NTNU – Trondheim
Norwegian University of
Science and Technology

Provision of Reliability Data for New Technology

Approach for estimation of failure rate
function for a sub-sea pump

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Reliability, Availability, Maintainability and Safety (RAMS)
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Preface

This work is part of Master's thesis in Approach to Estimation of Failure rate of a subsea pump at NTNU as part of the study program MSc. RAMS 2010-12 during the spring semester of 2012.

Trondheim, 2012-06-20

(Your signature)

Indra Praveen Vardelly

Acknowledgment

I would like to thank my supervisor Marvin Rausand for the guidance in work and literature search and patience with feedback during semester. I would also like to thank Elin Tronhus at Valgrida library for loaning me "ikke Utlån" books for extended durations multiple times.

V.I.P.

Summary and Conclusions

This report presents an introduction to three Reliability database sources viz. OREDA, FIDES, MechRel. An evaluation of the methodologies for reliability prediction from these sources and important differences. It presents description of pump from OREDA and important differences and similarities between topside and subsea pumps. A detail discussion about Failure descriptors and Maintainable items of pump found in OREDA is provided. An understanding of Reliability influence factor is described and FMECA is carried out on pump. Another methodology based on literature survey is analysed and discussion about the assumption of constant failure rate pays way to proposal of an approach for estimating a estimating a life profile of subsea pump.

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MASTERKONTRAKT

- uttak av masteroppgave

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2. Studieopplysninger

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Studieprogram **Reliability, Availability, Maintainability and Safety (RAMS)**

3. Masteroppgave

Oppstartsdato **25. jan 2012**	Innleveringsfrist **20. jun 2012**
Oppgavens (foreløpige) tittel **Provision of Reliability Data for New Technology** **Approach for estimation of failure rate function for a sub-sea pump**	
Oppgavetekst/Problembeskrivelse As part of the project thesis the candidate shall work on the following. 1. Document a literature survey of relevant reliability data sources and evaluate these with respect to applicability and quality. The data sources shall, as a minimum,include OREDA, MechRel and FIDES. 2. Give a brief technical description of a subsea pump and its topside counterpart and highlight similarities and differences, technical, as well as operational and environmental. 3. Carry out an FMECA with focus on the failure causes and mechanisms for the two pumps. 4. Analyze the information found in OREDA for pump, especially related to the contribution from maintainable items and failure descriptors. 5. Identify the reliability influencing factors for both topside and subsea application and illustrate them by Bayesian networks. 6. Discuss the constant failure rate assumption made in OREDA and discuss whether or not the same assumption may be made for a subsea application. 7. Based on a literature survey, identify approaches to extrapolate data from one application to another to estimate plant specific failure rates. The survey shall, as a minimum cover the approaches outlined by Brissaud, et al(20...	
Hovedveileder ved institutt **Professor Marvin Rausand**	Medveileder(e) ved institutt
Merknader **1 uke ekstra p.g.a påske.**	

Side **1** av **2**

Figure 1: contract

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Chapter 1

Introduction

Reliability prediction methods with different models of approach are developed all across the world and new models are in the process of developing. The need for new approaches and new models is a constantly developing thing along with other developments. The main reason for this is, technology is developing very fast to adapt to faster changes and harness new resourceful ways for everything possible. Sub-sea technology is not very old and is developing very fast into a dynamic technology because of its reach. The challenges also arise and here, a pump is part of that technological development. The pump, which is used all over the world in different applications, has found its one of the most difficult application. The task is to stay at seabed, 3000 meters below sea level and do the pumping job with odd fluids and harsh operations. Challenge is to make it available to do its job. The sub-sea technology demands high reliability because it provides high reliability and cost-efficiency. So the qualification of an existing topside pump is the objective for many companies. If not being part of the process, an approach to a *good* direction is the right step. Many good directions exist. So the objective is to frame an approach to estimate the reliability parameter, in this case it is a *failure rate*.

1.1 Background

The sub-sea production technology is into new phase with development of smart fields, enhanced oil production, higher safety, more reliable processes and new approaches, all working towards cost-effectiveness. The sub-sea pump is aimed at providing all these services. The aim to achieve it in greater confidence is a statistical problem. To the world it is an absolute necessity for current scenario. The pump as a topside unit exists and performs some of the functions. Few companies have manufactured and want to improve it in terms of safety and reliability of its functionality in a growing market. So this report aims to approach it from a student perspective.

Problem Formulation

The problem in approaching to estimate failure rate function for a sub-sea pump is there is no data available about its failures or behavior in that environment. Even if it is available, it is out of my reach and this is the problem. The investigation about the problem revealed about few database sources which present reliability prediction models and these are extensively used in many countries. Their approaches and presentations vary because they have made it suitable to their needs. Nonetheless it is is good learning resource and they are evaluated in this report.

Literature Survey

The main literature survey is evaluation of reliability database resources and to understand the methodologies developed. Understanding the context and applicability of these methodologies for the objective of this report. As a first step descriptions in *OREDA 1993, Guidelines for Data collection* is studied in detail. The next step is the evaluation of *OREDA 2009* database guide for both topside and sub-sea and investigation about failure modes of pump and its maintainable parts is carried out. Then *FIDES 2010* database and guidelines for reliability prediction is studies. The next database study involves *MechRel 2009* and its approach towards mechanical equipment. The methodology proposed by *Brissaud et al 2010* is studied in detail. Apart from these, *Rausand and Hoyland, 2004 DNV-RP A205* is referred for many basic concepts and understanding estimation procedures.

1.2 Objectives

The main objectives of this Master's project are

1. The first objective is to document a literature survey of relevant reliability data sources

and evaluate these with respect to applicability and quality. The data sources shall, as a minimum, include OREDA, MechRel and FIDES.

2. To give brief technical description of a sub-sea pump and its topside counterpart and highlight similarities and differences, technical, operational and environmental.

3. To carry out FMECA with focus on the failure causes and mechanisms for the pump.

4. Analyze information found in OREDA for pump, especially related to the contribution from maintainable items and failure descriptors.

5. Identify the reliability influencing factors for sub-sea application and illustrate them by using Bayesian networks.

6. Discuss the constant failure rate assumption made in OREDA and discuss whether or not the same assumption may be made for a sub-sea application.

7. Based on a literature survey, identify approaches to extrapolate data from one application to another to estimate plant specific failure rates.

1.3 Limitations

The different approaches and methods developed in various database sources were very exhaustive to understand. The sub-sea pump information is not provided in any of them. So reliance on imagination and DNV-RP Guidelines is more for understanding the sub-sea application. Some information in company websites of Aker Solutions and Framo were not very exhaustive to make any use even to understand basic differences. The inadequate information regarding sub-sea pump, limited the FMECA.

1.4 Structure of the Report

The rest of the report is structured as follows. Chapter 1 evaluates the three database resources. Chapter 2 evaluates the case of a centrifugal sub-sea pump and its topside counterpart for information. The specific details about differences and similarities. Information about failure descriptors is evaluated and reliability influence factors are analyzed. Chapter 3 presents the discussion on assumptions of failure rates and new methods of approach in estimating the failure rate of sub-sea pump.

Chapter 2

Reliability Database Evaluation

The survey of various reliability databases are presented in this chapter. In consideration of respective aims and applicability, many consortium firms have developed their guidelines, reliability analysis approaches and Databases in a suitable manner. The primary objective of these databases is to contribute for an increased cost effectiveness and exchange of maintenance and operational data towards safety focus in lifecycle of the equipment. The aim is to understand and document various important differences and analysis of application. The quality of maintaining and weight-age considerations observed in these databases are highlighted. Approach and estimation of reliability parameters are analyzed and presented. The following three databases are considered ORDEDA, FIDES and MECHREL.

2.1 OREDA

The OREDA project *OREDA2009* database is a resource for reliability data from offshore equipment from participating companies in the project. It has served as an important vehicle for promotion of RAMS (*Reliability Maintainability Availability and Safety*) technology among the companies. It is primarily divided in to topside and subsea equipment but, also consists of some onshore equipment of E and P companies. The database has undergone changes and up-gradation with new population samples and inclusion of ISO standard 14 224, nonetheless within stated guidelines as in*OREDA1992*. The database is split into 3 separate files as following:

1. **Inventory** data containing description of *equipment unit* along with its technical data,

operating and environmental data.

2. **Failure** data containing all information about failures of equipment unit. Every failure event having a separate record, where a failure event is defined as *physical* failure of equipment.

3. **Maintenance** data containing all information about corrective and preventive maintenance of equipment unit.

Equipment Class is a group of items under same main function and are classified based on design and service. Each equipment unit is an individual item with in equipment class and the system hierarchy follows into *subunit* and *maintainable item*.Where a subunit is defined as a consistent unit under an equipment unit required for performing main function. A maintainable item is defined as the lowest level item with in the subunit which is subjected to repair and maintenance. System hierarchy is clearly delimited by defining equipment boundary for an equipment class to show the relation between surrounding and equipment unit. Over the years this boundary has changed within the database from OREDA 1993 to OREDA 2009 as per physical definition for equipment units. If we take for example a pump as an equipment class with (e.g.) centrifugal pump as a case, it has the following subunits units defined within the system boundary OREDA1993 guidelines :

1. start system

2. driving unit

3. power transmission

4. pump unit

5. control and monitoring

6. lubrication system

7. miscellaneous system

The first two subunits are defined to be outside the boundary in OREDA,2009. If we were to consider the sub sea application of this equipment unit "centrifugal pump", our boundary will differ as it should include *driving unit* because sensibly it is not feasible to have a driving unit 3000 meters above sea level for a pump below. Further the boundary will exclude *start system* as it is feasible and sensible to have it above on platform. The main observation is, in an equipment class, boundaries vary within same equipment unit as per the application over a period of time. It is possible that in the next OREDA edition the database for subsea equipment can show the shift in boundary for the centrifugal pump.

Moving down to *maintainable item* level database has records for failure modes, failure descriptor/mechanisms. The former is defined as an observed undesired change of state or possible transition in the item leading to failure. These states are grouped into 3 categories,

- a) unavailability of desired function
- b) function out of limits or lost
- c) indication of failure , there is no immediate functional failure.

Failure descriptor/mechanism is the immediate cause which is apparently observed as leading to failure. It is a technical observation of an attribute of failure event. These are strictly cause-related on subsystem level and as far as possible should *represent attributes to failure mode at subsystem level and attributes to failure cause at system level.* These can be related to following broad categories :

- Instrumentation failures
- Electrical failures
- Mechanical failures
- Materials failure
- Operational failures
- External causes

- Design/Manufacturing/Construction causes
- Unknown

The database contains observed failures for each failure mode through these mechanisms but is restricted to hardware failures. The OREDA 1993 guidelines contain a list of attributes to these failure descriptor categories. The recent OREDA 2009 database provides estimates of constant failure rates for each failure mode with specified uncertainties.

Failure effect is the observed failure and criticality at system level which contains the failure modes through these failure descriptors at lowest possible indenture. Therefore *maintainable items* are focused in deriving coherent estimated failure rates as they are in possession of change of states represented by failure modes. In the OREDA 2009 the *failure rate function* of these bottom part is considered to be constantly useful life as observed in a Bath-Tub curve shown in *Rausand and Høyland 2004*. Since there is repair and maintenance activity to bring the states of items to represent a fully functioning state, these are as good as new and observed failures are independent of age of the item meaning that chance failures intend no degradation of system and item as long as it is functioning. It deduces that the assumption of failure rate to be *close to constant* and is exponentially distributed with parameter λ. But many failure descriptors are also due to age and environment dependent attributes to the observed failure modes, affecting the transition of categories viz *Critical, Degraded, Incipient and Unknown* as described in OREDA2009. So the relational aspect of closeness to constant failure rate is of importance for study in the context of new application of same equipment unit, for example a centrifugal pump in sub-sea environment. To understand and delimit this aspect, a mental observation of this situation is presented in the 2.1. The states are represented as changed dimensions of the item in the 2.1. Depending on the overall dimensions, failure modes can be classified as stated in four categories. At the instance of termination of function, the overall apparent observation of the item towards higher system hierarchy is described as failure.The arrow marks in the fig2.1 is failure mechanism. The failure descriptors here are frames representing the attributes of apparent causes in transition to produce the mechanism for change of state to the item, which is being termed as failure mode and further leading to failure event.

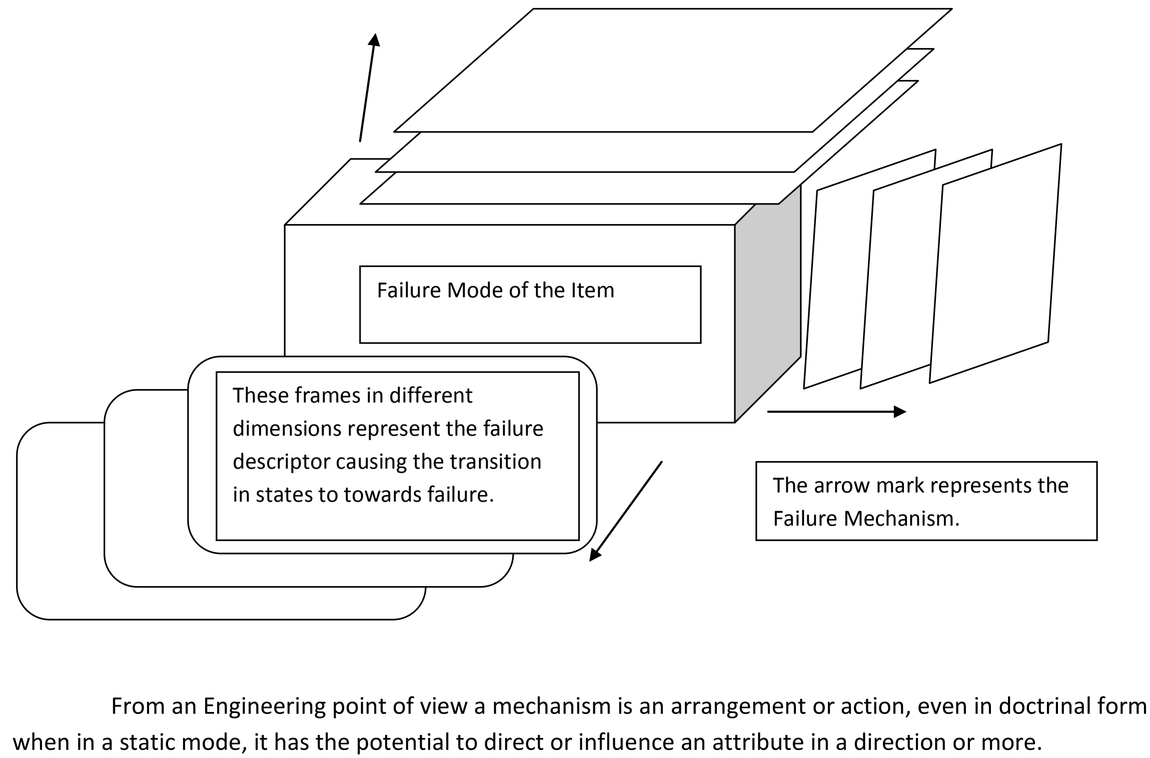

Figure 2.1: Representation of relations of failure, failure mode and failure descriptors

This understanding when applied in context of new application *sub-sea environment* for the equipment unit *centrifugal pump*, this aids in understanding the assumed closeness to constant failure rate and thus constant failure rate function. The data in OREDA disregards the problems from installation and manufacturing as part of burn-in or initial phase. Data after the quality testing after installation is considered if production starts in case of sub-sea equipment. Database contains tabulated descriptions failure rate combinations of two categories:

- Failure mechanism vs Failure Mode
- Maintainable item vs Failure Mode

Both tables are intended to understand the percentage contribution of each failure mode in combination with a particular maintainable item and with failure mechanism towards overall failure rate of the given failure mode. These are limited to registered failures events in database. It helps in performing FMECA and aids in maintenance activity for the equipment. The failure rate is estimated for 90 percent confidence interval for homogeneous sample over the aggregated time of service τ. But, in case of Multi-sample data, failure rate is calculated for 90 percent *uncertainty* interval. Moreover the failure rate in this case varies hugely from sample to sample from different installations. A final estimate θ^* of mean average failure rate θ is used where the failure rate λ is assumed to be a random variable (varying from sample to sample) with a *Gamma* distributed probability density function $\pi(\lambda)$. Analysts are required to observe caution for trade-offs for data relevance and population size during unavailability or from moving from lower taxonomy level to higher one. We proceed with this understanding to analyze other reliability databases as well for our application.

2.2 FIDES

The FIDES global methodology is developed by a consortium under French Ministry supervision. This global reliability engineering methodology guide for electrical and electronic components is divided into two parts:

- predictive reliability engineering guide

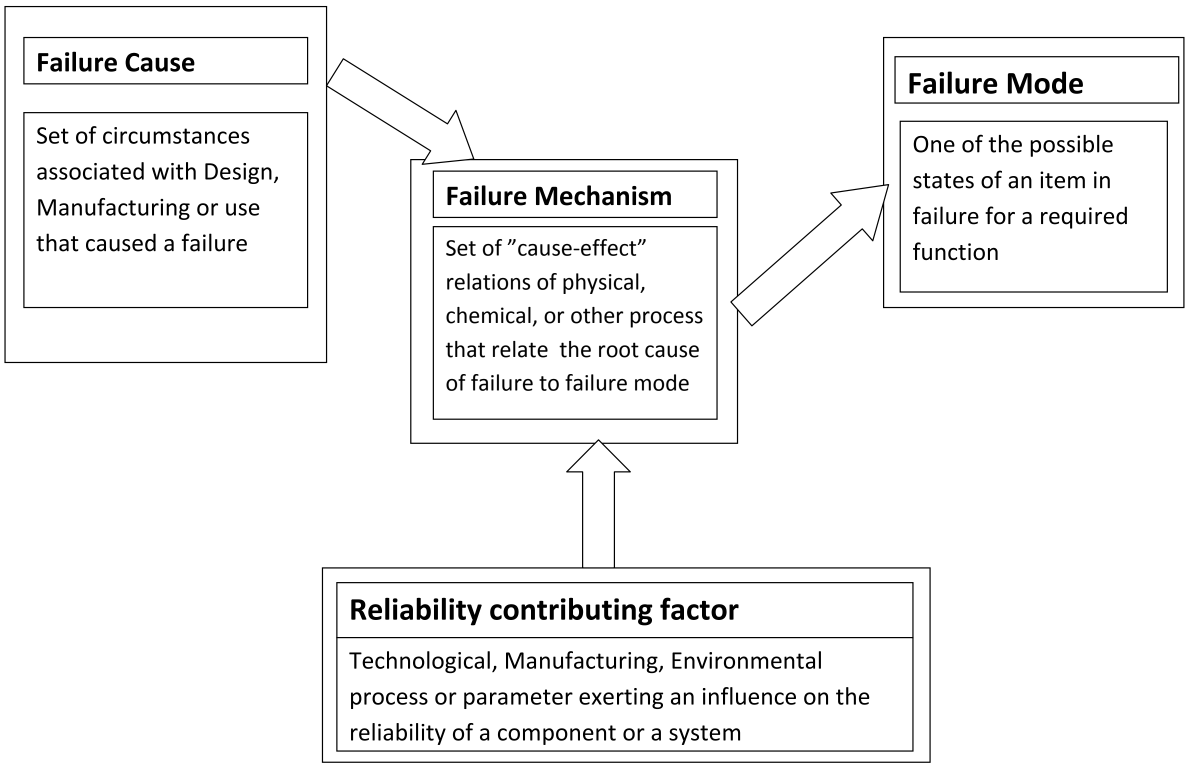

Figure 2.2: The defining logic for Failure Analysis given in FIDES 2010

- reliability process control and audit guide

This methodology is based on physics of failure and data analyses of operation feedback and existing models. So it differs from existing statistical interpretive analysis. The methodology is of interest in the context it takes into account of entire life profile. The failures related to development, manufacturing, operation and maintenance process, over stresses are taken into account. It defines *Reliability contributing factor* as technological, environmental, manufacturing process parameter exerting and influence on the reliability of a component or a system (FIDES 2010). The methodology does not include unconfirmed failures, software failures, failures due to missed maintenance activities and failures due to proven accidental aggressions (e.g use outside specification). The FIDES guide provides its logic in figure2.2 in defining its failure process. This methodology includes the assumption of constant failure rate in evaluation rate apart from physics of failure basis (of special cases in subassembly). It justifies with three important observations :

- Dispersion of failure mechanism in over large period tends to be constant.
- Accumulation of mechanisms is of large number and diversity of components, tending to be constant.
- System level observation of components with in the same system with large age differences tend to make rate constant.

FIDES method considers failures as largely the consequences of life situations encountered by the product. So the confidence on the predicted reliability evaluation can never be better than the confidence in the prediction of expected product life. It is therefore, FIDES aims to identify and control the factors influencing the reliability in the evaluation method. The methodology is originally developed for COTS items and is applicable all other special items provided the technical characteristics comply with the descriptions in guide. The data collection for evaluation method represents three domains over which FIDES defines and aims its methodology viz. *technological, process and use.* They represent item to product integration, practices in product specification to replacement and usage constraints in design to user operation. Therefore data on environments and product usage contain operating temperature, changes in temperature cycles, vibration, relative humidity, pollution level and over stress. Data from suppliers and manufacturer, data from product definition in life cycle and data on product lifecycle for thoroughness. The FIDES reliability model is represented by the following Equation.

$$\lambda = \left\{ (\sum_{physicalcontributions} \times (\Pi_{processcontributions} \right\}$$

This equation in practice actually becomes in reality becomes following equation

$$\lambda = \lambda_{Physical} \times \Pi_{PM} \times \Pi_{Process}$$

Where,

- $\lambda_{physical}$ represents the physical contributions.

- Π_{PM} represents the quality and technical control over manufacturing process of the *item*
- $\Pi_{Process}$ represents the quality and technical control over design, development, manufacturing and operation process of the *product containing the part*

$\lambda_{physical}$ encompasses the basic basic failure rate assigned to the element λ_0, the contribution related to acceleration factors to physical stress $\Pi_{acceleration}$ and the induced factors of overstresses $\Pi_{induced}$ from Mechanical ,Electrical and Thermal origin.

These are represented by the following equations :

$$\lambda_{physical} = \left\{ \sum_{physicalcontributions} (\lambda_0 \times \Pi_{acceleration})\right\} \times \Pi_{induced}$$

Where,

$$\Pi_{induced-i} = \{\Pi_{placement-i} \times \Pi_{application-i} \times \Pi_{ruggedising}\}^{0.511 \times Ln(C)}$$

where "i" represents a phase in the life profile of the product. (FIDES 2009) the above equation represents the influence of the item placement in the equipment (with regard to function), application of the usage environment and account of policy in product development. Here C is the sensitivity co-efficient.

Since the life profile of product is modeled in detail in this method, a step down levels of evaluating reliability are available depending on the project phase. *The families count prediction method* is applicable to early phase project , reliability evaluation needs to be produced from least amount of product definition and technological descriptions are very much simplified. *The parts count prediction method* is similar but more detail in constructing life phases. It is used to construct reliability in important areas. It is useful for very large systems. Finally reliability control is achieved by proposing a set of reliability influencing measures , so that it effects each phase of the life cycle. This is achieved from the reliability evaluation of life profile from above methods. We can distinguish a combination of these methods for the application of reliability prediction for a subsea centrifugal pump if the sample size of components is large with more diversity in components. A stress study can reveal if an assumption of default stress be fixed and taken as constant. The FIDES 2010 guideline book gives various examples in different application areas of electronic components and products.

2.3 MechRel

The database is developed by Naval Surface Warfare Center, USA. The development effort for predicting reliability and maintainability characteristics rely on failure rate data, design evaluation procedures, material properties,operating environment and critical failure modes at component level. The aim is to evaluate a design for Reliability and Maintainability of mechanical equipment. This implies the following objectives mentioned in MechRel handbook and software.

- evaluation of reliability for design in early stage of development.
- early estimate of potential spare parts requirement.
- quantification of *critical* failure modes in the context of stress or design analyses.
- determination of degree of degradation with time of a particular component.

The methodology also has objective for verification and design accelerated testing procedures and starts by identifying the observed deficiencies in normal failure rate data base and problems relating to their direct application. It succeeds in making a case from following four points.

- Mechanical components in general perform more than one function in a system and failure data for many non-standard applications are not easily available.
- The degradation of equipment is due to stress-related mechanism, fatigue and wear. This is not usually best described by constant failure rate distribution making data gathering for individual failure times a difficult process.
- Mechanical equipment differs from electronic equipment in terms of sensitivity to loading, operation mode and utilization rate. Data based on only one criterion is inadequate.
- Lack of application oriented failure data is needed as failure depends on application in mechanical equipment.

The study guide makes a rationale for observed complications in life estimating due to life-limiting failure modes (whose effective database of historical conditions are not properly available), such as corrosion, erosion, creep and fatigue. Further, type of loading (static, dynamic cyclic) and changes cycle in operating temperatures and pressure. It highlights the problem in determining the probability of occurrence for each failure mode in a traditional FMECA (which is originally developed for electronic equipment). The methodology approaches to predicting reliability by considering the effect of environment at the lowest part level (material properties are considered). Therefore the failure patterns on design life is analyzed and the approach is a combination of FMECA, FTA and RCM streamlined into design analysis of mechanical equipment. The models presented in its handbook are based on identified failures and their causes. The first step is to formulate equations with variables for each failure mode affecting the reliability from experimental data. Then the modification factor for each variable to reflect the quantitative impact on failure rate on individual part. The total failure rate is the sum of failure rates of component parts. Many parts can have deteriorating failure mechanism and so equations derived include parameters from engineering models for mechanical wear. This concept is also identified in *exida vol3,*, which explicitly mentions consideration of stress strength related failure modes in components (in a different context, it is in relation to electronic equipment). Then parameters related to environmental effects on material properties of the part. It is shown in figure2.3 The base failure rate of the component parts are multiplied by impact factors (depending on number of factors of application). The final failure rates of each component part is obtained and total failure rate is established. The handbook has a specific chapter on each component part generally used globally in all mechanical equipment. The derivation hugely varies depending on component and its application. This approach is different from FIDES where the former provides a complete life profile application of *product*. In MechRel guidebook, the combination of failure rates of *component part* are decided by maintenance philosophy established. If we consider the tendency of replacement of part as routine then tendency is towards a constant failure rate at system level. Many terms in the guidebook are sensitive to life expectancy and the guidebook is a continual research for improvement of "cause and effect" relationship. The understanding is that there are no simplistic approaches to predicting reliability of mechanical equipment and many combinations of methods are to be used to achieve the best predictions of

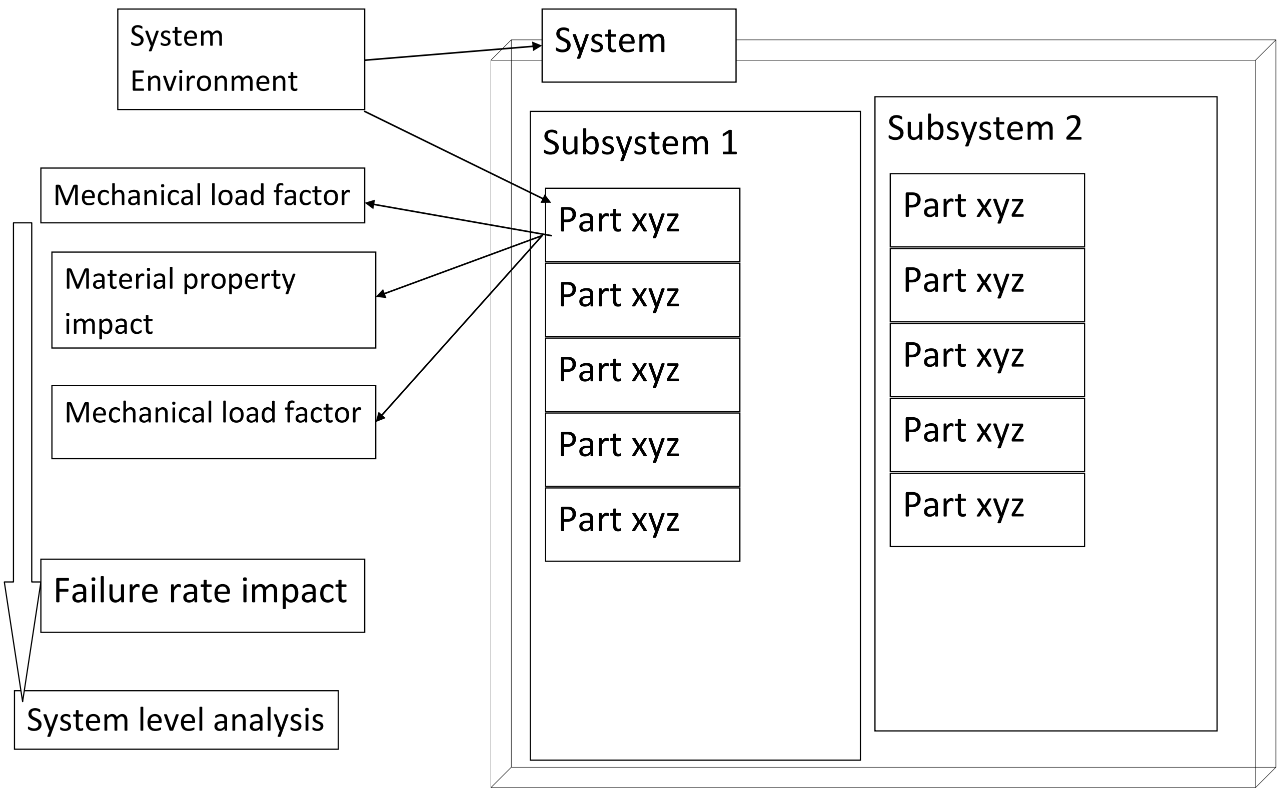

Figure 2.3: Failure rate for design analysis in Mechrel methodology

reliability, which as a minimum must contain the *effects of operating environment of the system at part level.*

Chapter 3

Pump, subsea and topside application

This chapter is technical description of a subsea pump and its topside counterpart to highlight similarities and differences of application in technical, operational and environmental conditions. It provides with necessary information for carrying out FMECA of the two pumps. Pumps are classified into many categories based on design and application areas and sufficient information is found in OREDA 2009 under the category *equipment class* with varying taxonomy levels. The usage and reasons for using pumps such as production enhancement, sea water pumping, fire fighting and water injection etc in offshore industry are well established and this chapter limits the discussion only up to pump function in relation to application. We first define the equipment boundary of the pump to understand what are the subsystems present in it for studying. This is well defined and mentioned in OREDA 2009 and its evaluation in this report in chapter *Reliability Database Evaluation*. So we start with those subsystems and proceed to respective applications. The diagram in figure3.1 represents a general pump system in entirety. The colored boundary lines vary according to application. General failure modes identified in pump which are listed in OREDA2009 are caused by failure mechanism grouped under 6 main categories. These are also provided in OREDA1993 guidelines under failure descriptors. The basic factors contributing to reliability through these descriptors from other processes are shown in figure3.2. The processes contributing to physical failure rate part and induced part are identified from FIDES method. The reliability influence through these failure descriptors varies between topside and sub-sea pump.

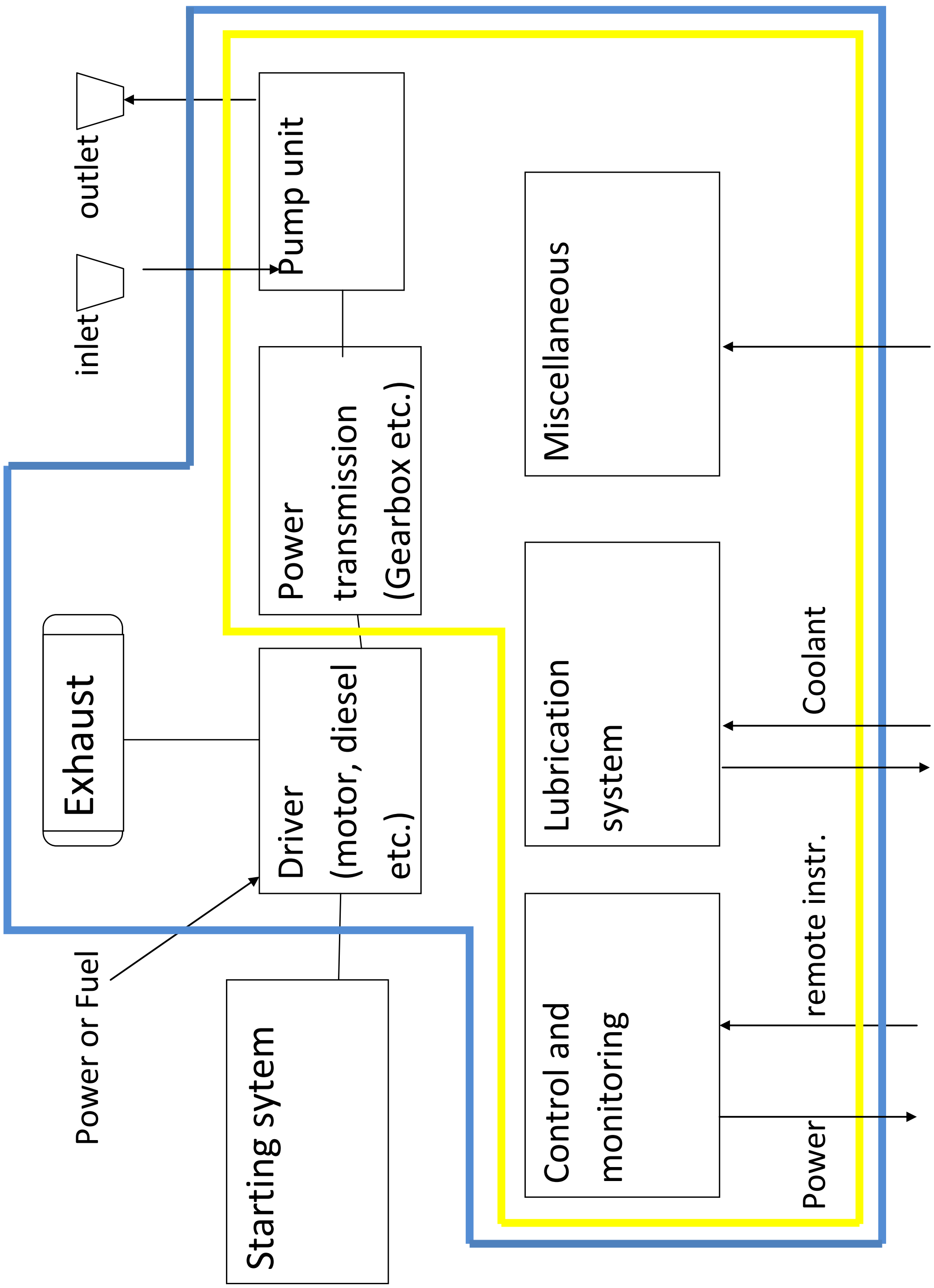

Figure 3.1: General pump equipment

3.1 Topside application

The topside pump description from OREDA 2009 defines its equipment boundary as shown in figure3.1. The yellow line represents the equipment boundary for topside pump in offshore application. In a typical centrifugal pump of this case can be divided into following component parts of subsystems.

- **Power Transmission** is the system function to transfer power from driver unit(not part of this system) to driven unit.
- **Pump** is the subsystem for creating specified pressure difference for sucking in pumping out fluid.
- **Control and monitoring** is the subsystem to monitor process parameters such as pressure, temperature, flow, speed and vibration etc.
- **Lubrication system** is to pump coolant and filter oil for lubrication to various other subsystems in the pump. It also cools the hot fluid and has a separate pump with it.
- **Miscellaneous** function has the cooling and heating system and has other filter to support the whole system as it functions in harsh environment.

In the table3.1 we can observe that every multiple subsystems have some common equipment unit such as *instruments, valves, seals.* It is important to note that at the lowest indenture level these are divided to further classification or some are more or less same. The exposure is different depending on which subsystem holds it. Instruments are broadly classified based on which parameter is being monitored such as *temperature, level, pressure, vibration, speed, flow or general* and the sensors are part of the instruments. The centrifugal pump does not contain the driver unit (electrical motor or diesel engine) as part of the pump system in the OREDA2009 database. It also eliminates the suction strainer, inlet and outlet valves from the definition of system boundary. OREDA 2009 database gives an extensive list of failure modes provided in *appendix.* The information about maintainable items in OREDA is presented in the 3.1 and some auxiliary units are termed as *unknown and subunit.* This list is exhaustive for topside equipment, but it is limited to observed failure events. This aids in performing FMECA.

Table 3.1: Centrifugal Pump, Subdivision in Maintainable items.

Centrifugal pump				
Power Transmission	Pump	Control and Monitoring	Lubrication system	Miscellaneous
Gearbox or Variable drive	support	Instruments	Instruments	Cooling and Heating system
Bearing	Casing	Cabling and Junction boxes	check valves	Filter, cyclone
Seals	impeller	control unit	Reservoir including heating system	
Lubrication	shaft	actuating device	pump with motor	
coupling to driver	seals	monitoring	filter	
coupling to driven	thrust bearing	wiring or internal power supply	cooler	
instruments	piping	valves	oil	
	valves		seals	

The environmental conditions are hostile but do not go as extreme as sub-sea conditions. The losses observed in pump are part of the failures we intend to avoid. These are characterized as *mechanical losses, hydraulic losses.* These are useful to understand the influence of mechanical properties on the parts which are involved in these losses. An FMECA is performed with the aid from failure modes listed in OREDA database and is presented in appendix. The percentage contribution of each failure mode to the total failure rate is provided in OREDA 2009 in combination with failure mechanisms and also maintainable items. In both combination cases, the failure modes pertaining to external leakages, abnormal instrument reading account to more than 52 percent failures (32 and 20 percent respectively). It is an important observation for consideration in designing a pump for new application. The failure descriptors facilitating the failure mechanism are given in OREDA 1993 guidelines and are listed in appendix. They are all defined in the external context of cause relations to failure mode. It means if an item has to answer the question "why did it change to different state ?" The answer is actually broad and the degree of our understanding depends on the factors which are included to answer. As a minimum, let us examine what it infers if we try to include the following answers :

- "It is exposed to change". Our assumption was, the item should perform the *desired change* and not change itself. Since we understand that *desired change* is the process performed simultaneously by many items which defines our system function, we have an expectation for the item to remain what it is while acting to perform a change in dynamic elements of the system. From this point of view we observe that the ability to change is built with in the item and so it changes, unless it has a mind of its own to process how to change itself (and this is not the case). It means, even though it is difficult to predict this change of state in the item, it is apparent that a factor of change representing inbuilt ability to change is necessary to include in answer.

- "Something changed it." Here we are looking at the constraints in the item which block the "external something" from changing it. When there is an interaction between the two, the interaction appears as strain and external something appears as stress in mechanical terms. It implies that stress is part of both the interaction and non-interaction. The probability of *stress applied by "something" not interacting with constraints in item* will lead to a probable change. For example, 30 units of load in a corrosive atmosphere, friction from lack of lubrication in high temperature. Stresses in general are more dynamic and it depends on to what extent we consider them in our confidence.

In both cases, the answer for change of state, from item's point of view is *inherent in item*. Therefore changed state of item points to various states describing relative cause within item and outside loss of process due to item. This is failure mode and the description encompassing all the factors, those mentioned and those part of process (of which item is part) is failure descriptor. We proceed with this understanding to study the application of topside centrifugal pump in sub-sea situation.

3.2 Sub-sea application

There is no description of sub-sea pump in OREDA. So we assume a scenario of same pump functioning deep in ocean at seabed. The equipment boundary changes at this application and the blue line in figure3.1 denotes the boundary of centrifugal pump. As we observe that driver unit is now included as part of the system, because seabed is assumed to be 3000 meters and it is not feasible to have a driver unit on platform for this case. The maintainable parts of the system are still same with an additional column from the driver subsystem.It contains the following :

- casing
- circuit breaker
- coupling
- Excitation
- instruments
- Overload protection
- radial bearing
- rotor

- stator
- thrust bearing

It will now also contain suction strainer, input and out valves as part of system. The driver unit should be electrical powered because sensibly it is not feasible to use a diesel or other combustion engine driver units deep on seabed. This raises the question of power supply which must contain a step down transformer near pump unit at seabed because the length is already 3 kilometers of cable. Usually it is part of starter unit which can be on platform above. But here it will have to be part of driver unit. The exhaust from driver unit is not any burnt gas, so it doesn't exist apart from outflow of used coolant and lubrication oil. The pressures at the bottom of seabed can be 15000 psi and water temperatures vary 4-10 degree Celsius. Subsea applications are preferred because of high reliability implying that subsea pump should have more reliability than its topside counterpart (this is conservative comparison). The subsea application has all the standard components of topside counterpart, but requires special consideration for high reliability. Maintenance philosophy is different and drastically changes from topside application. A subsea pump is normally designed to be intervention free for many years (example 5 years minimum, design life of SeaBooster pump developed by AkerSolutions claims a 30 years design life provided in their website). www.akersolutions.com This implies other new factors influencing failure mechanisms pertaining to mechanical properties and its effect on system failure is considered for more weight-age. The fluid medium in operation is more susceptible change.

The categories of maintainable items can be divided into two types

- categories with standard approach having no deteriorating mechanism in the absence of corrosion.
- categories with life profile based on fatigue, wear, stress, friction etc.

The system response to the items' failure mechanisms are to be analyzed as they will now show higher effects due to larger exposure. Failure modes at subsystem level arising from Wear rate of seals, extreme fluid conditions, extreme power conditions, Marine growth and Installations problems and motor temperature for extreme operating conditions are required for particular evaluation. So a top-down and bottom up evaluation of failure mode is required to analyze combined or overall failure modes for establishing a proper design process. OREDA 2009 database has no descriptive models for analyzing the failure rates arising from mechanical stresses, i.e a physics of failure model. Mechrel methodology has extensive equations for quantitative impact of the variables suitable for this application for particular items such as valves, gears, actuators etc., most of them are covered but they are not accurate for good statistical confidence. As population size increases and subsea experimental data is becomes available, Mechrel methodology contributes to next step.

3.2.1 Reliability influencing factors

The failure rate is influenced by processes in the figure 3.2. The failure rate of the item is consistent of base failure rate and reliability influencing factors from these processes through failure descriptors. Since the change of state in item through these failure descriptors under different set of technical and environmental conditions contribute to failure mode via failure mechanisms, The failure mode observed in higher degree of order is part of new failure rate. The influence diagram in figure**??** show the extended influence from failure mechanisms in maintainable items of a subsea pump. Since the diagram is very dense, some important influencing factors are listed below:

- Impeller : *fatigue, Design*
- Bearing : *contamination, Wear, manufacturing process*
- Seal: *installation damage, wear, leak*
- cooler: *other, design*
- Valves : *corrosion,leakage*
- Oil :emphsticking, contamination, deposits and so on.

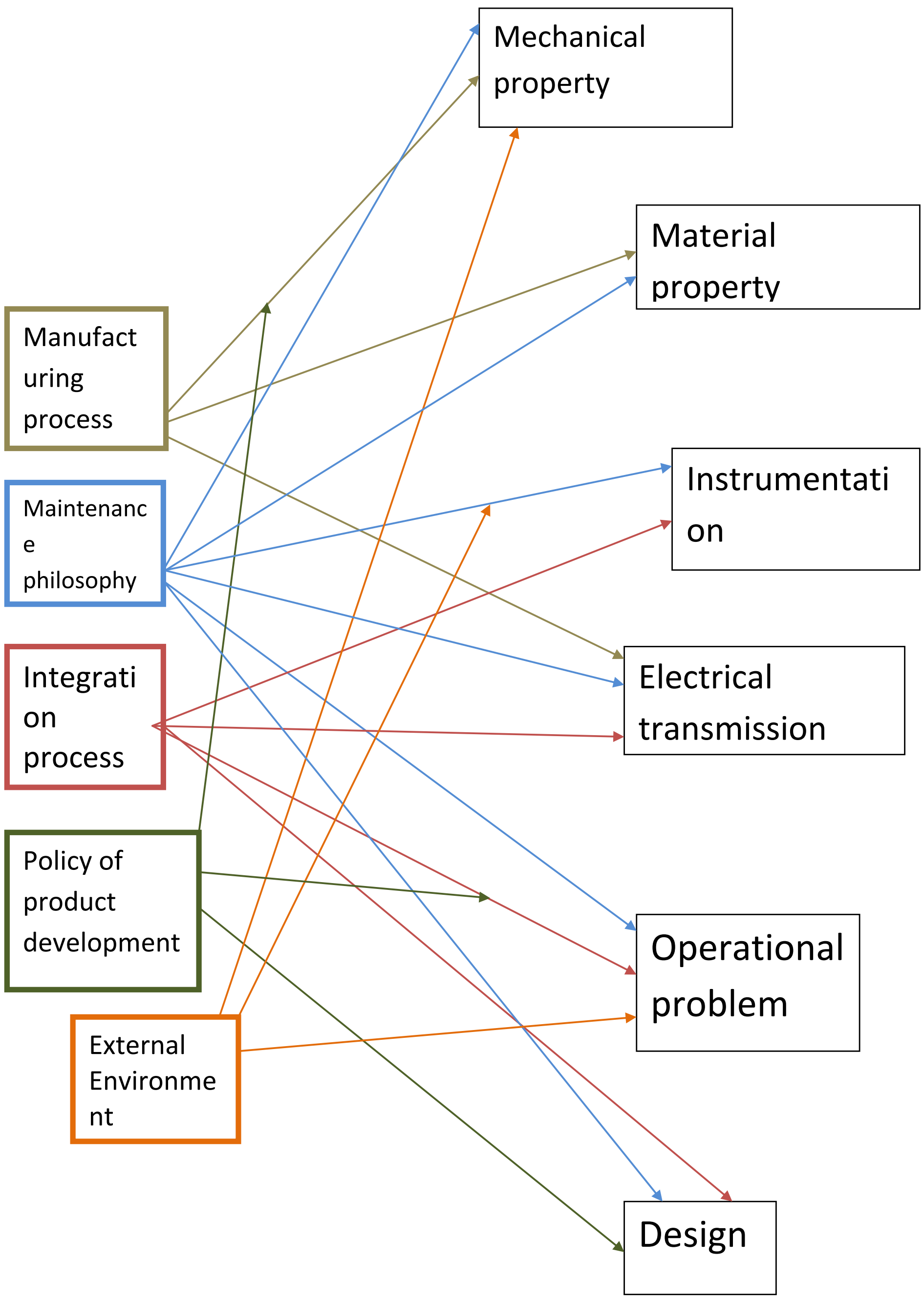

Figure 3.2: Processes contributing reliability to failure descriptors

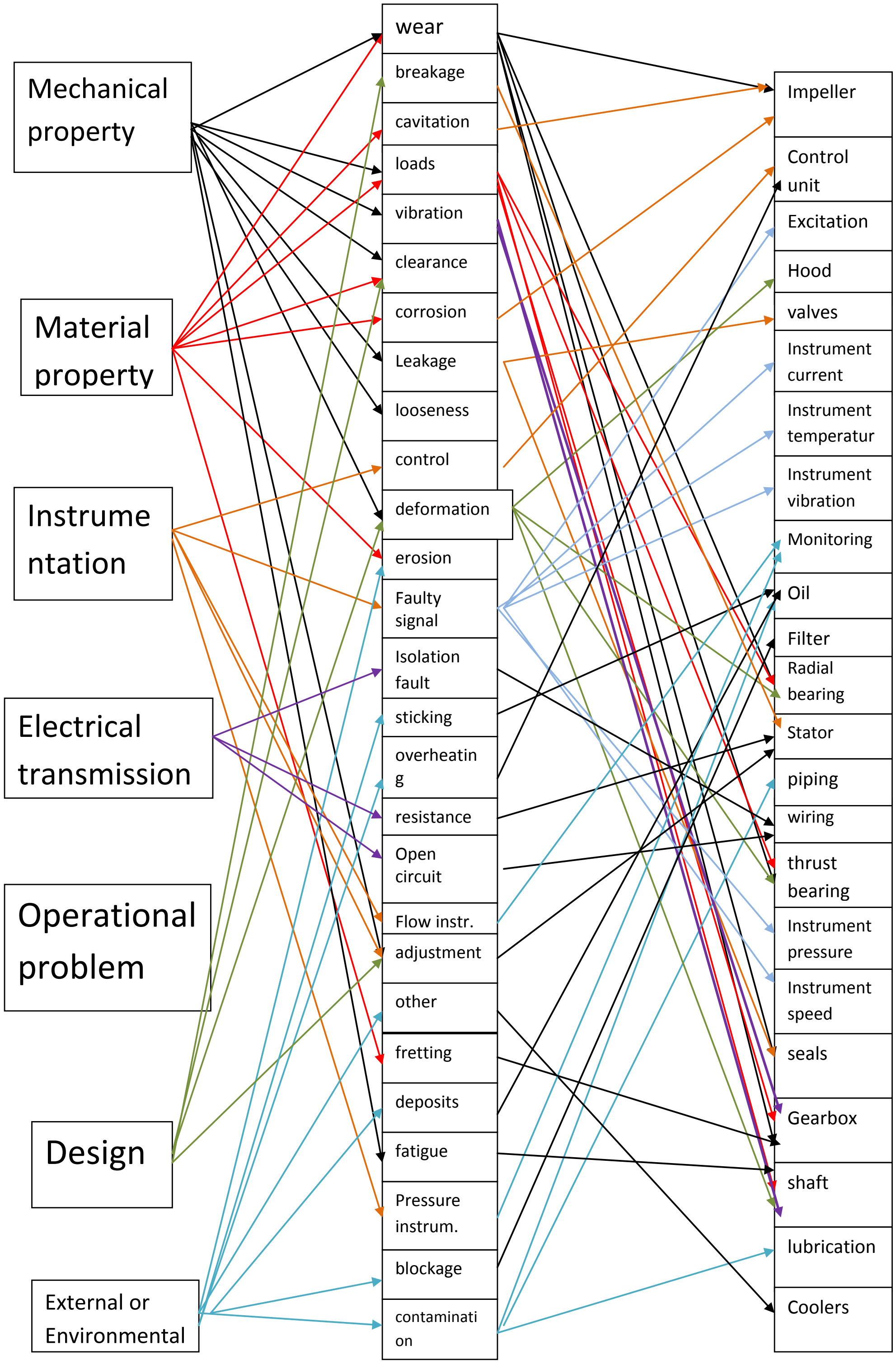

Figure 3.3: Reliability influence diagram from descriptors to maintainable parts through failure mechanisms

Chapter 4

Approaches to Failure rate

4.1 Assumptions and Discussion in light of OREDA

The OREDA database clearly disregards burn-in phase and wear-out phase of the bathtub curve portraying failure rate function as shown in *Rausand and Hoyland, 2004* for the purpose of close to constant failure rate assumption. The assumptions are based on maintenance philosophy of repair and replace before the onset of wear-out phase. The installation problems, quality checking procedure portrayed in burn-in phase is not taken in account of database evaluation. So the topside pump data also starts from the start of production after verification of the pump. The case for sub-sea pump varies at this stage. As discussed in chapter 1 of this report, the population sample for estimation of failure rate is adequate in topside pumps and will get better. The quality of sample size such as diversity and large number will gradually make a case for sub-sea pump as well. However, in this stage, the sub-sea pump life profile has to be evaluated. An initial modeling portraying burn-in phase with available experimental data in combination with factors from processes and physics of failure way of evaluation of failure rate is a good step. The initial base failure rate discussed in Mechrel methodology, even though with less accuracy in confidence should be considered for the following reasons.

- The initial base failure rate can be improved in confidence through quantification parameters of influences on reliability from expected environment and technical requirements.
- The failure rate function of components and influences in new hostile environment is not

yet established to be constant even with low confidence, because the database provides no sample of sub-sea pump. So this situation does not improve or is not any better than our assumption during burn-in phase evaluation period (we have not dis regarded the assumption of constant failure rate)

- We intend to approach only the part of life-profile and gradually improve the life profile with more accuracy. A mere straight assumption of constant failure rate clearly disregards the influences from many expected state changes of item due to inherent factors discussed in chapter 1 and 2 such as process and part sensitivity to over stresses inherent in the technology (especially when assuming subsea technology is new).
- Failure rate of mechanical equipment are relatively less universal which have larger influence from type of application. In our case the subsea pump also has new equipment unit within its boundary (driver unit). The weaknesses in accuracy of confidence may be examined via Bayesian approaches and expert judgment *(Lanternier et al. 2005).*

In the next section, we discuss this assumption in light of identifying any possible approach to extrapolate the data to reflect the change of states of items for further evaluation in consideration of reliability influencing factors identified in chapter 2.

4.2 Analysis of a different method

A new approach for combination of influencing factor and base failure rate of item is proposed by *Brissaud. et al, 2010* where the coefficients of influencing factors are multiplied according to the degree of reliability with base failure rate of item. he proposes the following equation.

$$\lambda_s = \Sigma_{i=1}^{n}\{\lambda_{i,mean}.\Pi_j C_j\}$$

The idea proposed is to fix the failure rate in the interval $\lambda_{min}, \lambda_{max}$
The method is discussed in seven steps.

1. Firstly establish a base failure rate representing the mean failure rate of the above provided interval. Then to identify the components of the system influenced by factors.

2. A influence diagram is drawn starting from hierarchy, the influence diagram is of at least four levels.

3. The influence indicators "I" are set on a numerical scale to from 0(least suitable) to 5(most suitable). For every influencing factor "j" So each indicator becomes I_j. This Indicator of influencing factor also has worst and best values.

4. Weights are assigned to each influencing factor according to potential effect experienced by item failure rates.

5. Indicator function is represented by indicator probability density function, implying Indicator is not a fixed point but varies. The probability function can be *uniform, triangular or Gaussian* depending on which criterion we evaluate indicator, if we have quantitative indices then the last is considered such as pressure, temperature etc.

6. Influencing functions formed are meant for calculating influencing coefficients. The coefficients so obtained at minimum, mean and maximum levels are assumed to have linear relation.

7. The influencing coefficients are calculated from the indicator function and the influencing functions representing coefficients from the previous step which represented the states of change mentioned in this report.

The method combines the qualitative representation of influencing factors and quantitative base failure rate. The method still relies on fixing a base failure rate from reliability data books. It implies that the method takes in the base failure rate of subsea pump from the base failure rate obtained from topside pump, which is based on constant failure rate. So the constant failure rate is extrapolated to the next level of our inferred level (meaning subsea application). The method justifies the treatment of uncertainty by using density indicator functions. The subsea pump is exposed to very high variations of influencing factors. It means that the many of the mechanical components present in the system will have behavior in many different ways. If a failure rate is estimated for all components of subsea pump, the overall failure rate is sum of the derived failure rates. The system response to component factor is lost in this process. Therefore the useful life period should be modeled with the final influencing factor of system on item in usage. So, we do not disregard the assumption of constant failure rate but proceed with life profile construction of the sub-sea pump where we approach the burn-in phase with Mechrel methodology. Then, we proceed with methodology proposed by *Brissaud.et al 2010.* At the end a normal wear out phase suitable for intervention. This way we get our life profile for sub sea pump and we intend to verify using a method for Reliability Audit mentioned in FIDES guidebook.

Chapter 5

Summary and Recommendations for Further Work

5.1 conclusions

This report presents the evaluation of three reliability databases namely OREDA, Mechrel, FIDES. We have analyzed the approaches presented for predicting reliability and underlying assumptions. In the next part of report, a pump is considered for studying. The centrifugal type is considered and its topside part is studied thoroughly from the OREDA database. The subsea counterpart is imagined and the important differences in system definitions, technical characteristics, environmental factors are highlighted. The similarities are understood and examined in the light of 3 different kinds of reliability prediction methods.A detail study about *failure descriptors and maintainable items* is presented based on OREDA. A discussion follows with in the same section and an independent understanding about "failure mode", and failure mechanisms is presented as part of the discussion. An FMECA of centrifugal pump is performed and is presented in appendix. In the process of understanding reliability influencing factors are presented and are sketched in chapter 2. In the proceeding chapter present discussion about constant failure rate in OREDA with the acquired knowledge from other database sources is presented. A situation is presented about how do we proceed to failure rate estimation for subsea pump and a rationale for the situation is described.

5.2 Conclusions

The important conclusion is we should proceed in modeling a natural life profile for subsea pump at this stage by dividing it in three life phases viz *burn-in, useful and wear out* stages. This gives us a good rationale to actually present a case for analysis of a new technology. It provides us with realistic approach to estimates as more and more experimental data with large variation pours in for verification. After the technology is established, we can use any of the methods. But at this stage, more important question to which way should we proceed for estimation is analyzed and identified. The combination of the life profile can then be verified and an established sub-sea pump can be available as a future work. This procedure could not be combined with guidelines provided in DNV- RP recommendations for new technology qualification because of difficulty and lack of realistic imagination or part of it. However, examples from DNV-RP are studied and understood for analyzing and understanding reliability influence factors and while performing FMECA of pump. An individual understanding of failure modes, failure descriptors, causes and characterization of influence factor is presented in chapter 1 and 2 and mental-picture is shown in the figure2.1. The evaluation of of data and definitions in OREDA, especially with respect to failure mechanisms is well understood and is presented in chapter2. Reliability influence diagram is too dense because of the large number of influences, nonetheless, effort is made to present without dividing it into too many parts. It is evaluated at 4 levels but in left to right direction and is presented in chapter 2. A lack of successful verification of life profile is a weakness in the report and performing FMECA had too many limitations, so it is focused only on identifying failure mechanisms and failure modes. The strength is in good learning about reliability databases, their estimation procedures is achieved.

Chapter 6

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Appendix A

Acronyms

FTA Fault tree analysis

MTTF Mean time to failure

R& M Reliability and maintainability

FMECA Failure Mode Effect Criticality Analysis

COTS Commercial Off the Shelf

OREDA Offshore Reliability Data

Appendix B

Additional Information

B.1 OREDA2009

The following are the failure modes listed the database for pumps in topside equipment

AIR	Abnormal instrument Reading
BRD	Breakdown
ELP	External leakage - process medium
ELU	External leakage – utility medium
ERO	Erratic output
FTS	Fail to start on demand
HIO	High output
INL	Internal leakage
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 B.1: Failure modes of topside pump

Appendix C

FMECA of Pump

Description of unit				Effect of failure			
#	**Part name**	**Function**	**Operational mode**	**Failure Mode**	**Failure cause or mechanism**	**On the Operating system**	**Severity Ranking of failure**
1	Bearing	Support to shaft depending on alignment and placement.	Running	Noise, Overheating, Structural deficiency	Corrosion, Vibration, Deformation, mechanical friction	Leakage , Structural failure, Increased power consumption	degraded
2	shaft	Power transmission from drive to driven	running	Structural deficiency, Noise, Low output	Looseness, erosion, vibration	Failure in power transmission, higher degree of vibration in system, increased power consumption	critical
3	seals	To maintain tolerances in gaps and pack the position.	Running	External leakages	Corrosion, Erosion, Overheating Material failure	Loss in output , increased power consumption, loss of instrumentation	degraded
4	Cabling and junction boxes	To connect to various power sources and intersections and switching functions	Continuous demand	Abnormal instrument failure, Fail to start	Erosion, open circuit, sticking, No signal	Termination of monitoring system, loss of power supply	degraded
5	Casing	To support the pressure difference and collect the fluid	Continuous operation	leakages	Corrosion mechanical failure	Deterioration in pump flow and cavitations	degraded
6	impeller	Transfer of energy to the fluid to increase pressure and flow.	Continuous operation	Structural deficiency	Wear, mechanical failure	Decrease in pump function	critical
7	filter	separate fluid particles	continuous	Leakage, Service failure	Corrosion , blockage	Polluted oil and coolant	incipient
8	Thrust bearing	To improve the power transmission	Continuous operation	Structural deviation, vibration	Corrosion, mechanical failure	Loss of power transmission	degraded

9	valves	To control flow	Conti nuous opera tion	Leakages, erratic output, parameter deviation, Service problem Fail to stop, fail to start	Corrosion , Combinati on failure, wear	Can become dangerous to control output and input	critical
10	piping	To contain and transport fluid	Conti nuous opera tion	Leakage , Structural deficiency, Parameter deviation	Corrosion , Deformati on, contamin ation	Subsystem has high probability of damage	degraded
11	wiring	To provide connections to power sources and signal transmitters	conti nuous	Abnormal reading, service problem, parameter deviation	Electrical failure, open circuit, looseness, isolation fault, breakage	Can lead to instrumentatio n failure	degraded
12	coolers	To cool the hot oil and dissipate extra heat	norm al	Structural deficiency	Mechanic al failure	Function is not affected	incipient
13	oil	To lubricate the moving parts	conti nuous	Leakage, Parameter deviation	contamin ation, external influence	Increased frictional losses	degraded
14	instru ments	To provide instrumenta tion control	conti nuous	Parameter deviation, abnormal reading, service problem	Control failure, leakage, open circuit, electrical failure, faulty signal, no signal, deformati on	Instrumentatio n failure, monitoring failure	degraded
15	monito ring	To represent real time functioning of system and control parameters	conti nuous	Parameter deviation, abnormal reading, service problem	Deformati on, signal problem breakage	Loss of observation and control of the system parameters	degraded

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