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Failure rates of safety critical equipment based on inventory attributes

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ABSTRACT: Reliable failure rate estimates of safety critical equipment is crucial for verifying performance requirements and for trending the safety performance of the equipment. Joint industry efforts, like OREDA, Exida and PDS handbooks, supported by international standardization on data collection such as ISO 14224, publish generic failure rates for selected equipment commonly used in the oil and gas industry. Such generic data builds on field experience and ensures a transfer of knowledge from the operational phase to new design projects. Currently, most generic data is generated for a specific equipment group, and not for separate inventory attributes, such as size, type/fabricate, service and flow medium. Some standards and methods, like MIL-HDBK-217F, suggest how to encounter effects of inventory attributes, but these approaches are also generic, and does not account for sector specific experience, i.e. from operation of oil and gas facilities. In light of the increased focus on digitalization, it is expected that the access to data will be improved, and it is therefore important to utilize these data more efficiently in the business sector in question. The PDS forum in Norway, who gathers most actors involved in Norwegian oil and gas industry, initiated a study to analyze operational data of safety critical equipment, with the purpose to study more specific and recent effects of inventory attributes. Data from several oil and gas facilities in Norway, both offshore and onshore, have been systematized and analyzed. The purpose of this paper is to present the approach used to analyze these data, including data collection and statistical methods, as well as the final results of the study. The starting point was inventory attributes suggested by expert judgments, and their effects were investigated with basis in the collected data. Information from the operating companies' maintenance system has been too sparse to support all suggested inventories, and the choice of inventory attributes were narrowed down for some selected equipment groups; fire and gas detectors, level transmitters, shutdown valves and pressure safety valves.

1 INTRODUCTION

1.1 *Background*

The Petroleum Safety Authority (PSA) in Norway requires (in Management Regulations, section 19) that the operators shall collect, process and use field-based reliability data to ensure that the safety systems perform according to specified requirements. A key task of safety management is therefore to register equipment failures and to use this information to verify that the systems are sufficiently reliable. For the oil and gas industry, it is vital to share field experience with new projects, to make realistic assumptions about the performance of new equipment in known operating environment. Equipment failures are therefore collected from several facilities under the framework of ISO 14224 (ISO 2016a), and generic failure rates based on operational experience are presented in PDS handbooks (SINTEF 2013a), OREDA handbooks (OREDA 2015a, OREDA 2015b) and Exida handbooks (Exida 2015).

Safety Instrumented Systems (SISs) perform safety critical functions such as to shut down the plant or isolate ignition sources. IEC 61508 (IEC 2010) and IEC 61511 (IEC 2016), which are mandatory standards to use for design and operation of SISs, suggest a risk-based approach to the formulation of reliability requirements. The starting point is a risk analysis, which defines the necessary risk reduction for each Safety Instrumented Function (SIF) carried out by a SIS. This risk reduction is translated into a Safety Integrity Level (SIL) requirement. Four different SIL levels are defined (SIL 1 – SIL 4), and for each level it is specified a required reliability performance interval. Probabilistic calculations are needed to demonstrate that each SIF meets the given SIL requirement. Since the risk analysis considers what is acceptable risk at a given facility it is important to use "realistic" reliability data when the performance of the SIFs are estimated. Realistic in this context means to consider historic field experience data, rather than data obtained strictly from analyses and/or from testing in a laboratory with controlled environment—not covering all possible failure causes experienced in operation. In other words, the reliability calculated in design should as far as possible reflect the reliability that is experienced under typical conditions in the operational phase. This is a requirement that is also emphasized and strengthened in the new edition of IEC 61511 (IEC 2016); operators must ensure that data are both credible, traceable, documented, and justified.

A practical challenge with generic data, is the time from data are collected to publishing of updated handbooks and data bases. The time lag is often five years or more, and it is therefore of interest for operators to collect and systemize their own operational experience. Many operators in Norway now carry out regular (e.g. annual) reviews of reported failures. The results from these reviews are then used to monitor reliability performance in operation, to give feedback to manufacturers (about problems experienced) and to make decisions about changes in functional test intervals (Hauge & Lundteigen 2008).

Reviews of failures reported on various Norwegian oil and gas facilities, indicate that failure rates for similar types of equipment can be quite different between facilities, even if the operating environment is more or less the same. This result may be explained by some variations in technology used (e.g. detection principle for gas detectors), process medium, the external environment, quality and frequency of maintenance and inspection, etc. Care should therefore be taken to use generic failure rates in studies for reliability demonstration without considering such influencing factors. Consequently, it is desirable to supplement generic failure rates (that represent an "average performance" for comparable equipment) with equipment characteristic parameters that can identify more specific values of failure rates, i.e. *inventory attributes* of the equipment (e.g. size of valve, type of detector, etc.). The term inventory attribute is introduced for equipment attributes particularly important for the reliability performance. For example, it may be of interest to distinguish between failure rates for different sizes of shutdown valves.

We foresee at least two applications for failure rates based on specific inventory attributes: 1) Monitoring the reliability of existing SIFs, allowing for the specific characteristics of the equipment, and 2) Calculating the reliability of new SIFs, or existing SIFs considering the influences of design, operation, environment and maintenance characteristics.

1.2 *Objective and scope of paper*

The main objective of this paper is to identify which inventory attributes that may be relevant for the four equipment groups; fire and gas detectors, level transmitters, shutdown valves and pressure safety valves, and to analyze which of the suggested inventory attributes (if any) are significant based on systemized field experience gathered by SINTEF in the period 2006–2016.

The content of this paper is based on work performed as a continuation of a research project funded by the Norwegian Research Council and the members of the PDS forum (www.sintef.no/pds). SINTEF has previously systematized failure data for six offshore and onshore oil and gas facilities (a total of more than 13000 maintenance notifications) in Norway. These failure reports, supplemented by additional expert judgements, have been used for selecting possible inventory attributes influencing the failure rates of some selected equipment types. Then, data for these inventory attributes have been collected (as complete as possible) to be able to analyze the possible impact of selected inventory attributes.

2 FAILURE DATA COLLECTION AND DATA FORMAT

2.1 *Generic data sources*

Generic failure rates are mainly derived from data collected by an organization and published in handbooks or as computerized databases (Rausand 2014). The failure rates can often be regarded as an average of the experienced performance for specific equipment groups.

The oil and gas industry has collected failure data over many years and for several offshore facilities, mainly on the Norwegian continental shelf. Relevant generic data sources are the OREDA handbooks, ref. OREDA (2015a) and OREDA (2015b), PDS handbooks, ref. SINTEF (2013a) and SINTEF (2013b), and the safety equipment reliability handbook (SERH) published by Exida (2015).

2.2 *Operator's data*

ISO 20815 (ISO 2008) on production performance assurance, emphasizes that the systematic collection and treatment of operational experience is considered as an investment and means for improvement of production and safety critical equipment. The oil and gas industry has been in the forefront of developing international standards on data collection with ISO 14224 (ISO 2016a).

Reliability data can help operators to plan the preventive maintenance, e.g. to optimize test intervals, avoid unscheduled stops and reduce the amount of corrective maintenance. Aggregated data, used to determine generic values of failure rates, represents an experience transfer from operation to analyses needed for new facilities and for installations of new systems.

Several operators are continuously working on systemizing their failure records, to have their own "preferred" data set. This data set can be used to estimate an average performance of equipment for a single facility or for several facilities with the same operator. If the amount of data is extensive, one can also estimate separate failure rates for specific equipment attributes.

2.3 *Failure data from operational reviews*

Failures revealed during operation and maintenance are reported by maintenance notifications. A notification allows some free text description of the failure and about the measures implemented to correct the failure. In addition, it is also possible to characterize the failure, by ticking off in lists of predefined classes of failure causes, failure modes, and detection methods. Most maintenance systems are aligned with ISO 14224 for data collection, and additional effort is needed to further classify the failures into Dangerous Detected (DD) failures, Dangerous Undetected (DU) failures and safe (S) failures, for alignment with IEC 61508 and IEC 61511 taxonomy. Information about inventory attributes of interest may be partly available in notifications and partly in SIS related documents, such as the Safety Requirements Specification (SRS), safety manuals, and Safety Analysis Reports (SARs).

The operating companies themselves can perform regular operational reviews, or they can use assistance from consultants or research institutes. In either case, it is important to involve personnel from key disciplines such as automation, safety and maintenance from the specific facility and company in question. The main purpose of the reviews is to verify the performance of SIL rated equipment and to give recommendations related to maintenance and testing. A secondary purpose of the review, as suggested in this paper, is to analyze such data in more detail to investigate the performance for various inventory attributes.

2.4 *Selection of equipment groups*

Several types of safety critical equipment are used in SIFs on an oil and gas facility. Operational reviews of safety critical equipment covers about twenty different equipment groups, however, some groups consist of few equipment units. To limit the scope of the analyses in the PDS project, it was decided to extract groups of equipment where:

- a certain amount of data (both failures and a certain amount of aggregated operational time) has been gathered.
- the equipment group is represented on several facilities.
- the equipment group is represented in several SIFs on a facility.
- the equipment types have some attributes that are considered as significant with respect to the failure rate.

The selection of equipment groups and inventory attributes was consulted with experts within the PDS forum participants in an experts meeting. The recommendation was to focus on fire and gas detectors, level transmitters, shutdown valves and pressure safety valves, since these groups both contain a significant amount of equipment and contain possible significant inventory attributes.

2.5 *Uncertainty & data collection challenges*

A major challenge when splitting up the failure rates according to inventory attributes is to obtain sufficient statistical confidence. If no DU failures have been experienced in an observation period, the statistical confidence is lower even if the observation time is quite extensive.

Quality of data is another challenge. It is important that we can rely on the information given in the notification, e.g. that the failure mode and the detection method have been classified correctly. Data collection is both time consuming and demanding; it is seldom straightforward to identify all relevant information from the maintenance records. To obtain correct information about the actual failure, it is often necessary to discuss individual notifications with operators and maintenance personnel. Such work is time consuming, but nevertheless rewarding, e.g. to avoid repeating (and thereby costly) failures. Many operational reviews reported repeating failures, where seemingly insufficient measures had been implemented to remove the cause of failure. For the purposes of analyzing inventory attributes, we have removed repeating failures, to avoid that these are given too high weight in the overall results.

From the operational reviews, we saw that the effects of local facility conditions were important and that based on our experience, should be considered. One facility may experience specific problems (e.g. icing) for some particular type of equipment, which are not observed at other facilities. Local conditions seem to be of particularly interest for the occurrence of Common Cause Failures (CCFs), i.e. failures that are dependent due to a shared cause and which occur close in time. An example of a local problem which turned out to be defined as a CCF, was a number of failures for shutdown valves caused by wrong type (here viscosity) of hydraulic oil. Some of the failures related to specific problems at one facility (such as the hydraulic oil problem) which are not likely to occur at other facilities, have been removed from our data set for the analyses of inventory attributes. Other local problems, that were defined as CCFs, were icing problems. Icing is often more challenging for facilities in the Barents Sea compared to the North Sea, however, unfortunate design solutions may also allow for icing to occur. Failures related to such conditions that may occur on several facilities, have *not* been removed from our data set for the analyses of inventory attributes.

3 STATISTICAL METHODS

For the analyses of data from operational reviews, the focus has been on DU failures since these failures will influence the most important performance requirements related to SIF equipment, such as the Probability of Failure on Demand (PFD) for a SIF. The total data set for analyses comprises all equipment units that have been involved in the operational reviews, i.e. has been part of equipment groups considered in the reviews. For each unit, data on inventory attributes has been collected together with the information about if the unit has experienced a DU failure or not in a predefined observation period.

It was decided to introduce a Generalized Linear Model (GLM) based on a binomial distribution, where only two possible outcomes are considered. The response variable is a discrete variable with two possible outcomes; 0 and 1, i.e. "No DU failure" or "DU failure", such that GLM can predict failure probability and assess effect on failure probability from the predefined inventory attributes. Other methods, such as lifetime modelling was also considered. However, since the observation period for some of the facilities does not cover the entire lifetime of the item and the time an item was put into operation is unknown for most of the components, such methods were disregarded.

GLM describes the statistical relationships between *response variables* $Y_1, Y_2, \ldots, Y_N$ and *explanatory variables* $x_1, x_2, \ldots x_k$ by estimating the corresponding inventory attributes $\beta_1, \beta_2, \ldots, \beta_k$. An explanatory variable is a type of independent variable that can affect response variables, which may be fixed by the experimental design. GLM are mostly based on maximum likelihood estimation and allows for regression modeling when response variables are distributed as one of the members of the exponential family. The model is given by:

$$y_i = \beta_0 + \beta_1 x_{i1} + \ldots + \beta_{ik} x_{ik} \quad (1)$$

and

$$y_i = g(\mu_i), \mu_i = E(Y_i). \quad (2)$$

Here, $g(\mu)$ is called the link function. Further, let $Yi \sim Binomial(n_i,p_i)$ express the response variables with failure probability p_i, i.e. the likelihood for an item to fail at a given time. Then the GLM model based on binomial distribution is given as:

$$\log(\frac{p_i}{1-p_i}) = \beta_{i0} + \beta_{i1} x_{i1} + \ldots + \beta_{ik} x_{ik}. \quad (3)$$

In this GLM, inputs are related to inventory attributes as well as failure data. Outputs of the model are related to failure probabilities that are used to check whether there is statistical significance. The formula of failure probability is:

$$p_i = \frac{\exp(\beta_{i0} + \beta_{i1} x_{i1} + \ldots + \beta_{ik} x_{ik})}{1 + \exp(\beta_{i0} + \beta_{i1} x_{i1} + \ldots + \beta_{ik} x_{ik})}. \quad (4)$$

We identify the parameters that significantly impact on the reliability performance by checking variables in the regression model with small p-values and large coefficients. A small p-value suggests that changes in the explanatory variable are associated with the changes in the response variable, i.e. the inventory attribute is significant and does influence the DU failure rate (based on our data and under the given assumptions). The exponential coefficient represents the change in the response variable when changing the categories of one inventory attribute holding the other explanatory variables constant.

4 DATA COLLECTION OF INVENTORY ATTRIBUTES

4.1 *General*

Collection of data for inventory attributes turned out to be a rather time-consuming activity. Only parts of the relevant information were (easily) found in the operator's maintenance system. It was necessary to supplement with information from other sources, such as process and instrument diagrams (P&IDs), data sheets and manufacturer specifications together with discussions with technical advisors and process engineers.

The manufacturer name was the most straightforward inventory attribute to obtain from the maintenance system. However, within an equipment group we would find some ("small") manufacturers that had not delivered more than a few equipment units each. Thus, to be able to achieve some rational results, the number of manufacturers were kept to a minimum by grouping all the "small" manufacturers into an "other" group. Grouping the outcomes represented by a small number of units into a common "other" category, was also performed for other attributes with several outcomes/categories.

4.2 *Fire and gas detectors*

The expert review meeting suggested the following inventory attributes for fire and gas detectors: *Manufacturer*, *measuring principle*, i.e. which physical principle the detection is based on, and *model type*. Table 1 shows in more detail the inventory attributes for point gas detectors. The same types of inventory attributes were selected for line gas detectors, smoke detectors and flame detectors.

For the analyses of detectors, we were in the fortunate situation to access more data than from the six facilities where SINTEF was involved in operational reviews. For this particular equipment group, it was possible to add the inventory attribute "facility", due to the extensiveness of data, to allow comparison in failure rates and effects of inventory attributes between different facilities.

4.3 *Level transmitters*

Level transmitters are often placed in a group called "process transmitters", together with temperature transmitters and pressure transmitter. In our analyses, we wanted to focus on the level transmitters alone, mainly because they are more dependent on measuring principle and operating conditions (various medium, foaming, calibration challenges, etc.) than the other transmitters. Measuring principles for level transmitters are divided into the categories; displacer, pressure, radar (guided wave radar) and others (nuclear, ultrasonic, servo, capacitance and magnetostrictive).

Table 2 shows the list of inventory attributes agreed upon among the experts to include in the analyses. However, due to lack of details in collected data, we were left with three credible inventory attributes; *manufacturer*, *measuring principle* and *number of medium phases*. Regarding the measuring principle, we made the following assumptions based on the type of vessels for which the transmitters were installed: Level transmitters for 1st stage separators and test separators normally measure three types of medium (e.g. oil, MEG/water and gas) while level transmitters in scrubbers, 2nd stage separators and 3rd stage separators are supposed to be used to measure for two types of medium, e.g. liquid/gas. In case this information about vessel type was not evident, the number of vessel outlet lines was checked against e.g. P&IDs to obtain number of fluid phases inside the vessels.

Despite the effort, we were left with several transmitters where information was missing. E.g., measuring principle was not identified for 10% of the transmitters and manufacturer was not identified for 11%.

Table 1. Inventory attributes—Point gas detectors.

Attributes	Incl.	Examples of categories
Manufacturer	YES	Autronica, Dräger, Simtronics…
Measuring principle	YES	IR, Wireless, Acoustic…*
Model	YES	HC200, PIR 7000, GD10…

*Catalytic gas detectors have been removed from the data set due to significant more DU failures than the rest of the measuring principles.

Table 2. Inventory attributes—Level transmitters.

Attributes	Incl.	Examples of categories
Manufacturer	YES	Vega, Fisher-Rosemount…
Measuring principle	YES	Displacer, Pressure, Radar…
No. of medium phases	YES	1, 2 or 3
Type of medium	NO	Hydrocarbon, Water, Chemical…
Type of vessel	NO	Separator, Scrubber, Tank…
Special problems	NO	Foaming, Sand, Scale…

4.4 *Shutdown valves*

The data collected through operational reviews contains in total 1245 Emergency Shutdown (ESD) and Process Shutdown (PSD) valves. Table 3 shows the inventory attributes selected in the expert review meeting. Unfortunately, it was necessary to remove all data from one of the facilities due to very sparse information on the inventory attributes manufacturer and (valve) size.

Categories for *manufacturer*, *size* and *type* of valve were obtained from the maintenance system and equipment and facility specific information such as data sheets and P&IDs.

The process *medium* exposing the valves was assessed by experts at one of the facilities: It was suggested that for each system at the facility a corresponding (typical) medium could be assumed, and this "mapping" between system and medium was adopted for the rest of the facilities.

To avoid too many categories for valve size, group size intervals were decided together with an expert. Criteria for these intervals were based on the valve and process characteristics, rather than

Table 3. Inventory attributes—PSD and ESD valves.

Attributes	Incl.	Examples of categories
Actuation principle	NO	Electric, Hydraulic, Pneumatic…
Manufacturer	YES	Tai Milano, Swagelok, BIS…
Medium	YES	Gas, HC liquid, Water…
Size	YES	0–1″, 1–3″, 3–18″ and >18″
Special problems	NO	Corrosion, Icing…
Type	YES	Ball, Gate, Butterfly, Other

Table 4. Inventory attributes—Pressure safety valves.

Attributes	Incl.	Examples of categories
Actuation principle	NO	Pilot, Spring, Pressure-vacuum…
Dirty or clean service	YES	Yes or No
Manufacturer	YES	Petrolvalves, O.M.S.,…
Medium	NO	Gas, HC liquid…
Size	NO	

having equally sized categories: E.g., valves less than 1″ has been defined as a separated category since they normally are water-based and attached with lower risk compared to bigger valves. Thus, the number of valves in each size category varies.

The categories for inventory attribute "actuation principle" was not straight forward to retrieve. This would require time-consuming manual information, and was only performed for one of the facilities. Hence, the actuation principle inventory attribute was removed from the analyses. Also, the inventory attribute "specific problems" (corrosion, icing and temperature changes) was removed, as this information required manual and rather time-consuming effort.

Table 3 lists the examples of categories assigned to selected inventory attributes. Also for this equipment group, information was missing. For example, we found that 14% of the valves had unknown manufacturer, 13% had unknown size and 8% had unknown type.

4.5 *Pressure safety valves*

The inventory attributes that were selected for pressure safety valves (PSVs) based on expert meeting are presented in Table 4. *Manufacturer* and size of valve were obtained from the maintenance system and equipment and facility specific information such as data sheets and P&IDs. However, we faced major problems with missing category information. E.g. for about 50% of the PSVs, information about the valve size was not found in the maintenance system. Thus, the inventory attribute "size" was not part of the PSV analyses. Unfortunately, we also had to remove data for PSVs from one of the facilities due to missing information.

Dirty or clean service, i.e. if the medium flowing through a PSV is "dirty" (e.g. including sand, crude oil, etc.) or "clean" (e.g. pure gas), was together with the actuation principle pointed out by the experts as a possible significant inventory attribute for the PSVs. To simplify the analyses, it was assumed that all PSVs installed in the same system had the same category (either "dirty" or "clean"). The inventory attribute "medium" was not included, since it would be partly correlated to the inventory attribute "service".

The actuation principle of the PSVs was identified to some extent in the maintenance system. As for ESD and PSD valves, it was very time-consuming to extract this information and this has not yet been performed. Hence, the actuation principle was not part of the analyses.

Table 4 summarizes the selected inventory attributes. Note that examples of categories are not provided for the inventory attribute "size" since it was decided to omit this one from the analyses.

5 ANALYSES AND RESULTS

5.1 *Assumptions*

The data for all the finally selected inventory attributes were for the analyses combined with information about how many DU failures that had been registered for the equipment group and the aggregated time in operation. In the data set, we removed DU failures that had been repeated for the same equipment, to avoid double counting of the same failure event.

For some of the inventory attributes, e.g. medium for PSD and ESD valves and dirty or clean service for PSVs, the categories are based on the assumption that all equipment installed in one particular system share the same medium and service; e.g. all valves in system number 43 (Flare system) is assumed to share the medium "gas" and "clean" service.

The number of predefined categories and of course how they are defined, e.g. size intervals and which categories belonging to the "other" category, will also impact the results.

Some assumptions have also been made regarding the analyses and for the data to fit the statistical analyses as described in section 3. E.g., the DU failures are assumed to be identically distributed and to occur stochastically independent. It is also assumed that inadequate information and missing data do not have any effect on the results of the analyses.

The observation periods from each facility is not equal and varies from two to 11 years for those facilities included in the data set. Thus, some assumptions about observation periods had to be made to get observations periods as equal as possible and to utilize all DU failures: The final periods should not be too short such that there would be very few observation periods with failure compared to observation periods without failures—then it would be more difficult getting significant results. On the other hand, the periods should not be too large such that multiple failures of the same component often would occur within the same period—then we would not utilize all the DU failures. Also, different observation period intervals were concerned in data analyses for fire and gas detectors compared to other equipment groups:

For those equipment groups with data from five or six facilities (PSD and ESD valves, level transmitters and PSVs) three–four years was regarded as one observation period. Then, for a facility with observation period between three and four years, each equipment unit was counted once in the total data set. For a facility with 11 years of operational experience, the inventory data was counted for three times in the total data set (and the DU-failures were distributed on the correct observation period based on the notification date).

For fire and gas detectors, where data from several facilities was included and many of those with shorter observation periods, two–three years was regarded as one observation period.

The GLM model was implemented in software R, which is a free software for statistical computing and graphics.

5.2 *Results*

The aim of the analyses was for each equipment group to identify which inventory attributes and related categories that became statistical significant (if any).

Table 5 shows the results of the analyses for each equipment group, listing the most significant inventory attributes and associated categories—with respect to the DU failure rate. Note that not all attributes and categories have been found to be significant, and they are therefore not listed. Neither are those categories less significant compared to two or more other categories. “Significant” implies that the inventory attribute and its associated category(s) either contribute to significantly higher failure rate or significantly lower failure rate compared to the other attributes/categories.

From Table 5 we see that the manufacturer, typically represented by one or two of the largest manufacturers, is significant for most of the equipment groups. For ESD and PSD valves the largest

Table 5. List of most significant inventory attributes and categories.

Equipment group	Attribute	Category
ESD/PSD valves	Size	>18″
	Medium	Gas, Water, …
	Manufacturer	*Confidentially*
Line gas detectors	Manufacturer	*Confidentially*
Point gas detectors	Measuring principle	IR
PSVs	Manufacturer	*Confidentially*
	Dirty or clean service	Dirty, clean

valves seem to have a higher failure rate compared to small valves. Also, the medium may be important for the failure rate for ESD/PSD valves.

One inventory attribute suggested by experts, and that we was able to analyze, was not found to be of significant in our analyses: “measuring principle” for level transmitters. This may be partly explained by inadequate level of details concerning inventory attributes in the applied data.

For the fire and gas detectors where data was available from several facilities, also the facility was included as a separate attribute. The results showed that some facilities turned out to contribute to significant higher or lower failure rates compared to the others.

6 RECOMMENDATIONS AND FURTHER WORK

Measures and means for improving the quality of data that are recorded into the maintenance system is an important area for further research. Today, the recording is mainly manual, and there lack a systematic way for consistent recording of information for more automatic extraction and analyses. Based on the results of this study, it is possible to suggest more specific categories of information to be recorded. It may be necessary to further investigate the implications of assumptions that were made for our analyses. Both those that were made to overcome practical obstacles, e.g. due to lack of information related to selected inventory attributes, and those made to simplify the selection of categories, e.g. about the relationship between categories for inventory attributes (e.g. clean service) and system number (e.g. flare system). It is also possible to perform other types of analyses, e.g. “big data” analyses, to identify significant inventory attributes particularly when the amount of data, inventory attributes and categories increases.

Operational experience indicates that similar equipment performs differently between facilities with a comparable operating environment. It is therefore desirable to supplement the generic data with inventory attributes that can explain the varying performance, and enable the reliability analyst to better predict the variations. Due to the limited information about inventory attributes, it is recommended that the operators increase the amount of relevant inventory information in their maintenance systems, in particular for safety critical equipment part of operational reviews. Then, the failure data and data for inventory attributes can be combined to perform in depth analyses.

Data collection is becoming increasingly important both with respect to quantity and quality. It is an important activity to provide feedback on experience from the operational phase to designers of new systems and for monitoring the operational performance of safety barriers. It is also an important activity seen in relation to the increasing trend of lifetime-extension for existing facilities. SINTEF and PDS forum is also working on means for enhancing the digitalization of failure reporting, classification, and analyses, to update the generic failure rates more frequently and to reduce the manual effort in this process. A higher level of automatic analyses of data can help when prioritizing resources needed to improve the overall quality of data.

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