SHAKTI CORP SAFETY ENGINEERING

Ex-DES Failures Analysis 2014

Ex-DES Failures Analysis – 2014

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

Appendix B: Reclassification Rationale – Engine component failures

Appendix C: Reclassification Rationale – Pneumatic / Hydraulic Control System failures

Appendix D: Reclassification Rationale – Electrical Control System failures

1 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 during the period January to December 2014.

The study was conducted for NSW Trade & Investment.

*Coal Mine Health and Safety Act 200*2 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

(1) 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

NSW Government - Mine Safety Report No. SB12-01 of March 2012 introduced an Ancillary Report Form for collection of all ExDES reported 56(1)(m) incidents. The main purpose of the Ancillary Report was to improve the quality of data gathered, a copy of which is attached in Appendix A of this report.

ExDES failures collected using the Ancillary Report have been analysed and reported for the calendar years 2012 to 2014.

Report 13012	2012
Report 14009	2013
Report 15004	2014

In comparison with data collected prior to 2012, there has been a consistent improvement in the quality, organisation and the extent of data received with the Ancillary Reports during the period 2012 to 2014.

2 Overview

Figure 1 shows the reported failure rate per 100 DES systems per year from 2007 to 2014.
Figure 2 shows the number of reported failures from 2009 to 2014.

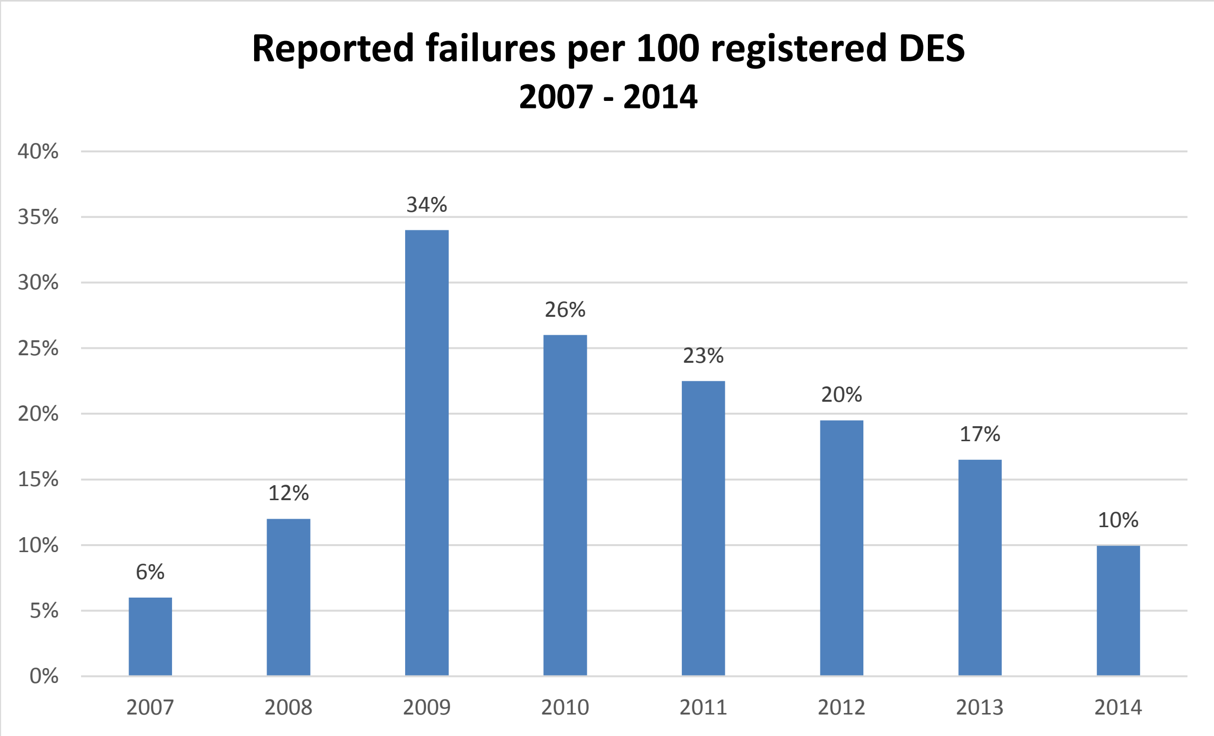


Figure 1

Figure 2

The number of reported incidents overall has shown to be steadily decreasing, from 181 incidents in 2012 to 165 incidents in 2013 and 130 incidents in 2014. However, as seen in the figures below, this trend is not apparent at the coalfield level.

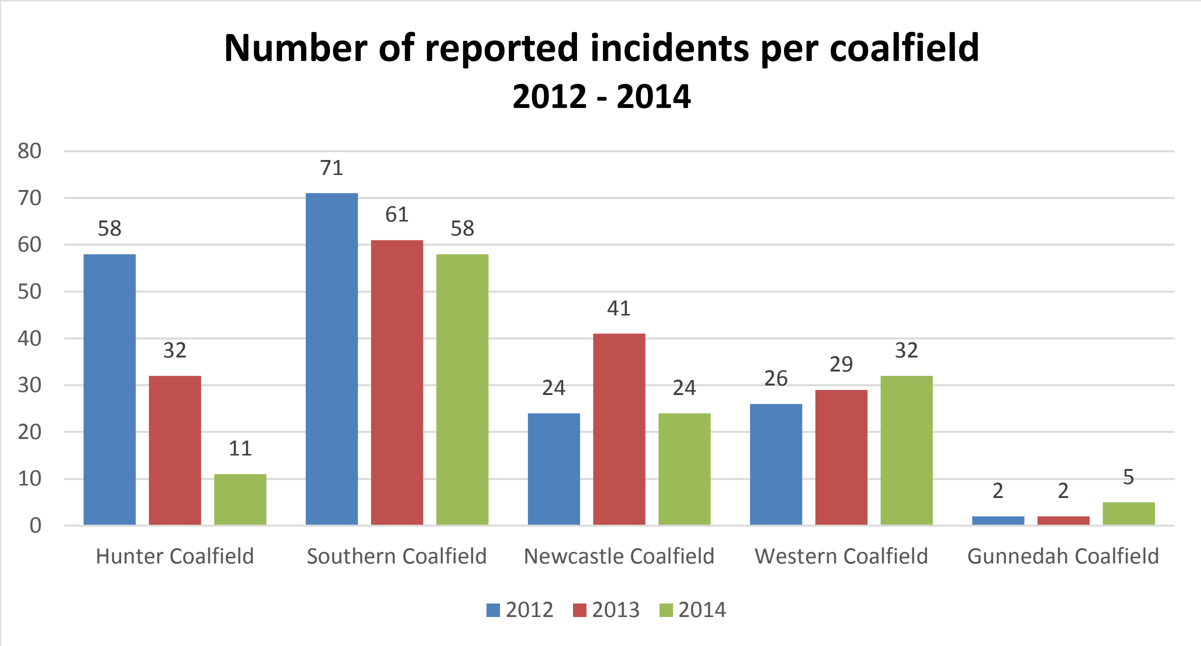


Figure 3

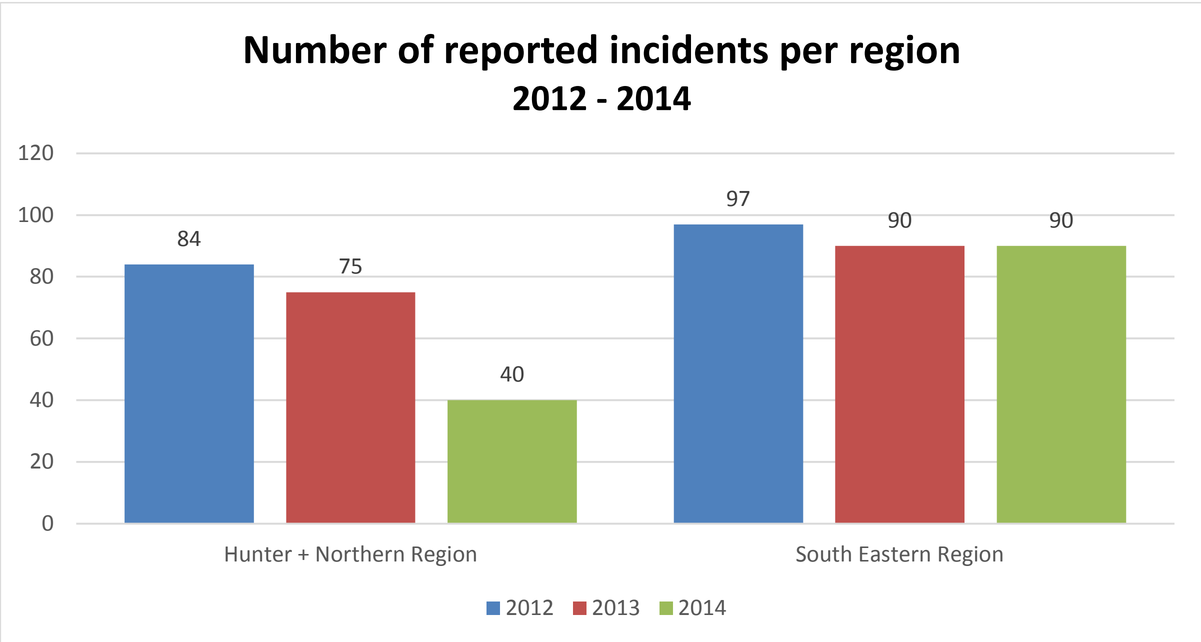


Figure 4

The number of reported incidents for individual mines can be seen in Figure 5 below. Mines without any reported DES failures have been omitted.

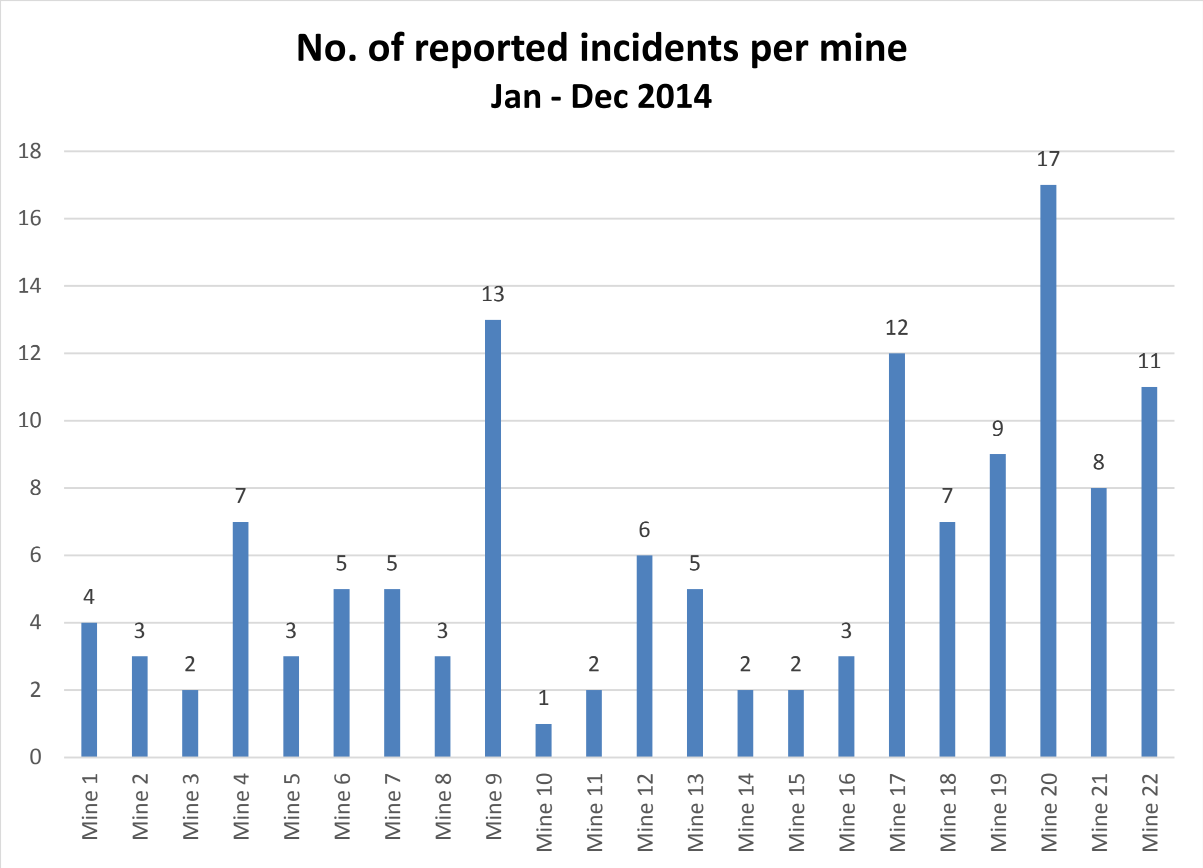


Figure 5

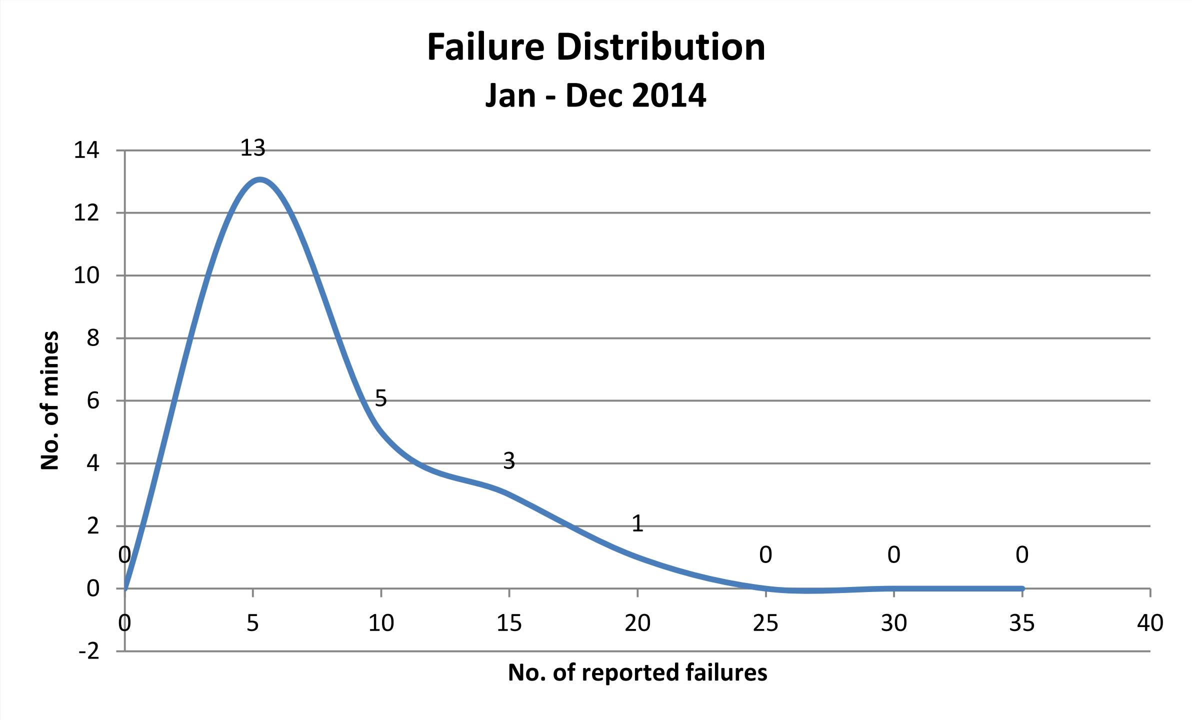


Figure 6

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

- Number of Mines with 0 failures: 0
- Number of Mines with 1 to 5 failures: 13
- Number of Mines with 6 to 10 failures: 5
- Number of Mines with 11 to 15 failures: 3
- Number of Mines with 16 to 20 failures: 1
- Number of Mines with 21 to 25 failures: 0
- Number of Mines with 26 to 30 failures: 0

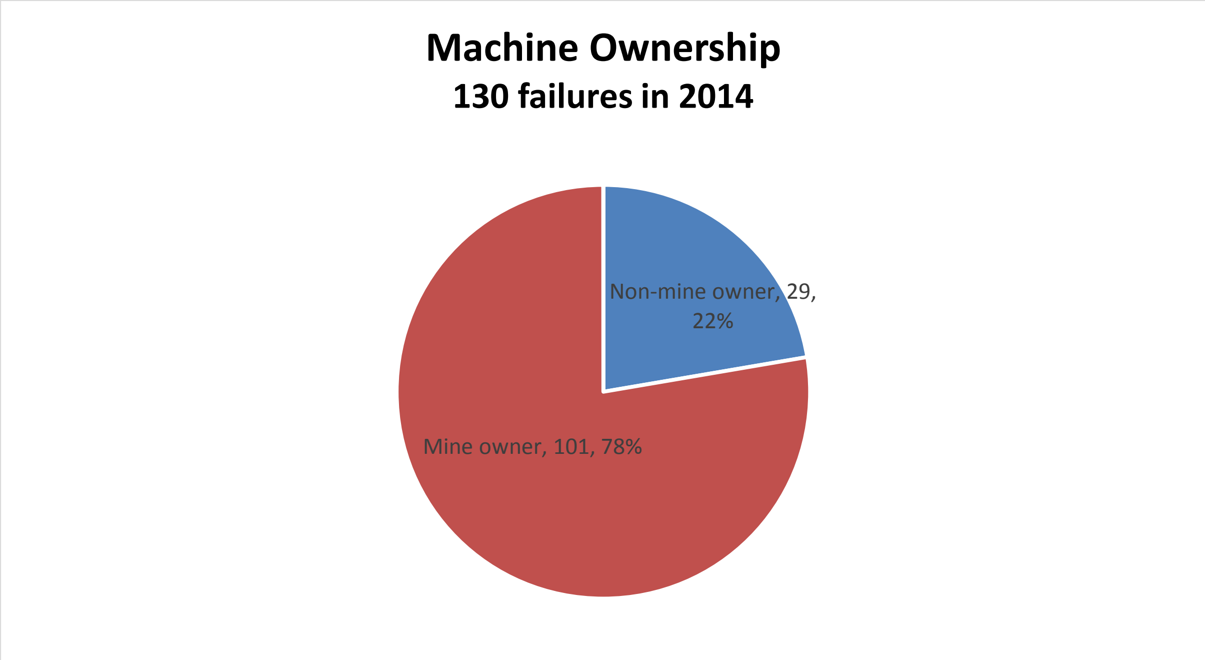
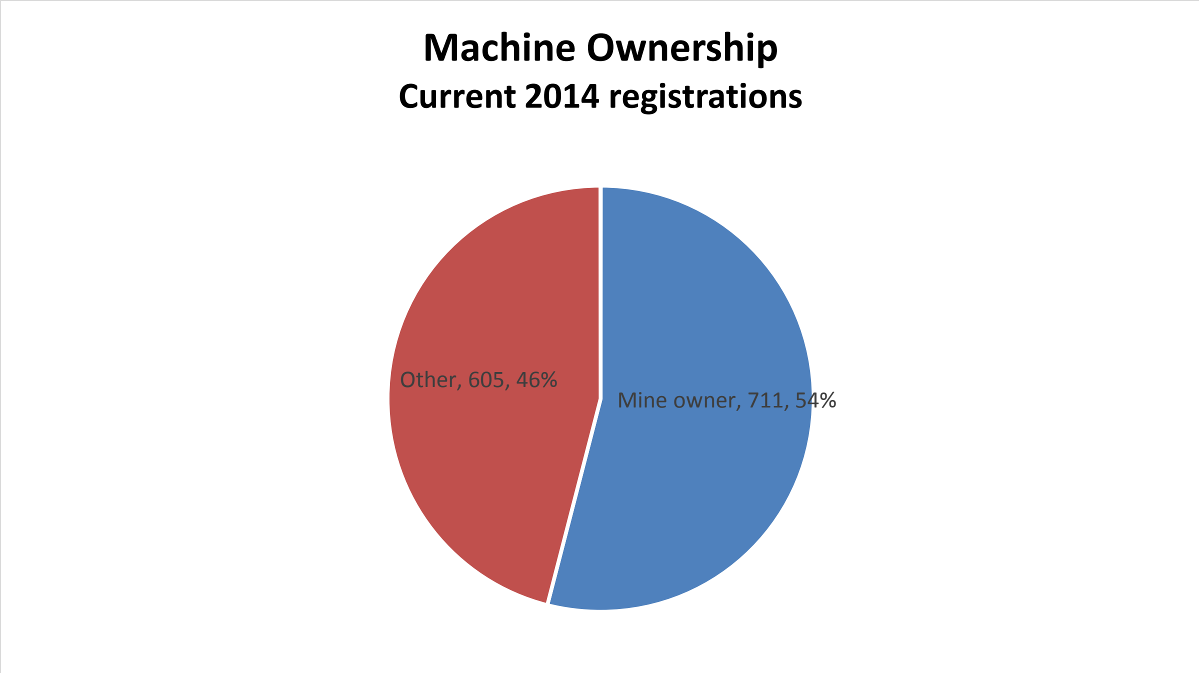


Figure 7

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 is almost a repeat of what was seen in the previous report, where the majority of reported ExDES failures came from mine owned machines. However, it remains that there may be incidents that go un-noticed / un-reported if they are detected once the machine is off the mine-site. Note the near 50-50 distribution of mine / non-mine ownership in Figure 8 below.



* Source: Master of Plant item registration 13.xlsx received on 16.02.2015; DES Item Reg – Current. Only items with a current MIR registration during the period of the 1st of January to the 31st of December 2014, inclusive, were factored.

Figure 8

3 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 System (DES) that failed and their modes of failure.

Part II: Miners' Recommendations

The Ancillary Report (Appendix 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 and presents them for each subsystem.

Part III: OEM Failures

This part of the study presents the results in terms of non-specific OEMs. It presents a ratio of the number of failures and locations to the number of machines in the inventory of the NSW Underground Coal Mining Industry.

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

4 Failure Locations and Modes

This section analyses the location and the components of the DES 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.

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)		

Figure 9
Excerpt from Ancillary Report

Out of the total of 130 incidents reported in 2014, Figure 10 shows the failure proportioning into three main categories.

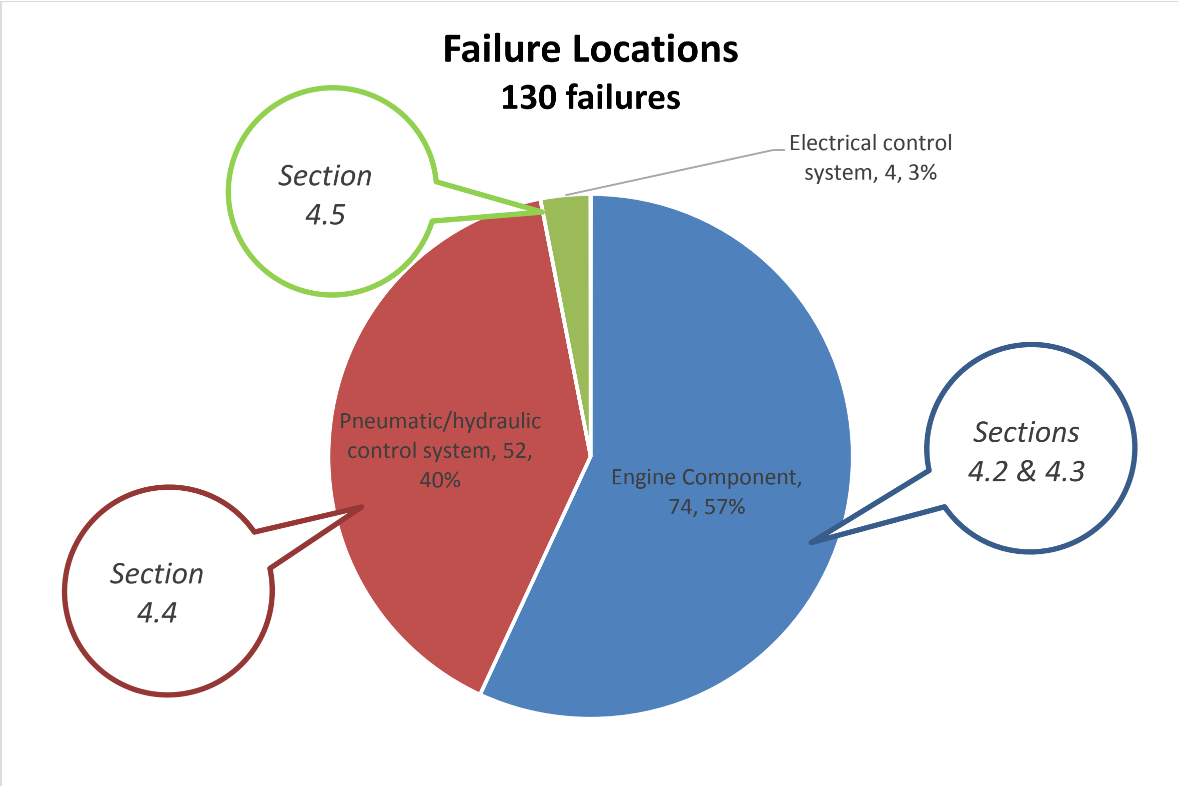


Figure 10

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 130 incidents to Major Engine or Control System components as per Table 1 below:

Failure Location		Incidents	% Contribution to failures
Pneumatic/hydraulic Control System		52	39%
Exhaust flame trap (wet/dry)	**Engine components**	21	16%
Exhaust manifold		15	11%
Intake manifold		13	10%
Intake flame trap & housing		5	4%
Exhaust pipe(s)		8	6%
Engine head		5	4%
Forced induction (turbo / supercharger)		5	4%
Engine block & cylinders		2	2%
Electrical control system		4	3%
Total Reported Incidents - 2014		**130**	**100%**

Table 1
Contributors to component failure

4.2 Failure locations of engine components – Breakdown

In Table 1, Engine components constitute 74 out of the 130 failures and are shown on a pie chart in Figure 11.

This section analyses the failures of Engine components in 2014, as shown in Figure 11 and repeated in Table 2.

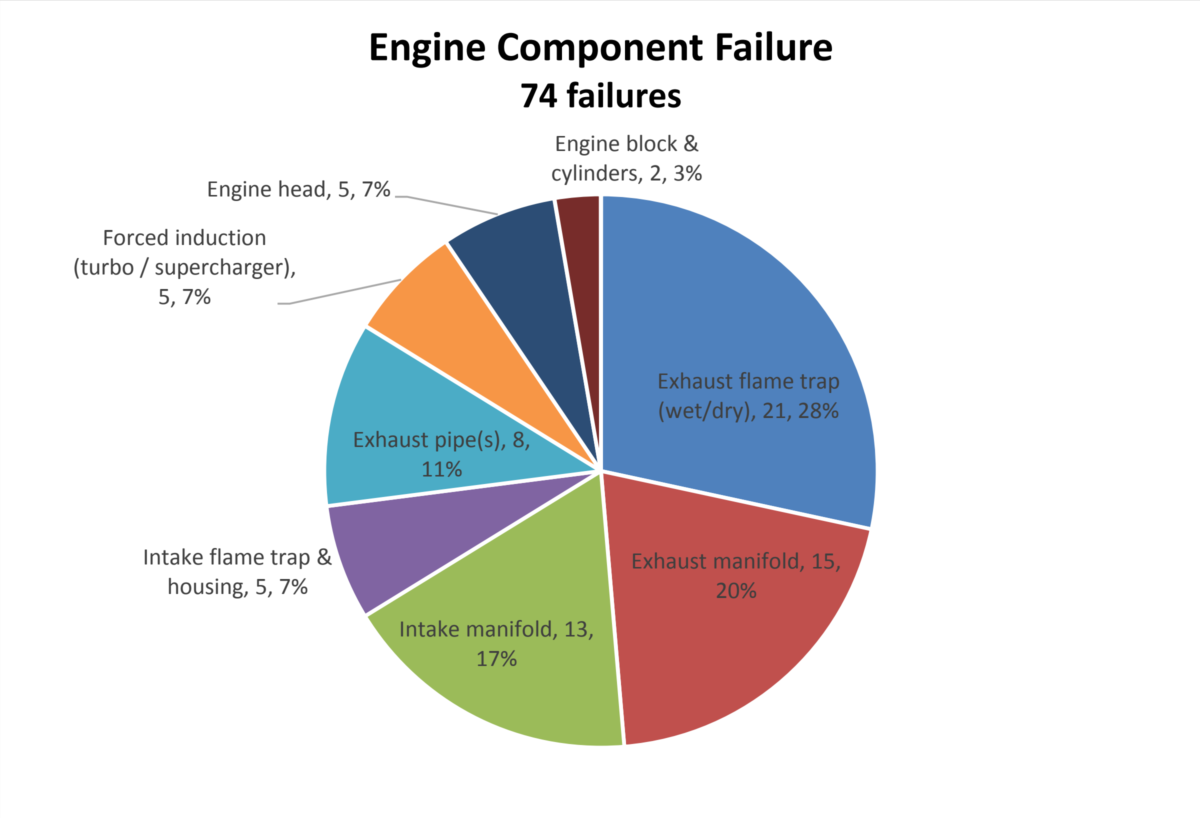


Figure 11

Engine component	Failures			% Contribution to total failures		
	2012	2013	2014	2012	2013	2014
Exhaust flame trap (wet/dry)	58	23	21	32%	14%	16%
Exhaust manifold	7	22	15	4%	13%	11%
Intake manifold	9	16	13	5%	10%	10%
Intake flame trap & housing	11	14	5	6%	8%	4%
Exhaust pipe(s)	12	9	8	7%	5%	6%
Forced induction (turbo / supercharger)	3	6	5	2%	4%	4%
Engine head	3	6	5	2%	4%	4%
Engine block & cylinders	1	4	2	1%	2%	2%
Total	104	100	74	58%	61%	56%

Table 2
Contributors to Engine component failure

4.2.1 Classification

The following pages present pie charts analysing failures of engine components and their failure modes:

- Pie chart as per Ancillary Reports
- Pie chart on reclassification (refer Appendix B) after:
  - Cognizance of causal factors
  - Categorisation of unspecified and "other" entries.

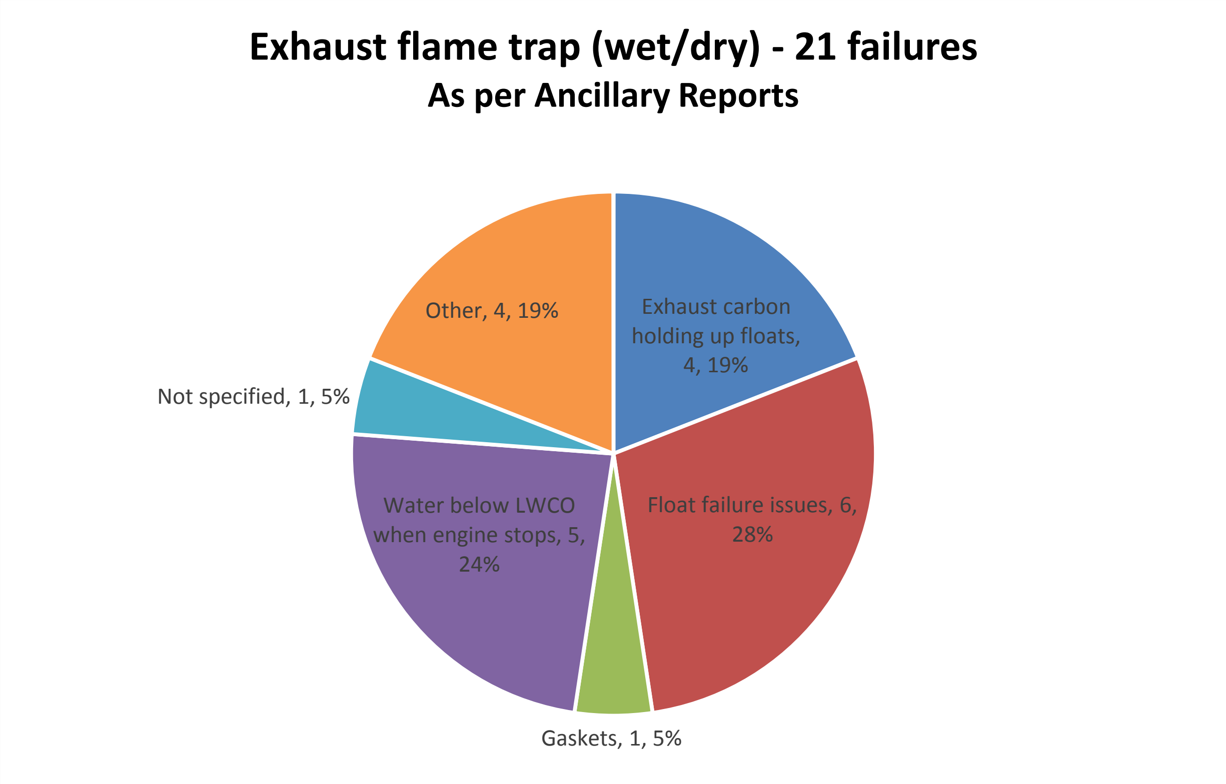


Figure 12

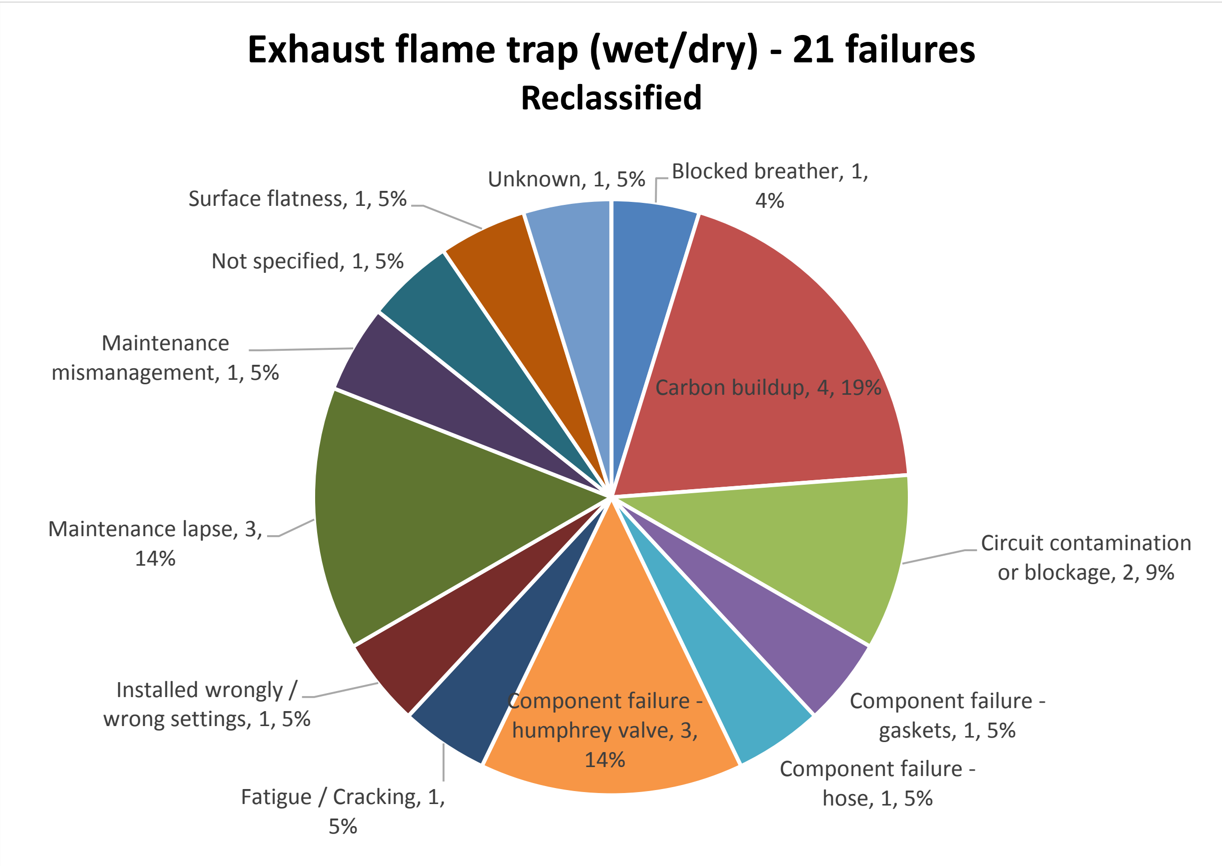


Figure 13

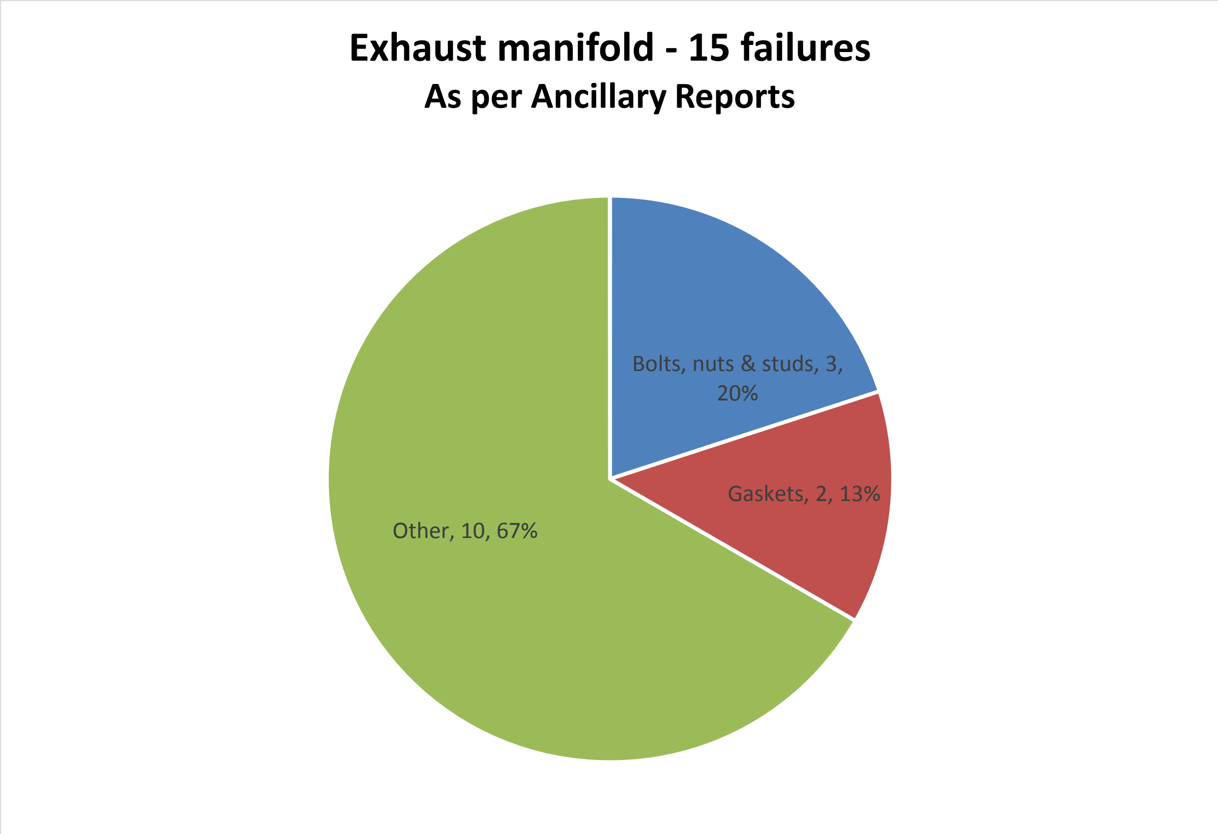


Figure 14

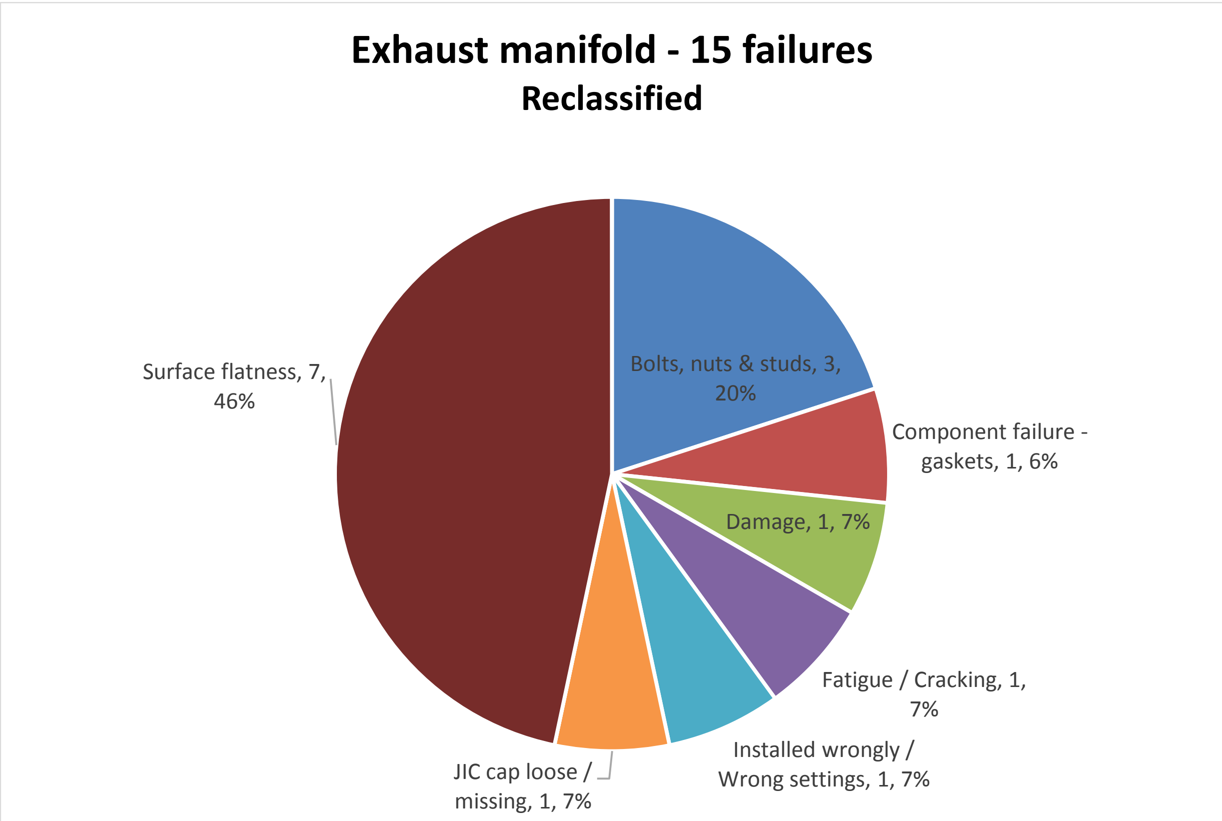


Figure 15

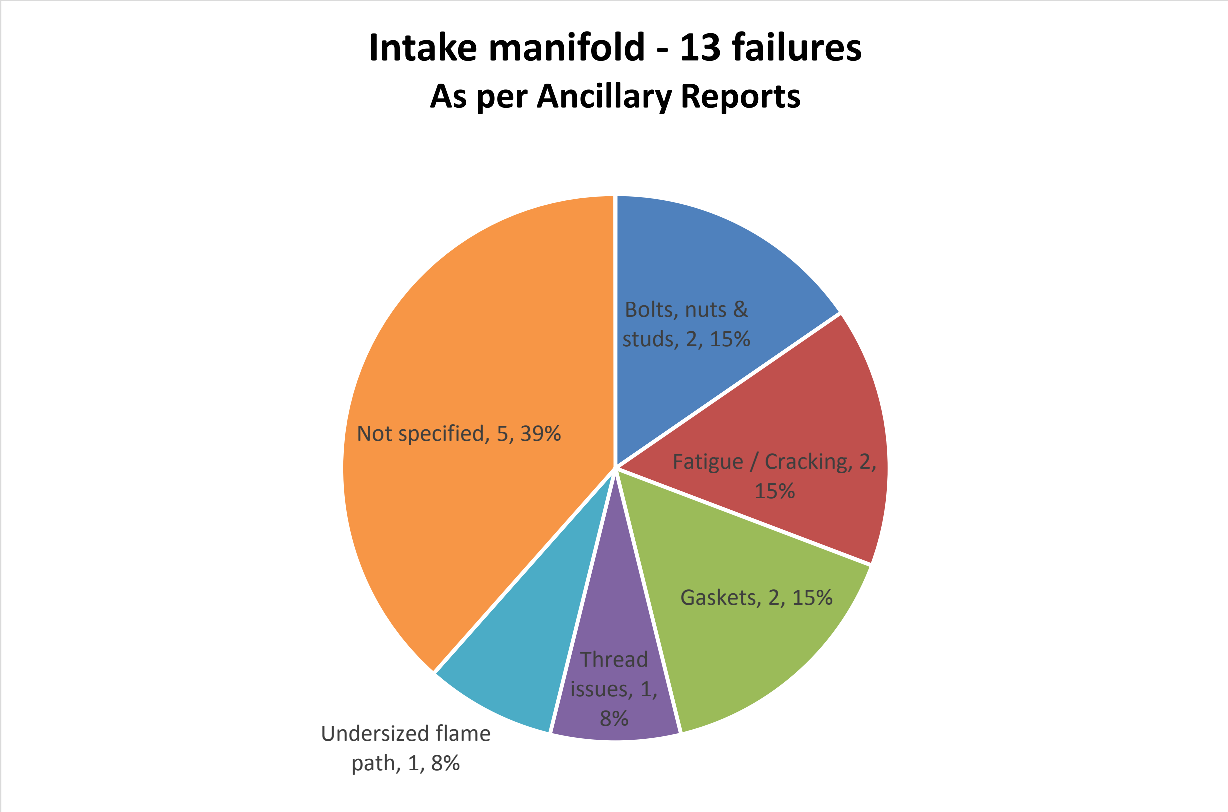


Figure 16

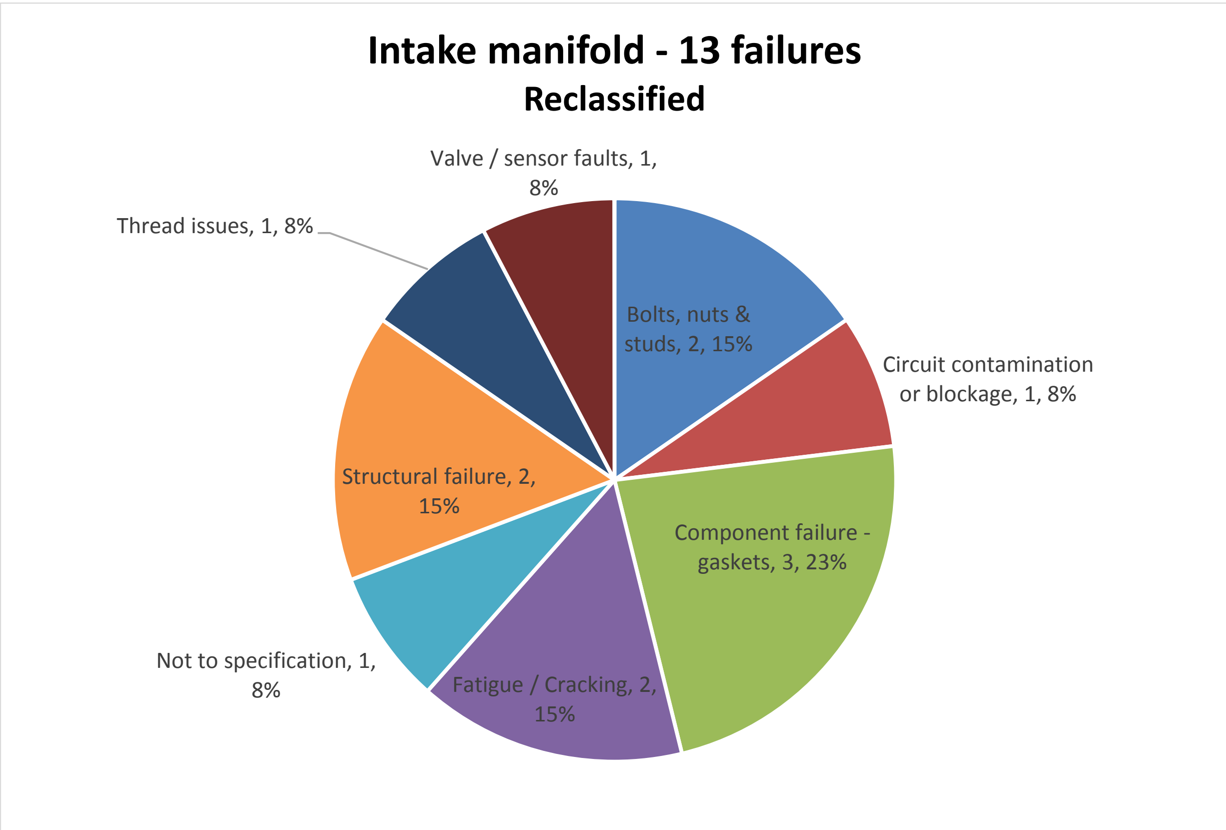


Figure 17

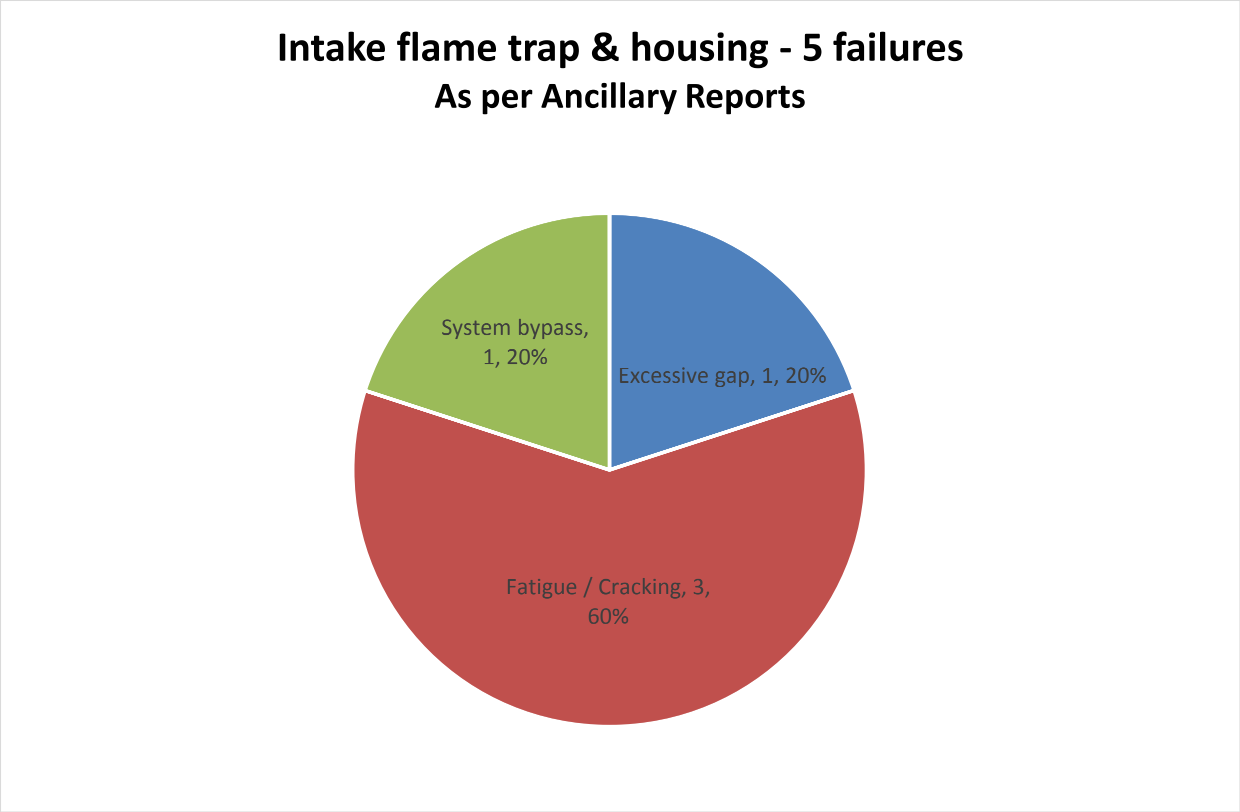


Figure 18

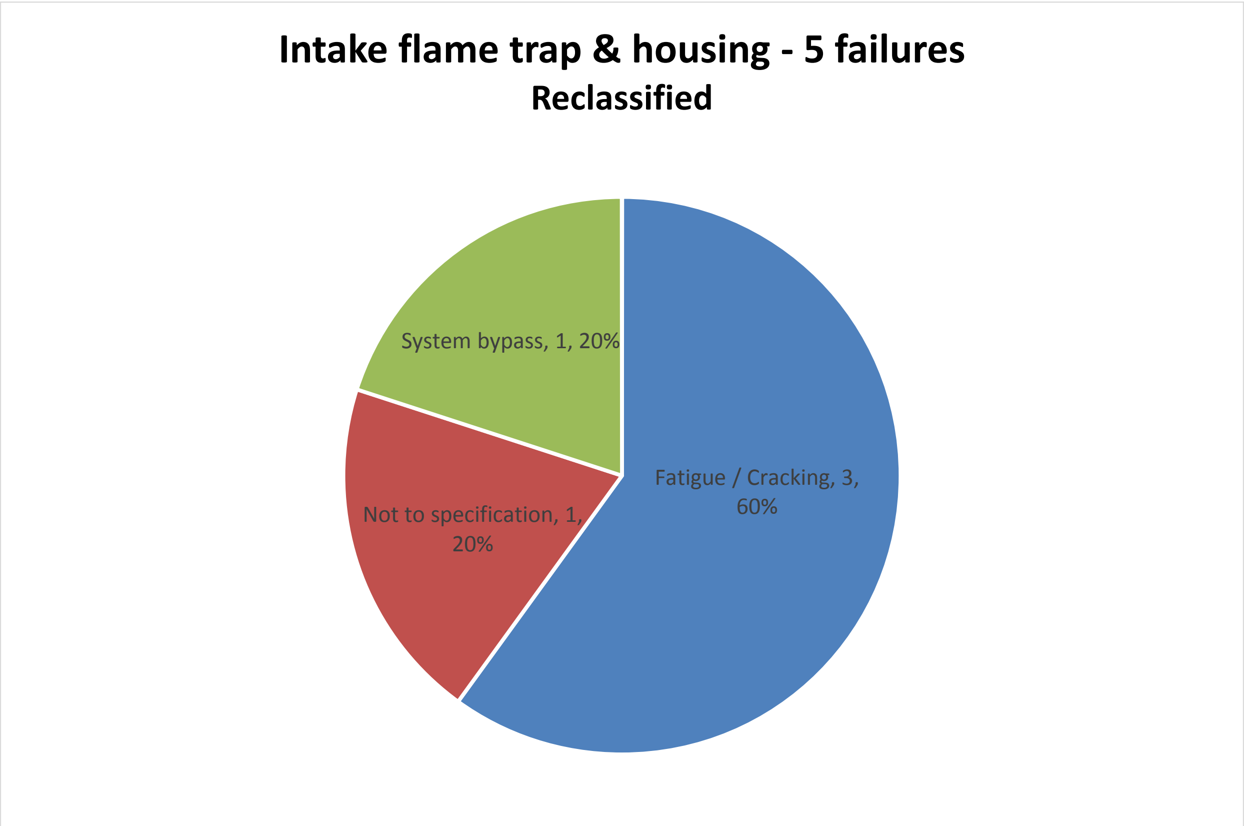


Figure 19

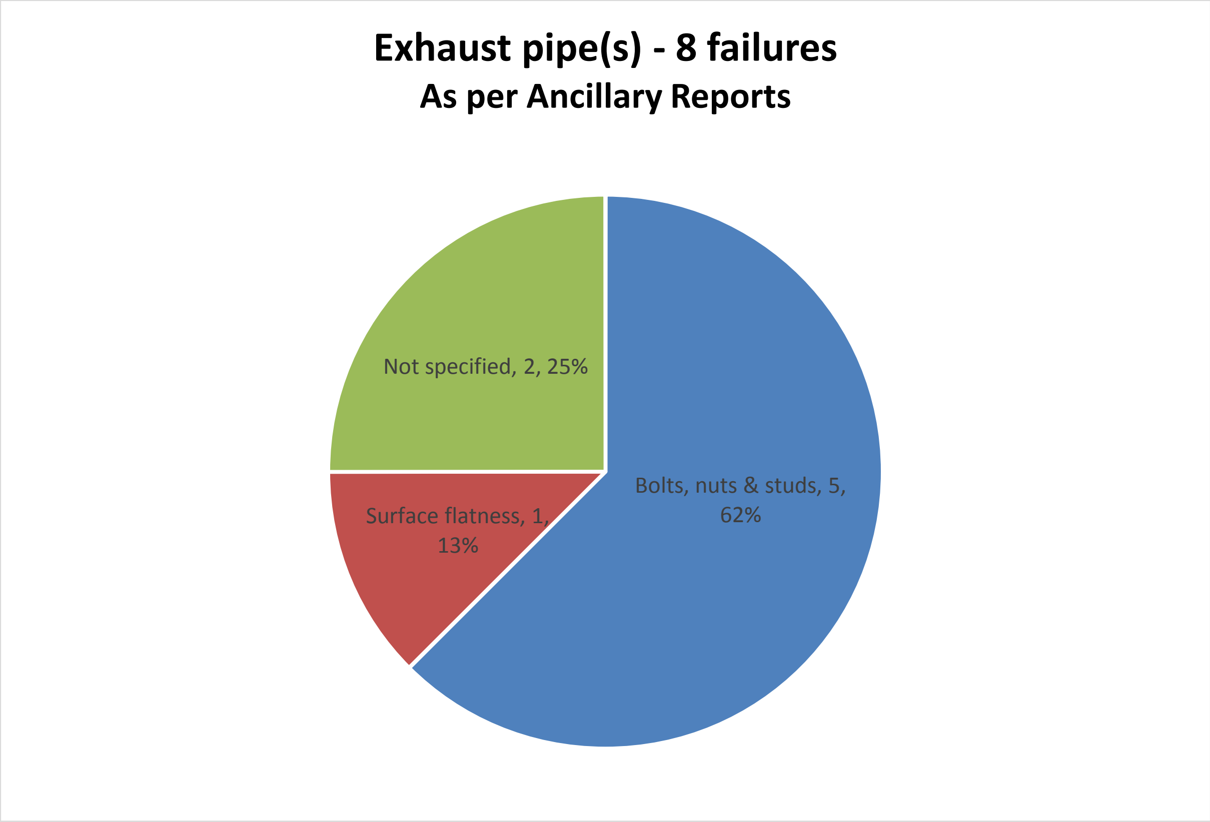


Figure 20

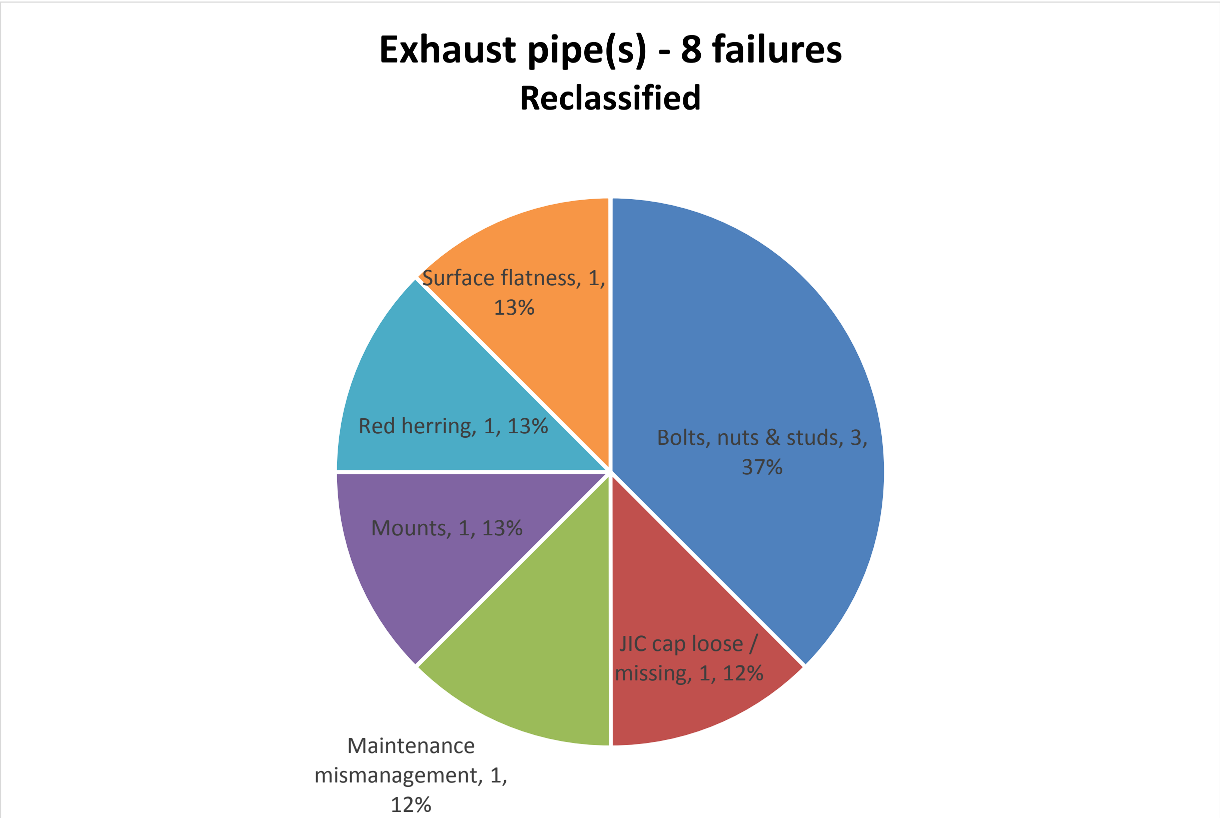


Figure 21

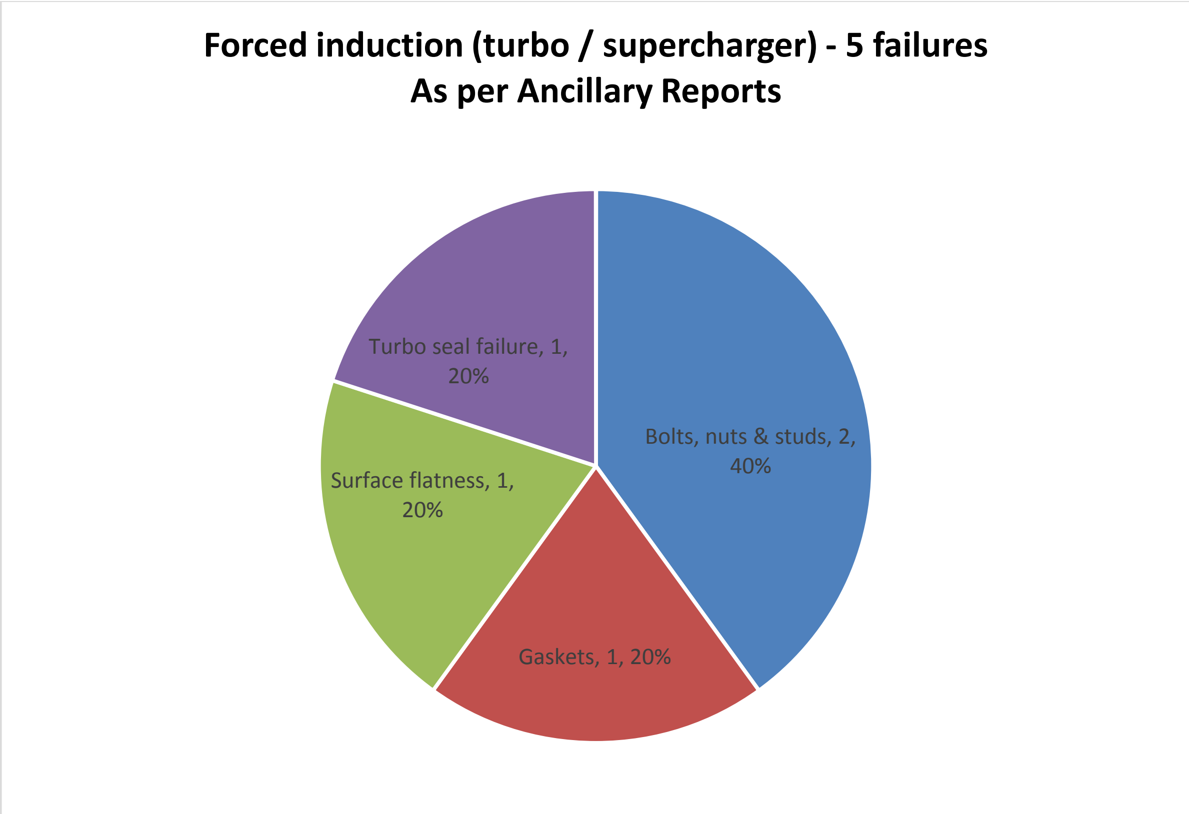


Figure 22

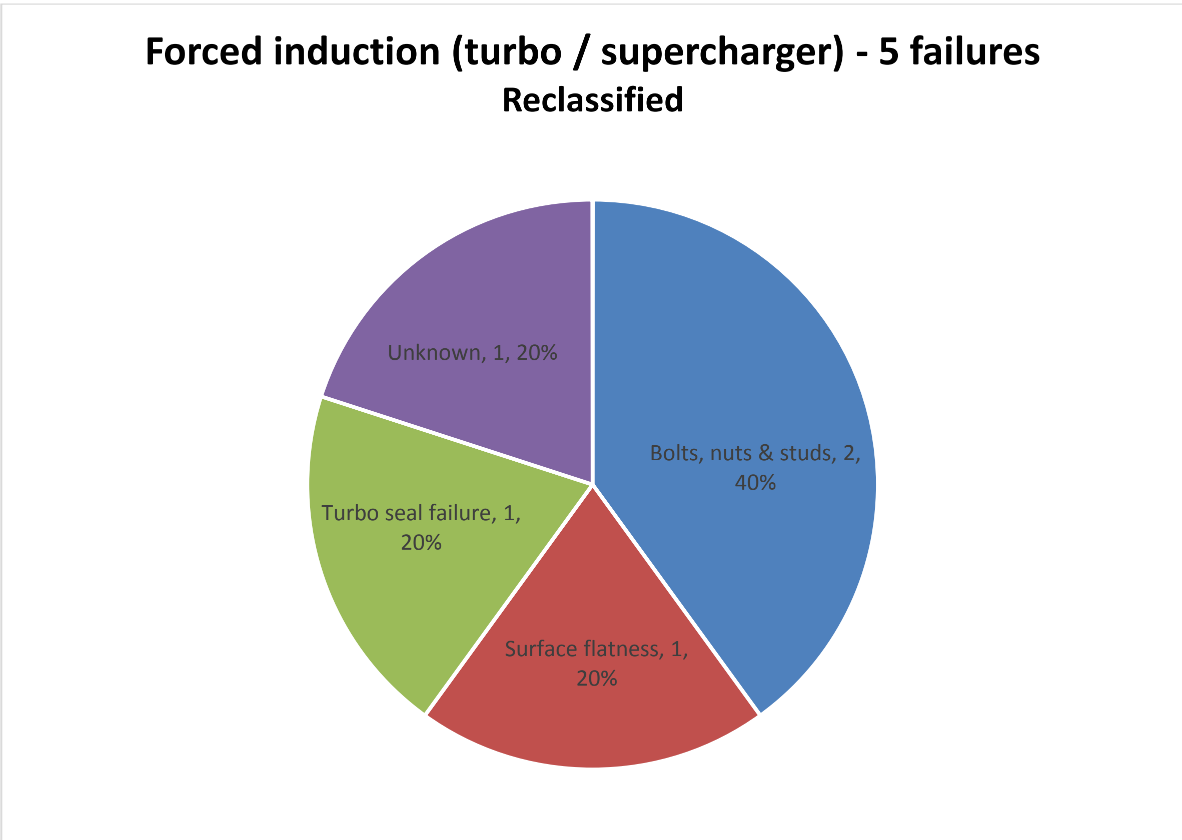


Figure 23

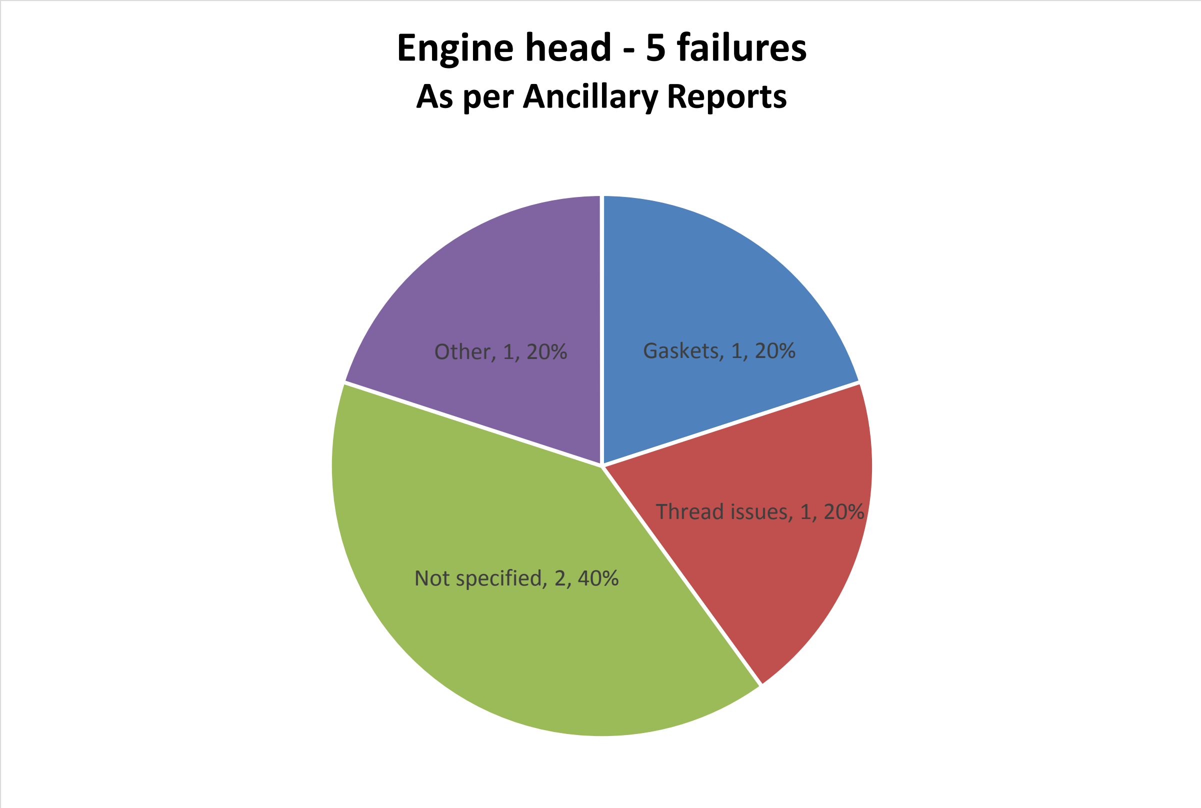


Figure 24

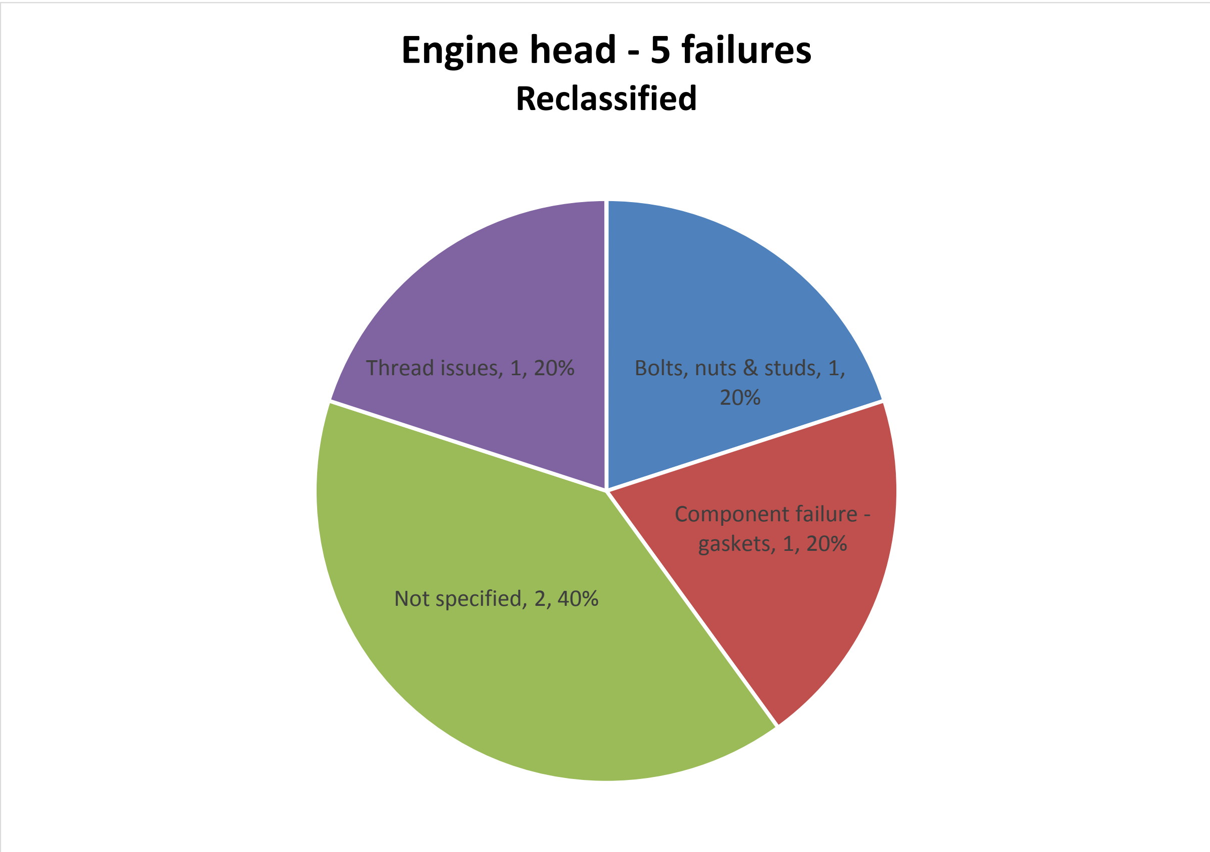


Figure 25

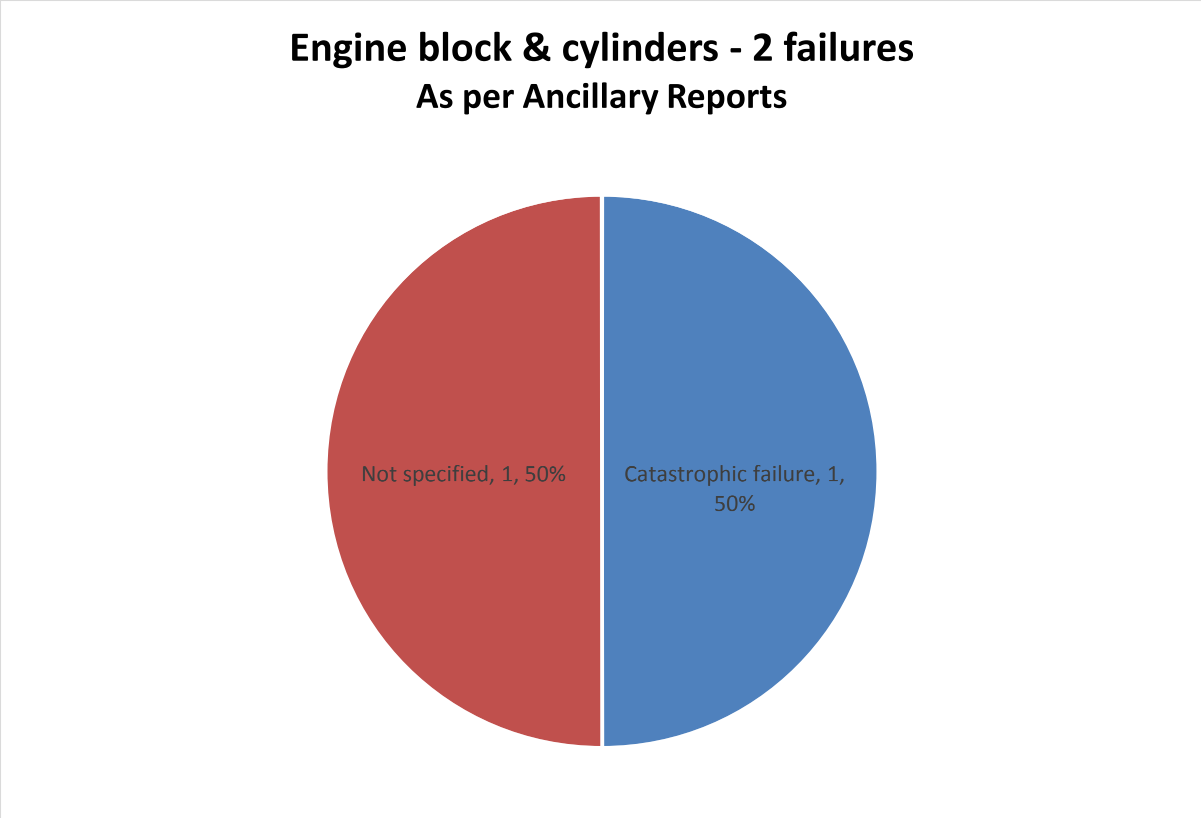


Figure 26

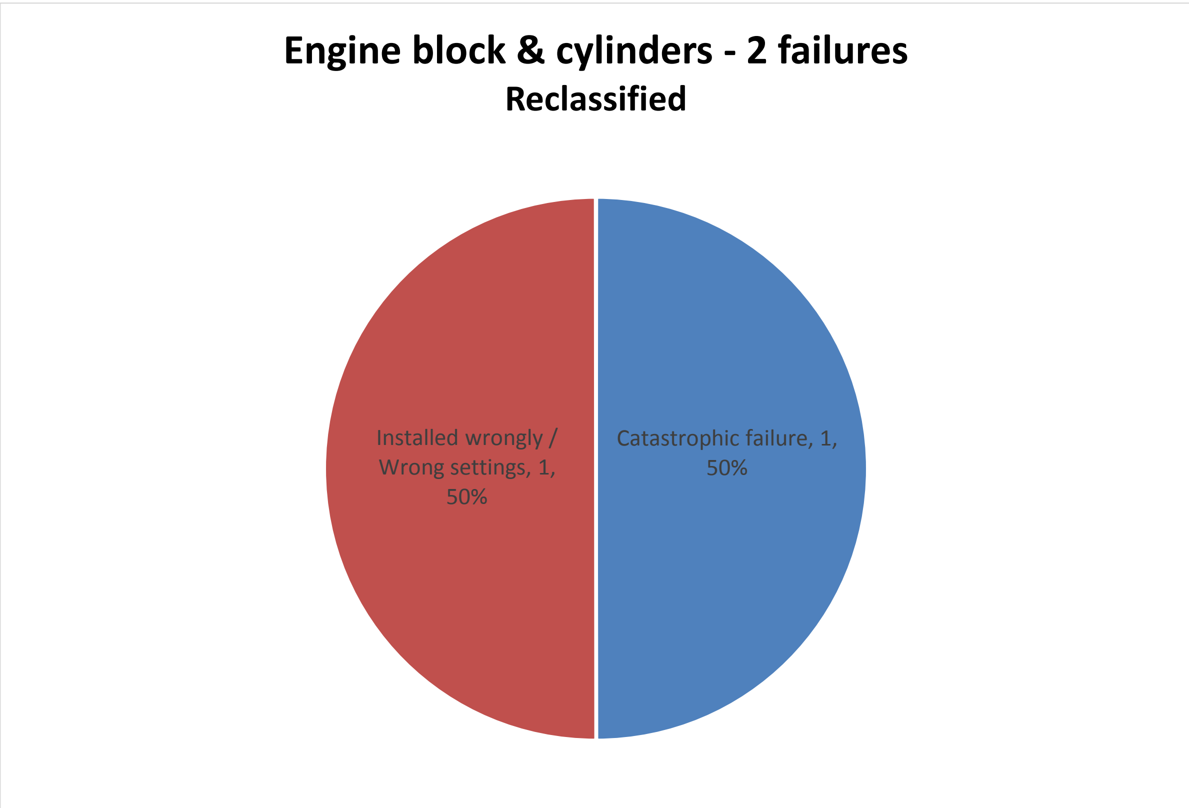


Figure 27

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 in Figure 29 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 28
Excerpt from Ancillary Report

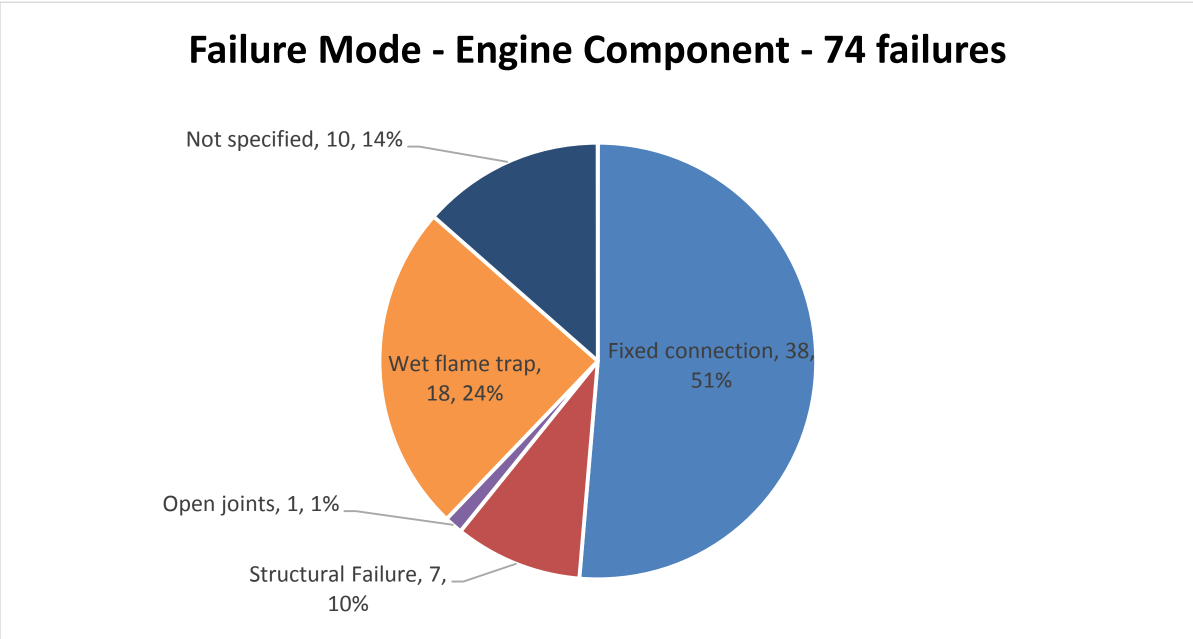


Figure 29

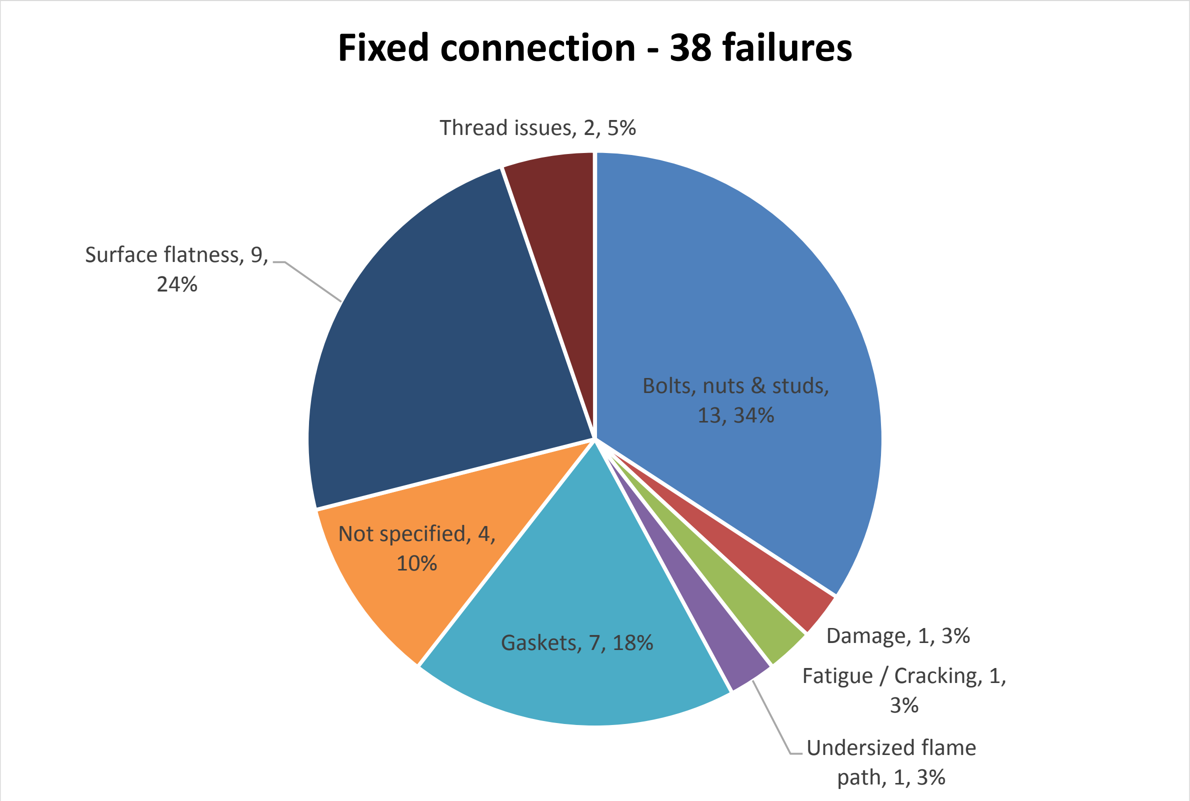


Figure 30

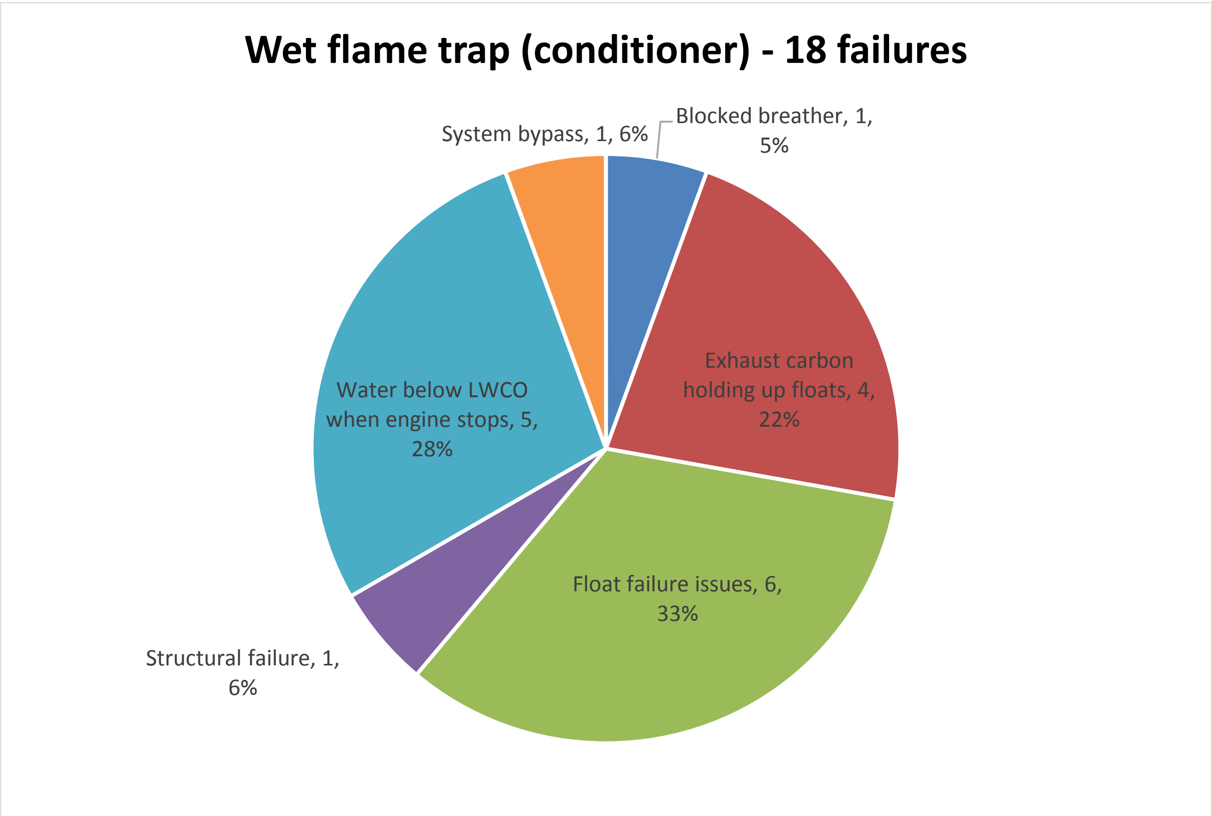


Figure 31

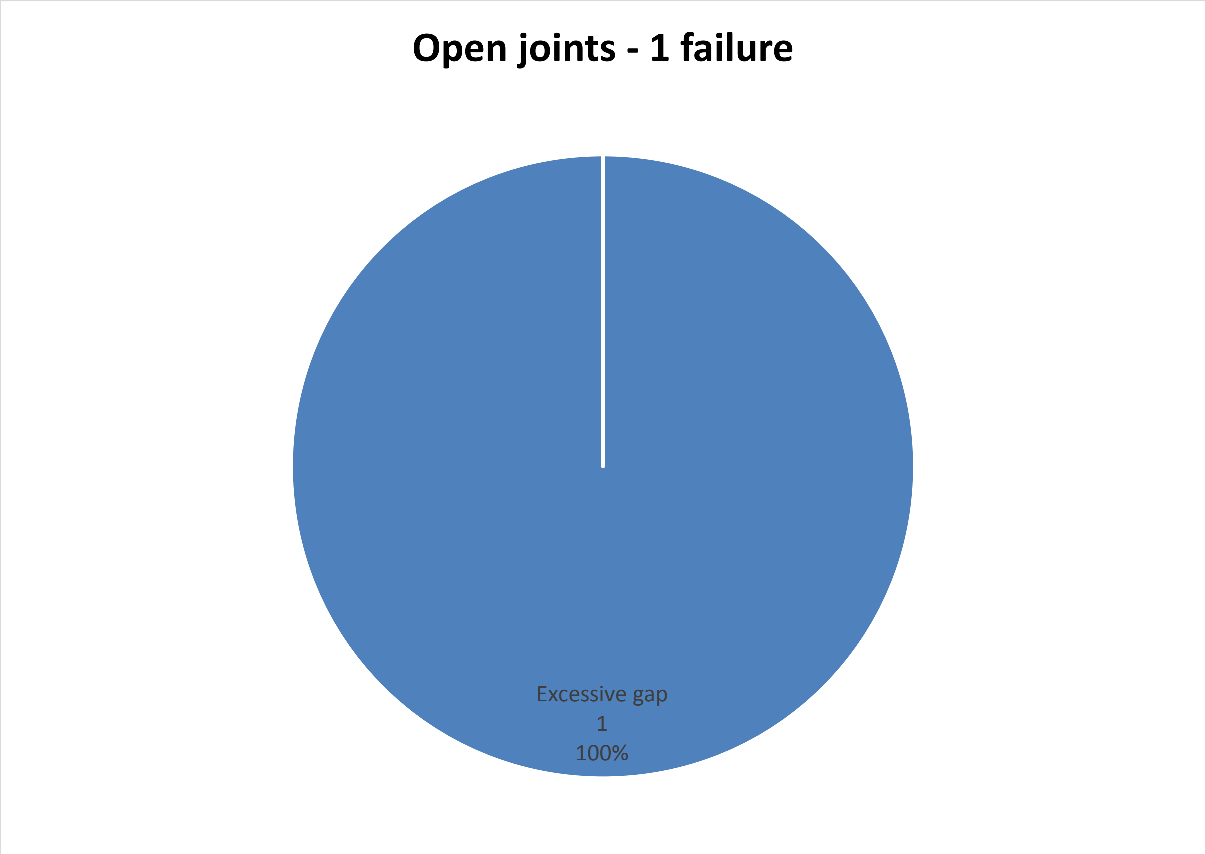


Figure 32

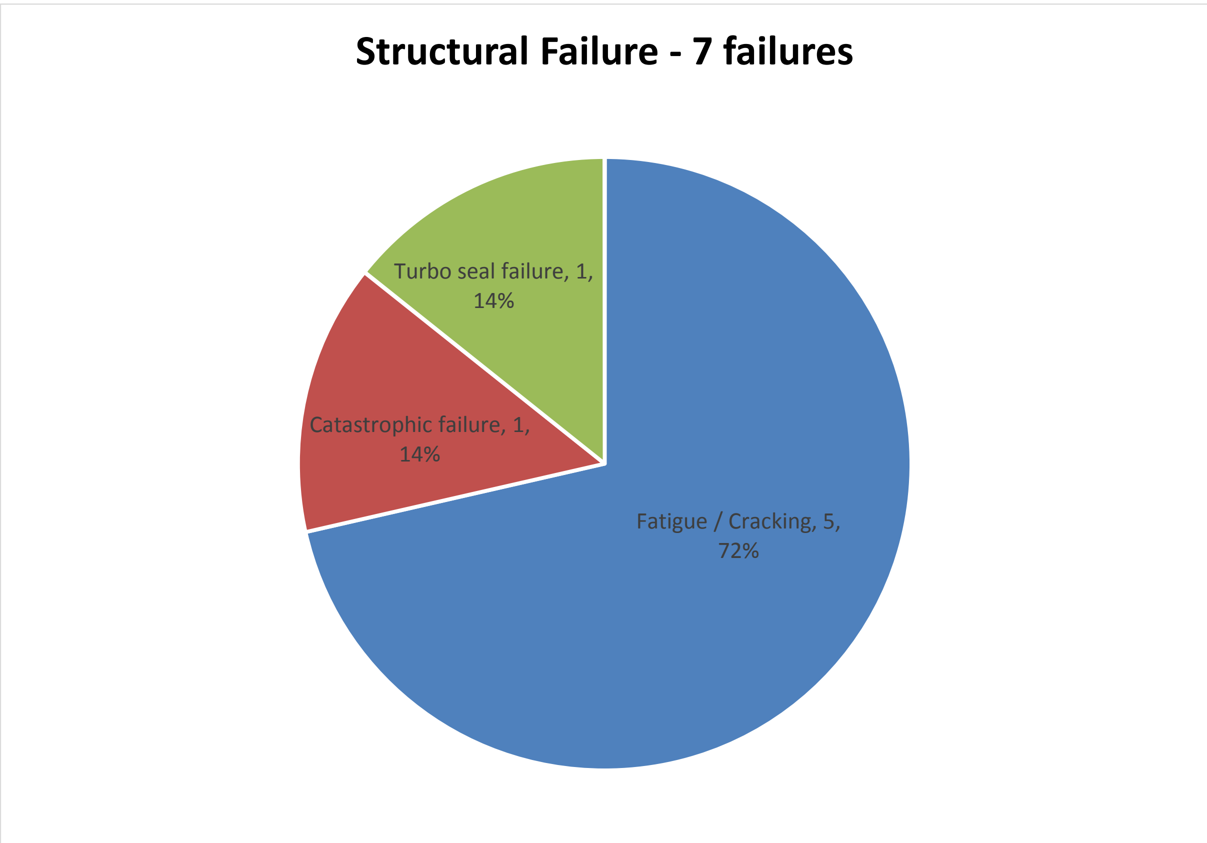
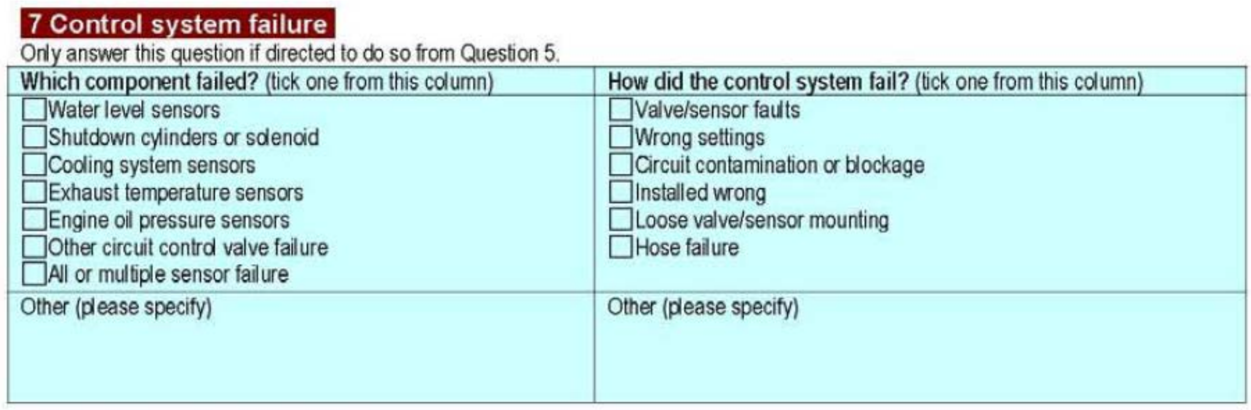


Figure 33

4.4 Failure modes of Pneumatic / Hydraulic Control System

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 34
Excerpt from Ancillary Report

A breakdown of the 52 Pneumatic / Hydraulic Control System components is shown in Table 3 below:

Pneumatic / Hydraulic Control System component	Failures			% Contribution to total failures		
	2012	2013	2014	2012	2013	2014
Shutdown cylinders or solenoid	39	23	12	22%	14%	23%
Other circuit control valve failure	15	11	18	8%	7%	34%
Water level sensors	6	11	10	3%	7%	19%
Cooling system sensors	7	10	10	4%	6%	21%
All or multiple sensor failure	2	4	0	1%	2%	0%
Engine oil pressure sensors	2	3	1	1%	2%	2%
Exhaust temperature sensors	1	0	0	1%	0%	0%
Other	5	3	1	3%	2%	2%
Total	**77**	**65**	**52**	**43%**	**39%**	**40%**

Table 3
Contributors to Pneumatic / Hydraulic Control System component failure

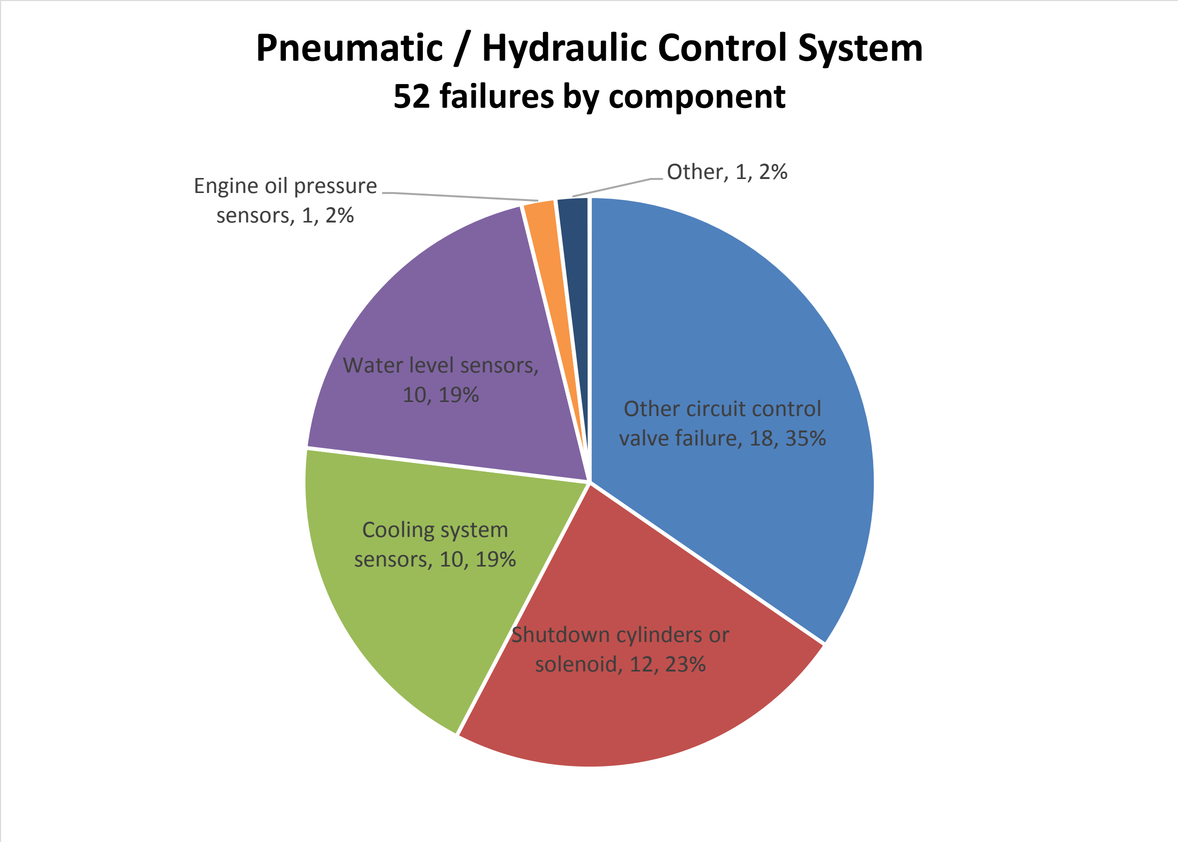


Figure 35

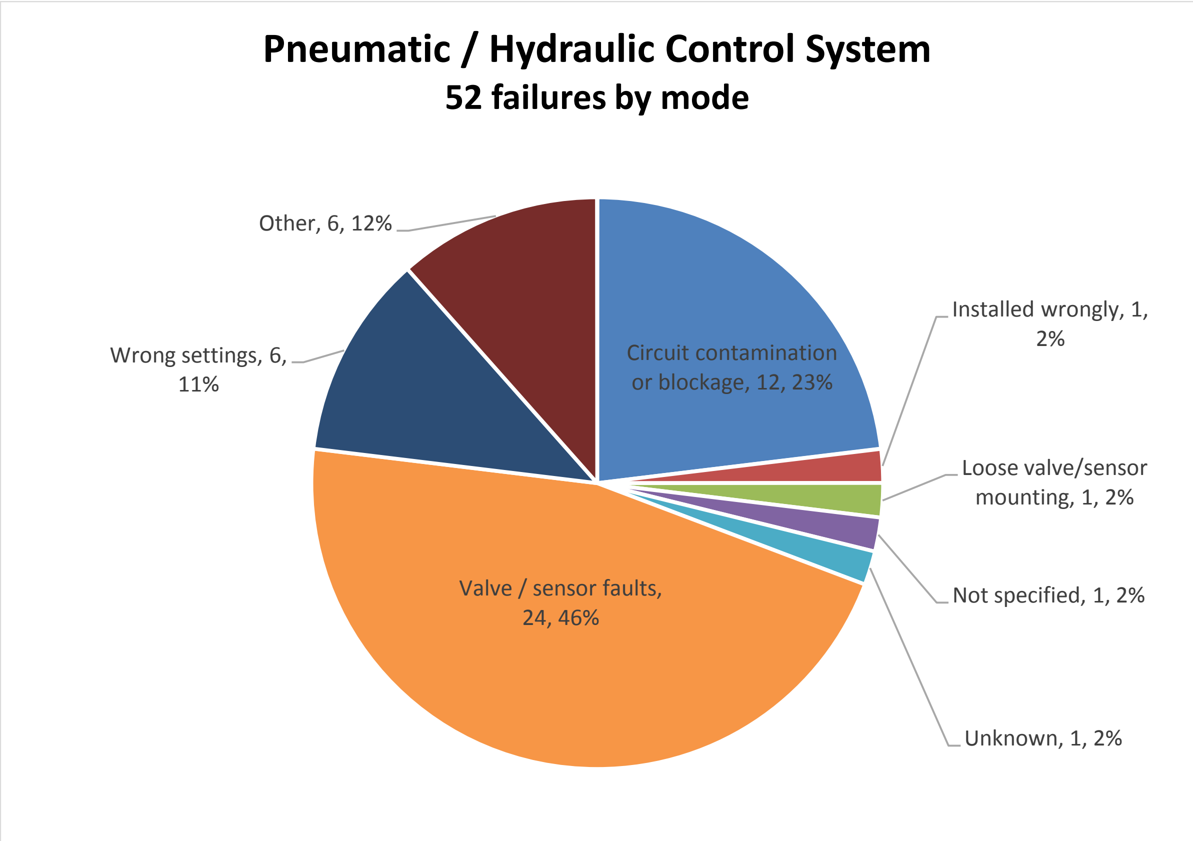


Figure 36

4.4.1 Classification

The following pages present dual pie charts analysing failures of control system components and their failure modes:

- Pie chart as per Ancillary Reports
- Pie chart on reclassification (refer Appendix C) after:
    - Cognizance of causal factors
    - Categorisation of unspecified and “other” entries.

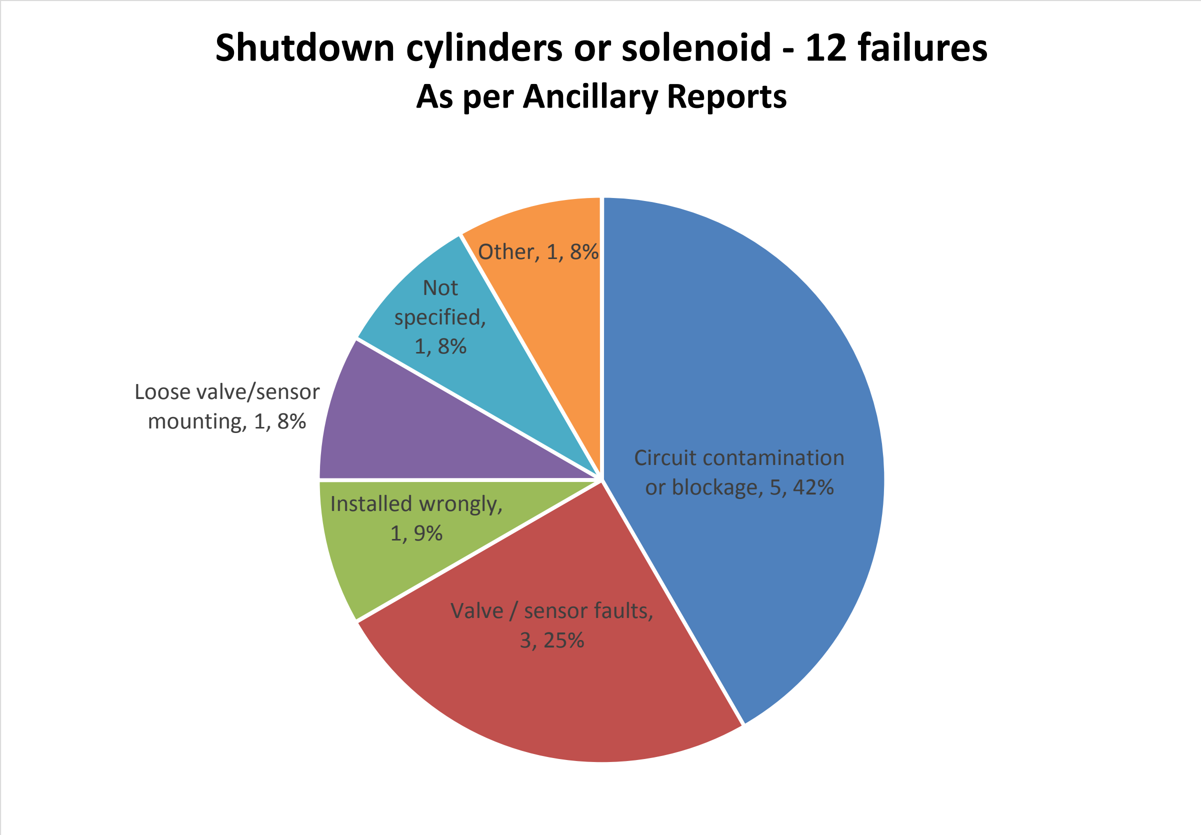


Figure 37

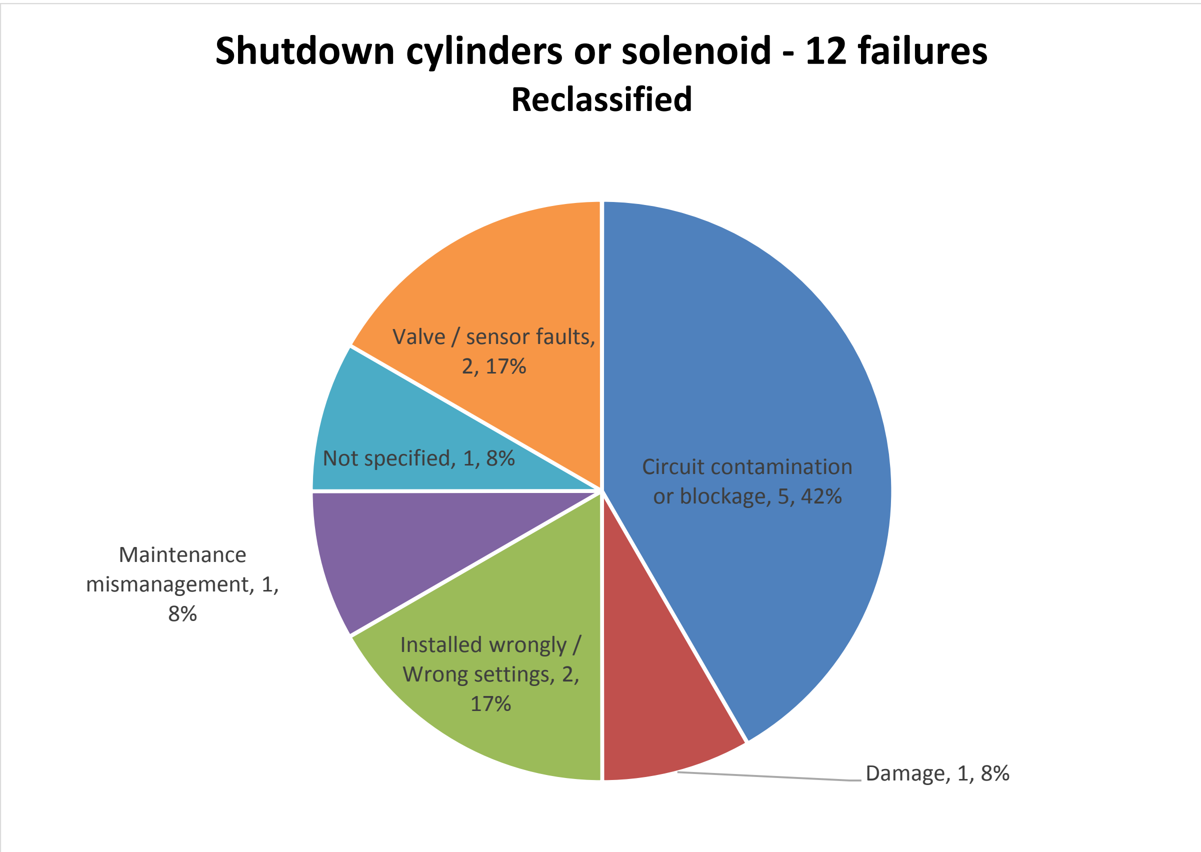


Figure 38

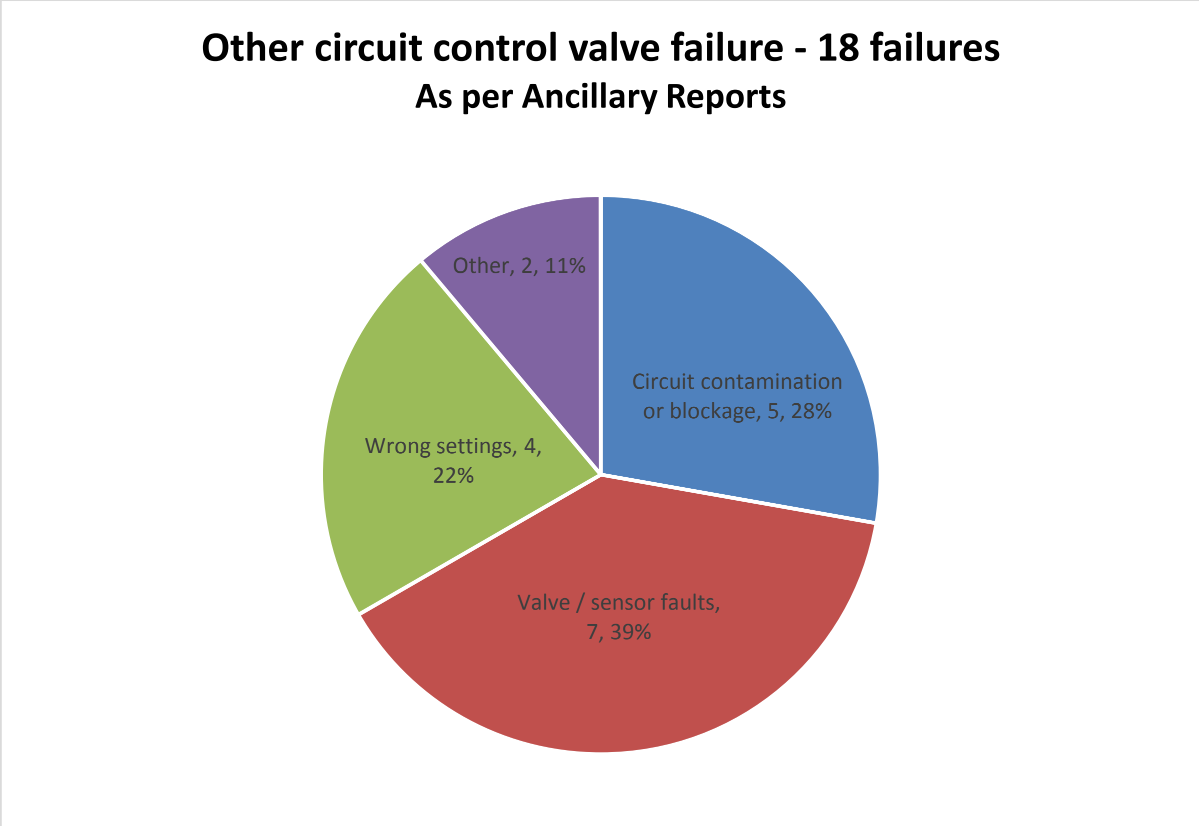


Figure 39

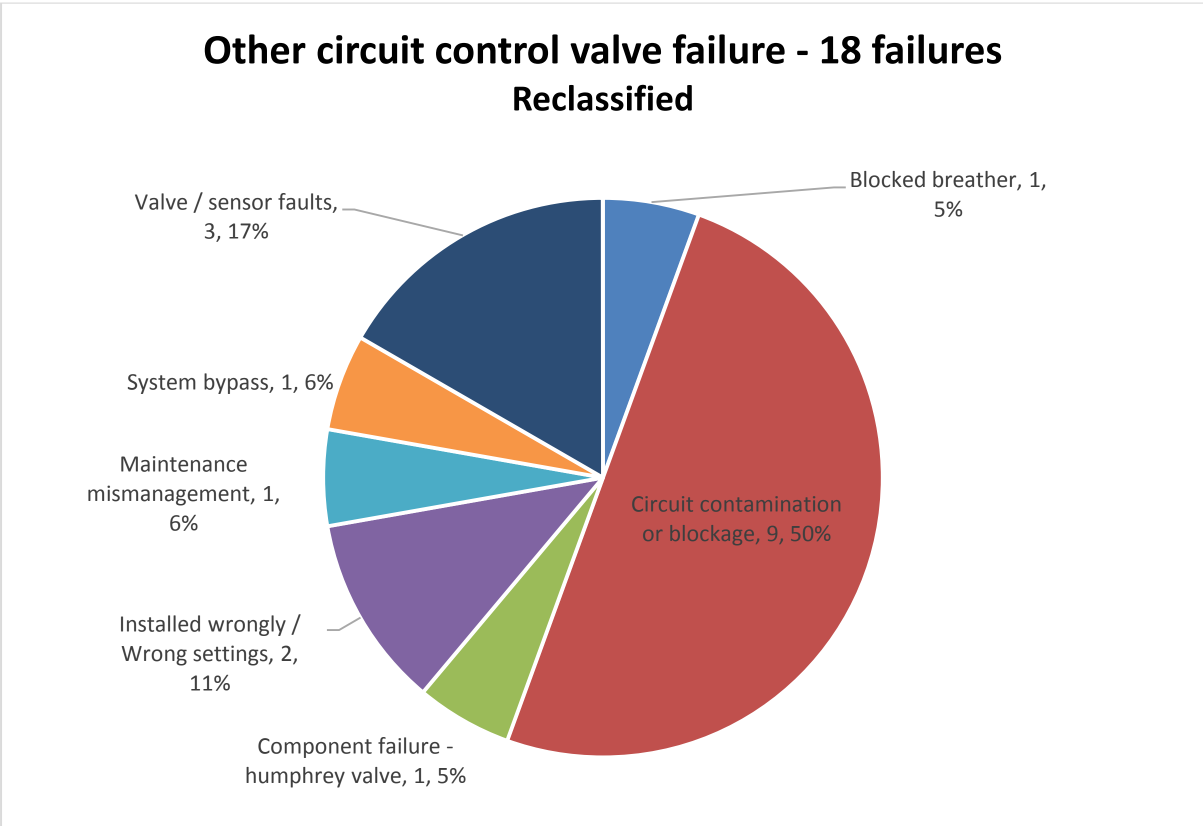


Figure 40

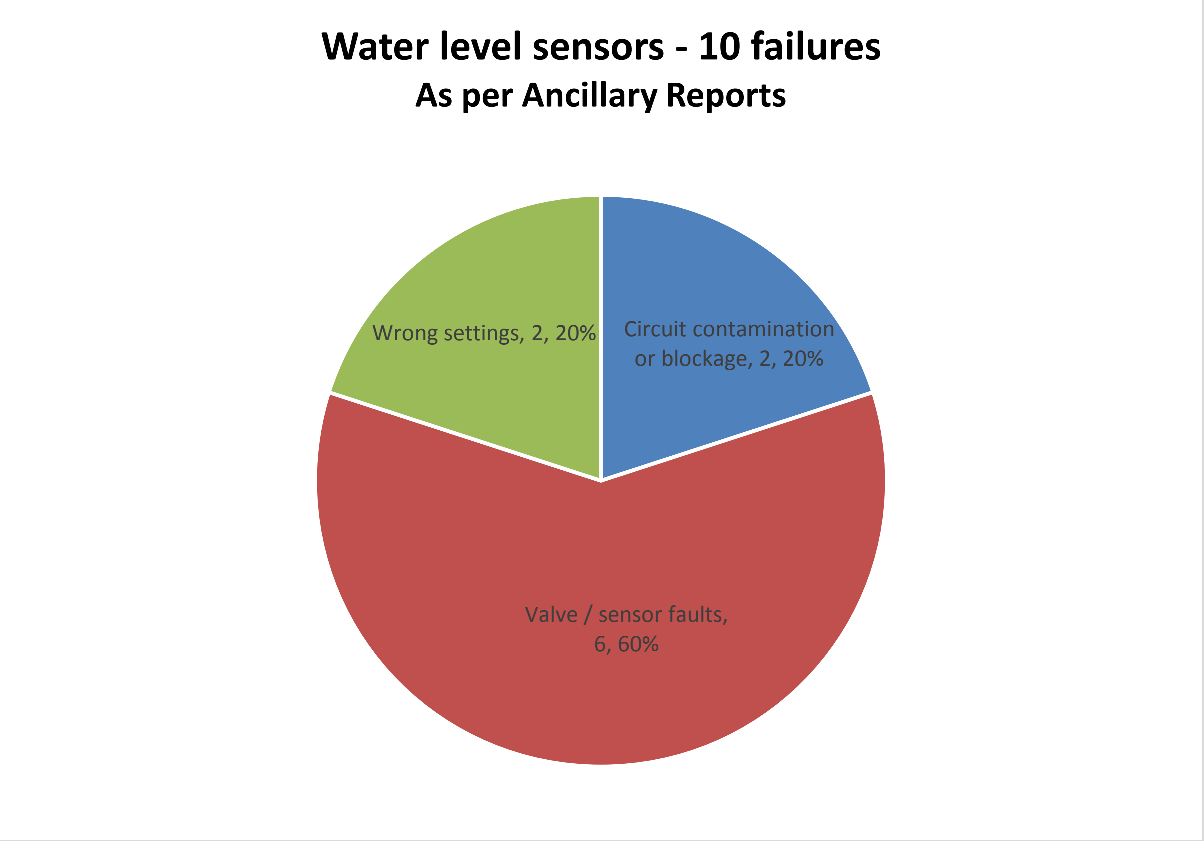


Figure 41

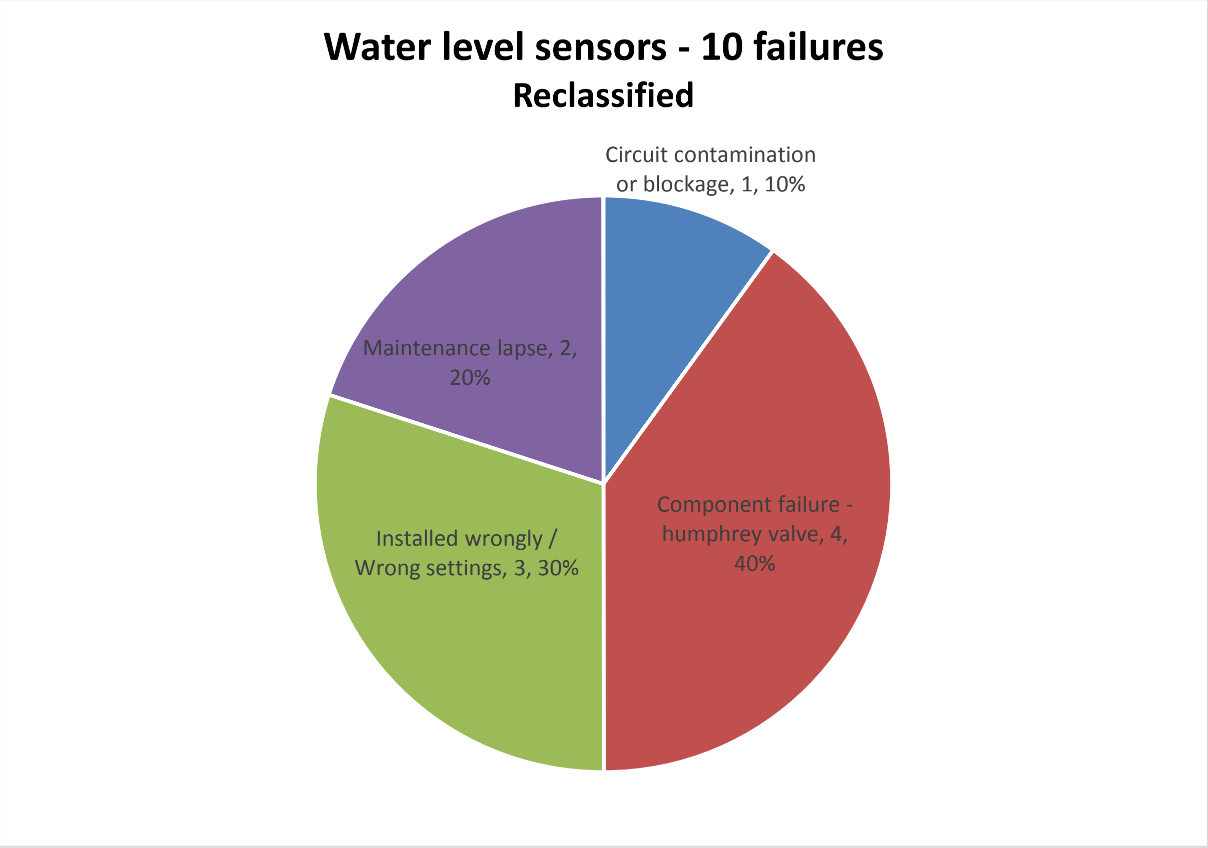


Figure 42

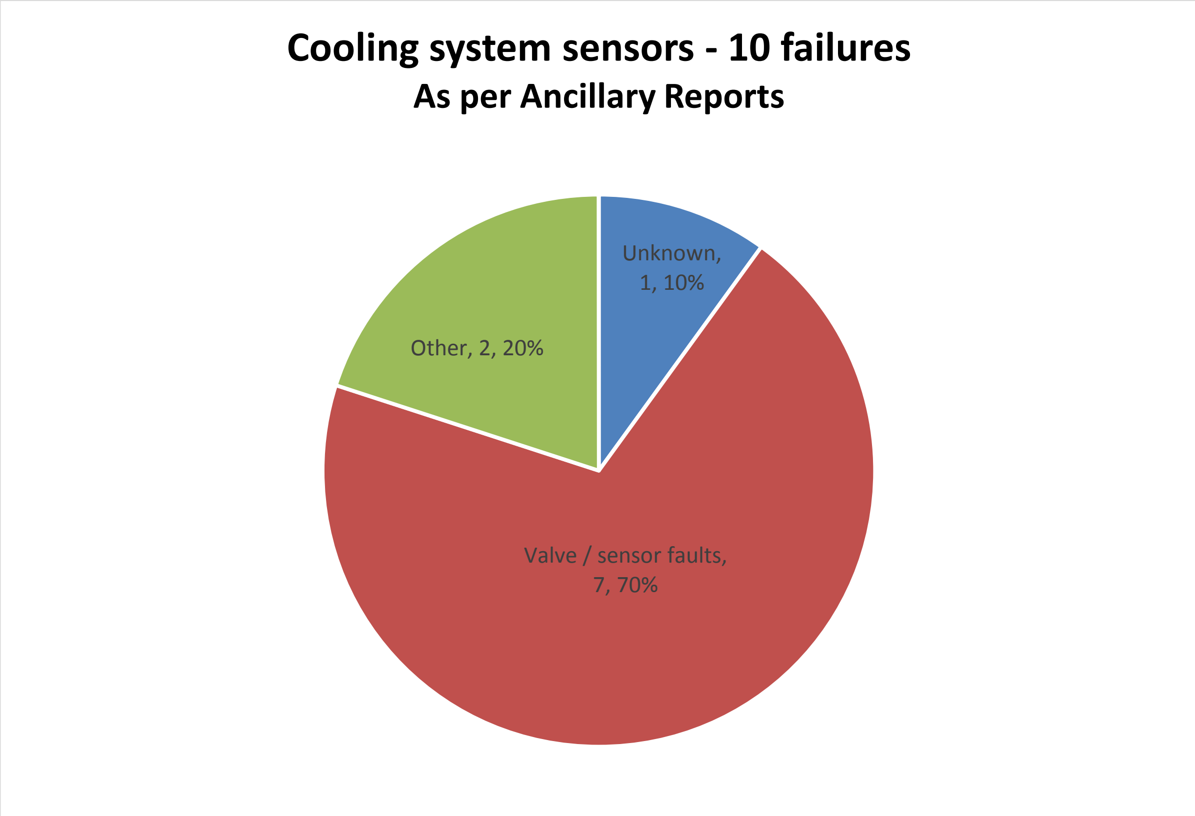


Figure 43

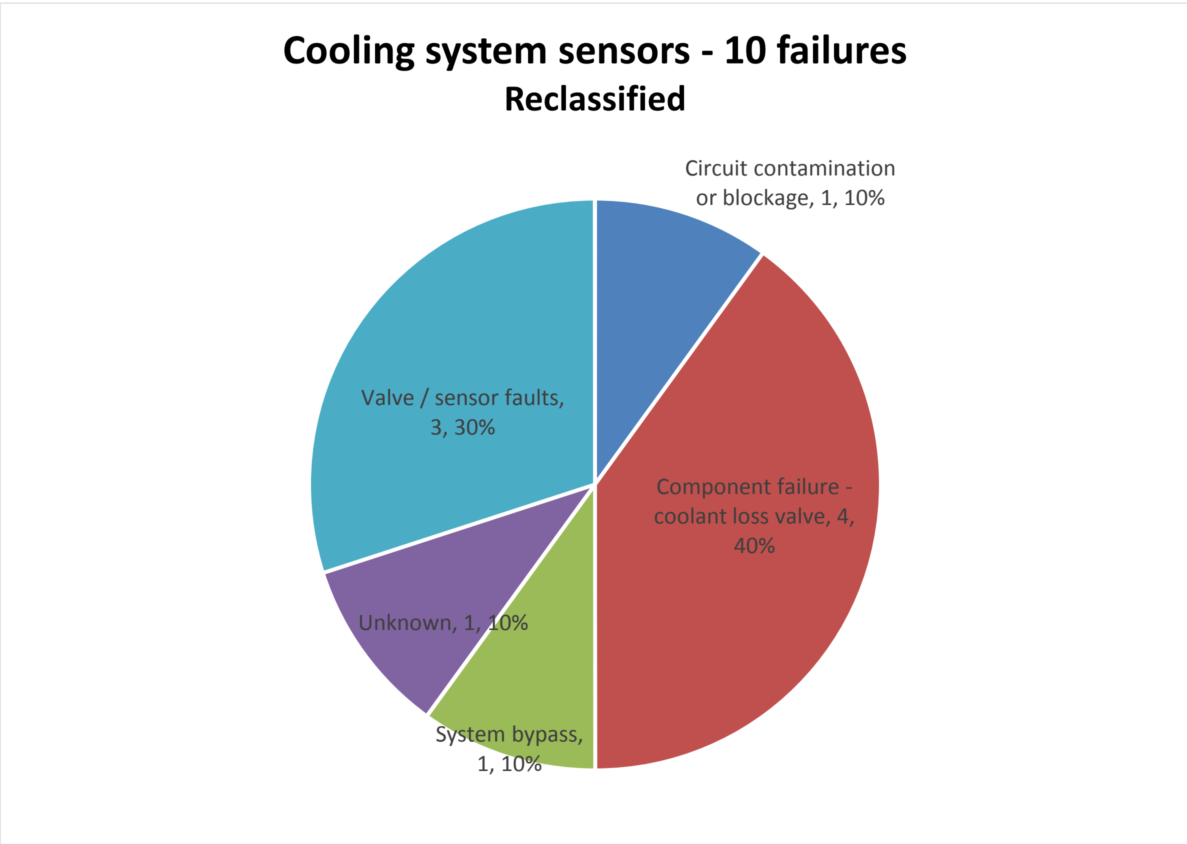


Figure 44

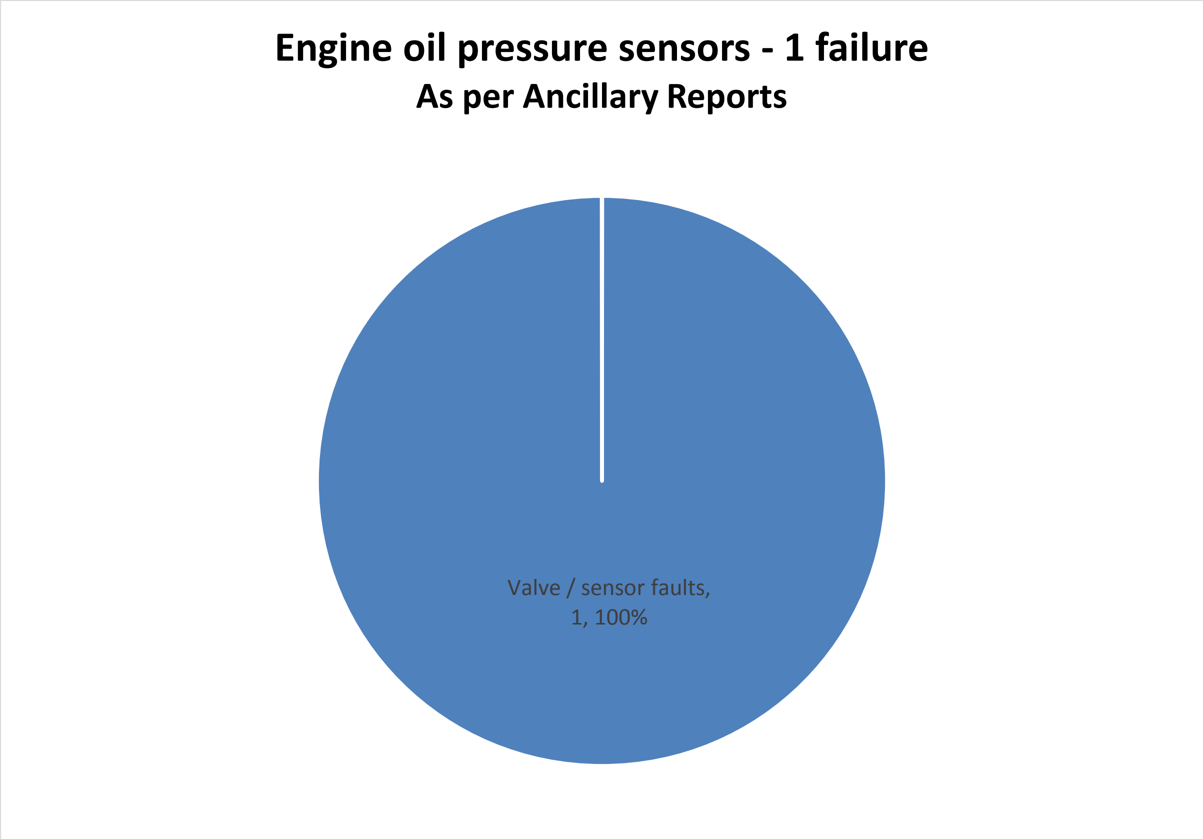

Engine oil pressure sensors - 1 failure
As per Ancillary Reports
Valve / sensor faults,
1, 100%

Figure 45

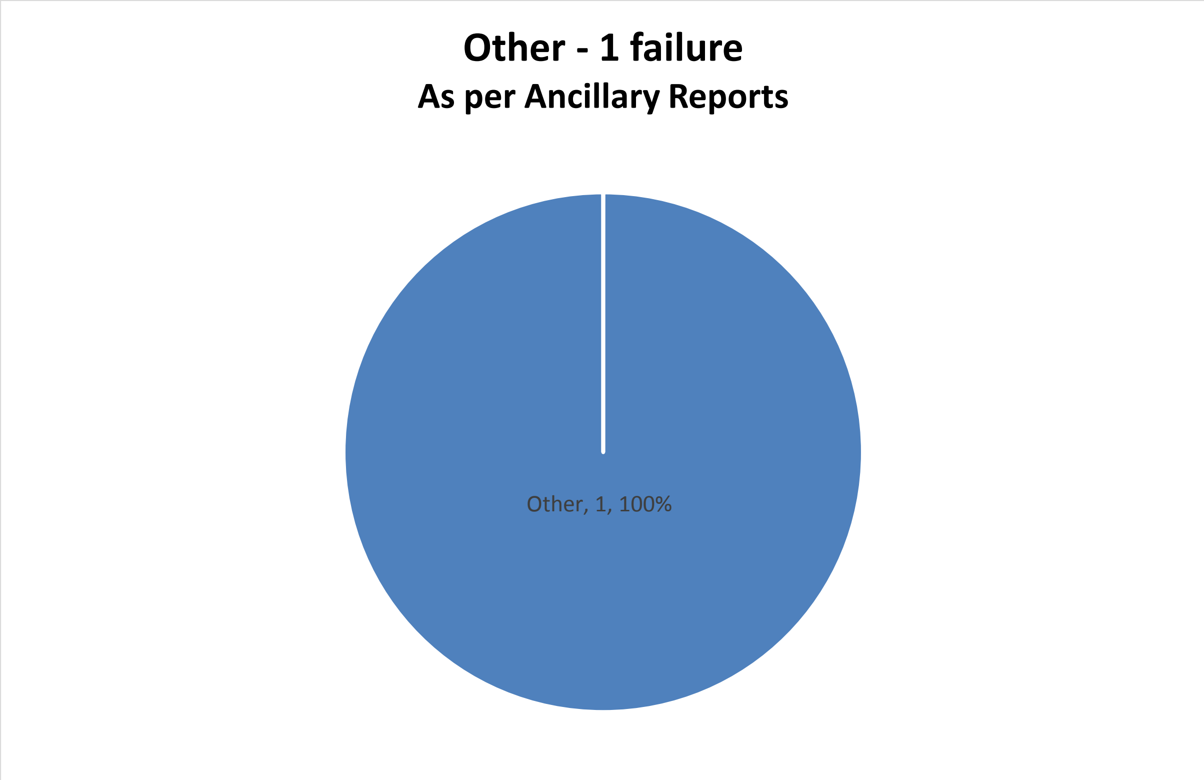


Figure 46

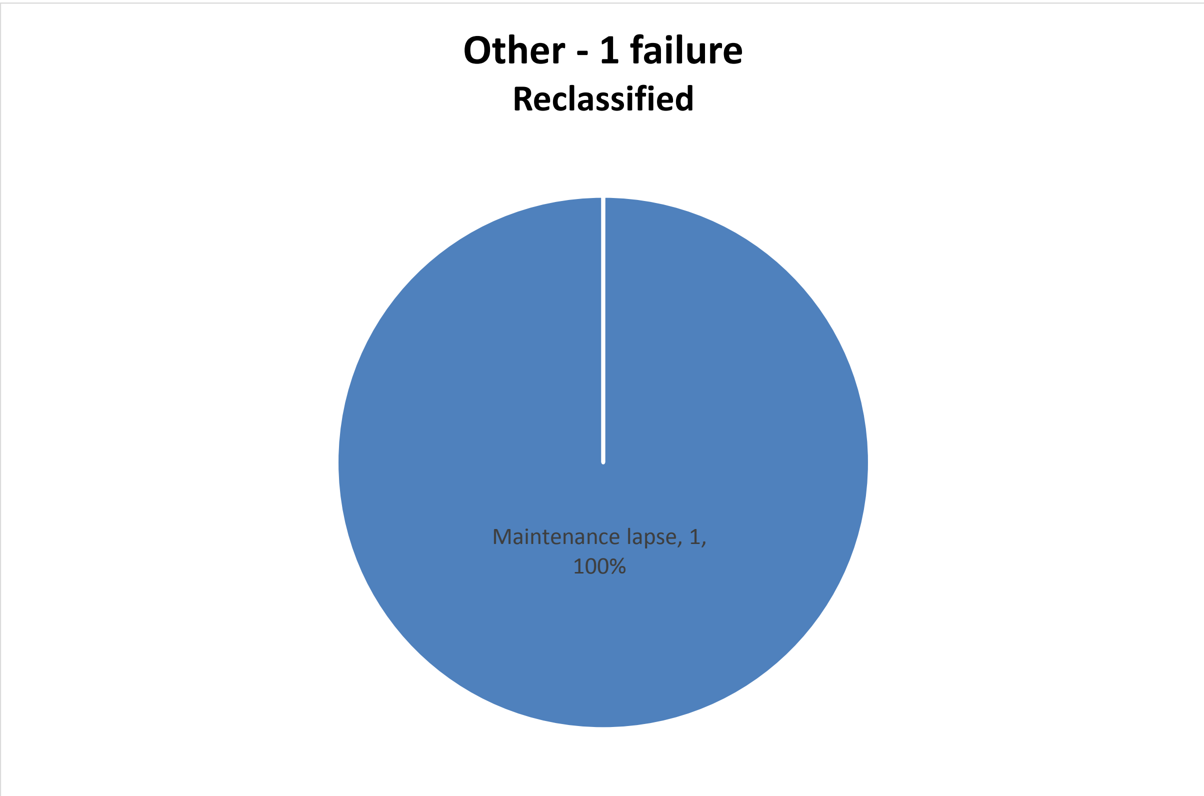


Figure 47

4.5 Failure modes of electrical control system

For the failure of a 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 ☐ 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 48
Excerpt from Ancillary Report

A breakdown of the 4 Electrical Control System components is shown in Table 4 below:

Electrical Control System component	Failures	% contribution to 2014 failures
Shutdown cylinders or solenoid	2	2%
Cooling system sensors	2	2%
Total	**4**	**3%**

Table 4
Contributors to Electrical Control System component failure

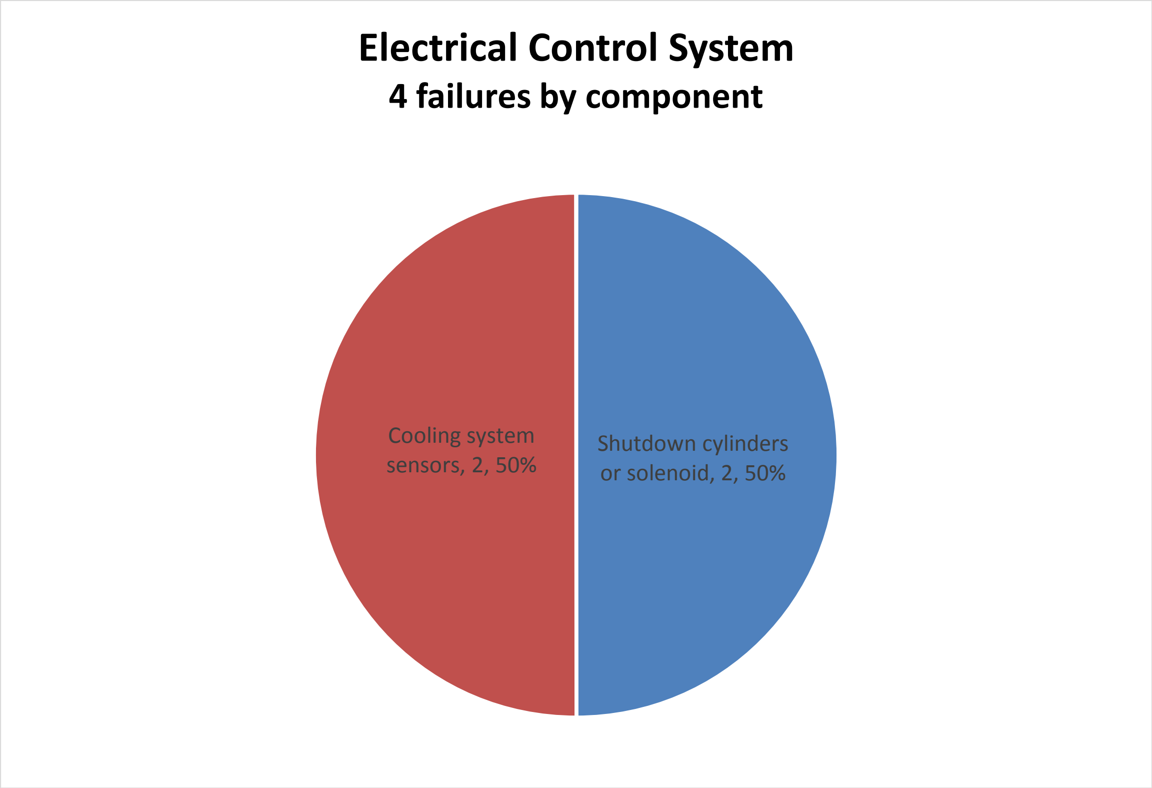


Figure 49

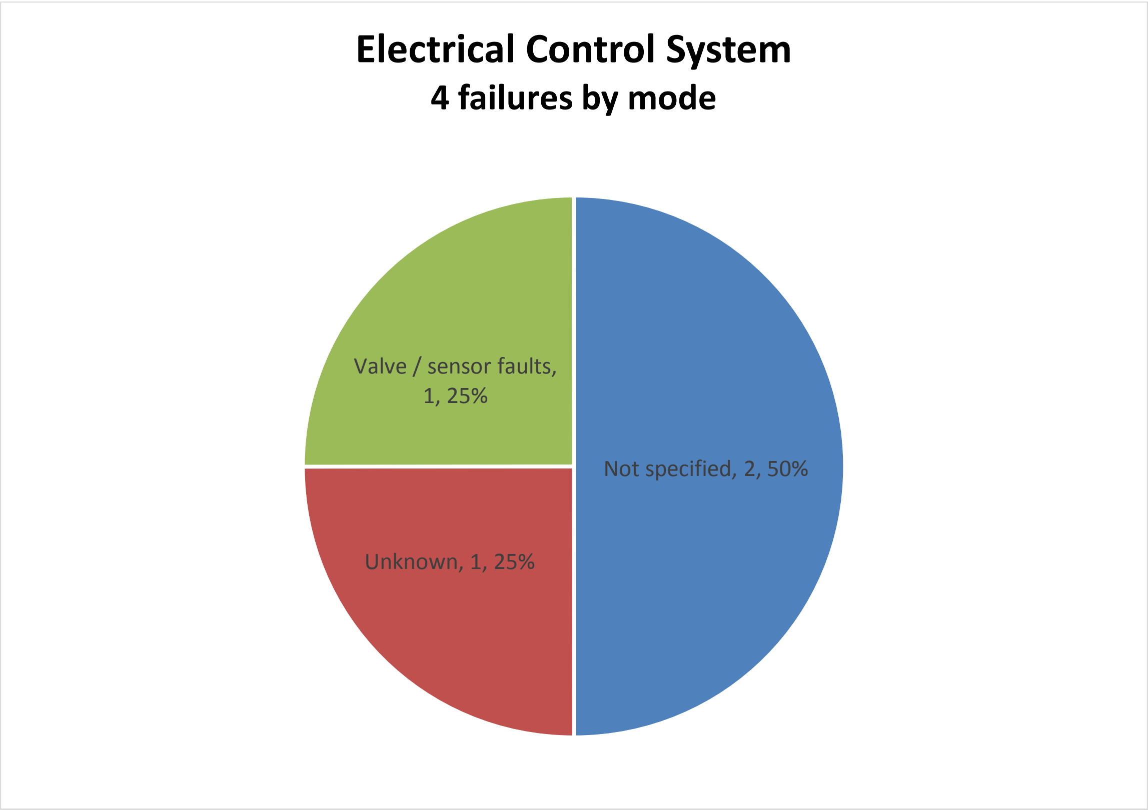


Figure 50

4.5.1 Classification

The following pages present dual pie charts analysing failures of control system components and their failure modes:

- Pie chart as per Ancillary Reports
- Pie chart on reclassification (refer Appendix D) after:
  - Cognizance of causal factors
  - Categorisation of unspecified and "other" entries.

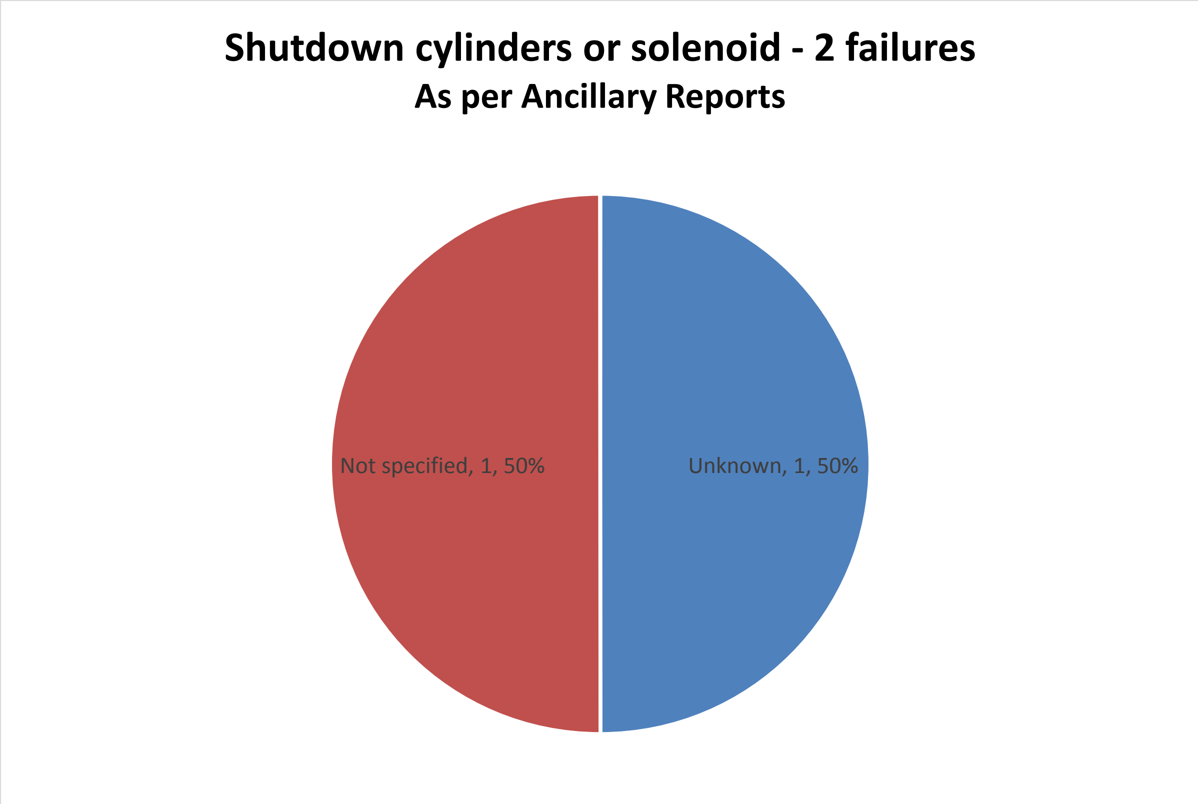


Figure 51

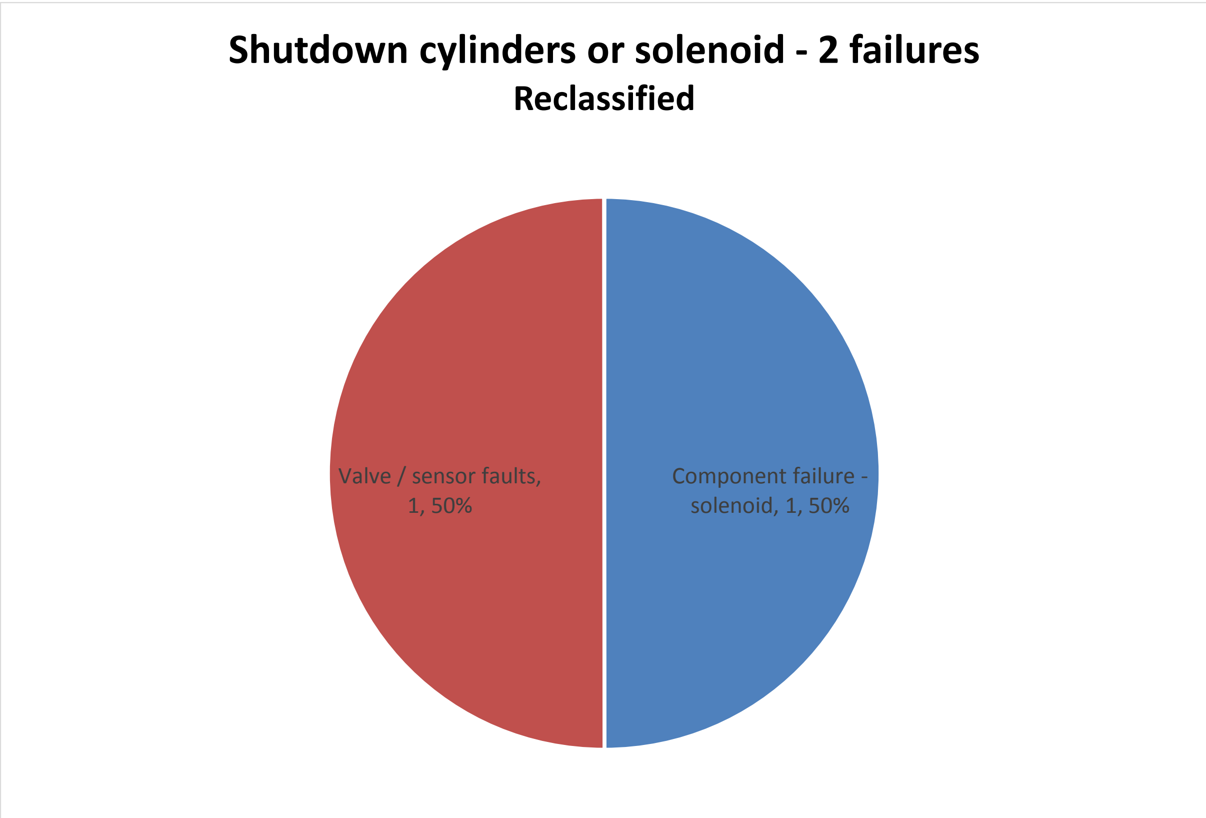


Figure 52

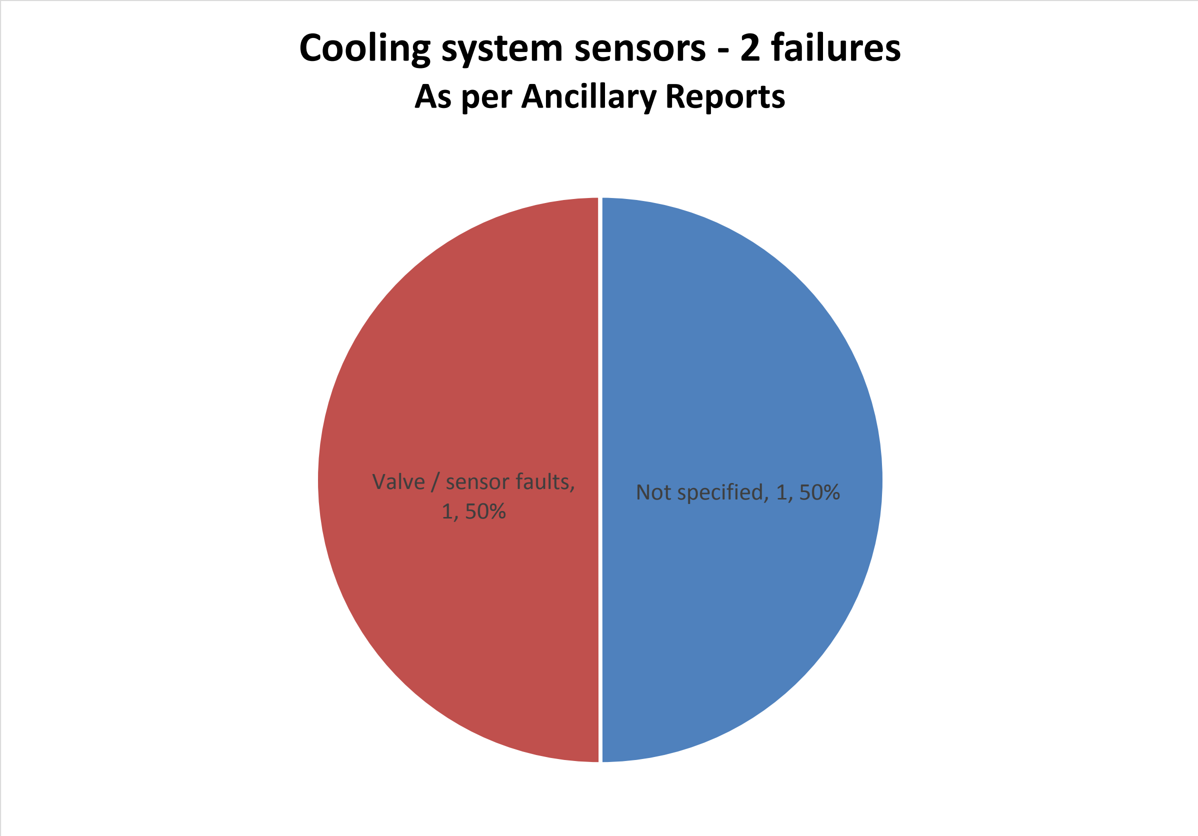


Figure 53

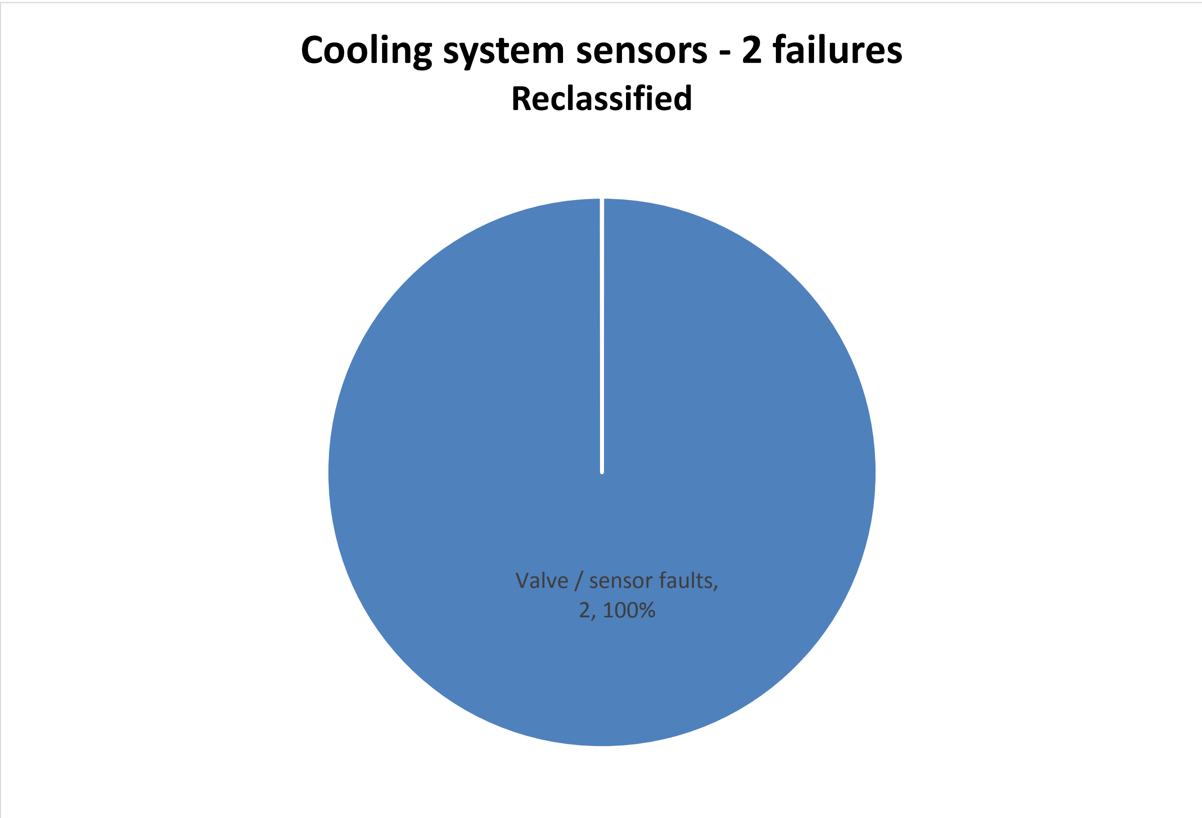
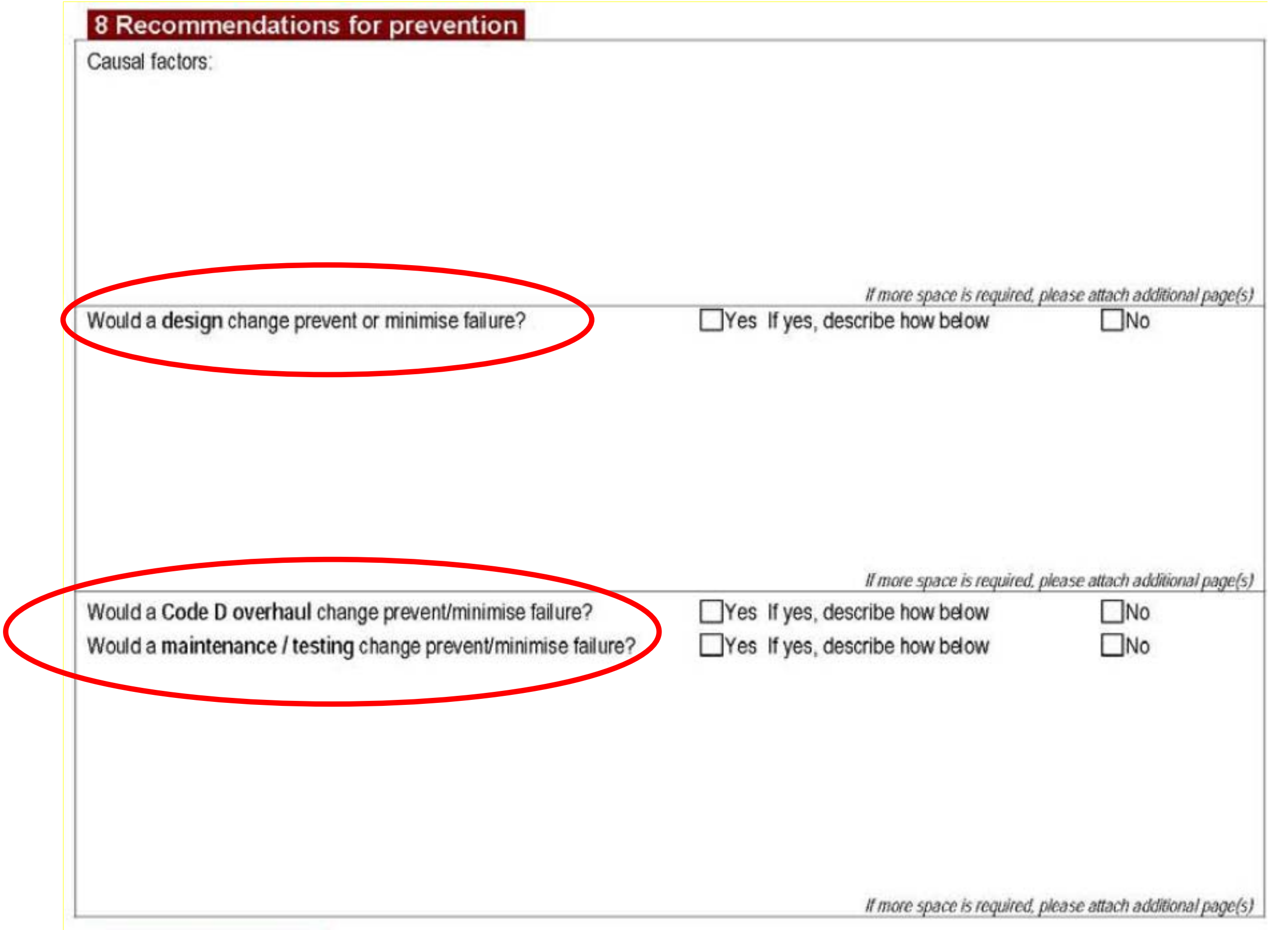


Figure 54

5 Miners' Recommendations

The Ancillary Report (Appendix 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 55
Excerpt from Ancillary Report

This part of the study compiles the design, maintenance and testing changes proposed by the end users and presents them for the major contributors to the 2014 failures.

Out of a total of 98 recommendations received in 2014, 72 were design based and 26 were maintenance based. This is shown in Figure 56 along with a comparison from 2012 and 2013.

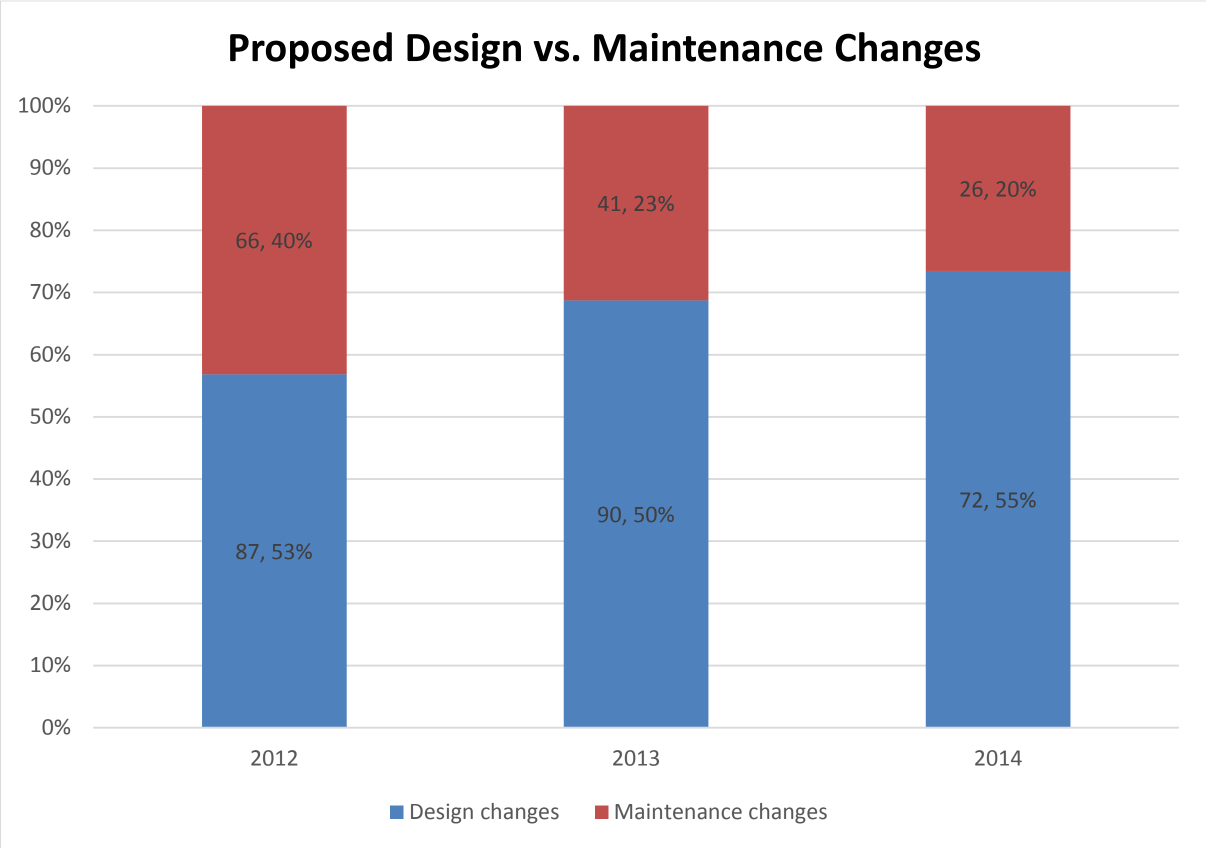


Figure 56

5.1 Major contributors

Table 5 below ranks the contributors to the 2014 failures drilling down to a lower level of component categories such as Wet flame traps and Open joints along with their contributory ranking for 2014.

Rank	Component	No. of failures	%
1	Fixed connection	38	29.2%
2	Wet flame trap	18	13.8%
3	Other circuit control valve failure	18	13.8%
4	Shutdown cylinders or solenoid	14	10.8%
5	Cooling system sensors	12	9.2%
6	Water level sensors	10	7.7%
7	Not specified	10	7.7%
8	Structural failures	7	5.4%
9	Open joints	1	0.8%
10	Engine oil pressure sensors	1	0.8%
11	Other	1	0.8%
	Total number of failures in 2014	**130**	**100%**

Table 5
Contributors to component failure

The following pages list the Design and Maintenance / Testing related comments from the Ancillary Reports of 2014 for the following major contributors:

Rank	Major component	No. of failures	%
1	Fixed connection	38	29.2%
2	Wet flame trap	18	13.8%
3	Other circuit control valve failure	18	13.8%
5	Shutdown cylinders or solenoid	14	10.8%
6	Cooling system sensors	12	9.2%
7	Water level sensors	10	7.6
8	Structural failures	7	5.3%
	Major contributors	**118**	**90.0%**

Table 6
Major contributors to component failure

5.2 Fixed connections

Failures in 2014	Failures	% Contribution	Contributor Rank
130	38	29.2	1

No.	Design related comments
1	Redesign exhaust mounting system, sagging causes load on scrubber - possibly use larger bolts to secure fixed joints
2	Improved gasket material
3	Update approval drawings to reflect changes and provide change management
4	Redesign of manifold area minimise build up and the chance of corrosion pitting
5	Remove "top" label stamped on the bottom of the gasket
6	Allow better access to inspect/maintain areas
7	Lock wire the bolt heads
8	Redesign clamping system, currently fragile and delicate
9	Design and welding of scrubber leads to thin material - prone to cracking through fatigue
10	De-stress components before machining

No.	Maintenance / Testing related comments
1	Review code D timings
2	Machine incorrectly assembled during code D
3	Exhaust conditioner bolts/brackets to be specified in service sheets for inspection
4	Inspection regime for Injector copper washer at specified intervals
5	Note gas test point specifically to be soapy water test weekly
6	Check all bolts, nuts and studs during routine maintenance tasks
7	More frequent soapy water tests
8	Include required bolt lengths in DES approval drawings and Code D checks

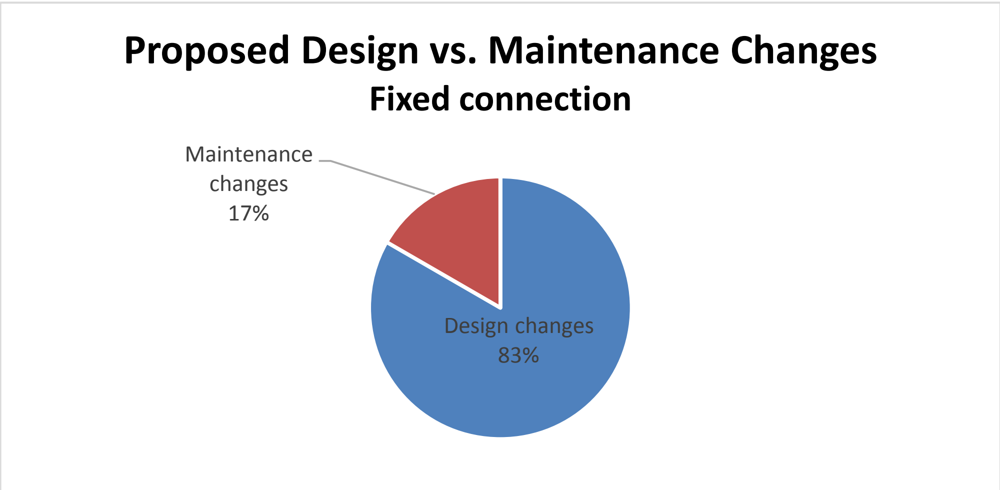


Figure 57

5.3 Wet flame traps

Failures in 2014	Failures	% Contribution	Contributor Rank
130	18	13.8	2

No.	Design related comments
1	Change to electronic water level sensors/floats
2	Change to electronic engine management system
3	Replace air supply float fitting to stainless steel to prevent corrosion
4	Increase amount of weld on fitting
5	Add bracing to support float assembly
6	Remove needle valves from circuit
7	Remove single point of failure
8	Cover shutdown valves to prevent bypass

No.	Maintenance / Testing related comments
1	Increase cleaning frequency of scrubber

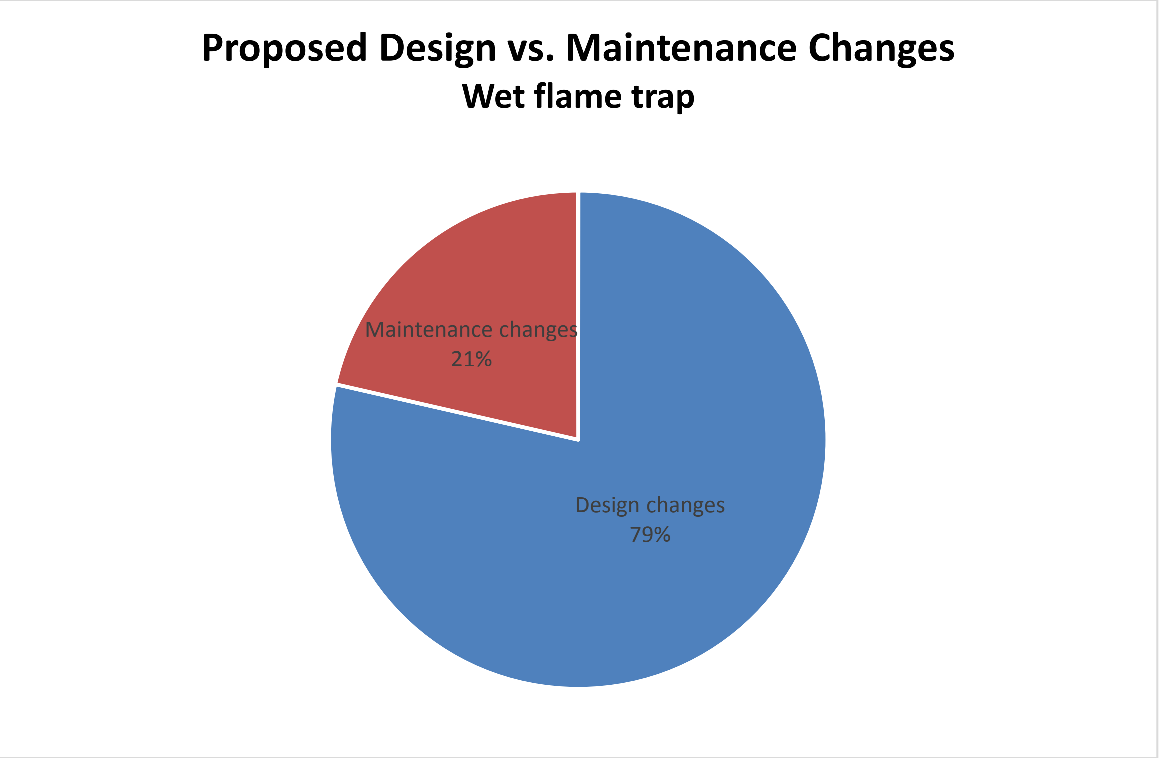


Figure 58

5.4 Other circuit control valves

Failures in 2014	Failures	% Contribution	Contributor Rank
130	18	13.8	3

No.	Design related comments
1	Change to electronic system
2	Possibly change to type 2 strangler valve
3	Install automatic lubricator to vehicles
4	Remove air safety circuit
5	Better pneumatic circuit filtering
6	Review design/duty cycle of regulating valve

No.	Maintenance / Testing related comments
1	Add lock nut to weekly service check
2	Replace failed component on all machines to be maintained
3	Regularly add lubricant through pneumatic circuit
4	Review circuit filtration and lubrication

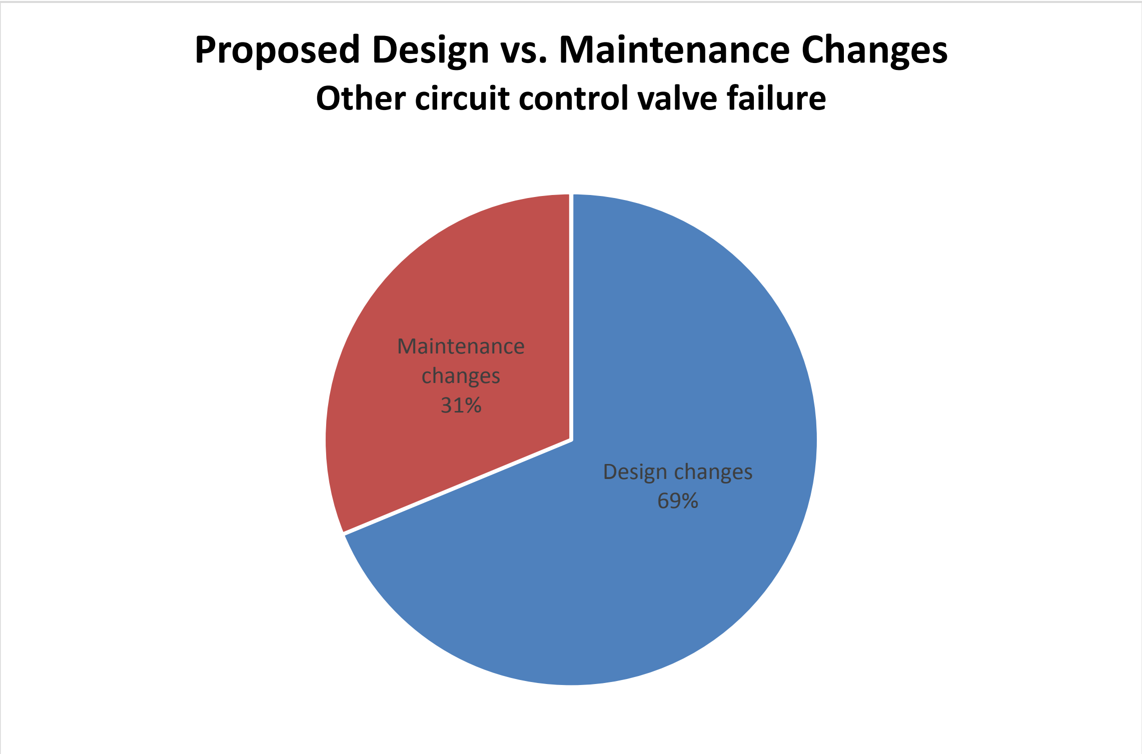


Figure 59

5.5 Shutdown cylinders or Solenoids

Failures in 2014	Failures	% Contribution	Contributor Rank
130	14	10.8	4

No.	Design related comments
1	Review cylinder design - add inline fitter or switch to double acting cylinder
2	Change to electronic shutdown system
3	Redesign mount bracket for easier maintenance access

No.	Maintenance / Testing related comments
1	Flush safety circuit airlines regularly
2	Review maintenance schedule of bolt tension
3	Add visual inspection to weekly service
4	Implement regular replacement of cylinders until design is upgraded

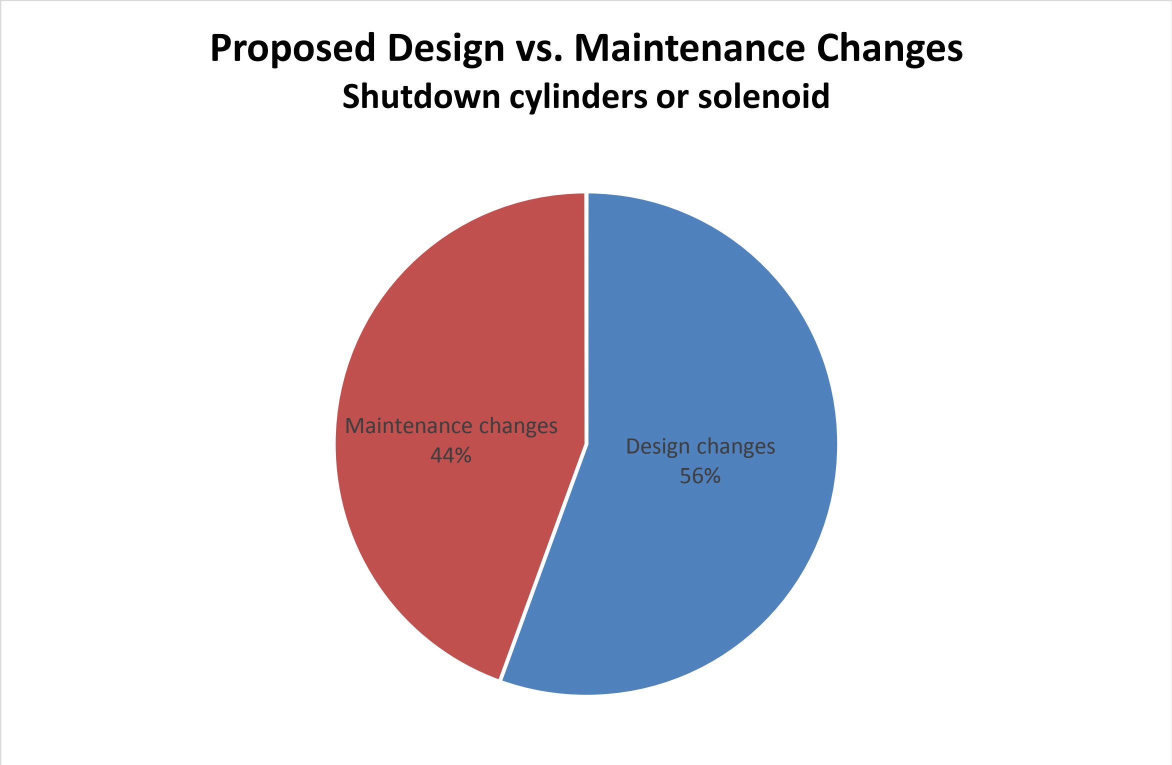


Figure 60

5.6 Cooling system sensors

Failures in 2014	Failures	% Contribution	Contributor Rank
130	12	9.2	5

No.	Design related comments
1	Implement electronic, new, or heavy duty valve design
2	Use fail safe shut down system
3	Fit hoses that cannot be kinked – prevent bypass

No.	Maintenance / Testing related comments
1	Shorter component change out cycle
2	Review air system maintenance procedures

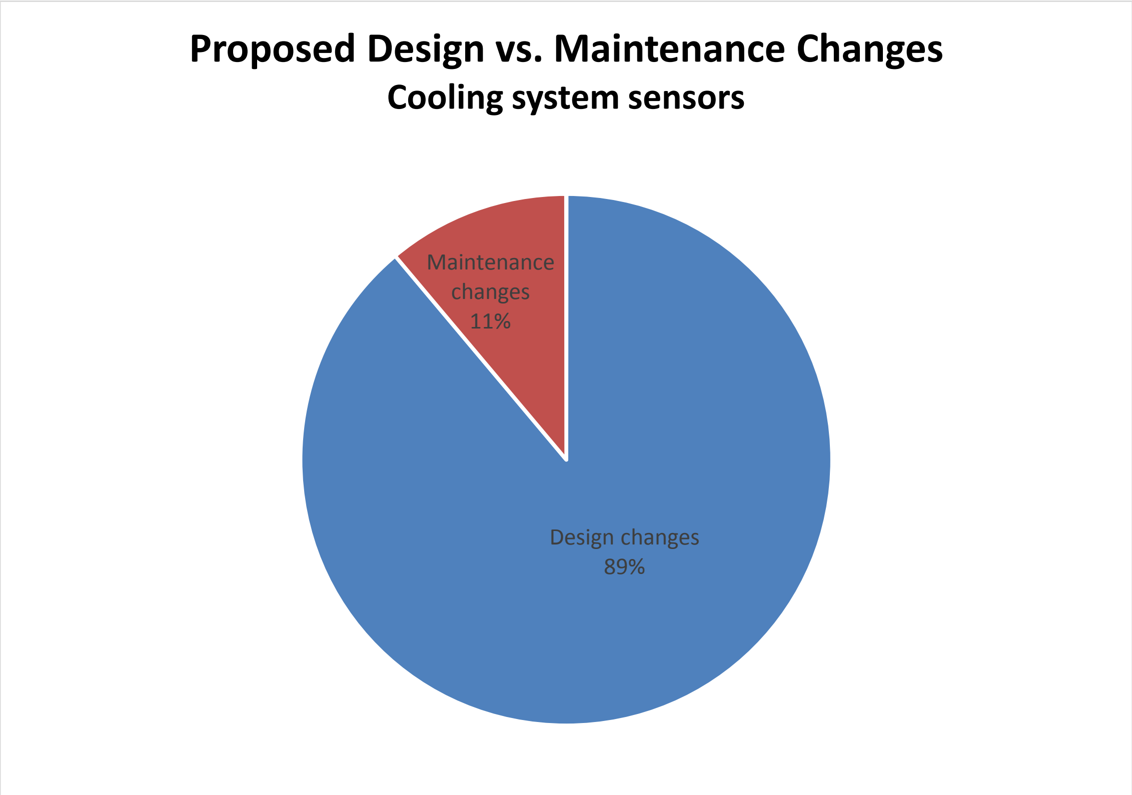


Figure 61

5.7 Water level sensors

Failures in 2014	Failures	% Contribution	Contributor Rank
130	10	7.7	6

No.	Design related comments
1	Eliminate Humphrey valves from circuit
2	Switch to electronic shutdown system

No.	Maintenance / Testing related comments
1	More frequent flushing of the scrubber with clean water
2	More frequent testing of individual Humphrey valves
3	Replace Humphrey valves more frequently – 3 monthly
4	Review on-site maintenance practices to avoid maintenance errors
5	Function test safety circuit elements following adjustments

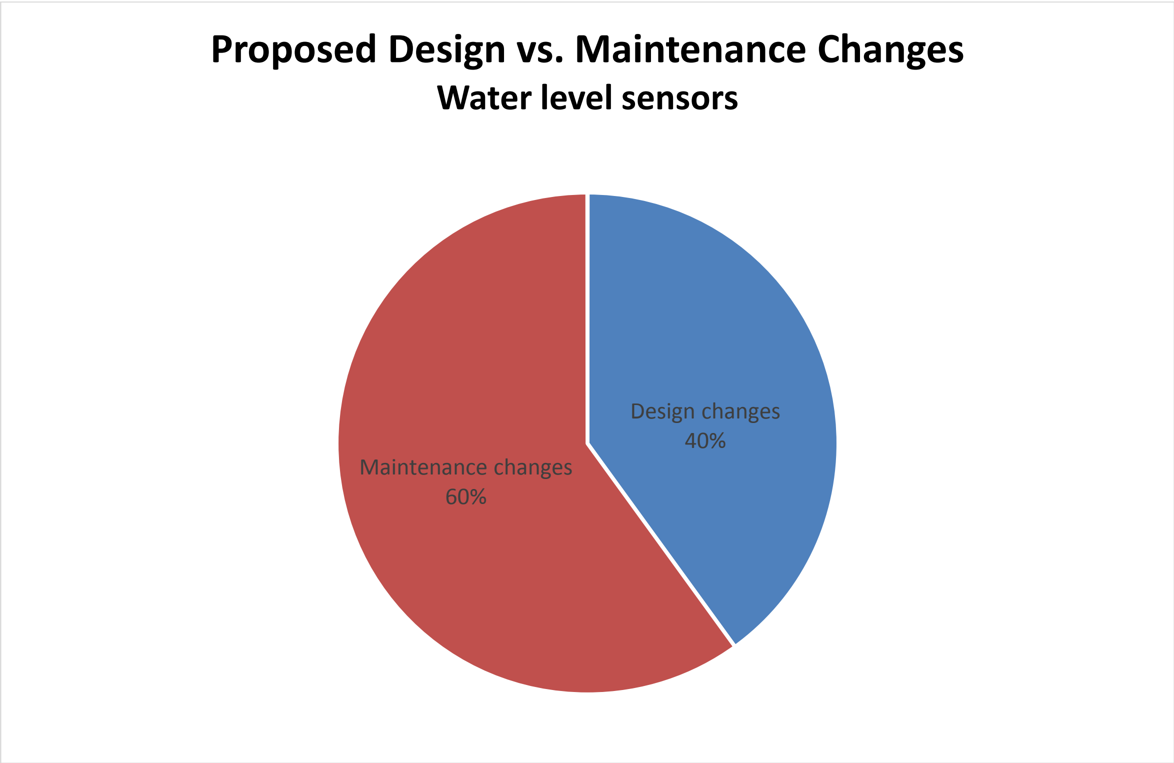


Figure 62

5.8 Structural failures

Failures in 2014	Failures	% Contribution	Contributor Rank
130	7	5.4	7

No.	Design related comments
1	Redesign inlet manifold
2	Improve exhaust flame trap support – extra welds or support brackets
3	Remove stress point around flame trap housing weld

No.	Maintenance / Testing related comments
1	Refine maintenance strategy to improve explosion protection properties lifecycle
2	Ether test was unable to detect leak – only detected on code D hydrostatic test

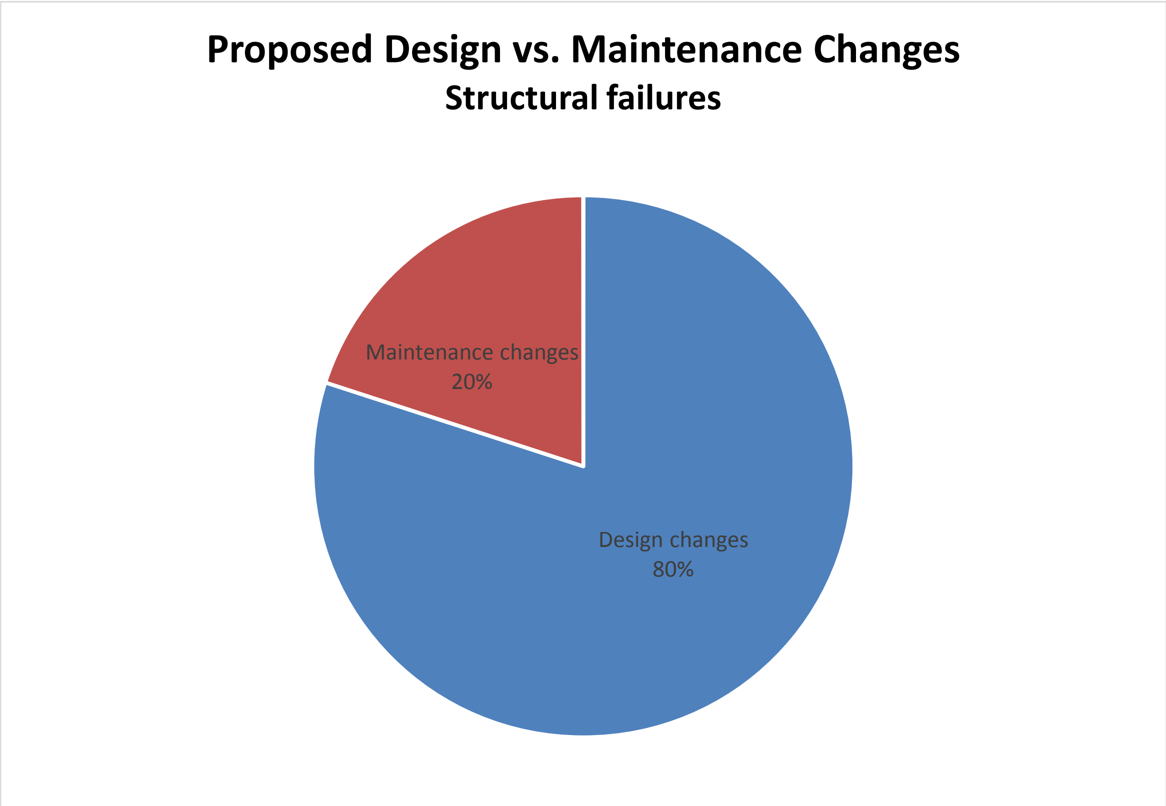


Figure 63

5.9 Conclusions

Ex-DES Failures Analysis 2012 (Report 13012) concluded that a substantial portion of maintenance changes proposed during the study period could be obviated by incorporating appropriate design modifications and that 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.

Design changes recommended dominate across the board in 2014 as compared to maintenance changes.

This could be indicative of a continuing paradigm shift towards:

- Advanced technology
- Enhanced condition monitoring
- Automatic diagnostics
- Minimising the need for human intervention.

6 OEM Statistics

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

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

The purpose of this section is to present data on non-specific major OEMs:

- Major OEMs whose machines constitute the industry inventory
- Number of machines per major OEM that constitute the industry inventory
- Number and locations of failures per OEM for the period Jan – Dec 2014

A consolidated list of non-specific current OEMs and the number of machines in the current inventory* is presented in the table below. OEMs with no reported incidents for the 2014 period are not listed in this section.

Current OEM	Machines in Inventory
OEM A	474
OEM B	409
OEM C	185
OEM D	97
OEM E	68
OEM F	31
OEM G	34
OEM H	4
Total machines in Inventory	**1308**

* Source: Master of Plant item registration 13.xlsx received on 16.02.2015; DES Item Reg – Current. Only items with a current MIR registration during the period of the 1st of January to the 31st of December 2014, inclusive, were factored. OEMs whose machines had no reported incidents for the 2014 period are not listed in this table.

Table 7

6.1 Reported failures per OEM

Listed below are the reported failures per OEM.

OEM	2014 Failures	% Contribution	Machines in inventory	Failures % of inventory
OEM A	62	48%	474	13%
OEM B	34	26%	409	8%
OEM C	18	14%	185	10%
OEM D	10	8%	97	10%
OEM G	2	2%	34	6%
OEM H	2	2%	4	50%
OEM E	1	1%	68	1%
OEM F	1	1%	31	3%
Total number of failures in 2014	**130**	**100%**	**1308**	

Table 8

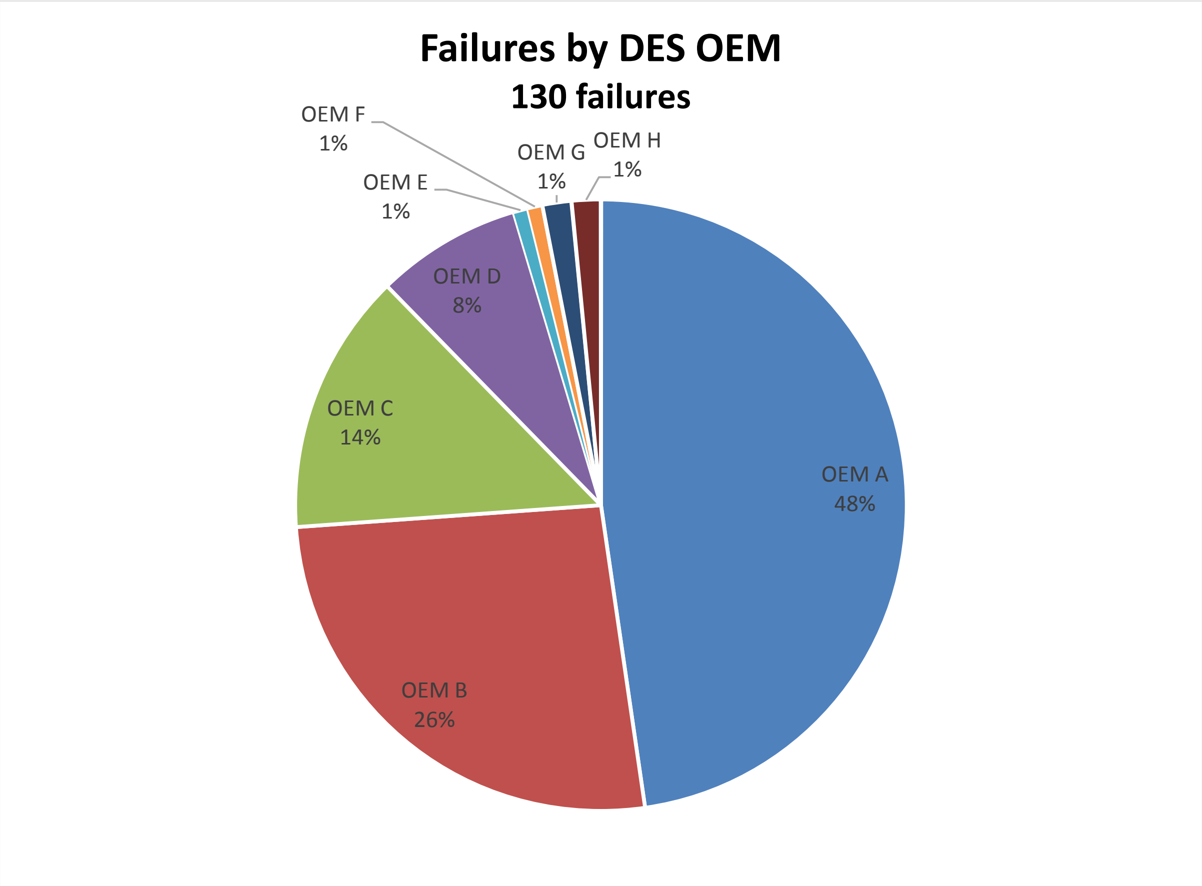


Figure 64

The OEM-wise distribution of failures along with their respective inventory numbers (refer Table 8) are recorded in the plot below:

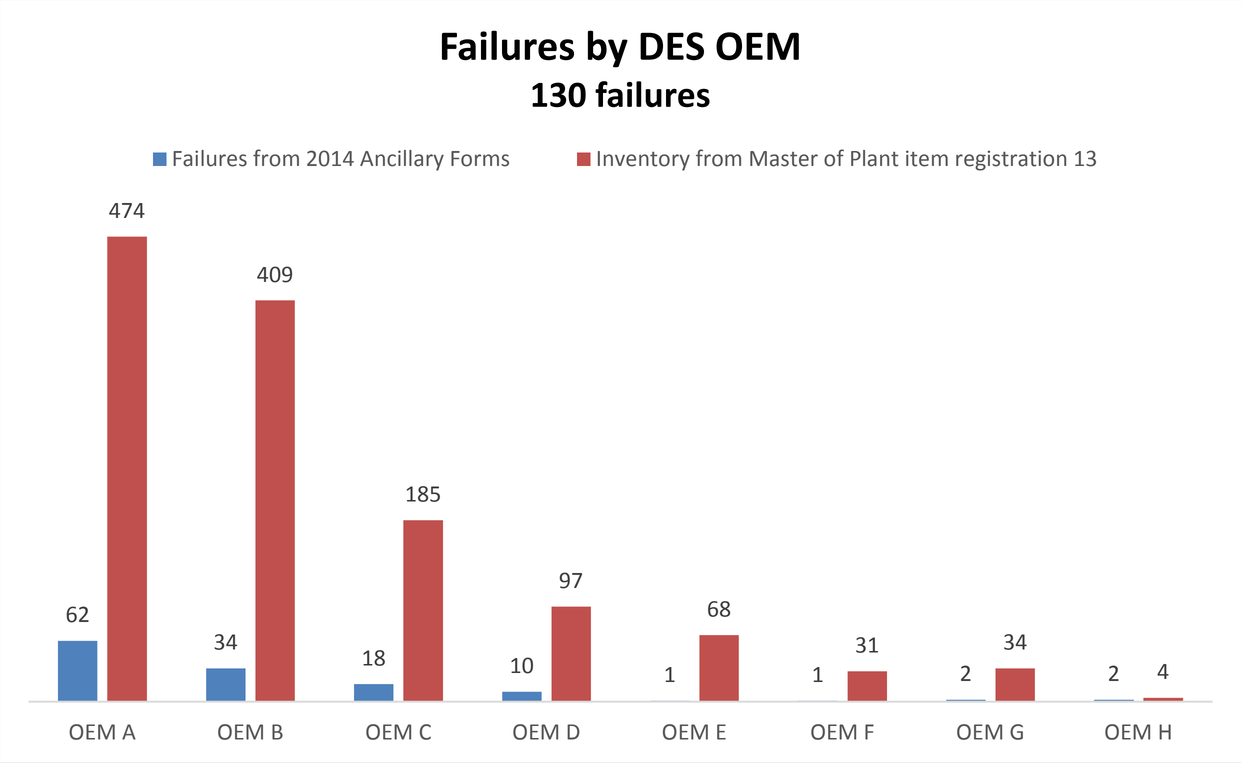


Figure 65

The number of failures per item registered in the current inventory is shown below.

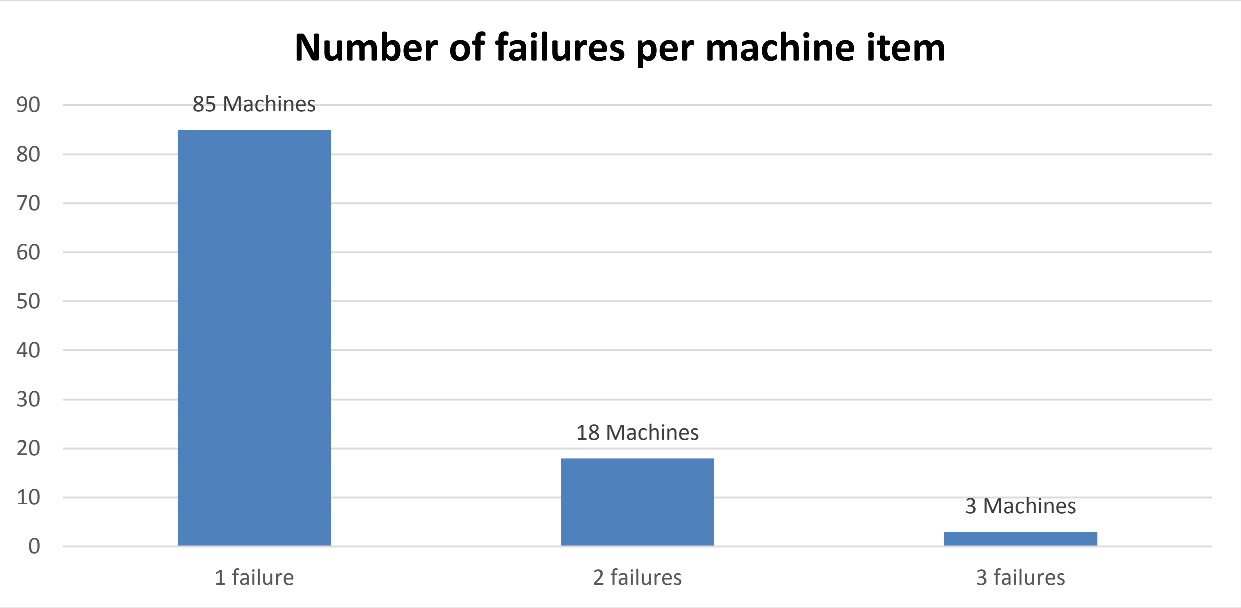


Figure 66

6.2 Intentionally Blank

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6.3 Engine component failures by OEM

The OEM-wise distribution of the Engine component failures along with their respective inventory numbers are recorded in the plot below:

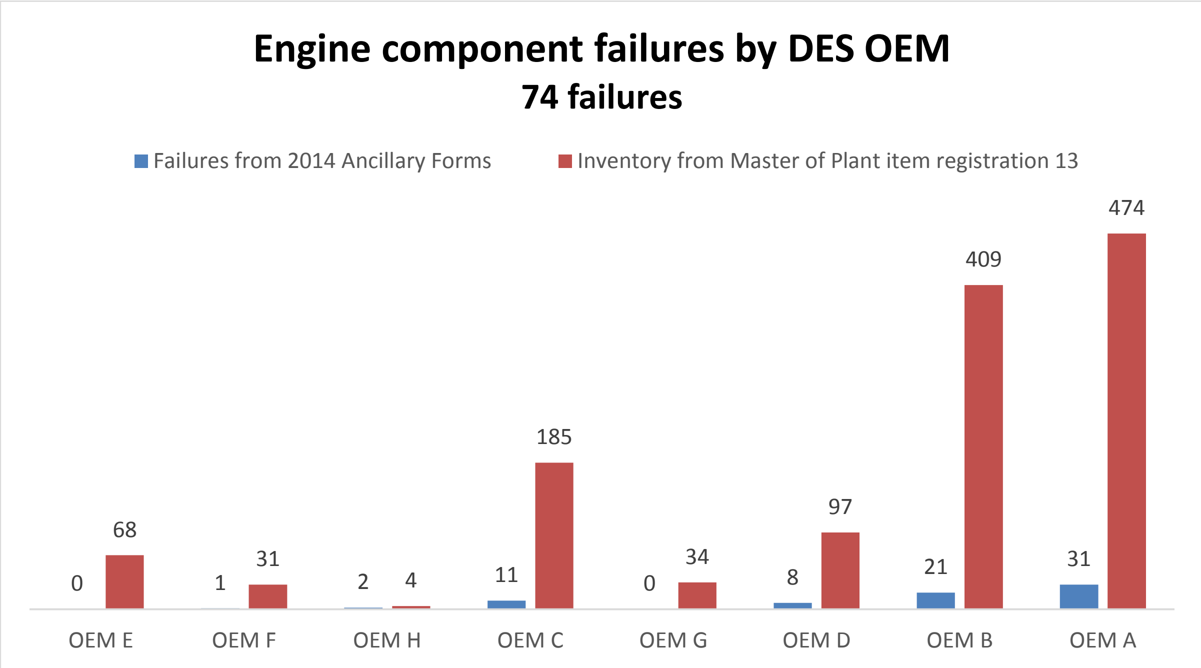

Figure 67

An excerpt of the 2014 data from Table 2 is shown below.

Engine component	Incidents	% Contribution to 2014 failures
Exhaust flame trap (wet/dry)	21	16%
Exhaust manifold	15	11%
Intake manifold	13	10%
Intake flame trap & housing	5	4%
Exhaust pipe(s)	8	6%
Forced induction (turbo / supercharger)	5	4%
Engine head	5	4%
Engine block & cylinders	2	2%

Table 9
Contributers to Engine component failure

The following sections present plots on each of the above engine component failures vs. the OEMs.

6.3.1 Exhaust flame trap (wet/dry) failures

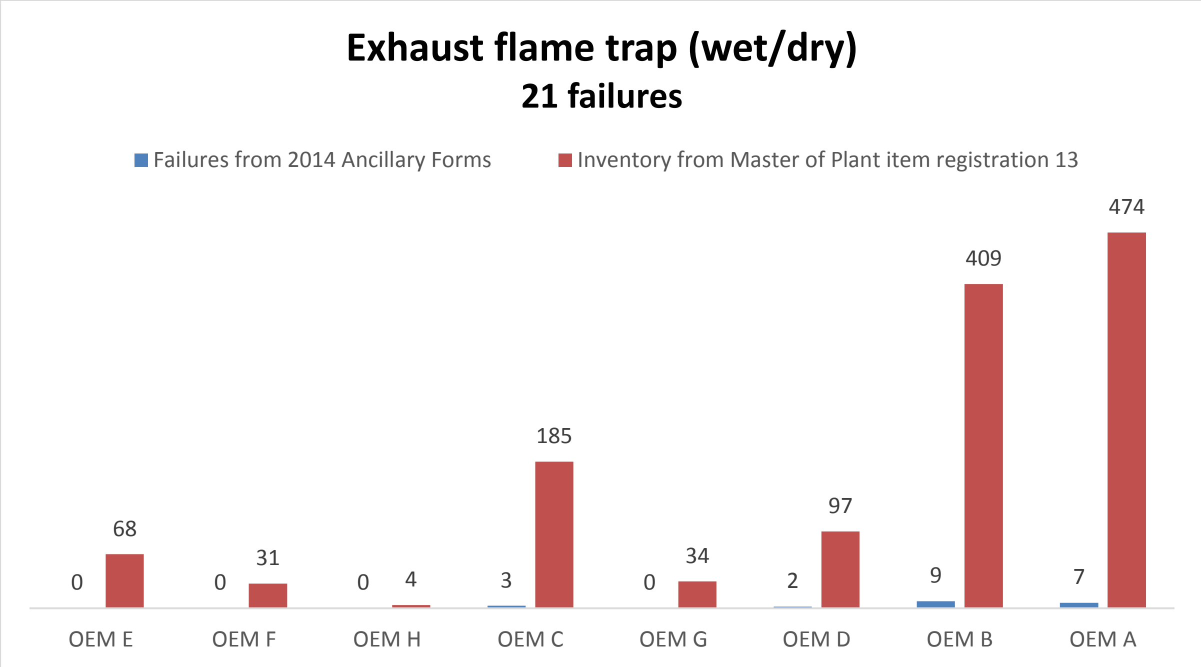

Figure 68

6.3.2 Exhaust manifold failures

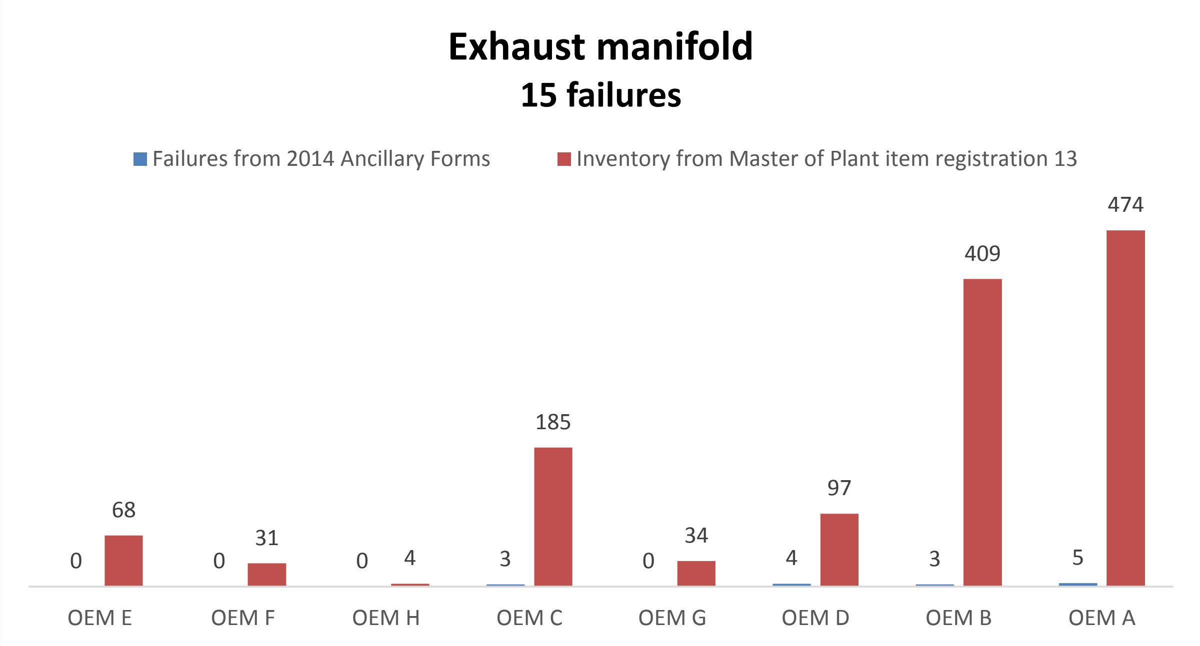

Figure 69

6.3.3 Intake manifold failures

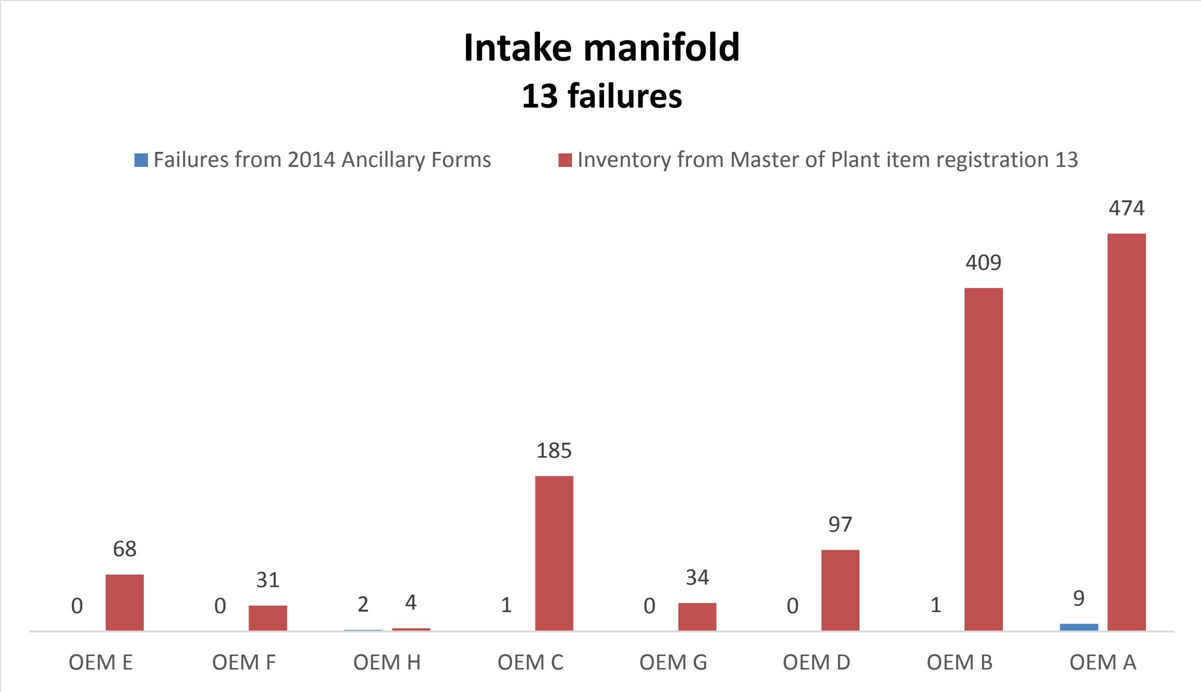

Figure 70

6.3.4 Intake flame trap & housing failures

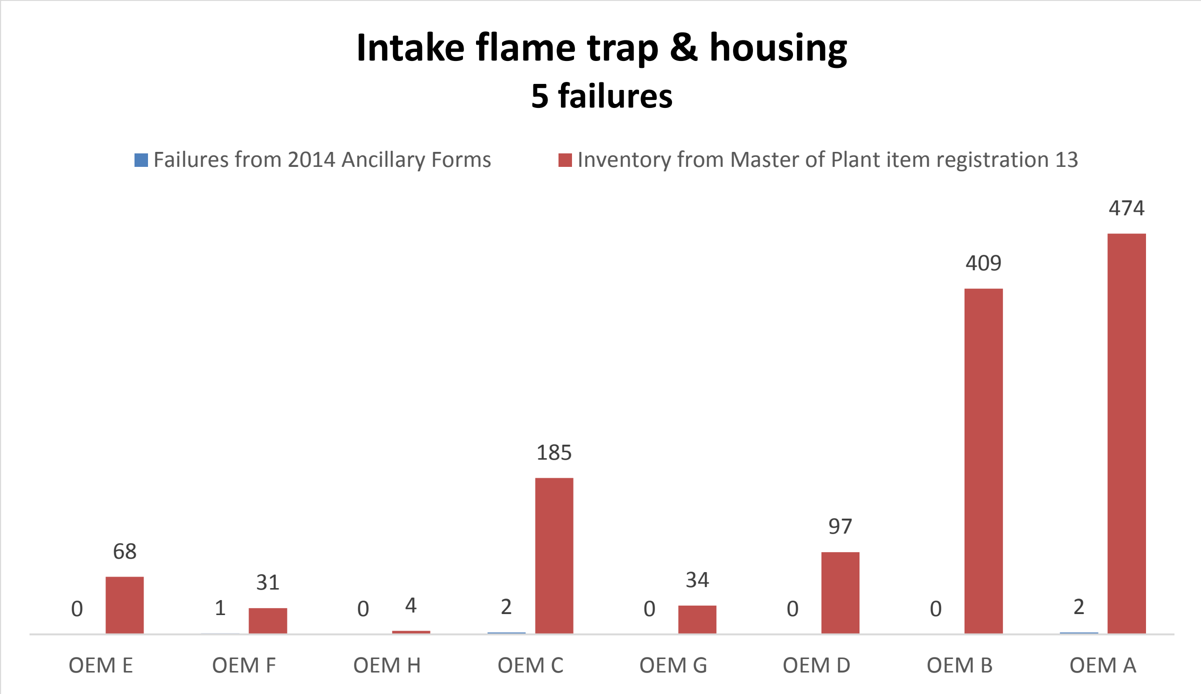

Figure 71

6.3.5 Exhaust pipe(s) failures

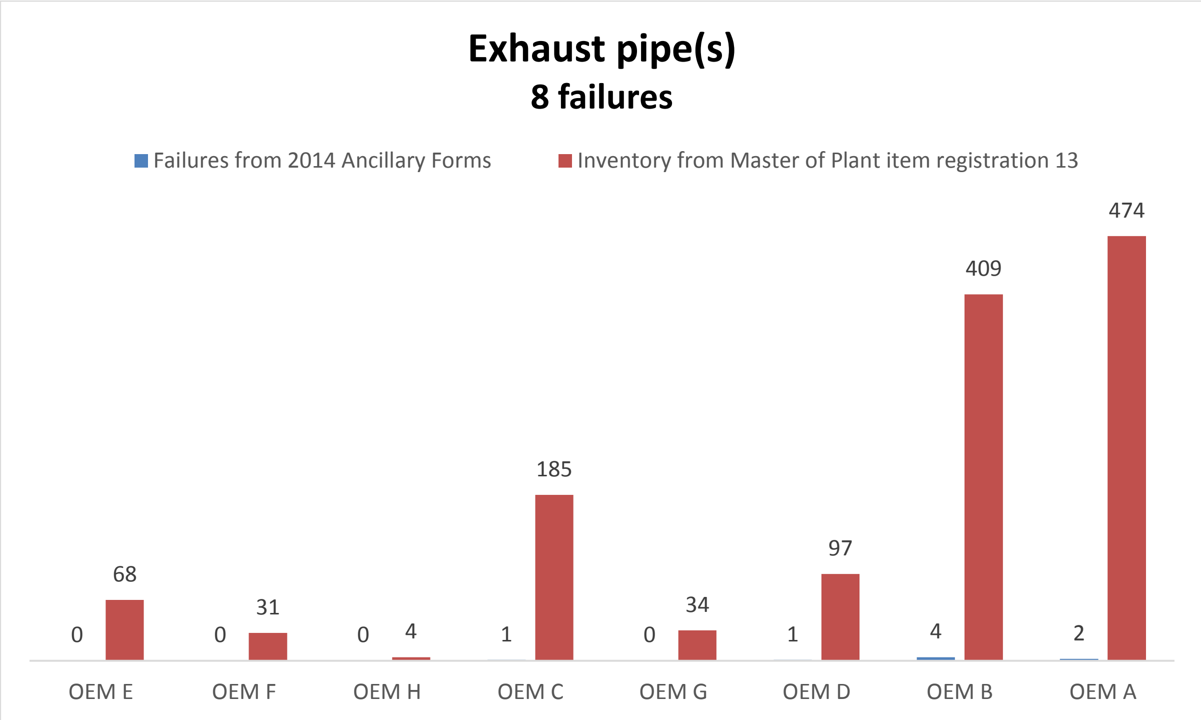

Figure 72

6.3.6 Forced induction (turbo / supercharger) failures

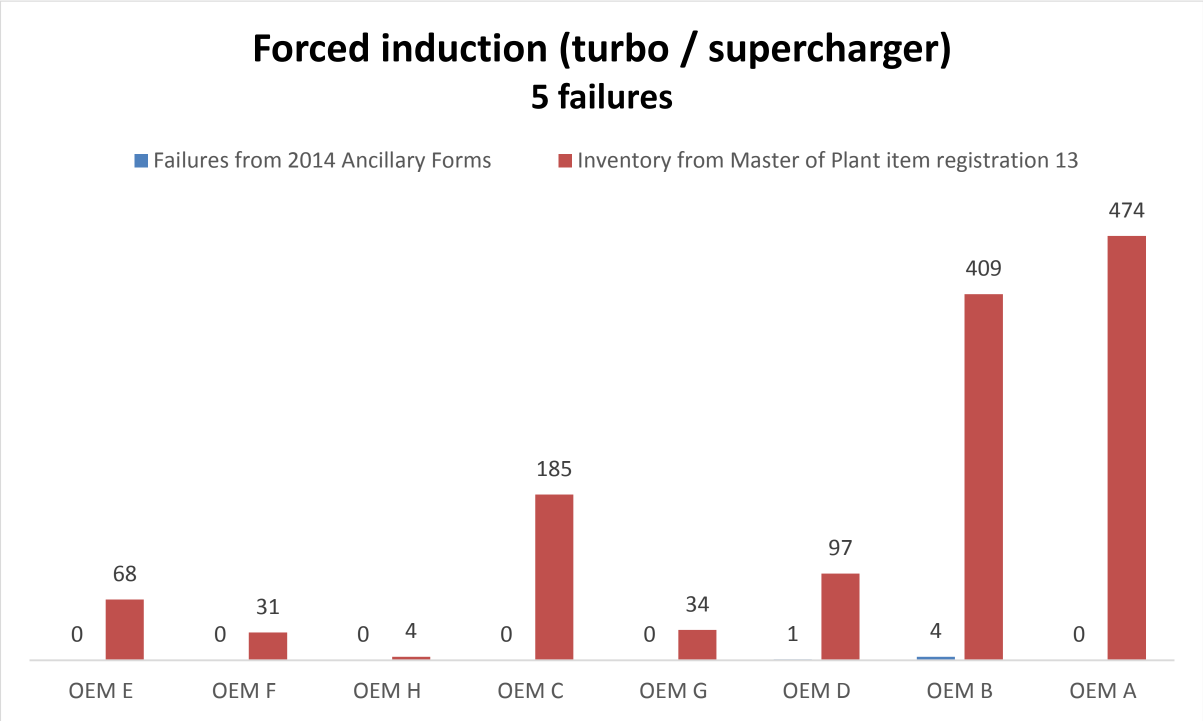

Figure 73

6.3.7 Engine head failures

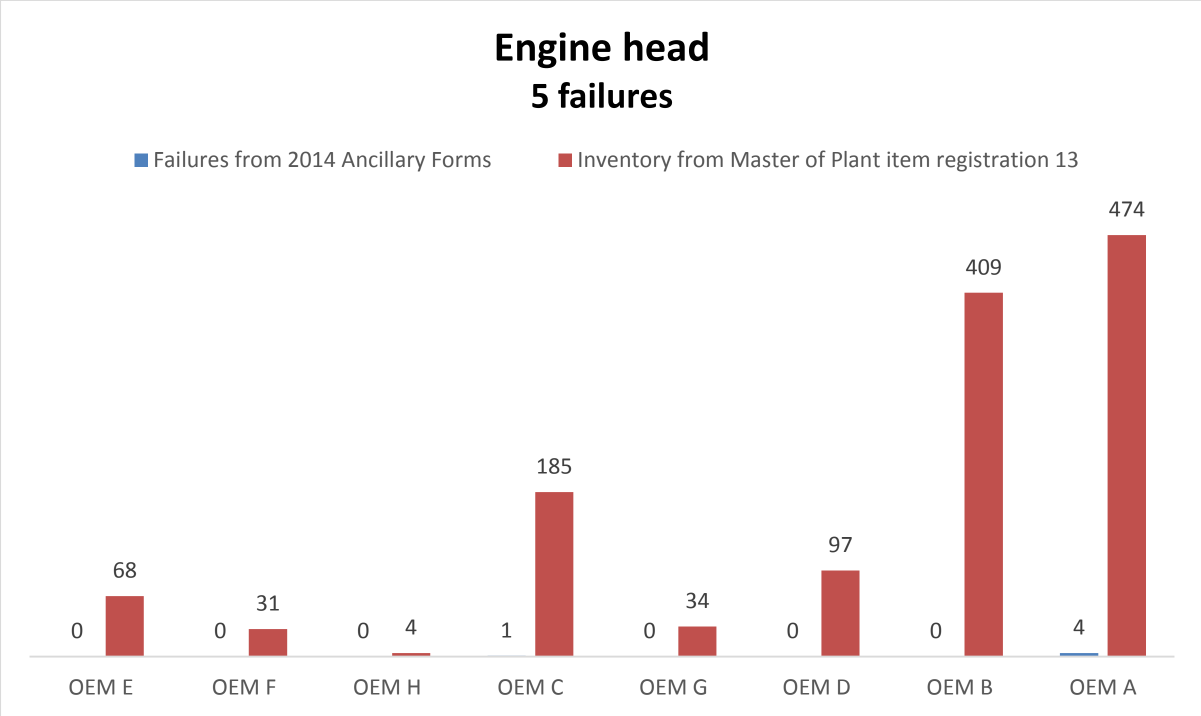

Figure 74

6.3.8 Engine block & cylinders failures

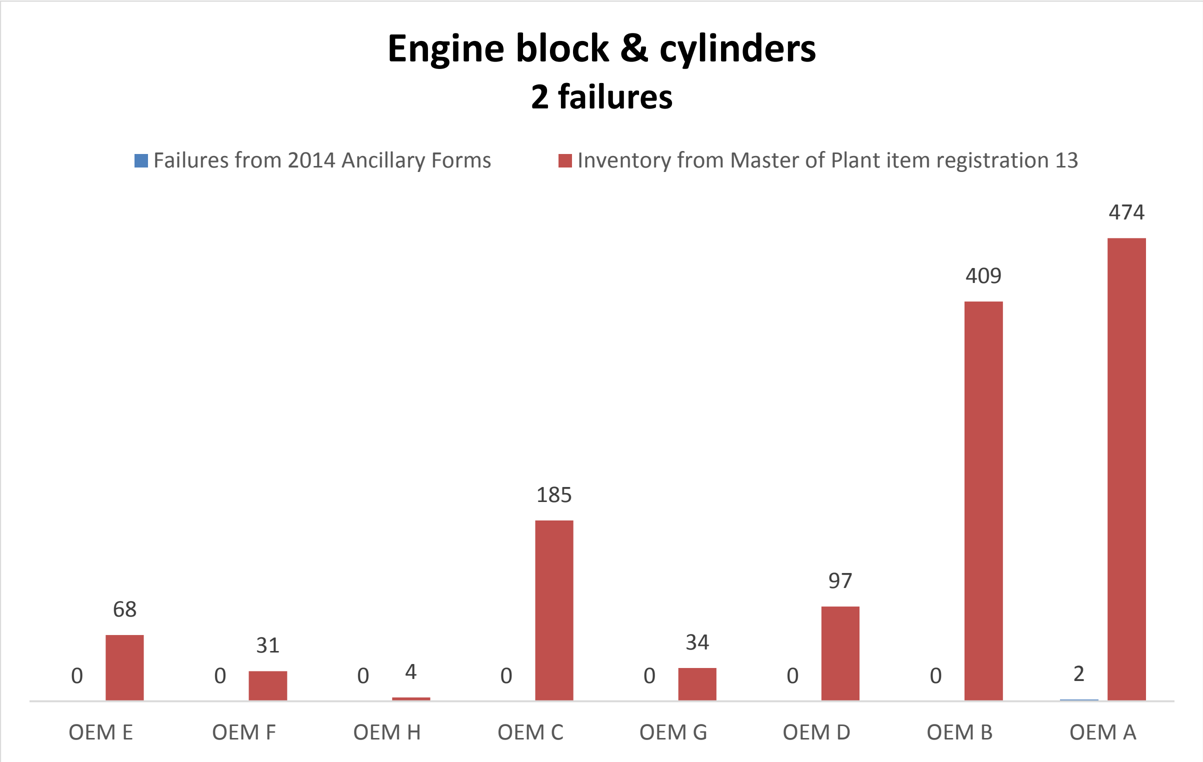

Figure 75

6.4 Pneumatic/Hydraulic Control System failures by OEM

The non-specific OEM-wise distribution of the Pneumatic / Hydraulic Control System failures along with their respective inventory numbers (refer Table 7) are recorded in the plot below.

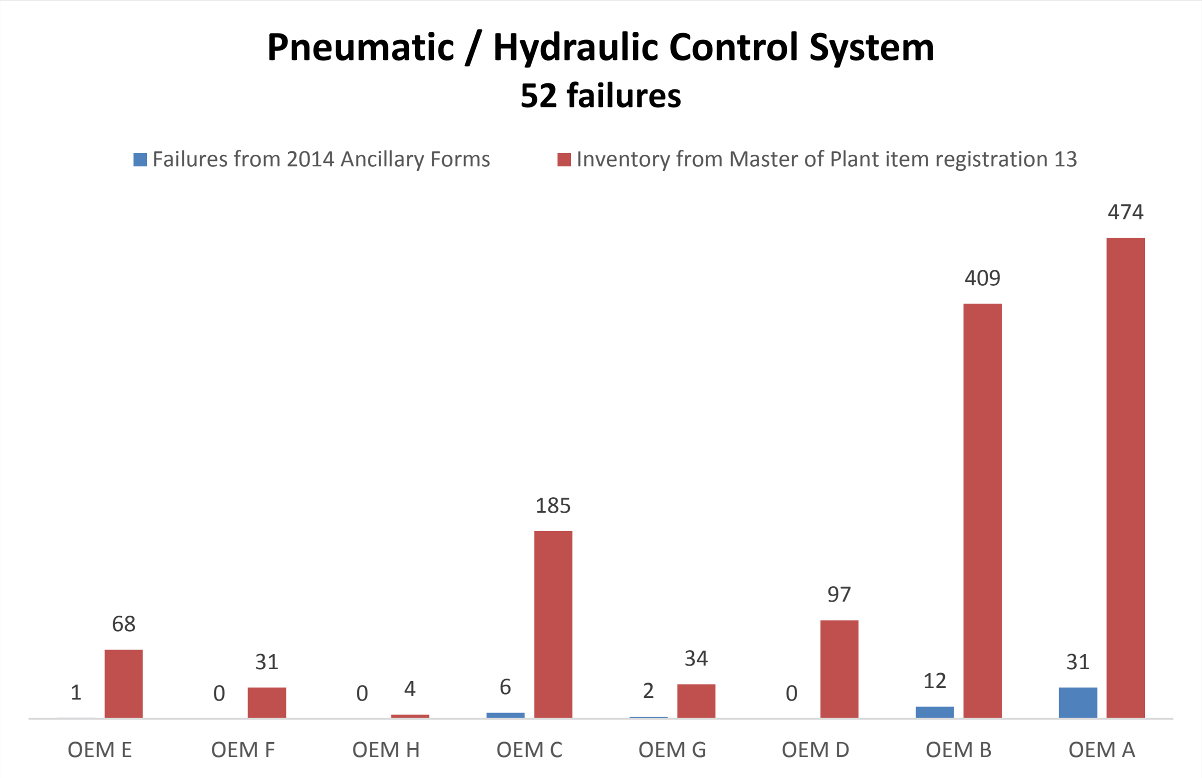

Figure 76

An excerpt of the 2014 data from Table 3 is shown below.

Pneumatic / Hydraulic Control System component	Failures	% contribution to 2014 failures
Shutdown cylinders or solenoid	12	9%
Other circuit control valve failure	18	14%
Cooling system sensors	10	8%
Water level sensors	10	8%
Engine oil pressure sensors	1	1%
Other	1	1%
Total	**52**	**40%**

Table 10
Contributors to Pneumatic / Hydraulic Control System component failure

The following sections present plots on each of the above pneumatic / hydraulic control system component failures vs. the non-specific OEMs.

6.4.1 Shutdown cylinders or solenoid failures

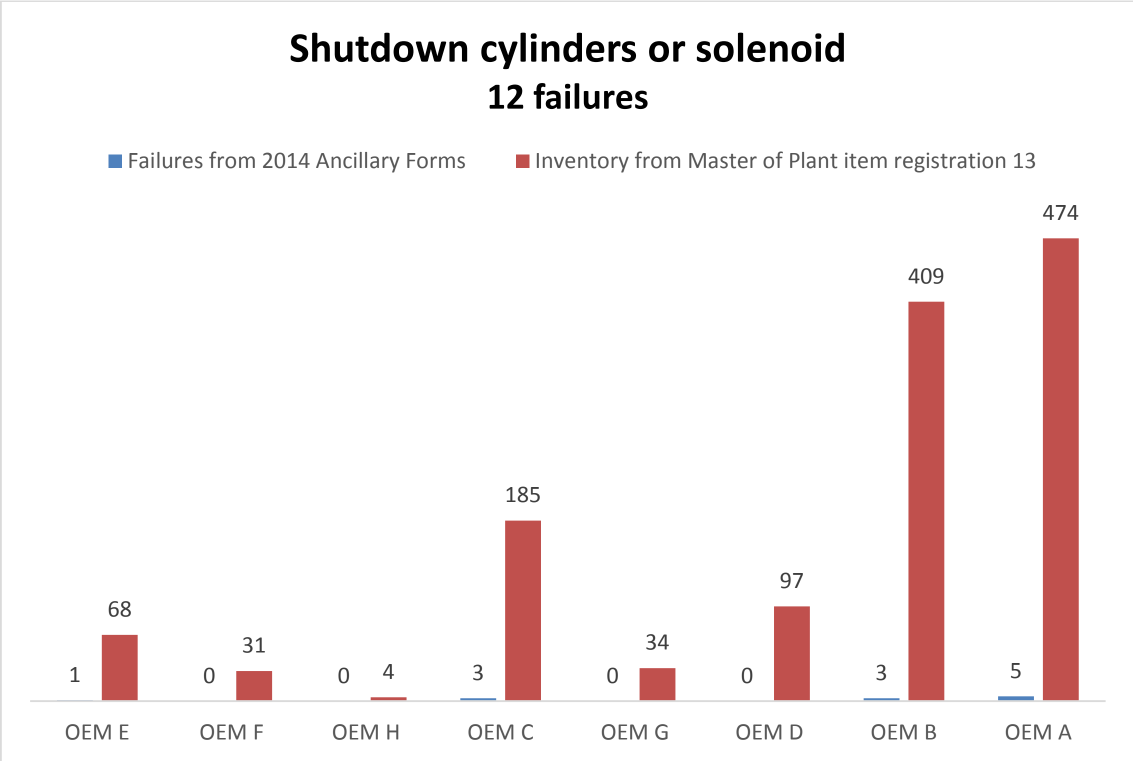

Figure 77

6.4.2 Other circuit control valve failures

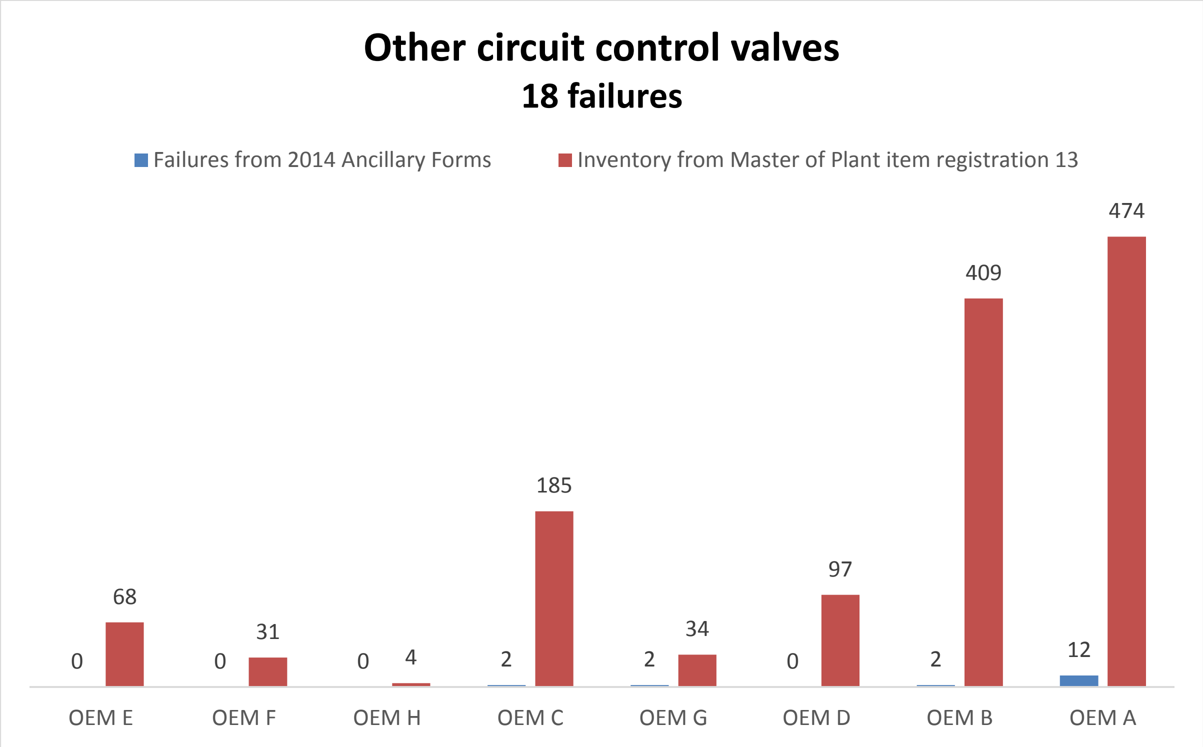

Figure 78

6.4.3 Water level sensor failures

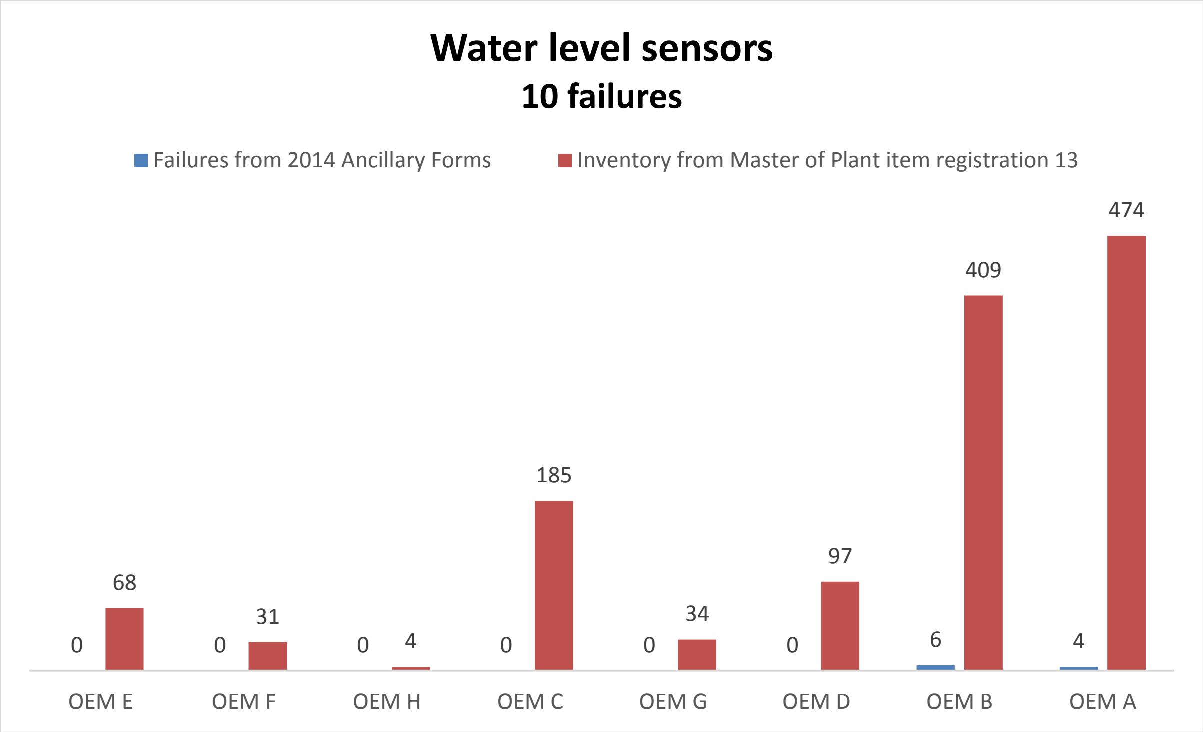

Figure 79

6.4.4 Cooling system sensor failures

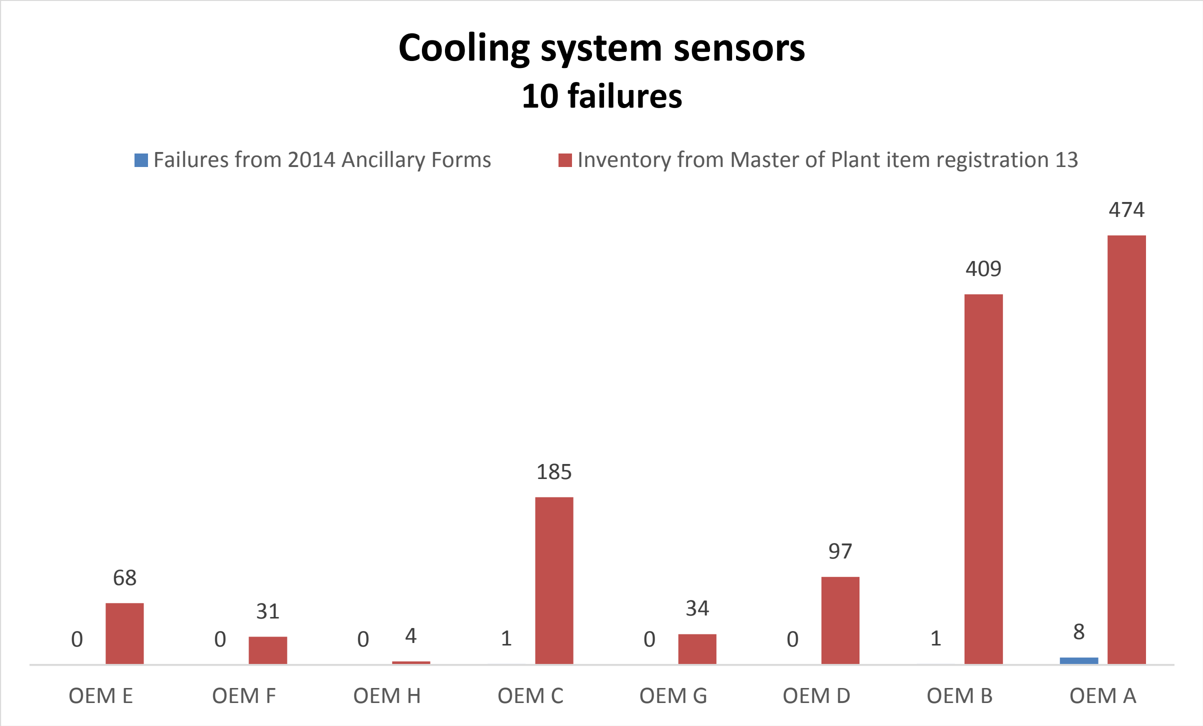

Figure 80

6.4.5 Engine oil pressure sensor failures

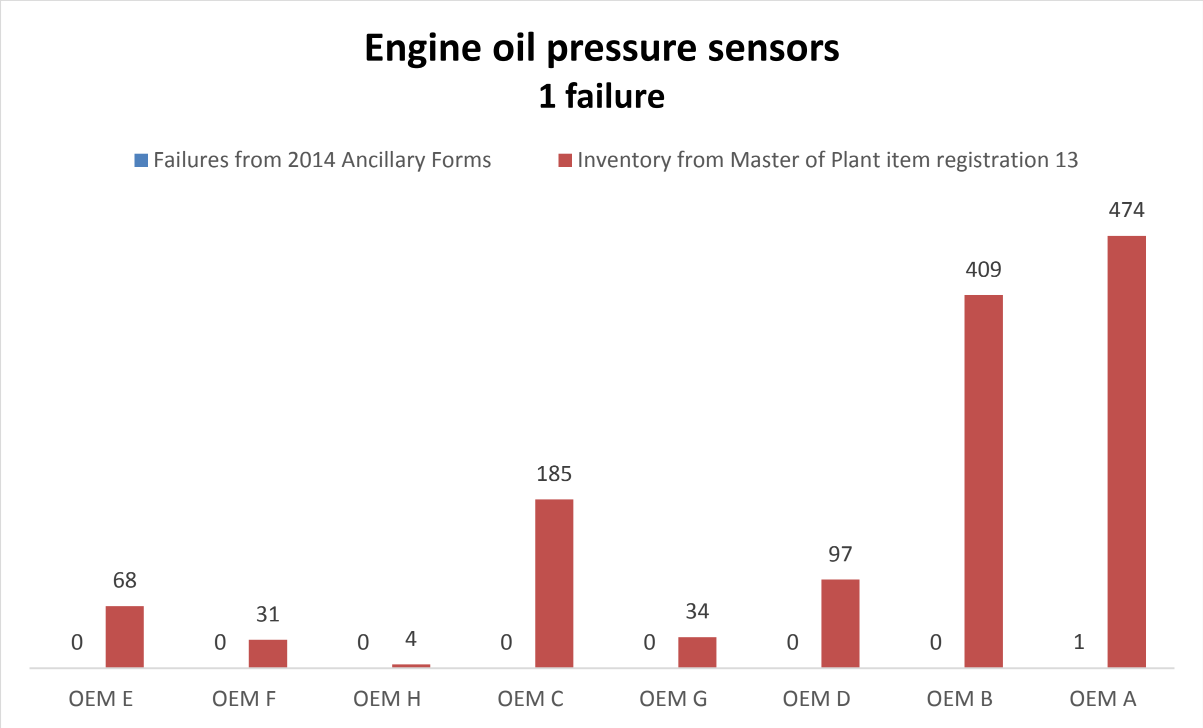

Figure 81

6.4.6 Other failures

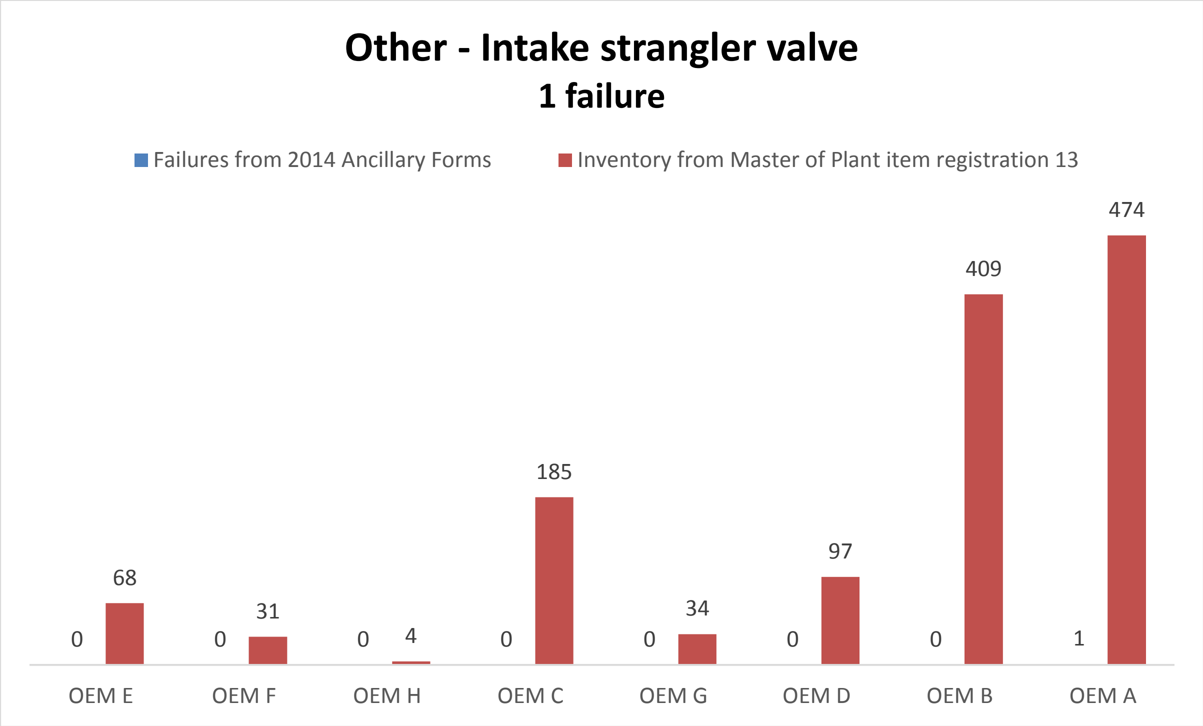

Figure 82

6.5 Electrical Control System failures by OEM

The non-specific OEM-wise distribution of the Electrical Control System failures along with their respective inventory numbers (refer Table 7) are recorded in the plot below.

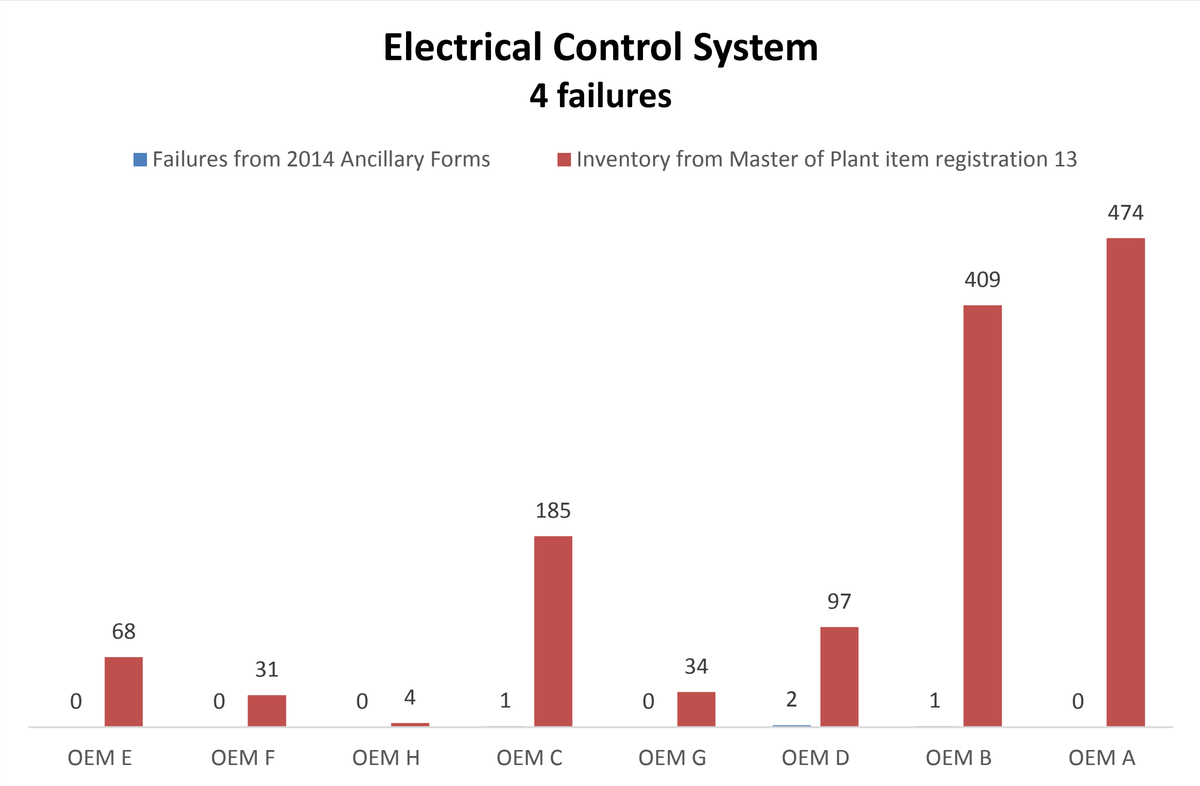

Figure 83

Table 4 is repeated below:

Electrical Control System component	Failures	% contribution to 2014 failures
Shutdown cylinders or solenoid	2	2%
Cooling system sensors	2	2%
Total	**4**	**3%**

Table 4 (repeated)
Contributors to Electrical Control System component failure

The non-specific OEM-wise distribution of the Electrical Control System failures along with their respective inventory numbers (refer Table 7) are recorded in the plot below.

6.5.1 Shutdown cylinders or solenoid failures

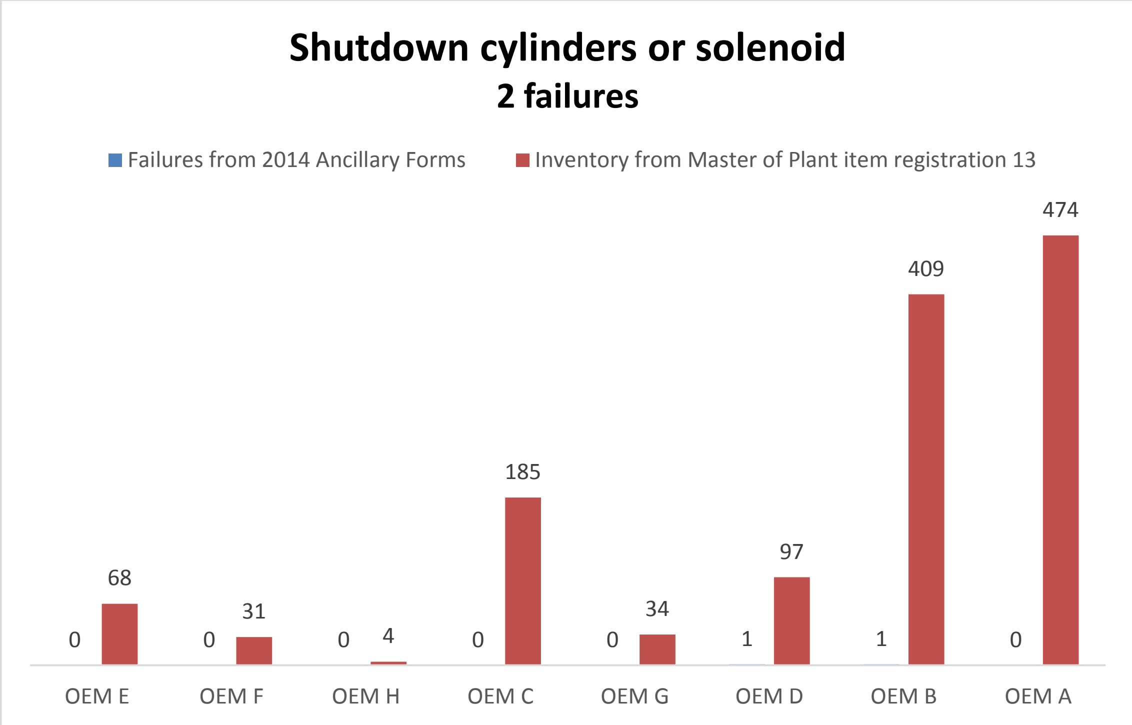

Figure 84

6.5.2 Cooling system sensor failures

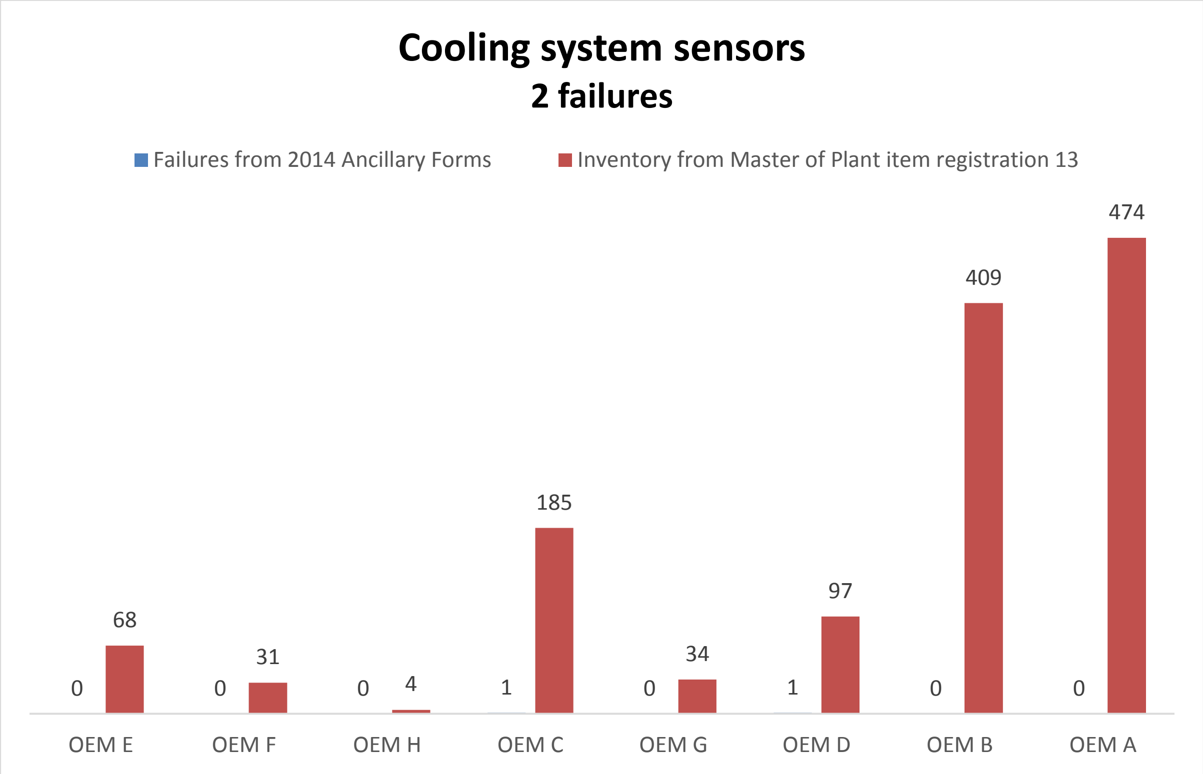

Figure 85

7 Conclusions

7.1 Failures down by 20%

There was a significant drop overall for ExDES failures by approximately 20% i.e., 165 in 2013 to 130 in 2014.

7.2 Top Failure Modes

The Top Failure Modes from the 130 ExDES failures during the period January to December 2014 are shown below:

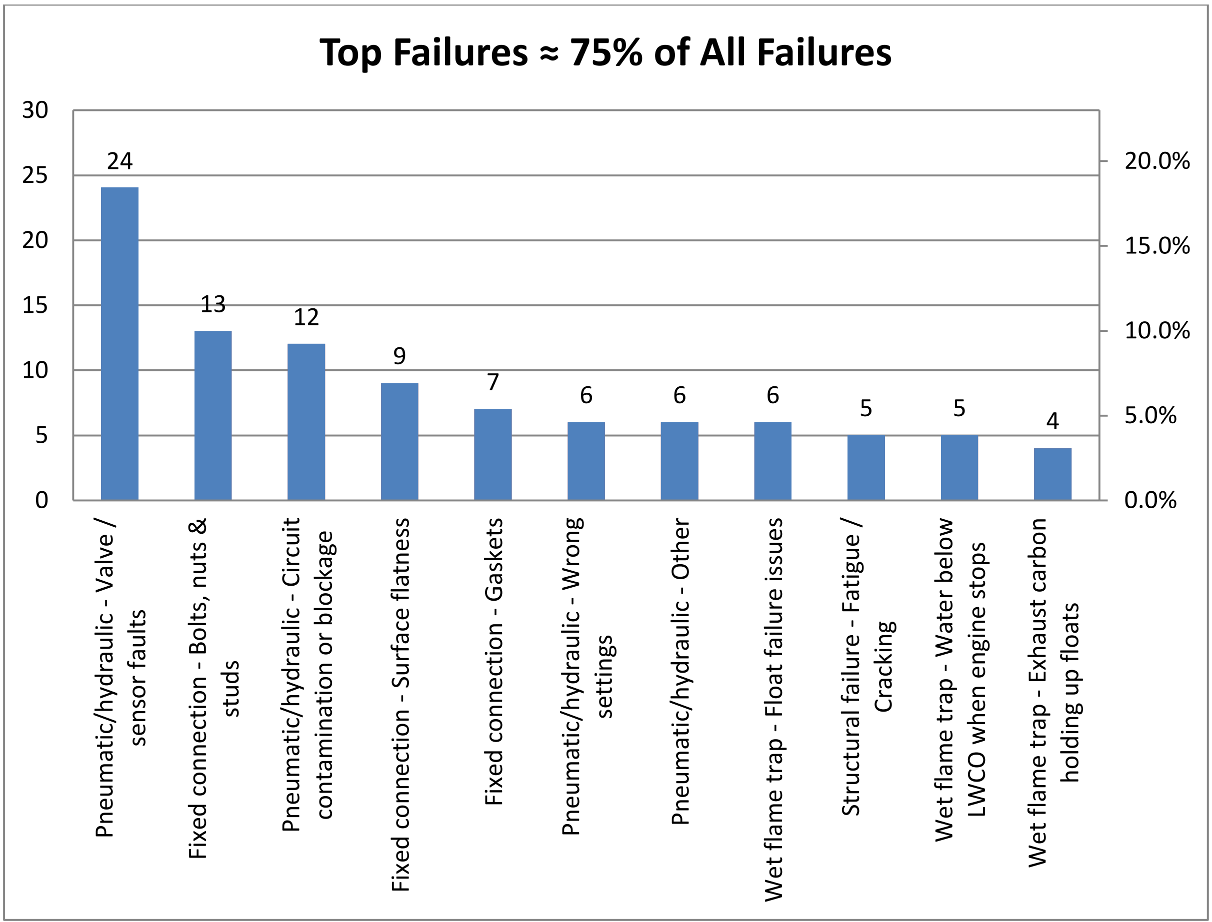

Figure 86

The top five failures above are in line with what was observed in 2013. However, Surface flatness features as a top failure mode in 2014.

7.3 Proposed Design vs. Maintenance changes

Out of a total of 98 Miners' recommendations received in 2014, 72 were design based and 26 were maintenance based. Figure 56 (repeated below) shows a continuing shift towards design based recommendations.

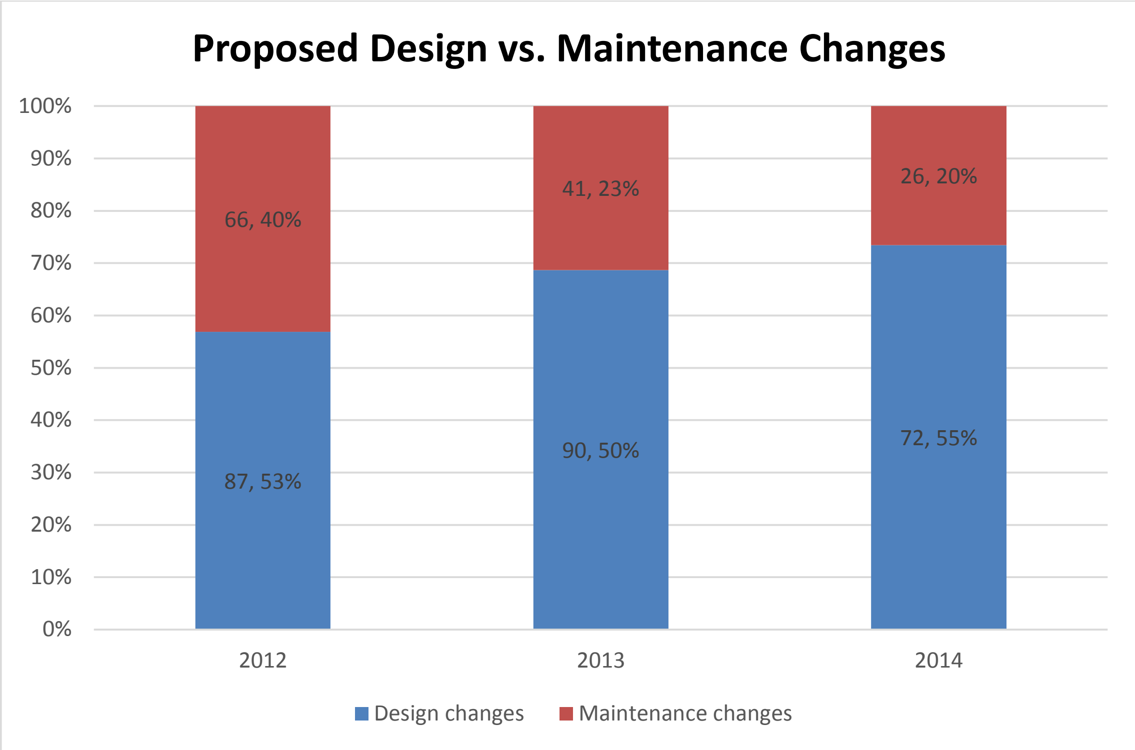

Figure 56 (repeated)

7.4 Functional Safety Management

Control measures in ExDES broadly fall into two categories – safety components and safety functions. While safety components include the likes of positive flametraps, open and closed joints, typical safety functions would be a wet flametrap scrubber and coolant temperature control.

Both safety components and functions are required to be subjected to Functional Safety Management regimes such as control and avoidance of systematic failures, configuration management, version control and documentation requirements. In addition, safety functions need to be assessed for conformance to the required integrity metrics such as PL / CAT / SIL.

The Functional Safety Management regimes and more importantly the "culture" is to be setup and implemented at both the OEM and the End-user domains for enhanced effectiveness.

o-o-o-o

8 Acronyms & Definitions

DES	Diesel Engine System
End-user	Mine site / Coal Operation
ExDES	Explosion Protected Diesel Engine System
Industry	NSW Underground Coal Mining Industry
MDA	Mine Design Approval (NSW Government – Department of Trade & Investment)
MDR	Mine Design Registration (NSW Government - Department of Trade & Investment)
OEM	Original Equipment Manufacturer

9 Status of Document

9.1 Liability

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

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9.2 Revision Record

Version	Revision	Date	History
V1	R0	22.02.2015	Kick-off version
V1	R1	02.03.2015	Post-internal review
V1	R2	02.03.2015	Removal of duplicate entry
V1	R3	13.03.2015	Release of Internal Report
V1	R4	13.03.2015	Release of Publication Report

Status: V1, R4

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10 Bibliography

1. 2014 ExDES Failures database "COA-AR ExDES Diesel Engine Systems Ancillary Report following 56(1)(m) In Service Failure of Explosion Protected Systems 150116.xlsx"

2. 2014 Inventory database "Master of Plant item registration 13.xlsx"

3. Report 13012 – ExDES Failures Analysis 2012 – DTI Internal Report – NSW Government – Trade & Investment, May 2013, Revision V1R4 by Shakti Corp Pty Ltd.

4. Report 14009 – ExDES Failures Analysis 2013 – DTI Internal Report – NSW Government – Trade & Investment, June 2013, Revision V1R4 by Shakti Corp Pty Ltd.