NSW GOVERNMENT | Trade & Investment Mine Safety

Mechanical Engineering Update

In-service failures of explosion protected diesel engine systems during 2012

Background

NSW Mine Safety engaged a safety engineering consultant to review in-service failures of explosion protected diesel engine systems (ExDES) reported under clause 56(1)(m) of the *Coal Mine Health and Safety Regulation 2006* during 2012.

This report follows Safety Bulletin SB12-01 *In-service failures of explosion protected diesel engine systems during 2010 and 2011* and utilised the data collected through the gazetted ExDES ancillary forms. A copy of the consultant's report Explosion protected diesel engine systems (ExDES) Failures Analysis Report (by Shakti Corp Pty Ltd) is attached to the electronic version of this update.

Outcomes

There continues to be an improvement in the failure rate per 100 registered ExDEs over the past 12 months. The reported failure rate has reduced to less than 20% (per 100 registered ExDESs) over the past three years. While this reduction is encouraging, further improvements are still required.

Key aspects of the report include:

- Pneumatic/hydraulic control system failure accounted for 43% of all failures. Shutdown cylinder failure accounted for 50% of failures, circuit contamination was a significant factor. There were no reported electrical control system failures. Some Original Equipment Manufacturers (OEMs) reported no failures of their pneumatic/hydraulic control systems.
- Exhaust flame trap issues accounted for 32% of all failures. Of that, carbon build-up was a significant factor.
- Issue with bolts, nuts, studs, gaskets on fixed joints and excessive gaps on open joints were also key factors.
- Failures were equally proportioned between mine-owned machines and contractor/hirer-owned machines
- Both maintenance and design improvement recommendations were equally reported in the ancillary forms.
- Some engine types performed better than others. Each original equipment manufacturer will be provided with their own data.
- Almost all failures were due to systematic issues as opposed to random hardware failures.

Recommendations

1. The recommendations in SB12-01 *In-service failures of explosion protected diesel engine systems during 2010 and 2011*still apply and should be considered by all designers and people with management or control of ExDES.
2. A stronger emphasis on the functional safety aspect of control system is required by designers and maintenance personel.

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3. For new ExDESs, designers should consider self monitoring control systems with inbuilt diagnostics.
4. Joints, fasteners, supporting brackets and fittings should be engineered to good engineering practice. Flexible joints may need to be considered in some applications.
5. Maintenance people should proof test all safety functions periodically and ensure adequate regular cleaning of wet exhaust conditioners (daily).
6. Designs should include complete code D information including assembly and alignment of all joints.
7. With the high failure rate of shutdown cylinders, the integrity and reliability of emergency shutdown systems to perform the shutdown function is paramount.
8. Automatic methane detectors should be installed and used on ExDES so engines shut down in a timely manner.

Strategies

There remains a need to continue to improve the reliability of the explosion protection characteristics of ExDESs. Any Ex failure of an ExDES is unacceptable. All safety functions and joints associated with ExDES need to have a very low probability of failure on demand.

To provide more information on this analysis and to outline proposed design changes to new ExDES a consultative meeting with interested stakeholders will be held in the Maitland region on the 26 November 2013. If you are interested in being part of the consultative meeting please forward your expression of interest to Lyndon Hughes at lyndon.hughes@industry.nsw.gov.au before 5 November 2013.

Signed

Peter Sunol
Senior Inspector of Mechanical Engineering
Mine Safety Operations

NOTE: Please ensure all relevant mechanical people in your organisation receive a copy of this update and are informed of its content. This update should be processed in a systematic manner through the mine's (or other PCBU's) information and communication process.

Explosion protected diesel engine systems (ExDES) Failures Analysis Report

Produced on behalf of NSW Mine Safety

by Shakti Corp

October 2013

ACKNOWLEDGEMENTS

This survey was conducted by Shakti Corp on behalf of NSW Trade & Investment Mine Safety:

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1.0 INTRODUCTION

This report presents the findings from an analysis of the in-service failures of explosion protection characteristics of explosion-protected plant in NSW underground coal mines between January and December 2012.

The study was conducted for NSW Trade & Investment Mine Safety.

Coal Mine Health and Safety Act 2002 aims to secure the health, safety and welfare of people in connection with coal operations. *Coal Mine Health and Safety Regulation 2006* (CMH&SR) prescribes certain matters for the purposes of this Act.

Clause 56(1)(m) of the CMH&SR 2006 is reproduced below:

56 Notification of certain incidents at or in relation to coal operations:

section 110 (1) (c) of the Act

The following are declared to be incidents or matters that are required to be notified for the purposes of section 110 (1) (c) of the Act:

(m) the in-service failure of the explosion-protection characteristics of explosion-protected plant

This report is a sequel Safety Bulletin SB12-01, which presented an analysis of 56(1)(m) Failures from January 2010 to July 2011 and also introduced an ancillary report form for all ExDES reported 56(1)(m) failures. The main purpose of the ancillary report was to improve the quality of data gathered, a copy of which is attached in Annexure A of this report. In comparison with data collected prior to 2012, there has been a significant improvement in the quality, organisation and the extent of data received with the new ancillary reports.

This report analyses the first 181 failures being the first 12 months of data collected through the ancillary report between January and December 2012.

2.0 OVERVIEW

Figure 1 shows the reported failure rate per 100 DES systems per year from 2007 to 2012.

Figure 2 shows the number of reported failures from 2009 to 2012.

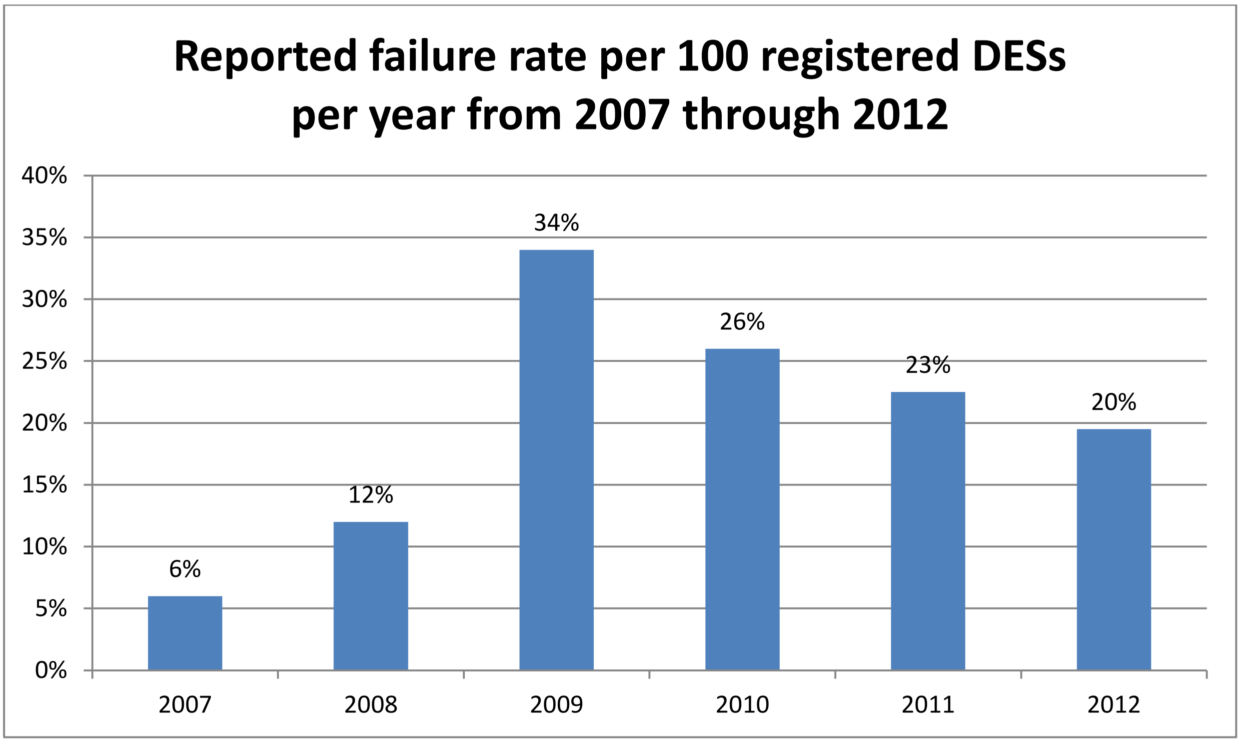


Figure 1

Figure 2

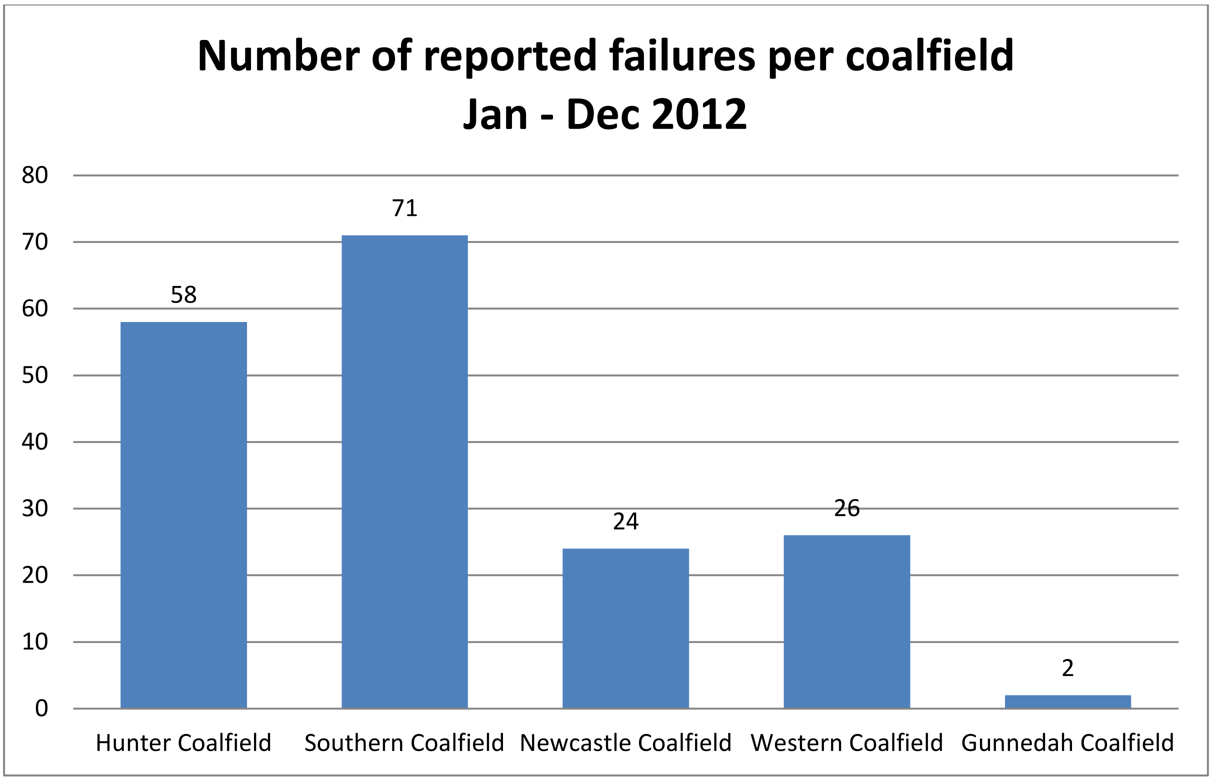


Figure 3

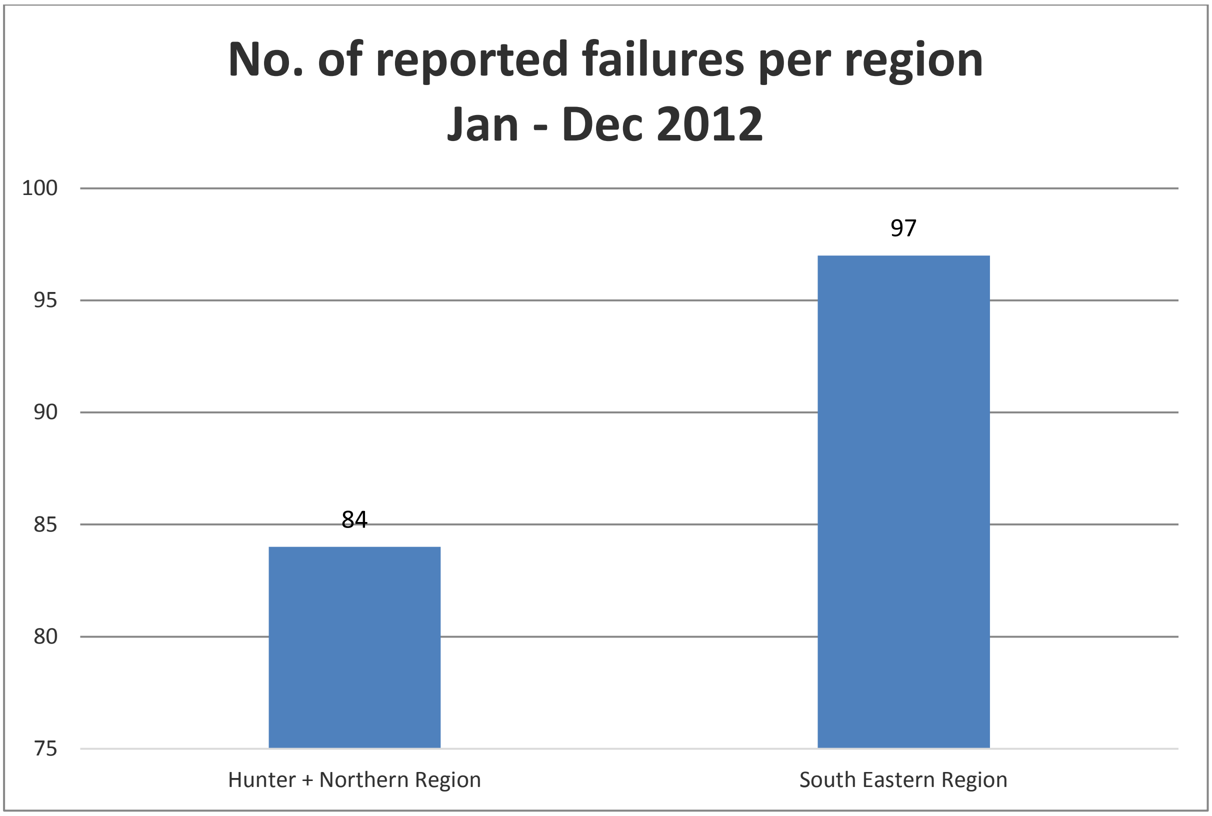


Figure 4

The number of reported failures for individual mines can be seen in Figure 5 below.

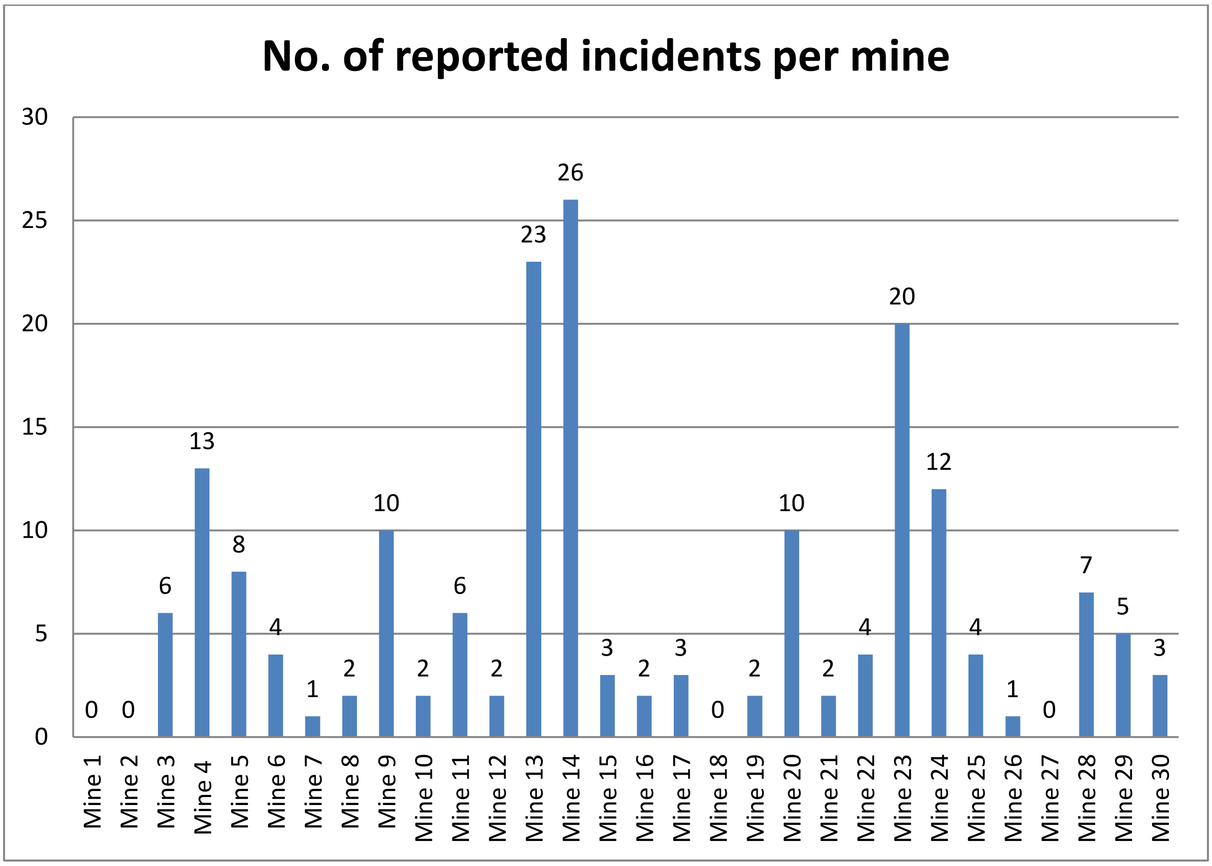


Figure 5

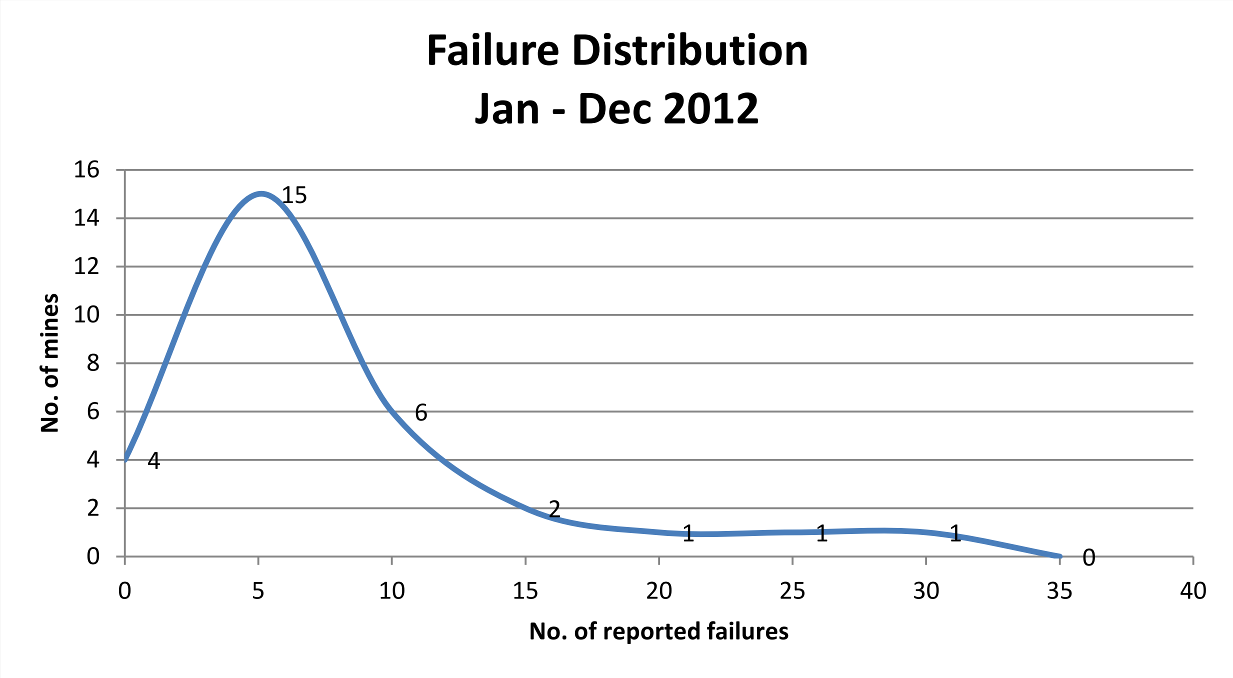


Figure 6

The Failure Distribution curve in Figure 6 is to be interpreted as follows:

• Number of Mines with 0 failures:	4
• Number of Mines with 1 to 5 failures	15
• Number of Mines with 6 to 10 failures	6
• Number of Mines with 11 to 15 failures	2
• Number of Mines with 16 to 20 failures	1
• Number of Mines with 21 to 25 failures	1
• Number of Mines with 26 to 30 failures	1

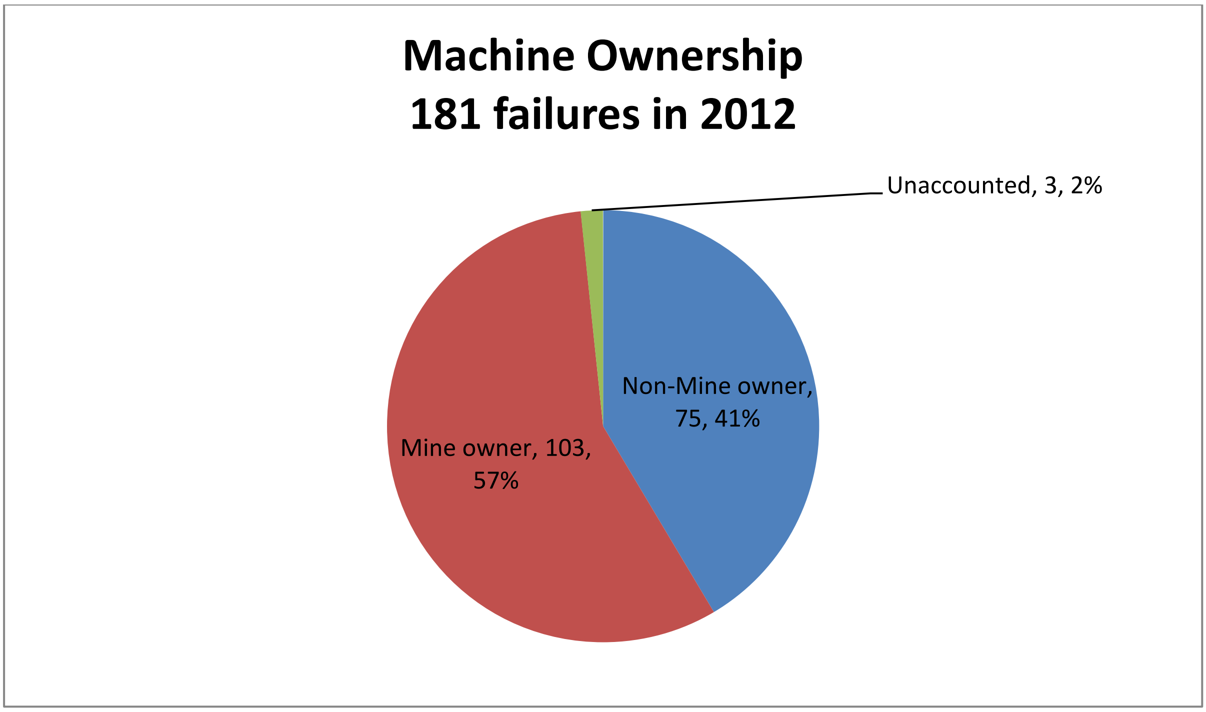


Figure 7

The pie chart in Figure 7 shows the contributions to the total failures from mine-owned and non-mine owned machines. The latter category predominantly comprises of machine hirers. The distribution initially suggests that mine owned machines have contributed more i.e., 57% as opposed to non-mine owned machine contribution of 41%. But, this also highlights the fact that there may be incidents that go unnoticed if they are detected once the machine is off the mine site.

3.0 THE STUDY

The findings of the study are presented in three parts:

Part I: Failure locations and modes

Analysis of the location and the components of the Diesel Engine Shutdown (DES) System that failed and their modes of failure.

Part II: Miners' recommendations for prevention

the ancillary report (Annexure A) prompts for design and/or maintenance/testing changes that would prevent / minimise failure. This part of the study compiles the changes proposed by the end users (miners) and presents them for each subsystem.

Part III: OEM statistics

This part of the study presents an analysis of non-specific OEM failures against their inventory levels.

OEM-specific failure analysis will be provided to each OEM separate from this report as addenda.

The following sections present in detail the three parts of the study.

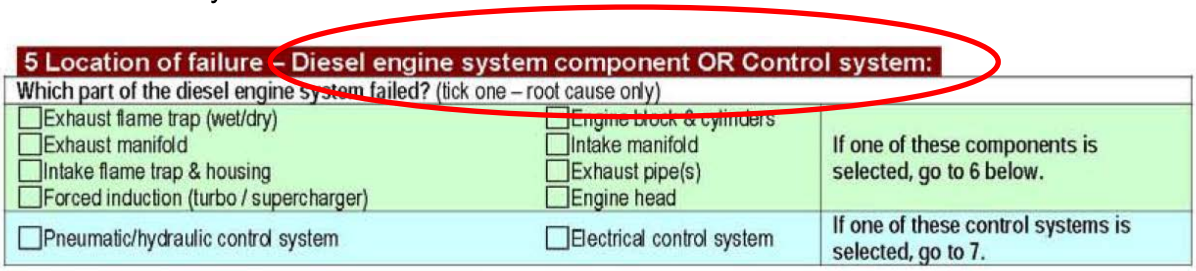
4.0 FAILURE LOCATIONS AND MODES

This section analyses the location and the components of the DES system that failed and their modes of failure.

4.1 FAILURE LOCATIONS

The ancillary report (refer Annexure A) broadly classifies "Location of failure" into two categories:

- Diesel engine system component
- Control system



5 Location of failure – Diesel engine system component OR Control system:		
Which part of the diesel engine system failed? (tick one – root cause only)		
☐Exhaust flame trap (wet/dry) ☐Exhaust manifold ☐Intake flame trap & housing ☐Forced induction (turbo / supercharger)	☐Engine block & cylinders ☐Intake manifold ☐Exhaust pipe(s) ☐Engine head	If one of these components is selected, go to 6 below.
☐Pneumatic/hydraulic control system	☐Electrical control system	If one of these control systems is selected, go to 7.

Figure 8
Excerpt from ancillary report

Out of the total of 181 failures reported in 2012, Figure 8 shows the failure proportioning into these two categories:

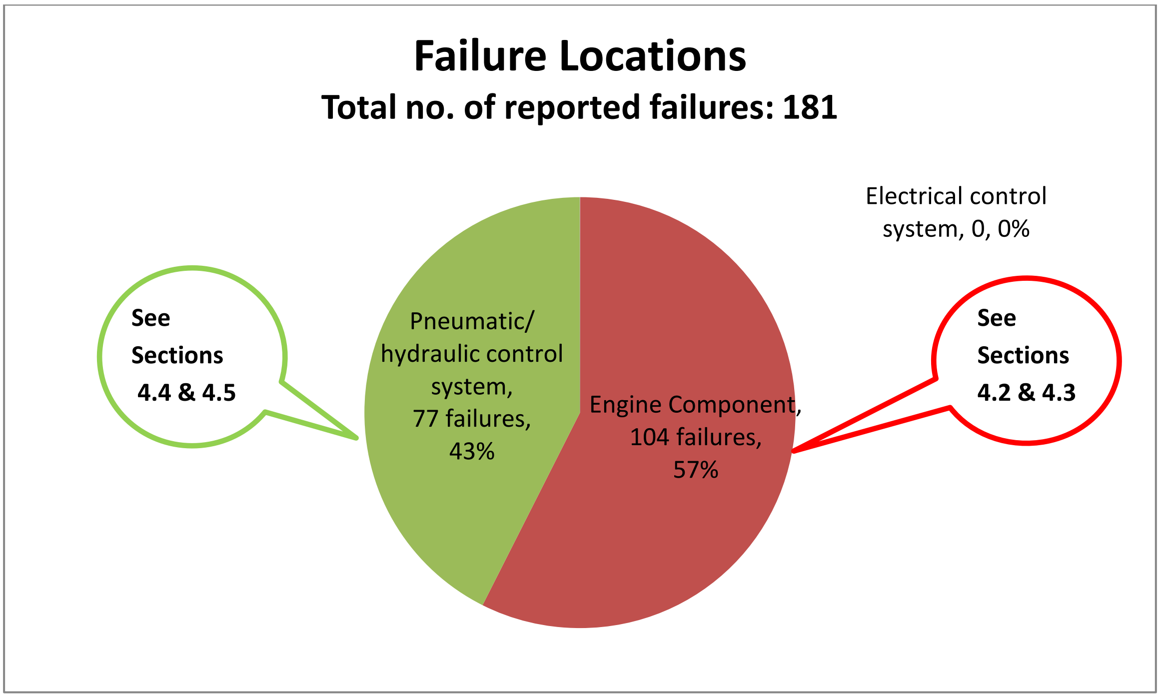


Figure 9

A breakdown of the components that failed within the two major categories is shown in the next pages.

The ancillary reports attributed the total of 181 failures to major engine or control system components as per Table 1 below:

Failure Location		Failures	% Contribution to 2012 failures
Pneumatic/hydraulic control system		77	43%
Exhaust flame trap (wet/dry)		58	32%
Exhaust pipe(s)		12	7%
Intake flame trap & housing		11	6%
Intake manifold	**Engine**	9	5%
Exhaust manifold	**Components**	7	4%
Forced induction (turbo / supercharger)		3	2%
Engine head		3	2%
Engine block & cylinders		1	1%
Electrical control system		0	0%
Total Reported Failures - 2012		**181**	**100%**

Table 1
Contributors to component failure

4.2 FAILURES OF ENGINE COMPONENTS - BREAKDOWN

In Table 1, engine components constitute 104 out of the 181 failures and are shown on a pie chart in Figure 9.

This section analyses the failure modes of the major contributors to engine component failures, as shown in Figure 9 and reproduced in Table 2.

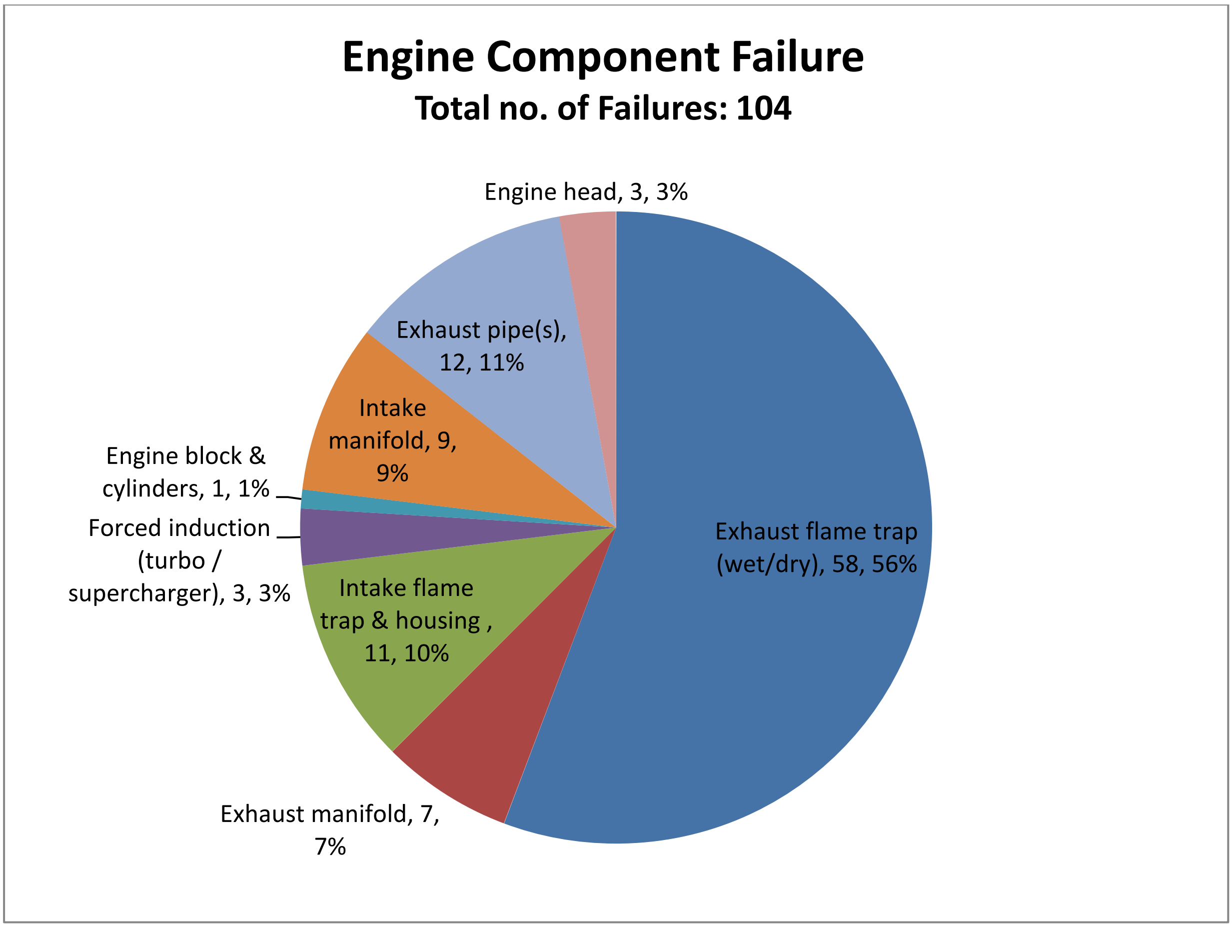


Figure 10

Major contributors to Engine Component Failure	Failures	% Contribution to 2012 failures
Exhaust flame trap (wet/dry)	58	32%
Exhaust pipe(s)	12	7%
Intake flame trap & housing	11	6%
Intake manifold	8	5%
Exhaust manifold	7	4%

Table 2
Major contributors to engine component failure

Consolidation

The following pages present pie charts on failure location and mode proportions for each of the major contributors in Table 2:

- As per ancillary reports
- Consolidated (refer Annexure B) after:
  - Cognisance of causal factors
  - Grouping of locations/modes

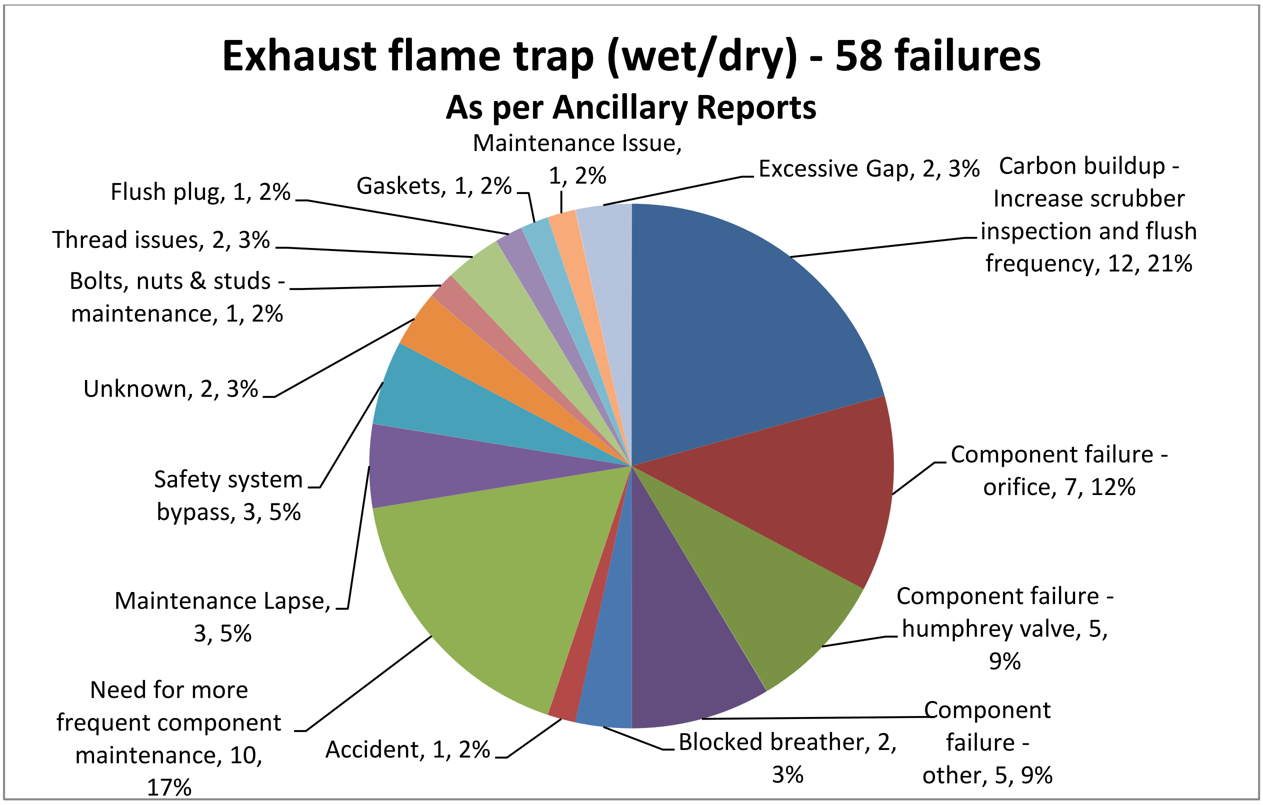


Figure 11

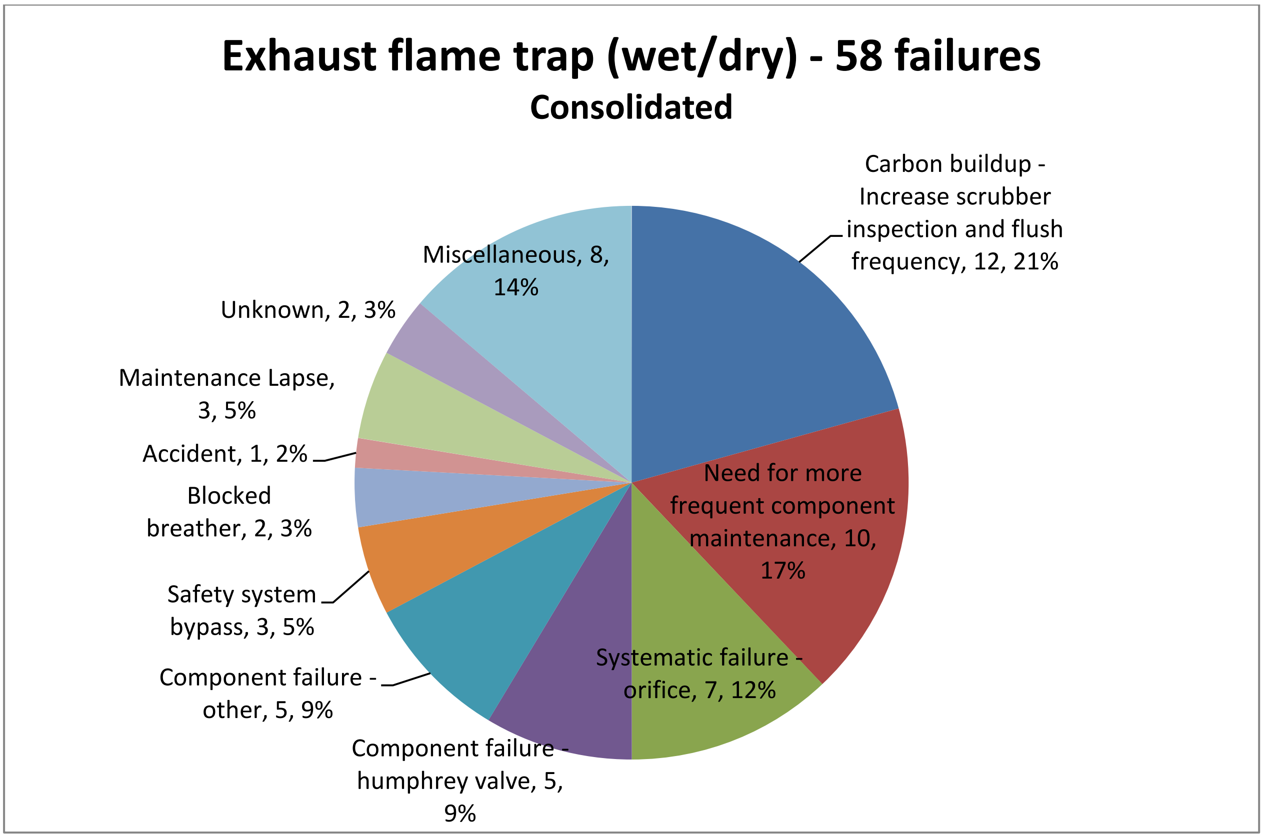


Figure 12

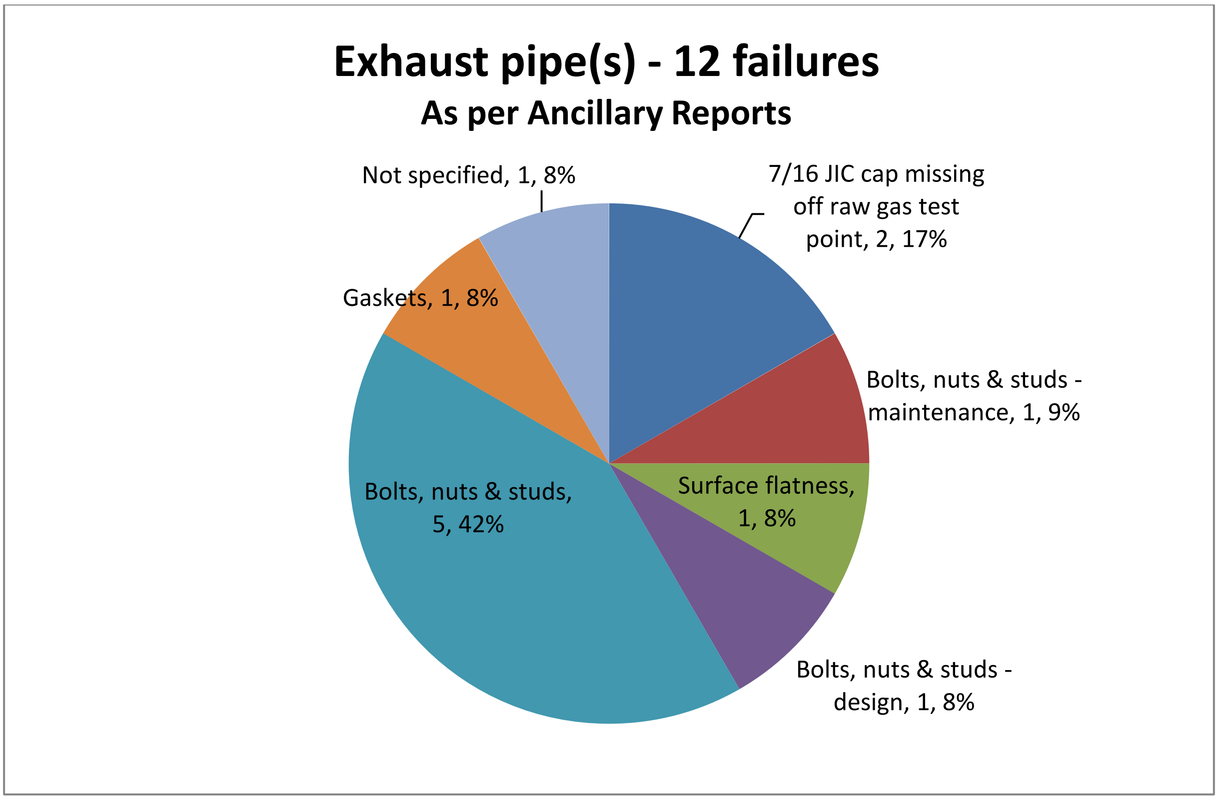


Figure 13

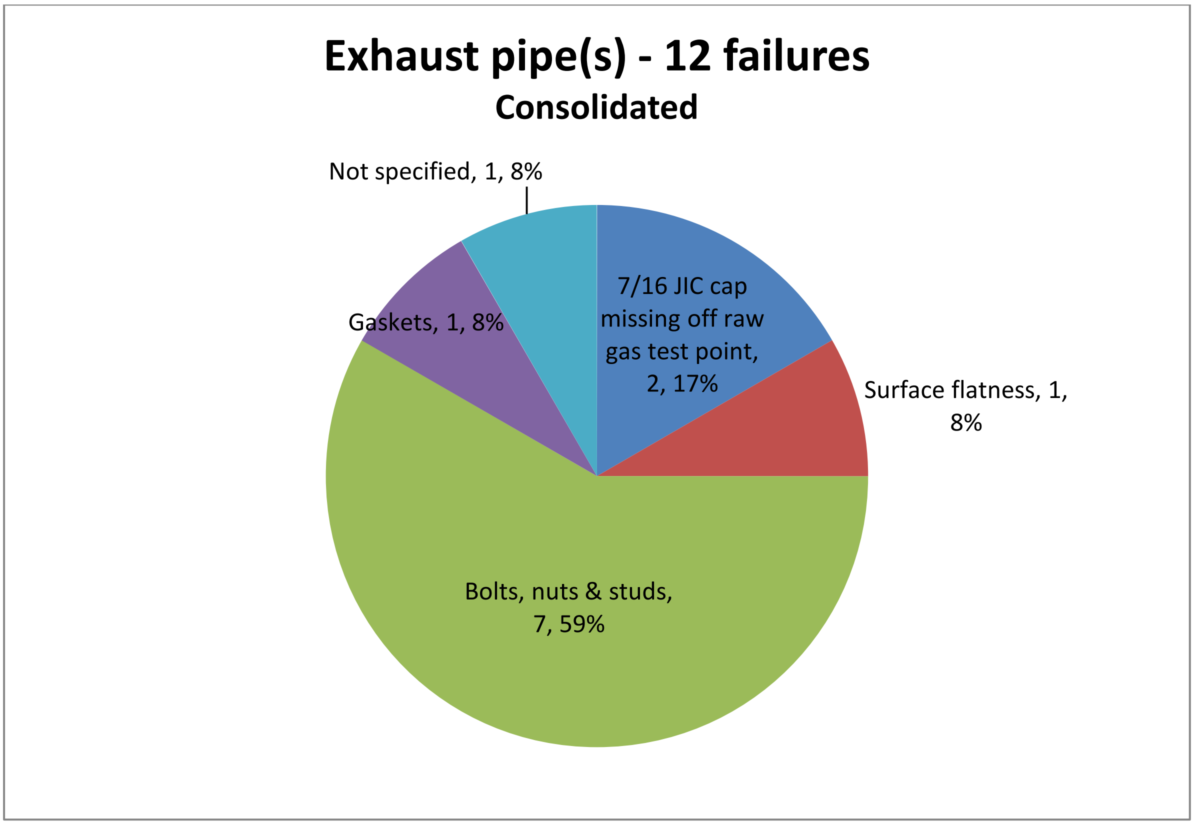


Figure 14

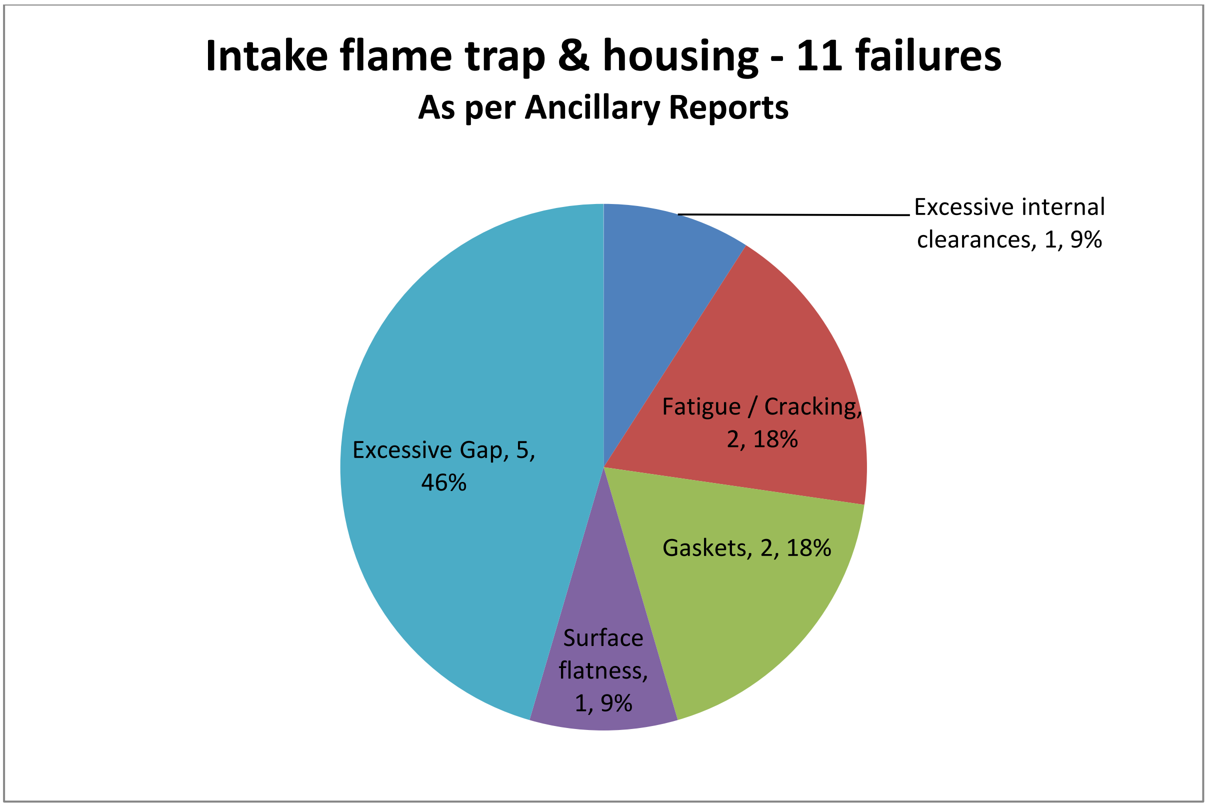


Figure 15

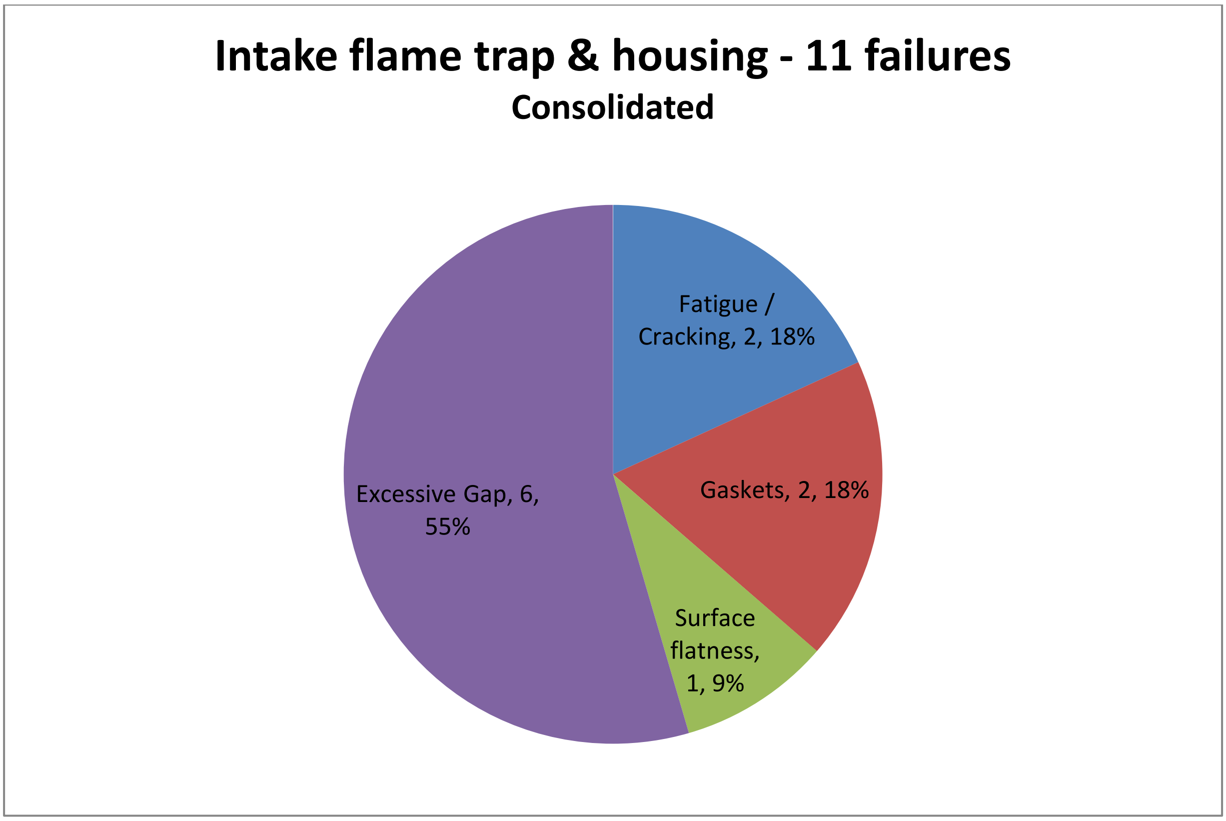


Figure 16

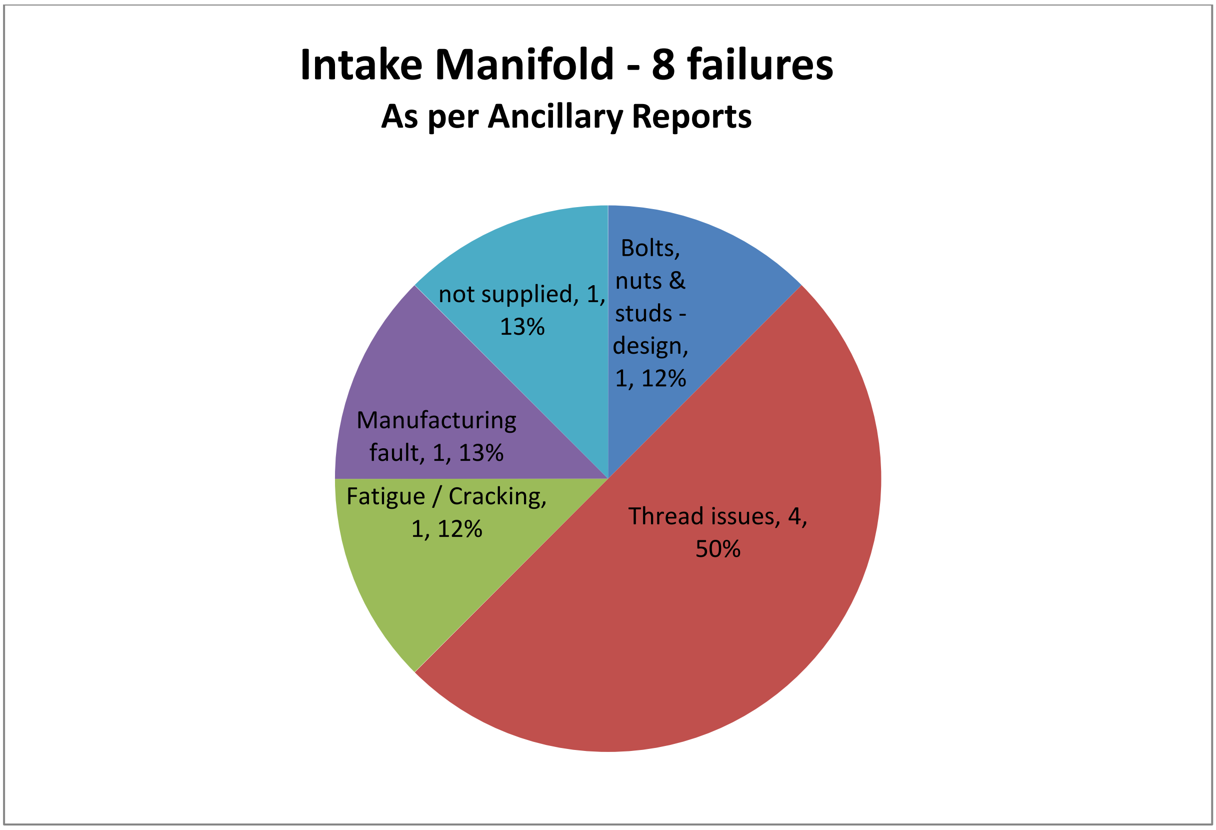


Figure 17

Consolidation deemed unnecessary

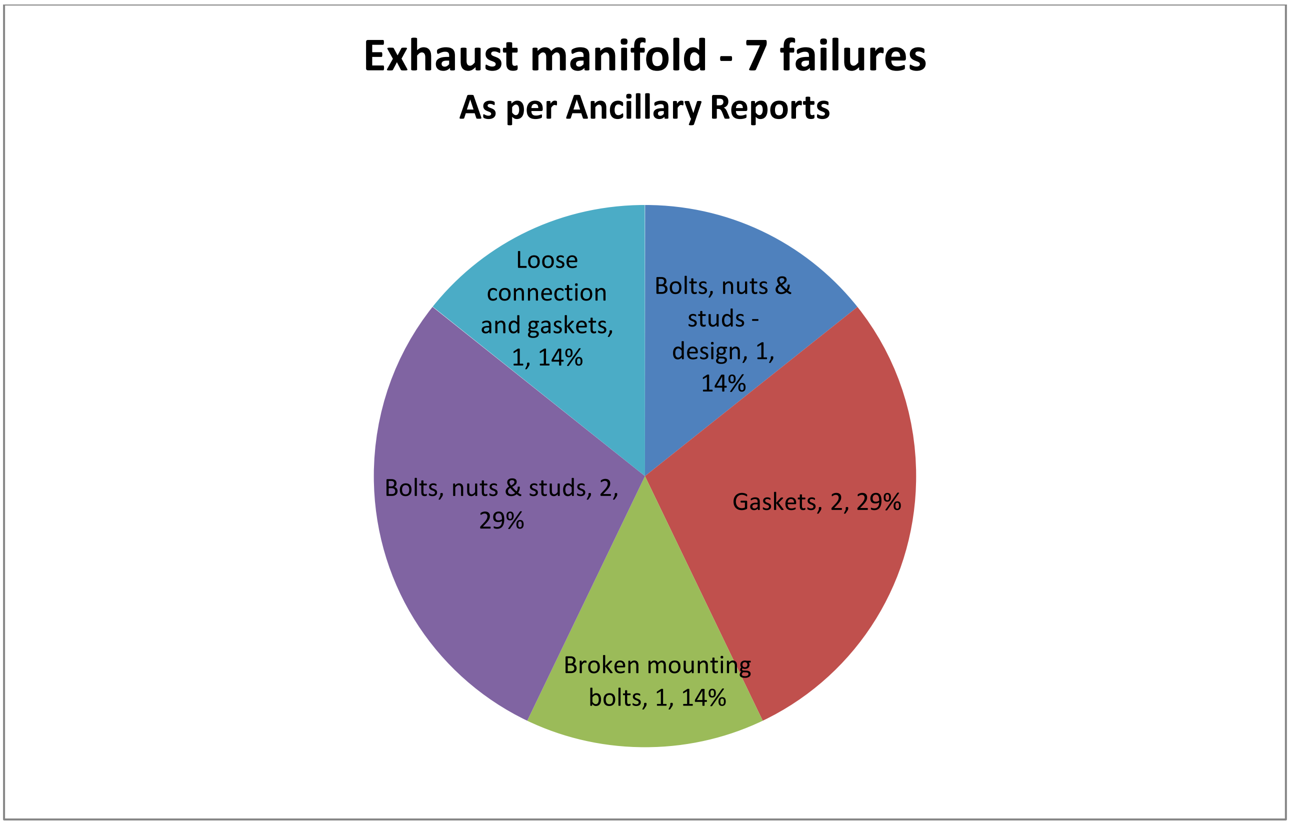


Figure 18

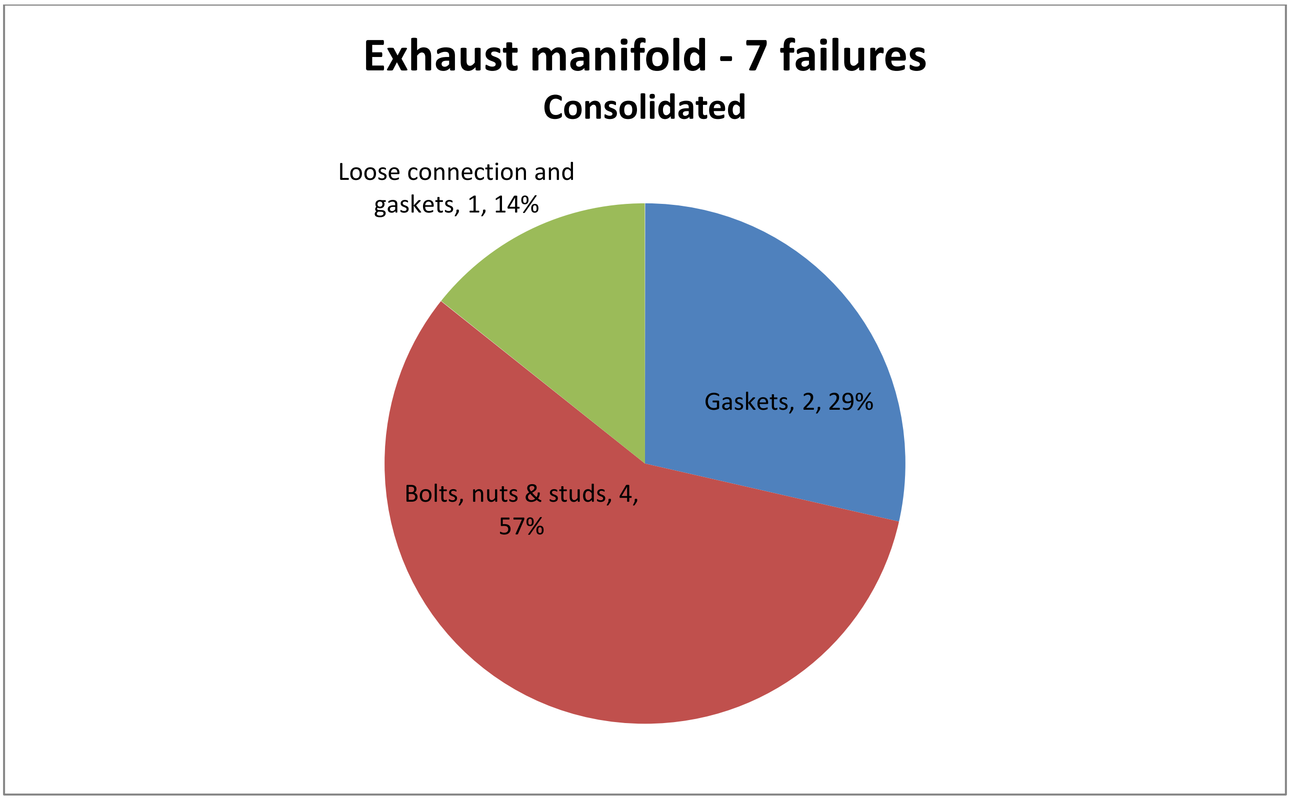


Figure 19

4.3 Failure modes of engine components - breakdown

For the failure of an engine component, the ancillary report prompts for a selection of failure modes as shown below. The failure mode distributions for each of the components listed in Figure 19 below are shown in the next pages.

6 Failure Mode of Engine Component

Which major component failed? Tick one from this column:	**How did the major component fail?** Tick one only (initial cause) from the same row:	
☐ Wet flame trap (conditioner):	☐ Exhaust carbon holding up floats ☐ Float failure issues ☐ Structural failures	☐ Water below LWCO² when engine stops ☐ Blocked breather ☐ Excessive backpressure ☐ Other
☐ Fixed connection (issues):	☐ Bolts, nuts & studs ☐ Gaskets ☐ Thread issues	☐ Surface flatness ☐ Damage ☐ Other
☐ Open joints (issues):	☐ Surface flatness / finish ☐ Excessive gap ☐ Thread issues	☐ Bolts, nuts & studs ☐ Damage ☐ Other
☐ Positive flame trap element:	☐ Damage ☐ Excessive internal clearances	☐ Other
☐ Structural failures:	☐ Fatigue / Cracking ☐ Corrosion ☐ Physical contact damage	☐ Catastrophic failure ☐ Turbo seal failure ☐ Other
☐ Excessive surface temperature:	☐ Cooling system failure	☐ Other
☐ Other (please specify the component and how it failed)		

Figure 20
Excerpt from ancillary report

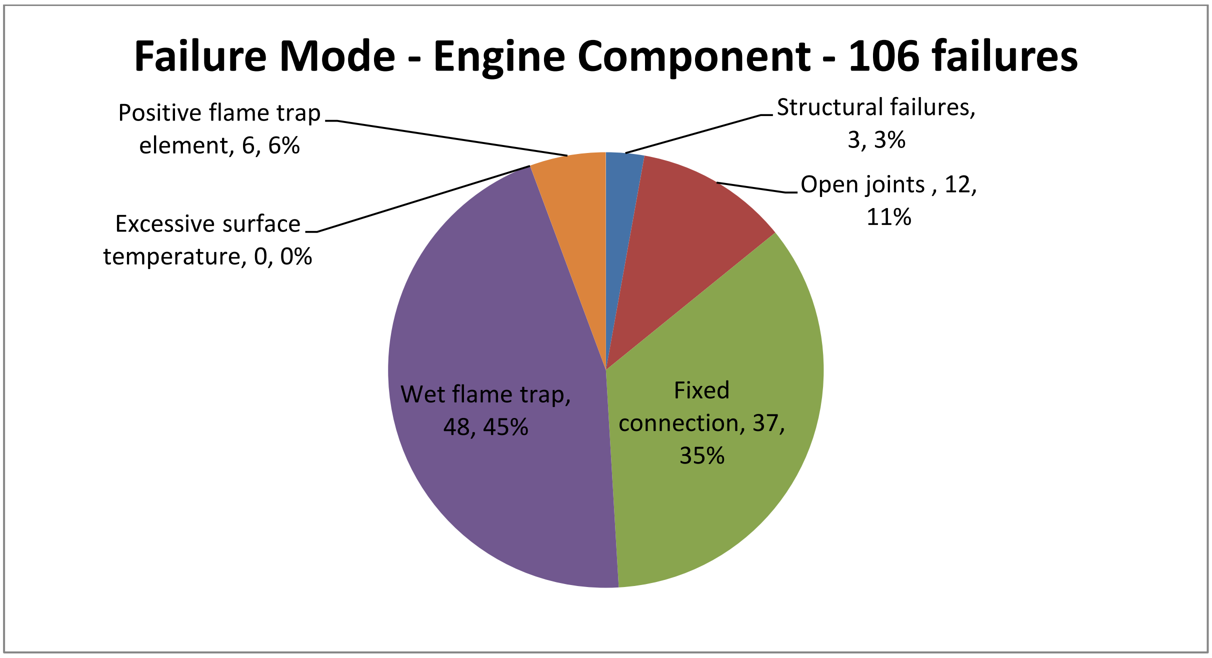


Figure 21

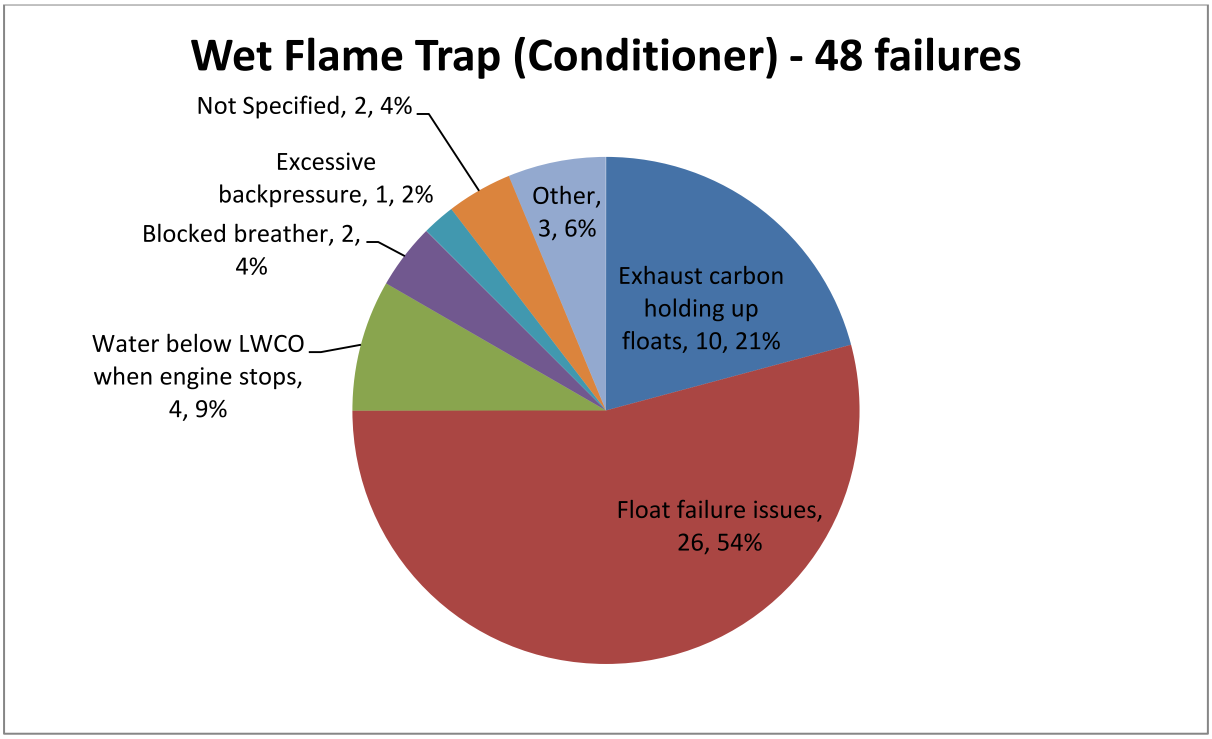


Figure 22

Of the 10 failures due to exhaust carbon holding up floats reported in Figure 21 above:

- 9 out of 10 reports recommended more frequent cleaning of scrubber with detergent / special scrubber cleaner
- 3 out of 10 reports recommended change in technology where particulate filter was not required/float system more tolerant to carbon
- 1 out of 10 reports pointed out that the new baffle in scrubber captured more contaminants exacerbating the issue.

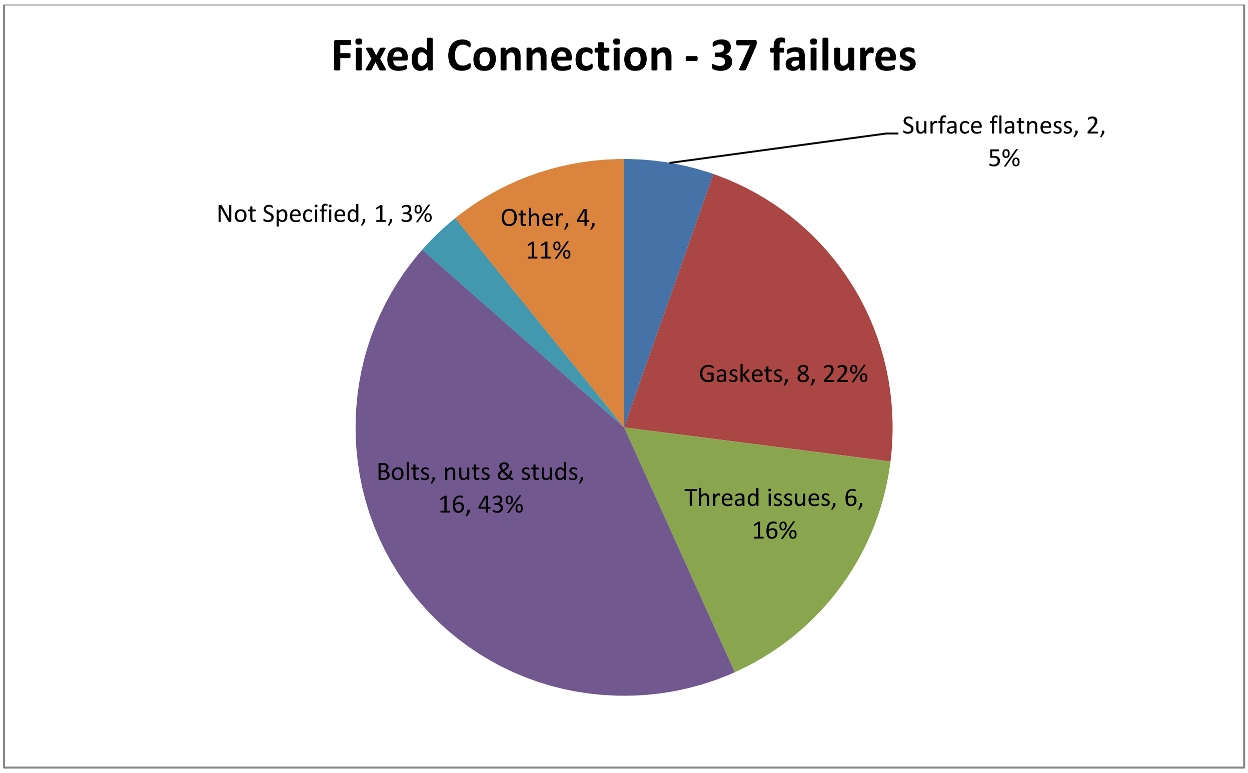


Figure 23

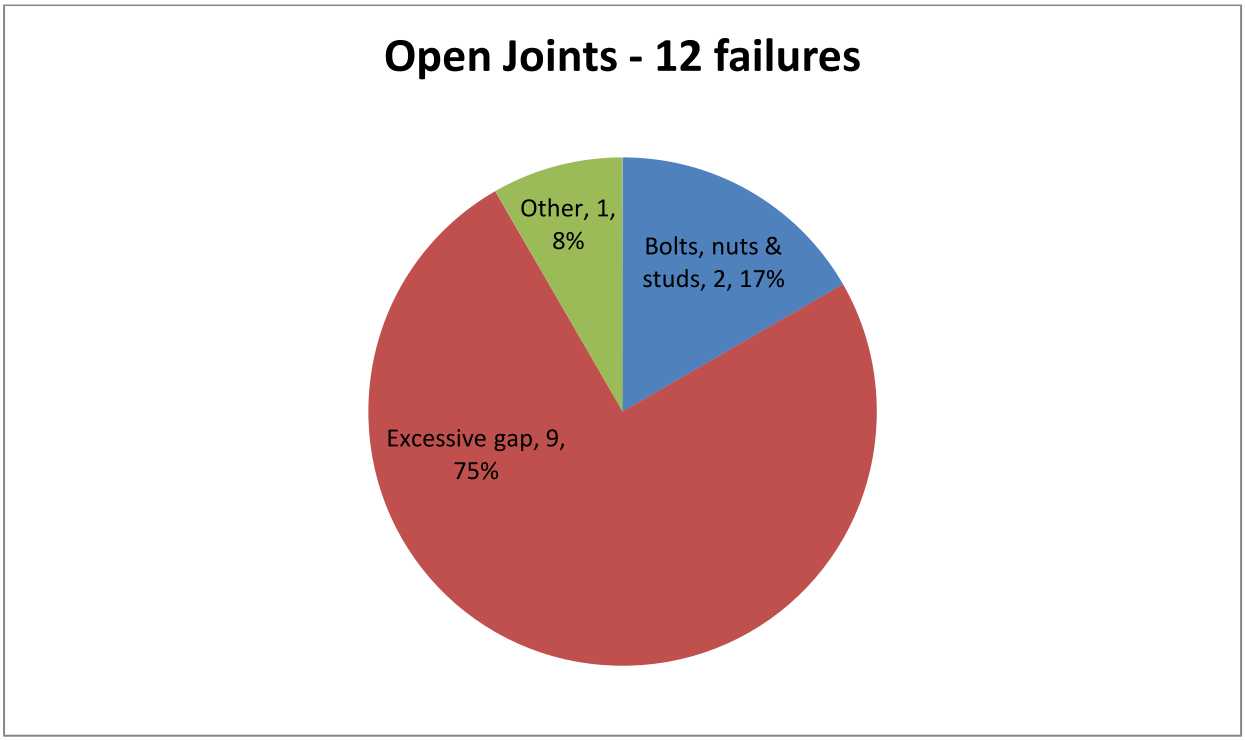


Figure 24

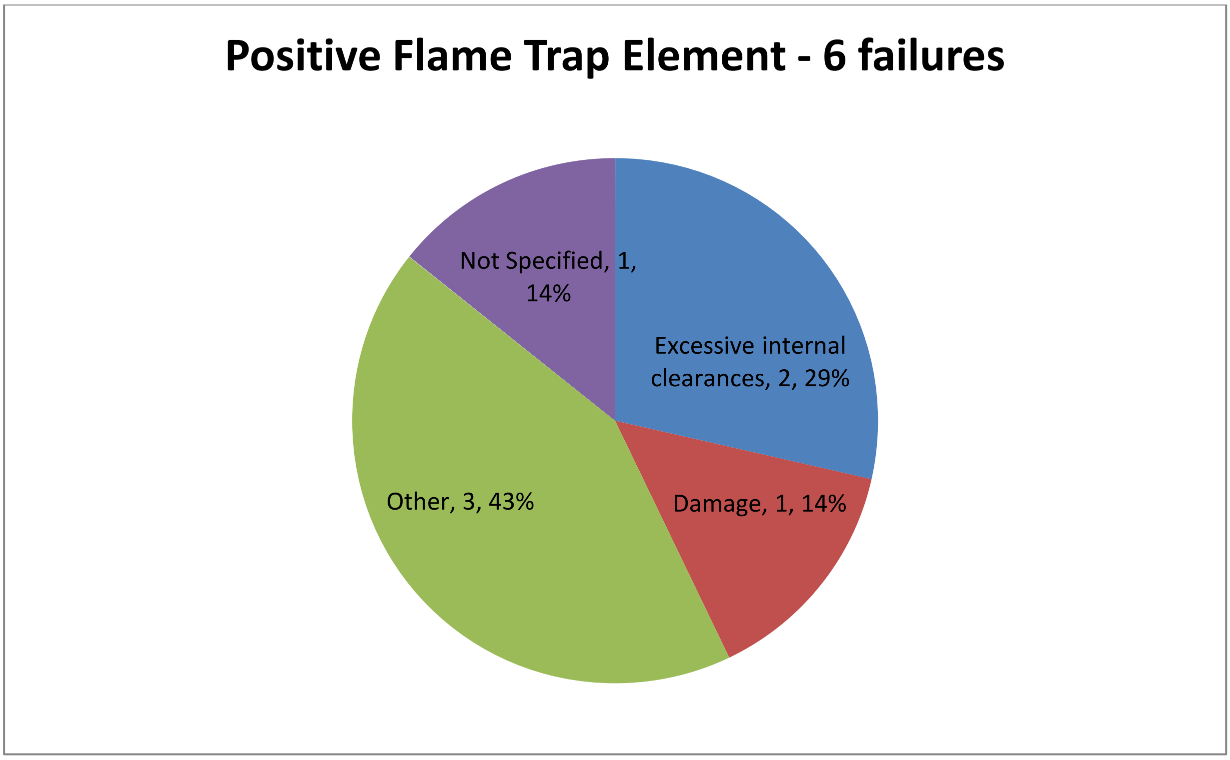


Figure 25

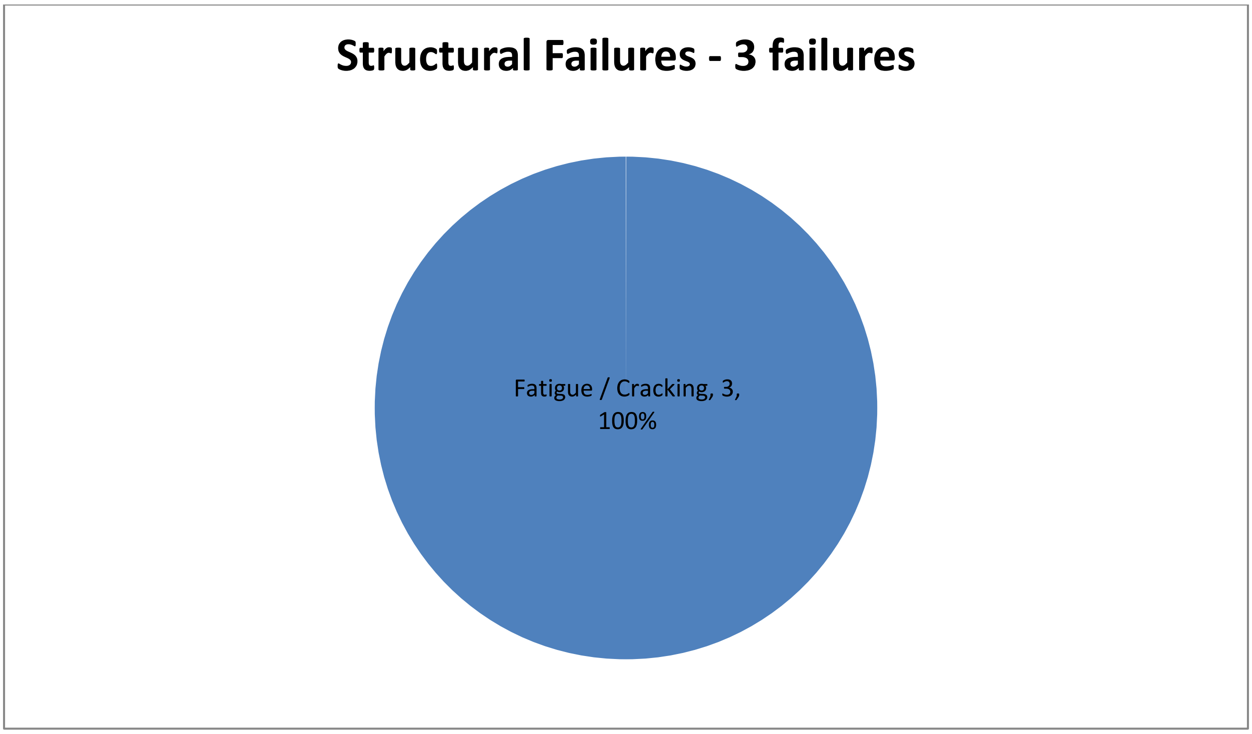


Figure 26

4.4 FAILURES OF PNEUMATIC/HYDRAULIC CONTROL SYSTEM – BREAKDOWN

A breakdown of the 77 pneumatic / hydraulic control system components out of a total of 181 failures from Table 1 is shown in Table 3 and Figure 26 below:

Pneumatic / Hydraulic Control System Component	Failures	% Contribution to 2012 failures
Shutdown cylinders or solenoid	39	22%
Other circuit control valve failure	15	8%
Cooling system sensors	7	4%
Water level sensors	6	3%
Other	5	3%
Engine oil pressure sensors	2	1%
All or multiple sensor failure	2	1%
Exhaust temperature sensors	1	1%
Total	**77**	**43%**

Table 3

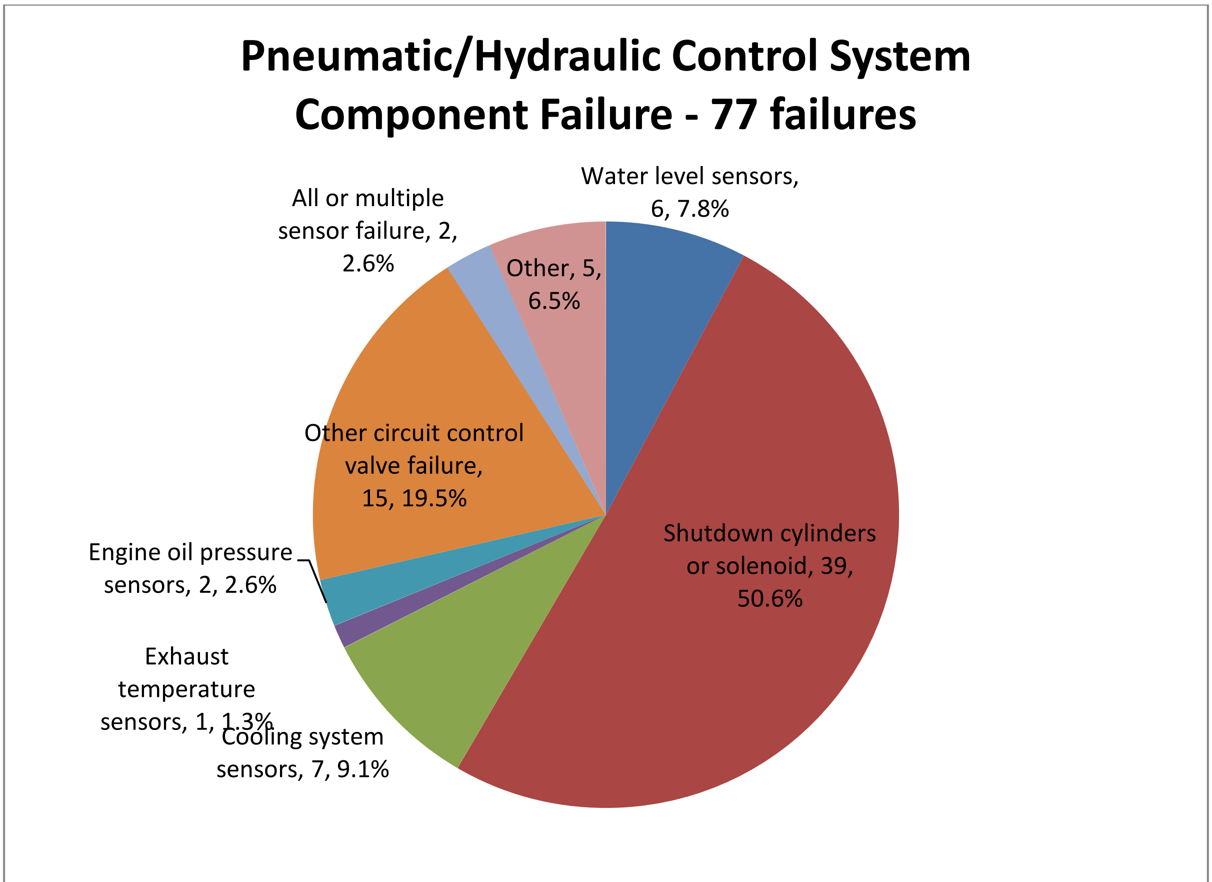


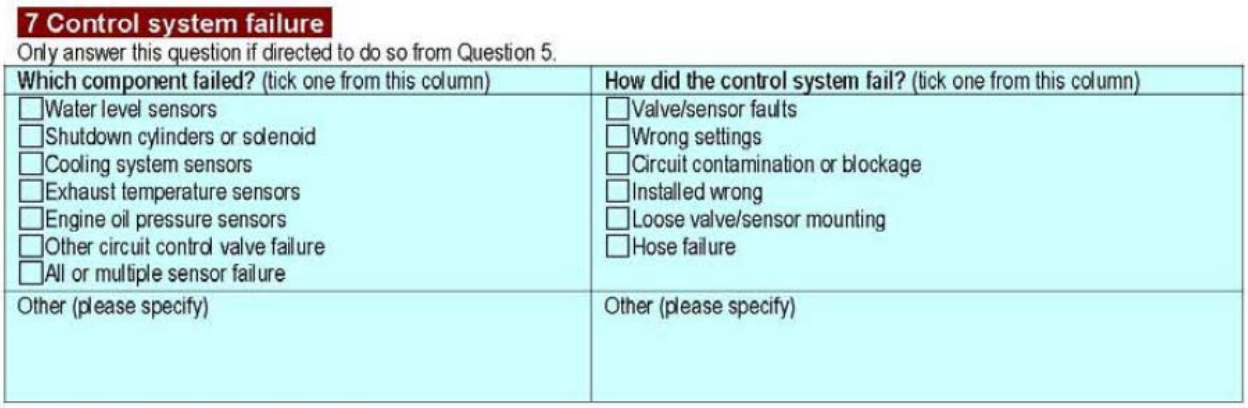
Figure 27

This section analyses the failures of the major contributors to the hydraulic/pneumatic control system component failures shown in Figure 26 and listed in Table 4 below:

Pneumatic / Hydraulic Control System Component	Failures	% Contribution to 2012 failures
Shutdown cylinders or solenoid	39	22%
Other circuit control valve failure	15	8%
Cooling system sensors	7	4%
Water level sensors	6	3%

Table 4
Major contributors to pneumatic / hydraulic control system component failure

For the failure of a pneumatic/hydraulic control system component, the ancillary report prompts for a selection of failure modes as shown below:



7 Control system failure

Only answer this question if directed to do so from Question 5.

Which component failed? (tick one from this column)	**How did the control system fail?** (tick one from this column)
☐ Water level sensors	☐ Valve/sensor faults
☐ Shutdown cylinders or solenoid	☐ Wrong settings
☐ Cooling system sensors	☐ Circuit contamination or blockage
☐ Exhaust temperature sensors	☐ Installed wrong
☐ Engine oil pressure sensors	☐ Loose valve/sensor mounting
☐ Other circuit control valve failure	☐ Hose failure
☐ All or multiple sensor failure	
Other (please specify)	Other (please specify)

Figure 28
Excerpt from ancillary report

Consolidation

The following pages present pie charts on failure location and mode proportions for each of the major contributors in Table 4:

- As per ancillary reports
- Consolidated (refer Annexure B) after:
    - Cognisance of causal factors
    - Grouping of locations/modes
    - Categorisation of “OTHER” entries

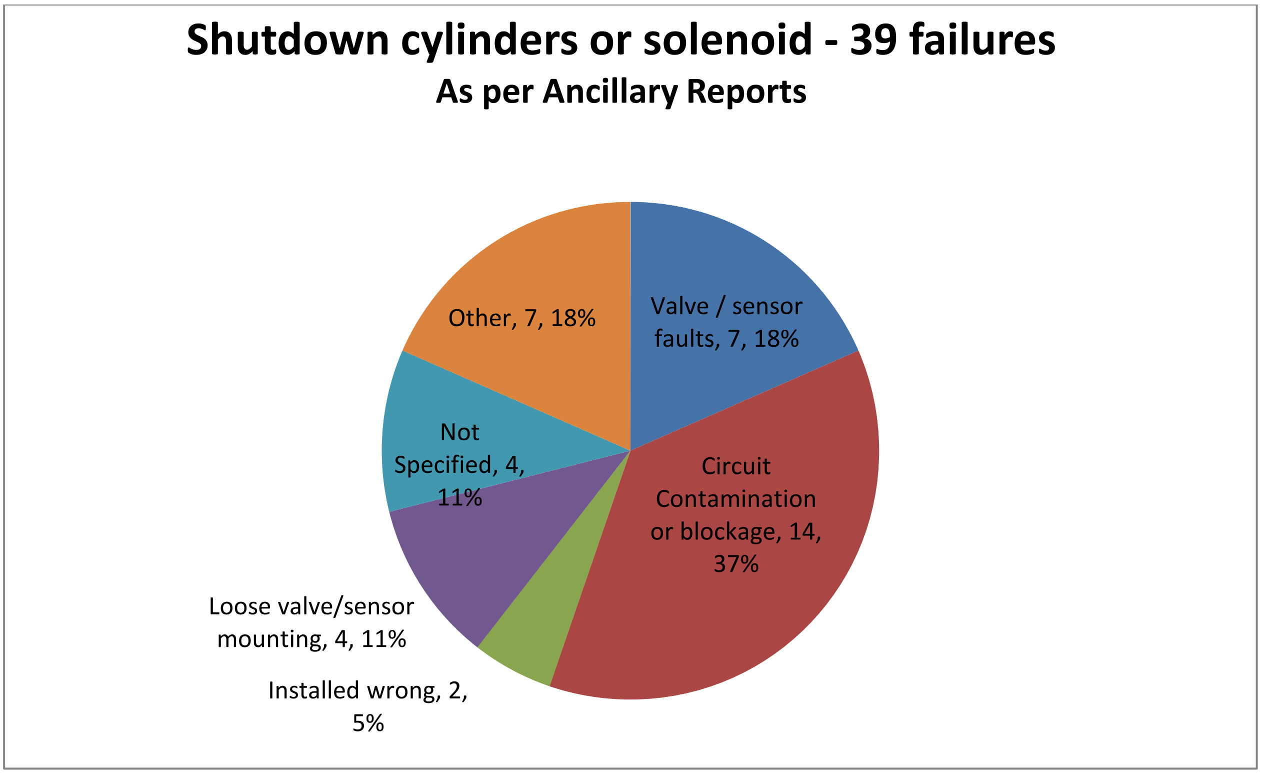


Figure 29

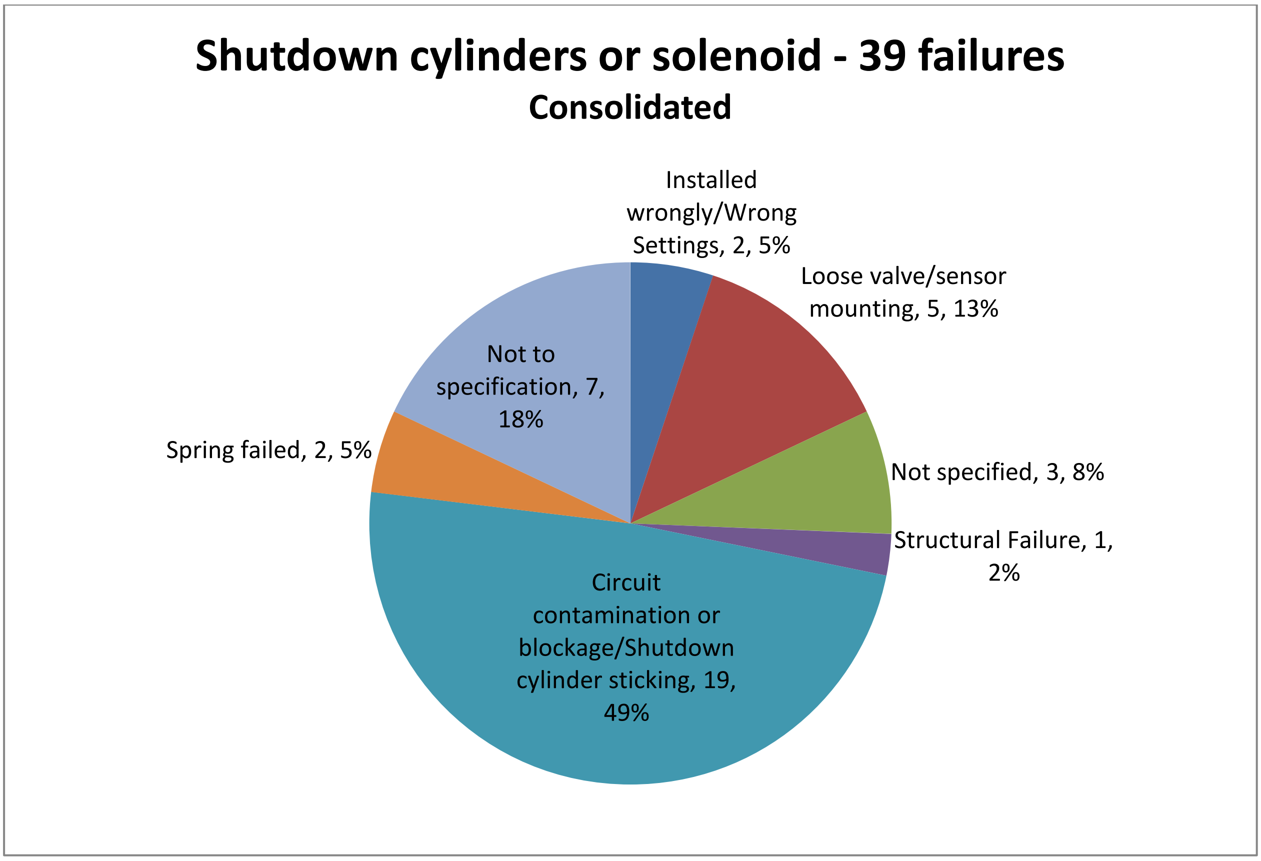


Figure 30

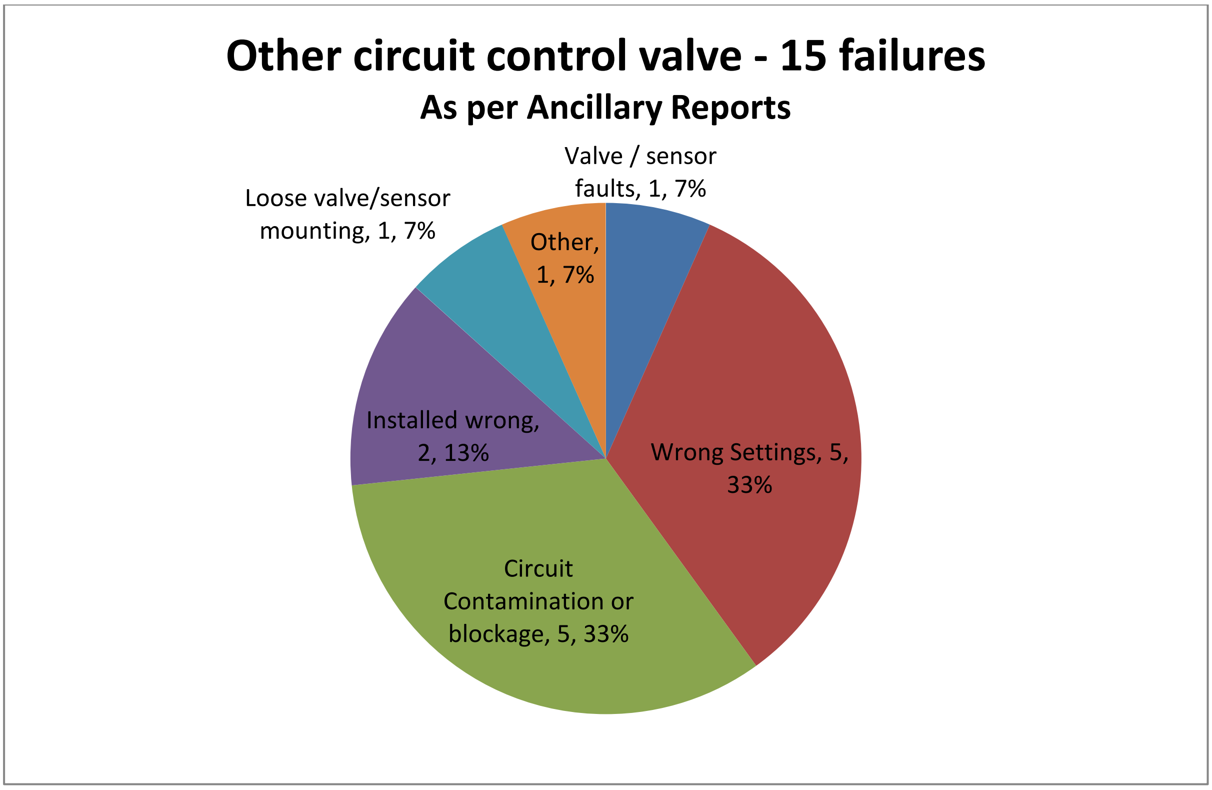


Figure 31

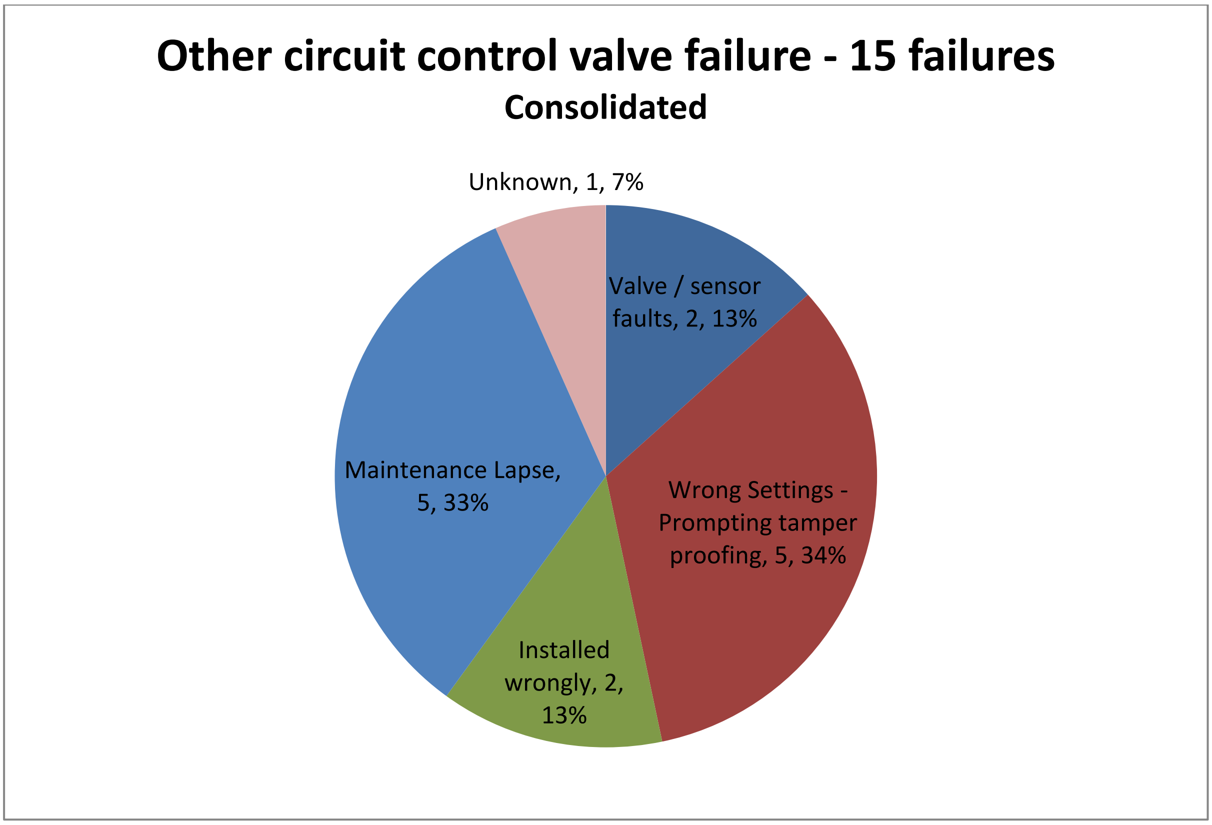


Figure 32

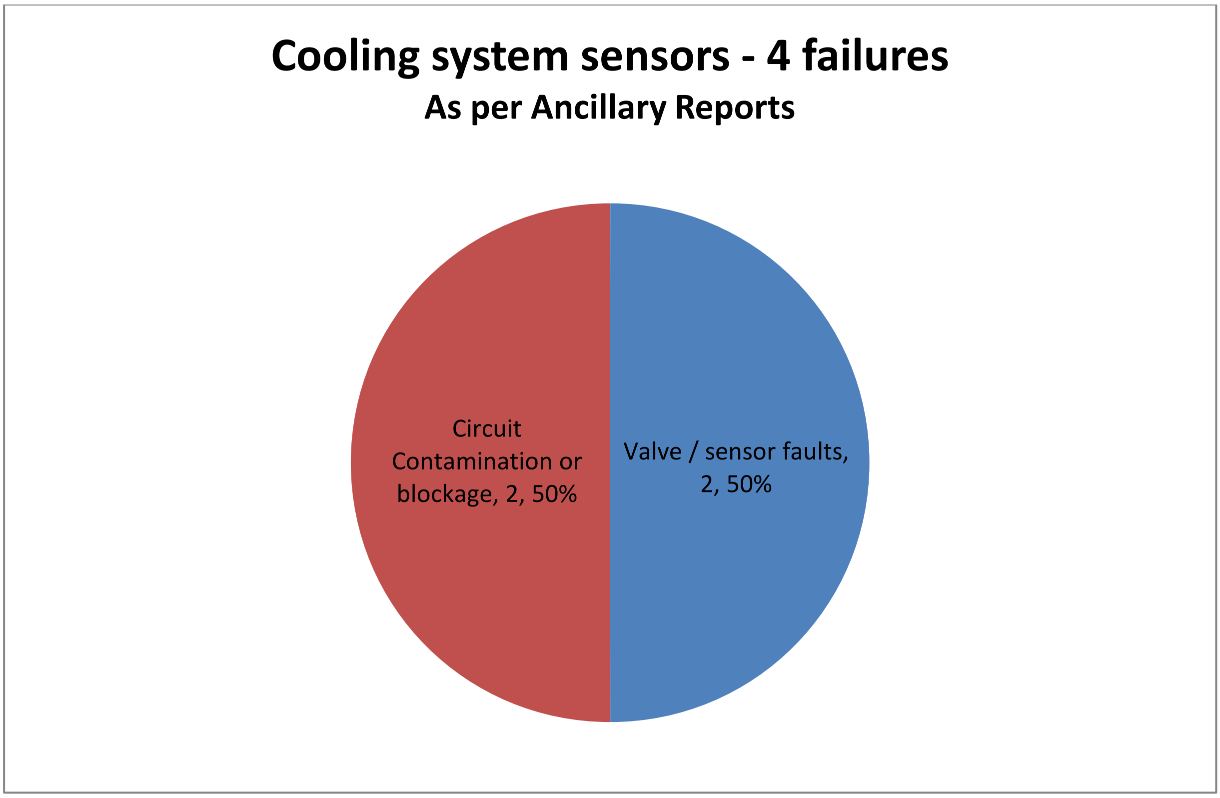


Figure 33

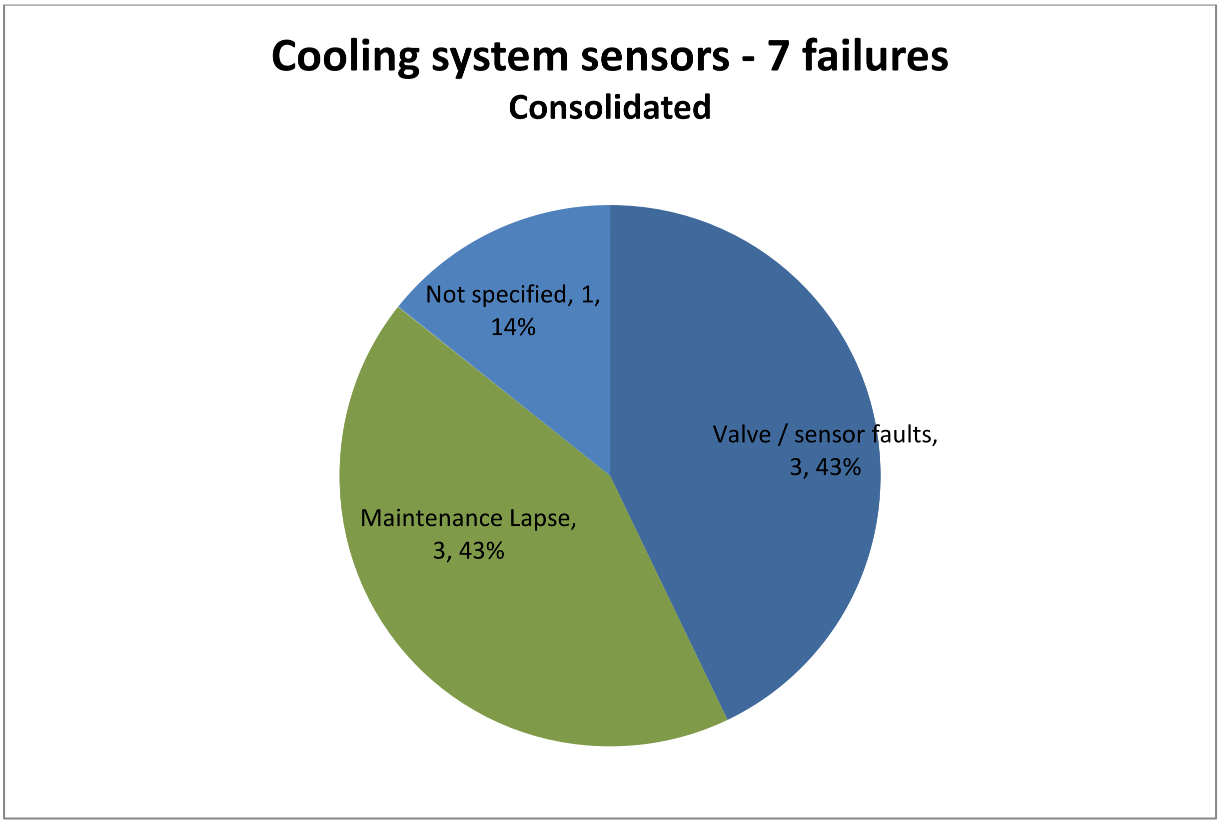


Figure 34

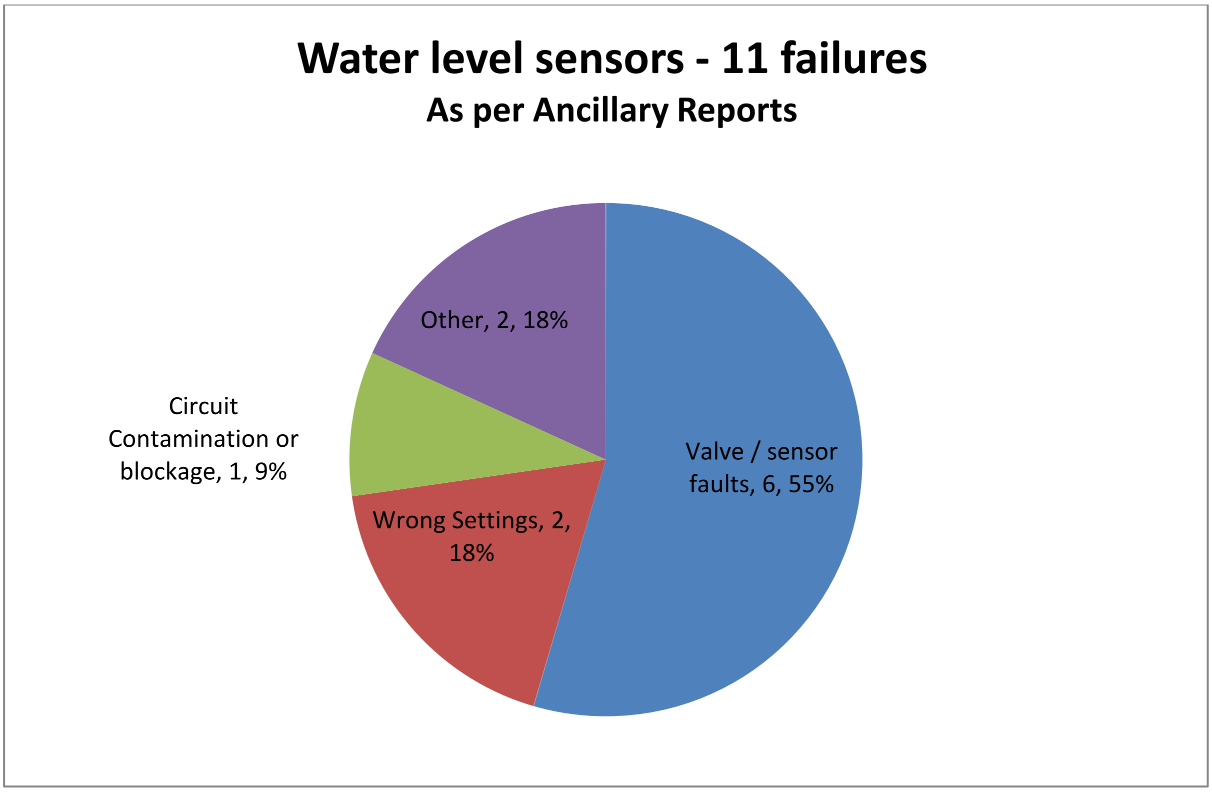


Figure 35

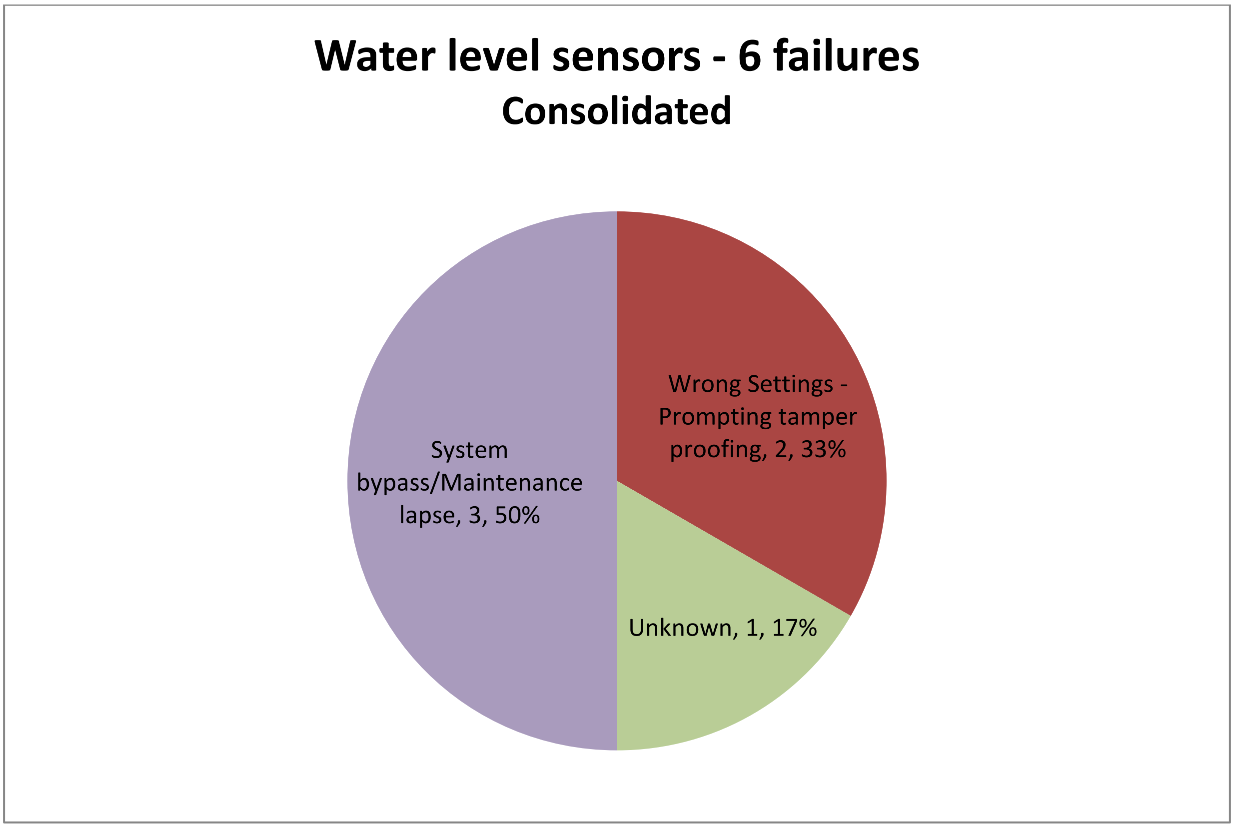
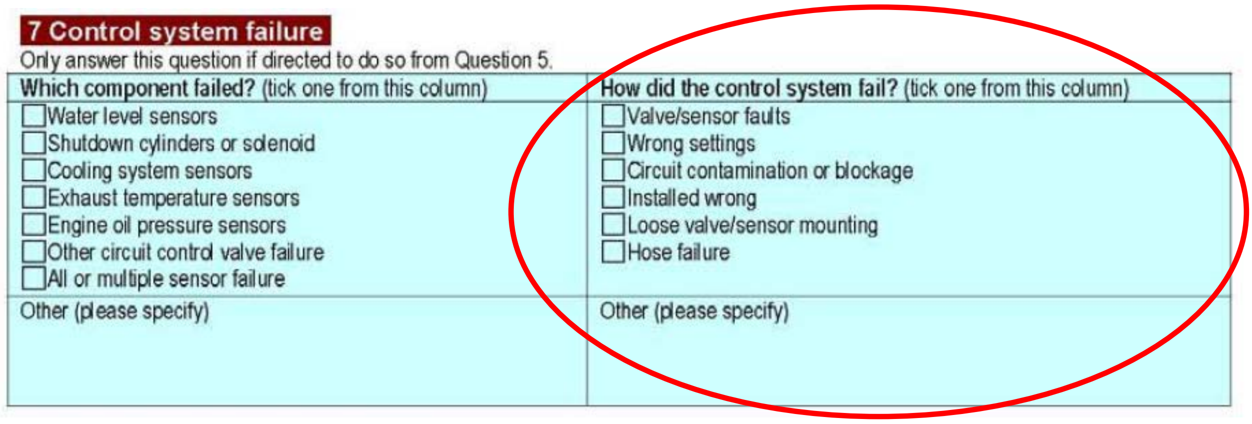


Figure 36

4.5 FAILURE MODES OF PNEUMATIC/HYDRAULIC CONTROL SYSTEM – BREAKDOWN

The overall failure modes of pneumatic/hydraulic control system components highlighted in Figure 36 is shown as a pie chart in Figure 37 below.



7 Control system failure

Only answer this question if directed to do so from Question 5.

Which component failed? (tick one from this column)	How did the control system fail? (tick one from this column)
☐ Water level sensors ☐ Shutdown cylinders or solenoid ☐ Cooling system sensors ☐ Exhaust temperature sensors ☐ Engine oil pressure sensors ☐ Other circuit control valve failure ☐ All or multiple sensor failure	☐ Valve/sensor faults ☐ Wrong settings ☐ Circuit contamination or blockage ☐ Installed wrong ☐ Loose valve/sensor mounting ☐ Hose failure
Other (please specify)	Other (please specify)

Figure 37

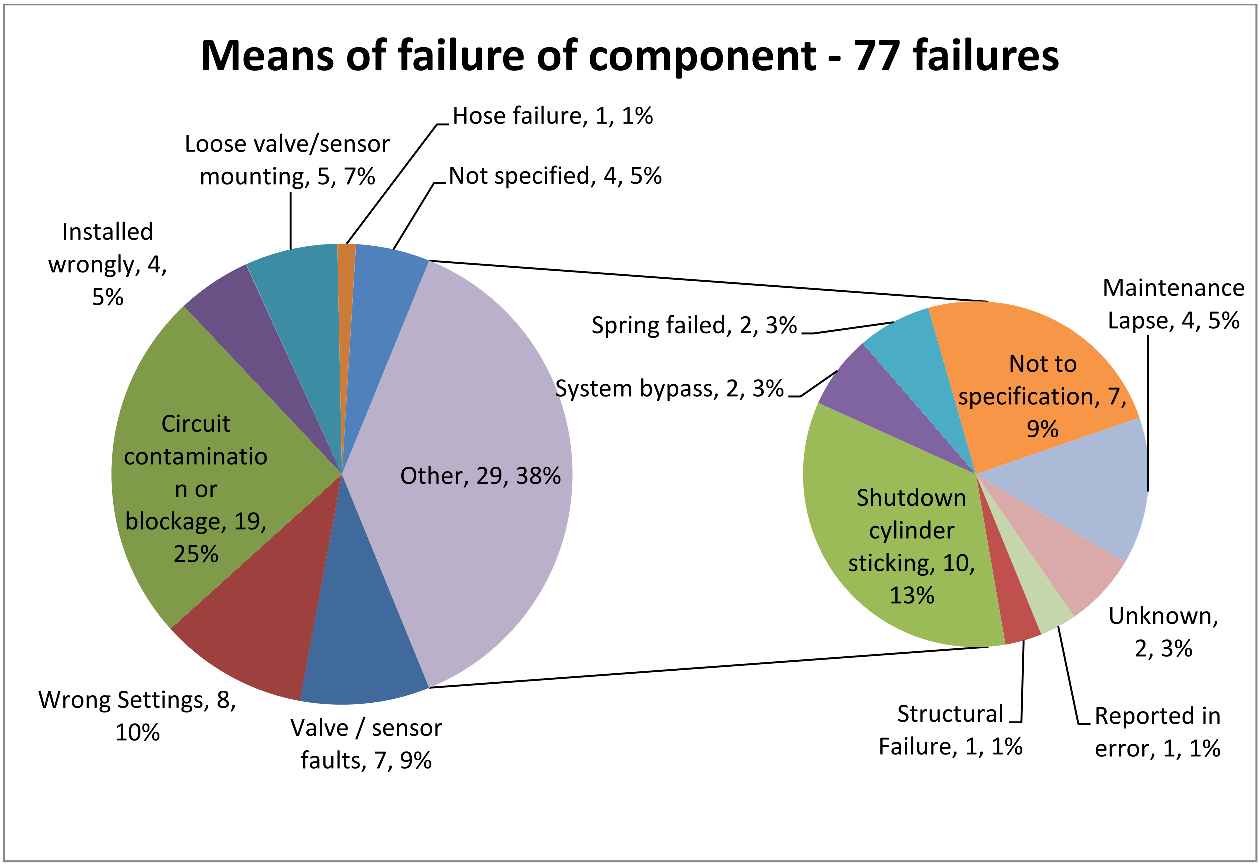
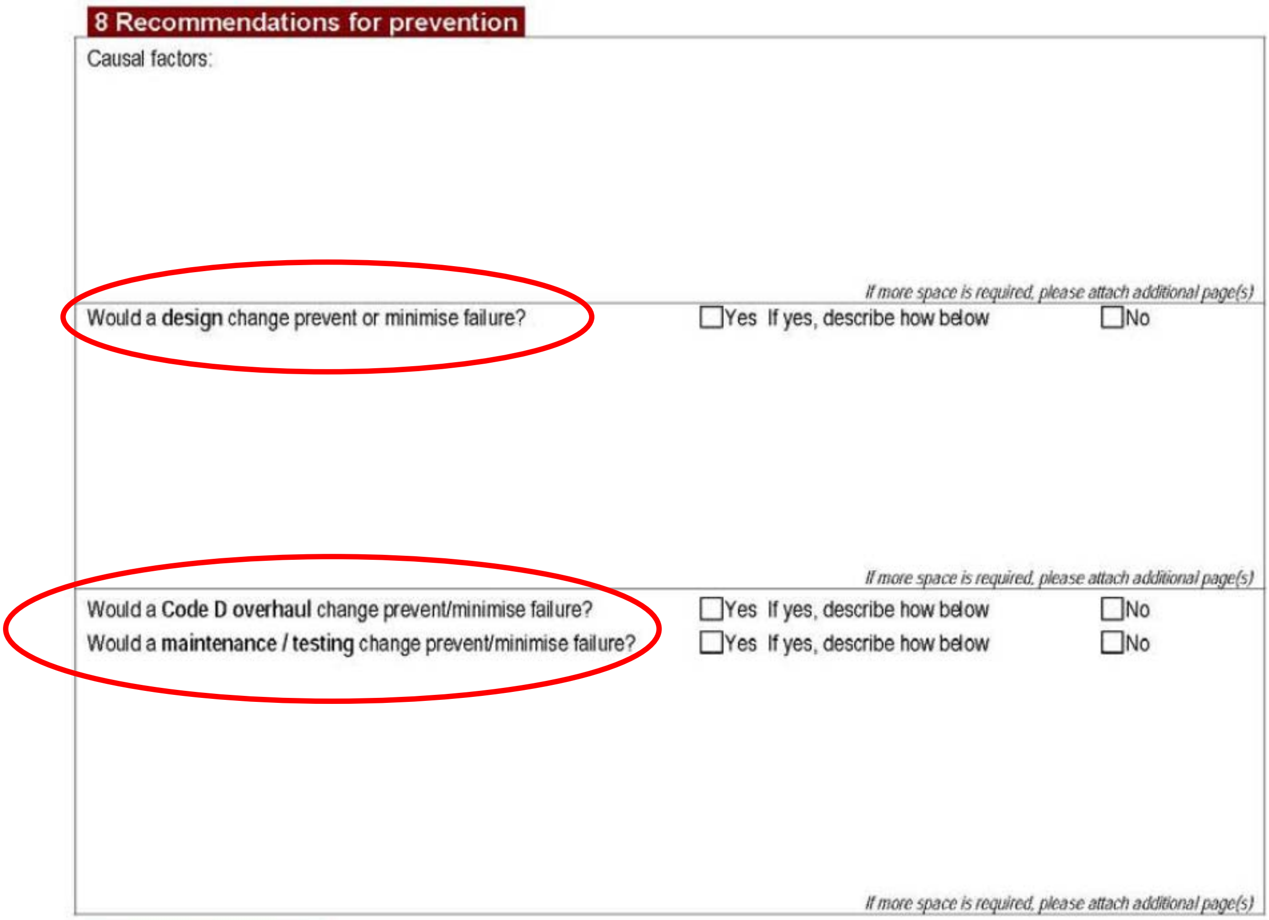


Figure 38

5.0 MINERS' RECOMMENDATIONS FOR PREVENTION

The ancillary report (Annexure A) prompts for design and/or maintenance/testing changes that would prevent / minimise failure as shown below:


8 Recommendations for prevention

Causal factors:

If more space is required, please attach additional page(s)

Would a **design** change prevent or minimise failure? ☐Yes If yes, describe how below ☐No

If more space is required, please attach additional page(s)

Would a **Code D overhaul** change prevent/minimise failure? ☐Yes If yes, describe how below ☐No

Would a **maintenance / testing** change prevent/minimise failure? ☐Yes If yes, describe how below ☐No

If more space is required, please attach additional page(s)

Figure 39
Excerpt from ancillary report

This part of the study compiles the design, maintenance and testing recommendations proposed by the end users and presents them for the major contributors to the 2012 failures.

5.1 Major contributors

Table 5 below ranks the contributors to the 2012 failures. Essentially, the same as Table 1 but drills down into a lower level of component categories such as fixed connections, open joints, etc.

Rank	Major Component	No. of failures	%
1	Wet flame trap	47	26.0%
2	Shutdown cylinders or solenoid	39	21.5%
3	Fixed connection	38	21.0%
4	Other circuit control valve failure	15	8.3%
5	Open joints	12	6.6%
6	Cooling system sensors	7	3.9%
7	Other	7	3.9%
8	Water level sensors	6	3.3%
9	Structural failures	3	1.7%
10	Positive flame trap element	2	1.1%
11	Engine oil pressure sensors	2	1.1%
12	All or multiple sensor failure	2	1.1%
13	Exhaust temperature sensors	1	0.6%
14	Excessive surface temperature	0	0.0%
	Total number of failures in 2012	**181**	**100%**

Table 5
Contributors to component failure

The following pages list the design and maintenance/testing recommendations from the ancillary reports of 2012 for the following major contributors:

Rank	Major Component	No. of failures	%
1	Wet flame trap	47	26.0%
2	Shutdown cylinders or solenoid	39	21.5%
3	Fixed connection	38	21.0%
4	Other circuit control valve failure	15	8.3%
5	Open joints	12	6.6%
6	Cooling system sensors	7	3.9%
8	Water level sensors	6	3.3%
	Total number of failures in 2012	**164**	**90.6%**

Table 6
Major contributors to component failure

5.2 WET FLAME TRAP

Failures in 2012	Failures	% Contribution	Contributor Rank
181	47	26.0	1

No.	Design recommendations
1	More reliable Humphrey valves
2	Split diaphragms in Humphrey valves
3	Solid or closed cell foam filled float
4	System to hose all breathers
5	Float actuator going out of adjustment
6	Introduce a waste-gate valve
7	Wire braid hoses
8	Individual float test procedures (without crimping hoses)
9	Float assembly magnets (1 issue)

No.	Maintenance / Testing recommendations
1	More frequent cleaning of the scrubber (with detergent)
2	Daily flushing of the scrubber
3	Frequent replacement of rubber diaphragms on Humphrey valves
4	Clean carbon build-up in orifice
5	Clean / blow breathers
6	More frequent change-out of Humphrey valves
7	Inspect / replace rubber diaphragms / gaskets
8	Education and training on the importance of maintaining / testing safety functions
9	More frequent proof testing (not function testing)
10	Plugging of air horns

Table 7

The comments listed in the tables above are the various unique entries from the ancillary reports and are not ranked in any order. The pie chart below consolidates the numbers of design vs. maintenance/testing recommendations from the ancillary reports and is not directly derived from the number of listings in the tables above.

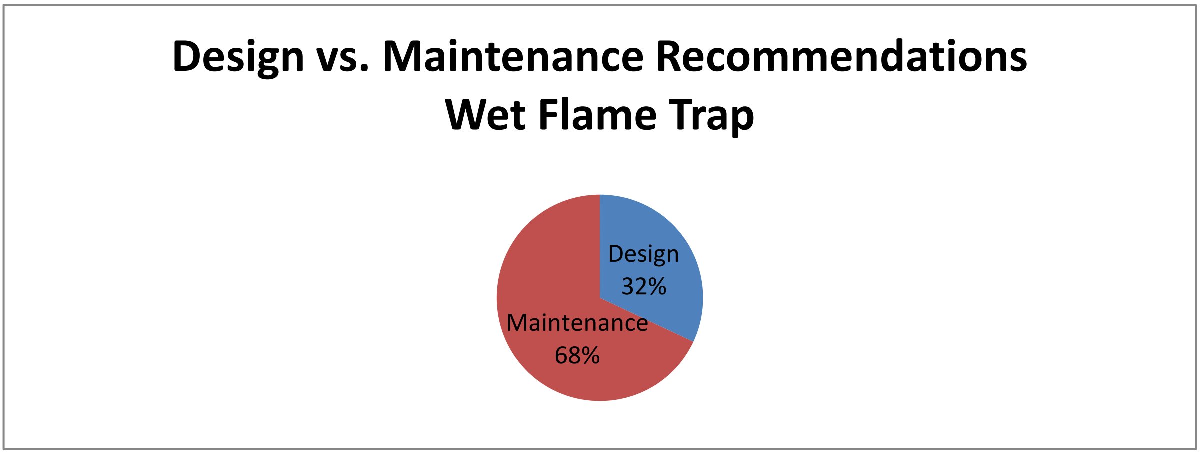


Figure 40

5.3 Shutdown cylinders or solenoid

Failures in 2012	Failures	% Contribution	Contributor Rank
181	39	21.5	2

No.	Design recommendations
1	Cylinder position to be fixed and not adjustable
2	Better access to check and install bolts
3	Filter / lubricator rather than just filter
4	Better means of draining water trap(ped)
5	Better wiper seal

No.	Maintenance / Testing recommendations
1	Check for damage / cracked brackets
2	Tension checks
3	Increased maintenance of filters, lubricators and breathers
4	Users suggest increased maintenance
5	Shorter replacement intervals

Table 8

The comments listed in the tables above are the various unique entries from the ancillary reports and are not ranked in any order. The pie chart below consolidates the numbers of design vs. maintenance/testing recommendations from the ancillary reports and is not directly derived from the number of listings in the tables above.

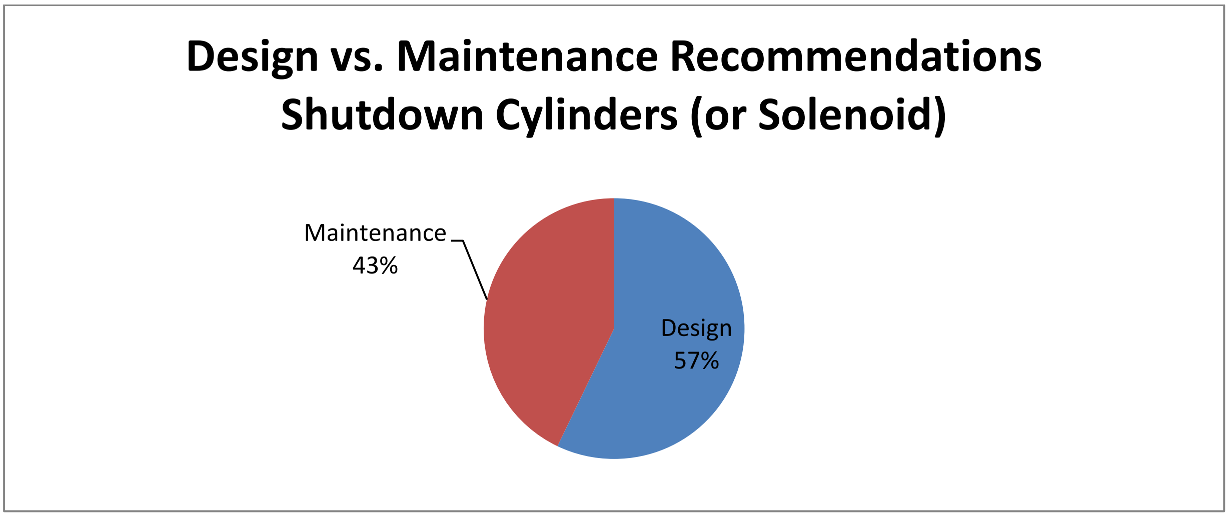


Figure 41

5.4 Fixed connections

Failures in 2012	Failures	% Contribution	Contributor Rank
181	38	21.0	3

No.	Design recommendations
1	Additional stay for turbo
2	Turbo brace
3	Tighter manufacturer tolerances
4	Fine threads required
5	Damaged gaskets
6	Incorrect installation
7	Include design tolerances on drawings
8	Install studs so bolt length issues will not occur
9	Manifold out of specification
10	Broken bolts
11	Flush/drain plug locking mechanism required
12	No torque settings provided in OEM procedures
13	Mounting holes and threads out of specification
14	Surface imperfections/wear in threaded sections
15	Mounting face tapered and under minimum thickness - Out of specification
16	Gasket material too hard

No.	Maintenance / Testing recommendations
1	Lapse e.g. cover on top of fuel pump missing
2	More frequent component replacement
3	Support bracket not fitted
4	Check bolts/nuts not torqued (often loose)

Table 9

The comments listed in the tables above are the various unique entries from the Ancillary reports and are not ranked in any order. The pie chart below consolidates the numbers of design vs. maintenance/testing recommendations from the ancillary reports and is not directly derived from the number of listings in the tables above.

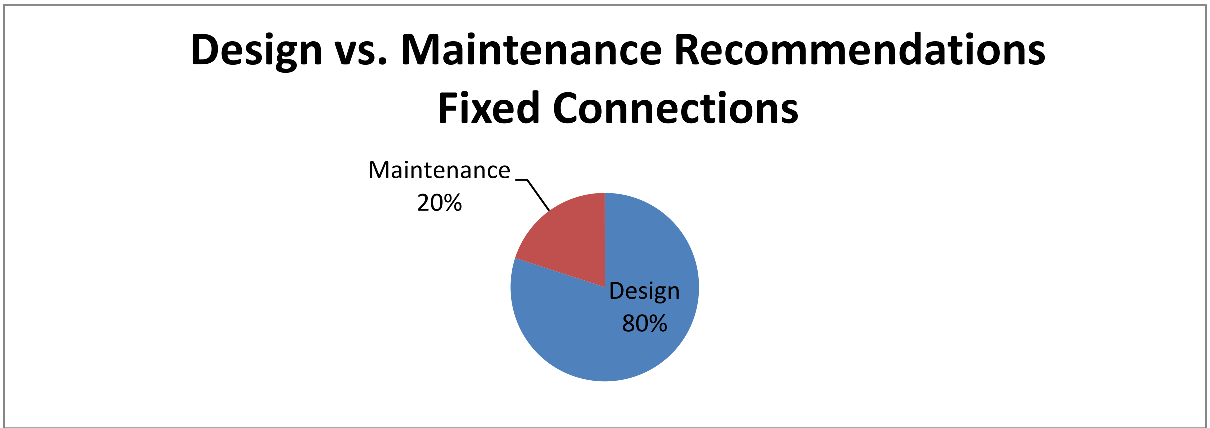


Figure 42

5.5 OTHER CIRCUIT CONTROL VALVES

Failures in 2012	Failures	% Contribution	Contributor Rank
181	15	8.3	4

No.	Design recommendations
1	Single line component
2	Fixed needle valves
3	Tamper proof adjustment screws
4	Fixes orifice sizing
5	Tamper proofing of air regulators
6	Springs
7	Pressure regulators
8	Users suggest the need for more frequent replacement intervals than suggested by OEM

No.	Maintenance / Testing recommendations
1	Pneumatic filters and lubricator maintenance
2	More frequent replacement of valves
3	Increased monitoring of air pressure
4	Thorough scrubber cleaning with conditioner (daily?)
5	Cleaning plungers regularly
6	More frequent replacement of filters and diaphragm rubbers
7	Draining air receivers

Table 10

The comments listed in the tables above are the various unique entries from the ancillary reports and are not ranked in any order. The pie chart below consolidates the numbers of design vs. maintenance/testing recommendations from the ancillary reports and is not directly derived from the number of listings in the tables above.

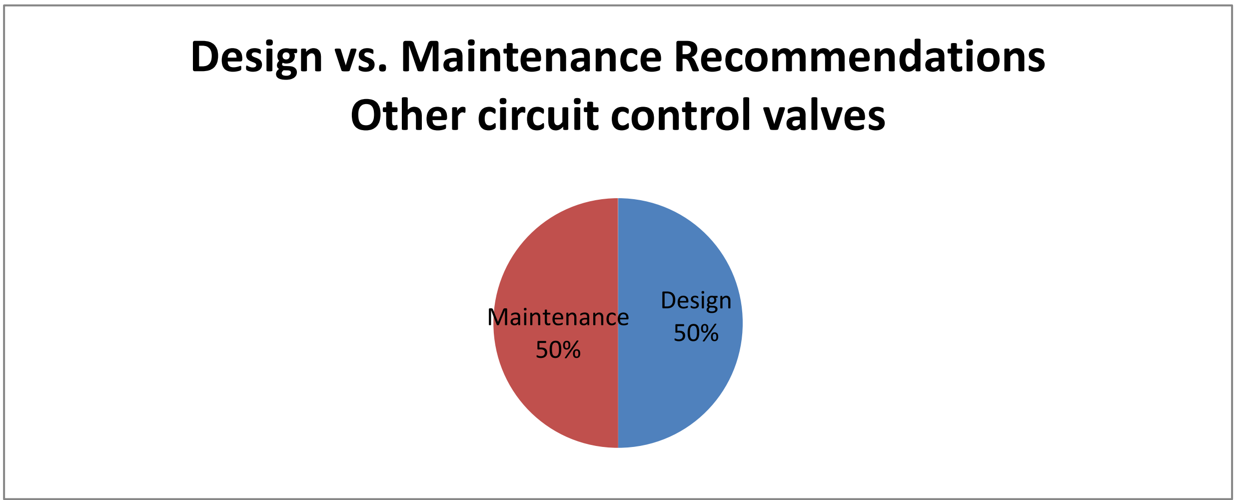


Figure 43

5.6 OPEN JOINTS

Failures in 2012	Failures	% Contribution	Contributor Rank
181	12	6.6	5

No.	Design recommendations
1	Incorrect installation
2	Turbo mounting studs broken
3	Loose injectors
4	Excessive gap

No.	Maintenance / Testing recommendations
1	Maintenance Lapse

Table 11

The comments listed in the tables above are the various unique entries from the ancillary reports and are not ranked in any order. The pie chart below consolidates the numbers of design vs. maintenance/testing recommendations from the ancillary reports and is not directly derived from the number of listings in the tables above.

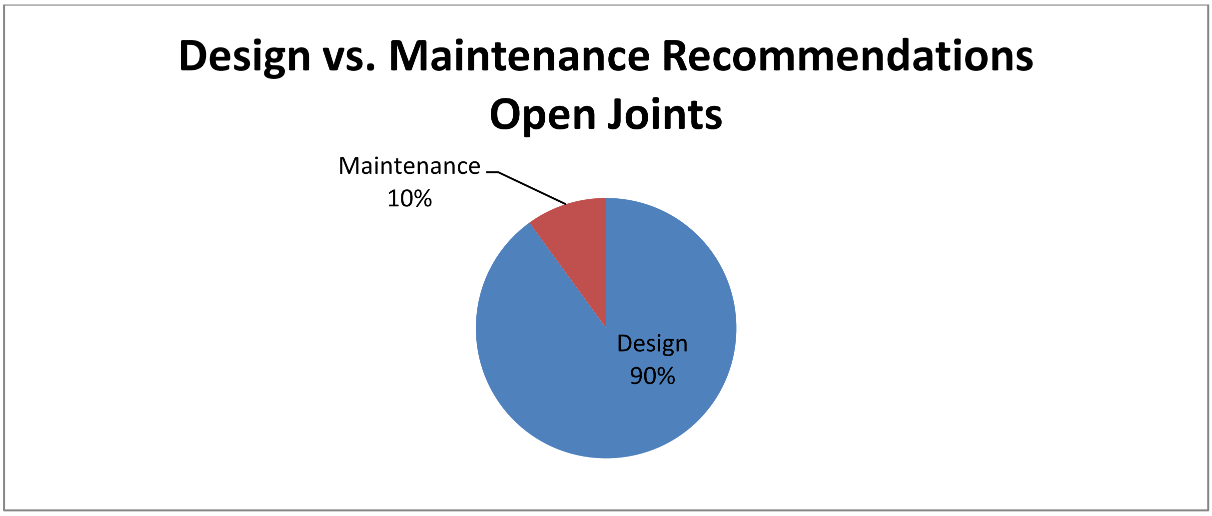


Figure 44

5.7 Cooling system sensors

Failures in 2012	Failures	% Contribution	Contributor Rank
181	7	3.9	6

No.	Design recommendations
1	Increased component reliability
2	Tamper proofing

No.	Maintenance / Testing recommendations
1	Review replacement intervals
2	Regular function testing (proof testing)
3	Misuse / Abuse

Table 12

The comments listed in the tables above are the various unique entries from the ancillary reports and are not ranked in any order. The pie chart below consolidates the numbers of design vs. maintenance/testing recommendations from the ancillary reports and is not directly derived from the number of listings in the tables above.

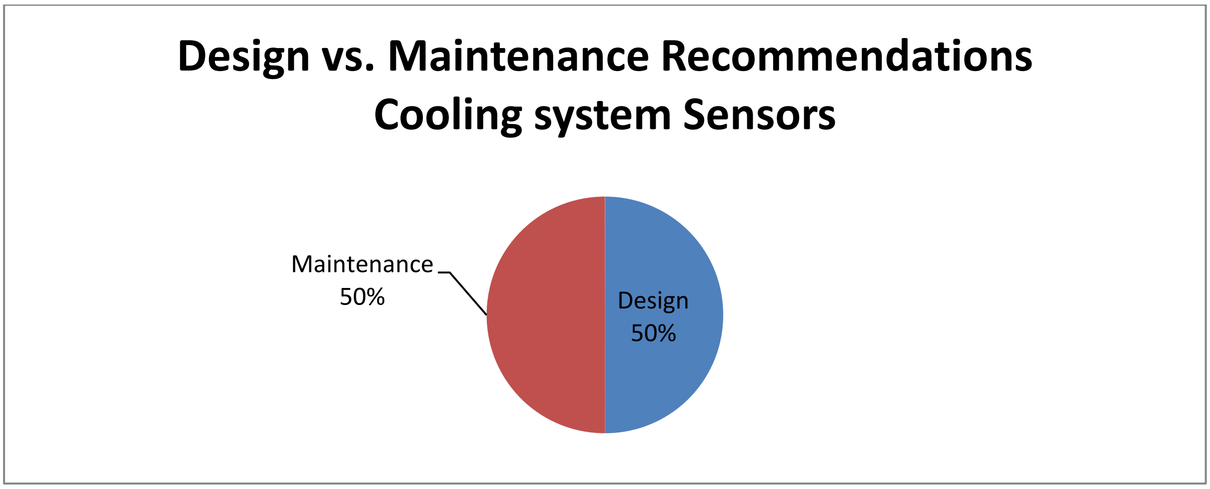


Figure 45

5.8 Water level sensors

Failures in 2012	Failures	% Contribution	Contributor Rank
181	6	3.3	8

No.	Design recommendations
1	Need for tamper proofing

No.	Maintenance / Testing recommendations
1	Incorrect adjustment
2	Misuse / Abuse
3	Lapse

Table 13

The comments listed in the tables above are the various unique entries from the ancillary reports and are not ranked in any order. The pie chart below consolidates the numbers of design vs. maintenance/testing recommendations from the ancillary reports and is not directly derived from the number of listings in the tables above.

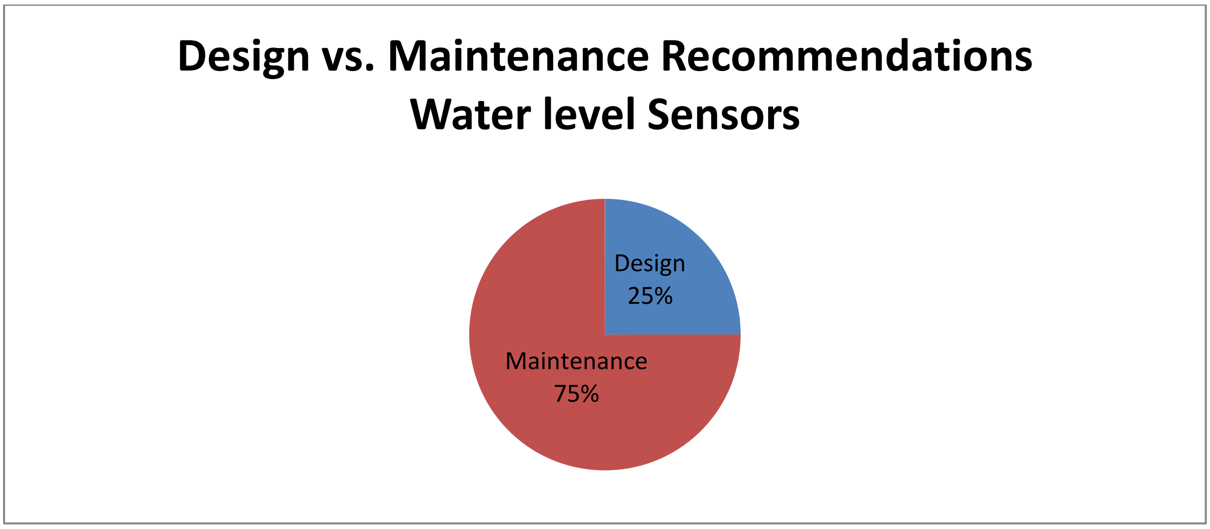


Figure 46

5.9 CONCLUSIONS

Design vs. maintenance recommendations apportioning reveal the following:

Maintenance recommendations dominate in wet flame trap and water level sensors, while design recommendations dominate in shutdown cylinders, fixed connections and open joints. Equal weighting of design and maintenance recommendations is noticed in other circuit control valves and cooling system sensors.

However, on critical analysis, it is concluded that a substantial portion of maintenance recommendations proposed could be obviated by incorporating appropriate design modifications. Such an approach would fall in line with the 3-step method proposed in classical risk management practices including AS 4024 – Safety of Machinery:

Step 1: Inherently safe design measures

Step 2: Safeguarding and possibly complementary protective measures

Step 3: Information for use about residual risk.

6.0 OEM STATISTICS

This section presents an analysis of non-specific OEM failures against their inventory levels.

OEM-specific Failure Analysis will be provided to each OEM separate from this report as Addenda.

A consolidated list of major OEMs including their past OEM references and the number of machines in the current inventory* is shown in Table 14.

Current OEM	Machines in Inventory
OEM A	450
OEM B	401
OEM C	176
OEM D	85
OEM E	58
OEM F	26
OEM G	33
Total machines in Inventory (major OEMs)	**1229**

* Source: Item Registration 130320.xls received on 27.03.2013; DES Item Reg – Only Current lists a total of 1250 machines.

Table 14

6.1 Reported failures per OEM

Listed below are the reported failures per OEM.

OEM	2012 Failures	Failures % of 2012	Machines in Inventory	Failures % of Inventory
OEM A	79	44%	450	18%
OEM B	55	30%	401	14%
OEM C	31	17%	176	18%
OEM E	9	5%	58	16%
OEM F	5	3%	26	19%
OEM D	2	1%	85	2%
OEM G	0	0%	33	0%
Total	**181**	**100%**	**1229**	

Table 15

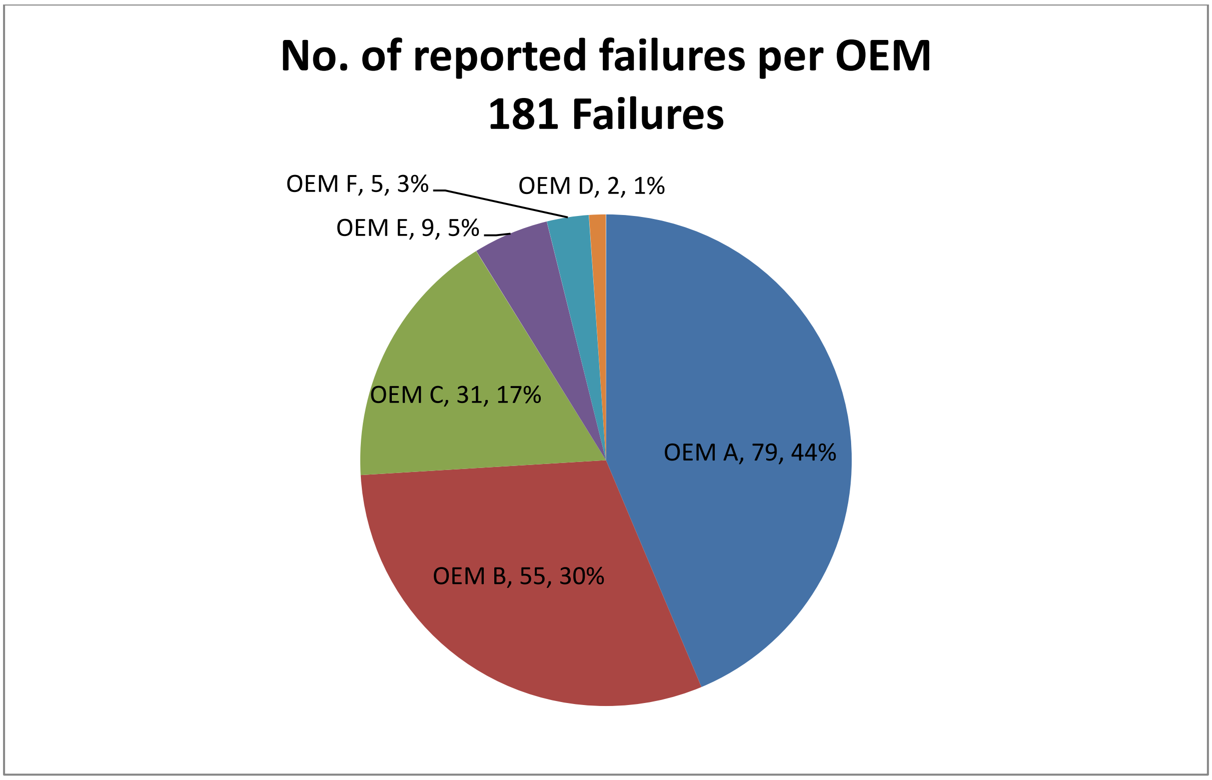


Figure 47

The OEM-wise distribution of these failures along with their respective inventory numbers (refer Table 15) are recorded in the plot below:

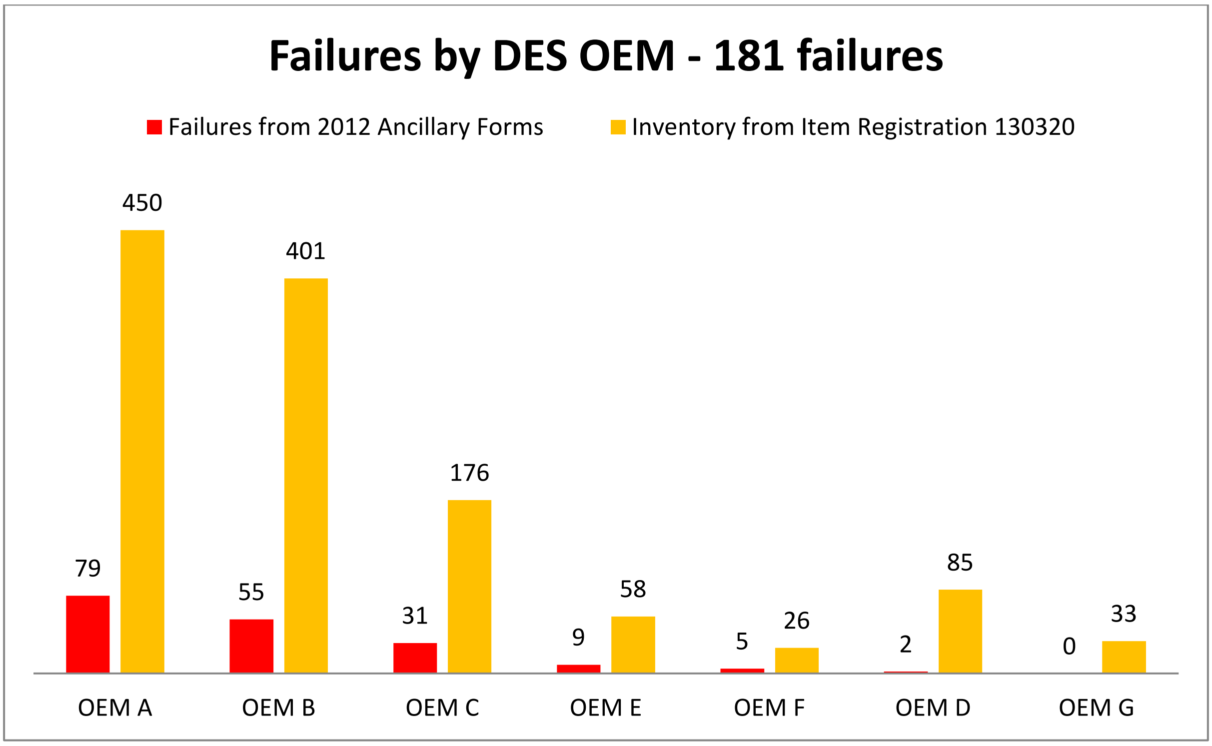


Figure 48

6.2 Intentionally Blank

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6.3 ENGINE COMPONENT FAILURES BY DES OEM

The OEM-wise distribution of the engine component failures along with their respective inventory numbers (refer Table 15) are recorded in the plot below:

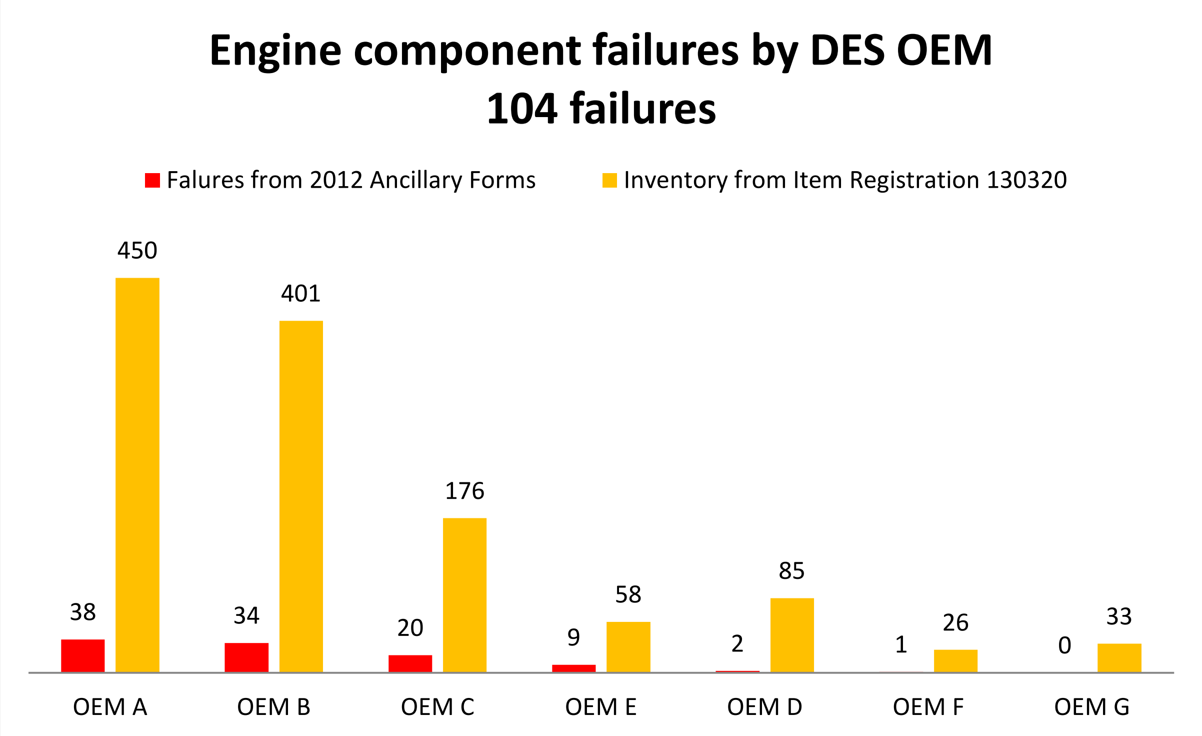

Figure 49

Out of the 104 Engine component failures, major contributors were shown in Table 2 which is repeated below:

Engine Component	Failures	% Contribution to 2012 failures
Exhaust flame trap (wet/dry)	58	32%
Exhaust pipe(s)	12	7%
Intake flame trap & housing	11	6%
Intake manifold	9	5%

Table 2 (repeated)
Major contributors to engine component failure

The following sections present plots on each of the above engine component failures vs. the OEMs. Some entries have been omitted due to incomplete data.

6.3.1 EXHAUST FLAME TRAP (WET/DRY) FAILURES

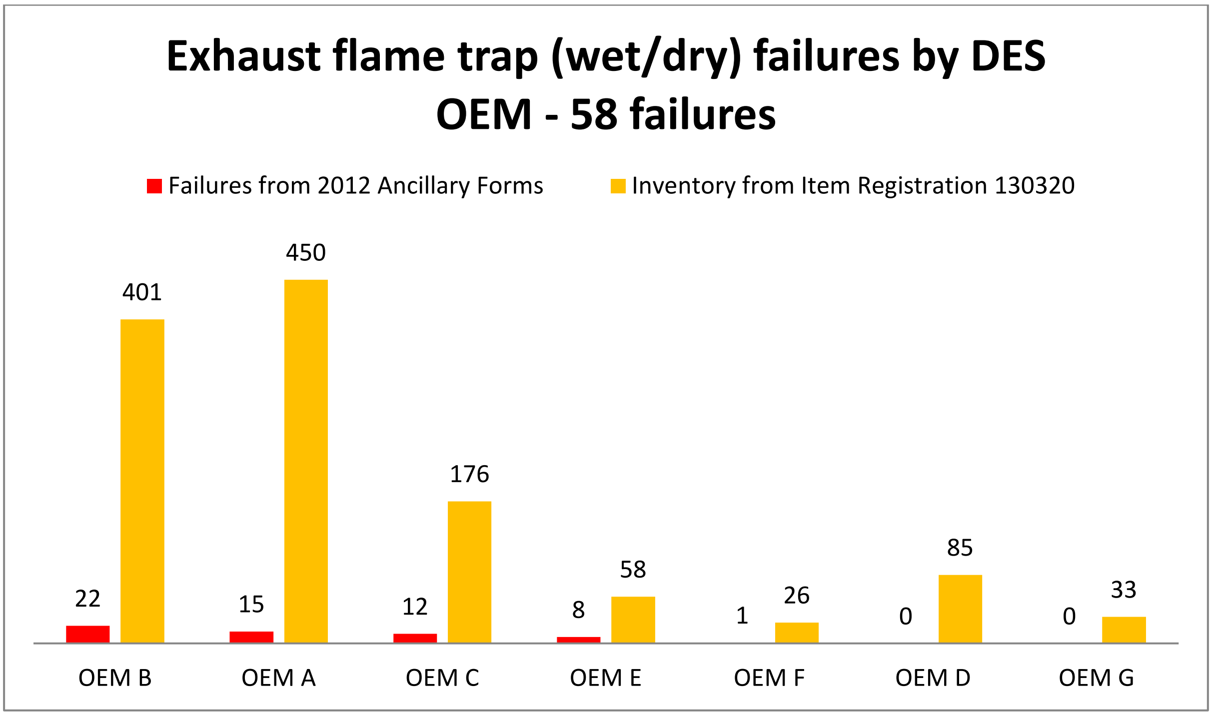

Figure 50

6.3.2 EXHAUST PIPE(S) FAILURES

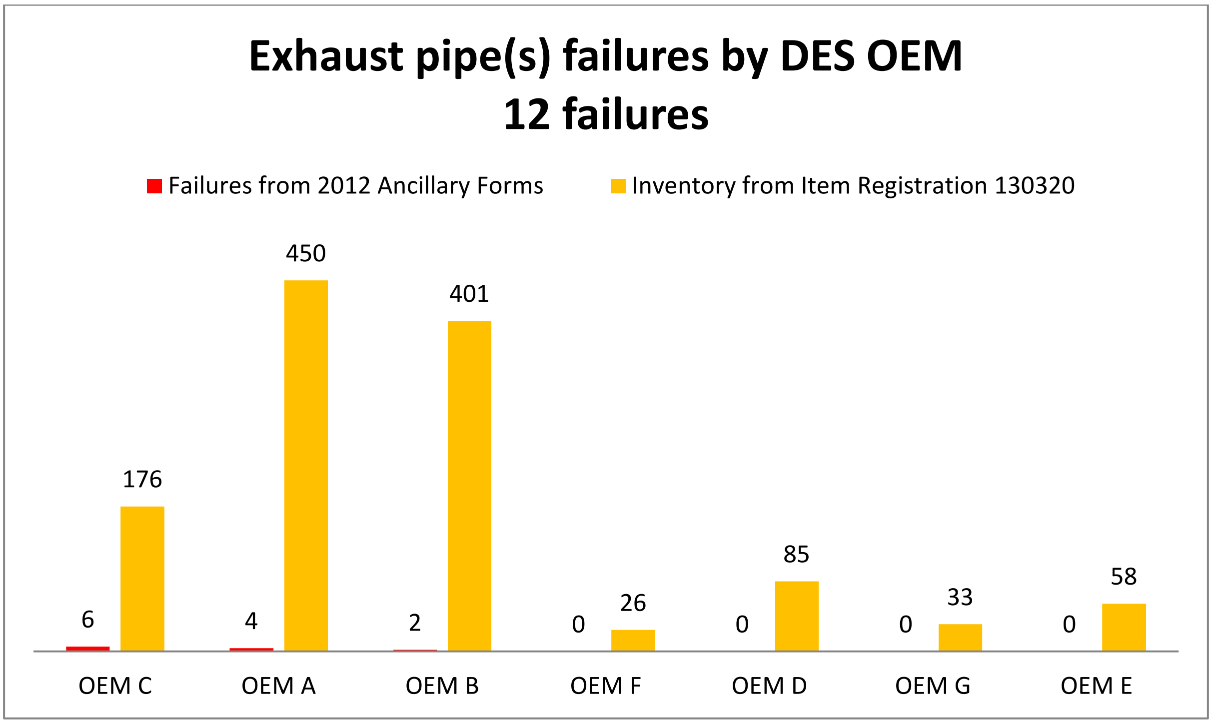

Figure 51

6.3.3 INTAKE FLAME TRAP & HOUSING FAILURES

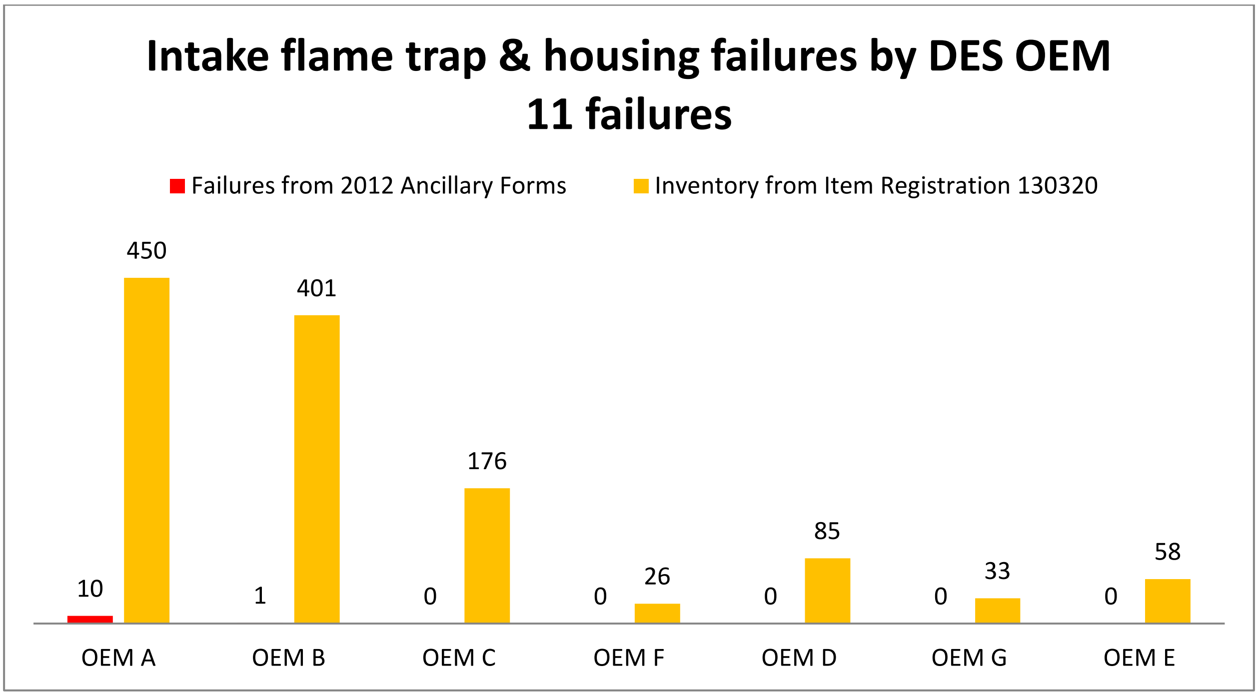

Figure 52

6.3.4 INTAKE MANIFOLD FAILURES

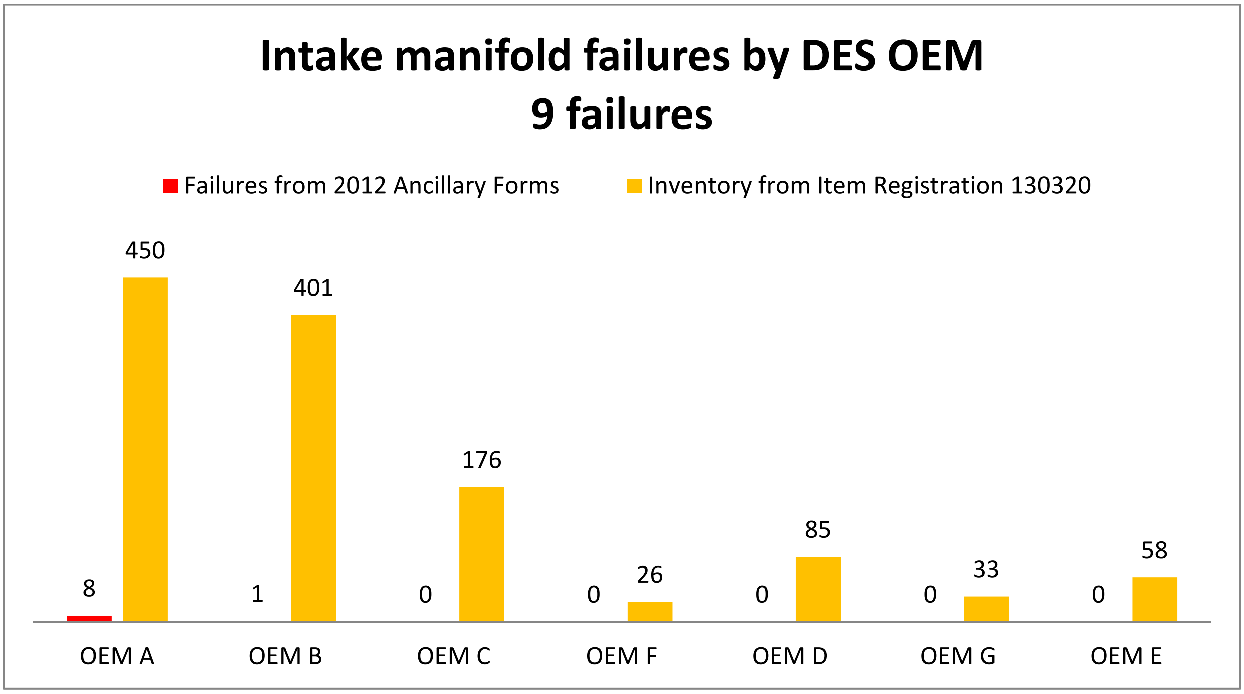

Figure 53

6.4 Pneumatic / Hydraulic Control System by DES OEM

The OEM-wise distribution of the pneumatic/hydraulic control system failures along with their respective inventory numbers (refer Table 15) are recorded in the plot below:

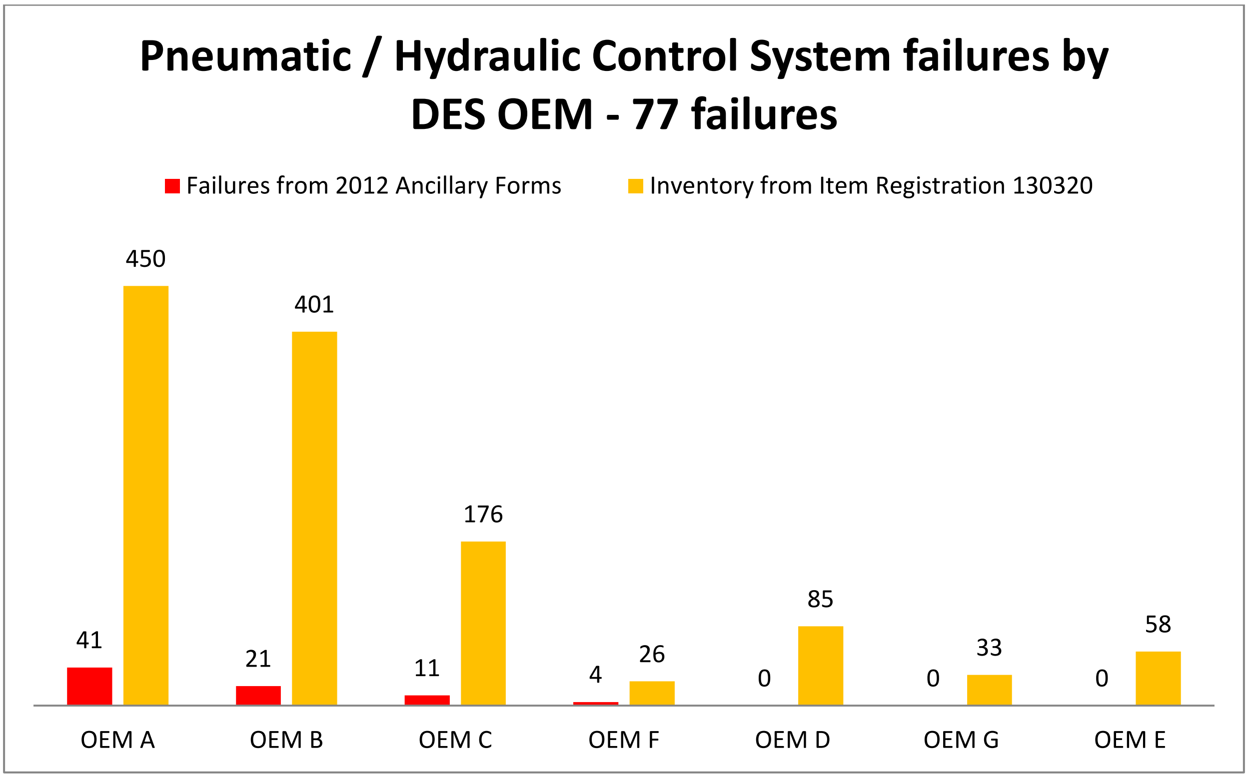

Figure 54

Out of the 77 Pneumatic / Hydraulic control system component failures, major contributors were shown in Table 4 which is repeated below:

Pneumatic / Hydraulic Control System Component	Failures	% Contribution to 2012 failures
Shutdown cylinders or solenoid	39	22%
Other circuit control valve failure	15	8%
Cooling system sensors	7	4%
Water level sensors	6	3%

Table 4 (repeated)
Major contributors to pneumatic / hydraulic control system component failure

The following sections present plots on each of the above control system component failures vs. the OEMs . Some entries have been omitted due to incomplete data.

6.4.1 SHUTDOWN CYLINDERS OR SOLENOID FAILURES

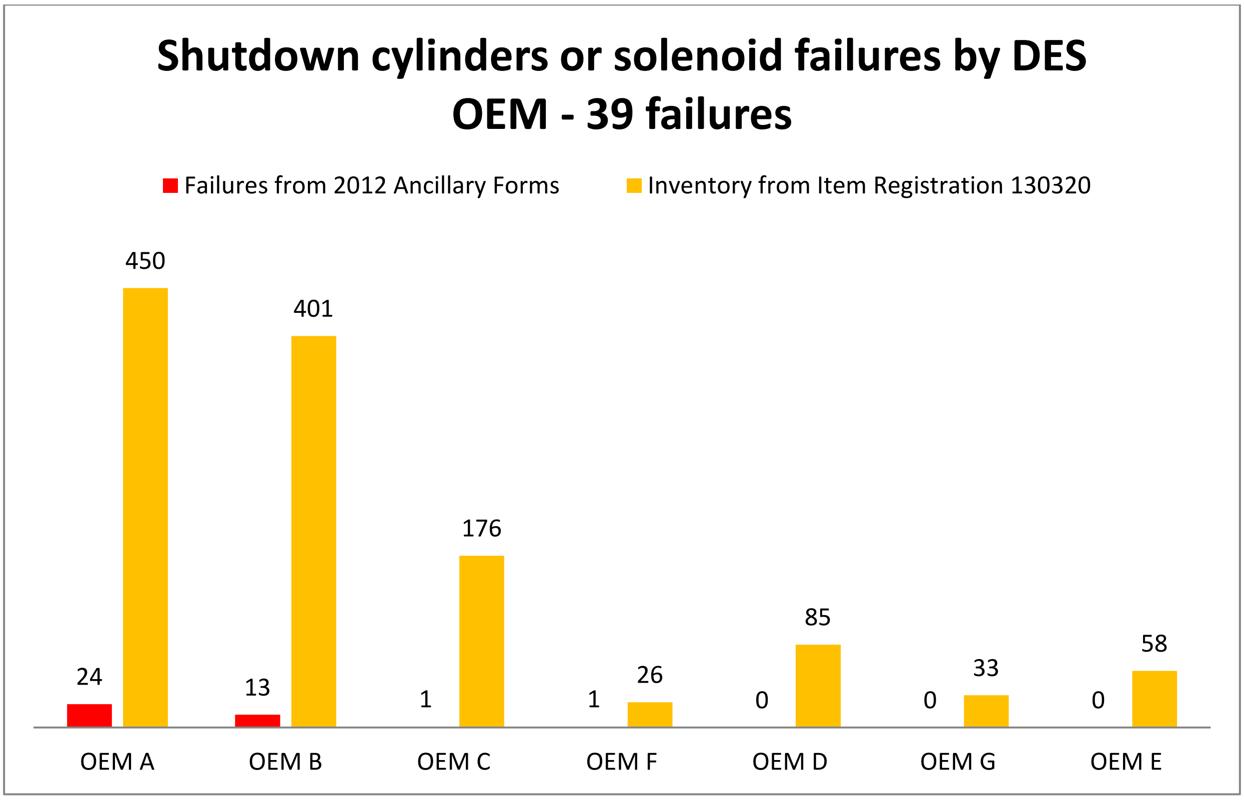

Figure 55

6.4.2 WATER LEVEL SENSOR FAILURES

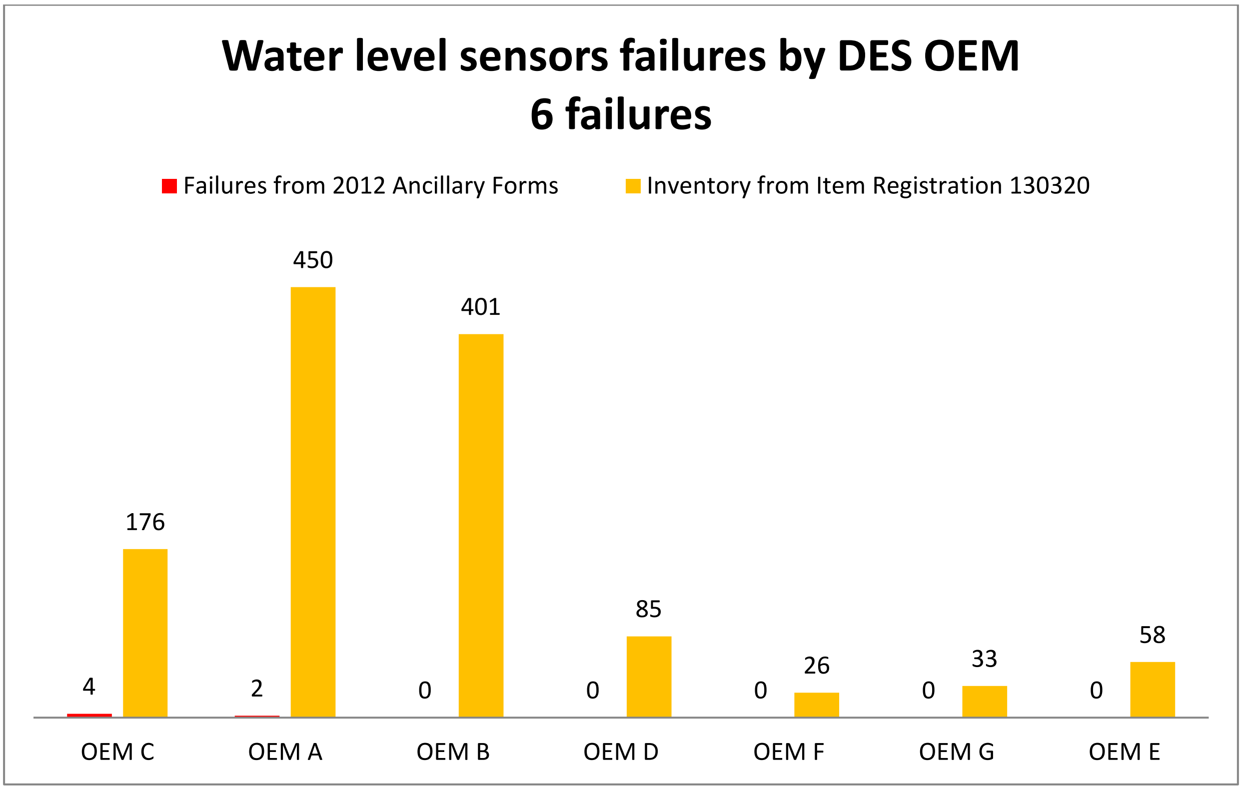

Figure 56

6.4.3 OTHER CIRCUIT CONTROL VALVE FAILURES

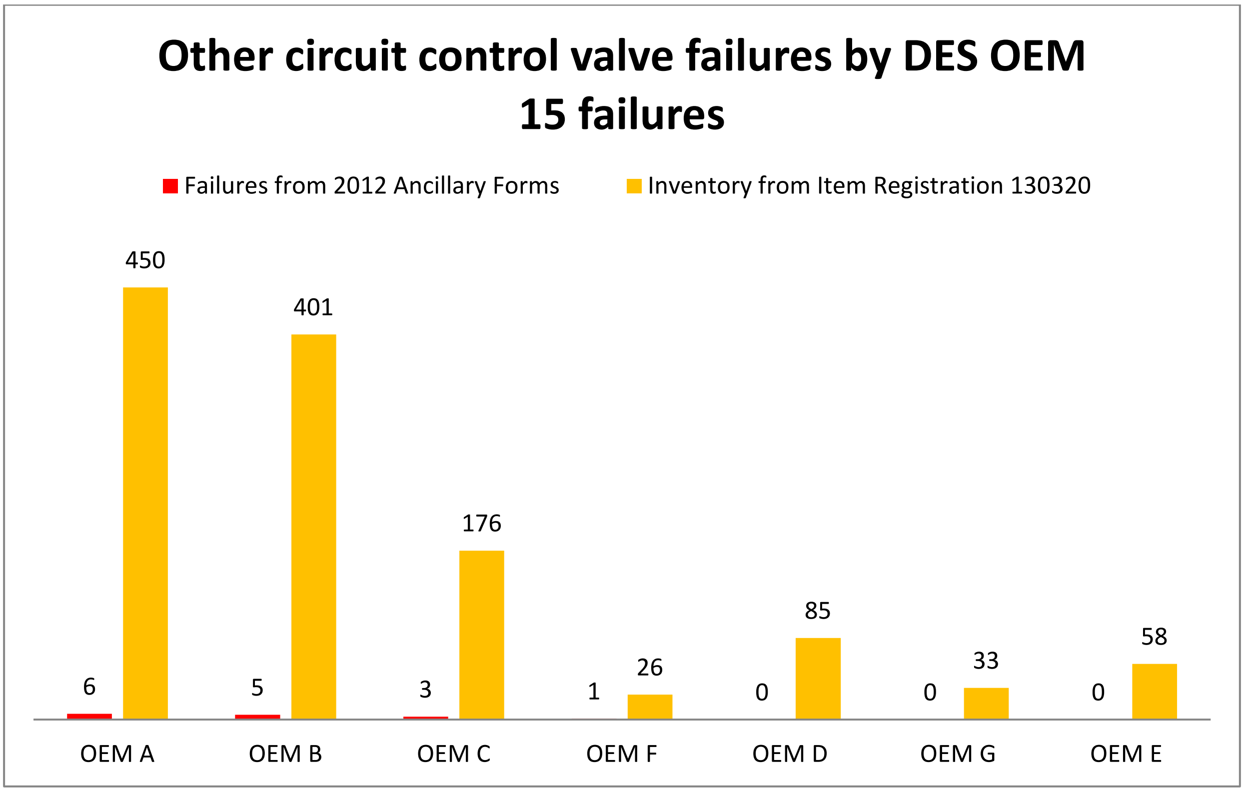

Figure 57

6.4.4 COOLING SYSTEM SENSOR FAILURES

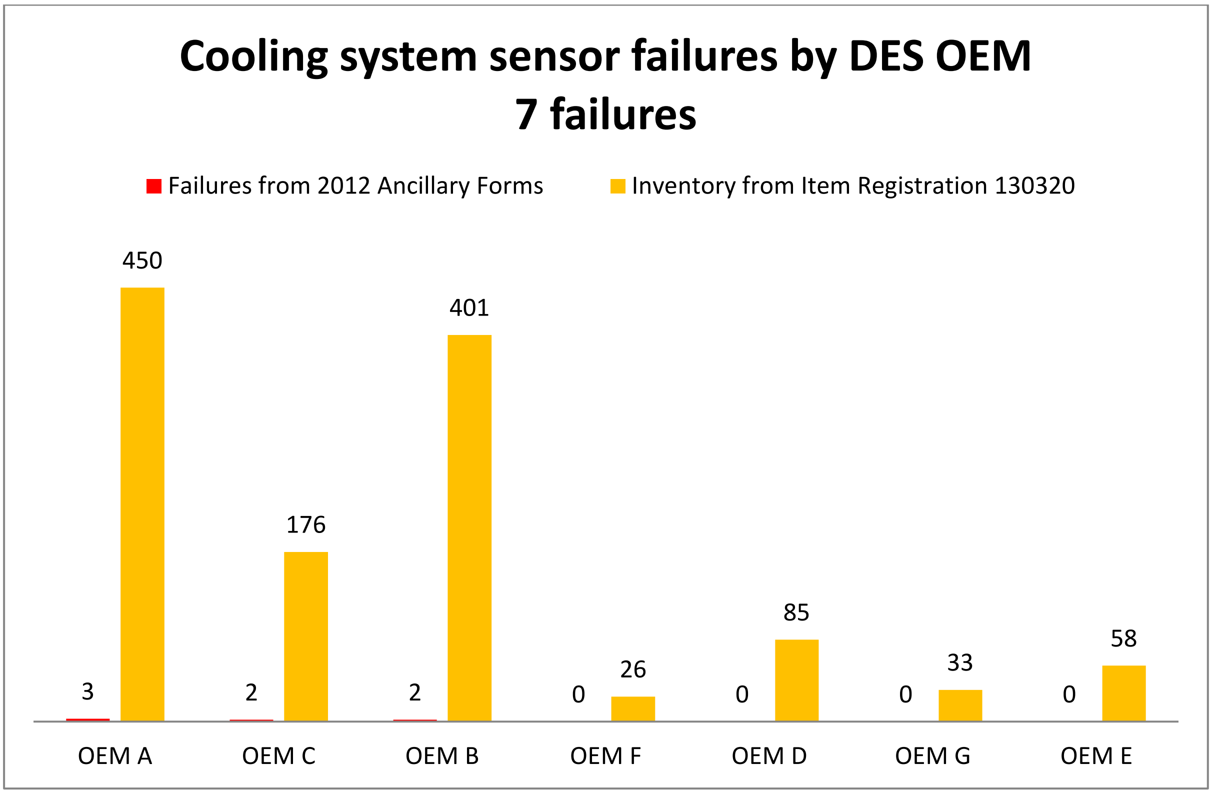

Figure 58

7.0 CONCLUSIONS

7.1 Top 10 failure modes

The top 10 failure modes from the 181 ExDES failures during the period January to December 2012 in the NSW underground coal mining industry are shown below:

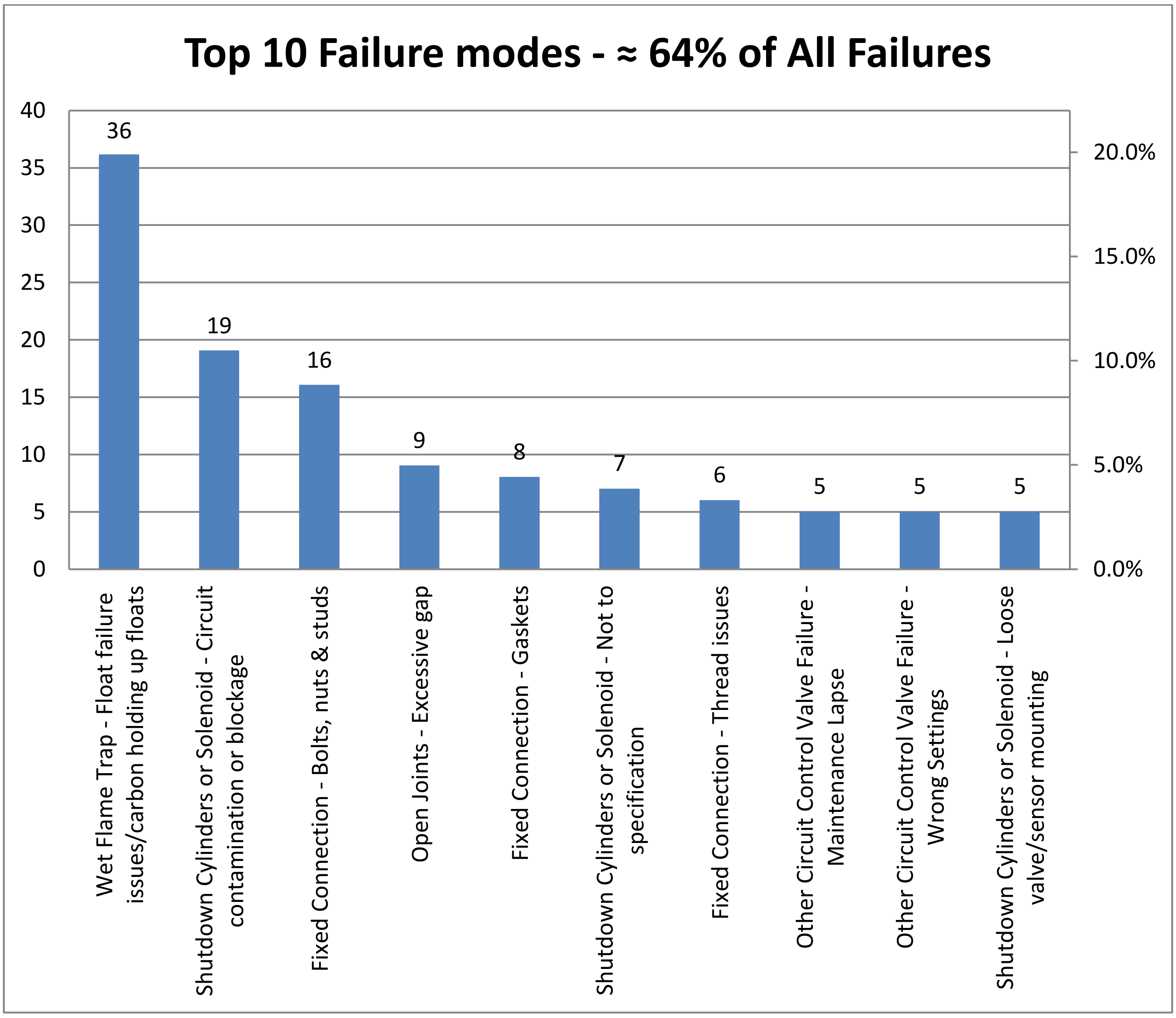

Figure 59

7.2 PROPOSED DESIGN VS. MAINTENANCE RECOMMENDATIONS

Maintenance recommendations dominate in wet flame trap and water level sensors, while design recommendations dominate in shutdown cylinders, fixed connections and open joints. Equal weighting of design and maintenance recommendations is noticed in other circuit control valves and cooling system sensors.

However, a substantial portion of maintenance recommendations proposed could be obviated by incorporating appropriate design modifications. This would help alleviate the extent of breakdown maintenance required and resources could be better deployed towards routine maintenance.

7.3 FUNCTIONAL SAFETY MANAGEMENT

The data analysis clearly reveals that almost all failures were due to systematic* issues as opposed to random hardware failures**. An effective mechanism to deal with the systematic issues which involve both the OEM and the End-users, as proven in other safety critical industries, would be to introduce a Functional Safety Management regime resulting in increased accountability of both parties.

* Systematic failure: failure; related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation or other relevant factors.
(IEC/AS 61508.4-2010)

** Random failure: failure; occurring at a random time, which results from one or more of the possible degradation mechanisms in the hardware.
(IEC/AS 61508.4-2010)

o-o-o-o

8.0 ACRONYMS & DEFINITIONS

DES	Diesel Engine Shutdown System
End-user	Mine site/coal operation
ExDES	Explosion Protected Diesel Engine System
Industry	NSW underground coal mining industry
MDA	Mine Design Approval (NSW Trade & Investment)
MDR	Mine Design Registration (NSW Trade & Investment)
OEM	Original Equipment Manufacturer

9.0 STATUS OF DOCUMENT

9.1 LIABILITY

This report is based largely on the information provided by NSW Trade & Investment Mine Safety, OEMs, End-users and other stake holders.

Shakti Corp Pty Ltd, its employees and its reviewers accept no liability, consequential or otherwise, for the correctness of the standards and/or the references on which the report is based or from the use of the results obtained from this report.

To the extent permitted by law,

1. Shakti Corp excludes all warranties, conditions and the consumer guarantees, whether implied by law or otherwise; and

2. Shakti Corp's liability under in relation to the services it provides is limited to, at its option:
   a. Supplying of the services again; or
   b. Payment for the cost of having the services supplied again.

3. Shakti Corp is not liable to the Client for any indirect or consequential loss or damage (including loss of revenues, profits, business or goodwill) which arises out of or in connection with the supply of these services.

10.0 BIBLIOGRAPHY

1. Safety Bulletin SB12-01 – *Inservice failures of explosion protected diesel engine systems during 2010 and 2012*

2. ExDES 56-1-m Incidents 130123.xls - NSW Trade & Investment Mine Safety.

3. 56-1-m ExDES All Data 130311 EXTERNAL.xls – NSW Trade & Investment Mine Safety.

4. Copy of Item Registration 130320.xls – NSW Trade & Investment, Mine Safety.

5. 130123 ExDES 56-1-m Incident Analysis for 2012.xls – NSW Trade & Investment, Mine Safety.

6. DES Design rego holders & takeovers.xls – NSW Trade & Investment, Mine Safety.

7. Report 13012_V1R4 – Ex-DES Failures Analysis 2012 – DTI Internal Report, May 2013 – NSW Trade & Investment Mine Safety

Annexure A

Ancillary Report

Ancillary Report – In Service Failure of Explosion Protected Diesel Engine Systems, Clause 56(1)(m)

Pursuant to Clause 59 of the Coal Mine Health and Safety Regulation 2006, this form is gazetted and additional to the Coal Notification of Incident Form. This Report must be completed and submitted to NSW Trade & Investment within 21 days for all notifiable incidents subject to Clause 56(1)(m) in relation to explosion protected diesel engine systems.

1 About the coal operation where the incident occurred:

Name of coal operation:	
Date of incident:	Mine Identification No. (if known):

2 Machine identification

MDR[1] or MDA[1]:	MIR[1]:
Machine Manufacturer:	Machine Model:
Machine Owner:	

3 Last inspections

Date of last Code D:	Registered Service Facility (RSF) No.:
Date the failed component / part of system was last inspected or tested:	

4 Type of Ex Failure:

There was potential for, or there was evidence of: (only tick the most likely one)

☐ Spark external to engine ☐ Flame external to engine ☐ Surface temperature to exceed 150 deg C

5 Location of failure – Diesel engine system component OR Control system:

Which part of the diesel engine system failed? (tick one – root cause only)

☐ Exhaust flame trap (wet/dry) ☐ Exhaust manifold ☐ Intake flame trap & housing ☐ Forced induction (turbo / supercharger)	☐ Engine block & cylinders ☐ Intake manifold ☐ Exhaust pipe(s) ☐ Engine head	**If one of these components is selected, go to 6 below.**
☐ Pneumatic/hydraulic control system	☐ Electrical control system	**If one of these control systems is selected, go to 7.**

6 Failure Mode of Engine Component

Which major component failed? Tick one from this column:	**How did the major component fail?** Tick one only (initial cause) from the same row:	
☐ Wet flame trap (conditioner):	☐ Exhaust carbon holding up floats ☐ Float failure issues ☐ Structural failures	☐ Water below LWCO[2] when engine stops ☐ Blocked breather ☐ Excessive backpressure ☐ Other
☐ Fixed connection (issues):	☐ Bolts, nuts & studs ☐ Gaskets ☐ Thread issues	☐ Surface flatness ☐ Damage ☐ Other
☐ Open joints (issues):	☐ Surface flatness / finish ☐ Excessive gap ☐ Thread issues	☐ Bolts, nuts & studs ☐ Damage ☐ Other
☐ Positive flame trap element:	☐ Damage ☐ Excessive internal clearances	☐ Other
☐ Structural failures:	☐ Fatigue / Cracking ☐ Corrosion ☐ Physical contact damage	☐ Catastrophic failure ☐ Turbo seal failure ☐ Other
☐ Excessive surface temperature:	☐ Cooling system failure	☐ Other
☐ Other (please specify the component and how it failed)		

Go to Question 8.

[1] MDR – Mine Design Registration number. MDA – Mine Department Approval number. MIR – Mine Item Registration number.
[2] LWCO – Low Water Cut-Out.

7 Control system failure

Only answer this question if directed to do so from Question 5.

Which component failed? (tick one from this column)	**How did the control system fail?** (tick one from this column)
☐Water level sensors ☐Shutdown cylinders or solenoid ☐Cooling system sensors ☐Exhaust temperature sensors ☐Engine oil pressure sensors ☐Other circuit control valve failure ☐All or multiple sensor failure	☐Valve/sensor faults ☐Wrong settings ☐Circuit contamination or blockage ☐Installed wrong ☐Loose valve/sensor mounting ☐Hose failure
Other (please specify)	Other (please specify)

8 Recommendations for prevention

Causal factors:

If more space is required, please attach additional page(s)

Would a **design** change prevent or minimise failure? ☐Yes If yes, describe how below ☐No

If more space is required, please attach additional page(s)

Would a **Code D overhaul** change prevent/minimise failure? ☐Yes If yes, describe how below ☐No

Would a **maintenance / testing** change prevent/minimise failure? ☐Yes If yes, describe how below ☐No

If more space is required, please attach additional page(s)

9 Other Comments

If more space is required, please attach additional page(s)

10 Signature

Have you informed the manufacturer of this failure? ☐ Yes ☐ No

Signature of Manager of Mechanical Engineering:	Name: Date signed:

NOTES

1. Clause 56(1)(m) of the *Coal Mines Health and Safety Regulation 2006* requires notification of any incident or matter involving the '*in-service failure of the explosion protection characteristics of explosion protection plant*'.

   This Ancillary Report is to provide a consistent approach for all underground coal mines.

2. The AS 3584.2 standard stipulates the explosion protection characteristics and defines the components (characteristics) which form part of an explosion protected diesel engine system.

3. All '*diesel engine system used in underground mines at a coal workplace*' must be both design and item registered under Part 5.2 of the *OHS Regulation 2001* before use.

4. For the purpose of clarifying the above provisions, the Department requires the following to be reported –
   '*Any incident or matter where it is evident an explosion protected diesel engine system has been (or is likely to have previously been) operating in a **non-explosion protected condition***'.
   A **non-explosion protected condition** means a condition which has potential to ignite either; coal dust on the surface of the engine; or methane in the surrounding atmosphere.

5. Examples of **matters which must be notified** include, (but are not limited to) –

   a) any explosion protection characteristic failures when discovered during use, routine maintenance or overhaul;

   b) the failure of a diesel engine system to shut down when required by the control sensors, for example – loss of water in the scrubber; excessive system temperature (above 150°C); failure of engine cooling system, etc;

   c) a catastrophic failure of the diesel engine system which protrudes external to the engine, such as turbochargers, superchargers, piston, valves, connecting rods, etc.;

   d) the failure of a primary and backup control sensor, for example temperature, floats, etc;

   e) the failure of an explosion protected open joint which exceeds the specified dimensions for explosion protection;

   f) looseness of any explosion protected fixed joint (gasket joint);

   g) deterioration or significant damage to any dry type flame trap;

   h) the failure or loosening of any screw type explosion protection joint;

   i) the failure to replace any explosion protected component, such as a cap, plug, flame trap or other like component, after carrying out maintenance activities;

   j) any evidence of a fire or spark external to the explosion protected joints, flametrap or water conditioner ;

   k) any catastrophic failure of a turbo in a dry type exhaust system;

   l) failure of the cooling system, and/or sensors such that the external surface temperature of the diesel engine and /or exhaust gas temperature at the flametraps appears to have exceeded 150°C;

   m) evidence of thermal degradation of an exhaust filter; and

   n) the water level not being at or above the minimum safe water level when the diesel engine shuts down automatically.

6. Examples of **matters which are not required to be notified** include, (but not limited to) –

   a) the failure of a single sensor where backup sensors are installed, functional and the diesel engine system is not in a un-explosion protected condition; for example –

      (i) a single exhaust float failure where a backup float is fitted and functional;

      (ii) a single temperature sensor failure where a backup sensor is fitted and functional;

   b) the failure of an engine to start;

   c) stopping of the engine system because a sensor has operated;

   d) failing of the engine cooling system where the engine shuts down; and

   e) any other failure which does not render the diesel engine system in an un-explosion protected condition.

Please contact your local NSW Trade and Investment office if you require assistance completing the form.

NSW Trade and Investment Offices located in coal mining regions
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Annexure B

Consolidation of Failures

Bases

ExDES Failure Analysis 2012

Exhaust Flame Trap

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Exhaust carbon holding up floats		Carbon buildup
		Component failure - orifice
Float failure issues		Component failure - humphrey valve
Water below LWCO when engine stops		Component failure - other
Structural failures		Structural failure
Blocked breather		Blocked breather
Excessive backpressure		Accident
Other		Need for more frequent component maintenance
Mechanical damage to the scrubber tank		Maintenance Lapse
Pressure relief valve		Safety system bypass
Crimped Hose		Unknown
Not Specified		Not Specified

ExDES Failure Analysis 2012

Exhaust Pipes

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Surface Flatness	→	Surface Flatness
Gaskets	→	Gaskets
Bolts, nuts & studs	→	Bolts, nuts & studs
Other		
Bolts , nuts & studs – design		
Bolts, nuts & studs – maintenance		
7/16 JIC cap missing	→	7/16 JIC cap missing
Not Specified	→	Not Specified

ExDES Failure Analysis 2012

Intake Flame Trap & Housing

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Excessive gap	→	Excessive gap
Excessive internal clearances	↗	
Fatigue / Cracking	→	Fatigue / Cracking
Gaskets	→	Gaskets
Surface Flatness	→	Surface Flatness

ExDES Failure Analysis 2012

Exhaust Manifold

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Gaskets	→	Gaskets
Bolts, nuts & studs	→	Bolts, nuts & studs
Other		
Bolts , nuts & studs – design	→	
Broken mounting bolts	→	
Loose connection and gaskets	→	Loose connection and gaskets

ExDES Failure Analysis 2012

Shutdown Cylinders or Solenoid

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Loose valve/sensor mounting		Loose valve/sensor mounting
Installed wrong		
Wrong Settings		Installed wrongly/Wrong Settings
Valve / Sensor faults		
Circuit contamination or blockage		Circuit contamination or blockage/Shutdown cylinder sticking
Other		
Shutdown cylinder sticking		
Not specified		Not specified
Structural Failure		Structural Failure
Spring failed		Spring failed
internal buffer in shutdown cylinder undersized		Not to specification

ExDES Failure Analysis 2012

Other Circuit Control Valve Failure

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Installed wrongly		Installed wrongly
Valve / sensor faults		Valve / sensor faults
Wrong Settings		Wrong Settings - Prompting tamper proofing
Circuit contamination or blockage		Maintenance Lapse
		Unknown
Loose valve/sensor mounting		
Hose failure		Hose failure
Other		
Structural Failure		

ExDES Failure Analysis 2012

Cooling System Sensors

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Re-categorised		
Valve / sensor faults		Valve / sensor faults
Circuit contamination or blockage		Maintenance Lapse
		Not specified

ExDES Failure Analysis 2012

Water Level Sensors

Failure Consolidation

Ancillary form fields	Distribution	Consolidation
Wrong Settings		Wrong settings – Prompting tamper proofing
Circuit contamination or blockage		Unknown
Valve / sensor faults		Re-categorised
Other		
Crimped Hose		
System bypass		System bypass/Maintenance lapse