OREDA

Offshore Reliability Data Handbook

4th Edition

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OREDA® = registered trade mark name of OREDA (Offshore Reliability Data)

[1] The companies listed below are those being members of OREDA in 2002.

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PART I

INTRODUCTION

THE OREDA PROJECT

The Offshore Reliability Data (OREDA) project was established in 1981 in co-operation with the Norwegian Petroleum Directorate. The initial objective of OREDA was to collect reliability data for safety equipment. The current organisation, as a co-operating group of several oil companies, was established in 1983, and at the same time the scope of OREDA was extended to cover reliability data from a wide range of equipment used in oil and gas exploration and production. Offshore topside and subsea equipment are primarily covered, but some onshore E & P equipment is also included.

The main objective of the OREDA project is to contribute to an improved safety and cost-effectiveness in design and operation of oil and gas exploration and production facilities; through collection and analysis of maintenance and operational data, establishment of a high quality reliability database, and exchange of reliability, availability, maintenance and safety (RAMS) technology among the participating companies.

PROJECT PHASES

Phase I (1983 - 1985)

The purpose of phase I was to collect and compile data from offshore drilling and production operations. The data were published in the OREDA-84 handbook. An objective of the handbook was to demonstrate the ability of the eight participating oil companies to co-operate on this issue and create a forum for a common co-operative process in this field. Data was collected on a wide area of equipment (large population) but not with as much detailed information as in later phases.

Phase II (1987 - 1990)

The scope was adjusted to only collect data on production critical equipment, to improve the quality of the data, and to store the data in a PC database format. A tailor-made PC program (called the OREDA software) was developed to aid the collection and analysis of the data. The data were published in the OREDA-92 handbook. This Handbook also contains the data collected in phase I.

Phase III (1990 - 1992)

The number of equipment categories was increased, and more data on maintenance programs were collected. The data quality was improved by means of the comprehensive "Guidelines for Data Collection" and through quality control. The OREDA software was modified into a more general-purpose data collection tool, and its user interface was improved. The data collected in this phase are contained in the OREDA-97 handbook.

Phase IV (1993 - 1996)

A new general software was developed for data collection and analysis, plus specific software and procedures for automatic data import and conversion. Data were collected mainly for the same equipment as in phase III, and the data collection was - to a greater extent - carried out by the companies themselves. Data on planned maintenance are included.

Phase V (1997 – 2000)

Some new equipment classes were included and more focus was given on collecting subsea data. As a parallel activity, the ISO standard 14 224: "*Petroleum and natural gas industries - Collection and exchange of reliability and maintenance data for equipment*" was developed and issued in July 1999. A revised version including downstream equipment is currently being developed by ISO TC67 Workgroup 4 with the secretariate at NTS in Oslo. (See: http://www.nts.no/)

Phase VI were completed in 2001 and **phase VII** is planned to last 2002 - 2003.

Up-to-date information on the OREDA project is available on the Internet address:

http://www.oreda.com

PARTICIPANTS

During phase IV and V several changes have been experienced in company participation in OREDA as to new companies joining and leaving OREDA as well as companies being merged/sold. The following summarise the companies that have contributed with data in these phases:

Companies	Phase IV	Phase V	Comments
AGIP	√	√	
BP.	√	√	
Chevron	√	√	Merged with Texaco
ELF	√	√	Merged with TOTAL
Esso/Exxon	√	√	(Merged with Mobil)
Norsk Hydro	√	√	
Phillips Petroleum Company Norway	√		
Statoil	√	√	
Saga Petroleum	√		Sold to Norsk Hydro
Shell	√	√	
Texaco		√	Merged with Chevron
TOTAL	√		Merged with Elf

ORGANISATION

OREDA is managed by a Steering Committee with one member and one deputy member from each of the participating oil companies. The Steering Committee elects one of its members as chairman and appoints a Project Manager. The Project Manager co-ordinates the activities approved by the Steering Committee, including data quality assurance. Det Norske Veritas served as Project Manager during phases I and II; SINTEF during phases III - V, and act as current project manager in Phase VII.

EQUIPMENT CATEGORIES COVERED IN THE DIFFERENT PHASES

Table 1 shows the equipment categories that have been included in the four OREDA handbooks (including this one). Most of the equipment derives from offshore installations, but a few equipment units from onshore E&P have also been included. In phase V more emphasis has been placed on collection of subsea data.

Table 1 Equipment classes covered by the four OREDA Handbooks

System	Equipment class	Phase I (-84 edition) (1983 – 85)	Phase II (-92 edition)[2] (1987 – 90)	Phase III (-97 edition) (1990 – 92)	Phase IV (2002 edition) (1993 – 96)	Phase V (2002 edition) (1997 – 00)	SUM
		No. of units	No. of units	No. of units	No. of units	No. of units	No. of units
Rotating machinery	- Gas Turbines		109	54	56	28	247
	- Compressors	17	50	45	75	56	243
	- Combustion engines				39	64	103
	- Pumps	478	271	103	294	152	1298
	- Turboexpanders				7	8	15
	- Electric generators	76		49	87	8	220
	- Electric motors				56	122	178
Static equipment	- Vessels	359	329	54	148	51	941
	- Heaters and boilers				8	1	9
	- Heat exchangers	519	170	75	51	17	832
Other topside	- Valves	658	645	899	821	349	3372
	- F&G detection equipment	3683		5828	79	779	10369
	- Process sensors/control	3740		487	140	69	4436
Misc. equipment phase I only	- Misc. el. systems	1321					1321
	- Misc. safety systems	1703					1703
	- Misc. utility systems	1035					1035
	- Drilling systems	880					880
Subsea equipment	- Control systems			14		17	31
	- Wellhead & X-mas tree			21		83	104
	- Pipelines					144	144
	-Template					4	4
	- Manifold					29	29
	- Risers					42	42
	- Running tools					6	6
	- Misc. equipment (phase II)		15				15
Total		**14469**	**1589**	**7629**	**1841**	**2037**	**27565**

2 The –92 edition do also contain the data issued in the –84 version.

SCOPE OF THE OREDA HANDBOOK

The OREDA handbook presents high quality reliability data for offshore equipment collected during phase IV and V of the OREDA project. The intention of the handbook is to provide both quantitative and qualitative information as a basis for RAMS analyses.

For each *topside* equipment unit, the following information is presented:

- A drawing illustrating the boundary of the equipment unit, i.e., a specification of subunits and so-called maintainable items that are part of the equipment unit.
- A listing of all failure modes, classified as *critical*, *degraded* or *incipient*, respectively.
- The observed number of failures for each failure mode.
- The aggregated observed time in service for the equipment unit, classified as calendar time, operational time, and number of demands.
- An estimate of the failure rate for each failure mode with associated uncertainty limits.
- A repair time estimate, i.e., the number of man-hours required to repair the failure and restore the function.
- A repair time estimate, i.e., the elapsed time in number of hours required repairing the failure and restoring the function. This time is the *active* repair time, i.e. the time when actual repair work was being done.
- Supportive information, e.g., number of items and installations.
- A cross-tabulation of maintainable item versus failure mode, and of failure descriptor/-cause versus failure mode.

For each *subsea* equipment unit, the following information is presented:

- A drawing illustrating the boundary of the equipment unit, i.e., a specification of subunits and components that are part of the equipment unit.
- A listing of all components.
- The observed number of failures for each component.
- The aggregated observed time in service for the equipment unit, classified as calendar time.
- An estimate of the failure rate for each component with associated uncertainty limits.
- A repair time estimate, i.e., the elapsed time in number of hours required repairing the failure and restoring the function. This time is the *active* repair time, i.e. the time when actual repair work was done.
- Supportive information, e.g., number of items and installations.
- A cross-tabulation of component versus failure mode, of subunit versus failure mode, of equipment unit versus failure mode and of failure descriptor/-cause versus failure mode.

LIMITATIONS

Information released from each participating company has been kept confidential by rendering it anonymous. Only generic data are published. The single event information, which is the basis for the estimates, is (in most cases) gathered from two or more installations, and consequently the figures in the handbook reflect a weighted average of the experience.

The OREDA project is so far restricted to failure data collected on hardware components and systems; information about human errors is not included. Nevertheless, component failures may have been caused by human errors and, therefore, implicitly, human errors are included in the failure rate estimates.

Details and limitations of the methods used are described in the section "ESTIMATION PROCEDURES" on page 23.

THE OREDA TOPSIDE DATA STRUCTURE

GENERAL

In order to collect data and analyse them in a consistent manner, a taxonomy description has been developed in the OREDA project. The following gives a summary of that taxonomy to better understand the platform on which these data have been collected and stored. Note that some of the parameters given in this description are not included in the generic data presented in this handbook, but contained in the source database.

MAIN DATA CATEGORIES

For each equipment category the database is split into three separate database files: an *Inventory* part, a *Maintenance* part, and a *Failure* part.

The **Inventory** part contains a description of each *equipment unit* for which data have been collected, e.g., pump. This description contains technical data (e.g., capacity, size) as well as some operating and environmental data (e.g., operating mode, vibrations). The inventory description for each equipment unit is stored in an *Inventory record* in the database.

The **Failure** part contains the failure events being experienced for an equipment unit (inventory) during the period of surveillance; one record for each failure event. The failure events are always related to one equipment unit (inventory).

The **Maintenance** part contains information about the corrective and the scheduled preventive maintenance program for each equipment unit (e.g., maintenance action, interval, man-hours). Data on corrective maintenance is related to its preceding failure, while data on preventive maintenance is related to the equipment unit.

SYSTEM HIERARCHY

The various items are classified into equipment categories termed *Equipment classes* e.g. pumps, compressors, valves etc. Each individual item within a class is termed an *Equipment Unit* (e.g. one pump). Each equipment class is further classified according to its design characteristics and type of service (system). Table 2 gives an example for the two equipment classes *Pumps* and *Fire & Gas detectors.*

Equipment within an equipment class is subdivided in two lower indenture levels, called *subunits* and *maintainable items (MI)*. This subdivision is purely hierarchic and has the following interpretation:

Level 1 – Equipment Unit: The highest level used in OREDA and typically includes an equipment unit with one main function, e.g. pump, compressor.

Level 2 – Subunit: An equipment unit is subdivided in several subunits, each with one function required for the *equipment unit* to perform its main function. Typical subunits are e.g., cooling, lubrication. The subunits may be redundant, e.g., two independent start units.

Level 3 - Maintainable Item (MI): These are subsets of each subunit and will typically consist of the lowest level units that are due for preventive maintenance.

The hierarchy is illustrated in Figure 1.

Table 2 System Classification (Example)

EQUIPMENT CLASS		DESIGN CLASS		SYSTEM	
Description	Code	Description	Code	Description	Code
Pumps	PU	Centrifugal Reciprocating Rotary	CE RE RO	Water fire fighting Sea water injection Oil handling Gas utilities Gas processing	FF WI OH GU GP ....
Fire & Gas detectors	FG	Smoke/combustion Heat Flame Hydrocarbon gas H2S gas	BS BH BF AB AS	Fire detection Gas detection	FD GD

(Example: PU-RO-OH indicate a rotary pump used in oil handling)

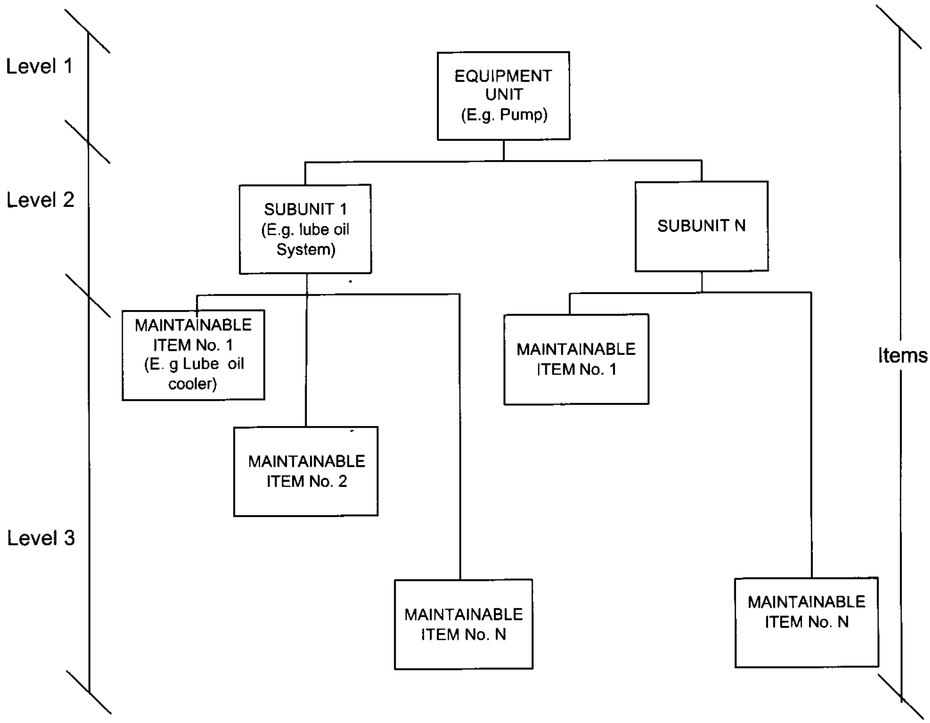

Figure 1 System Hierarchy

Several subunits may be relevant for several equipment categories (e.g., lubrication system, starting system). In these cases the subunits are given the same name and the same set of MIs. This is done in order to standardise the subunits/MIs as much as possible, although some of the MIs in these subunits may not apply for all equipment categories.

EQUIPMENT BOUNDARIES

To compare failure events from different equipment categories, installations, or sources, it is important to have a common definition of which components or parts that are to be included in an inventory. The *boundary* defines parts associated with the generic item that are considered to be essential for its function or that are sold by the manufacturer as part of the item. For example, the power transmission (e.g. gear) is included within the boundary for a pump, while the driver (e.g. el.motor) is not. The boundary is normally sufficiently determined by a boundary diagram as illustrated in Figure 2. Further, a tabular description as shown in Table 3 lists those subunits and MIs that are included within the boundary.

The boundaries are established to confine the same items as the corresponding tag numbers or sub-tag numbers used by the participating oil companies. The equipment units correspond to the companies' main tag level, while the subunits correspond to the sub-tag level.

When establishing the equipment boundaries, the following principles have been applied:

- The connected units are excluded from the equipment unit boundary unless specifically included by the boundary specification. *Failures that occur in a connection (e.g. leak) are included* unless it is known specifically that it has occurred on the connected item outside the boundary.

- When a driver and the driven unit use common subunits (e.g., lubrication), failures of this subunit is as a common rule related to the *driven* unit.

- Failures on drivers (e.g. gas turbine) and driven units (e.g. compressors) are presented for each of those equipment classes *separately.* When e.g. a failure rate for a combination of driver and driven units is needed (e.g. compressors driven by gas turbines) the combined values from those two equipment classes should be used.

- Instrumentation is included only where this equipment has specific control and/or monitoring function for the equipment unit and/or is locally mounted (sensors). Instrumentation of a more general use, such as supervisory system (SCADA) is, as a rule, not included.

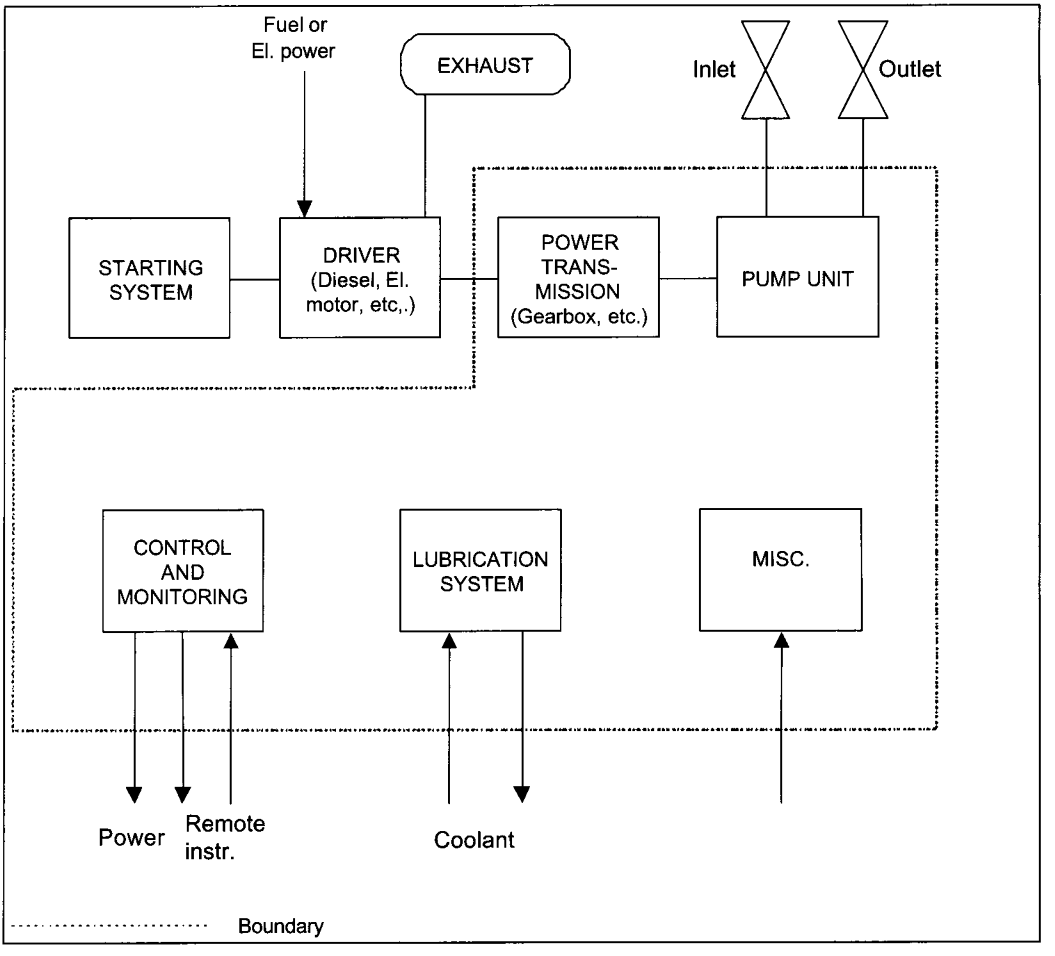

Figure 2 Boundary Definition, Pumps

INVENTORY DATA

For each equipment unit there is an inventory description divided into two parts:

1. One part common to all equipment categories (e.g., manufacturer, model, function, operating time).

2. One part containing equipment category specific data (e.g., capacity, size, power consumption).

Table 3 Subdivision in Maintainable Items, Pumps

EQUIPMENT CLASS	PUMPS				
SUBUNITS	**Power transmission**	**Pump unit**	**Control and Monitoring**	**Lubrication system**	**Miscell-aneous**
MAINTAINABLE ITEMS	• Gearbox • Bearing • Seals • Lubrication • Coupling to driver • Coupling to driven unit	• Support • Casing • Impeller • Shaft • Radial bearing • Thrust bearing • Seals • Valves • Piping • Cylinder liner[1] • Piston[1] • Diaphragm[2]	• Control unit • Actuating device • Monitoring unit • Internal pwr supply • Valves	• Reservoir • Pump w/ motor • Filters • Cooler • Valves • Piping • Oil	• Purge air • Cooling/ heating system • Filter, cyclone • Pulsation damper • Others

FAILURE DATA

In OREDA a failure event is defined as a *physical* failure of equipment. This implies that all events where a work order is issued, and some maintenance action carried out, would be considered as failure in OREDA (see the definitions on page 40).

For each failure a description (record) of the failure is given in the database together with the corrective action(s) carried out to restore the item to normal operating condition. The information is partly based on numeric data, partly on codes selected from a predefined menu, and partly on free text.

THE OREDA SUBSEA DATA STRUCTURE

MAIN DATA CATEGORIES

The OREDA subsea database consists of three main parts: An *Inventory* part, a *Failure* part, and a *Maintenance* part.

The **Inventory part** contains a description of each Equipment Unit (e.g. an X-mas tree). It contains technical and operational data on all three indenture levels applied: (1) Equipment Unit, (2) Subunit and (3) Component level.

The **Failure part** contains the failure events experienced for one Equipment Unit during the period of surveillance; one failure record for each failure event. If no failures are experienced for a specific equipment unit, the corresponding failure database will be empty. Subsea failures are linked to the lowest level in the equipment hierarchy, the component level.

The **Maintenance part** contains information about the corrective maintenance/ intervention being carried out (e.g. maintenance action, downtime, resources) and is related to a failure event record.

SYSTEM HIERARCHY

The *system hierarchy* in OREDA, subsea part, is broken down into four levels starting on top viz.:

- **Field/Installation:** This is an identifier for the subsea field and its installation(s). For each field several installations may be included.
- **Equipment unit:** An equipment unit on the highest equipment level used in OREDA which typically includes a unit with one main function, e.g. X-mas tree, control system, etc.
- **Subunit:** An equipment unit is subdivided in several subunits, each with function(s) required for the *equipment unit* to perform its main function. Typical subunits are e.g. umbilical, HPU etc. The subunits may be redundant, e.g. two independent HPUs.
- **Component:** These are subsets of each subunit and will typically consist of the lowest level items that are being repaired or replaced as a whole (e.g. valve, sensor etc)

The hierarchy is illustrated in Figure 3.

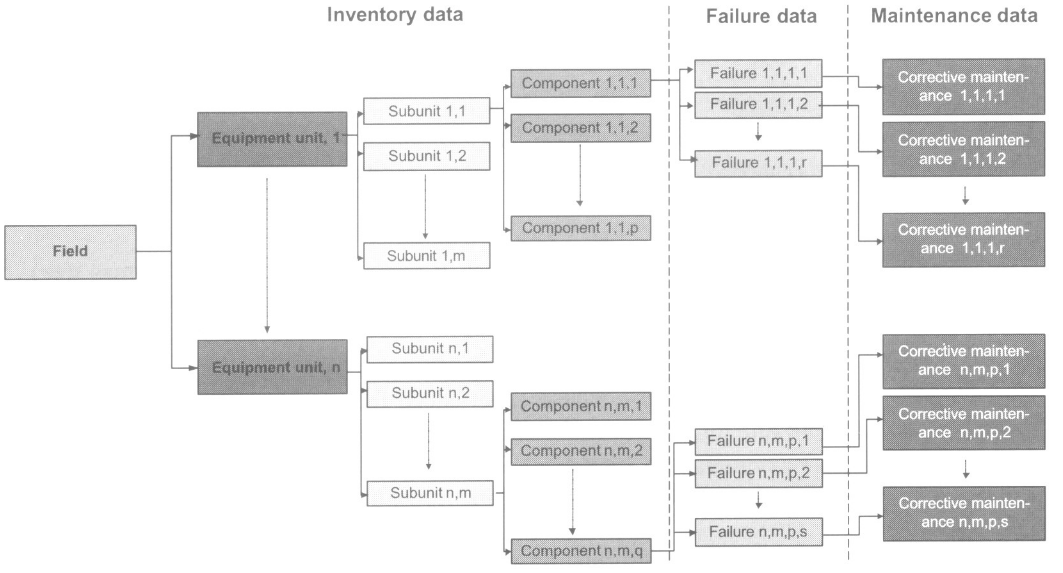

Figure 3 - System hierarchy

The failures and corrective maintenance actions are as shown in Figure 3 linked to the component where they occurred.

EQUIPMENT BOUNDARIES

The boundaries of what constitutes a subsea system and the various levels in the inventory need to be clearly defined to ensure that in-service times and failures are allocated correctly. A typical equipment level boundary used in OREDA is illustrated in Figure 4. Boundary details for the each equipment class are given in each equipment class chapter respectively.

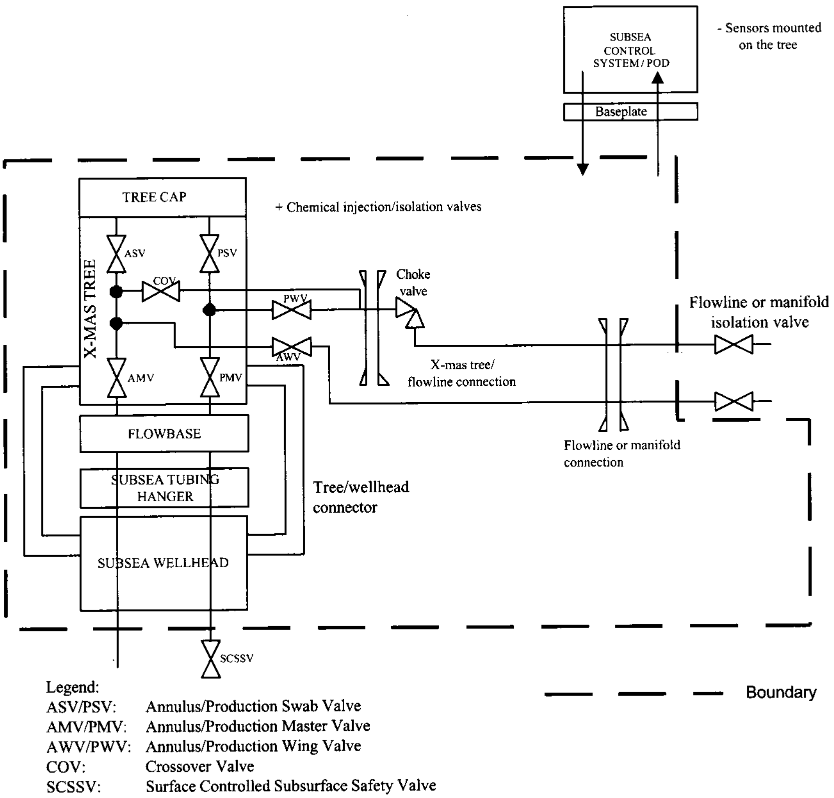

Figure 4 - Boundary definition, X-mas tree

INVENTORY DATA

The inventory data are used to describe an equipment unit and its associated subunits and components, to be able to compare equal with equal and retrieve relevant data from the database. Furthermore, the inventory data may represent explanatory variables affecting the observed reliability.

These data are mainly of static character; i.e. they do not change in course of time. They are also recorded once for each item. Some are, however, of a more dynamic nature and may change during the surveillance period (e.g. no. of demands).

Failure Event and Maintenance Data

For each failure a description of the failure is given together with the maintenance/intervention (corrective action) carried out to restore the item to normal operating conditions. This information is divided in two event records:

- *Failure*; i.e. description of the failure event
- *Maintenance/intervention*; i.e. description of the maintenance action

These records contain a set of attributes describing the failure and maintenance action respectively. The attributes are based on numeric data, codes selected from a predefined menu, and free text description.

ESTIMATION PROCEDURES

The main purpose of the OREDA-2002 handbook is to present average failure rate estimates together with repair time estimates. This section presents a brief description of the statistical methods that are used.

FAILURE RATE

The *failure rate* function tells us how likely it is that an item that has survived up to time t, will fail during the next unit of time. If the item is deteriorating, this likelihood will increase with the age t. A man who has reached the age of 95 years will obviously have a higher probability of dying during the next year than a 20 years old man. The failure rate function will therefore usually be a function of the time - or, the age of the item.

To give a mathematical definition of the failure rate function, we start with the time to failure, T, of the item, i.e., the time from the item is put into operation until the first failure occurs. It is generally impossible to predict the exact value of the time to failure, and T will therefore be a random variable with some distribution. The failure rate function, $\lambda(t)$, may now be defined mathematically as:

$$\lambda(t)\cdot\Delta t \approx \Pr(t < T \leq t + \Delta t \mid T > t)$$

The right hand side of this equation denotes "the probability that the item will fail in the time interval $(t,\ t + \Delta t)$, when the item is still functioning at time t" or with other words: "the probability that an item that has reached the age t will fail in the next interval $(t,\ t + \Delta t)$." The approximation is sufficiently accurate when Δt is the length of a very "short" time interval.

The failure rate function is sometimes also called 'hazard rate' or 'force of mortality'.

The life of a technical item may generally be split into three different phases: the *burn-in* (or infant mortality) phase, the *useful life* phase, and the *wear-out* phase. The failure rate function will usually have different shapes in the three phases. As illustrated in Figure 5, the failure rate function may be decreasing in the burn-in phase, close to constant in the useful life phase, and increasing in the wear-out phase. The curve in Figure 5 is called a "bath-tub" curve because of its characteristic shape, and is often claimed to be a realistic model for mechanical equipment.

If we assume that the failure rate function is constant during the useful life phase, this means that the item is not deteriorating during this phase. The deterioration will start when, or if, the item enters the wear-out phase.

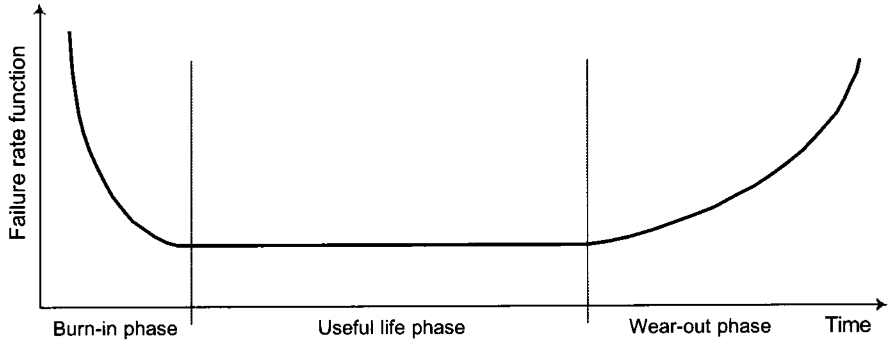

Figure 5 Bath-Tub Shape of the Failure Rate

So-called burn-in problems may be caused by inherent quality problems in the item, or by installation problems. Inherent quality problems may sometimes be removed by careful quality testing prior to installation. Installation problems have been disregarded in the OREDA data collection, notably for most *topside equipment*. The burn-in phase is therefore not included in the OREDA database, and we may assume that the data collection is started with the useful life phase. For subsea equipment data is collected on a whole lifetime basis, i.e. data collection starts when the equipment is installed and ready for its intended service. This means that the equipment may no necessarily have been

Many of the items covered in OREDA are subject to some maintenance or replacement policy. The items will thereby often be replaced or refurbished before they reach the wear-out phase.

The main part of the failure events in the OREDA database will therefore come from the useful life phase, where the failure rate is close to constant.

All the failure rate estimates presented in this handbook are therefore based on the assumption that the failure rate function is *constant* and independent of time, in which case $\lambda(t) = \lambda$.

Note

- No statistical tests have been performed to verify the assumption of a constant failure rate.
- Since data are assumed to come from "bottom" of the bath-tub curve, the failure rate estimates presented therefore represent some kind of minimum over the entire life cycle of the equipment.

An important implication of the constant failure rate assumption is that an item is considered to be "as good as new" as long as it is functioning. All failures are purely chance failures and independent of the age of the item.

The mean time to failure, MTTF, may be calculated as

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

These and related concepts are thoroughly discussed in e.g., Høyland and Rausand (1994).

ESTIMATORS AND UNCERTAINTY LIMITS FOR A HOMOGENEOUS SAMPLE

When we have failure data from identical items that have been operating under the same operational and environmental conditions, we have a so-called *homogeneous sample.* The only data we need to estimate the failure rate λ in this case, are the observed number of failures, n, and the aggregated time in service, τ.

The estimator of λ is given by:

$$\hat{\lambda} = \frac{\text{Number of failures}}{\text{Aggregated time in service}} = \frac{n}{\tau}$$

See e.g. Høyland and Rausand (1994) for further details.

The aggregated time in service, τ, may be measured either as calendar time or operating time, and both these are presented in the data tables in Part II.

Note that this approach is valid only in the following situations:

- Failure times for a specified number of items, with the *same* failure rate λ, are available.
- Data (several failures) is available for *one* item for a period of time, and the failure rate λ is constant during this period.
- A combination of the two above situations, i.e., there are several items where each item might have several failures. This is the typical situation for the OREDA data.

In the data tables in Part II of the handbook, estimates are given for each failure mode.

Uncertainty intervals for the failure rate

The uncertainty of the estimate $\hat{\lambda}$ may be presented as a 90% confidence interval. This is an interval (λ_L, λ_U), such that the "true value" of λ fulfils:

$$\Pr(\lambda_L \le \lambda < \lambda_U) = 90\%$$

With n failures during an aggregated time in service τ, this 90% confidence interval is given by:

$$\left(\frac{1}{2\tau} z_{0.95,2n}, \frac{1}{2\tau} z_{0.05,2(n+1)} \right)$$

where $z_{0.95,\nu}$ and $z_{0.05,\nu}$ denote the *upper* 95% and 5% percentiles, respectively, of the χ^2-distribution with ν degrees of freedom, see Table 4, page 31.

Example
Assume that n = 6 failures have been observed during an aggregated time in service $\tau = 10000$ hours.

The failure rate estimate is then given by:

$$\hat{\lambda} = n/\tau = 6 \cdot 10^{-4} \text{ failures per hour}$$

and a 90% confidence interval is given by:

$$\left(\frac{1}{2\tau} z_{0.95,2n}, \frac{1}{2\tau} z_{0.05,2(n+1)}\right) = \left(\frac{1}{20000} z_{0.95,12}, \frac{1}{20000} z_{0.05,14}\right) = (2.6 \cdot 10^{-4},\ 11.8 \cdot 10^{-4})$$

The estimate and the confidence interval are illustrated in Figure 6.

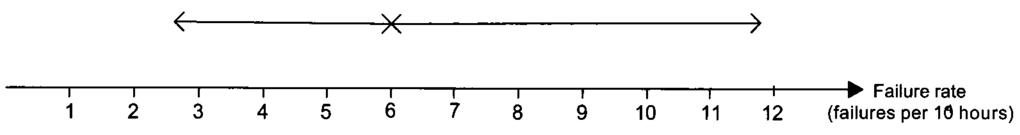

Figure 6 Estimate and 90% Confidence Interval for the Example.

Note
The given interval is a confidence interval for the failure rate for the items we have data for. There is no guarantee that items installed in the future will have a failure rate within this interval.

MULTI-SAMPLE PROBLEMS

In many cases we do not have a homogeneous sample of data. The aggregated data for an item may come from different installations with different operational and environmental conditions, or we may wish to present an "average" failure rate estimate for slightly different items. In these situations we may decide to merge several more or less homogeneous samples, into what we call a multi-sample.

The various samples may have different failure rates, and different amounts of data - and thereby different confidence intervals. This is illustrated in Figure 7.

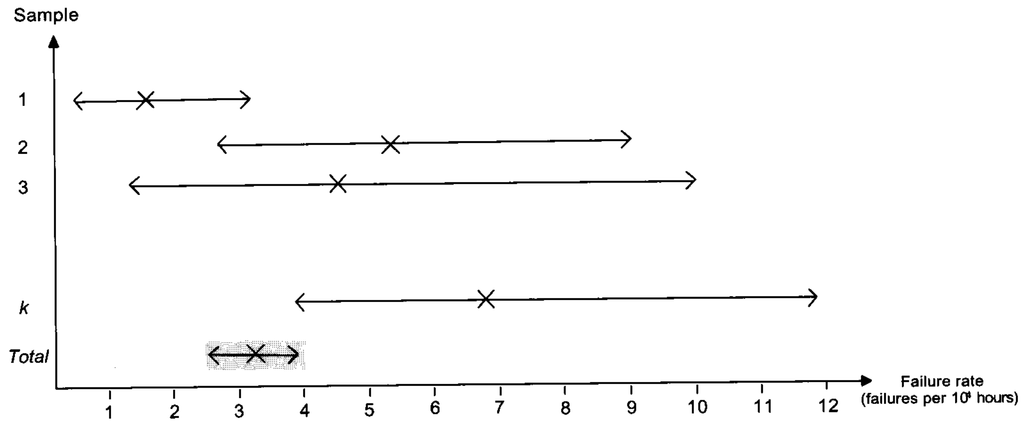

Figure 7 Multi-Sample Problem

To merge all the samples, and estimate the "average" failure rate as the total number of failures divided by the aggregated time in service will not always give an adequate result. The 'confidence' interval will especially be unrealistically short, as illustrated in Figure 7. We therefore need a more advanced estimation procedure to take care of the multi-sample problem.

Below, the so-called OREDA-estimator of the "average" failure rate in a multi-sample situation is presented together with a 90% uncertainty interval. Spjøtvoll (1985) gives a rationale for the estimation procedure.

The OREDA-estimator is based on the following assumptions:

- We have k different samples. A sample may e.g., correspond to a platform, and we may have data from similar items used on k different platforms.
- In sample no. i we have observed n_i failures during a total time in service τ_i, for $i = 1, 2, \ldots, k$.
- Sample no. i has a constant failure rate λ_i, for $i = 1, 2, \ldots, k$.
- Due to different operational and environmental conditions, the failure rate λ_i may vary between the samples.

The variation of the failure rate between samples may be modelled by assuming that the failure rate is a random variable with some distribution given by a probability density function $\pi(\lambda)$.

The mean, or "average" failure rate is then: $\theta = \int_0^\infty \lambda \cdot \pi(\lambda)\,\mathrm{d}\lambda.$

and the variance is: $\sigma^2 = \int_0^\infty (\lambda - \theta_\Lambda)^2 \cdot \pi(\lambda)\,\mathrm{d}\lambda.$

To calculate the multi-sample OREDA-estimator, the following procedure is used:

1. Calculate an initial estimate $\hat{\theta}_1$ of the mean ("average") failure rate θ, by pooling the data:

$$\hat{\theta}_1 = \frac{\text{Total no. of failures}}{\text{Total time in service}} = \frac{\sum_{i=1}^{k} n_i}{\sum_{i=1}^{k} \tau_i}$$

2. Calculate:

$$S_1 = \sum_{i=1}^{k} \tau_i$$

$$S_2 = \sum_{i=1}^{k} \tau_i^2$$

$$V = \sum_{i=1}^{k} \frac{(n_i - \hat{\theta}_1 \tau_i)^2}{\tau_i} = \sum_{i=1}^{k} \frac{n_i^2}{\tau_i} - \hat{\theta}_1^2 S_1$$

3. Calculate an estimate for σ^2, a measure of the variation between samples, by:

$$\hat{\sigma}^2 = \frac{V - (k-1)\hat{\theta}_1}{S_1^2 - S_2} \times S_1 \quad \text{when greater than 0, else 0.}$$

4. Calculate the final estimate θ^* of the mean ("average") failure rate θ by:

$$\theta^* = \frac{1}{\sum_{i=1}^{k} \frac{1}{\frac{\hat{\theta}_1}{\tau_i} + \hat{\sigma}^2}} \times \sum_{i=1}^{k} \left(\frac{1}{\frac{\hat{\theta}_1}{\tau_i} + \hat{\sigma}^2} \times \frac{n_i}{\tau_i} \right)$$

5. Let $SD = \hat{\sigma}$

In the data tables in Part II of the handbook θ^* corresponds to the mean (column 4), and *SD* corresponds to the standard deviation (column 6).

The *lower* and *upper* "uncertainty" values are given by:

$$\int_{Lower}^{Upper} \pi(\lambda)\, d\lambda = 90\%$$

Since the distribution $\pi(\lambda)$ is not known in advance, the following pragmatic approach is used:

6. $\pi(\lambda)$ is assumed to be the probability density function of a *Gamma* distribution with parameters α and β.

7. The parameters α and β are estimated by:

$$\hat{\beta} = \frac{\theta^*}{\hat{\sigma}^2}$$

$$\hat{\alpha} = \hat{\beta} \cdot \theta^*$$

8. The following formulas are now applied:

$$Lower = \frac{1}{2\hat{\beta}} z_{0.95,2\hat{\alpha}}$$

$$Upper = \frac{1}{2\hat{\beta}} z_{0.05,2\hat{\alpha}}$$

where $z_{0.95,v}$ and $z_{0.05,v}$ denote the *upper* 95% and 5% percentiles, respectively, of the χ^2-distribution with ν degrees of freedom, see Table 4, page 31. In situations where ν is not an integer, an interpolation in the χ^2-distribution is performed.

Note 1
More detailed analysis of the OREDA data (see Vatn 1993) has indicated that there may be a large variation between installations. The multi-sample OREDA estimator should therefore as a rule be used instead of the n/τ estimator which is based on a homogeneous sample. The variation between the samples (installations) is measured by the standard deviation SD.

Note 2
In the OREDA-84 and OREDA-92 handbooks, a slightly different approach was taken. The mean value was estimated with the same procedure as in this handbook, but the *lower* and *upper* values were given a slightly different interpretation.

Note 3
In the case of $k = 1$, the procedure cannot be used. In this case the n/τ estimate is given for the mean, and the *lower* and *upper* values should be interpreted as a traditional 90% confidence interval.

Note 4
If no failures are observed for an item, the following approach is used to obtain lower, mean and upper values for “All failure modes”:

1. Let $\hat{\lambda}_P$ denote the failure rate estimate (“mean”) one level up in the taxonomy hierarchy.

2. Let τ denote the total time in service (operational or calendar) for the item of interest

3. Let

$$\alpha = 1/2$$

$$\beta = \frac{1}{2\hat{\lambda}_P} + \tau$$

4. An estimate for the failure rate is now

$$\hat{\lambda} = \frac{\alpha}{\beta}$$

5. The standard deviation is given by

$$SD = \sqrt{\frac{\alpha}{\beta^2}}$$

6. A 90% uncertainty interval is given by

$$\left(\frac{1}{2\beta} z_{0.95,2\alpha}, \frac{1}{2\beta} z_{0.05,2\alpha)}\right) = \left(\frac{0.002}{\beta}, \frac{1.9}{\beta}\right)$$

ESTIMATION OF DEMAND PROBABILITIES

If information about "number of demands" is given (see Section "Data table, Reliability Data", page 32) it is possible to estimate the demand probability. The demand probability is always related to one specific failure mode, for example a critical fail to start. The demand failure probability is estimated by:

$$\hat{p} = \frac{n}{d}$$

where n is the number of failures with the appropriate failure mode, and d is the number of demands. Note that in the data table presentations the demand probabilities may apparently look different. The reason for this is that in some cases there are registered "demand failures", but the number of demands is not recorded for one or more inventories. For these inventories, the demand failures are not added to the total number of demand failures for that data table.

PERCENTAGE POINTS OF THE CHI-SQUARE DISTRIBUTION

Table 4 Percentage Points of the Chi-square (χ^2) Distribution

$\Pr(Z > z_{\alpha,\nu}) = \alpha$

ν/α	0.995	0.990	0.975	0.950	0.05	0.025	0.010	0.005
1	0.00	0.00	0.00	0.00	3.84	5.02	6.63	7.88
2	0.01	0.02	0.05	0.10	5.99	7.38	9.21	10.60
3	0.07	0.11	0.22	0.35	7.81	9.35	11.34	12.84
4	0.21	0.30	0.48	0.71	9.49	11.14	13.28	14.86
5	0.41	0.55	0.83	1.15	11.07	12.38	15.09	16.75
6	0.68	0.87	1.24	1.64	12.59	14.45	16.81	18.55
7	0.99	1.24	1.69	2.17	14.07	16.01	18.48	20.28
8	1.34	1.65	2.18	2.73	15.51	17.53	20.09	21.96
9	1.73	2.09	2.70	3.33	16.92	19.02	21.67	23.59
10	2.16	2.56	3.25	3.94	18.31	20.48	23.21	25.19
11	2.60	3.05	3.82	4.57	19.68	21.92	24.72	26.76
12	3.07	3.57	4.40	5.23	21.03	23.34	26.22	28.30
13	3.57	4.11	5.01	5.89	22.36	24.74	27.69	29.82
14	4.07	4.66	5.63	6.57	23.68	26.12	29.14	31.32
15	4.60	5.23	6.27	7.26	25.00	27.49	30.58	32.80
16	5.14	5.81	6.91	7.96	26.30	28.85	32.00	34.27
17	5.70	6.41	7.56	8.67	27.59	30.19	33.41	35.72
18	6.26	7.01	8.23	9.39	28.87	31.53	34.81	37.16
19	6.84	7.63	8.91	10.12	30.14	32.85	36.19	38.58
20	7.43	8.26	9.59	10.85	31.41	34.17	37.57	40.00
25	10.52	11.52	13.12	14.61	37.65	40.65	44.31	46.93
26	11.16	12.20	13.84	15.38	38.89	41.92	45.64	48.29
27	11.81	12.88	14.57	16.15	40.11	43.19	46.96	49.64
28	12.46	13.56	15.31	16.93	41.34	44.46	48.28	50.99
29	13.12	14.26	16.05	17.71	42.56	45.72	49.59	52.34
30	13.79	14.95	16.79	18.49	43.77	46.98	50.89	53.67
40	20.71	22.16	24.43	26.51	55.76	59.34	63.69	66.77
50	27.99	29.71	32.36	34.76	67.50	71.42	76.15	79.49
60	35.53	37.48	40.48	43.19	79.08	83.30	88.38	91.95
70	43.28	45.44	48.76	51.74	90.53	95.02	100.42	104.22
80	51.17	53.54	57.15	60.39	101.88	106.63	112.33	116.32
90	59.20	61.75	65.65	69.13	113.14	118.14	124.12	128.30
100	67.33	70.06	74.22	77.93	124.34	129.56	135.81	140.17

TOPSIDE DATA TABLE FORMATS

DATA TABLE, RELIABILITY DATA

Each data table contains an identification of the item and the estimated reliability parameters. The figures provided should be interpreted on the basis of the assumptions specified in the boundary definition for each equipment category and the estimation method applied. The format of the data table is shown in Figure 8.

Taxonomy no		Item								
Population	Installations	Aggregated time in service (10^6 hours)					No of demands			
		Calendar time *		Operational time †						
Failure mode	No of failures	Failure rate (per 10^6 hours).					Active rep.hrs	Repair (manhours)		
		Lower	Mean	Upper	SD	n/τ		Min	Mean	Max
Comments										

Figure 8 Format of the Reliability Data Tables

The various entries of the data table are explained in the following:

Taxonomy number and Item

The taxonomy number is a numerical identification of the item. The description of the item is given in a hierarchical structure. Only data from items of this generic category of components/equipment are input to the estimates presented in the quantitative part of the data table.

Population

Total number of items forming the basis for the estimates.

Installations

Total number of installations (platforms) covered by the data surveillance for the item in question.

Aggregated time in service

Two types of time scales are presented as the basis for the failure rate estimates; calendar time and operational time. The aggregated time in service for the total population is given for both time scales. Note that while the calendar time is given with high certainty, the operational time has in many cases to be based on estimates (by the data collector).

Number of demands

The accumulated number of demands/cycles for the total population is given when available. In several cases these numbers are based on estimates and not accurate measurements.

Failure mode

This column contains a brief description of the manner in which the failure occurred, when such information is available.

Number of failures

The total number of failure events is presented for each failure mode. The accumulated number of failures is presented as "All modes".

Failure rate

The failure rate columns present estimates of the failure rate for each failure mode. Results are given both under the "multi-sample" assumption, and under the assumption of homogeneous data sets. In the multi-sample situation the failure rate is assumed to vary between installations (platforms), and each platform represents one sample. The following entries are included:

Mean — An estimate of the "average" failure rate with respect to the specified failure mode, obtained by using the OREDA estimator.

(Lower, Upper) — A 90% uncertainty interval for the failure rate.

SD — A standard deviation indicating the variation between the multiple samples.

n/τ — The total number of failures divided by the total time in service, i.e., the estimate of the failure rate we would use for a homogeneous sample.

All the entries are measured per 10^6 hours and refer either to calendar time (marked *) or operational time (marked †).

Active repair time (hours)

This column contains the average calendar time (hours) required to repair and return the item to a state where it is ready to resume its functions. Active repair time is the time when actual repair work is being done. It does not include time to shut down the unit, issue work order, wait for spare parts, start-up after repair etc. The active repair time is therefore normally shorter than the *downtime* where some of the activities indicated above may be included.

Note:

During the data collection exercises it has been very difficult to obtain data regarding active repair times. In the OREDA database there is a good coverage of "restoration man-hours" data, whereas the data for "active repair time" is rather sparse. It should also be noted that active repair hours are highly influenced by how maintenance is organised on the platform. The figures for active repair times should therefore only be used as an indication of what the actual active repair times would be. It is highly recommended to use some kind of expert judgement in addition to the values given in the handbook.

Repair (manhours)

The repair columns present three values of the repair time (man-hours). The *mean* value is the average number of man-hours recorded to repair the failure and restore the function. The *min* and *max* values are the lowest and highest number of man-hours recorded for the repair of the item.

Comments

When available the on on-demand failure probability is given in the Comment field.

DATA TABLE, MAINTAINABLE ITEM VERSUS FAILURE MODE

The reliability data presented in the data table in Figure 8 (page 32) does not give information on which part of the equipment has failed. In the *Maintainable Item versus Failure Mode* listing the relative contribution from each maintainable item to the total failure rate may be obtained. The figures in the table represent *percentages of occurrence* for each combination of failure mode and maintainable item. The row sum represents the total percentage of failures that are related to the actual maintainable item. Note that several maintainable items might be assigned to each failure record. In such situations, the "score" for the actual maintainable item/failure mode combination is set to $1/n$, where n is the number of maintainable items listed for that failure record. The column sum represents the contribution for each failure mode in percentages.

This information is valuable input to an FMEA/FMECA analysis. The FMEA/FMECA analysis is further a major part of a reliability centred maintenance (RCM) analysis. As the RCM methodology focuses on failure causes, it is also important to have information regarding failure causes as discussed in the next section. Note that several maintainable items might be assigned to each failure record.

DATA TABLE, FAILURE DESCRIPTOR VERSUS FAILURE MODE

In the *Failure Descriptor versus Failure Mode* listing the relative contribution from each failure descriptor (cause) to the to the total failure rate may be obtained. The figures in the table represent percentages of occurrence for each combination of failure descriptor and failure mode. The row sum represents the total percentage of failures that are related to the actual failure descriptor. The column sum represents the contribution for each failure mode in percentages.

As mentioned above, the information about failure causes is essential in an RCM analysis. For example scheduled replacement of units is only applicable if one or more failure causes may be related to ageing, wear, corrosion etc.

SUBSEA DATA TABLE FORMATS

DATA TABLE, RELIABILITY DATA

Each data table contains an identification of the item and the estimated reliability parameters. The figures provided should be interpreted on the basis of the assumptions specified in the boundary definition for each equipment category and the estimation method applied. The format of the data table is shown in Figure 8.

Taxonomy no		**Item**										
Population	**Installations**						**Aggregated time in service (10^6 hours)**					
		Failure data					**Calendar time**					
Component	**No of units**		**Severity class**				**Failure rate (per 10^6 hours).**					**Active repair time (hours)**
		#	**C**	**D**	**I**	**U**	**Lower**	**Mean**	**Upper**	**SD**	***n/τ***	**Mean**
Subunit no. 1 Component no. 1 Component no..2												
Subunit no. 2 Component no....												
Equipment level												
Comments For components with no failures, n is set to 0.5 based on a non-informative prior. * Mean failure for the common component is used in the estimator.												

Figure 9 Format of the Reliability Data Tables

The various entries of the data table are explained in the following:

Taxonomy number and Item

The taxonomy number is a numerical identification of the item. The description of the item is given in a hierarchical structure. Only data from items of this generic category of components/equipment are input to the estimates presented in the quantitative part of the data table.

Population

Total number of items forming the basis for the estimates.

Installations

Total number of installations (platforms) covered by the data surveillance for the item in question.

Aggregated time in service

The aggregated time in service for the total population is given for calendar time scale for the equipment unit level. A subunit and its related component(s) may have different calendar time recorded as the latter is recorded individually for each subunit and component in the database.

Component

This column contains the list of subunits and component for which the failure data is presented. The subunits are in bold letters. The equipment unit level data are presented in the last row. The number of items on each level is listed in the table.

Number of failures

The total number of failure events (#) is presented for each subunit and component. The criticality distribution is given for each item i.e. critical (C), degraded (D), incipient (I) and unknown (U).

Failure rate

The failure rate columns present estimates of the failure rate for each subunit and component. Results are given both under the "multi-sample" assumption, and under the assumption of homogeneous data sets. In the multi-sample situation the failure rate is assumed to vary between installations (platforms), and each platform represents one sample. The following entries are included:

Mean	An estimate of the "average" failure rate with respect to the specified failure mode, obtained by using the OREDA estimator.
(Lower, Upper)	A 90% uncertainty interval for the failure rate.
SD	A standard deviation indicating the variation between the multiple samples.
n/τ	The total number of failures divided by the total time in service, i.e., the estimate of the failure rate we would use for a homogeneous sample.

All the entries are measured per 10^6 hours and refer to calendar time.

Active repair time (hours)

This column contains the elapsed calendar time (hours) required to repair and return the item to a state where it is ready to resume its functions. This is the part of the total repair time used on-site. The *mean* value is the average number of hours recorded to repair the failure and restore the function. Active reapir time should not be mixed with *downtime* which my additionally include time periods such as shutdown, repair vessel mobilisation, start-up after repair etc.

Comments

The comment field presents comments to the calculation of failure rates.

For components with no failures, n is set to 0.5 based on a non-informative prior.
* Mean failure for the common component is used in the estimator.

DATA TABLE, COMPONENT VERSUS FAILURE MODE

The reliability data presented in the data table in Figure 8 (page 32) give information on which part of the equipment has failed. The *Component versus Failure Mode* lists the number failure modes for each component. The figures in the table represent number of occurrence for each combination of failure mode and component. The row sum represents the total number of failures that are related to the actual component. The column sum represents the total number of each failure mode.

This information is valuable input to an FMEA/FMECA analysis (see e.g. IEC 812). The FMEA/FMECA analysis is further a major part of a reliability centred maintenance (RCM) analysis (see e.g. Rausand and Vatn 1997). As the RCM methodology focuses on failure causes, it is also important to have information regarding failure causes as discussed in the next section.

DATA TABLE, SUBUNIT VERSUS FAILURE MODE

The *Subunit versus Failure Mode* lists the number of failure modes for each subunit. The figures in the table represent number of occurrence for each combination of failure mode and subunit. The row sum represents the number of failures that are related to the actual subunit. The column sum represents the number of each failure mode.

DATA TABLE, EQUIPMENT UNIT VERSUS FAILURE MODE

The *Equipment unit versus Failure Mode* table lists the number of failure modes at the equipment unit level.

DATA TABLE, FAILURE DESCRIPTOR VERSUS FAILURE MODE

In the *Failure Descriptor versus Failure Mode* listing the relative contribution from each failure descriptor (cause) to the to the total failure rate may be obtained. The figures in the table represent percentages of occurrence for each combination of failure descriptor and failure mode. The descriptor is presented for each component. The row sum represents the total percentage of failures that are related to the actual failure descriptor for each component. The column sum represents the contribution for each failure mode in percentages.

MISCELLANEOUS ESTIMATION PROCEDURES

NO FAILURES ARE OBSERVED FOR A SPECIFIC FAILURE MODE

In the data tables failure rate estimates are only presented for those failure modes for which failures have been recorded. The standard failure rate estimate in this situation is $\hat{\lambda} = 0$. An alternative procedure for estimating the failure rate in this situation is given under Note 4 on page 29. To use the procedure, the term *"All failure modes"* should be replaced with the failure mode of interest. Further information may be obtained from the Internet address:

http://www.sintef.no/oreda/analysis/

WEIGHTING OREDA-2002 DATA WITH OTHER DATA SOURCES

In many RAMS analyses, data may also be available from other sources than this handbook. For offshore RAMS analyses, the most obvious data source in addition to this book, is the previous handbooks. A method for weighting data from OREDA-97 and OREDA-2002 is given below. The method is based on an approach suggested in the OREDA Data Analysis Guidelines (Vatn 1993).

The calculations are repeated for all failure modes of interest. Let λ_{III} denote the mean failure rate for Phase IV and V data (column 4) in the OREDA-2002 handbook. Further, let SD_{III} denote the standard deviation in column 6. λ_{II} is the corresponding mean in the OREDA-97 handbook. A weighted failure rate estimate is given by:

$$\hat{\lambda} = \frac{\lambda_{II}^2 + \lambda_{III}^2 \left(\lambda_{II}/\lambda_{III} + |\lambda_{II} - \lambda_{III}|/SD_{III} \right)^2}{\lambda_{II} + \lambda_{III} \left(\lambda_{II}/\lambda_{III} + |\lambda_{II} - \lambda_{III}|/SD_{III} \right)^2}$$

where $|x|$ denotes the absolute value of x.

If in addition, standard deviation and uncertainty limits are required, please consult the Internet address:

http://www.sintef.no/oreda/analysis/

where also a rationale for the above procedure is given.

DEFINITIONS[3]

The main terminology used in the OREDA-97 handbook is defined in this section. The specific definitions of the terminology and parameters used in the statistical estimation procedures are included in the section "Estimation Procedures".

Terms marked with **(C)** are categorised in pre-defined codes.

Active Repair Time
Active repair time is the total (calendar) time required to repair and return the item to a state where it is ready to resume its functions.

This excludes the time to detect the failure, time to isolate the equipment from the process before repair, delay and waiting for spare parts or tools, and any time after the repair has been completed if the item is not put into service immediately. Time for testing is included when such testing is an integrated part of the repair activity.

Boundary
The interface between an item and its surroundings.

Calendar Time
The interval of time between the start and end of data surveillance for a particular item.

Component (C) – Subsea
These are subsets of each subunit (subsea inventory) and will typically consist of the lowest level items that are repaired/replaced as a whole (e.g. valve, sensor etc.).

Equipment unit
The highest indenture level including subunits and smaller entities belonging to that equipment unit. Equipment unit corresponds in most cases to tag number for topside equipment.

Failure
The termination or the degradation of the ability of an item to perform its required function(s). It includes:

- Complete failure of the item
- Failure of part of the item that causes unavailability of the item for corrective action
- Failure discovered during inspection, testing, or preventive maintenance that requires repair
- Failure on safety devices or control/monitoring devices that necessitates shutdown, or reduction of the items capability below specified limits.

The following outages are not considered as failures:

- Unavailability due to preventive or planned maintenance

[3] Useful definitions related to this Handbook will also be found in the standards ISO 14224 and NORSOK Z016.

- Shutdown of the item due to external conditions, or where no physical failure condition of the item is revealed. A shutdown is not to be considered a failure unless there is *some recorded maintenance activity.*

A required function is defined as any function necessary to maintain the item's capability of providing its output at specified capacity and quality. Note that a failure could be either complete loss of function or function degradation below an acceptable limit.

A failure will normally require a work order and involvement by maintenance personnel.

Failure Descriptor (C)
An attribute of the failure event that can be easily deduced technically. The failure descriptor is the *apparent, immediate cause* of the failure and is related to *subunit level.*

Failure Mode (C)
The effect by which a failure is observed on the failed unit. The failure modes describe the loss of required system function(s) that result from failures, or an undesired change in state or condition. The failure mode is related to the equipment unit level. The failure mode is a description of the various abnormal states/conditions of an equipment unit, and the posssible transition from correct to incorrect state.

The failure mode can be subdivided in two major classes:

1. Demanded change of state is not achieved

2. Undesired change in conditions (state)

The first class typically comprises events like fail-to-start/stop and fail-to-open/close, i.e. directly related to a failure of the *function* of the unit. The latter category can either be related to *function* and *condition* as follows:

a) Undesired change in *manner of operation* (e.g. spurious stop, high output)

b) Undesired *change of condition* (e.g. vibration, leakage). This category does not affect the function immediately, but may do so if not attended to within a reasonable time.

(See e.g., Rausand and Øien (1996) for a thorough discussion of failures and failure modes).

Item
A common term used to denote any level of hardware assembly; i.e. equipment unit, subunit, maintainable items and parts.

Maintainable Item (C)
An item that constitutes an assembly of parts that are normally the lowest indenture level during maintenance.

Number of Demands
The total number of times an item is required to perform its specified function(s) during the calendar time.

Operational Time
The period of time during which a particular item performs its required function(s), between the start and end of data surveillance.

Population
The total number of items of one particular type in service during the period of the event data surveillance.

Sample
The group of items of one particular type in service - described by its taxonomy code - on one installation during the period of the event data surveillance.

Severity Class Types (C)
CRITICAL FAILURE: A failure which causes immediate and complete loss of a system's capability of providing its output.

DEGRADED FAILURE: A failure which is not critical, but which prevents the system from providing its output within specifications. Such a failure would usually, but not necessarily, be gradual or partial, and may develop into a critical failure in time.

INCIPIENT FAILURE: A failure which does not immediately cause loss of a system's capability of providing its output, but which, if not attended to, could result in a critical or degraded failure in the near future.

UNKNOWN: Failure severity was not recorded or could not be deduced.

The severity class is used to describe effect on operational status and the severity of loss of output from the system. Each failure has been associated with only one severity class, either critical, degraded or incipient, *independently of the failure mode and failure cause.* The severity classification is confined to the location and use of the *equipment unit* that has failed.

Subunit (C) - Topside
An assembly of items that provides a specific function that is required for the equipment unit to achieve its intended performance. Corresponds frequently with sub-tag number(s).

Subunit (C) - Subsea
A subsea equipment unit is subdivided in several subunits, each with function(s) required for the *equipment unit* to perform its main function. Typical subunits are e.g. umbilical, HPU etc. The subunits may be redundant, e.g. two independent HPUs.

Taxonomy (C)
A systematic classification of items into generic groups based on factors possibly common to several of the items, e.g. functional type, medium handled.

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