of Electrical, Electronic, Sensing Component and Mechanical Equipment Reliability Data For Nuclear-Power Generating Stations, IEEE, NY, 1984.

EIREDA European Industry Reliability Data Handbook, C.E.C.- J.R.C./ICEI 21020 ISPRA (Varese) Italy, DF-DER/SPT 93206 Saint Denis (Paris) France, 1991.

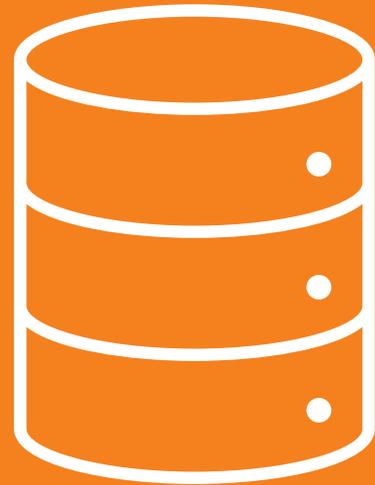
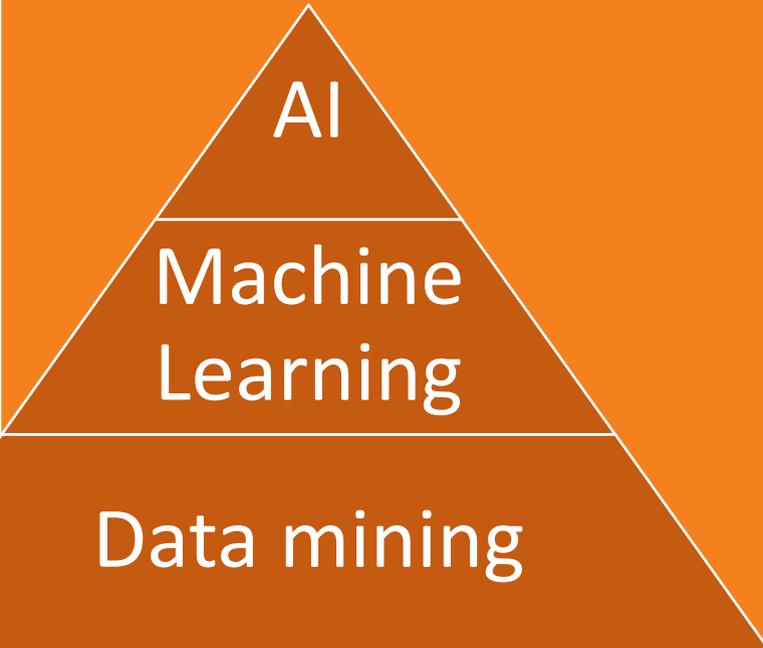
T-Book Reliability Data of Components in Nordic Nuclear Plants. ATV Office, Vallingby, Sweden, 1991.

Offshore Reliability Data Handbook 3-d Edition, **OREDA-97**, DNV, Hovic, Norway, 1997.

Guidelines for Process Equipment Reliability Data with Data Tables, Center for Chemical Processes Safety, **American Institute of Chemical Engineers**, New York, NY, 1989.



CUARTA GENERACIÓN



Naturaleza de las bases de datos de falla

	Tipo de equipo	Condiciones	Política de Mant.	Población	Periodo de observación
Propia	✓	✓	✓	✓	✓
Instalaciones similares	✓	✓	✗	✗	✗
Genérica (industrias similares)	≈	✗	✗	✓	✓
Literatura	✓	✗	✗	✗	✗
Opinión de experto (subjetiva, permite hacer consideraciones específicas).	≈	≈	≈	✗	✗

- Definir que **bases de datos de falla** son más convenientes para usar es la parte más delicada y laboriosa.
 - ✓ **Datos propios, experiencia previa.** Funciones de distribución de densidad de probabilidad determinadas a través del mejor ajuste a los datos de campo.
 - ✓ **Datos genéricos, fuentes abiertas:** OREDA, IEEE, EXIDA, PARLOC, etc.
Datos genéricos, fuentes privadas: consultoras, institutos u organizaciones privados, etc.
 - ✓ **Opinión de expertos:** basado en la opinión de personal con experiencia en O&M de esos equipos.
 - ✓ **Combinación de fuentes:** teorema de Bayes.



Data del fabricante - **(Generalmente privada / confidencial)**

Bases de datos de confiabilidad y mantenibilidad

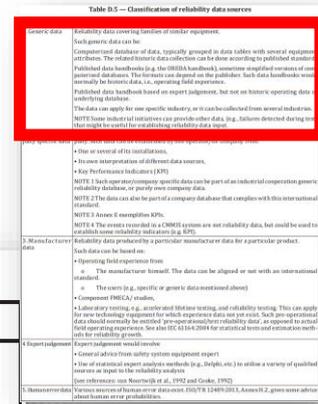
Fuentes de datos

Table 4 — Classification of reliability data sources

Source of data	Description
1. <i>Generic data</i> (see 3.4.16)	<p>Reliability data covering families of similar equipment.</p> <p>Such generic data can be:</p> <p>Computerized database of data, typically grouped in data tables with several equipment attributes. The related historic data collection may be done according to published standards (e.g. ISO 14224^[15] for petroleum, petrochemical and natural gas industries)</p> <p>Published data handbook^[19], sometime simplified versions of computerized databases. The formats may depend on the publisher. Such data handbooks would normally be historic data, i.e. operating field experience.</p> <p>Published data handbook based on expert judgement, but not on historic operating data or underlying database.</p> <p>The data may apply for one specific industry, or it may be collected from several industries.</p> <p>NOTE Some industrial initiatives may provide other data, (e.g. failures detected during test) that might be useful for establishing reliability data input.</p>

[Fuente: ISO 12489 Reliability Model and Calculation of Safety Systems (2013) – Section 13.2 “Reliability data sources”]

[Fuente: ISO 14224 Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment (2016) – Annex D “Typical requirements for data”, Table D.5 “Classification of reliability data sources”]



Bases de datos de confiabilidad y mantenibilidad

Fuentes de datos

Source of data	Description
2. <i>Operator/ company specific data</i>	<p>Reliability data or reliability indicators based on operating field experience of a single company. Such data can be established by one operator/oil company from:</p> <ul style="list-style-type: none"> • One or several of its installations, • Its own interpretation of different data sources, • Key Performance Indicators (KPI) <p>NOTE 1 Such operator/company specific data may be part of an industrial cooperation generic reliability database, or purely own company data.</p> <p>NOTE 2 The data may also be part of a company database that might comply with an international standard (e.g. ISO 14224[15]).</p> <p>NOTE 3 ISO 14224[15] Annex E exemplifies KPIs.</p> <p>NOTE 4 The events recorded in a CMMIS system are not reliability data, but could be used to establish some reliability indicators (e.g. KPI).</p>

[Fuente: ISO 12489 Reliability Model and Calculation of Safety Systems (2013) – Section 13.2 “Reliability data sources”]

[Fuente: ISO 14224 Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment (2016) – Annex D “Typical requirements for data”, Table D.5 “Classification of reliability data sources”]

Table D.5 – Classification of reliability data sources

Source of data	Description
1. <i>Generic data</i>	<p>Reliability data covering families of similar equipment.</p> <p>Such generic data can be:</p> <ul style="list-style-type: none"> • Component-level database of data, especially grouped in data tables with several equipment attributes. The related historic data collection can be done according to published standards. • Published data handbooks (e.g. the OREDA handbook), sometimes categorized according to asset general categories. The forecasts can depend on the publisher. Such data handbooks would normally be historic data, i.e. operating field experience. • Published data handbooks based on expert judgement, but not on historic operating data or modelling database. <p>The data can apply for one specific industry or it can be collected from several industries.</p> <p>NOTE 1: Some industrial industries can provide other data, (e.g. failure detected during start-up or during testing) for the reliability data sources.</p>
2. <i>Company specific data</i>	<p>Such data can be established by one operator/oil company from:</p> <ul style="list-style-type: none"> • One or several of its installations, • Its own interpretation of different data sources, • Key Performance Indicators (KPI) <p>NOTE 1: Such operator/company specific data can be part of an industrial-cooperation generic reliability database, or purely own company data.</p> <p>NOTE 2: The data can also be part of a company database that complies with this international standard.</p> <p>NOTE 3: Annex E exemplifies KPIs.</p> <p>NOTE 4: The events recorded in a CMMIS system are not reliability data, but could be used to establish some reliability indicators (e.g. KPI).</p>
3. <i>International standard</i>	<ul style="list-style-type: none"> • Operating field experience from <ul style="list-style-type: none"> o The manufacturer/owner. The data can be aligned or not with an international standard. o The users (e.g. specific or generic data mentioned above) • Component FMECA studies, • Laboratory testing, e.g. accelerated life test testing, and reliability testing. This can apply for the reliability equipment that which experience data are not reach. Such experimental data should normally be verified by operator/owner reliability data, or exposed to actual field operating experience (e.g. ISO 14224-2016 for statistical tests and estimation methods for reliability growth). • Expert judgement based on user • General advice from safety system equipment expert <p>The all mentioned expert analysis methods (e.g. Weibull, etc.) to allow a degree of quantification on expert in the reliability analysis.</p> <p>[see references see Norrie (8) et al., 1992 and Cooke, 1992]</p> <p>For more information on oil and petroleum, ISO 14224-2016, annex 2, please visit laboratory error or probabilities.</p>



Bases de datos de confiabilidad y mantenibilidad

Fuentes de datos

<p>3. <i>Manufacturer data</i></p>	<p>Reliability data produced by a particular manufacturer data for a particular product. Such data may be based on:</p> <ul style="list-style-type: none"> • Operating field experience from <ul style="list-style-type: none"> • The manufacturer himself. The data can be aligned or not with an international standard (e.g. ISO 14224[15]). • The users (e.g. specific or generic data mentioned above) • Component FMECA/ studies, • Laboratory testing, e.g. accelerated life time testing, reliability testing. This may apply for new technology equipment for which experience data not yet exist. Such pre-operational data should normally be entitled 'pre-operational/test reliability data', as opposed to actual field operating experience. See also IEC 61164[50] for statistical tests and estimation methods for reliability growth.
<p>4. <i>Expert judgement (see references[26] and[27])</i></p>	<p>Expert judgement would involve</p> <ul style="list-style-type: none"> • General advice from safety system equipment expert • Use of statistical expert analysis methods (e.g. Delphi, etc.) to utilize a variety of qualified sources as input to the reliability analysis
<p>5. <i>Human error data</i></p>	<p>Various sources of human error data exist and H.2 gives some advice about human error probabilities.</p>

Table D.5 — Classification of reliability data sources

Source of data	Description
1. Generic data	<p>Reliability data covering families of similar equipment.</p> <p>Such generic data can be:</p> <ul style="list-style-type: none"> • Component-level data, typically grouped in data tables with several equipment attributes. The related history data collection can be done according to published standards. • Published data handbooks (e.g. the OREDA handbook), covering aggregated sources of component data. The forecasts can depend on the publisher. Such data handbooks would normally be historic data, i.e. operating field experience. • Published data handbooks based on expert judgement, but not on historic operating data or underlying database. <p>The data can apply for one specific industry or it can be collected from several industries.</p> <p>NOTE 1 Some industrial industries can provide other data, (e.g., failure detection during test) that might be useful for establishing reliability data input.</p>
2. Operator data	<p>Reliability data on reliability indicators based on operating field experience of a single company. Such data can be established by one operator/field company from:</p> <ul style="list-style-type: none"> • In-use or several of its installations. • In-use interpretation of different data sources. • Key Performance Indicator (KPI). <p>NOTE 2 Such operator-company specific data can be part of an industrial-operator generic reliability database or partly own company data.</p> <p>NOTE 3 The data can also be part of a company database that complies with this international standard.</p> <p>NOTE 4 Some enterprises KPIs.</p> <p>NOTE 5 The events recorded in a CMMS system are not reliability data, but could be used to</p>
3. Expert judgement	<p>Each data can be based on:</p> <ul style="list-style-type: none"> • Operating field experience from <ul style="list-style-type: none"> • The manufacturer himself. The data can be aligned or not with an international standard. • The users (e.g. specific or generic data mentioned above) • Component FMECA/ studies. • Laboratory testing, e.g. accelerated life time testing, and reliability testing. This can apply for new technology equipment for which experience data not yet exist. Such pre-operational data should normally be entitled 'pre-operational/test reliability data', as opposed to actual field operating experience. See also IEC 61164-2014 for statistical tests and estimation methods for reliability growth. <p>Expert judgement would involve:</p> <ul style="list-style-type: none"> • General advice from safety system equipment expert • Use of statistical expert analysis methods (e.g. Delphi, etc.) to utilize a variety of qualified sources as input to the reliability analysis <p>[see references: see Bourne [6] et al., 1992 and Cooke, 1992]</p>
4. Human error data	<p>Various sources of human error data exist and H.2 gives some advice about human error probabilities.</p>

[Fuente: ISO 12489 Reliability Model and Calculation of Safety Systems (2013) – Section 13.2 “Reliability data sources”]

[Fuente: ISO 14224 Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment (2016) – Annex D “Typical requirements for data”, Table D.5 “Classification of reliability data sources”]



Data propia

Horno 5

$$f_i = (i - 0.5) / (n + 0.4) \quad x = \ln(r - \delta); \quad Y = \ln[-\ln(1 - F(f_i))]$$

No.	TEF	RM [F(f _i)]	Valores X	Valores Y
1	0.1670	0.034865765	-1.789761467	-5.288672364
2	0.1670	0.012108262	-1.789761467	-4.407752342
3	0.2500	0.019230769	-1.386294361	-3.941550387
4	0.2500	0.026353276	-1.386294361	-3.622839017
5	0.2500	0.033475783	-1.386294361	-3.379596825
6	0.3330	0.040598291	-1.099612789	-3.183378183
7	0.3330	0.047720798	-1.099612789	-3.018039081
8	0.3330	0.054843305	-1.099612789	-2.875256545
9	0.5000	0.061965812	-0.693147181	-2.749358519
10	0.5000	0.069088319	-0.693147181	-2.636787714
11	0.5000	0.076210826	-0.693147181	-2.534877668
12	0.5000	0.083333333	-0.693147181	-2.441716399
13	0.5830	0.090455840	-0.539568093	-2.355862158
14	0.5830	0.097578348	-0.539568093	-2.276202161
15	0.5830	0.104700855	-0.539568093	-2.201858915
16	0.6670	0.111823362	-0.404965233	-2.132128321
17	0.6670	0.118945869	-0.404965233	-2.066436774
18	0.6670	0.126068376	-0.404965233	-2.004310768
19	0.7500	0.133190883	-0.287682072	-1.945354862
20	0.7500	0.140313390	-0.287682072	-1.892325394
21	1.0000	0.147435897	0.000000000	-1.849211137
22	1.0830	0.154558405	0.079734968	-1.784409407
23	1.0830	0.161680912	0.079734968	-1.735247893
24	1.1670	0.168803419	0.154436353	-1.687989892
25	1.1670	0.175925926	0.154436353	-1.642504344
26	1.2500	0.183048433	0.223143551	-1.598619308
27	1.3330	0.190170940	0.291852042	-1.552974302
28	1.3330	0.197293447	0.287432041	-1.515191614
29	1.3330	0.204415954	0.287432041	-1.475436943
30	1.4170	0.211538462	0.346541961	-1.438685172
31	1.4170	0.218660969	0.346541961	-1.399353008
32	1.5000	0.225783476	0.405465108	-1.362954087
33	1.5000	0.232905983	0.405465108	-1.327475010
34	1.6670	0.240028490	0.511025604	-1.292897526
35	1.6670	0.247150997	0.511025604	-1.259168331
36	1.6670	0.254273504	0.511025604	-1.226230773
37	1.8330	0.261396011	0.605953969	-1.194044334
38	2.0000	0.268518518	0.693147181	-1.162564183
39	2.1670	0.275641026	0.773343723	-1.132190788
40	2.1670	0.282763533	0.773343723	-1.101567576
41	2.1670	0.289886040	0.773343723	-1.071980636

$$y = \ln \left[\ln \left(\frac{1}{1 - F(f)} \right) \right]; \quad x = \ln(r - \delta); \quad b = \beta \ln \theta \quad (****)$$

De la expresión (**) se concluye que el parámetro de escala, β, es la pendiente de la recta de regresión.

De la expresión (**) se observa que el parámetro de escala, θ, está en función del intercepto b de la recta de regresión y del parámetro de escala: por lo tanto:

Resultados de la Macro Método del Papel

Ecuación $y = 0.6995x - 1.9514$

Pendiente 0.69950000

Intercepto -1.95140000

β	0.69950000
θ	16.2762491

$$\beta = 0.6995 \quad (8)$$

Resultados Ajuste RARE - DISTEST

Ecuación $y = 0.69860771x - 1.94921137$

Pendiente 0.69860771

Intercepto -1.94921137

β	0.70216394
θ	16.2703596

Método Gráfico (Cálculo simple del Rango Medio)

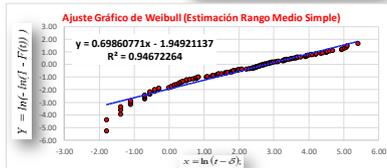
Ecuación $y = 0.69860771x - 1.94921137$

Pendiente 0.69860771

Intercepto -1.94921137

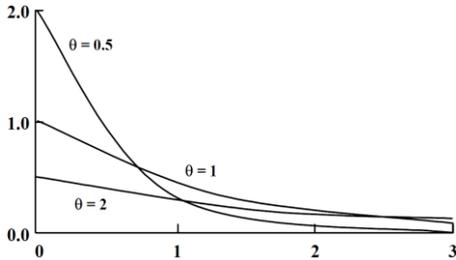
β	0.69860771
θ	16.2632539

$$\theta = e^{\frac{-(-1.9514)}{0.6995}} = 16.276 \quad (9)$$

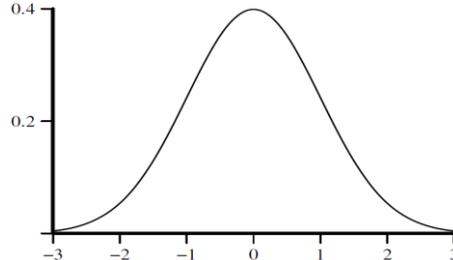


Distribuciones para ajustar datos propios

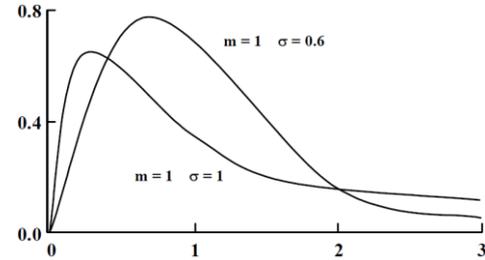
Fuente: Murphy, K. et al. (2007).- *Raptor 7.0 Tutorial Workbook*. Third edition. Raptor/Arinc



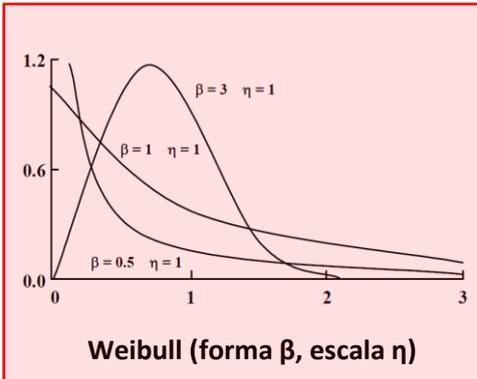
Exponencial (media θ)



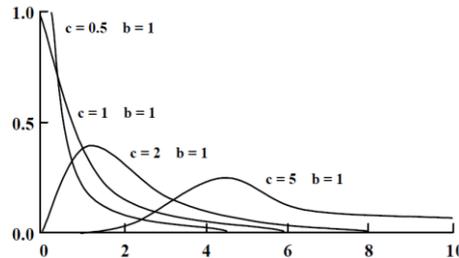
Normal (media m , desv. est. σ)



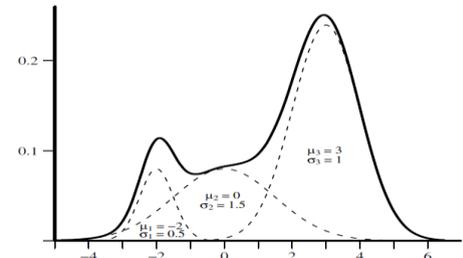
Lognormal (media m , desv. est. σ)



Weibull (forma β , escala η)



Gamma (forma c , escala b)



Multimodal



Datos propios (históricos de equipos e instalaciones)

Horno 5

i: número del registro
n: total de registros

δ : parámetro de localización (cero)

$$F_i = (i - 0.3) / (n + 0.4) \quad x = \ln(\tau - \delta); \quad Y = \ln(-\ln(1 - F(i)))$$

No.	TEF	RM [F(i)]	Valores X	Valores Y
1	0.1670	0.004985755	-1.789761467	-5.298672364
2	0.1670	0.012108262	-1.78761467	-4.407782342
3	0.2500	0.019230769	-1.386294361	-3.941550387
4	0.2500	0.026353276	-1.386294361	-3.622839017
5	0.2500	0.033475783	-1.386294361	-3.379956825
6	0.3330	0.040598291	-1.099612789	-3.163378183
7	0.3330	0.047720798	-1.099612789	-3.01803981
8	0.3330	0.054843305	-1.099612789	-2.875205445
9	0.5000	0.061965812	-0.693147181	-2.749358519
10	0.5000	0.069088319	-0.693147181	-2.636787714
11	0.5000	0.076210826	-0.693147181	-2.534877868
12	0.5000	0.083333333	-0.693147181	-2.441716399
13	0.5830	0.090455840	-0.539568093	-2.355862158
14	0.5830	0.097578348	-0.539568093	-2.276202161
15	0.5830	0.104700855	-0.539568093	-2.201858915
16	0.6670	0.111823362	-0.404965233	-2.132128321
17	0.6670	0.118945869	-0.404965233	-2.066436774
18	0.6670	0.126068376	-0.404965233	-2.004310768
19	0.7500	0.133190883	-0.287682072	-1.945354862
20	0.7500	0.140313390	-0.287682072	-1.889235394
21	1.0000	0.147435897	0.000000000	-1.835668229
22	1.0830	0.154558405	0.079734968	-1.784409407
23	1.0830	0.161680912	0.079734968	-1.735247893
24	1.1670	0.168803419	0.154436353	-1.687999892
25	1.1670	0.175925926	0.154436353	-1.642504344
26	1.2500	0.183048433	0.223143551	-1.598619308
27	1.3330	0.190170940	0.287432041	-1.556219042
28	1.3330	0.197293447	0.287432041	-1.515191614
29	1.3330	0.204415954	0.287432041	-1.475436943
30	1.4170	0.211538462	0.348541961	-1.436865172
31	1.4170	0.218660969	0.348541961	-1.399395308
32	1.5000	0.225783476	0.405465108	-1.362954087
33	1.5000	0.232905983	0.405465108	-1.327475010
34	1.6670	0.240028490	0.511025604	-1.292897526
35	1.6670	0.247150997	0.511025604	-1.259166331
36	1.6670	0.254273504	0.511025604	-1.226230773
37	1.8330	0.261396011	0.605953969	-1.194044334
38	2.0000	0.268518519	0.693147181	-1.162564183
39	2.1670	0.275641026	0.773343723	-1.131750788
40	2.1670	0.282763533	0.773343723	-1.101567576
41	2.1670	0.289886040	0.773343723	-1.071980636

$$y = \ln \left[\ln \left(\frac{1}{1 - F(i)} \right) \right]; \quad x = \ln(\tau - \delta); \quad b = \beta \ln \theta \quad (***)$$

De la expresión (***) se concluye que el parámetro de forma, β , es la pendiente de la recta de regresión.

De la expresión (***) se observa que el parámetro de escala, θ , está en función del intercepto b de la recta de regresión y del parámetro de escala, por lo tanto:

Resultados de la Macro Método del Paper

Ecuación $y = 0.6995x - 1.9514$

Pendiente 0.69950000

Intercepto -1.95140000

β 0.69950000

θ 16.2762491

$$\beta = 0.6995 \quad (8)$$

Resultados Ajuste RARE - DISTEST

Ecuación $y = 0.698607708800051x - 1.94921137$

Pendiente 0.69860771

Intercepto -1.94921137

β 0.70216394

θ 16.2703996

Método Gráfico (Cálculo simple del Rango Medio)

Ecuación $y = 0.69860771x - 1.94921137$

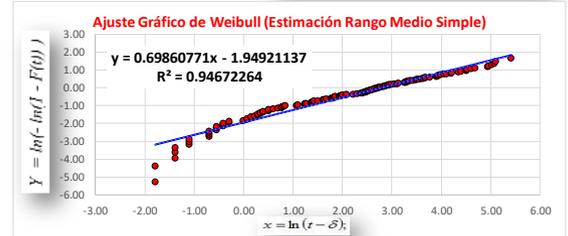
Pendiente 0.69860771

Intercepto -1.9492114

β 0.69860771

θ 16.2832539

$$\theta = e^{\left(\frac{-1.9514}{0.6995} \right)} = 16.276 \quad (9)$$



Weibull



OREDA Project

Data Genérica



Y ahora ... OREDA@Cloud



2015

Offshore and Onshore Reliability Data 6th Edition Volume 1 - Topsides Equipment

Published by the OREDA participants:

- BP Exploration Operating Company Ltd
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- Galco
- GE SUEZ E&P Norge AS
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Prepared by

View: Full | Filter: All | Operational time

Failure mode	No of Fail	Failure rate (per 10,000 hours)						Failure probability (per 10,000 hours)	Failure rate (per year)	Average time between failures (hours)	Heatmaps		
		Lower	Mean	Upper	DC	OP	DF				Mean	Max	Min
Seal	114	0.47	2.43	6.67	24.68	63.29	0.23	2.65	40.0	0.00156	3.0	3.0	3.0
High level	26	0.00	0.18	0.31	0.58	1.04	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total - total - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total - total - total - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total - total - total - total - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - total - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - total - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total - total - total - total - total - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - total - total - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - total - total - total - total - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - automatic	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0
High level - total - manual	0	0.00	0.00	0.00	0.00	0.00	0.00000	0.00	0.00	0.000000	0.0	0.0	0.0
High level - total	26	0.00	0.17	0.31	0.54	1.01	0.00008	0.28	35.0	0.000002	1.0	1.0	1.0



OREDA

Empresas participantes

Fase XIII



Participante	Fase del estudio (período)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
	81-84	85-88	89-93	94-96	97-99	00-01	02-03	04-05	06-08	09-11	12-14	15-17	18-20
1 BP Norway Limited U.A. / BP	●	●	●	●	●	●	●	●	●	●	●	●	●
2 Elf Equitaine Norge A/S / ELF	●	●	●	●	●								
3 Norsk Agip A/S / ENI / Eni S.p.S. E&P Division	●	●	●	●	●	●	●	●	●	●	●	●	●
4 A/S Norske Shell / Shell	●	●	●	●	●	●	●	●	●	●	●	●	
5 Norsk Hydro a.s.	●	●	●	●	●	●	●						
6 Den Norske stats oljeselskap a.s.	●												
7 Saga Petroleum a.s.	●	●	●	●									
8 Total Oil Marine p.l.c. / Total	●	●				●	●	●	●	●	●	●	●
9 Statoil		●	●	●	●	●	●						
10 Exxon / Esso / ExxonMobil		●	●	●	●	●	●	●	●	●	●		
11 Phillips Petroleum Company Norway / Conono		●	●	●		●	●	●	●	●	●		
12 AGIP				●	●								
13 Chevron				●	●	●							
14 Texaco					●	●							
15 Engie E&P Norge AS (former name: GDF Suez)												●	
17 Gassco								●	●	●	●	●	●
19 Petrobras S.A.												●	●
21 Equinor								●	●	●	●	●	●
23 Modec													●

- Proyecto de **mas de 40 años** (desde 1981), en **13 fases**, **20+ participantes**.
- Activos de la industria del **Oil & Gas** (costa afuera - **offshore**).
- Captura organizada de datos de confiabilidad y mantenimiento (**alta calidad**).
- Mas de **40,000 fallas** y **75,000** registros de mantenimiento en **15,000+ equipos** ubicados en **300+ instalaciones**.
- **6 ediciones** en físico (1984, 1992, 1997, 2002, 2009, 2015 hoy en electrónico).
- **Data complementaria** (puede combinarse).
- Base para **desarrolló de la norma ISO 14224** en 1999.

38 Familias de equipo (26 en superficie y 12 submarinos)**Equipos cubiertos por OREDA**

Rotating machinery	Mechanical equipment	Control & Safety	Subsea equipment
Combustion engines	Cranes	Control Logic Units	Control systems
Compressors	Heat exchangers	Fire & Gas detectors	Dry tree riser
Electric generators	Heaters and Boilers	HVAC	El. power distribution
Electric motors	Loading arms	Input devices	Flowlines
Gas turbines	Swivels	Nozzles	Manifolds
Pumps	Turrets	Power transformers	Pipelines
Steam turbines	Vessels	UPS	Production risers
Turboexpanders	Winches	Valves	Running tools
		Frequency converters	Subsea pumps
		Switchgear	Subsea vessels
			Templates
			Wellhead & X-mas trees

Alineación con la ISO-14224

Establece el límite de batería para equipos (Nivel 6)

División de los equipos en subunidades (Nivel 7)

Items Mantenibles (Nivel 8)

Define los modos de falla típicos para el tipo de equipo

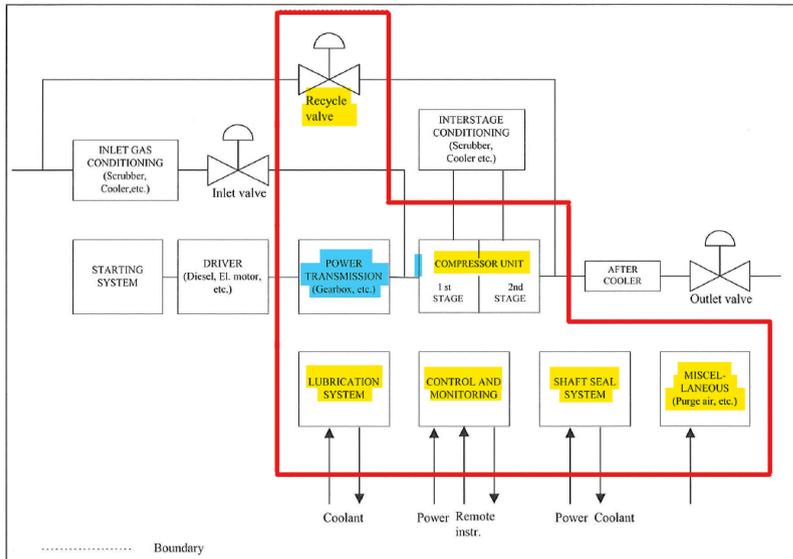


Figure 8 – Compressors, boundary definition

Table 15 – Electric Motors, subdivision in Maintainable Items

ELECTRIC MOTORS				
Electric motor	Control and monitoring ^a	Lubrication system	Cooling system	Miscellaneous
Excitation	Actuating device	Cooler	Fan ^b	Hood
Radial bearing	Control unit	Filter	Filter	
Rotor	Internal power supply	Motor	Heat exchanger	
Stator	Monitoring	Oil	Motor	
Thrust bearing	Piping	Piping	Piping	
	Seals	Pump	Pump	
	Sensors	Reservoir (incl. heating system)	Valves	
	Valves	Seals		
	Wiring	Valves		

^a Normally no extra control system for motors. For motors of Ex(p) class (pressurized) the internal pressure is monitored. Temperature may be monitored on large motors.
^b Including fan motor.
 (For all subunits the Mis "Unknown" and "Subunit" are included.)

List of Failure Modes

- AIR Abnormal instrument reading
- BRD Breakdown
- ELU External leakage - Utility medium
- ERO Erratic output
- FTS Fail to start on demand
- HIO High output
- LOO Low output
- NOI Noise
- OHE Overheating
- OTH Other
- PDE Parameter deviation
- SER Minor in-service problems
- STD Structural deficiency
- STP Fail to stop on demand
- UNK Unknown
- UST Spurious stop
- VIB Vibration

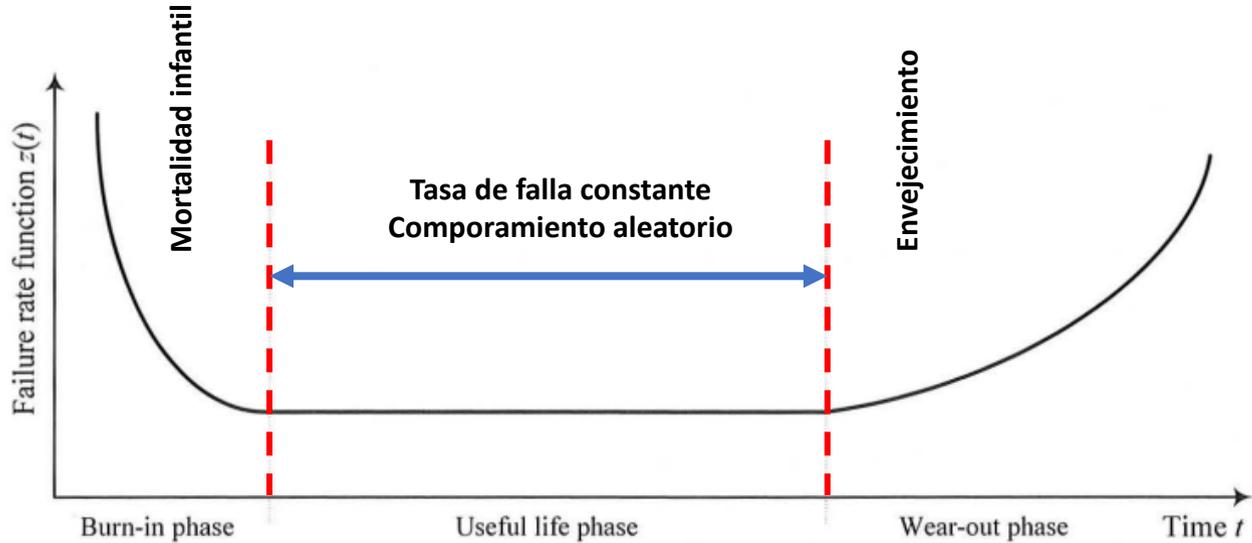
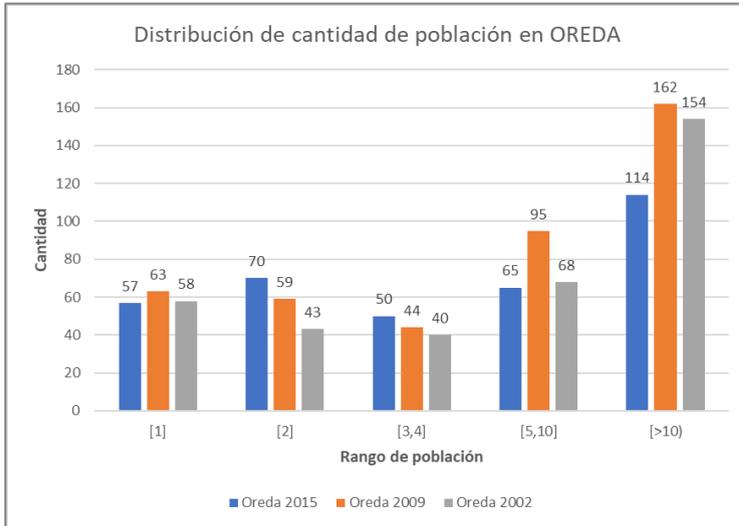


Figure 3 – Bath-tub shape of the failure rate

Población: Número total de equipos tomados para las estimaciones.

Instalaciones: Número total de instalaciones tomadas para las estimaciones.



Taxonomy no 2.2.2.9		Item Electric Equipment Electric Motors Pump Oil export					Aggregated time in service (10 ⁶ hours)				No of demands 108			
Population 12		Installations 3		Calendar time * 0.4683		Operational time † 0.3858								
Failure mode	No of failures	Failure rate (per 10 ⁶ hours)					Active rep. hrs				Manhours			
		Lower	Mean	Upper	SD	n/f	Mean	Max	Mean	Max				
Critical	13*	0.27	23.27	75.33	27.36	27.76	14	90	22	157				
	13†	2.01	28.90	76.65	25.18	33.43								
Abnormal instrument reading	2*	0.02	3.66	13.24	4.89	4.27	2.0	3.0†	2.0	3.0†				
	2†	0.07	4.32	13.85	4.90	5.14								
Breakdown	1*	0.01	3.90	15.46	5.77	2.14	14	14†	28	28†				
	1†	0.02	6.02	23.58	8.76	2.57								
External leakage - Utility medium	7*	0.05	11.49	43.85	16.16	14.95	18	90†	29	157†				
	7†	0.24	13.31	41.54	14.77	18.00								
Fail to start on demand	1*	0.01	1.94	6.64	2.45	2.14	4.0	4.0†	4.0	4.0†				
	1†	0.04	2.30	7.20	2.57	2.57								
Vibration	1*	0.01	1.94	6.64	2.45	2.14	24	24†	48	48†				
	1†	0.04	2.30	7.20	2.57	2.57								
Other	1*	0.01	1.94	6.64	2.45	2.14	4.0	4.0†	4.0	4.0†				
	1†	0.04	2.30	7.20	2.57	2.57								
Degraded	1*	0.01	1.94	6.64	2.45	2.14	1.0	1.0†	1.0	1.0†				
	1†	0.04	2.30	7.20	2.57	2.57								
Vibration	1*	0.01	1.94	6.64	2.45	2.14	1.0	1.0†	1.0	1.0†				
	1†	0.04	2.30	7.20	2.57	2.57								
Incipient	4*	1.20	9.87	25.51	7.98	8.54	49	125†	74	210†				
	4†	0.99	14.97	43.41	14.35	10.29								
Minor in-service problems	1*	3E-3	2.19	9.01	3.42	2.14	125	125†	210	210†				
	1†	0.26	2.87	7.93	2.57	2.57								
Vibration	3*	1.32	7.32	17.29	5.14	6.41	23	57†	28	70†				
	3†	1.00	11.24	31.06	10.07	7.72								
Unknown	1*	0.01	3.90	15.46	5.77	2.14	4.0	4.0†	6.0	6.0†				
	1†	0.02	6.02	23.58	8.76	2.57								
Vibration	1*	0.01	3.90	15.46	5.77	2.14	4.0	4.0†	6.0	6.0†				
	1†	0.02	6.02	23.58	8.76	2.57								
All modes	19*	19.25	39.77	66.29	14.52	40.57	20	125	31	210				
	19†	18.44	48.60	90.44	22.46	48.86								
Comments														
On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 0.0 - 10 ⁶														

Modos de falla

Critical failure: Falla que causa la pérdida inmediata de un equipo de realizar su función.

Degraded failure: Falla no crítica pero que evita que un equipo desarrolle su función bajo los rangos mínimos necesarios.

Incipient failure: Falla que no causa la pérdida de función de un equipo, pero que si no se atiende, puede llegar a ser degraded o critical.

Unknown: La severidad de la falla no pudo ser deducida o registrada.

All Modes:

Critical + Degraded + Incipient + Unknown

ISO 14224

Taxonomy no 2.2.2.9		Item Electric Equipment Electric Motors Pump Oil export									
Population 12	Installations 3	Aggregated time in service (10 ⁶ hours)					No of demands 108				
		Calendar time * 0.4683			Operational time † 0.3858		Active rep. hrs		Manhours		
Failure mode	No of failures	Failure rate (per 10 ⁶ hours)					n / t	Mean	Max	Mean	Max
		Lower	Mean	Upper	SD	n / t					
Critical	13 [*] 13 [†]	0.27 2.01	23.27 28.50	75.33 76.65	27.36 25.18	27.76 33.43		14	90	22	157
Abnormal instrument reading	2 [*] 2 [†]	0.02 0.07	3.66 4.32	13.24 13.85	4.89 4.90	4.27 5.14		2.0	3.0 [*]	2.0	3.0 [*]
Breakdown	1 [*] 1 [†]	0.01 0.02	3.90 6.02	15.46 23.58	5.77 8.76	2.14 2.57		14	14 [*]	28	28 [*]
External leakage - Utility medium	7 [*] 7 [†]	0.05 0.24	11.49 13.31	43.85 41.54	16.16 14.77	14.95 18.00		18	90 [*]	29	157 [*]
Fail to start on demand	1 [*] 1 [†]	0.01 0.04	1.94 2.30	6.64 7.20	2.45 2.57	2.14 2.57		4.0	4.0 [*]	4.0	4.0 [*]
Vibration	1 [*] 1 [†]	0.01 0.04	1.94 2.30	6.64 7.20	2.45 2.57	2.14 2.57		24	24 [*]	48	48 [*]
Other	1 [*] 1 [†]	0.01 0.04	1.94 2.30	6.64 7.20	2.45 2.57	2.14 2.57		4.0	4.0 [*]	4.0	4.0 [*]
Degraded	1 [*] 1 [†]	0.01 0.04	1.94 2.30	6.64 7.20	2.45 2.57	2.14 2.57		1.0	1.0 [*]	1.0	1.0 [*]
Vibration	1 [*] 1 [†]	0.01 0.04	1.94 2.30	6.64 7.20	2.45 2.57	2.14 2.57		1.0	1.0 [*]	1.0	1.0 [*]
Incipient	4 [*] 4 [†]	1.20 0.99	9.87 14.97	25.51 43.41	7.98 14.35	8.54 10.29		49	125 [*]	74	210 [*]
Minor in-service problems	1 [*] 1 [†]	3E-3 0.26	2.19 2.87	9.01 7.93	3.42 2.57	2.14 2.57		125	125 [*]	210	210 [*]
Vibration	3 [*] 3 [†]	1.32 1.00	7.32 11.24	17.29 31.06	5.14 10.07	6.41 7.72		23	57 [*]	28	70 [*]
Unknown	1 [*] 1 [†]	0.01 0.02	3.90 6.02	15.46 23.58	5.77 8.76	2.14 2.57		4.0	4.0 [*]	6.0	6.0 [*]
Vibration	1 [*] 1 [†]	0.01 0.02	3.90 6.02	15.46 23.58	5.77 8.76	2.14 2.57		4.0	4.0 [*]	6.0	6.0 [*]
All modes	19 [*] 19 [†]	19.25 18.44	39.77 48.60	66.29 90.44	14.52 22.46	40.57 48.86		20	125	31	210
Comments											
On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 0.0 - 10 ⁶											



Modos de falla

Critical failure: Falla que causa la pérdida inmediata de un equipo de realizar su función.

Degraded failure: Falla no crítica pero que evita que un equipo desarrolle su función bajo los rangos mínimos necesarios.

Incipient failure: Falla que no causa la pérdida de función de un equipo, pero que si no se atiende, puede llegar a ser degraded o critical.

Unknown: La severidad de la falla no pudo ser deducida o registrada.

Fuente Taxonomía	Descripción	Distribución de TTF según tipo de falla				Porcentaje de falla total		
		Fallo crit.	Fallo degr.	Fallo incip.	Desc.	0%	50%	100%
OREDA 2009 1.3.1.5	Electric generator, Turbine driven (gas, steam)	100.00%						
OREDA 2015 3.3.2	Valves described by application, ESD, Ball (5.1-10) inch	90.63%	9.37%					
OREDA 2015 3.2.7	Compressors, Centrifugal Turbine	64.18%	25.37%	10.45%				
OREDA 2009 2.1.2.2.2	Gas turbine	60.00%		40.00%				
OREDA 2015 1.1.2	Vessels, Flash Drum	48.45%	37.32%	13.26%	0.98%			
OREDA 2015 3.2.4	Input Devices, Pressure	46.40%	53.50%					
OREDA 2009 2.2.1	Electric motors, Compressor	42.37%	18.64%	33.89%	5.08%			
OREDA 2015 4.4.2.1	Valves described by application, Shut-Off	41.62%	19.18%	37.61%	1.59%			
OREDA 2015 4.2.3	Valves described by application, ESD, Ball (1.1-5.0) inch	35.82%	43.28%	21.64%				
OREDA 2015 1.1.1.4	Pumps, Centrifugal Fan, Vent and blowdown	31.14%	36.25%	32.12%	0.49%			
OREDA 2015 4.4.5.1.2	Heat exchangers, Plate Fin	28.59%	14.30%	57.18%				
OREDA 2009 1.1.3	Heaters and boilers, Electric Boiler	27.15%	32.30%	38.49%	2.06%			
OREDA 2015 4.4.5.1.1	Valves described by application, ESD, Ball (10.1-20) inch	25.03%	25.03%	50.00%				
OREDA 2015 4.4.5.1.5	Control Logic Units	24.99%	24.99%	50.01%				
OREDA 2009 4.4.10	Control Logic Unit, Process control	18.94%	54.07%	27.04%				
OREDA 2015 4.4.12.3	Input Devices, Flow	16.71%		83.29%				
OREDA 2015 1.3.1.2	Vessels, Scrubber	15.38%	63.46%	19.23%	1.92%			
OREDA 2015 4.4.13	Input Devices, Temperature	11.11%	77.78%	11.11%				
OREDA 2015 4.4.5.1.3	Control Logic Units, F&G detection	7.67%	15.39%	76.90%				
OREDA 2009 3.1.2	Valves described by application, Blowdown, Ball	6.06%	48.49%	45.46%				
OREDA 2015 4.3.2	Valves described by application, Relief, PSV Conventional		100.00%					
OREDA 2015 4.3	Valves described by application, Process control		50.02%	50.02%				
OREDA 2015 4.2.1	Compressors, Screw				100.00%			
OREDA 2015 4.2.4	Valves described by application, ESD, Ball (30.1-40) inch				100.00%			
OREDA 2015 4.3.3	Pumps, Centrifugal, Condensate processing				100.00%			
EXIDA 2003 1.2.3	Indicador y transmisor de flujo				100.00%			
EXIDA 2003 1.6.2	Indicador y transmisor de temperatura				100.00%			
IEEE-493:2007	Burner				100.00%			
IEEE-493:2007	Burner separator				100.00%			
IEEE-493:2007	Condensate Tank				100.00%			
IEEE-493:2007 H20-100	Air Pre Filter				100.00%			
IEEE-493:2007 H20-300	Air Post Filters				100.00%			
IEEE-493:2007 H4-000	Air dryer				100.00%			

Modos de falla

No. Failures: Falla que causa la pérdida inmediata de un equipo de realizar su función.

* : Basado en tiempo calendario

† : Basado en tiempo operacional

$\frac{n}{\tau}$: Falla que causa la pérdida inmediata de un equipo de realizar su función.

$$\lambda = \frac{n}{\tau} = \frac{19}{0.3888 (106 \text{ hrs})} = 48.86 \text{ (por } 10^6 \text{ hrs)}$$

$$MTBF = \frac{\tau}{n} = \frac{10^6 \text{ hrs}}{48.86} = 20466 \text{ hrs}$$

Taxonomy no 2.2.2.9		Item Electric Equipment Electric Motors Pump Oil export									
Population 12	Installations 3	Aggregated time in service (10 ⁶ hours)						No of demands 108			
		Calendar time * 0.4683			Operational time † 0.3888			Mean		Max	
Failure mode		No of failures	Failure rate (per 10 ⁶ hours)					Active rep. hrs		Manhours	
			Lower	Mean	Upper	SD	n/fc	Mean	Max	Mean	Max
Critical		13 [†]	0.27	23.27	75.33	27.36	27.76	14	90	22	157
Abnormal instrument reading		13 [†]	2.01	26.90	76.65	26.18	33.43				
		2 [†]	0.02	3.66	13.24	4.89	4.27	2.0	3.0 [†]	2.0	3.0 [†]
Breakdown		2 [†]	0.07	4.32	13.65	4.90	5.14				
		1 [†]	0.01	3.90	15.46	5.77	2.14	14	14 [†]	28	28 [†]
		1 [†]	0.02	6.02	23.58	8.76	2.57				
External leakage - Utility medium		7 [†]	0.05	11.49	43.85	16.16	14.95	18	90 [†]	29	157 [†]
		7 [†]	0.24	13.31	41.54	14.77	18.00				
Fail to start on demand		1 [†]	0.01	1.94	6.64	2.45	2.14	4.0	4.0 [†]	4.0	4.0 [†]
		1 [†]	0.04	2.30	7.20	2.57	2.57				
Vibration		1 [†]	0.01	1.94	6.64	2.45	2.14	24	24 [†]	48	48 [†]
		1 [†]	0.04	2.30	7.20	2.57	2.57				
Other		1 [†]	0.01	1.94	6.64	2.45	2.14	4.0	4.0 [†]	4.0	4.0 [†]
		1 [†]	0.04	2.30	7.20	2.57	2.57				
Degraded		1 [†]	0.01	1.94	6.64	2.45	2.14	1.0	1.0 [†]	1.0	1.0 [†]
		1 [†]	0.04	2.30	7.20	2.57	2.57				
Vibration		1 [†]	0.01	1.94	6.64	2.45	2.14	1.0	1.0 [†]	1.0	1.0 [†]
		1 [†]	0.04	2.30	7.20	2.57	2.57				
Incipient		4 [†]	1.20	9.87	25.51	7.98	8.54	49	125 [†]	74	210 [†]
		4 [†]	0.99	14.97	43.41	14.35	10.29				
Minor in-service problems		1 [†]	3E-3	2.19	9.01	3.42	2.14	125	125 [†]	210	210 [†]
		1 [†]	0.26	2.87	7.93	2.57	2.57				
Vibration		3 [†]	1.32	7.32	17.29	5.14	6.41	23	57 [†]	28	70 [†]
		3 [†]	1.00	11.24	31.06	10.07	7.72				
Unknown		1 [†]	0.01	3.90	15.46	5.77	2.14	4.0	4.0 [†]	6.0	6.0 [†]
		1 [†]	0.02	6.02	23.58	8.76	2.57				
Vibration		1 [†]	0.01	3.90	15.46	5.77	2.14	4.0	4.0 [†]	6.0	6.0 [†]
		1 [†]	0.02	6.02	23.58	8.76	2.57				
All modes		19 [†]	19.25	39.77	66.29	14.52	40.57	20	125	31	210
		19 [†]	18.44	48.60	90.44	22.46	48.86				

Comments

On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 0.0 - 10³

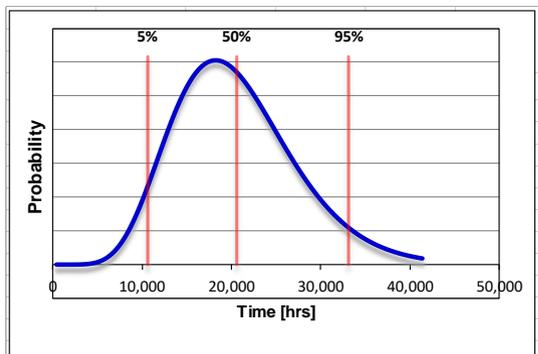


Tasa de falla (Distribución Gamma)

Intervalo de Certeza de 90%

Lower: (05%)

Upper: (95%)



Distribution	Gamma
Parameter 1 (Shape)	8.8
Parameter 2 (Scale)	2,337.0
Parameter 3 (Location)	0.0
Lower (5%)	10,644.0
Median (50%)	19,802.0
Upper (95%)	33,147.0
Mean	20,576.0
Standard Deviation (SD)	6,934.0
Variance	48,086,441.0

Taxonomy no 2.2.2.9		Item Electric Equipment Electric Motors Pump Oil export								
Population 12	Installations 3	Aggregated time in service (10 ⁶ hours)					No of demands 108			
		Calendar time * 0.4683		Operational time † 0.3888			Active rep. hrs		Manhours	
Failure mode	No of failures	Failure rate (per 10 ⁶ hours)					Mean	Max	Mean	Max
		Lower	Mean	Upper	SD	n/f				
Critical	13 [†]	0.27	23.27	75.33	27.36	27.76	14	90	22	157
	13 [†]	2.01	28.90	76.65	25.18	33.43				
Abnormal instrument reading	2 [†]	0.02	3.66	13.24	4.89	4.27	2.0	3.0 [†]	2.0	3.0 [†]
	2 [†]	0.07	4.32	13.85	4.90	5.14				
Breakdown	1 [†]	0.01	3.90	15.46	5.77	2.14	14	14 [†]	28	28 [†]
	1 [†]	0.02	6.02	23.58	8.76	2.57				
External leakage - Utility medium	7 [†]	0.05	11.49	43.85	16.16	14.95	18	90 [†]	29	157 [†]
	7 [†]	0.24	13.31	41.54	14.77	18.00				
Fail to start on demand	1 [†]	0.01	1.94	6.64	2.45	2.14	4.0	4.0 [†]	4.0	4.0 [†]
	1 [†]	0.04	2.30	7.20	2.57	2.57				
Vibration	1 [†]	0.01	1.94	6.64	2.45	2.14	24	24 [†]	48	48 [†]
	1 [†]	0.04	2.30	7.20	2.57	2.57				
Other	1 [†]	0.01	1.94	6.64	2.45	2.14	4.0	4.0 [†]	4.0	4.0 [†]
	1 [†]	0.04	2.30	7.20	2.57	2.57				
Degraded	1 [†]	0.01	1.94	6.64	2.45	2.14	1.0	1.0 [†]	1.0	1.0 [†]
	1 [†]	0.04	2.30	7.20	2.57	2.57				
Vibration	1 [†]	0.01	1.94	6.64	2.45	2.14	1.0	1.0 [†]	1.0	1.0 [†]
	1 [†]	0.04	2.30	7.20	2.57	2.57				
Incipient	4 [†]	1.20	9.87	25.51	7.98	8.54	49	125 [†]	74	210 [†]
	4 [†]	0.99	14.97	43.41	14.35	10.29				
Minor in-service problems	1 [†]	3E-3	2.19	9.01	3.42	2.14	125	125 [†]	210	210 [†]
	1 [†]	0.26	2.87	7.93	2.57	2.57				
Vibration	3 [†]	1.32	7.32	17.29	5.14	6.41	23	57 [†]	28	70 [†]
	3 [†]	1.00	11.24	31.06	10.07	7.72				
Unknown	1 [†]	0.01	3.90	15.46	5.77	2.14	4.0	4.0 [†]	6.0	6.0 [†]
	1 [†]	0.02	6.02	23.58	8.76	2.57				
Vibration	1 [†]	0.01	3.90	15.46	5.77	2.14	4.0	4.0 [†]	6.0	6.0 [†]
	1 [†]	0.02	6.02	23.58	8.76	2.57				
All modes	19 [†]	19.25	39.77	66.29	14.52	40.57	20	125	31	210
	19 [†]	18.44	48.60	90.44	22.46	48.86				

Comments

On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 0.0 - 10⁶



Active rep. hrs: tiempo calendario (Mean, Max) requerido para reparar hasta restaurar su función.

No está incluido:

- El tiempo para apagar la unidad
- Tiempo de emisión de orden de trabajo
- Tiempo de espera de refacciones
- Retrasos logísticos
- Tiempo para puesta en marcha post-reparación.
- Otros

OREDA indica que se debe aplicar un criterio de aceptación por parte del experto a la hora de utilizar estos valores, dado que estos valores presentados en oportunidades son basados en estimación.

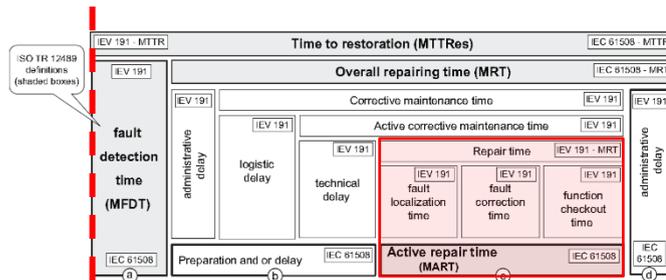
Taxonomy no 2.2.2.9		Item Electric Equipment Electric Motors Pump Oil export					Population 12		Installations 3		Aggregated time in service (10 ⁶ hours) 0.4683					No of demands 108			
		Calendar time *			Operational time † 0.3858						Active rep. hrs		Manhours						
Failure mode		No of failures	Failure rate (per 10 ⁶ hours)				Mean	Max	Mean	Max									
			Lower	Mean	Upper	SD	n/t												
Critical	13*	0.27	23.27	75.33	27.36	27.76	14	90	22	157									
	13†	2.01	28.90	76.65	25.18	33.43													
Abnormal instrument reading	2*	0.02	3.66	13.24	4.89	4.27	2.0	3.0†	2.0	3.0†									
	2†	0.07	4.32	13.85	4.90	5.14													
Breakdown	1*	0.01	3.90	15.46	5.77	2.14	14	14†	28	28†									
	1†	0.02	6.02	23.58	8.76	2.57													
External leakage - Utility medium	7*	0.05	11.49	43.85	16.16	14.95	18	90†	29	157†									
	7†	0.24	13.31	41.54	14.77	18.00													
Fail to start on demand	1*	0.01	1.94	6.64	2.45	2.14	4.0	4.0†	4.0	4.0†									
	1†	0.04	2.30	7.20	2.57	2.57													
Vibration	1*	0.01	1.94	6.64	2.45	2.14	24	24†	48	48†									
	1†	0.04	2.30	7.20	2.57	2.57													
Other	1*	0.01	1.94	6.64	2.45	2.14	4.0	4.0†	4.0	4.0†									
	1†	0.04	2.30	7.20	2.57	2.57													
Degraded	1*	0.01	1.94	6.64	2.45	2.14	1.0	1.0†	1.0	1.0†									
	1†	0.04	2.30	7.20	2.57	2.57													
Vibration	1*	0.01	1.94	6.64	2.45	2.14	1.0	1.0†	1.0	1.0†									
	1†	0.04	2.30	7.20	2.57	2.57													
Incipient	4*	1.20	9.87	25.51	7.98	8.54	49	125†	74	210†									
	4†	0.99	14.97	43.41	14.35	10.29													
Minor in-service problems	1*	3E-3	2.19	9.01	3.42	2.14	125	125†	210	210†									
	1†	0.26	2.87	7.93	2.57	2.57													
Vibration	3*	1.32	7.32	17.29	5.14	6.41	23	57†	28	70†									
	3†	1.00	11.24	31.06	10.07	7.72													
Unknown	1*	0.01	3.90	15.46	5.77	2.14	4.0	4.0†	6.0	6.0†									
	1†	0.02	6.02	23.58	8.76	2.57													
Vibration	1*	0.01	3.90	15.46	5.77	2.14	4.0	4.0†	6.0	6.0†									
	1†	0.02	6.02	23.58	8.76	2.57													
All modes	19*	19.25	39.77	66.29	14.52	40.57	20	125	31	210									
	19†	18.44	48.60	90.44	22.46	48.86													

On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 0.0 - 10⁶

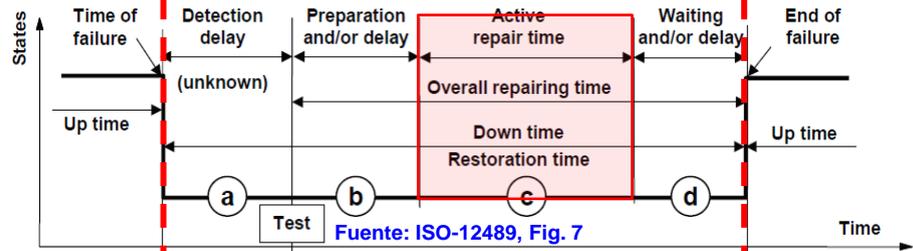


- Tiempo llave en mano
- Wrench Time
- Active Time

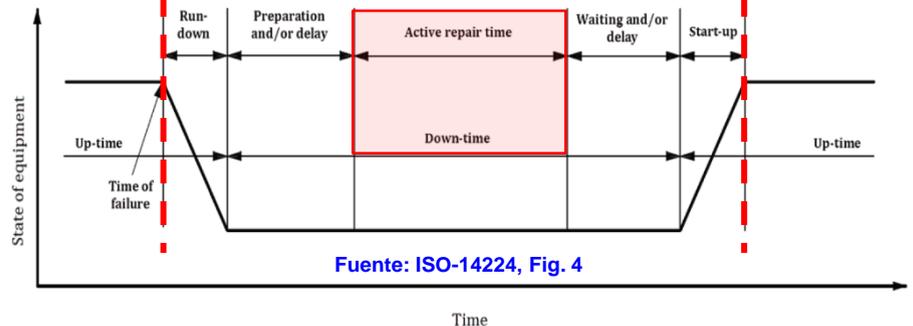
OREDA hace mención a la figura 4 de la norma ISO-14224.



Fuente: ISO-12489, Fig. 5



Fuente: ISO-12489, Fig. 7



Fuente: ISO-14224, Fig. 4



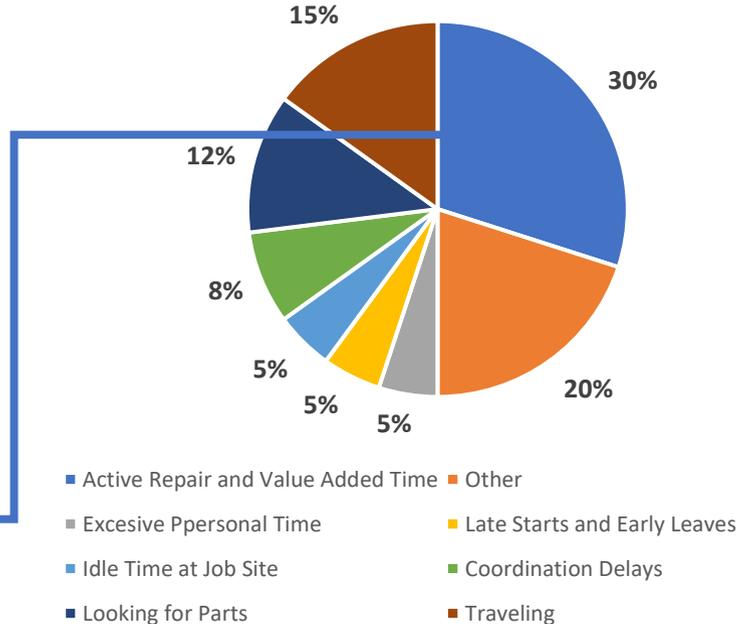
Tiempo Activo de Reparación:

El “**tiempo activo o de llave**”, como usualmente se le conoce en la industria, se ubica tan sólo en el rango del **25% al 35%** para el **promedio** de las industrias [Shickel (2020), Palmer, R. (2006), Wireman (2015) y Gulati, R. (2013)] con valores **bajos extremos del 20%** [Wireman (2015)] y valores topes **clase mundial del 60%** [Gulati, R. (2013), Wireman (2015)], aun cuando Palmer asegura que mantenerlo de manera continua en 60% es prácticamente imposible y que la banda del 50% al 55% es más representativa para las empresas clase mundial.

Tiempo activo
Tiempo fuera de servicio
30%

Fuente: Shickel (2020)

Distribución del Tiempo fuera de servicio (Down Time) (%)



Durante la fase de O&M Tiempo Fuera de Servicio (Down-time)

Distribución de tiempos registrada por Palmer (2006) en varios estudios de campo realizados entre los años 1990 a 1993.

Categoría	Ref. 1			Ref. 2	Ref. 1&2		
	1990	1991	1993	1993	Prom	Min	Max
Tiempo activo ("wrench time")	37.45	37.70	35.08	38.54	37.19	35.08	38.54
Viajando a/desde sitio de trabajo	22.03	21.46	15.33	14.24	18.27	14.24	22.03
Asignación del trabajo	3.95	5.14	1.80	11.11	5.50	1.80	11.11
Inicio retrasado / fin de labores adelantado	6.05	5.95	7.87	3.82	5.92	3.82	7.87
En espera de materiales/repuestos	2.18	1.37	2.76	5.90	3.05	1.37	5.90
En espera de herramientas	2.18	4.10	4.83	1.74	3.21	1.74	4.83
Esperando/recibiendo instrucciones	3.15	2.81	3.87	6.60	4.11	2.81	6.60
Retrasos por permisología	0.56	0.88	0.69	0.35	0.62	0.35	0.88
Esperando que otro trabajo termine (interferencia)	2.26	1.45	0.28	0.35	1.09	0.28	2.26
Esperando por operaciones	1.86	0.96	1.24	0.69	1.19	0.69	1.86
Retrasos por el clima	0.00	0.56	0.00	0.00	0.14	0.00	0.56
Reuniones	0.56	0.40	0.28	2.08	0.83	0.28	2.08
Entrenamiento	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Personal inactivo (sin razón para estarlo)	1.86	2.97	2.21	0.35	1.85	0.35	2.97
En el baño	0.80	0.80	1.24	0.00	0.71	0.00	1.24
Descansos (autorizados/programados)	10.90	10.21	13.67	8.33	10.78	8.33	13.67
Personal en asuntos personales	0.16	0.16	0.97	1.04	0.58	0.16	1.04
Otros	0.10	0.03	0.01	0.35	0.12	0.01	0.35
No contabilizado (personal no visto en el área)	3.95	3.05	7.87	4.51	4.85	3.05	7.87
Total	100.00	100.00	100.00	100.00	100.00		

37%

Fuente: Palmer

Palmer, Richard (2006).- Maintenance Planning and Scheduling Handbook. Editorial McGraw-Hill, segunda edición
Ref. 1: Palmer (2006), Apéndice H Ref. 2: Palmer (2006), Apéndice G



Disponibilidad

$$A_o = \frac{MTTF}{MTTF + MTTR}$$

$$\lambda = \frac{n}{\tau} = \frac{19}{0.3888} = 48.86$$

$$MTTF = \frac{1}{\lambda} = 0.0204$$

$$A_o = \frac{0.0204 * 10^6}{0.0204 * 10^6 + 20 * (3)} = 99.71\%$$

Taxonomy no 2.2.2.9		Item Electric Equipment Electric Motors Pump Oil export									
Population 12	Installations 3	Aggregated time in service (10 ⁶ hours)					No of demands 108				
		Calendar time * 0.4683		Operational time † 0.3888			Active rep. hrs		Manhours		
Failure mode		No of failures	Failure rate (per 10 ⁶ hours)				Mean	Max	Mean	Max	
			Lower	Mean	Upper	SD	n/fc				
Critical	13 [†]	0.27	23.27	75.33	27.36	27.76	14	90	22	157	
	13 [‡]	2.01	26.90	76.65	26.18	33.43					
Abnormal instrument reading	2 [‡]	0.02	3.66	13.24	4.89	4.27	2.0	3.0 [†]	2.0	3.0 [†]	
	2 [†]	0.07	4.32	13.65	4.90	5.14					
Breakdown	1 [†]	0.01	3.90	15.46	5.77	2.14	14	14 [†]	28	28 [†]	
	1 [‡]	0.02	6.02	23.58	8.76	2.57					
External leakage - Utility medium	7 [†]	0.05	11.49	43.85	16.16	14.95	18	90 [†]	29	157 [†]	
	7 [‡]	0.24	13.31	41.54	14.77	18.00					
Fail to start on demand	1 [†]	0.01	1.94	6.64	2.45	2.14	4.0	4.0 [†]	4.0	4.0 [†]	
	1 [‡]	0.04	2.30	7.20	2.57	2.57					
Vibration	1 [†]	0.01	1.94	6.64	2.45	2.14	24	24 [†]	48	48 [†]	
	1 [‡]	0.04	2.30	7.20	2.57	2.57					
Other	1 [†]	0.01	1.94	6.64	2.45	2.14	4.0	4.0 [†]	4.0	4.0 [†]	
	1 [‡]	0.04	2.30	7.20	2.57	2.57					
Degraded	1 [†]	0.01	1.94	6.64	2.45	2.14	1.0	1.0 [†]	1.0	1.0 [†]	
	1 [‡]	0.04	2.30	7.20	2.57	2.57					
Vibration	1 [†]	0.01	1.94	6.64	2.45	2.14	1.0	1.0 [†]	1.0	1.0 [†]	
	1 [‡]	0.04	2.30	7.20	2.57	2.57					
Incipient	4 [†]	1.20	9.87	25.51	7.98	8.54	49	125 [†]	74	210 [†]	
	4 [‡]	0.99	14.97	43.41	14.35	10.29					
Minor in-service problems	1 [†]	3E-3	2.19	9.01	3.42	2.14	125	125 [†]	210	210 [†]	
	1 [‡]	0.26	2.87	7.93	2.57	2.57					
Vibration	3 [†]	1.32	7.32	17.29	5.14	6.41	23	57 [†]	28	70 [†]	
	3 [‡]	1.00	11.24	31.06	10.07	7.72					
Unknown	1 [†]	0.01	3.90	15.46	5.77	2.14	4.0	4.0 [†]	6.0	6.0 [†]	
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Vibration	1 [†]	0.01	3.90	15.46	5.77	2.14	4.0	4.0 [†]	6.0	6.0 [†]	
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All modes	19 [†]	19.25	39.77	66.29	14.52	40.57	20	125	31	210	
	19 [‡]	18.44	48.60	90.44	22.46	48.86					

Comments

On demand probability for consequence class: Critical and failure mode: Fail to start on demand = 0.0 · 10⁶



Maintainable item versus failure mode, to be continued

Item: Electric Motors

	AIR	BRD	ELU	FTS	LOO	NOI	OHE	OTH
Actuating device	-	-	-	0.75	-	-	-	-
Cabling & junction boxes	-	-	-	3.76	-	-	-	-
Casing	-	-	-	-	-	-	-	-
Circuit breaker	-	-	-	0.75	-	-	-	-
Control unit	0.75	-	-	1.50	-	-	-	0.75
Cooler(s)	-	-	0.75	0.75	-	-	-	-
Excitation	-	-	-	-	-	-	-	-
Fan	-	-	-	-	-	0.75	-	-
Fan w/motor	-	-	-	-	-	-	4.51	-
Hood	-	-	-	-	-	-	-	1.50
Instrument, current	-	-	-	-	-	-	-	-
Instrument, frequency/RPM	-	-	-	-	0.75	-	-	-
Instrument, general	3.76	-	-	2.26	-	-	-	-
Instrument, temperature	-	-	-	0.75	-	-	-	-
Instrument, vibration	-	-	-	-	-	-	-	-
Internal power supply	-	-	-	3.76	-	-	-	-
Motor	-	-	1.50	-	-	-	-	-
Other	-	-	0.75	2.26	-	-	-	2.26
Overload protection	-	0.75	-	1.50	-	-	-	-
Piping	-	-	2.26	-	-	1.50	-	-
Radial bearing	-	-	-	-	-	-	-	-
Reservoir incl. heating system	-	-	-	0.75	-	-	-	-
Rotor	-	-	-	-	0.75	-	-	-
Seals	-	0.75	-	-	-	-	-	-
Stator	-	0.75	-	-	-	0.75	-	-
Subunit	-	1.50	-	-	0.75	-	-	-
Thrust bearing	-	-	-	-	-	2.26	-	-
Unknown	2.26	1.50	0.75	0.75	-	-	0.75	3.76
Valves	-	-	0.75	-	-	-	-	-
Total	6.77	5.26	6.77	19.55	2.26	5.26	5.26	8.27

Failure mechanism versus failure mode, to be continued

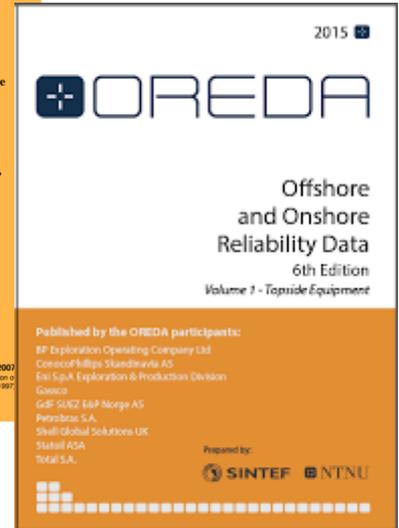
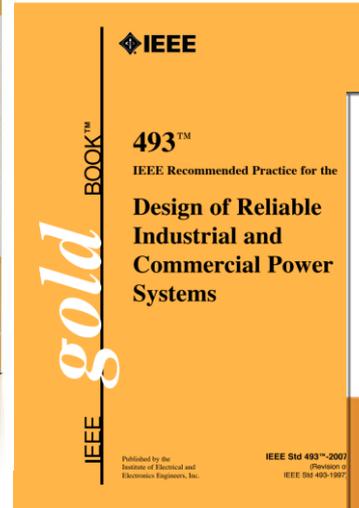
Item: Electric Motors

	AIR	BRD	ELU	FTS	LOO	NOI	OHE	OTH
Blockage/plugged	-	-	-	0.75	-	-	-	-
Breakage	-	1.50	-	-	-	-	0.75	-
Clearance/ alignment failure	-	-	-	-	-	-	-	-
Combined causes	-	-	-	-	-	-	-	0.75
Common mode failure	-	-	-	-	-	-	-	-
Control failure	0.75	-	-	3.76	-	-	-	0.75
Corrosion	-	-	-	-	-	-	-	-
Earth/isolation fault	-	0.75	-	-	-	-	-	0.75
Electrical failure - general	-	1.50	-	8.27	-	-	2.26	0.75
Erosion	-	-	-	-	-	-	-	-
Fatigue	-	-	-	-	0.75	-	-	-
Faulty power/voltage	-	-	-	0.75	0.75	-	-	0.75
Faulty signal/indication/alarm	1.50	-	-	-	-	-	-	-
Instrument failure - general	3.76	-	-	2.26	-	-	-	-
Leakage	-	-	6.77	-	-	-	-	-
Looseness	-	-	-	-	-	0.75	-	-
Material failure - general	-	-	-	-	-	-	-	2.26
Mechanical Failure - general	-	0.75	-	-	0.75	4.51	2.26	-
No power/ voltage	-	-	-	1.50	-	-	-	-
No signal/indication/alarm	0.75	-	-	0.75	-	-	-	-
Out of adjustment	-	-	-	-	-	-	-	0.75
Overheating	-	0.75	-	-	-	-	-	-
Short circuiting	-	-	-	0.75	-	-	-	-
Sticking	-	-	-	-	-	-	-	-
Unknown	-	-	-	-	-	-	-	1.50
Vibration	-	-	-	0.75	-	-	-	-
Total	6.77	5.26	6.77	19.55	2.26	5.26	5.26	8.27



OTRAS FUENTES GENÉRICAS

Vs



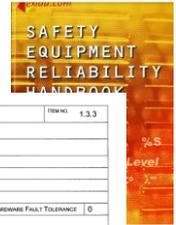
Exida - Estudios SIL/SIS



Safety Equipment Reliability Handbook - 4th Edition



The SERH provides a collection of failure rate data that is applicable for use in Safety Instrumented System (SIS) conceptual design verification in the process industry. The Safety



EQUIPMENT ITEM: Generic Radar Level Transmitter		ITEM NO: 1.3.3				
GENERAL INFORMATION						
MANUFACTURER	Generic equipment					
MODEL	—					
ANALOG/DIGITAL	Analog					
MEASUREMENT TYPE	Level - Radar					
ARCHITECTURE TYPE	B	HARDWARE FAULT TOLERANCE: 0				
DATA SOURCE	exida Comprehensive Analysis					
REVISIONS	None					
FAILURE RATE DATA						
		Per 10 ⁶ HOURS (FIT)				
FAIL LOW	1500					
FAIL HIGH	600					
FAIL DANGEROUS UNDETECTED						
FAIL DANGEROUS UNDETECTED	400					
FAIL SAFE UNDETECTED						
FAIL SAFE UNDETECTED						
FAIL NO EFFECT						
SFF (%)	84.0					
APPLICATION EXAMPLE						
APPLICATION	PLC DETECTION BEHAVIOR	λ^{LD}	λ^{SD}	λ^{SU}	λ^{DU}	SFF (%)
Low Trip	< 4 mA	1500				60.0
Low Trip	> 20 mA		1500	600	400	84.0
Low Trip	< 4 mA & > 20 mA	1500		600	400	84.0
High Trip	< 4 mA		600	1500	400	84.0
High Trip	> 20 mA	600			1900	24.0
High Trip	< 4 mA & > 20 mA	600		1500	400	84.0
High Trip	-			600	1900	24.0

Generic Heat Detector	Generic 2-/3-Wire RTD	Moore Industries TRY-DIN	Moore Industries ECT 4-wire Isolator	Pepperl+Fuchs KFD2-SL-Ex 1.48
Generic IR Gas Detector	Generic 4-Wire RTD	Rosemount 3144P	Moore Industries ECT Splitter	Pepperl+Fuchs KFD2-SL-4
Det-Tronics X3301	Honeywell STT 250	WIKA T32 HART	Pepperl+Fuchs ED2-STC (V) 4-* (2-wire)	Pepperl+Fuchs KFD2-SL2-Ex 1.**
Generic Flow Switch	Rosemount 3051C	Yokogawa YTA	Pepperl+Fuchs KFA*-SOT2-Ex*	Generic 2-Way Solenoid
Generic Flow Transmitter-Corolis Meter	Rosemount 3051S	Generic Flame Scanner	Pepperl+Fuchs KFA*-SR2_ Ex*	Generic 3-Way Solenoid
Generic Flow Transmitter-Mag Meter	Rosemount 3051T	Generic Limit Switch	Pepperl+Fuchs KFD2-HMM-16	Generic 4-Way Solenoid
Rosemount 8800C	Siemens SITRANS P, DS III	Generic Piezoelectric Vibration Switch	Pepperl+Fuchs KFD2-SOT2-Ex*	Generic Booster Relay
Generic Level Switch	Smr LD290, LD291, and LD301	Generic Push Button	Pepperl+Fuchs KFD2-SR2-Ex*	Generic I/P Transducer
Generic Level Transmitter	SOR SGT	Generic Analog Input/Trip Amplifier	Pepperl+Fuchs KFD2-SR2-Ex2.2S	Generic Motor Speed Drive Interrupt
Generic Radar Level Transmitter	Yokogawa EJA	Generic Intrinsic Barrier	Pepperl+Fuchs KFD2-ST2-Ex*	Generic Motor Starter
Endress+Hauser FTL 325N+FEL58	Generic Proximity Switch	Generic Isolated Switch Amplifier	Pepperl+Fuchs KFD2-STC(V)4-* (2-wire)	Generic Quick Exhaust Valve
Endress+Hauser FTL325P+FEL57	Pepperl+Fuchs NCB2-V3-N0*/NOCN4-V3-N0*	Generic Relay	Pepperl+Fuchs KFD2-STC(V)4-* (3-wire)	Fisher cnpntrls DVC6000 0-20 mA
Endress+Hauser Micropilot M FMR 23*	Pepperl+Fuchs NCB2-12GM35-N0/NCN4-12GM35-N0	Generic Time Delay Relay	Generic Intrinsic Safety Barrier	Fisher Controls DVC6000 4-20 mA
Endress+Hauser Micripilot M FMR 24*	Pepperl+Fuchs NCB5-18GM40-N0/NCN8-18GM40-N0	Generic Transmitter Supply Isolator	Generic Solenoid Driver	Metso Automation VG 800
Magnetrol Eclipse Model 705	Pepperl+Fuchs NCN-F31*-N4*	Elcon Hid 2026(SK)	Generic Tome Delay Relay	Bettis CB-Series
Magnetrol Eclipse Model 708	Pepperl+Fuchs SC2-N0/SC3,5-N0	Elcon Hid 2030 (SK)	Pepperl+Fuchs GmbH	Bettis G-Series
Generic DP/Pressure Switch	Pepperl+Fuchs SJ2-N*/SJ3,5-*N*	Elcon Hid 2842	Pepperl+Fuchs KFD2-SD-Ex1.17	Generic Air Operated Ball Valve
Generic DP/Pressure Transmitter	Generic Temperature Switch	Elcon Mux 2700	Pepperl+Fuchs KFD2-SD-Ex1.36	Generic Air Operated Butterfly Valve
ABB 600T	Generic Temperature Transmitter	Endress +Hauser Fieldgate FXA520	Pepperl+Fuchs KFD2-SD-Ex 1.48	Generic Air Operated Gate Valve
Honeywell ST 3000	Generic Thermocouple	Moore Industries ECA	Pepperl+Fuchs KFD2-SL-Ex 1.17	Generic Air Operated Globe Valve
MycroSENSOR 345 XTC	Moore Industries	Moore Industries ECT 2-wire Isolator	Pepperl+Fuchs KFD2-SL-Ex 1.36	Generic Control Valve



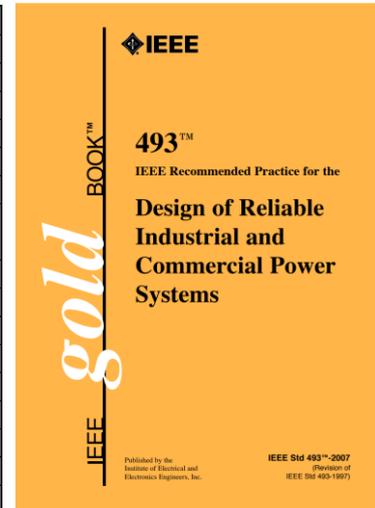
IEEE-493-2007

Design of Reliable Industrial and Commercial Power Systems

61 TIPOS DE EQUIPOS

IEEE 493-2007 - RP Design of Reliable Industrial and Commercial Power Systems

Equipo	Cant	Equipo	Cant	Equipo	Cant	Equipo	Cant
Accumulator	3	Compressor	4	Inverters	2	Strainer	8
Air compressor	3	Condensers	5	Meter	4	Switch	24
Air dryer	2	Control panel	6	Motor generator set	5	Switchgear	9
Air handing unit	2	Convectors	4	Motor starter	3	Tank	6
Arrester	2	Cooling tower	5	Motor electric	11	Thermostat	2
Battery	6	Damper assembly	3	Motor mechanical	3	Transducer	4
		Diesel engine generator	7	Pipe	4	Transformer, dry	7
Blower	2	Drive	2	Piping	10	Transformer, liquid	9
Boiler	6	Evaporator	5	Pressure control	2	UPS	3
Bus duct	3	Fan	5	Pressure regulator	2	Valve	29
Cabinet heaters	3	Filter	6	Pump	5	Valve operator	4
Cable	20	Fuse	6	Radiators	2	Volatge regulator	2
Cable connection	3	Gas turbine genrator	6	Rectifiers	2	Water-cooling coil	2
Capacitor bank	3	Gauge	2	Heat exchanger	5		0
Charger	2	Heater	3	Heater	3		0
Chiller	11	Humistat	2	Control systems	3		0
Cicuit breaker, 600 V.	13						



Motor Electric

DC

Induction

- ≤ 600 V
- > 600 V

Single Phase

- ≤ 5 A
- > 5 A

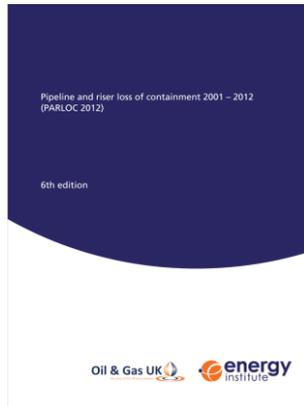
Synchronous

- ≤ 600 V
- > 600 V

Category			Class	Unit - years	Failures	Failure rate (failures/year)	MTBF	MTTR	MTM	MDT
Motor, electric				27880.2	27	0.00097	9045589.3	241.52	0.5662	0.921
	DC			754.8	11	0.01457	601071.27	582	0.4228	0.904
	Item:	E29-100	Motor, electric, dc	754.8	11	0.01457	601071.3	582	0	0.904
	Induction			712.5	13	0.01825	480090.46	3.38	2.9576	2.967
	Item:	E29-210	Motor, electric, induction, ≤600 V	361.4	4	0.01107	791448	1	1	1.336
	Item:	E29-220	Motor, electric, induction, >600 V	351.1	9	0.02564	341709.3	4.44	3	3.311
	Single phase			26034.5	1	0.00002	44718136	xxx	0.6247	0.625
	Item:	E29-310	Motor, electric, single phase, ≤5 A	25345.3	0	0.00002 ^a	43534240 ^a	0	0	0.491
	Item:	E29-320	Motor, electric, single phase, >5 A	689.3	1	0.00145	6037872	3	1	0.716
	Synchronous			378.5	2	0.00135	6500894.1	xxx	2.2088	2.576
	Item:	E29-410	Motor, electric, synchronous, ≤600 V	147.8	0	0.00345 ^a	2538917.6 ^a	0	2	2
	Item:	E29-420	Motor, electric, synchronous, >600 V	230.7	2	0.00867	1010304	36	3	4.65

MTTR: The mean time to replace or repair a failed component. **Logistics time associated with the repair, such as parts acquisitions, crew mobilization, are not included.**





Pipeline and Riser Loss Of Containment 2001 – 2012 (PARLOC 2012)

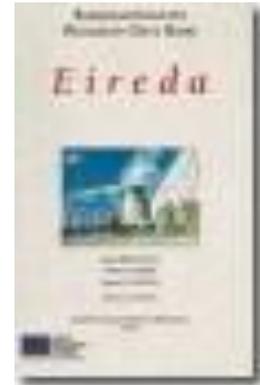


WellMaster RMS

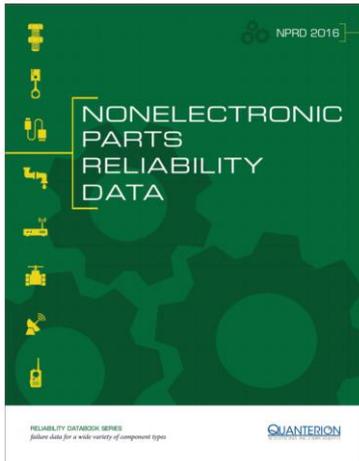
(Reliability Management System)

The global **well & subsea equipment** reliability database and analysis solution for **oil & gas** operators

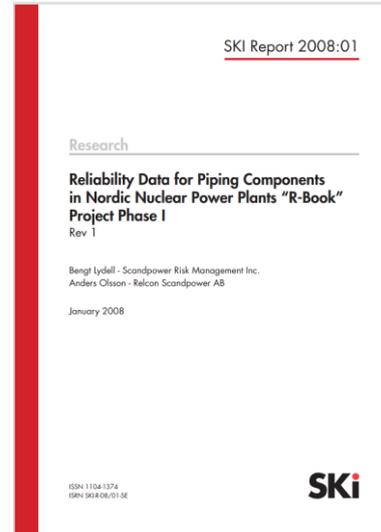
<https://www.exprosoft.com/products/wellmaster-rms/>



EIREDA.PC (European Industry Reliability Databank) This is a computer version of the EIREDA data bank. Data therefore relate to the **electrical, mechanical, and electromechanical** equipment of **nuclear plants**. This database was **created in 1990** and regrouped data drawn from SRDF and other database of EDF (AMPERE Data Bank for example).

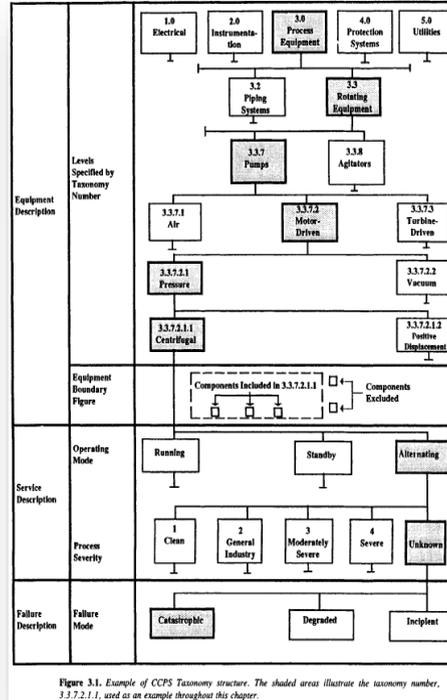


The 2016 Edition of the Nonelectronic Parts Reliability Data publication (NPRD-2016) presents field failure rate data on a wide variety of electrical assemblies and electromechanical/mechanical parts and assemblies. Compared to its predecessor NPRD-2011 publication, NPRD-2016 adds 138,000 new parts and over 370 billion part hours, representing approximately a 400% increase in content. The expanded part types and data in NPRD-2016 cover ground, airborne and naval environments.



The scope of the research project which is described in SKI Report 2008:01 is to derive piping component failure rates and rupture probabilities from piping failure reports stored in the OECD Nuclear Energy Agency OPDE database.





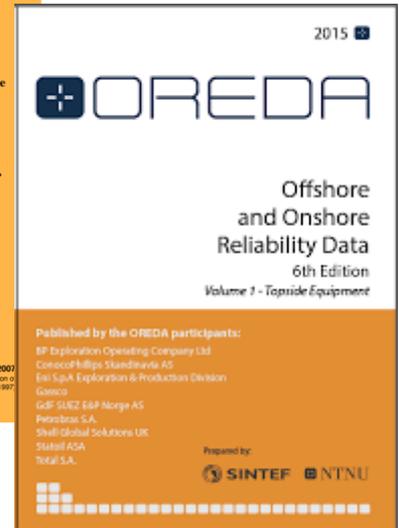
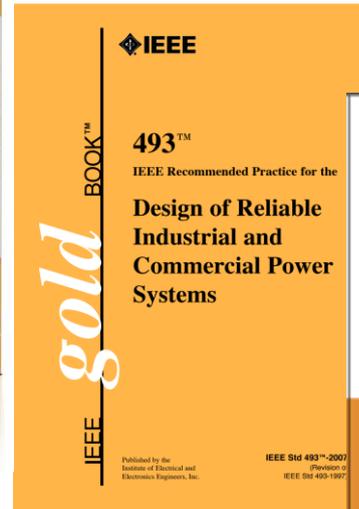
Example of CCPS Taxonomy structure. The shaded areas illustrate the taxonomy number, 3.3.7.2.1.1, used as an example throughout this chapter.

Guidelines for Process Equipment Reliability Data with Data Tables (1989)

Fuente: Center for Chemical Process Safety of the American Institute of Chemical Engineers (1989).- *Guidelines for Process Equipment Reliability Data with Data Tables.* ISBN: 0816904227,9780816904228

COMPARACIONES

Vs



POR QUÉ LAS DIFERENCIAS?

- Las tasas de falla y tiempos para reparar de diferentes fuentes abiertas podieran ser sustancialmente diferentes. Incluso entre una edición y otra del proyecto OREDA
- Importante conocer los critérios y premisas bajo los cuales se registraron los datos para los diferentes equipos:
 - ✓ Definición del equipo, los componentes que lo integran y límites de batería.
 - ✓ Tamaño de la población/muestra de equipos los cuales se le registran los datos.
 - ✓ Cantidad de eventos o datos registrados (fallas y reparaciones).
 - ✓ Instalaciones donde están instalados y operan los equipos: contexto operacional (campo, laboratorio, etc.)
 - ✓ Patrones de uso (stress) de los equipos (OREDA no registra patrones de uso).
 - ✓ Si consideran o no errores humanos. Conocimientos y experiencia del personal relacionado con el diseño, fabricación, instalación y el mantenimiento (OREDA no diferencia o separa esta causa).
 - ✓ Cultura, organización y políticas empresariales para ejecución del mantenimiento (mantenibilidad principalmente).
 - ✓ Políticas de repuestos, herramientas adecuadas, etc. (mantenibilidad principalmente).



EXIDA vs OREDA vs IEEE

Extracción de las filas de dato de IEEE-493-2007 para Válvula de Compuerta y Bola

Category		Class	Unit - years	Failures	Failure rate (failures/year)	MTBF	MTTR	MTTM	MDT
	Gate		17394.5	3	0.00017	50792032	5.67	0.8333	1.135
	Ball		2653.5	2	0.00019	45578400	xxx	0.1577	0.164

- EXIDA
 - OREDA
 - IEEE
- FITS: 10^9

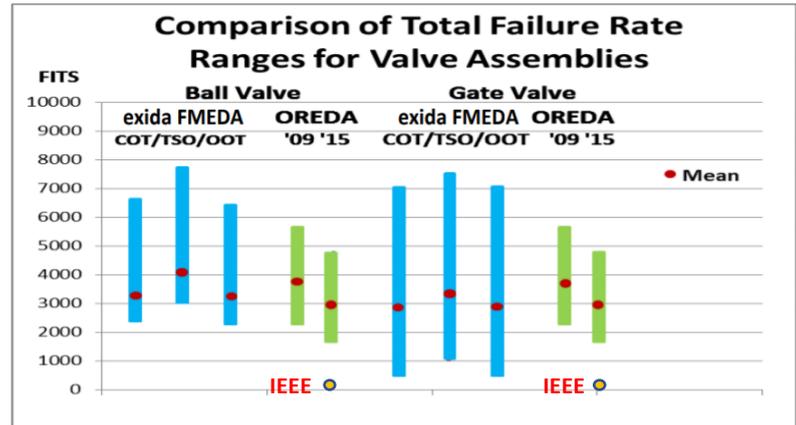


Figure 3. Comparison of FMEDA Predicted Failure Rates and OREDA Estimated Failure Rates for Ball and Gate Valve Assemblies

Fuente: W. Goble et Al.- Comparing FMEDA predicted failure rates to OREDA estimated failure rates for sensor and valve assemblies. EXIDA LLC. 2016



EXIDA vs OREDA

Conclusiones de: W. Goble et Al.- Comparing FMEDA predicted failure rates to OREDA estimated failure rates for sensor and valve assemblies. EXIDA LLC. 2016.

- Los estudios indicaron que **la data de FMEDA y OREDA son comparables**. Para los equipos analizados, las **tasas de falla promedio de FMEDA resultaron algo menores que las de OREDA**.
- Entre **las razones** del porque las diferencias se puede mencionar:
 - ✓ OREDA incluye dentro de sus **límites de batería** elementos (ítems) que no tienen un equivalente en los análisis FMEDA.
 - ✓ OREDA incluye **fallas humanas** mientras que FMEDA no.
 - ✓ La comparación entre FMEDA y OREDA fue hecha considerando **condiciones de servicio normal**, no severo. Es probable, sin embargo, que alguna data de OREDA haya sido obtenida bajo un **servicio severo**.
 - ✓ Alguna data de válvulas en aplicaciones ESD de OREDA provino de **poblaciones relativamente pequeñas**.
- **FMEDA** permite la **predicción** de **tasas de fallas inherentes al producto**.
- **OREDA captura** las **tasas de falla inherentes al producto**, así como las asociadas a **prácticas específicas del sitio** y las inducidas por **falla humana**.



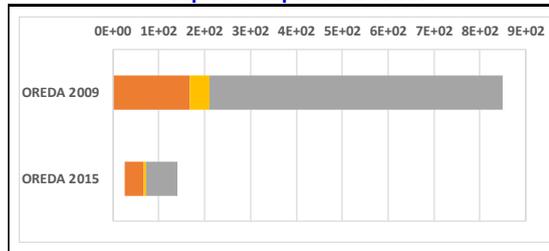
Comparación de Data para “Vessels Flash Drum (3.2.4)” OREDA 2015 vs 2009

Vessels

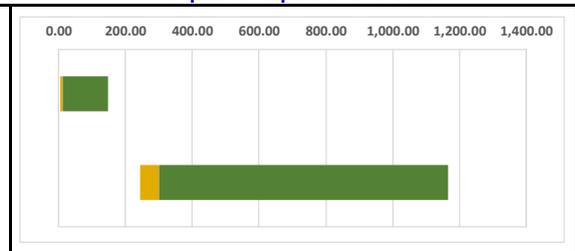
Reliability Equipment Information

SOURCE	Data						Failure Rate (operational) [por 10 ⁶ hrs]					TTR (calendar) [hrs]			Ao
	TAX	POP	INST	C.T.	OP.T.	N.F.	LOWER	MEAN	UPPER	SD	N/T	Min	Mean	Max	
OREDA 2009	3.2.4	33	7	1.1348	1.0038	265	3E-04	167.13	849.47	366.39	263.99	0.30	5.5	147	1
OREDA 2015	3.2.4	2	1	0.0745	0.0744	5	26.46	67.16	141.24	30.04	67.16	0.00	243	1166	0

Graphic Comparisson of TTF



Graphic Comparisson of TTR



LITERATURA ABIERTA

Article citation info:

GÖLBAŞI Ö, DEMREL N. Risk based reliability allocation methodology to set a maintenance priority among system components: a case study in mining. Eksploatacja i Niezawodność – Maintenance and Reliability 2017; 19 (2): 191–202, <https://doi.org/10.17531/ein-2017.2.6>.

Onur GÖLBAŞI
Nuray DEMREL

RISK-BASED RELIABILITY ALLOCATION METHODOLOGY TO SET A MAINTENANCE PRIORITY AMONG SYSTEM COMPONENTS: A CASE STUDY IN MINING

OPARTA NA OCENIE RYZYKA METODOLOGIA ALOKACJI NIEZAWODNOŚCI POLEGAJĄCA NA USTALANIU PRIORYTETÓW UTRZYMANIA RUCHU ELEMENTÓW SYSTEMU: STUDIUM PRZYPADKU Z DZIEDZINY GÓRNICHTWA

This study aims to build up a maintenance priority methodology for system components with the help of existing literature on reliability allocation. The offered methodology was applied to two high-capacity earthmovers using actual datasets collected by operations in Tuncbilek Coal Mine, Turkey. Prioritization of maintenance for components was achieved by adapting their operational risk factors to a generic reliability allocation algorithm. In this sense, direct and indirect financial consequences of component failures were considered in estimation of risk severity factors where component reliabilities were assessed comprehensively with top-to-bottom evaluation to determine risk occurrence factors. This paper is the first initiative in component maintenance prioritization in the mining sector where machinery reliabilities have a vital importance in production. In addition, previous studies have generally used reliability allocation as weakness detection tool in design and development of their systems. In this basis, this paper utilizes reliability allocation in instantaneous measurement of component maintenance requirements during operation.

Keywords: maintenance priority, reliability allocation, risk assessment, production systems.

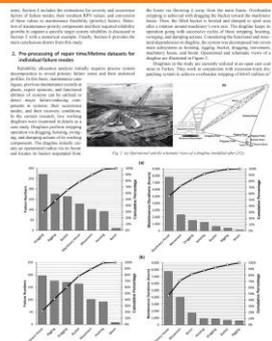
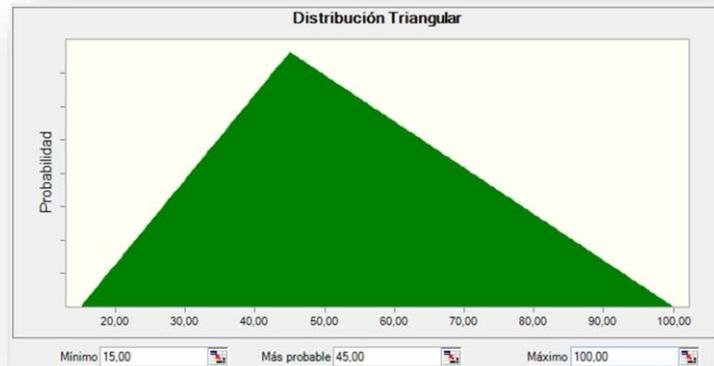


Table IV. Lifetime Parameters of Dragline-1 Components

Code	Model	Parameter	p-value	Code	Model	Parameter	p-value
Dragging Unit				Hoisting Unit			
DR1	Weibull-3P	$\beta=0.9; \eta=812.3; \gamma=15.8$	0,258	H01	Lognormal-2P	$\mu^*=6.8; \sigma^*=2.0$	0,284
DR2	Weibull-2P	$\beta=1.3; \eta=1,085.0$	>0,250	H02	Loglogistic-2P	$\mu^*=7.4; \sigma^*=0.2$	0,205
DR3	Loglogistic-2P	$\mu^*=6.7; \sigma^*=0.5$	0,168	H03	GRP	$\beta=1.5; \eta=7,361.1; RF=0\%$	Not iid
DR4	Weibull-3P	$\beta=0.8; \eta=732.2; \gamma=9.8$	0,233	H04	Weibull-2P	$\beta=0.9; \eta=10,402.7$	>0,250
DR5	Weibull-2P	$\beta=0.9; \eta=1,820.2$	>0,250	H05	GRP	$\beta=1.7; \eta=10,566.2; RF$	Not iid
DR6	Weibull-2P	$\beta=1.0; \eta=5,509.9$	>0,250				
Bucket Unit				Rigging Unit			
BU1	GRP	$\beta=0.7; \eta=788.9; RF=0\%$	Not iid	R11	Weibull-2P	$\beta=1.1; \eta=2,420.1$	>0,250
BU2	Weibull-2P	$\beta=0.6; \eta=11,528.2$	>0,250	R12	Weibull-2P	$\beta=0.8; \eta=3,438.4$	0,224
BU3	GRP	$\beta=0.8; \eta=942.8; RF=92\%$	Not iid	R13	Weibull-3P	$\beta=1.5; \eta=595.2; \gamma=51.9$	>0,500
BU4	Weibull-3P	$\beta=0.9; \eta=873.4; \gamma=31.3$	>0,500	R14	No Failure Data	-	-
BU5	GRP	$\beta=0.9; \eta=988.8; RF=85\%$	Not iid	R15	Lognormal-2P	$\mu^*=9.5; \sigma^*=0.4$	0,836
				R16	GRP	$\beta=0.7; \eta=1,176.4; RF=0.72$	Not iid
Machinery House Unit				Movement Unit			
MH1	GRP	$\beta=0.8; \eta=1,472.2; RF$	Not iid	M01	GRP	$\beta=0.5; \eta=490.7; RF=78\%$	Not iid
MH2	GRP	$\beta=0.7; \eta=758.4; RF=90\%$	Not iid	M02	Weibull-2P	$\beta=1.1; \eta=1,635.7$	0,156
MH3	Exponential-2P	$\lambda=0.1E-2; \gamma=13.0$	>0,250	M03	GRP	$\beta=1.4; \eta=3,322.3; RF=0\%$	Not iid
MH4	No Failure Data	-	-				
Boom Unit							
B01	Weibull-3P	$\beta=0.4; \eta=2,675.6; \gamma=16.2$	>0,250				

Not iid: Not identically and independently distributed

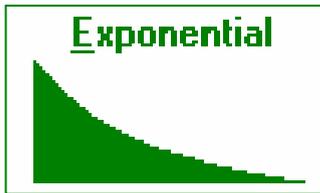
Opinión de experto



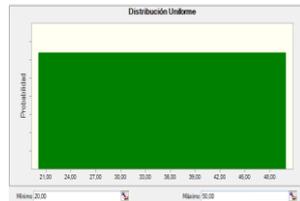
VALORES SUGERIDOS POR EXPERTOS

Opinión de expertos

- Información **proveniente de personal familiarizado, con experiencia**, en el tipo de equipos y proceso analizados. Puede ser personal propio (gerencia de mantenimiento, operaciones, ingeniería, etc.), o externo (reconocido).
- **Información colectada a través de entrevistas o mesas de trabajo** multidisciplinarias, usando estrategias que permita capturar la información con la mínima subjetividad posible.
- Ajuste con distribuciones apropiadas para “opinión de experto”: **BetaPert, Triangular, LogNormal, Uniforme, Exponencial y Weibull.**



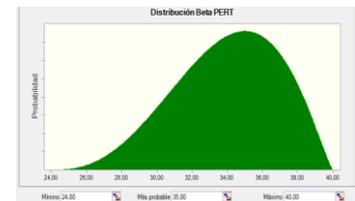
Exponencial
(promedio)



Rectangular
(min-max)



Triangular
(min, más probable, max)



BetaPERT
(min, más probable, max)

Opinión de expertos – Registro formal de la información

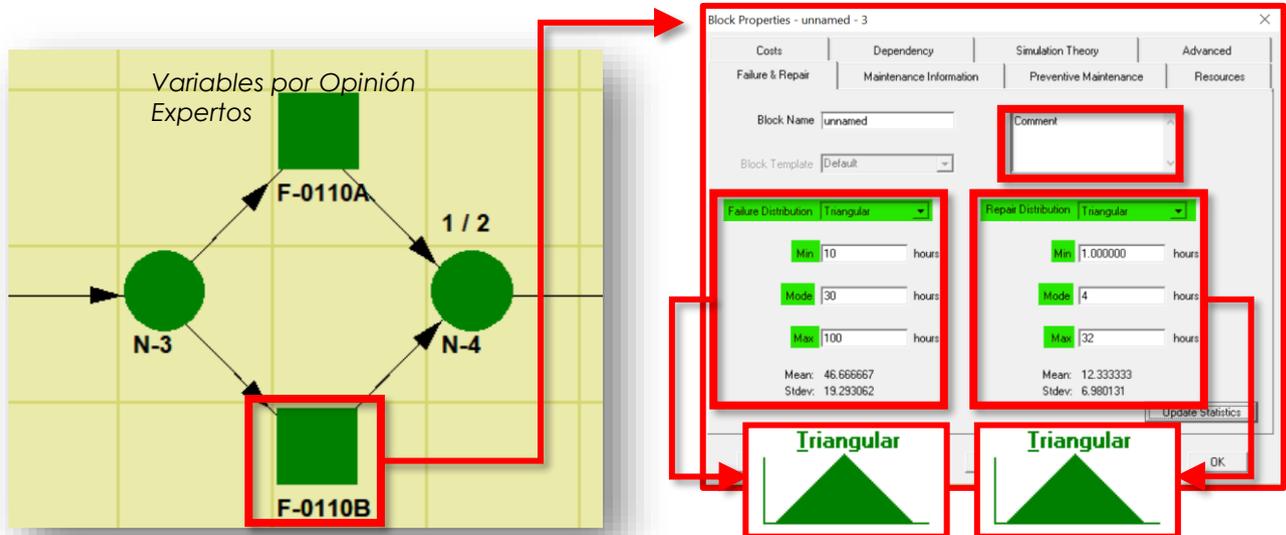
PREDICTIVA 21		Equipo														
		Opinión de Expertos														
		Experto 1 (Nombre y Apellido)			Experto 2 (Nombre y Apellido)			Experto 3 (Nombre y Apellido)								
No	Tiempo Para Falla (hrs.)	Tiempo Para Reparar Activo + Logística, Repuestos, otros (hrs.)			Tiempo Para Falla (hrs.)			Tiempo Para Reparar Efectivo + Logística, Repuestos, otros (hrs.)		Tiempo Para Falla (hrs.)		Tiempo Para Reparar Efectivo + Logística, Repuestos, otros (hrs.)				
1	Minimo	Tiempo Para Falla (TPF) [hrs] - Opinión de Expertos														
2								Máximo	Minimo	Más Probable	Máximo	Minimo	Más Probable	Máximo		
3																
4																
5																
6		Experto 1		Experto 2		Experto 3		Datos Combinados (E1 + E2 + E3)		Distribución						
7		Param 1	Param 2	Param 1	Param 2	Param 1	Param 2	Param 1	Param 2							
8	2,190															
8	2,190	17520.0		17520.0				17520.0		Exponencial	336.0	2,190.0	4,380.0	8,760.0	168.0	17,520.0
9	2,190	17520.0		17520.0				17520.0		Exponencial	336.0	2,190.0	4,380.0	8,760.0	168.0	17,520.0
10	2,190	17520.0		17520.0				17520.0		Exponencial	336.0	2,190.0	4,380.0	8,760.0	168.0	17,520.0
	26,280	17520.0		17520.0				17520.0		Exponencial	504.0					
		17520.0		17520.0				17520.0		Exponencial						
		9998.2	1.96	3644.7	3.25	6026.9	2.93	6556.6	2.7	Weibull						
		9998.2	1.96	3644.7	3.25	6026.9	2.93	6556.6	2.71	Weibull						
		9998.2	1.96	3644.7	3.25	6026.9	2.93	6556.6	2.71	Weibull						
		43596.5	5.87	43596.5	5.87			43596.5	5.87	Weibull						

- Datos ID del **equipo**
- Datos ID de los **expertos**
- **Opinión** de cada experto
- Ajuste de opinión a una **distribución (*)**
- **Promedio** de opiniones

(*) Con software especializado, con **SOLVER** de Excel, etc.

Caracterización de los Bloques de confiabilidad (RBs)

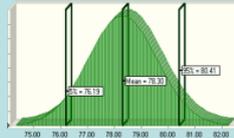
Funciones de distribución de densidad de probabilidad (pdf) para los indicadores **TPF** (tiempo para falla) y **TPR** (tiempo para reparar)



Combinación de fuentes

Teorema de Bayes

**Experiencia Previa
(Datos Genéricos)
Tasa de Falla OREDA
(λ_{OREDA})**



μ_{OREDA} : Media de la Distribución de I_{OREDA}
 σ_{OREDA} : Media de la Distribución de I_{OREDA}

**Evidencia
("N" Datos de equipos propios)**

Datos de Fallas
(Tiempos de Operación hasta la Falla)

$t_{c1}, t_{c2}, \dots, T_r$

r = Número de equipos que han fallado

Datos Censados
(Tiempos de Operación de equipos que no han fallado)

$t_{c1}, t_{c2}, \dots, T_{c(N-r)}$

$N-r$ = Número de equipos que no han fallado

Dato Mejorado

$$\lambda_{mejorada} = \frac{r + \frac{(\mu_{OREDA})^2}{(\sigma_{OREDA})^2}}{\left(\sum_{i=1}^t t_j + \sum_{j=1}^{N-r} t_{c_j} \right) + \frac{\mu_{OREDA}}{(\sigma_{OREDA})^2}}$$

Conclusiones



CONCLUSIONES

- La colección y el procesamiento de datos de confiabilidad son la **base** de los estudios **cuantitativos** que soportan la decisión de mejora y optimización de la gestión de activos.
- Es indispensable establecer “**reglas claras**” y estandarizar las premisas sobre las cuales se hará la colección y procesamiento de los bases de datos. En ese sentido, la norma **ISO 14224 es una excelente guía**.
- Aun cuando existe una gran variedad de bases de datos estructuradas y fuentes serias de información, hay una **carencia y necesidad** de tener **datos confiables** en **otros segmentos industriales**.
- Importante **promover la experiencia OREDA** como proyecto piloto exitoso **a otros segmentos** de la industria (minería, manufactura, automotriz, etc.)
- **Mídanse/compárense** (benchmarking) a través del dato de confiabilidad y mantgenibilidad.

