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RELIABILITY OF BLOWOUT PREVENTERS TESTED UNDER FOURTEEN AND
SEVEN DAYS TIME INTERVAL

STUDY REPORT

SUBMITTED TO
MINERALS MANAGEMENT SERVICES
OF
THE U.S. DEPARTMENT OF INTERIOR

FINAL

SUBMITTED BY
TETRAHEDRON, INC.

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Results presented in this report are based on the data received from the industry.

1.0 SUMMARY

BOP reliability study has been completed. Statistical analyses were done on data collected from the oil industry using a 99% confidence level. Results of the analyses indicated that:

- BOP failure rate when tested at interval between 8 to 14 days can not be claimed to be different than when tested between 0 to 7 days.
- Failure rate of most components were also not significantly different when tested between 0-7 and 8-14 days time interval.
- Failure rate of initial tests were greater than subsequent tests.
- Results obtained from this analysis are valid only for the interval ranges studied. They do not show significant correlation between failure rate and interval between test. This result should not be extrapolated to draw conclusions on other time interval failure rates.

2.0 PROBLEM STATEMENT

2.1 Blowout Preventers

Blowout prevention Systems (referred to as Blowout Preventer, BOP, in this study) are used in oil and gas fields during drilling operations to prevent uncontrolled release of reservoir fluids. BOPs considered in this study are composed of all systems required to operate the blowout preventers under varying rig and well conditions. These systems are: blowout preventers, choke and kill lines, choke manifold, and auxiliary equipment. It does not include marine riser. Appendix A provides figures of typical BOP systems.

2.2 Current Regulation

In accordance with Federal Regulations as published in 30 CFR section 250.57 surface and subsea blowout preventers must be tested:

- (a) when installed;
- (b) before drilling out each string of casing or before continuing operations in cases where the cement is not drilled out;
- (c) at least once each week, but not exceeding 7 days between pressure tests, alternating between control stations. A period of more than 7 days between BOP tests is allowed when there is a stuck drill pipe or there are pressure control operations, and remedial efforts are being performed, provided that the pressure tests are conducted as soon as possible and before normal operation resumes.

2.3 Request to Change Current Regulation

Each test requires substantial time and effort and causes delay in drilling operations. The oil industry feels that testing within seven days (as discussed in section 2.2(c) above) is not necessary because:

- (i) Seven day testing hampers flow of drilling activity and leads to inefficiency.
- (ii) Too much testing can cause component failure due to exposure to high pressures and abrasive materials.
- (iii) Testing within fourteen days will provide at least same level of protection as the seven day test interval.

In 1992, the oil industry requested Minerals Management Services (MMS) of the U.S. Department of Interior to evaluate the required current seven day test frequency and to see if this could be extended to fourteen day interval. MMS in reviewing this request decided to do a study to see if *within* fourteen day test interval will provide the same amount of safety as *within* seven day test interval.

3.0 PREVIOUS STUDIES

3.1 Study Performed by MMS

In 1993, MMS began a review of the BOP testing and maintenance requirements. This included:

- Evaluating two SINTEF studies sponsored by Norwegian Petroleum Directorate (NPD).
- Gathering BOP test data from drilling operations.
- Holding workshop and gathering industry input.
- Conducting study of BOP test charts. Study included:
 - Building a database.
 - Analysis of data.

The MMS study indicated that failures rates were substantially greater than recorded by SINTEF. In addition, it was also determined that percentage of good tests varied with duration of test intervals as shown below:

1 to 7 days	= 57%
8 to 12 days	= 48%
13 to 15 days	= 38%

This data showed a trend that BOP performance decreased as the test interval increased. Based on these results and discussions with industry, MMS decided that a second study was necessary to assess BOP performance on the Outer Continental Shelf.

3.2 Study Performed by SINTEF

This study was performed to ascertain the reliability of both surface and subsea BOPs in the Norwegian sector of the North Sea. The study indicated that:

- Surface BOPs fail more often than subsea BOPs due to less redundancy in safety mechanism.
- High failure rate is associated with inadequate preventive maintenance.

4.0 SCOPE OF CURRENT STUDY

MMS and the U.S. petroleum industry considered it essential to perform a more thorough study that can lead to conclusions on whether 14 day test interval will provide safe operating conditions at a drilling site. MMS and industry worked together in setting the parameters for the study. The following industry groups participated in selecting the contractor for the study:

American Petroleum Institute
Independent Petroleum Association of America
International Association of Drilling Contractors
National Ocean Industries Association
Offshore Operators Committee

MMS and these industry groups hired Tetrahedron, Inc. on February 13, 1996, to assess BOP performance. Tasks to be performed under this study included:

- (i) Meeting with MMS and the industry for developing a study method that will be acceptable to all parties involved.
- (ii) Review of existing data/information collected by MMS.
- (iii) Developing methodologies including data acquisition forms/techniques, data evaluation and quality control and data analyses methods.
- (iv) Data analyses and reporting.
- (v) Development of data base.
- (vi) Presentation of the results at a workshop.

5.0 MEETING WITH THE STAKE HOLDERS

5.1 First Meeting

A kick-off meeting was held in Houston on February 27, 1996. Participants in the meeting were representatives from MMS, Tetrahedron, Inc., American Petroleum Institute, Independent Petroleum Association of America, International Association of Drilling Contractors, National Ocean Industries Association, and Offshore Operators Committee.

Purpose of this meeting was to develop a plan for the acquisition of data that will be acceptable to both the industry and regulatory agency. Highlights of the outcome of this meeting are given below:

1. The study will include only BOP systems. Diverter systems are not included in the scope of this study.
2. BOP test reports will be submitted by contractors in a preferred format for consistency and for the purpose of capturing all relevant information. The preferred format will be developed by Tetrahedron, Inc. and provided to the contractors by MMS.
3. A "condition of approval" will be developed and mailed to the industry under which they may perform BOP testing within 14 days instead of 7 days and submit test results for analyses.
4. Each test result submitted by the contractor/operator should be supported by test report, charts and diagrams maintaining consistent equipment identification numbering.
5. Terminologies used in the study were defined for maintaining consistency.

5.2 Second Meeting

Second meeting was held on August 28, 1996 at the MMS office in New Orleans with the stake holders. Highlights of the meeting are given below:

- Phase I report was presented by Tetrahedron, which indicated that based on the data, there was not enough evidence to claim that BOP failure rates when tested between 1-7 days and 8-14 days are different.
- Following decisions were taken:
 - (i) More data was to be gathered to see if there is difference in the failure rates of surface and subsea BOPs.

- (ii) Analysis of BOP component failures was to be included in the study.
- (iii) Analysis of failure rates for each day (between 0 to 14 days) and its relationship to "test interval" was to be developed as part of the study.
- (iv) Database was to be developed in Excel.

6.0 REVIEW OF EXISTING DATA

Data collected by MMS was reviewed to see the randomness of distribution. It was noticed that the data concentrated around 7 day and 14 day test period. Raw data indicated that failure rate increased as time interval between tests increased. No statistical analysis was done to validate this result.

7.0 METHODOLOGY

7.1 Data Acquisition

Data was acquired for analyses through the office of MMS from the drilling contractors/operators. "BOP and Choke Manifold Test Report" forms were provided to them which in most cases were filled out and sent along with pressure charts and relevant diagrams. In some cases companies used their own forms to provide the data for this study. A sample of "BOP and Choke Manifold Test Report" is provided in Appendix B. This form was prepared in accordance with the agreement reached in the "kick-off meeting" and was accepted by MMS and the industry before being sent out.

7.1.1 Data Transfer and Recording

Figure 7.1 is a flow diagram showing how the data was transferred, recorded and analyzed. All data were sent to MMS by the industry. MMS forwarded this data to Tetrahedron. Tetrahedron recorded the data and assigned numbers as they were received in a database for tracking purposes. Data was then forwarded to Tetrahedron's blowout prevention expert for review, validation and comments. The BOP expert filled out a performance evaluation form for each failed BOP. Data along with the performance evaluation form was sent back to the data recorder for recording in the main database that captured information on each BOP test including *operator, leasewell, contractor, rigname, date, location of BOP, test duration, success/failure, test type, test fluid, time pressure held, and components failed*. The data entered into the database was analyzed using statistical techniques as described in section 7.3.

7.2 Data Validation

All data received from the oil field was validated by reviewing the reports and the charts to see if all information provided was accurate. Validation was done by the BOP expert who also ensured that there was consistency between reports. This was important because reports came from many different sources which had to be standardized for analysis.

For each failure, the BOP expert filled out a *performance evaluation form* that indicated the component that failed, type of BOP (surface or subsea), test duration, and BOP expert's comments (if any) on the report.

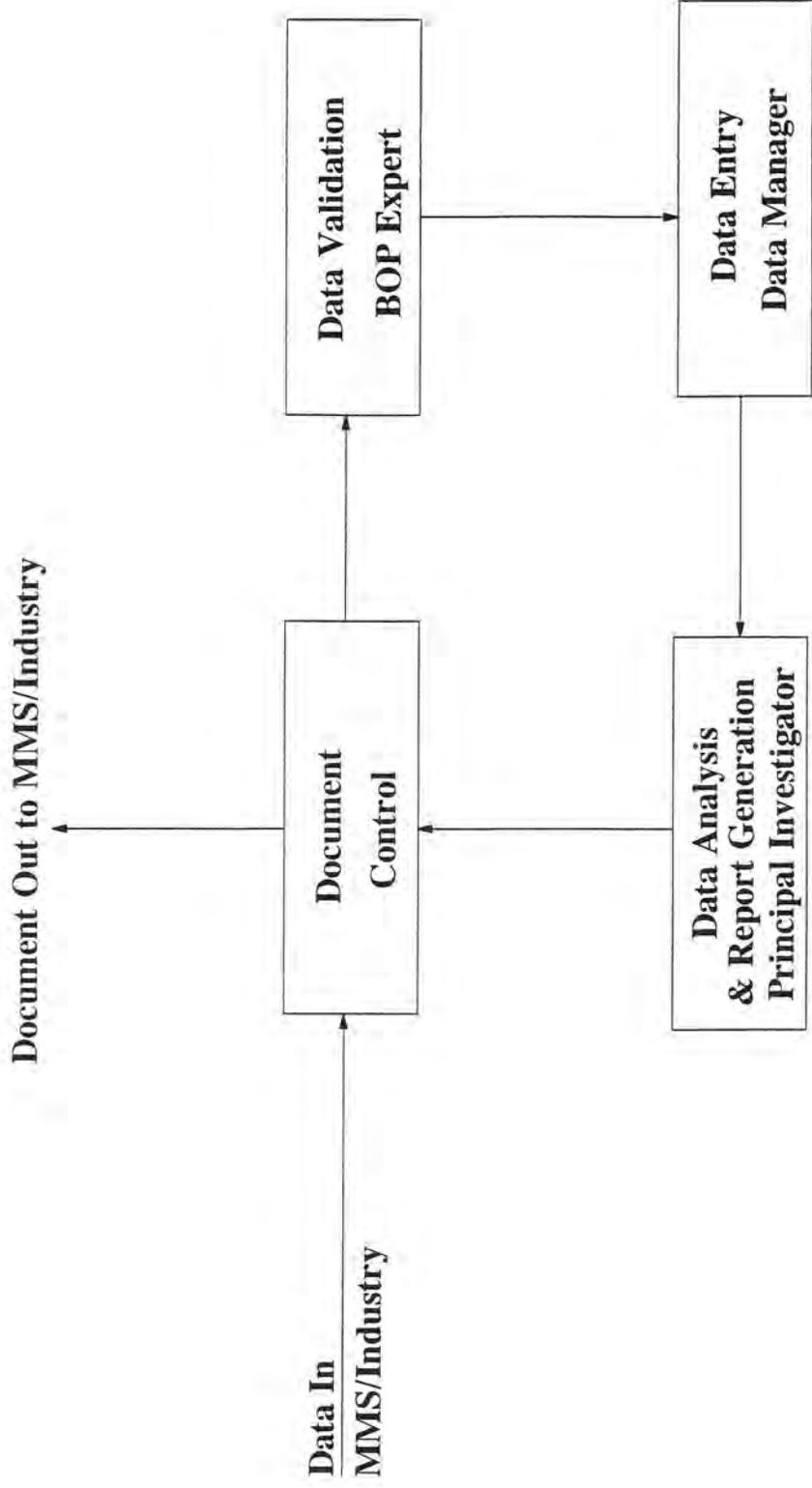


Figure 7.1 Work Flow Chart for BOP Study

7.2.1 Definitions

In this study BOP failure has been defined as given below:

BOP Failure: For both subsequent and initial test, a test was considered to have failed if any piece of equipment had to be physically repaired or sent to shop for repairs even if it had back-up.

A subsequent test was considered to have failed if any critical equipment failed during a pressure test. A critical equipment is defined as any equipment which would be required to hold well bore pressure in a well control situation and did not have a backup.

BOP Non-Failure: Failure to obtain test data resulting from test equipment failures, air in line, bump in chart, realigned chart or other errors not associated with actual testing of BOP was not considered a BOP failure.

For non-critical equipment (equipment that have backup), a subsequent test, was not considered failed if it could be functioned or operated without repair and would obtain good test within three test runs.

In case of initial test, if any piece of equipment could be functioned or operated without repair showing good test, it was not considered a failure irrespective of the number of test runs required to reach the successful test.

Initial Test: Initial test is defined as any test that is conducted when a blowout preventer is installed at the well. Many reports received from the industry designated tests as initial test with "test interval" greater than zero, indicating that other test(s) have been conducted on the BOP before. It was considered legitimate designation based on following rationale:

- (i) If an initial test fails and components of the BOP have to be repaired, then subsequent test after repair is also considered initial test.
- (ii) If after conducting an initial test no activity is performed that will expose the BOP to pressure environment, then subsequent test is considered initial test.

In this study we have included all tests that were designated "initial test" in the reports as such.

Connection Failure: Connection failures that were considered as BOP failures in this study included:

- (i) Ring gasket connections on flanges of rams, annulars, inside choke valves, inside kill line valves, bonnet seal connections.

- (ii) Well head connections.
- (iii) Any connections on BOP equipment that did not have backup.

Connection failures that were not considered as BOP failures included:

- (i) Test equipment and related test equipment connections (i.e. chiksan line connections).
- (ii) Drilling rig equipment (i.e. mud pump body connections, valve cap gaskets, liner gaskets, union leaks on mud line and stand pipe.)
- (iii) Ring gasket connection down stream of choke.

7.3 Statistical Techniques Used in the Study

It is essential to use statistical methods when inference about a population is to be made based on data from a sample. Variations between samples within a population resulting from natural distribution should be considered. Two samples from same population can have different "mean values". These mean values may be large depending upon the variance in the population. Therefore, before we infer that two samples that are different come from two separate populations, we must compare their mean values in light of the variance that exist in the data. In this study we selected a significance level of 99%, meaning that we would not consider that samples came from two different populations unless we were 99% certain. In other words, we want to be 99% sure that we do not erroneously reject our hypothesis that failure rates in 0-7 days time interval and 8-14 days time interval represent the same population. Rejection of the hypothesis would indicate that time interval between tests has an effect on the failure rates.

Note: Population in this study refers to all the BOP systems that will be used under similar conditions.

Statistical techniques used in this study assume normal distribution of the data as the sample size (n) is large (>30).

7.3.1 Sampling

Random sampling technique was used for collecting data from the industry. Data were received from the industry in random fashion without any geographical, drilling contractor, operator bias. Data were received at the MMS office and forwarded to Tetrahedron where they were numbered in the order they were received for tracking purposes. It was then separated into three categories by *time interval between tests*. The purpose of this separation was to see if each time interval represented a separate population. The time intervals used were:

- 0 to 7 days between tests
- 8 to 14 days between tests
- Initial tests

7.3.2 Hypothesis Testing

Hypothesis testing is usually used when finding differences between two population means or proportions. Such a test was considered appropriate for this study since the objective is to see if the proportion of failures under various time intervals between tests are different.

For this study we have used a probability of error in our inference to be 1% (significance level, $\alpha = 0.01$). This means that 99% of the time when our hypothesis (null hypothesis) about the population is correct we will not reject it based on our sample outcome. In other words we can be 99% confident that we do not erroneously reject our null hypothesis.

Eight hypotheses were tested as given in Table 7-1.

TABLE 7-1

<p>Hypothesis 1: Proportion of failures in BOPs when tested between 0 to 7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 2: Proportion of failures in BOPs when tested between 0 to 7 days "P_1" and initial tests "P_2" are equal.</p> <p>Hypothesis 3: Proportion of failures in BOPs when tested between 8 to 14 days "P_1" and initial tests "P_2" are equal.</p>
<p>Hypothesis 4: Proportion of failures when tested between 0 to 7 days for surface BOPs "P_1" and subsea BOPs "P_2" are equal.</p> <p>Hypothesis 5: Proportion of failures when tested between 8 to 14 days for surface BOPs "P_1" and subsea BOPs "P_2" are equal.</p> <p>Hypothesis 6: Proportion of failures in <i>surface BOPs</i> when tested between 0 to 7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 7: Proportion of failures in <i>subsea BOPs</i> when tested between 0 to 7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 8: Proportion of failures in <i>subsea BOPs (total)</i> "P_1" and <i>surface BOPs (total)</i> "P_2" are equal.</p>

In addition, for component failure additional 22 hypotheses were tested as shown in Table 7-2.

TABLE 7-2

<p>Hypothesis 1: Proportion of failures in "Annular" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 2: Proportion of failures in "Pipe Ram" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 3: Proportion of failures in "Blind Ram" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p>
<p>Hypothesis 4: Proportion of failures in "Kill Manual" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 5: Proportion of failures in "Kill Remote" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 6: Proportion of failures in "Manifold Manual" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p>
<p>Hypothesis 7: Proportion of failures in "Manifold Remote" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 8: Proportion of failures in "Choke Manual" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 9: Proportion of failures in "Choke Remote" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p>
<p>Hypothesis 10: Proportion of failures in "Drill String Valve" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 11: Proportion of failures in "Inside BOP" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p> <p>Hypothesis 12: Proportion of failures in "Connections" when tested between 0-7 days "P_1" and between 8 to 14 days "P_2" are equal.</p>

Hypothesis 13: Proportion of failures in "Test equipment" when tested between 0-7 days "P₁" and between 8 to 14 days "P₂" are equal.

Hypothesis 14: Proportion of failures in "Other Failed Parts" when tested between 0-7 days "P₁" and between 8 to 14 days "P₂" are equal.

Hypothesis 15: Proportion of failures in "Annular" when tested between 0-7 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Hypothesis 16: Proportion of failures in "Ram (pipe and blind ram combined)" when tested between 0-7 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Hypothesis 17: Proportion of failures in "Manifold Valve (manual and remote combined)" when tested between 0-7 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Hypothesis 18: Proportion of failures in "Inside BOP and Drill String Valve combined" when tested between 0-7 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Hypothesis 19: Proportion of failures in "Annular" when tested between 8-14 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Hypothesis 20: Proportion of failures in "Ram (pipe and blind ram combined)" when tested between 8-14 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Hypothesis 21: Proportion of failures in "Manifold Valve (manual and remote combined)" when tested between 8-14 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Hypothesis 22: Proportion of failures in "Inside BOP and Drill String Valve combined" when tested between 8-14 days for surface BOPs "P₁" and subsea BOPs "P₂" are equal.

Following test procedure was used for all tests:

Null Hypothesis H_0 : P₁ is equal to P₂

Alternate Hypothesis H_A : P₁ is not equal to P₂

and the test statistics used is:

$$Z = (p_1 - p_2) / \left(\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2} \right)^{1/2}$$

Reject H_0 if absolute value of $Z > Z_{0.005}$

or Reject H_0 if absolute value of $Z > 2.575$

Note: "P" refers to population and "p" refers to sample.

7.3.3 Regression Analysis

Regression analysis helps to create mathematical models that show a relationship between two or more variables. Purpose of these models are to develop methods for predicting a value of a dependent variable. For this study, "failure rate" was selected as the dependent variable, and "time interval between tests" was used as the independent variables. Multiple regression, which can incorporate more than one independent variable, was considered appropriate for this study. Stepwise selection procedure for variables was used to eliminate effects of multicollinearity.

7.3.4 Model Definition

A model was tested to see if there was significant correlation between dependent (failure) and independent variables (time). Analysis of Variance (ANOVA) was conducted on the data to achieve this objective.

Model Description

A fourth order polynomial was selected to model failure rate as a function of time interval between tests as shown below:

$$F = b_0 + c_1t + c_2t^2 + c_3t^3 + c_4t^4$$

where:

F = Failure rate

b and c = constants

t = time interval between tests

Hypothesis for the Test

Null hypothesis $H_0 = c_1 = c_2 = c_3 = c_4 = 0$

Alternate hypothesis $H_A =$ at least one of the "c" is not equal to zero.

8.0 RESULTS

8.1 Data Summary

A total of 155 test reports were analyzed for this study. Summary of data acquired is presented in Table 8.1

TABLE 8.1 DATA SUMMARY

Test Outcome	0-7 Day Interval	8-14 Day Interval	Initial Test	Total
Success	27	48	17	92
Failure	13	23	27	63
Total	40	71	44	155

8.2 Test Outcome by Type of BOP

Test data were also separated by BOP type (surface or subsea). A summary of data by BOP type is presented in Table 8.2. Five test reports that are part of Table 8.1 did not indicate type of BOP (surface or subsea), therefore, were not included in Table 8.2.

TABLE 8.2 TEST OUTCOME BY TYPE OF BOP

Test Outcome	Surface (0-7 days)	Surface (8-14 days)	Subsea (0-7 days)	Subsea (8-14 days)
Success	13	15	13	31
Failures	7	15	5	7
Total	20	30	18	38

8.3 Hypotheses Test Results

Hypotheses tests were conducted as discussed in section 7.3.2. Results of the tests are summarized in Table 8.3

TABLE 8.3 Hypotheses Test Results

Test #	Hypothesis	P_1	P_2	Test Statistics	$Z_{0.005}$	Comments
1.	Proportion of failures in BOPs when tested between 0 to 7 days " P_1 " and between 8 to 14 days " P_2 " are equal.	.325	.324	.01	2.575	Based on data, we cannot say that it is different.
2.	Proportion of failures in BOPs when tested between 0 to 7 days " P_1 " and initial " P_2 " are equal.	.325	.614	-2.67	2.575	Based on data, we can say that it is different.
3.	Proportion of failures in BOPs when tested between 8 to 14 days " P_1 " and initial test " P_2 " are equal.	.324	.614	-3.15	2.575	Based on data, we can say that it is different.
4.	Proportion of failures when tested between 0 to 7 days for surface BOPs " P_1 " and subsea BOPs " P_2 " are equal.	.350	.278	.48	2.575	Based on data, we cannot say that it is different.
5.	Proportion of failures when tested between 8 to 14 days for surface BOPs " P_1 " and subsea BOPs " P_2 " are equal.	.50	.180	2.90	2.575	Based on data, we can say that it is different.
6.	Proportion of failures in <i>surface BOPs</i> when tested between 0 to 7 days " P_1 " and between 8 to 14 days " P_2 " are equal.	.35	.50	-1.07	2.575	Based on data, we cannot say that it is different.
7.	Proportion of failures in <i>subsea BOPs</i> when tested between 0 to 7 days " P_1 " and between 8 to 14 days " P_2 " are equal.	.278	.180	.80	2.575	Based on data, we cannot say that it is different.
8.	Proportion of failures in <i>subsea BOPs (total)</i> " P_1 " and <i>surface BOPs (total)</i> " P_2 " are equal.	.21	.42	2.37	2.575	Based on data, we cannot say that it is different.

8.4 Relationship Between Failure Rate and Test Interval

Failure rate for each time interval was calculated from the data and is presented in Table 8.4 (Failure Rate Summary) below. Initial tests were included in this analysis.

Table 8.4 Failure Rate Summary

No.	Interval Between Tests (days)	Sample Size	Failure Rate
1	0	32	.469
2	1	4	.75
3	2	3	.33
4	3	5	1.00
5	4	6	1.00
6	5	13	.31
7	6	8	.56
8	7	8	.38
9	8	11	.55
10	9	2	0
11	10	9	.44
12	11	8	.25
13	12	10	.40
14	13	17	.31
15	14	19	.26

As discussed in section 7.3.3 and 7.3.4, regression analysis was conducted to determine correlation between failure rate and time interval between tests. The ANOVA for the data as obtained from SAS (Statistical Analysis System) computer output is provided below:

```
Variable t2 entered          R-square =0.29743161
      DF      Sum of Squares      Mean Square  F      Prob>F
Regression      1      0.07049873      0.07049873  4.23  0.0667
Error           10      0.16652627      0.01665263

Variable      Parameter Estimate  Stand. Error  Sum of Squares      F      Prob>F
Intercept    0.50575813      0.05681276   1.31970463      79.25  0.0001
t2         -0.00116512      0.00056627   0.07049873      4.23  0.0667
```

No other variable met the 0.1500 significance level for entry into the model

According to this analysis, failure rate (F) may be represented by the following equation:

$$F = 0.506 - 0.00117t^2$$

Where "t" is the time in days between tests.

The ANOVA shows that none of the constants in the equation $F = b_0 + c_1t + c_2t^2 + c_3t^3 + c_4t^4$, except b_0 (0.5058) and c_2 (-0.001), could be considered significant. The R-square value (0.2974) even with these two constants is very low and indicates that there is no significant correlation between failure rate and time interval between tests.

8.5 Component Failure

The final factors to be analyzed were the individual components that were found to have failed during testing. These components included:

- | | |
|--------------------------|--|
| 1. Annular | 8. Choke manual valve |
| 2. Piperam | 9. Choke remote valve |
| 3. Blindram | 10. Drill string valve |
| 4. Kill manual valve | 11. Inside BOP |
| 5. Kill remote valve | 12. Connections |
| 6. Manifold manual valve | 13. Test equipment |
| 7. Manifold remote valve | 14. Other failed parts (pod, hammer union, choke swaco, hose etc.) |

A summary of component failure distribution is presented in Tables 8.5 (a) & (b). Graphical presentation of this data is provided in Figures 8-1 through 8-3. Please note that the number of tests analyzed for 0-7 days, 8-14 days, and initial test intervals were 40, 71, and 44 respectively.

TABLE 8.5(a) DATA SUMMARY

Component	Failure (0-7 days) (Total 40 tests)	Failure (8-14 days) (Total 71 tests)	Initial Test (Total 44 tests)	Total
Annular	2	4	2	8
Piperam	1	4	0	5
Blindram	1	1	1	3
Kill Manual Valve	0	0	2	2
Kill Remote Valve	0	1	2	3
Manifold Manual V.	2	9	9	20
Manifold Remote V.	0	1	2	3
Choke Manual Valve	0	0	0	0
Choke Remote Valve	0	0	0	0
Drill String Valve	0	2	5	7
Inside BOP	3	2	4	9
Connection	0	0	3	3
Test Equipment	1	2	4	7
Other Failed Parts	0	1	3	4
Total	10	27	37	74

8.5.1 Hypotheses Test Results

Hypotheses tests were conducted as discussed in section 7.3.2. Results of the tests are summarized in Table 8.5.1.

Table 8.5(b) Component Failure by Category of Test and BOP Type

Component	Surface BOP (0-7 days)	Surface BOP (8-14 days)	Subsea BOP (0-7 days)	Subsea BOP (8-14 days)	Surface BOP (Initial Test)	Subsea BOP (Initial Test)
Annular	1	4	1	0	2	0
Pipe Ram	0	3	1	1	0	0
Blind Ram	0	1	1	0	1	0
Kill Manual V.	0	0	0	0	2	0
Kill Remote V.	0	1	0	0	1	1
Manifold Manual V.	0	5	2	4	5	4
Manifold Remote V.	0	1	0	0	2	0
Choke Manual V.	0	0	0	0	0	0
Choke Remote V.	0	0	0	0	0	0
Drill String V.	0	2	0	0	3	2
Inside BOP	1	2	2	0	2	2
Connection	0	0	0	0	3	0
Test Equipment	1	0	0	2	2	2
Other Parts	0	0	0	1	3	0

1-7

8-14

38

30

18

20

5/133

4/133

10/133

22/270

5/10

BOP COMPONENT FAILURE IN 0-7 DAYS TEST INTERVAL (IN PERCENTAGE)

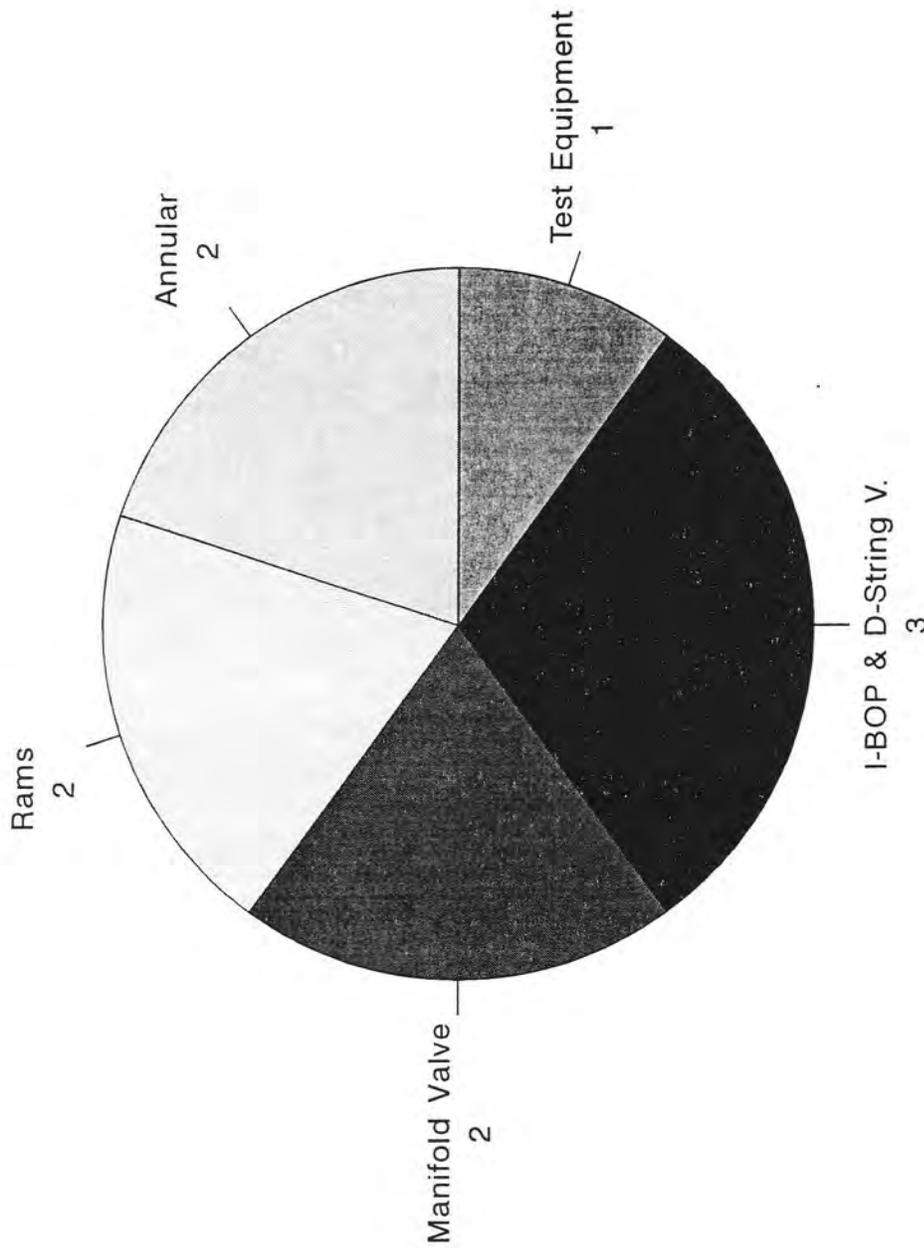


FIGURE 8-1

BOP COMPONENT FAILURE IN 8-14 DAYS TEST INTERVAL (IN PERCENTAGE)

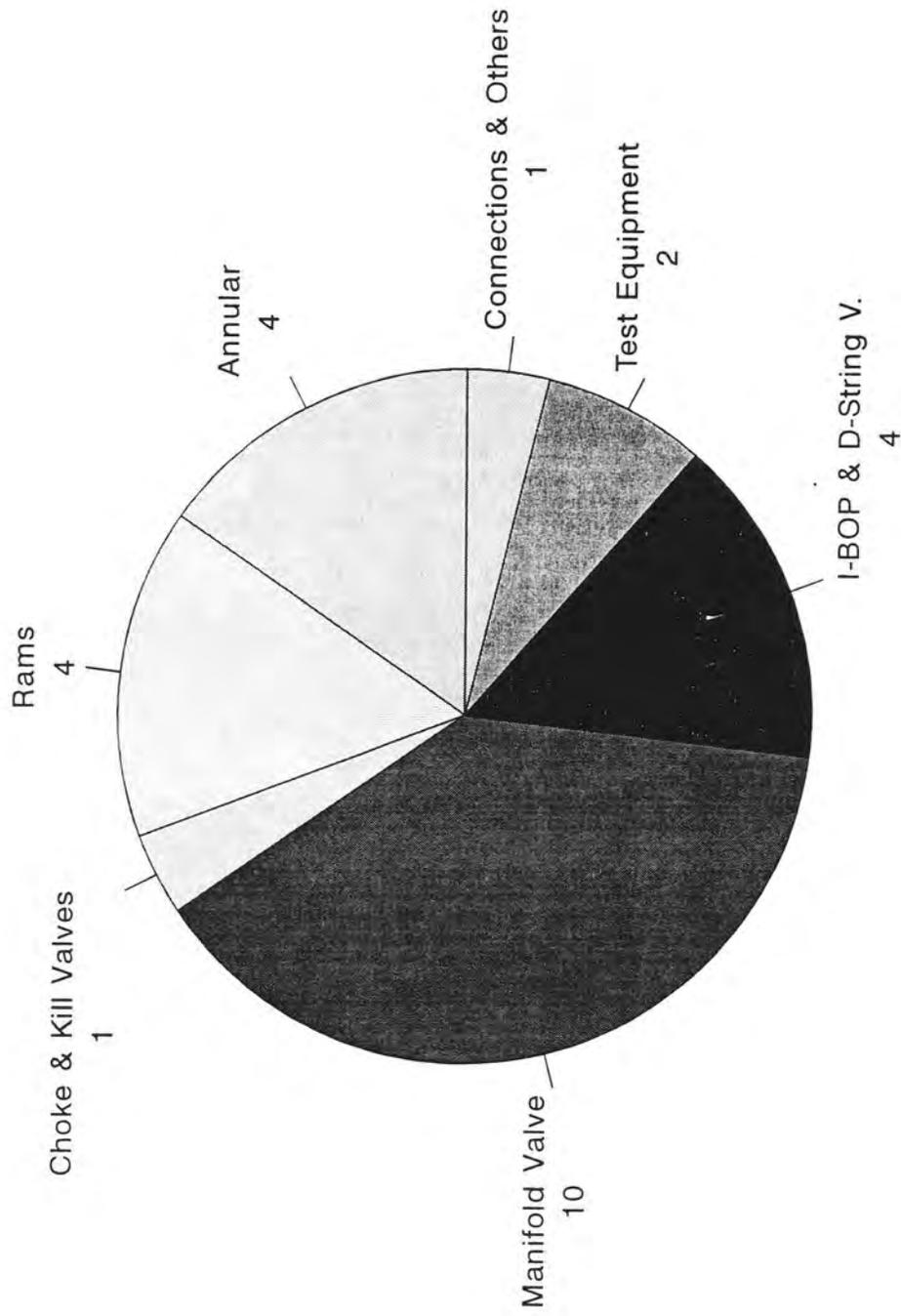


FIGURE 8-2

BOP COMPONENT FAILURE IN INITIAL TESTS

(IN PERCENTAGE)

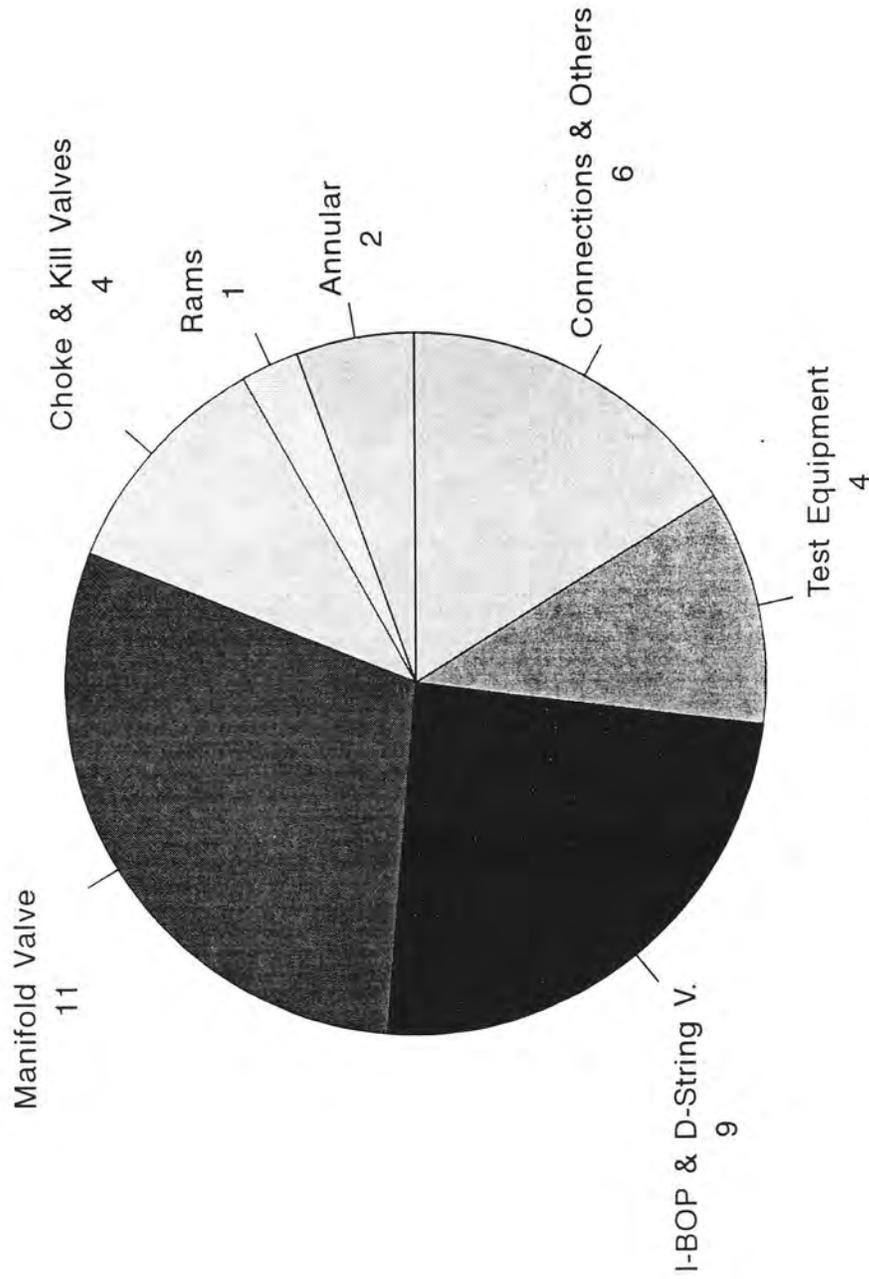


FIGURE 8-3

TOTAL BOP COMPONENT FAILURE (IN PERCENTAGE)

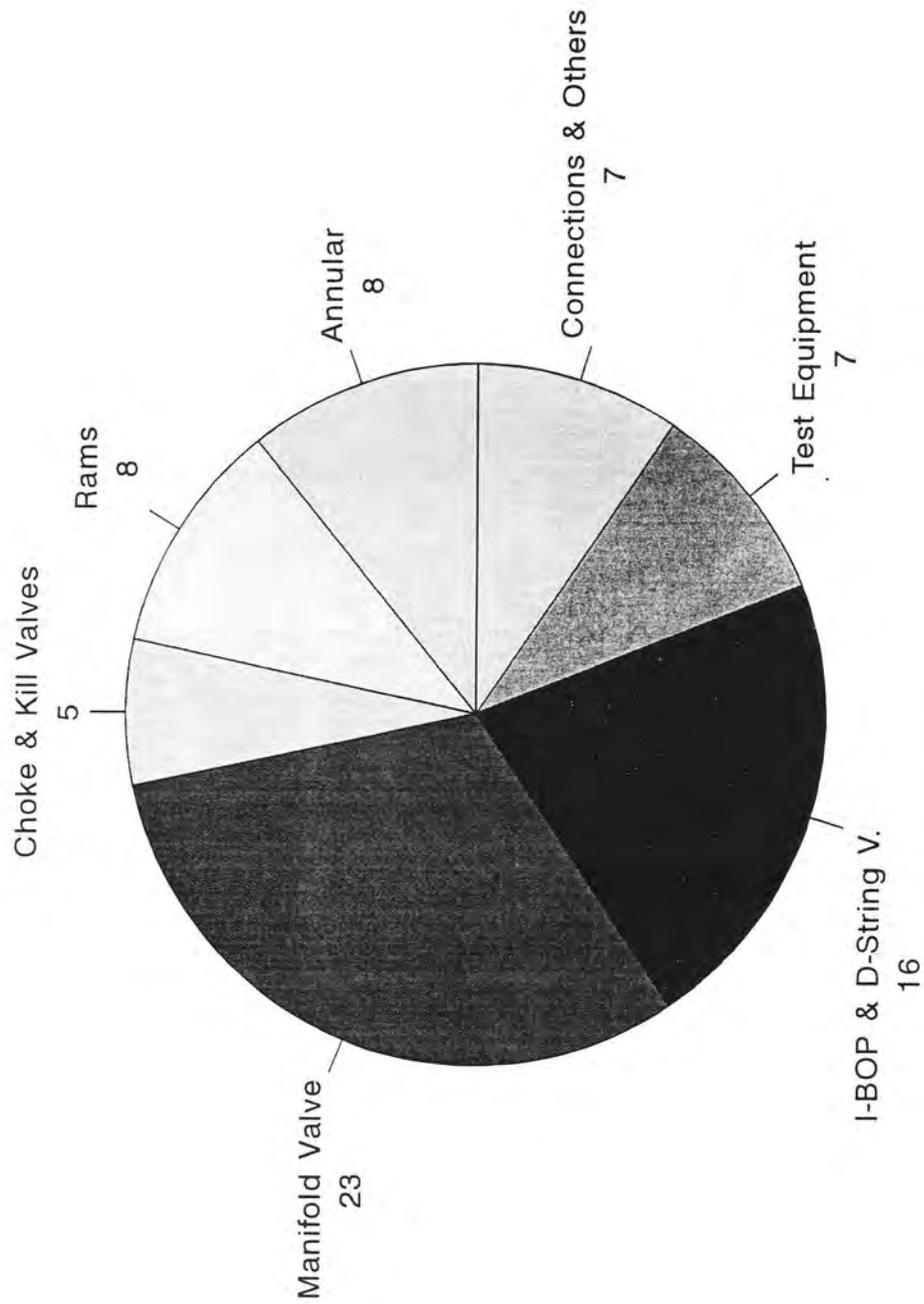


FIGURE 8-4

TABLE 8.5.1 Hypotheses Test Results for Component Failures

Test #	Hypothesis	p1	p2	Test Statistic	Z _{0.005}	Comments
1.	Proportion of failures in "Annular" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	.05	.056	-.14	2.575	Based on data, we cannot say that it is different.
2.	Proportion of failures in "Pipe Ram" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	.025	.056	-.84	2.575	Based on data, we cannot say that it is different.
3.	Proportion of failures in "Blind Ram" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	.025	.014	.39	2.575	Based on data, we cannot say that it is different.
4.	Proportion of failures in "Kill Manual Valve" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	0.0	0.0	2.575	Based on data we cannot say that it is different
5.	Proportion of failures in "Kill Remote Valve" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	.014	-1.00	2.575	Based on data, we cannot say that it is different.
6.	Proportion of failures in "Manifold Manual Valve" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	.05	.127	-1.47	2.575	Based on data, we cannot say that it is different.
7.	Proportion of failures in "Manifold Remote Valve" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	.014	-1.00	2.575	Based on data, we cannot say that it is different.
8.	Proportion of failures in "Choke Manual Valve" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	0.0	0.0	2.575	Based on data we cannot say that it is different.
9.	Proportion of failures in "Choke Remote Valve" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	0.0	0.0	2.575	Based on data we cannot say that it is different.

10.	Proportion of failure in "Drill String Valve" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	.028	-1.43	2.575	Based on data, we cannot say that it is different.
11.	Proportion of failures in "Inside BOP" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	.075	.028	1.02	2.575	Based on data, we cannot say that it is different.
12.	Proportion of failures in "Connections" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	0.0	0.0	2.575	Based on data we cannot say that it is different.
13.	Proportion of failures in "Test Equipment" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	.025	.028	-.10	2.575	Based on data, we cannot say it is different.
14.	Proportion of failures in "Other Failed Parts" when tested between 0 to 7 days "p1" and between 8 to 14 days "p2" are equal.	0.0	0.14	-.51	2.575	Based on data, we cannot say that it is different.
15.	Proportion of failures in "Annular" when tested between 0-7 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	0.05	.056	-.08	2.575	Based on data, we cannot say that it is different.
16.	Proportion of failures in "Ram (pipe and blind ram combined)" when tested between 0-7 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	0.0	.11	-1.49	2.575	Based on data, we cannot say that it is different.
17.	Proportion of failures in "Manifold Valve (manual and remote combined)" when tested between 0-7 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	0.0	.11	-1.49	2.575	Based on data, we cannot say that it is different.
18.	Proportion of failures in "Inside BOP and Drill String Valve combined" when tested between 0-7 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	.05	.11	-.93	2.575	Based on data, we cannot say that it is different.
19.	Proportion of failures in "Annular" when tested between 8-14 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	.13	0	2.12	2.575	Based on data, we cannot say that it is different.

20.	Proportion of failures in "Ram (pipe and blind ram combined)" when tested between 8-14 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	.13	.026	1.56	2.575	Based on data, we cannot say that it is different.
21.	Proportion of failures in "Manifold Valve (manual and remote combined)" when tested between 8-14 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	.20	.11	1.01	2.575	Based on data, we cannot say that it is different.
22.	Proportion of failures in "Inside BOP and Drill String Valve combined" when tested between 8-14 days for surface BOPs "P ₁ " and subsea BOPs "P ₂ " are equal.	0.13	0.0	2.15	2.575	Based on data, we cannot say it is different.

9.0 CONCLUSIONS

Following conclusions can be drawn from this BOP reliability study:

1. No statistically significant difference exists in failure rates for all BOPs (surface and subsea included) tested between 0 to 7 days interval and between 8 to 14 days interval.
2. Component failures are not affected by the BOP test interval in general.
3. There is not a significant correlation between failure rate and BOP test interval.
4. Subsea BOPs have smaller failure rate than surface BOPs.

10.0 FUTURE STUDY

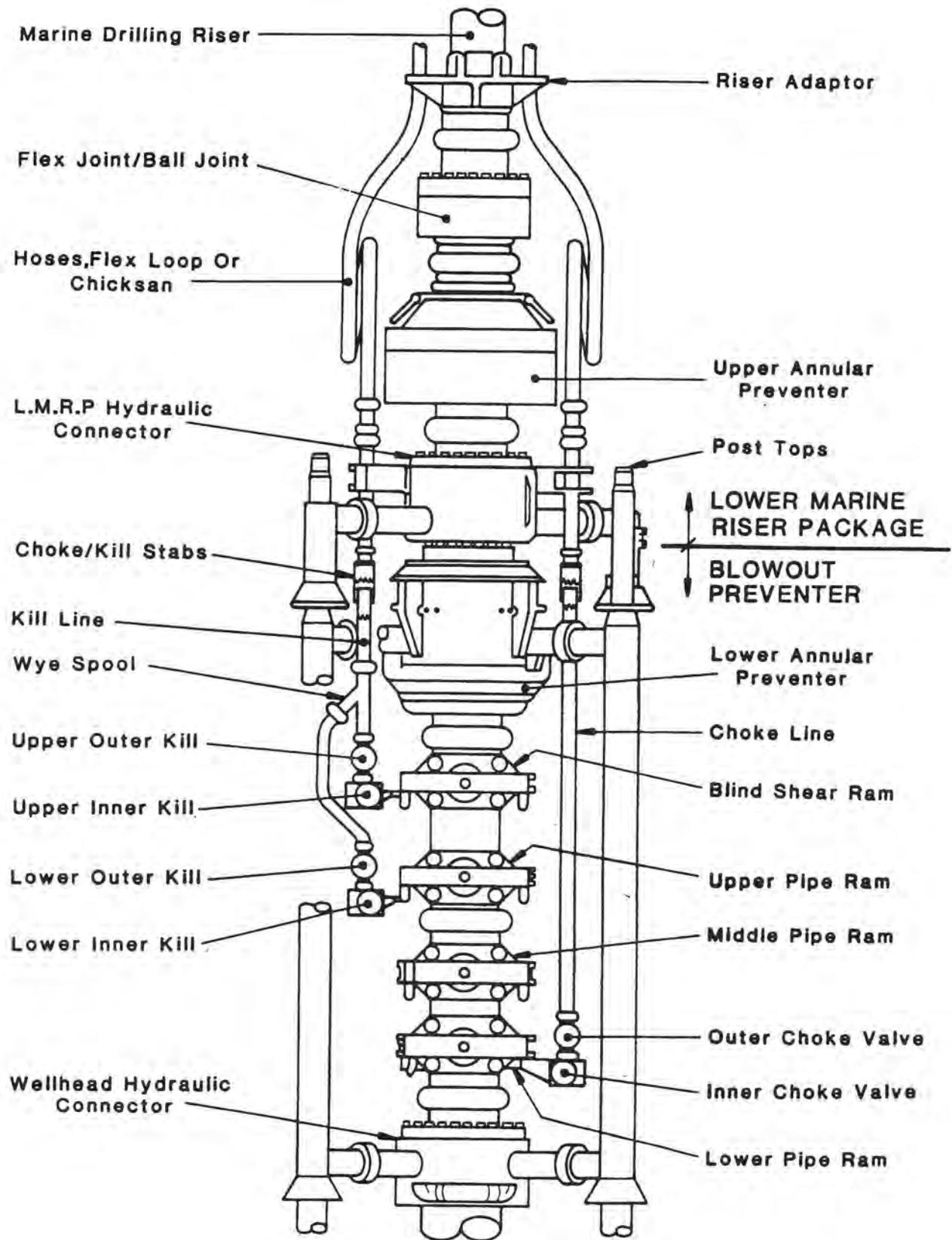
Enough data has been collected to conduct future study in BOP reliability. This study could include:

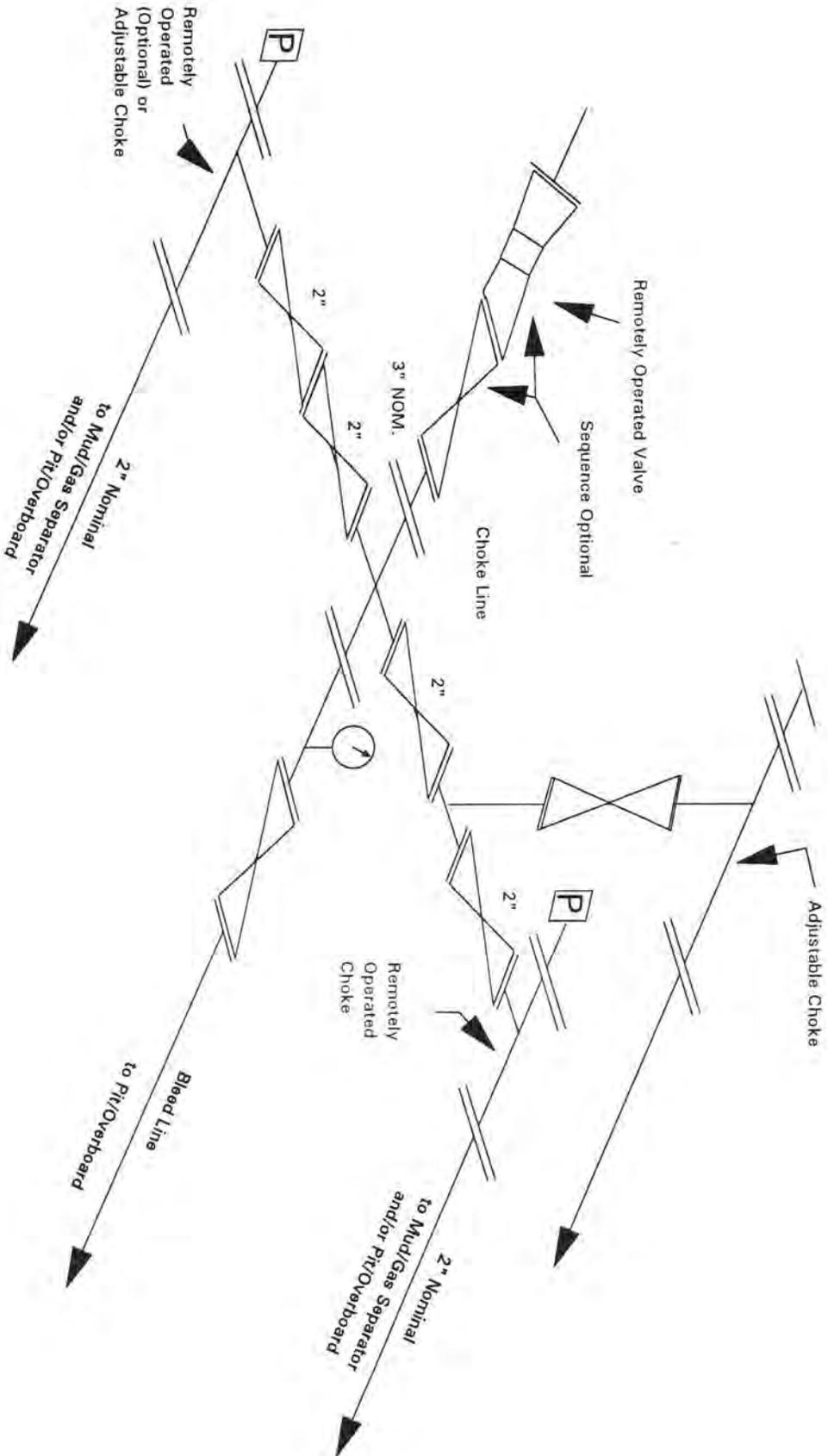
- Analysis of type of fluid used for BOP testing and its correlation with failure.
- Regression analyses of component failure to determine which components have a greater impact on BOP failure.

APPENDIX A

TYPICAL BOP SYSTEMS

Subsea BOP Stack





**EXAMPLE CHOKE MANIFOLD ASSEMBLY FOR 10M AND 15M
RATED WORKING PRESSURE SERVICE - SURFACE INSTALLATION**

(Isometric Illustration - not to scale)

APPENDIX B

BOP and Choke Manifold Test Report Form

FAILURE REPORT

Operator: _____; Lease/Well: _____; Date: _____; Driller's Point of Contact: _____; Phi: _____
Contractor: _____; Rig Name: _____; Surface BOP: YES / NO; Subsea BOP: YES / NO

• Test No. _____
• Description (include manufacturer, model, pressure rating and size): _____

• Describe part which failed (include manufacturer and type): _____

• Did failed component have back-up? YES / NO; Explain: _____

• Cause of failure: _____

• Is the failed component rental equipment? YES / NO
• Action taken to correct failure, achieving successful test: _____

• Prevention measures recommended to mitigate recurrence: _____

• Test No. _____
• Description (include manufacturer, model, pressure rating and size): _____

• Describe part which failed (include manufacturer and type): _____

• Did failed component have back-up? YES / NO; Explain: _____

• Cause of failure: _____

• Is the failed component rental equipment? YES / NO
• Action taken to correct failure, achieving successful test: _____

• Prevention measures recommended to mitigate recurrence: _____

