Comparing FMEDA Predicted Failure Rates to OREDA Estimated Failure Rates for Sensor and Valve Assemblies

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EXECUTIVE SUMMARY

Failure rates predicted by Failure Modes Effects and Diagnostic Analysis (FMEDA) are compared to failure rates estimated from the Offshore Reliability Data (OREDA) project for sensor and valve assemblies. Because the two methods of data analysis are fundamentally different in nature, it may be surprising that, when appropriately compared, the results from the two methods are generally quite similar. The nature of the published data for FMEDA and OREDA is explored. The relative merits of each method are discussed.

INTRODUCTION

Three recent studies have compared failure rate predictions obtained from FMEDA [1, 2] to failure rate estimations obtained from analysis of field failure data (FFD) gathered by the OREDA project [3, 4]. The first study, reported in [5, 6], explained how to interpret the data contained in the failure rate tables published by OREDA. It also demonstrated that and explained why a *direct* comparison of published FMEDA failure rates to published OREDA failure rates is inappropriate. Whereas FMEDA predicts failure rates for individual devices, OREDA collects data by subsystems (called assemblies) which generally include multiple devices. In addition, the initial study constructed composite FMEDAs that more closely matched the totality of devices and failure modes captured by OREDA's critical severity failure rate estimates for two different valve assemblies listed under the OREDA application "Emergency Shut Down" (ESD). The second study, reported in [7, 8], proposed a methodology for extracting appropriate failure modes associated with dangerous failures from OREDA critical severity data and matching those to FMEDA predicted dangerous failure rates, λ_D, and applied the methodology to OREDA data again for the OREDA ESD application. The third study, reported at [9], compared total failure rates (minimum, mean, and maximum) constructed from FMEDA data for all ball valve and all gate valve assemblies to mean total failure rates and 90% confidence intervals for OREDA data.

Comparisons from the first two studies yielded results indicating that FMEDA and OREDA data were comparable but that FMEDA failure rates were generally somewhat less than the OREDA numbers. These differences have several explanations. OREDA includes within its assembly equipment data-collection boundaries devices with no comparable FMEDA analyses. OREDA also includes human-initiated failures which FMEDA does not. The comparisons were based on FMEDA's performed for normal, not severe, service and it is likely that at least some of the OREDA data represented severe service. Lastly, by limiting the OREDA data to OREDA ESD applications, some of the valve data came from relatively small equipment populations. The third study yielded results indicating that FMEDA and OREDA data were quite comparable.

This paper provides a complete report on the most recent research which extends the above mentioned third study to include a variety of sensor assemblies. Following a Notation Section, this paper

- provides sufficient background on FMEDA prediction and OREDA estimation to make the paper self-contained
- describes the key differences between this extended third study and the first two studies
- summarizes the data used from both FMEDA and OREDA sources for sensor and valve assemblies
- describes how various OREDA data were used to identify failures reported by OREDA under the critical severity class that are not accounted for by FMEDA analysis
- summarizes the results for mean and 90% confidence limits for OREDA failure rates recomputed after some OREDA failures, not accounted for by FMEDA, are eliminated
- compares FMEDA predictions and OREDA estimations for total failure rate, λ_T, for two sensor assemblies and three specific FMEDA applications of two different valve assemblies
- concludes with a discussion of the results and a comparison of the two techniques in general.

TERMINOLOGY & NOTATION

The term “application” is used by FMEDA and OREDA to mean quite different things. In FMEDA, “application” describes the particular way in which a device is configured for use in a safety system. For example, a sensor may be configured so that a high reading results in a trip command (“trip high” application) or, conversely, that a low reading triggers a trip command (“trip low” application). Similarly, when a trip command is issued, it may cause a valve to close (“close on trip” application) or to open (“open on trip” application). The term “application” is used by OREDA to designate the specific use of the device. For example, a ball valve may have many applications for which data is recorded separately; specifically, a ball valve could be used in any number of “applications” including: ballast water, condensate processing, crude oil handling, emergency shut down, fuel gas, gas (re)injection, gas export, etc. Thus throughout this paper, when the authors refer to “application,” the term is prefaced by FMEDA or OREDA to give a better sense of the type(s) of application(s) being referenced.

AIR	abnormal instrumentation reading
COT	close on trip
COT-FS	close on trip – full stroke
COT-TSO	close on trip – tight shut off
DOP	delayed operation
ELP	external leakage – process medium
ELU	external leakage – utility medium
ESD	emergency shut down
FFD	field failure data
FIT	failure/10^9 hours
FMEDA	Failure Modes, Effects and Diagnostic Analysis
FTC	fail to close on demand
FTF	fail to function on demand
FTO	fail to open on demand
FTR	fail to regulate
HIO	high output
INL	internal leakage
LCP	valve leakage in closed position
LOU	low output, unknown reading
NOO	no output
OOT	open on trip
OREDA	Offshore Reliability Data
OTH	other
SER	minor in-service problems
SHH	spurious high level alarm signal
SLL	spurious low level alarm signal
SPO	spurious operation
UNK	unknown

λ_D	dangerous constant failure rate
λ_{EL}	external leakage constant failure rate (applicable to valve assemblies)
λ_S	safe constant failure rate
λ_T	total constant failure rate – sum of λ_D, λ_S (for sensor assemblies) and sum of λ_D, λ_{EL}, λ_S (for valve assemblies)

BACKGROUND

FMEDA Predictions

The FMEDA technique is performed on a specific device (e.g., ball valve, pressure transmitter, temperature sensor, electronic module, etc.) specified down to the manufacturer and series/model. Based on the specifics of the design, the parts used to execute the design, the design margins, any automatic diagnostics, the specific use and the environment in which the device will be deployed, the FMEDA produces predictions for the dangerous detected and undetected failure rates, the safe detected and undetected failure rates, the diagnostic annunciation failure rates, the no effect failure rates, the dangerous and safe diagnostic coverages (for devices with self-diagnostic capabilities), and the useful life. The analysis is FMEDA application-specific because a particular failure mode may be dangerous in one FMEDA application but safe in a different FMEDA application; for example, consider the difference when a valve opens on trip (OOT) vs closes on trip (COT). Currently six different environmental profiles for equipment may be used in the FMEDA method. These profiles include cabinet mounted or climate controlled, general field mounted (two versions with differences in internal temperatures), off shore subsea, off shore topside and process wetted.

FMEDA analysis requires a validated database of failure modes and failure rates for the parts which comprise the various devices [2, 10, 11]. This database slightly skews the part failure rates to be certain that the device failure rates will be conservative. However, currently the FMEDA analysis does not account for the effects of site-specific end-user activities. Essentially FMEDA predicts the inherent failure rate of a specific product in a specific FMEDA application and environment assuming that all end-users will take all appropriate end-user actions to insure that

- the equipment is appropriate to the task, properly installed and calibrated, and correctly functioning when installed,
- all in-service maintenance is correctly and completely performed on schedule,
- the equipment is maintained so that no ageing occurs prior to proof testing which is completely and correctly performed, and
- the equipment is replaced when its useful life can no longer be extended by maintenance and refurbishment.

Over the years, a large number of devices have been subjected to FMEDA analysis and all FMEDA results have been collected and retained in a FMEDA database (separate and different from the validate parts failure mode and rate database used by FMEDA). The

FMEDA's in the database are continuously calibrated against FFD as such data become available. FMEDA's are updated if the parts database changes significantly. Based on this FMEDA database, generic failure rates are being compiled [12] giving the minimum, maximum, mean and 25, 50, 75 and 90 percentile of all failure rates for devices of a common type assuming a specific use. Other percentiles can be extracted from the FMEDA database but are not published. Note that the percentiles are not confidence intervals because the FMEDA data does not represent a statistical sample of failures. Rather it provides the known range of failure rate predictions for similar devices which differ by design and manufacture. For example, FMEDA's have been performed on a total of 106 specific ball valves (manufacturer and series/model). These 106 ball valves include, for example, 31 different floating ball valves, 37 different trunnion-mounted ball valves, etc. The total number of different FMEDA's for ball values is 999 which is large because a specific ball valve may have been subjected to multiple analyses under different uses, environments, levels of diagnostic testing, etc.

OREDA Estimations

The OREDA project was established in 1981. Its main objective is to "improved safety and cost-effectiveness in design and operation of oil & gas E[xploration] &P[roduction] 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 [3, 4]." OREDA has published six editions of its reliability data handbook in 1984, 1992, 1997, 2002, 2009, and 2015.

OREDA divides equipment according to equipment classes and further subdivides those classes by equipment taxonomy. Boundaries are defined for each assembly/equipment taxonomy for which data are collected; the data are environment specific (to subsea and topside). However, in most cases, the lowest level taxonomy includes more than one device. For example, for the assembly "valves" the boundary includes not only the valve itself but also an actuator and solenoid or pilot valve as well as position monitoring equipment. The data are not specific to a single device much less to a manufacturer and series/model. A wealth of information for the equipment is published including the following items: population, number of installations, aggregated time in service (both calendar and operational time), failure mode/severity class, number of failures, the mean of the estimated constant failure rate, lower and upper 90% uncertainty level for the estimated constant failure rate, and standard deviation for the estimated constant failure rate under the assumption of multi-sample population and the estimated constant failure rate under the assumption of a homogeneous sample population. Arguably, OREDA has produced the most significant collection of FFD available.

OREDA equipment data was collected in phases. For the assembly "valves" the 2009 edition includes data from Phases V, VI, and VII covering periods of time between 1997 and 2003 and includes 907 unique units. For the assembly "valves" the 2015 edition includes data from Phases VI, VII, and VIII covering periods of time from 2000 to 2008 and includes 703 unique units. So the population size of a given type of equipment may vary from one handbook edition to the next and may actually decrease in later editions as some data are eliminated. Furthermore, since the data are collected from actual (but unidentified) specific devices and since the specific device distribution is unknown, the results of statistical analysis of the data may or may not apply to a different population or to a particular device. By virtue of the data collection methods, failures initiated by humans are, implicitly, included in the failure rate estimates [3, 4]. This means that the estimated failure rates include not only the inherent product failures but also failures due to site-specific end-user actions.

KEY DIFFERENCES IN THIS EXTENDED THIRD STUDY COMPARED TO THE FIRST TWO STUDIES

This extended third study differs from the previous two studies in certain important ways. This extended study compares sensor assembly data in addition to valve assembly data. The sensor data includes IR fire and gas sensors and pressure sensors/transmitters. Also, rather than limiting the use of OREDA valve assembly data to a specific OREDA application (e.g., ESD), this study used all “ball valve” and all “gate valve” data that could be identified as likely belonging to OREDA applications where the valve assembly spends most of its time in a stationary position with movement of the valve or other assembly components (actuators, solenoids, etc.) occurring infrequently. This matches the assumption of analysis under which FMEDAs are performed, i.e., that the equipment is deployed in a low demand safety function. This increased the size of the equipment populations available in OREDA for comparisons.

Further, by utilizing published OREDA data regarding the relationship between failure mechanisms and failure modes, it was often, but not always, possible to identify individual failures recorded by OREDA which would not be accounted for by FMEDA. Specifically, these included

- failures due to failure mechanisms related to monitoring equipment for which no comparable FMEDA exists,
- human-initiated failures due to failure mechanisms associated with improper calibration or alignment, corrosion or wear, and
- some failures associated with failure mechanisms, such as contamination, likely associated with severe service
- functional failures due to software failures.

Eliminating these failures from OREDA data and reassessing the OREDA estimates insures a more appropriate “apples-to-apples” comparison between FMEDA and OREDA failure rates.

ASSEMBLIES INCLUDED IN THE EXTENDED STUDY

The original intent of the extended third study was to compare failure rates predicted by FMEDA to estimates computed from OREDA data for all sensor, logic solver, and final element assemblies recorded by ORDEA. However, in a number of cases, OREDA data were not sufficiently large and in other cases, FMEDA data did not include particular devices that occur in the OREDA assemblies. In order to be sure that sufficient data existed for statistically significant comparisons, data from the OREDA handbooks from 2009 and 2015 were included provided that

- OREDA data for an assembly type (sensor, logic solver, final element) had at least 1 critical failure reported on a population of at least 100 assemblies with a minimum total operating time of at least 1,000,000 hours, and
- FMEDA has device data for the devices in the OREDA assembly.

Based on these criteria, the following OREDA assemblies were compared

- IR Fire & Gas Sensor Assemblies (flame and hydrocarbon gas) (2009, 2015)
- Pressure Sensor/Transmitter Assemblies (2015 only)
- Ball and Gate Valve Assemblies (2009, 2015)

Other types of sensors and valves were not included because FMEDA/OREDA data did not meet the above criteria. In particular, logic solvers were not included because OREDA did not record any critical failures on logic solver assemblies.

DATA SOURCES

FMEDA Data

Because FMEDA's are performed on individual devices while OREDA data are recorded for assemblies, i.e., collections of equipment, for the purposes of failure rate comparisons it is necessary to construct composite FMEDA predicted failure rates which include the same failure modes as those reported in the critical severity class of OREDA equipment assemblies.

To accomplish this task, the mean failure rates for dangerous failures, λ_D, and safe failures, λ_S, were computed for all IR sensors and summed to find the mean total failure rate, λ_T. The minimum and maximum total failure rates over all IR sensor designs for which FMEDA's have been performed were also noted. The same procedure was used to find mean λ_T and minimums and maximums for pressure/transmitter assemblies. However, in the case of pressure/transmitter assemblies these metrics were computed two ways – with and without pressure seals. Finally, the mean failure rates for λ_D, λ_S, and failures due to external leakage, λ_{EL}, were computed for all ball valve, gate valve, actuator, and solenoid FMEDA's in the FMEDA database for three types of FMEDA applications, viz., close-on-trip full stroke (COT-FS), close-on-trip tight shut off (COT-TSO), and OOT. Based on this data, the overall mean λ_T, was computed for the "valve assemblies" (as defined by OREDA) by averaging all combinations of valves, actuators and solenoids within a given FMEDA application category. The minimum and maximum failure rate values were also recorded. Table 1 summarizes the results for IR fire and gas detectors and pressure/transmitter assemblies, and Table 2 summarizes the results for ball valve and gate valve assemblies.

Table 1 Summary of Failure Rates Based on Composite FMEDAs for Sensor Assemblies

	IR Fire & Gas Detector Assemblies FITS	Pressure Sensor/Transmitter Assemblies FITS	
		With Seal	**Without Seal**
Maximum	5370	2235	2083
Mean	1790	705	613
Minimum	380	269	223

Table 2 Summary of Failure Rates Based on Composite FMEDAs for Valve Assemblies

	Ball Valves Assemblies FITS			Gate Valves Assemblies FITS		
FMEDA Application	**COT-FS**	**COT-TSO**	**OOT**	**COT-FS**	**COT-TSO**	**OOT**
Maximum	6604	7754	6391	7027	7538	7048
Mean	3260	4093	3246	2869	3337	2876
Minimum	2428	3027	2358	503	1023	503

OREDA Data

The OREDA data handbooks publish assembly data for sensors in a fairly straightforward way and the data for IR fire and gas and for pressure sensors used in this study is summarized in Table 3. The first four data rows are information taken directly from the handbooks. The last row summarizes the number of failures listed under the critical severity class that could potentially be matched to failures accounted for in FMEDA analysis. The differences between the last two rows represent the number of failures (including fractional failures) that were eliminated as explained in the next section because FMEDA analysis does not account for them.

Table 3 Summary of OREDA Sensor Assembly Data Used in Extended Study

	IR Fire and Gas Detector Assemblies (Flame & Hydrocarbon Gas)		Pressure Sensor/ Transmitter Assemblies
Handbook Editions	**2009**	**2015**	**2015**
Population	248	285	324
# Installations	7	10	4
Operating Time (10^6 hrs)	7.4108	7.8285	10.4318
# Critical Severity Failures	42	25	5
# Critical Severity Failures Accounted for in FMEDA	17.64	13.77	4

The OREDA data handbooks publish valve assembly data two different ways. Under taxonomy numbers 4.4.x., one can find valve failure data grouped by OREDA applications such as blowdown, ESD, relief, etc. Under each OREDA application for taxonomy numbers 4.4.x.x one can find information about populations of specific valve types such as ball, butterfly, gate, etc. This study focused on ball and gate valve assemblies as these were the only two specific valve types with sufficient populations in OREDA data to make relevant comparisons. Under taxonomy numbers 4.5.x, one can find valve failure data grouped by valve type such as ball, butterfly, gate, etc. and it is in this section that one can find information about failure mechanisms vs failure rates for each valve type.

Table 4 summarizes the information gathered from taxonomy numbers 4.5.x. for ball and gate valves from the 2009 and 2015 editions of the OREDA data handbooks. Again, the first four data rows are information taken directly from the handbooks. The last row summarizes the number of failures listed under the critical severity class that could potentially be matched to failures accounted for in FMEDA analysis. The differences between the last two rows represent the number of failures (including fractional failures) that were eliminated as explained in the next section because FMEDA analysis does not account for them.

Table 4 Summary of OREDA Ball and Gate Valve Assembly Data Used in Study

	Ball Valve Assemblies			**Gate Valve Assemblies**	
Handbook Editions	**2009**	**2015**	**2015 reduced**	**2009**	**2015**
Population	149	196	76	228	177
# Installations	20	17	?	19	14
Operating Time (10^6 hrs)	3.8918	7.7661	3.2582	4.1853	4.0534
# Critical Severity Failures	28	66	14	22	15
# Critical Severity Failures Accounted for in FMEDA	18.59	---	11.67	15.58	12

In Table 4 the column “2015 reduced” requires some explanation. In 2015 under taxonomy number 4.4.2.1, the OREDA blowdown application with ball valve assemblies has a population of 120 distinct assembly units. This represents more than 60% of the total 2015 ball valve data. These 120 units generated a total of 125 failures over all failure modes and all failure severity classes with 52 of the failures belonging to the critical severity class. There is no other OREDA application category in either ball or gate valves in either 2009 or 2015 where such a large percentage failures are recorded on such a large part of the total population. Clearly this data is not representative of the failures otherwise observed and recorded for ball valves, yet it dominates the 2015 data. Therefore, the authors decided to remove this one OREDA application in 2015 from the ball valve data and this removal generated the column “2015 reduced.” While this reduced the number of assemblies below the “100 assembly” criteria, the significant operating time (in excess of the “1,000,000 hours” criteria) resulted in the reduced ball valve data being included in the comparisons.

The other OREDA data relevant to this study come from the tables of failure mechanisms vs failure modes. An example of this data is provided below as Table 5 and is used in the next section to explain how OREDA failures not accounted for in FMEDA analysis are removed. In OREDA, the entries in the table represent the percentage of the total failure rate (estimated over all severity classes) attributable to each combination of failure mechanism and failure mode. In Table 5, the entries represent the actual number of failures rather than the percentage of total failures as this makes using this information in the next section of this paper easier. Note that the abbreviations for the columns in Table 5 are defined in the Notation section. Also note that there are a total of 93 failures over all failure modes and all severity classes. Of these 93 failures a total of 28 are failures belonging to the critical severity class.

Table 5 Example of Failure Mechanisms vs Failure Modes for Ball Valve Assemblies 2009

Modes*	AIR	DOP	ELP	ELU	FTC	FTO	FTR	INL	LCP	OTH	SER	STD	UNK
Mechanisms													
Blockage	2				1								
Breakage										1			
Corrosion	1		1							8		3	
Instrument failure - gen†					5	3							
Leakage			4	5				4	1				
Looseness										1			
Material failure - gen†			2					2					
Mechanical failure - gen†	1	1	2	1	3			5			1		1
Other										1			
Out of Adjustment	1	4											
Sticking		1			1	1	1				1		
Unknown		8			4	1		1		1	3		4
Wear									1				
Total	5	14	9	6	14	5	1	12	2	12	5	3	5
* Note that the abbreviations for all Modes are defined in the Notation section. † gen means general													

ELIMINATING OREDA FAILURES WHICH ARE NOT ACCOUNTED FOR IN FMEDA ANALYSIS

The purpose of this comparative study is to match the failures recorded by OREDA as closely as possible to the failures that would be accounted for in a FMEDA analysis. To this end, where possible, it is useful to identify OREDA failures which are not accounted for in FMEDA analysis so that they can be eliminated prior to data comparisons. The procedure for such elimination is best demonstrated by example.

Consider Table 6 which summarizes the 28 failures in the critical severity class by failure mode of the ball valve Assemblies from the 2009 OREDA data. Note that not all failure modes from Table 5 appear in Table 6 because Table 6 summarizes only failures of critical severity.

Table 6 Summary of Critical Failures by Failure Mode for Ball Valve Assemblies 2009

Failure Modes*	DOP	ELP	ELU	FTC	FTO	FTR	INL	LCP
# critical severity failures	2	1	1	14	5	1	3	1
* Note that the abbreviations for the Failure Modes are defined in the Notation section.								

Notice that there are exactly 14 failures associated with the failure mode FTC in Table 5 and exactly 14 critical severity failures associated with the failure mode FTC in Table 6. Clearly it can be inferred that all FTC failures in Table 5 were failures of critical severity. Furthermore, note in Table 5 that 5 failures (all of critical severity) are associated with instrumentation failures. Such failures would relate to the monitoring equipment which falls within the defined boundaries of the OREDA valve assembly but this monitoring equipment does not have a counterpart in the FMEDA database; therefore these failures would not be represented in the FMEDA analysis and should be eliminated from the OREDA failure count. A similar situation exists with respect to three of the five failures of critical severity associated with the FTO failure mode thus eliminating 3 additional failures from the OREDA failure count.

In the above two examples, it was possible to determine that all of the failures of a given failure mode in Table 5 were of critical severity and thus eliminate failures related to failure mechanisms not accounted for by FMEDA. Sometimes, one knows that one or more of several failures are not accounted for by FMEDA but one cannot be sure if they are failures of critical severity. For example, consider the failure mode LCP. In Table 6 there is only one occurrence of the LPC failure mode. In Table 5, there are two failures associated with the LPC failure mode and one should be eliminated because it involves wear which is not accounted for in the FMEDA analysis. However, it is not possible to know if the failure due to wear was a failure of critical severity or not. It is reasonable to treat this problem statistically and eliminate 0.5 failures from the OREDA failure count in Table 6 based on the 50% possibility that the failure of critical severity was associated with wear.

Further, it is possible to cross-reference additional information within the OREDA handbooks to perform further eliminations either with certainty or statistically. Failure mechanism vs failure modes tables are also available by OREDA application and if the OREDA application contains data on only one valve type, this can be a source that supports additional failure eliminations.

Based on these elimination principals, the last row of Tables 3 and 4 summarize the relevant OREDA failure count that remained after failure elimination was performed based on best available information. Additional details about the OREDA data used in this extended study along with documentation of failures eliminated and rationales for the eliminations can be found in the Appendix.

RECOMPUTING FAILURE RATES BASED ON REVISED OREDA DATA

Based on the revised failure counts in the final row of Tables 3 and 4 along with the operating time recorded for each data set, it is possible to recompute the OREDA means and the limits of a 90% confidence interval for listed sensor and valve assemblies using the formulas provided by OREDA in [3] and [4] on page 25 in both references. These are given in Tables 7 and 8 with full computational details in the Appendix and the summary of results in Table A.8. Note that once failures are eliminated from OREDA data, computation of the failure rates means and confidence limits requires the homogenous data assumption as there is insufficient published data to compute the new failure rates taking into account the multi-installation nature of the data.

Table 7 Summary of Failure Rates Based on Revised OREDA Data for Sensor Assemblies

	IR Fire & Gas Detector Assemblies FITS		Pressure Sensor/ Transmitter Assemblies FITS
	2009	**2015**	**2015**
Upper 90% confidence limit	3544	2760	877
Mean	2381	1759	383
Lower 90% confidence limit	1531	1059	131

Table 8 Summary of Failure Rates Based on Revised OREDA Data for Valve Assemblies

	Ball Valves FITS		Gate Valves FITS	
	2009	**2015 reduced**	**2009**	**2015 reduced**
Upper 90% confidence limit	7039	5842	5667	4797
Mean	4777	3582	3727	2960
Lower 90% confidence limit	3112	2048	2306	1708

COMPARING FMEDA PREDICTIONS AND OREDA ESTIMATIONS

Now that the OREDA and FMEDA data have been matched as closely as possible, it is time to compare the failure rates for the sensor and valve assemblies.

Figures 1 and 2 show comparative plots for the sensor assemblies based on the data in Tables 1 and 7. Figure 3 shows comparative plots for the valve assemblies based on the data in Tables 2 and 8.

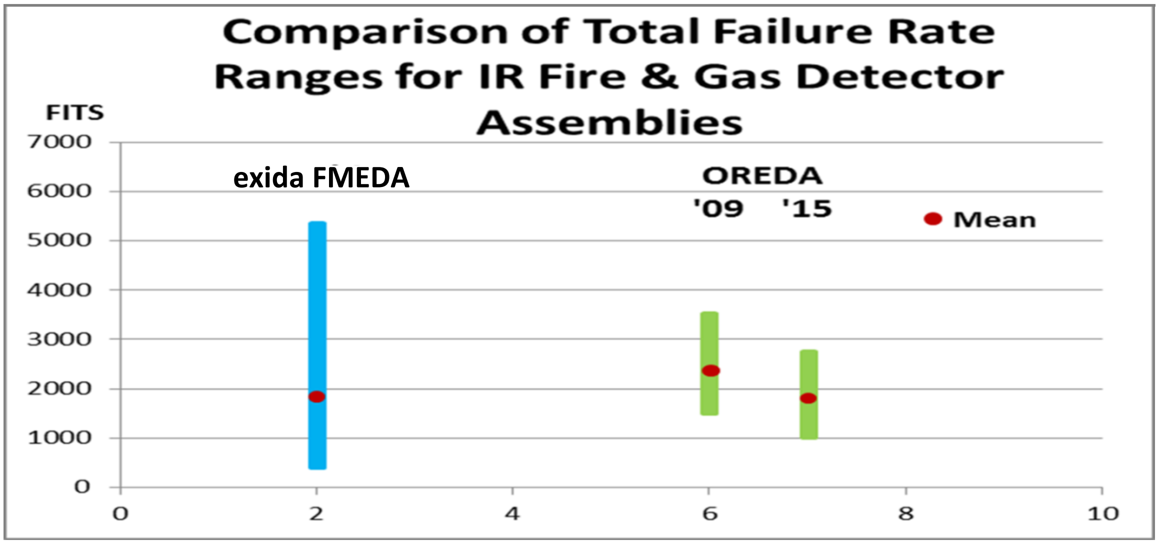

Figure 1 Comparison of FMEDA Predicted Failure Rates and
OREDA Estimated Failure Rates for IR Fire & Gas Detector Assemblies

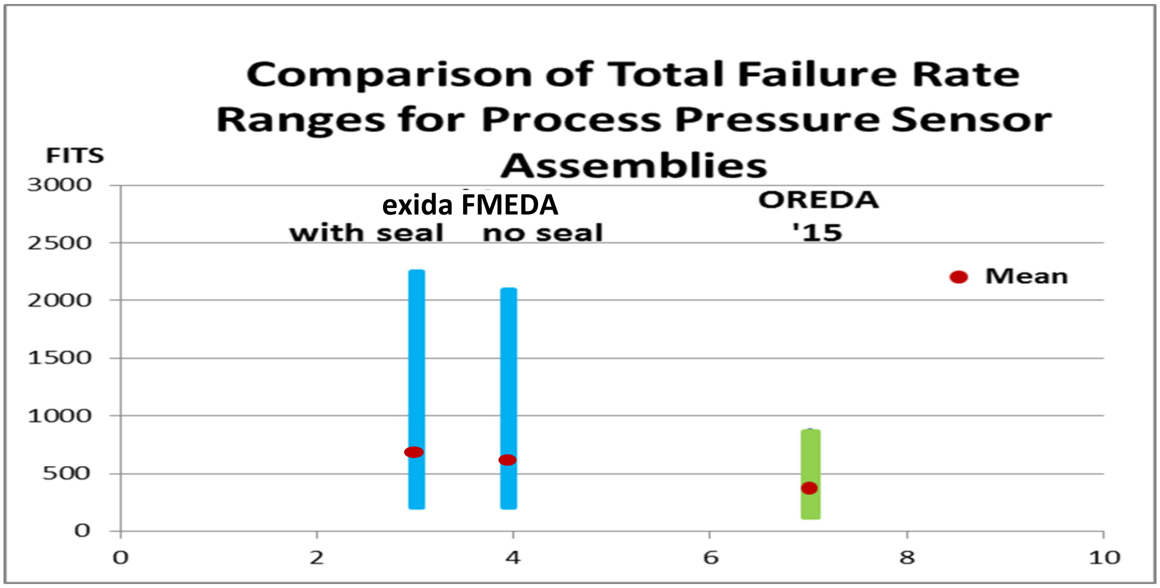

Figure 2 Comparison of FMEDA Predicted Failure Rates and
OREDA Estimated Failure Rates for Process Pressure Sensor/Transmitter Assemblies

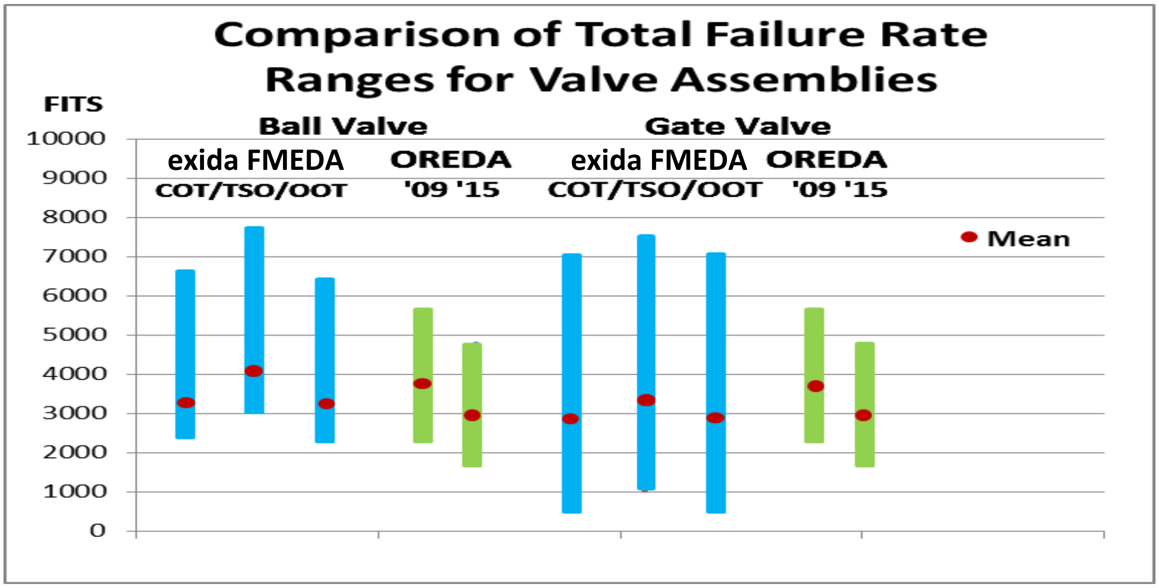

Figure 3. Comparison of FMEDA Predicted Failure Rates and OREDA Estimated Failure Rates for Ball and Gate Valve Assemblies

DISCUSSION OF RESULTS

Examining Figure 1 for the IR Fire & Gas Detector Assemblies, it is apparent that the FMEDA mean is just slightly smaller than the OREDA 2009 mean and almost the same as the OREDA 2015 mean. Further, the FMEDA minimum and maximum values fully encompass the lower and upper limits of the OREDA 90% confidence interval. Overall, Figure 1 shows an excellent match between comparable FMEDA and OREDA data for the included equipment.

Figure 2, for the pressure sensor/transmitter assemblies, shows the FMEDA means to be slightly larger than the OREDA mean. Further, the FMEDA minimums are slightly larger than the lower limit of the OREDA 90% confidence interval while the FMEDA maximums are clearly exceed the upper limit of the 90% confidence interval. Overall, Figure 2 shows a good match between comparable FMEDA and OREDA data for the included equipment.

Finally, in examining Figure 3 for the ball valve and gate valve assemblies, consider first a comparison of OREDA 2009 and OREDA 2015 data. For both the ball valve and gate valve assemblies, the OREDA 2009 estimates are consistently higher than the OREDA 2015 estimates. The OREDA 2009 data contained a substantial amount of older valve data which were eliminated by OREDA in the OREDA 2015 edition. Presumably the OREDA 2015 data is more representative of more recent performance. Next consider comparing the FMEDA predicted failure rates across the three FMEDA applications. The FMEDA COT-FS (labeled COT in Figure 3) and OOT applications show complete consistency. The FMEDA COT-TSO (labeled TSO in Figure 3) application shows higher means, minimums and maximums as would be expected due to the more severe requirements of TSO.

Now, comparing FMEDA COT-FS (labeled COT in Figure 3) and OOT applications predicted means, minimums and maximums to the OREDA 2015 estimated means and lower and upper limits of OREDA 90% confidence limits, it is apparent that the FMEDA predicted mean failure rates are comparable to the OREDA 2015 estimated mean failure rate.

CONCLUSIONS

It is reasonable to conclude that, when compared in an “apples-to-apples” fashion, for the equipment analyzed in this paper, the FMEDA predictions and OREDA estimations are quite comparable. Additionally, this extended study serves as a further validation of the mechanical failure rates and failure modes database that drives the FMEDA analysis. Prior validating comparisons against FFD sources other than OREDA can be found at [13, 14].

FMEDA allows for the prediction of product inherent failure rates and can be used to analyze new designs and products even if FFD is not available. OREDA captures not only inherent product failures but also failures due to site-specific practices as well as human-initiate failures. It is realistic to include site-specific issues in failure rates and other safety parameters. exida includes these issues via its Site Safety Index™ (SSI). OREDA data may well provide meaningful data to calibrate the SSI.

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APPENDIX

INTRODUCTION

This appendix documents

- the OREDA data used in this study and the rationales for judging some OREDA failures to be of types not accounted for by FMEDA. This information is contained in Tables A1 – A7.
- the calculations performed on the number of remaining OREDA failures to compute the revised OREDA mean and upper and lower 90% confidence limit failure rates per OREDA equations on page 25 of both [3] and [4]. This information is contained in Table A8.

SUMMARY OF OREDA DATA USED IN THIS STUDY

Table A1. IR Fire & Gas Detector Assembly Data OREDA 2009

page #	Pop	Op time (10^6 hrs)	# failures / failure mode in critical severity class								
			Total	FTF	HIO	LOU	NOO	OTH	SHH	SLL	SPO
437	27	1.3608	1								1
447	221	6.0500	41	11			2		9	5	14
Tot	248	7.4108	42	11			2		9	5	15
# failures eliminated			24.36	5.86			2		5	3.5	8
Rationale: See Note				**1**			**2**		**3**	**4**	**5**
# failures remaining			17.64								

General Notes: All of the above data is from OREDA Fire & Gas Detectors. Data from p 437 is for "Flame - IR; data from p 447 is for "Hydrocarbon Gas - IR". Data from p 552 for "Smoke/Combination - IR" were not included as the FMEDA database does not contain a counterpart for this equipment.

Per p 436: No basis for eliminating the 1 critical failure for "Flame – IR"

Note 1: per p 446, all 12 FTF failures in the table on p 446 are critical but 11 are IR failures and 1 is a photo electric failure; of the 12 failures a total of 6 failures can be eliminated due to contamination (2), out of adjustment (2) and vibration(2); of these 6 failures at least 5 **must be** critical IR failures and these can definitely be eliminated; of the remaining 7 critical failures (12-5) 1 can be eliminated and the chances that the one to be eliminated is IR are 6 out of the remaining 7 critical failures (85.7%).

Note 2: per p 446, both NOO failures are IR critical failures and can be eliminated due to contamination (1) and out of adjustment (1)

Note 3: per p 446, all 9 SHH failures are IR critical failures and 5 can be eliminated due to contamination (1) and out of adjustment (4)

Note 4: per p 446, there are a total of 6 SLL failures of which 5 are critical; of these 6 failures 4 should be eliminated due to contamination (1), corrosion (1) and out of adjustment (2); of these 4 at least 3 are critical and can definitely be eliminated; of the two that cannot be eliminated at least one must be critical; of the remaining 2 failures (6-3 -1) the chances that the additional 1 to be eliminated is critical are 1 out of 2 (50%)

Note 5: per p 446, all 14 SPO failures are critical IR failures of which 8 can be eliminated due to contamination (3), out of adjustment (3), vibration (2)

Table A2. IR Fire & Gas Detector Assembly Data OREDA 2015

page #	Pop	Op time (10^6 hrs)	# failures / failure mode in critical severity class								
			Total	FTF	HIO	LOU	NOO	OTH	SHH	SLL	SPO
377	21	0.7686	5				5				
381	264	7.0599	20	12	1	2	3				2
Tot	285	7.8285	25	12	1	2	8				2
# failures eliminated			11.23	7.83	0.89	0.5	1				1
Rationale: See Note				**1**	**2**	**3**	**4**				**5**
# failures remaining			13.77								

General Notes: All of the above data is from OREDA Fire & Gas Detectors. Data from p 377 is for “Flame - IR; data from p 381 is for “Hydrocarbon Gas - IR”. Data from p 384 for “Smoke/Combination - IR” were not included as the FMEDA database does not contain a counterpart for this equipment.

Per p 376: No basis for eliminating the 5 critical failures for “Flame – IR”

Note 1: per p 379, all 13 FTF failures in the table on p 379 are critical but 12 are IR failures and 1 is a catalytic failure; of the 13 failures a total of 8 failures can be eliminated due to contamination (7) or S/W failure (1); of these 8 failures at least 7 **must be** critical IR failures and these can definitely be eliminated; of the remaining 6 critical failures (13-7) 1 can be eliminated and the chances that the one to be eliminated is IR are 5 out of the remaining 6 critical failures (83.3%) for a total elimination of 7.83 failures

Note 2: per p 379, of the 19 HIO failures 1 is critical; of the 19 failures, 17 should be eliminated due to contamination (11) and out of adjustment (6); the chances that the 1 critical failure is among the 17 to be eliminated are 17 out of 19 (89.47%)

Note 3: per p 379, there are a total of 4 LOU failures of which 2 are critical; of the 4 failures, 1 should be eliminated due to out of adjustment; the chances that the critical failure is the one to be eliminated are 2 out of 4 (50%)

Note 4: per p 379, all 3 NOO failures are IR critical failures and 1 can be eliminated due to out of adjustment

Note 5: per p 379, both SPO failures are critical IR failures and 1 can be eliminated due to out of adjustment

Table A3. Pressure Sensor/Transmitter Assembly Data OREDA 2015

page #	Pop	Op time (10^6 hrs)	# failures / failure mode in critical severity class		
			Total	FTF	OTH
394	324	10.4318	5	2	3
Tot	324	10.4318	5	2	3
# failures eliminated			1	1	
Rationale: See Note				**1**	
# failures remaining			4		

Note 1: per p 395 both FTF failures are critical and 1 can be eliminated due to contamination

Table A4. Ball Valve Assembly Data OREDA 2009

page #	Pop	Op time (10^6 hrs)	# failures / failure mode in critical severity class												
			Total	**AIR**	**DOP**	**ELP**	**ELU**	**FTC**	**FTO**	**FTR**	**INL**	**LCP**	**OTH**	**SPO**	**STD**
505	5	0.1211	0												
510	19	0.6638	3		2				1						
517	2	0.0420	0												
531	88	2.3444	21			1		13	3		3	1			
577	15	0.3017	1						1						
610	3	0.0525	1					1							
629	16	0.3259	1				1								
644	1	0.0404	1							1					
Tot	149	3.8918	28		2	1	1	14	5	1	3	1			
# failures eliminated			9.41		0.8	0.11		5	3			0.5			
Rationale: See Note					**1**	**2**		**3**	**4**			**5**			
# failures remaining			18.59												

Note 1: per p 509 in OREDA Blowdown application there are a total of 5 DOP failures of which 2 (40%) can be eliminated due to “out of adjustment” failure mechanism

Note 2: per p 665 there are a total of 9 ELP failures of which 1 (11.11%) can be eliminated due to “corrosion” failure mechanism

Note 3: per p 665 there are a total of 14 FTC failures (all of critical severity) of which 5 can be eliminated due to” instrumentation failure – general” failure mechanism

Note 4: per p 665there are a total of 5 FTO failures (all of critical severity) of which 3 can be eliminated due to “instrumentation failure – general” failure mechanism

Note 5: per p 665there are a total of 2 LCP failures of which 1 (50%) can be eliminated due to “wear” failure mechanism

Table A5. Ball Valve Assembly Data OREDA 2015 Reduced

page #	Pop	Op time (10^6 hrs)	# failures / failure mode in critical severity class												
			Total	AIR	DOP	ELP	ELU	FTC	FTO	FTR	INL	LCP	OTH	SPO	STD
426	5	0.1211	0												
441	2	0.1010	0												
453	58	2.6046	9			1		1	2		3	1		1	
474	5	0.2477	1						1						
491	1	0.0505	1						1						
508	3	0.0525	1					1							
524	1	0.0404	1				1								
532	1	0.0404	1							1					
Tot	76	3.2582	14			1	1	2	4	1	3	1		1	
# failures eliminated			2.33						1.5			0.33		0.5	
Rationale: See Note									**1**			**2**		**3**	
# failures remaining			11.67												

Note 1: per p 490 in OREDA Process Control application there is a total of 1 FTO (of critical severity) failure which can be eliminated due to “no signal/indication/alarm” failure mechanism and per p 473 in OREDA EDS/PSD application there are a total of 2 FTO failures of which 1 (50%) can be eliminated due to “faulty signal/indication/alarm” failure mechanism

Note 2: per p 452 in OREDA EDS application there are a total of 3 LCP failures of which 1 (33.33%) can be eliminated due to “wear” failure mechanism

Note 3: per p 543 there are a total of 2 SPO failures of which 1 (50%) can be eliminated due to “instrumentation failure – general” failure mechanism

Table A6. Gate Valve Assembly Data OREDA 2009

page #	**Pop**	**Op time (10^6 hrs)**	**# failures / failure mode in critical severity class**												
			Total	**AIR**	**DOP**	**ELP**	**ELU**	**FTC**	**FTO**	**FTR**	**INL**	**LCP**	**OTH**	**SPO**	**STD**
541	48	1.0657	13			1		6	2					1	3
552	8	0.1386	2					1	1						
557	32	0.5519	1									1			
585	2	0.0350	0												
594	116	2.0228	1		1										
603	1	0.0173	0												
635	15	0.1817	0												
649	6	0.1669	5					3	1				1		
Tot	228	4.1799	22		1	1		10	4			1	1	1	3
# failures eliminated			6.42		1			3					0.75		1.67
Rationale: See Note					**1**			**2**					**3**		**4**
# failures remaining			15.58												
Note 1: per p 593 there is a total 1 DOP failure (of critical severity) which can be eliminated due to “clearance/alignment failure” failure mechanism **Note 2**: per p 722 there are a total 10 FTC failures (all of critical severity) of which 3 can be eliminated due to “instrument failure - general” failure mechanism **Note 3**: per p 723 there are a total of 4 OTH failures of which 3 (75%) can be eliminated due to “corrosion”, “out of adjustment” and “wear” failure mechanisms **Note 4**: per p 723 there are a total of 4 STD failures of which 2 are due to “instrument failure – general” failure mechanism. This implies that at least 1 of 3 critical failures above is to be eliminated. There remain (4-1) STD failures of which 1 (33%) can be eliminated due to “instrument failure – general.” Thus an additional 2 critical failures x 1/3 can be eliminated for a total of 1.67 eliminated STD failures.															

Table A7. Gate Valve Assembly Data OREDA 2015

page #	Pop	Op time (10^6 hrs)	# failures / failure mode in critical severity class												
			Total	**AIR**	**DOP**	**ELP**	**ELU**	**FTC**	**FTO**	**FTR**	**INL**	**LCP**	**OTH**	**SPO**	**STD**
463	23	1.3681	13			1		2	2		1			7	
479	32	0.5574	1									1			
495	116	2.0228	1		1										
528	6	0.1051	0												
Tot	177	4.0534	15		1	1		2	2		1	1		7	
# failures eliminated			3		1			1						1	
Rationale: See Note					**1**			**2**						**3**	
# failures remaining			12												

Note 1: per p 494 there is a total 1 DOP failure (of critical severity) that can be eliminated due to "clearance/alignment failure" failure mechanism
Note 2: per p 597 there are a total 2 FTC failures (all of critical severity) of which 1 can be eliminated due to "corrosion" failure mechanism
Note 3: per p 597 there are a total of 7 SPO failures (all of critical severity) of which 1 can be eliminated due to "instrument failure - general" failure mechanism

CALCULATION OF MEANS & CONFIDENCE LIMITS BASED ON REVISED OREDA FAILURE COUNTS

Per page 25 in [3] and [4], mean values were calculated as Mean = n/τ where n is the number of failures and τ is the operating time. The 90% confidence interval is given by $(1/(2\tau) \times Z_{0.95,2n}, 1/(2\tau) \times Z_{0.05,2(n+1)})$ where $Z_{0.95,\nu}$ and $Z_{0.05,\nu}$ denote the *upper* 95% and 5% percentiles, respectively, for the χ^2 distribution with ν degrees of freedom. For non-integer values of ν, the χ^2 tables were interpolated. Table A8 summarizes the results of the calculations.

Table A8. Summary of Calculations for Means and 90% Confidence Limits Based on Revised OREDA Failure Counts

Assembly Type	Year	Lower confidence Limit FITS	Mean FITS	Upper Confidence Limit FITS	n	τ 10^6 hrs	$Z_{0.95,2n}$	$Z_{0.05,2(n+1)}$
IR Fire & Gas	2009	1531	2381	3544	17.64	7.4108	22.695	52.533
IR Fire & Gas	2015	1059	1759	2760	13.77	7.8285	16.574	43.218
Pressure Sensor/Trans	2015	131	383	877	4	10.4318	2.733	18.307
Ball Valve	2009	3112	4777	7039	18.59	3.8918	24.221	54.785
Ball Valve	2015 reduced	2048	3582	5842	11.67	3.2582	13.348	38.071
Gate Valve	2009	2306	3727	5667	15.58	4.1799	19.281	47.400
Gate Valve	2015	1708	2960	4797	12	4.0534	13.848	38.885