Application of Crow-AMSAA to Predict Failure of Centrifugal Pumps with Increasing Failure Rates

By

Danial Syariman Razali Bin Mohd Razali

Dissertation submitted in partial fulfillment of
The requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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Approved by,

____
(AP Dr Ir Mohd Amin b. Abd Majid)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

DANIAL SYARIMAN RAZALI BIN MOHD RAZALI

ABSTRACT

The purpose of this research is to focus on the failure model analysis on the centrifugal pumps data using Crow-AMSAA. The data were analyzed using two trend test methods which were Mann test and Laplace test. The data that satisfied those tests were subjected to Crow-AMSAA failure model analysis. This project also analyzed and evaluated the differences in the result acquired with the Crow-AMSAA analysis and the actual data. The accuracy between the two parameters determined the accuracy of Crow-AMSAA analysis. Each of the pump selected, for which the criteria of selection were pumps with more than 5 failure occurrences, the result of each analysis procedure were reported. The graphs that were plotted in both the trend test and the Crow-AMSAA analysis were presented in this report. From the results of the analysis, the accuracy of the failure prediction of centrifugal pumps that were made using Crow-AMSAA as the prediction model were accurate with an error range of 16% to 19% percent.

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Sincerely,

Thank you.

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NOMENCLATURE

1. NHPP – non-homogenous Poisson process, each data point at related to one another and will influence the outcome of the next data point.
2. MTBF – mean time before failure, the average time before failure occurs
3. Crow-AMSAA – a failure mode analysis model that could be use as a prediction tool with the right data type.
4. Trending – shows that the data are dependent with one another

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The term Reliability Growth deals with the measurement and assessment of the reliability improvement of a product or process. In assessing that, a reliability parameter is utilized and tracked over time in different phases. There are various models that have been developed over the years to plan, track and project reliability improvement of systems either continuous or discrete [5]. This project will be researching on the effectiveness of one such model on prediction the failure time of centrifugal pumps. The model that will be used is Crow-AMSAA. This model adopted mean time before failure (MTBF) or Failure Rate as criterion in determining reliability growth. There are other parameters that Crow-AMSAA model can utilize in assessing reliability growth; the results are similar regardless of which parameter is chosen.

The data that were used for analysis in this project were failure occurrence for centrifugal pumps that were used in petroleum refineries. The reason centrifugal pumps failure occurrences were used as the primary data source is that there is still no suitable predictive maintenance program for centrifugal pumps [6]. Unexpected pump shut downs still is a major problem for most petroleum refineries, according to 2002 data a typical pump failure will cost approximately RM 17500 or USD 5000[13].

1.2 Problem Statement

The standard practice in failure analysis of centrifugal pump system is using the data and plugging it into a Weibull failure analysis model. The Weibull is a widely used technique for statistical data analysis especially data relating to product life [5]. Weibull analysis assumes that the pumps system does not age or deteriorate and independent of the previous pattern of failure. In truth, the pumps system does age and each repair would influence future failure occurrences. Non-homogenous Poisson process (NHPP) is define as a stochastic process where event would occur continuously and the intensity of the occurrences is a function of time. Pump systems failure occurrences could be model as NHPP, because of this Crow-AMSAA could be used to analysis the data and produce a prediction on the next failure occurrences.

Mean time between failures (MTBF) is an important parameter in determining pumps performance. In fact, it has been the best practice in the oil and gas refinery industry to use MTBF in performance analysis and maintenance. With the MTBF data pump users can discover the weak link in assembly and make necessary maintenance to improve the pumps likelihood of failure. Since MTBF plays a main role in pump performance it is importance to have ways in accurately calculate the MTBF for those pumps. Various method exist in determining MTBF, one such method is using Crow-AMSAA failure analysis model.

1.3 Objective of the Project

The main objective of the project is to analyze the performance of Crow-AMSAA failure model analysis in predicting the failure time of the centrifugal pumps. The performance of the Crow-AMSAA model would be determined by the cumulative MTBF that would be calculated from the analysis and the error between the predicted failure occurrences with the actual failure time.

1.4 Scope

The scope of the project is using Crow-AMSA to analyze the centrifugal pump systems failure occurrence data. The centrifugal pump failure data were from a petrochemical refinery plant. This project's analysis focused on system failure not the individual component failure.

The method involved only pumps that have more than 5 failure occurrences are selected for the analysis, the pump system that the data were acquired from have a redundancy system in place. This was the reasoning behind treating both the main pump and the redundancy system pumps were treated as one pumps. This is done primarily to increase the number of eligible pumps that could be analyzed. Each of the pumps selected have undergone through trend testing, because to ensure that the pump are eligible to Crow-AMSAA analysis.

CHAPTER 2

LITERATURE REVIEW

A literature review is a description of relevant literature works that gives an overview of what has been said, who the key writers are, what are the prevailing theories and hypotheses, what questions are being asked, and what method and methodologies are appropriate and useful. In the case of this project the literature review will be covering the basis of reliability growth theory and the failure analysis models that is use for this project and its development and theory which is the Crow-AMSAA model.

2.1 Centrifugal Pumps

The number one cause for unexpected shut down for centrifugal pumps are bearing and mechanical seal failure. The general components of a centrifugal pump can be seen in the figure below:

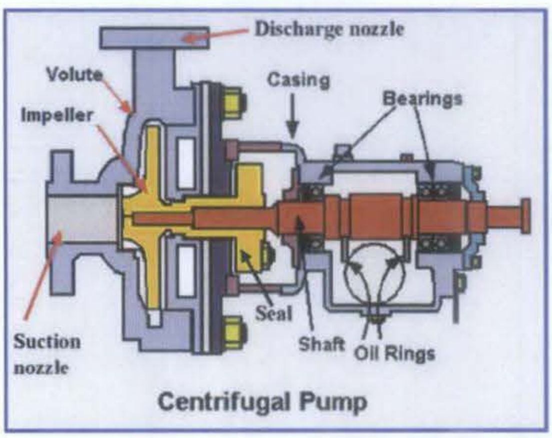

Figure 2.1 General components of a centrifugal pump [13]

Mechanical seals act as a check valve and a slider bearing. The main function of mechanical seals is that of a check valve to prevent liquid under pressure from leaking out of the pump, or from drawing air into the pump when under vacuum conditions [13]. Because the seal acts as a friction bearing the seal has an unpredictable life span. This component is replaced many times in a pump life cycle. Like all bearing mechanical seals need lubricant to function properly, in the case of this component the lubricant is the pump liquid itself. The quality of the liquid that is pump through the pump will affect the seal life [14].

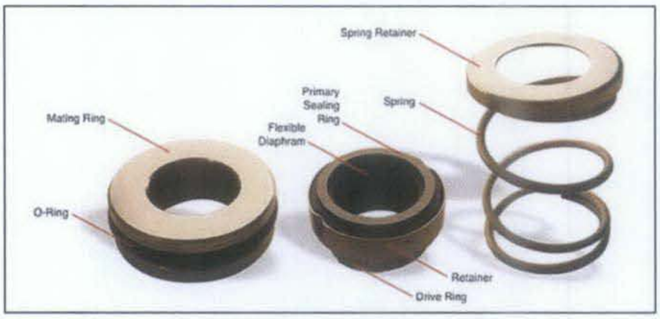

Figure 2.2 Components of a mechanical seal [14]

If the liquid contains particles within it while it is being pump, more often than not the particle that is in the pumped liquid is abrasive, for example sand particles in crude oil. This abrasive particle will flow with the liquid into the gap between the seal faces and this cause the carbon primary ring to be ground away. Also another cause for premature failure of mechanical seals are excessive heat, which can cause when the pump is denied lubricant. The heat generated without lubricant will not only damage the carbon ring but also the O-ring which is made from rubber-like substance called elastomer.

These two causes, abrasive particle and excessive heat are the main reason why mechanical seals fail prematurely. Even if the pump is working under the best conditions, mechanical seals would still be the most replace components of the centrifugal pumps.

Figure 2.3 Example of a prematurely failed mechanical seal [14]

Because of the unpredictable nature of the mechanical seal failure, predictive maintenance for centrifugal pumps are not applicable. The current practice in ensuring the reduction of unexpected shut of pumps is by close monitoring of the pumps condition [15]. The properties that are often monitored are pump suction and discharge pressure, and coordinate the readings with flow and motor amperage reading. This method even though tedious will provide a lot of useful information such as [15]:

- Whether the motor is near overload condition.
- Determine when to adjust the impeller or replacing the wear ring.
- Spot poor operating practices.
- Determine the shaft stability, whether it is deflecting or about to.

Close monitoring of shaft properties is a tedious process but one that have to be maintain so that the pumping operation will run smoothly.

2.1 Reliability Growth

The first prototypes during the development of a new complex system will contain flaws whether it is engineering or manufacturing in nature. Because of these flaws, these prototypes will undergo rigorous amount of testing to indentify the problem areas and take corrective action to fix those areas. The flaws that the prototypes have, the initial reliability will be below the system reliability goal or requirement. Reliability growth is the improvement of the product reliability over a period of time through correction action such as modifying the manufacturing process or design changes [3].

The concept of reliability growth is not just theoretical or absolute; reliability growth also takes account factors such as the management strategy toward corrective actions, effectiveness of the fixes, reliability requirements, and initial reliability level, reliability funding and competitive factors [5].

Reliability growth analyses are not only limited to new developing prototype but also can be applied to systems that are running in the field. Fielded system analyses are especially important when the system is subjected to a customer use environment. This interest in evaluating the system reliability based on actual customer usage failure data are motivated by several factors such as how different maintenance policies, or different levels of experience of the user impact the reliability of the system.

When complex system fail, most of the time the system is fixed or repaired, for example a centrifugal pumps when it shut down the pumps is analyze to identified the problem area, and steps are taken to fix that problem, rarely the pumps are scrapped and a new one is used to replace it. Because of this non-homogeneous Poisson process model is used when analyzing repairable system such as the centrifugal pumps from the example. Non-homogeneous Poisson process or NHPP recognize that failure intensity of a system is not constant as the system ages. Failure intensity can be defined as the probability of failure within the next Δt given that the system may or may not have failed [14]. For systems with minimal repair, the system failure rate is represented mathematically below;

$$u(t) = \lambda\beta t^{\beta-1} \qquad \text{...(1)}$$

Equation 1 shows a power expression where t is the age of the system, while λ is a scale parameter that has no physical meaning and β is a measure of the failure rate. If β is greater than 1, the failure rate is increasing. Conversely, if β is less than 1, the failure rate is decreasing. If β equal 1, the failure rate is considered to be constant or random. This system intensity function is a power law model; this model governs each succeeding system failure. This model is an extension of the Weibull distribution. Weibull distribution in this case will represent the first system failure.

2.2 Crow-AMSAA (NHPP)

The Crow-AMSAA model was develop by Dr. Larry H. Crow to track and quantify the reliability growth of product prototypes or manufacturing processes to help identify when the product or process have reach suffiecent reliability and can be put into production [1]. Nowadays, this model main purpose have shifted from determine reliability growth, to being use as a tool to monitor reliability and forcast failures in fielded systems. Crow-AMSAA is one of the few models that can represent statistically a repairable systems, which differentiate itself from Weibull distribution. Weibull distribution is a failure mode distribution of replaceable systems, and can only be used to model the first failure of a repairable system. Distictively Crow-AMSAA can model a system that has fail and been repaired numerous tiems [4]. Another advantage Crow-AMSAA have over Weibull is that it can handle multipe failure modes, but Weibull distribution a single failure mode or at most two.

Graphically, Crow-AMSAA is a log-log plot of cumulative failures versus cumulative time. The resulting plot will be linear and an equation of the form

$$n(t) = \lambda t^{\beta-1} \qquad \text{...(2)}$$

Where n(t) is the cumulative number of failures, t is the cumulative time, λ is a scale parameter that has no physical meaning, β is a measure of the failure rate. Below is a example of a Crow-AMSAA (C-A) plot:

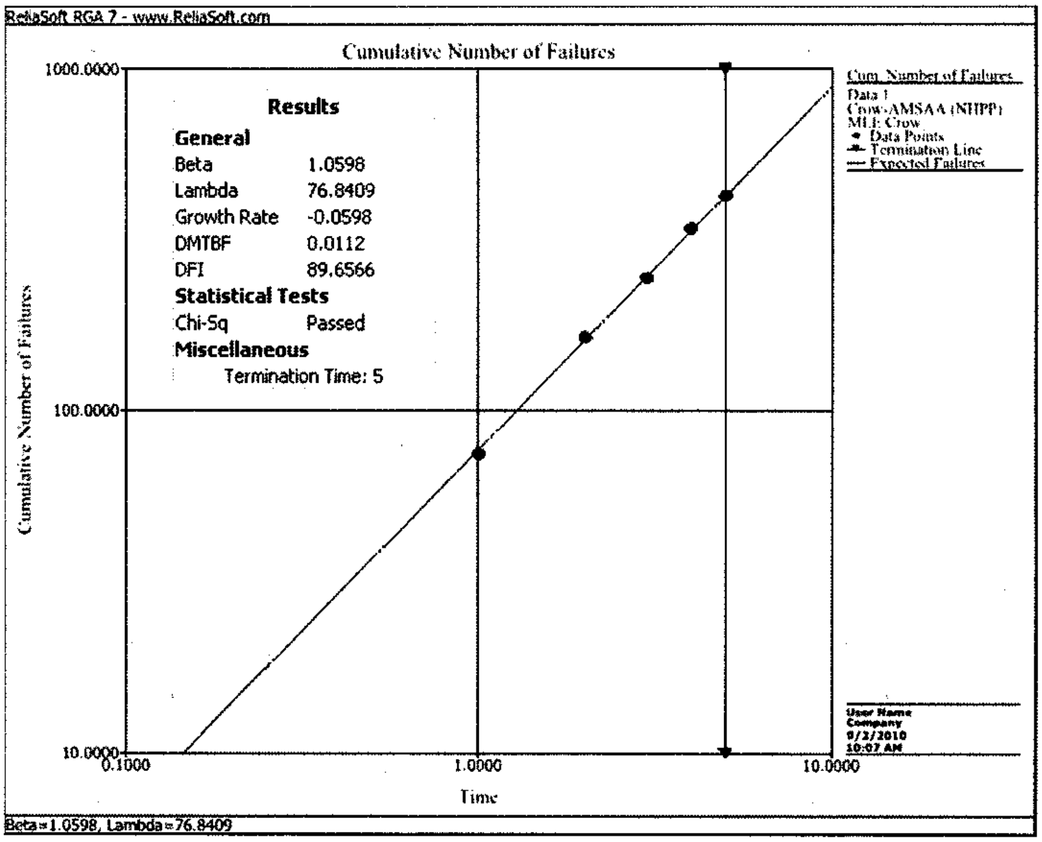

Figure 2.4 Log-Log plot of Cumulative Faults/100 Cable Miles versus Cumulative Time (Years) including Fit of Crow-AMSAA Model for 1977 Vintage URD Cable, 2004 to 2008 [7]

Cumulative failures are plotted on the Y-axis. Cumulative time is plotted on the X-axis. Trend line slope is mathematically represented in β in the equation above. B is a powerful indicator of increasing, decreasing, or a state of no improvement or deterioration. Y-intercept is the failure rate at time equal to 1 which is a value of interest to allow forecasting of failures. One other advantages of Crow-AMSAA are that this model can show reliability easily without starting the data acquisition at time zero.

From equation (2), the failure intensity can be derived [5],

$$\rho(t) = \frac{\beta}{n^{\beta}} T^{\beta-1} \qquad \ldots(3)$$

If $= \frac{1}{n^{\beta}}$, the intensity function $\rho(T) = \lambda_i T$ the instantaneous failure intensity is defined as [5]:

$$\lambda_i(T) = \lambda\beta T^{\beta-1} \qquad \ldots(4)$$

This is only applicable in the range T > 0, $\lambda > 0$ and $\beta > 0$. From the equation above the average number of failures with respect to T is [5]:

$$\theta(T) = \int_0^T \lambda_i(T)dT = \int_0^T \lambda\beta T^{\beta-1}\, dT = \lambda T^{\beta} \qquad ...(5)$$

The cumulative failure intensity, $\lambda_c = \lambda T^{\beta-1}$, from this the cumulative MTBF can be derive as [5]:

$$MTBF_c = \frac{1}{\lambda} T^{1-\beta} \qquad ...(6)$$

With this cumulative MTBF, reliability of the system can be track since for Crow-AMSAA model MTBF growth is an indicator to the reliability growth of the system.

CHAPTER 3

METHODOLOGY

This chapter will be focusing on two things which are the procedure taken in completing this project and the procedure that was used in the Crow-AMSAA analysis. The procedure of the project is represented in the flowchart below, Figure 3.1:

3.1 Research Methodology

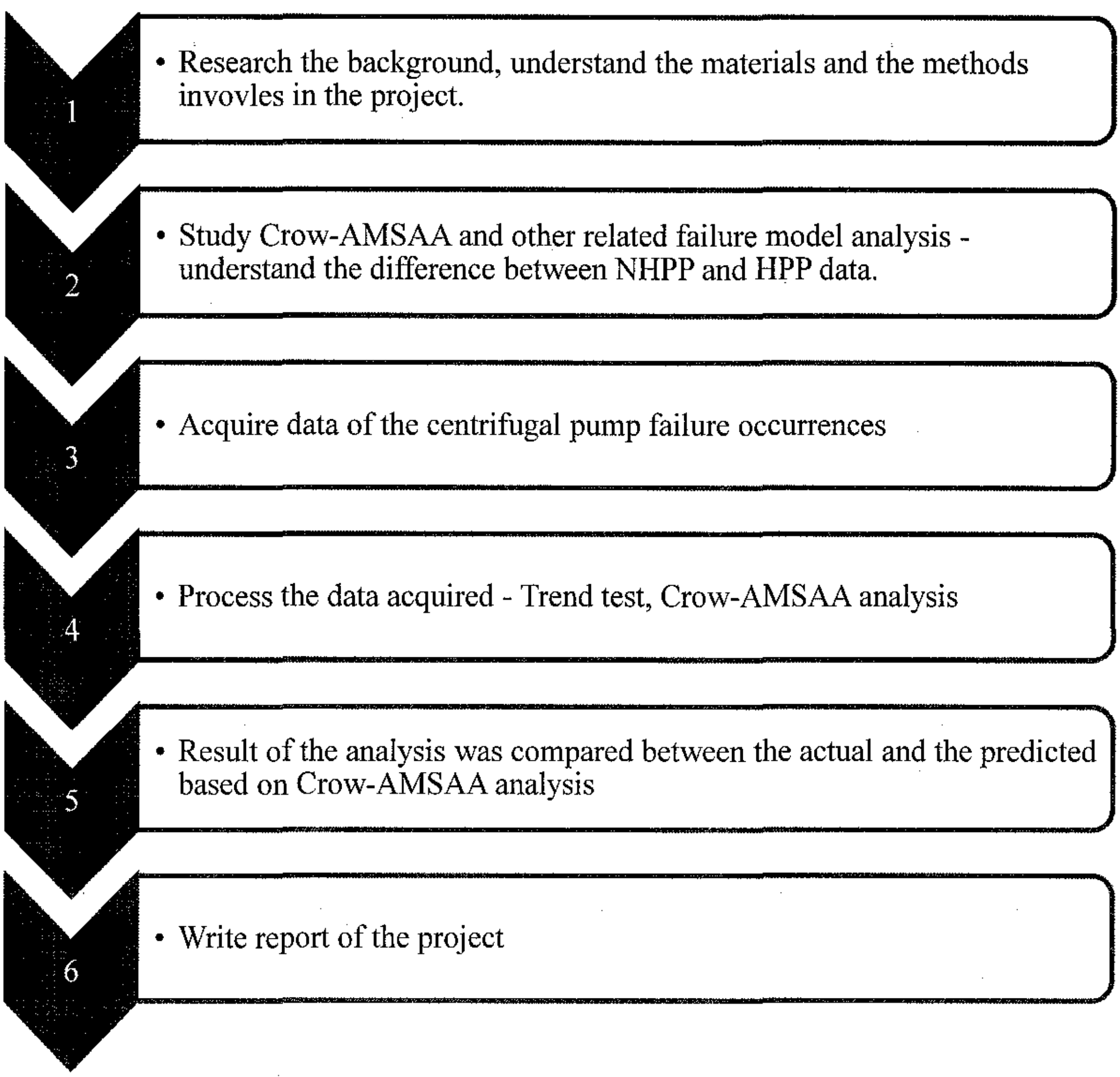

Figure 3.1 Research methodology flow chart

3.2 Analysis Procedure

Figure 3.2 shows the flow chart of the procedure of the analysis. These procedures are adopted to ensure that the data that was used for the Crow-AMSAA analysis were all non-homogeneous Poisson process (NHPP), since Crow-AMSAA analysis can only be applied to NHPP data type. The purpose of these procedures is to ensure that the method in obtaining the result for this project are scientific and organized, so that the finding could be represented with confidence.

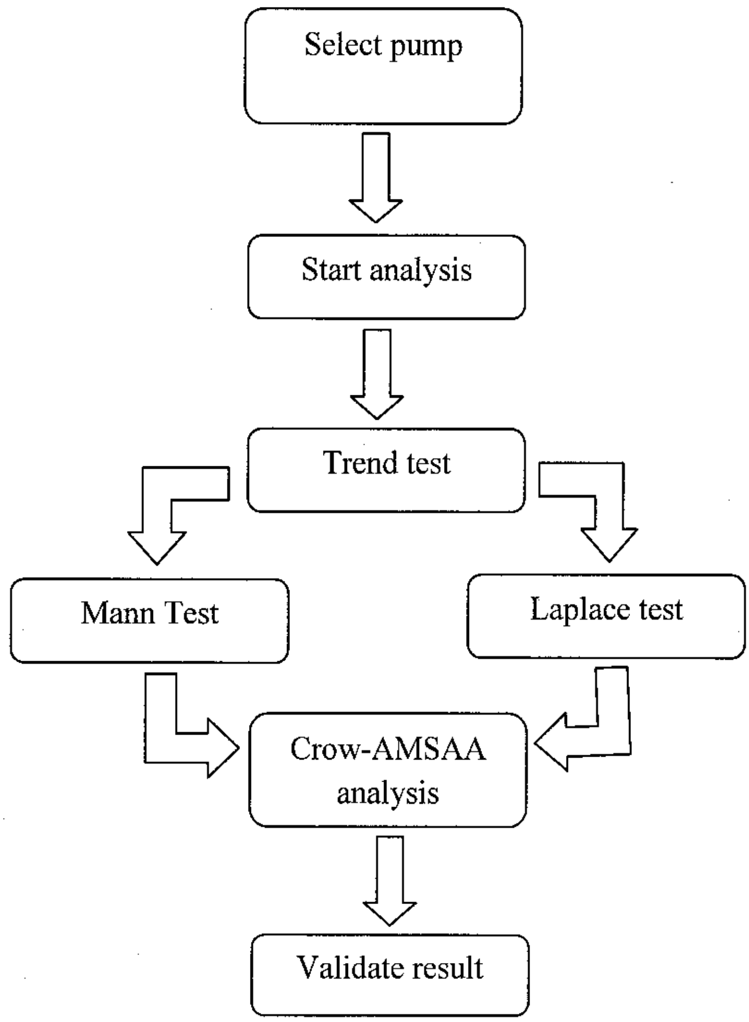

Figure 3.2 Flow chart of the analysis procedure

3.1.1 Step 1: Select Pump

From the data acquired, a pump is selected to undergoes the analysis the criteria of the pumps data that are going to be selected is the pump must have atleast 5 data points, meaning that the pump need to have atleast 5 failure occurrence, reason that this criteria is implimented is to ensure there is enough data to be use in step: trend testing. Without enough data point the trend test cannot be done or even if it can the result will not be accurate.

3.1.2 Step 2: Start Analysis

In this step the pump data is process, the data original recorded the failure occurance in date format, this step will convert those into number format this allows us to calculate important parameters such as cumulative time to failure and time between failures. All of this parameters are imortant for the upcoming steps.

3.1.3 Step 3: Trend Test

The data that have been process will undergone trend test, there is 2 types of trend testing that is use in this step; Laplace test and Mann test.The data shows trending when either one of the test pass, only then is the dta consider to have trending. If the data pass both test, then the data have trending and it is possible to use the data in Crow-AMSAA analysis.

3.1.3.1 Laplace Test

Laplace test in conducted by taking few metric parameter from the data and inputing the data into a laplace equation. The result will be compare to a predetemine value that is acquire from tables. This value is range is relative to the condifedence interval of the test. In this case the confidence interval use is 90%. There is two result from laplace test, failure truncated which use the (n-1) and sum of (n-1) of cumulative time as the α and β respectively in the laplace test equation. The other result whch is time truncated. This result uses the sum of cumulative time and total number of failure, n as α and β. In determinng the trending of data set, the data is consider to have trending when either the failure truncated or the time truncated falls within the confidence interval range. The equation of laplace test is shown below:

$$L = \frac{\frac{\sum_{j=1}^{n} T_j}{\hat{n}} - \frac{1}{2}(b+a)}{\sqrt{\frac{1}{12\hat{n}}(b-a)^2}}$$

...(7)

3.1.3.2 Mann-Whitney Test

Mann-Whitney test on the stationarity of a time series. The test can detect a monotonic trend in a time series a trend in a time series x(i), i=1,.....,N. The method is based on the calculation of the number of timnes that x(i) > x(j) with i<j for all i. If the sequence of x(i) are independent observation of the random vairalbe, then the number of reverse arrangemet which is the inequality of i and j, is a random vairalbe with mean, M = N(N-1)/4 and variance, M_e = N(2N+5)(N-1)/72. An observed number of reese arrangments significantly different from N(N-1)/4 indicates nonstationaity because of the possible presence of a trend in x(i).

The benefits of this trend test is that it is a simple and useful test that has the advantage of making no assumptions about a model for the possible trend.

3.1.4 Step 4: Crow-AMSAA Analysis

The cumuative time to failure and the cumulative are taken and log is applied to both, the data also can be appliied ln, this I to transform the data in log scale. Once that is down the data points is plots on a log plot. The best fit line is obtain and from there the slope of the line and the y-axis intercept of the best fit line is obtained, with these parameter the MTBF can be obtain from the basic mathematical formula that is highlighted in Chapter 2.

3.1.5 Step 5: Validate Result

In this step, the result in Crow-AMSAA analysis have to be validated first before it can be consider accrate. The result validation is conducted by finding out the theoritical time of nth failure, where nth failure is the last recorded failure instance in the data set. This theoritical time will be compared with the actual failure time. The error between them is converted into percentage so that the error can be easily evaluated.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

This chapter the results of the Crow-AMSAA analysis were displayed both in table and graphs that were used in the analysis. Sub-chapter 4.1.2 showed the result of each individual pumps that have been selected to be analyze, including the result of each step taken in the analysis which includes the graph that were produced.

4.1.1 Overall Results

The result of the overall finding were summarized, which could be seen in Table 4.1 tabulate the overall result such as, presents of trending, Crow-AMSAA analysis parameter and error percentage.

Table 4.1 Overall results of the analysis

Pump	Result of trend test		Result of Crow-AMSAA		Error percentage
	Mann	Laplace	Cumulative Failure at time t = 2500	Beta	
G801	No trending	Trending	3.0021	0.77	16%
G104	No trending	No trending		-	
G105	No trending	No trending	-	-	
G110	Trending	No trending	1.00647	0.77	18%
G121	No trending	No trending	-	-	
G151	No trending	No trending	-	-	

4.1.2 Individual Pump Results

The result are tabluted in corresponding to which pumps data it is from, for example all data and analysis for pump G102 were separated and organized into its own section.

4.1.2.1 Pump G801

First analysis: Calculating time to failure and cumulative time to failure

Table 4.2 shows the result in conversion of the failure time from date formate into hours.Also shown here is the cumulative time to failure and the number of failure that the pump experiecnce.

Table 4.2 Pump G801

g801 A/B/C	TIME TO FAILURE (HOURS)	CUMULATIVE TIME TO FAILURE	NO OF FAILURE
24/02/2000	6912	6912	1
08/12/2000	6528	13440	2
06/09/2001	16536	29976	3
27/07/2003	2400	32376	4
04/11/2003	3888	36264	5
14/04/2004	2136	38400	6
12/07/2004	13296	51696	7
17/01/2006	456	52152	8
05/02/2006	9048	61200	9
17/02/2007	5616	66816	10
09/10/2007	3360	70176	11
26/02/2008	5928	76104	12
30/10/2008	240	76344	13
09/11/2008	384	76728	14

Second analysis: Trend tests

This section shows the result the trend test both the Mann test and the Laplace test, the table contains the result of Mann test and the Laplace test, this could be seen in Table 4.3:

Table 4.3 Trend test G801

No of Failure	Mann Test	Cum MTBF
	3	6912.00
2	3	6720.00
3	0	9992.00
4	6	8094.00
5	4	7252.80
6	5	6400.00
7	0	7385.14
8	4	6519.00
9	0	6800.00
10	1	6681.60
11	1	6379.64
12	0	6342.00
13	1	5872.62
14	0	5480.57

Mann test
M (sum of mann test) = 28
$M_e = 45.5$
Result of mann test = no trending

Laplace test
Failure truncated = 1.417
Time truncated = 1.828
Confidence interval = -1.282/1.282
Result = trending

Figure 4.1 and figure 4.2 shows the graph produce when plotting the cumulative failure occurrences againt cumulative time. Figure 7 used a linear fitting model while figure 8 shows the plot with a exponential fitting model.

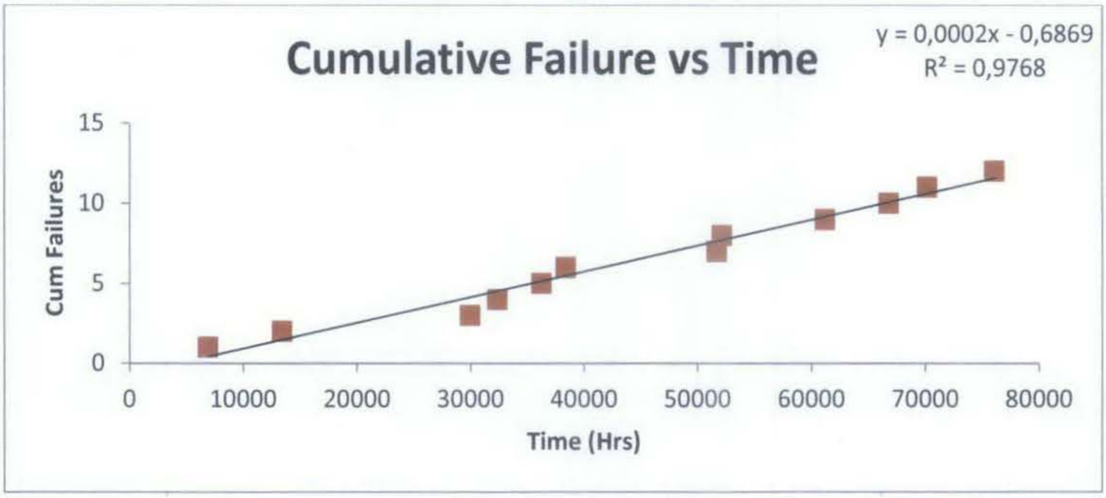

Figure 4.1 Trend test plot with linear fitting

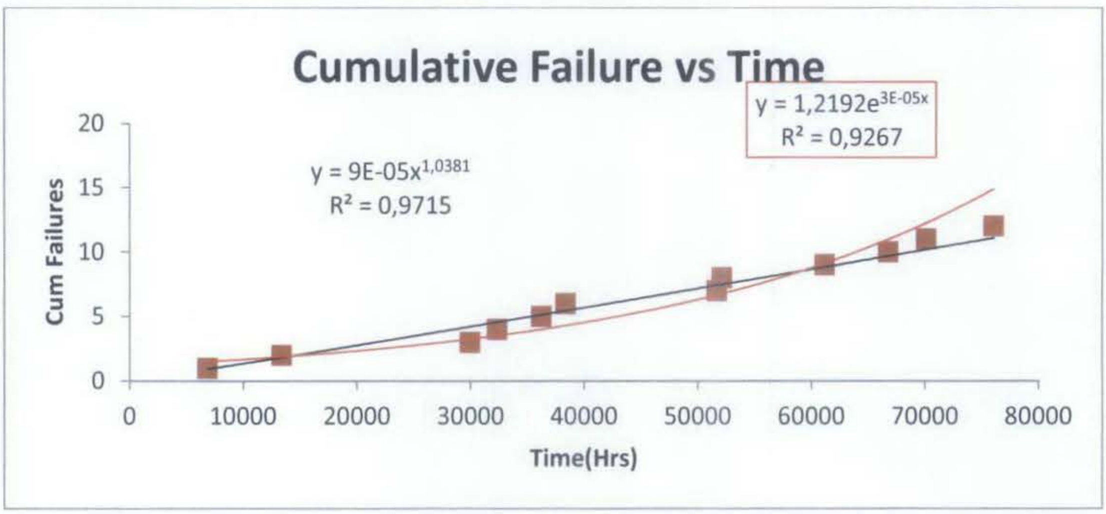

Figure 4.2 Trend test plot with exponential fitting

Third Analysis: Crow-AMSAA

This section potrays the result of the Crow-AMSAA analysis. Not all pump will undergo this analysis since not all pump data shows trending. Those pump that does undergoes this analysis the result that is tabulated are the cumulative MTBF and thedata point of both Y-axis and X-axis. Also in this section the C-A plot that is generated is also included. This can be seen in Table 4.4 below:

Table 4.4 Crow-AMSAA G801

Time to Failure (chronological)	Cum. Time to Failure	Cum MTBF	ln(cum TTF)	log(cum MTBF)
6912	6912	6912.00	8.841	3.840
6528	13440	6720.00	9.506	3.827
16536	29976	9992.00	10.308	4.000
2400	32376	8094.00	10.385	3.908
3888	36264	7252.80	10.499	3.861
2136	38400	6400.00	10.556	3.806
13296	51696	7385.14	10.853	3.868
456	52152	6519.00	10.862	3.814
9048	61200	6800.00	11.022	3.833
5616	66816	6681.60	11.110	3.825
3360	70176	6379.64	11.159	3.805
5928	76104	6342.00	11.240	3.802
240	76344	5872.62	11.243	3.769
384	76728	5480.57	11.248	3.739

In next table, Table 5, in this section show the metric parameter result such as the value of λ and β.

Table 4. 5 G801 Crow-AMSAA analysis results

Parameters		
No of failure	r =	14
End of observation time	T=	76728
Slope (MLE)	Beta =	0.44969354
Lambda		0.0890012
1-beta	b =	0.55030646
Cum. Mean time between failures	MTBF	5480.57143
Instantenous MTBF		12187.3474
Cumulative failure N(t), t=	2500	3.00211621
Next failure occurance, N=	15	89450.793

Figure 4.3 shows the log plot of the Crow-AMSAA analysis with a linear fitting. The plot was a cumulative failure versus cumulative time plot.

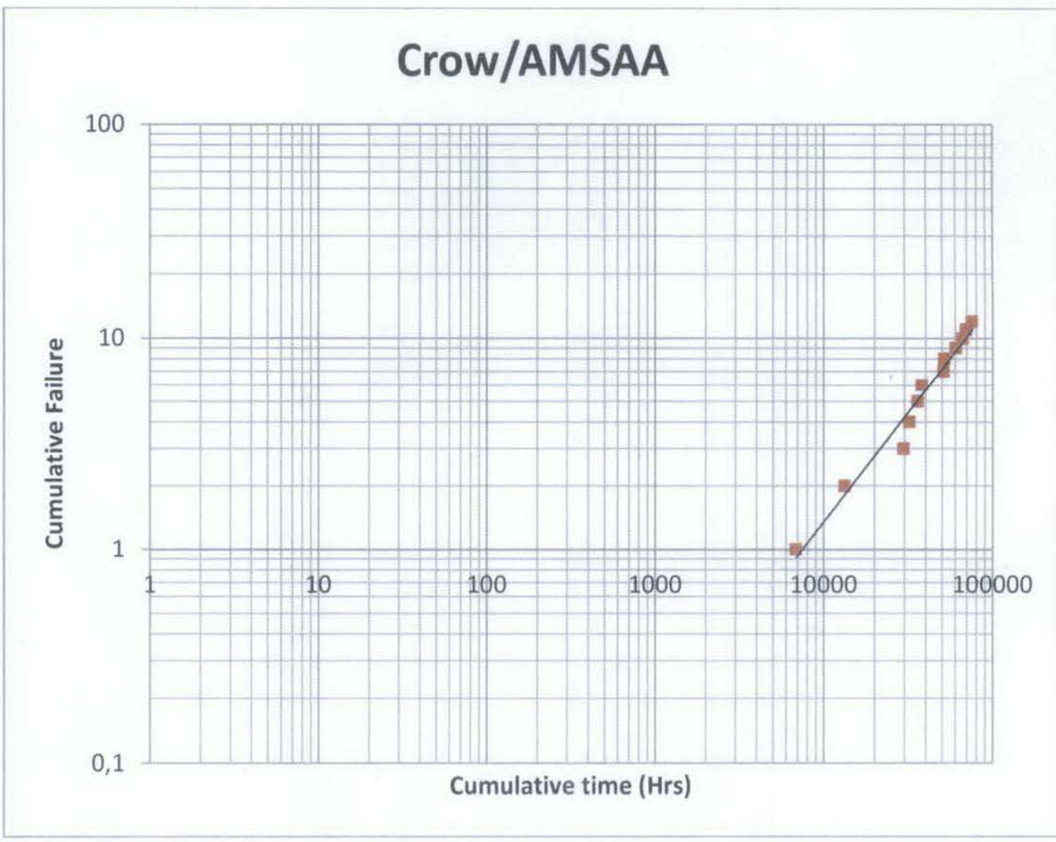

Figure 4.3 Crow-AMSAA plot G801

Fourth analysis: Validation of results

The actual 15^{th} failure occurrence (date): 17/08/2010 – 630days from failure 14th

The predicted 15^{th} failure occurrence: 89450.79hours from the first failure occurrence

The predicted 15^{th} failure occurrence (date): 05/09/2010 – 530.12 days from failure 14th

Error in prediction: (630 – 530.12)/630 = 0.15966 ~ 16%

4.1.2.2 Pump G121

First analysis: Calculating time to failure and cumuative time to failure. Table 4.6 shows the conversion results.

Table 4.6 G121 data

G121 a/b	TIME TO FAILURE (HOURS)	CUMULATIVE TIME TO FAILURE	NO OF FAILURE
10/25/1999	7728	7728	1
9/11/2000	2184	9912	2
12/11/2000	168	10080	3
12/18/2000	13296	23376	4
6/25/2002	8016	31392	5
5/25/2003	40848	72240	6
1/21/2008	3048	75288	7
5/27/2008	192	75480	8

Second analysis: Trend tests table 4.7 shows the result of the trend test both Laplace and Mann test.

Table 4.7 Trend test G121

No of Failure	Mann Test	Cum MTBF
1	3	7728.00
2	4	4956.00
3	5	3360.00
4	1	5844.00
5	1	6278.40
6	0	12040.00
7	0	10755.43
8	0	9435.00

Mann test
M (sum of mann test) = 14
M_e = 14
Result of mann test = no trending

Laplace test
Failure truncated = -0.593
Time truncated = 0.053
Confidence interval = -1.282/1.282
Result = no trending

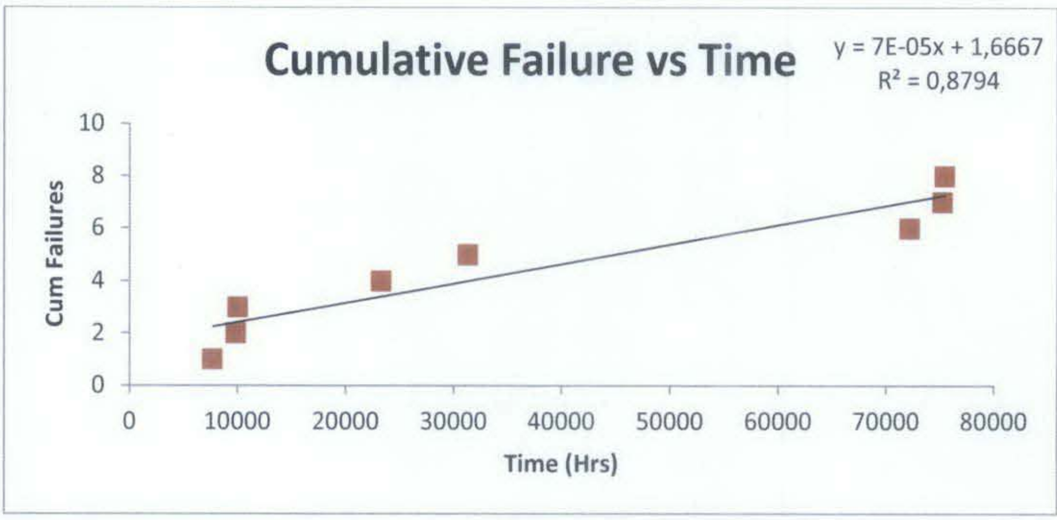

Figure 4.4 G121 trend test plot with linear fitting

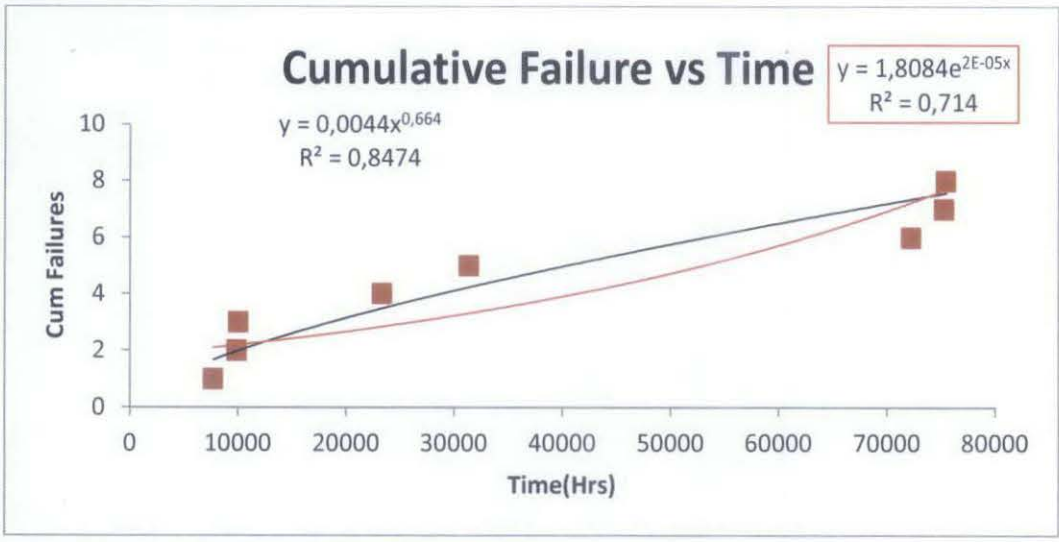

Figure 4.5 G121 trend test plot with exponential fitting

Figure 4.4 and 4.5 shows the trend test plot that was used to determine the R^2 of the data.

4.1.2.3 Pump G104

First analysis: Calculating time to failure and cumulative time to failure, table 4.8 shows the resutls of the initial analysis.

Table 4. 8 G104 data

G104 a/b	TIME TO FAILURE (HOURS)	CUMULATIVE TIME TO FAILURE	NO OF FAILURE
10/5/1999	12096	12096	1
2/20/2001	1584	13680	2
4/27/2001	4320	18000	3
10/24/2001	29352	47352	4
2/28/2005	4368	51720	5
8/29/2005	10752	62472	6

Second analysis: Trend tests, table 4.9 shows the result of the Mann test and the box contains the findings of both the Mann test and the Laplace test.

Table 4.9 Trend test G104

No of Failure	Mann Test	Cum MTBF
1	1	12096.00
2	4	6840.00
3	3	6000.00
4	0	11838.00
5	1	10344.00

Mann test
M (sum of mann test) = 9
M_e = 7.5
Result of mann test = no trending

Laplace test
Failure truncated = -0.593
Time truncated = 0.053
Confidence interval = -1.282/1.282
Result = no trending

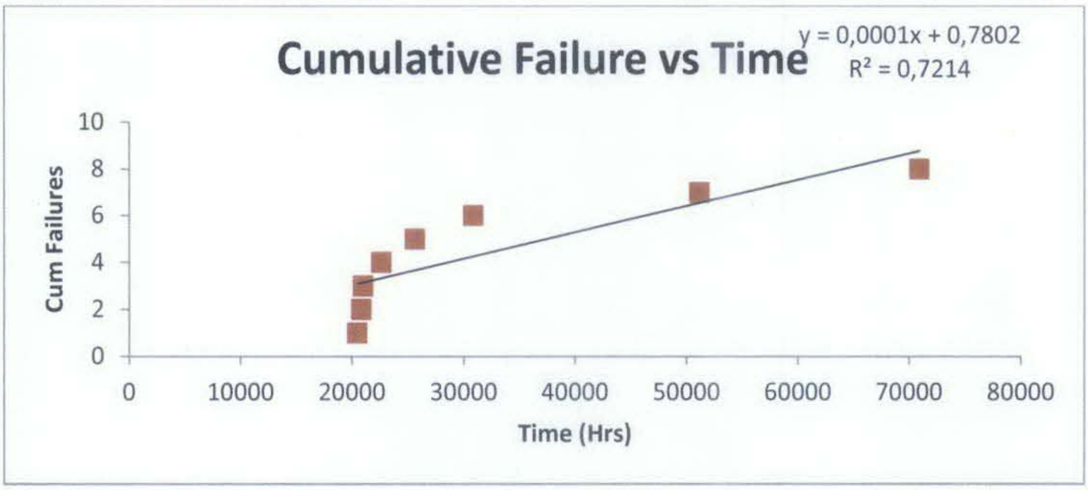

Figure 4.5 G104 trend test plot with linear fitting

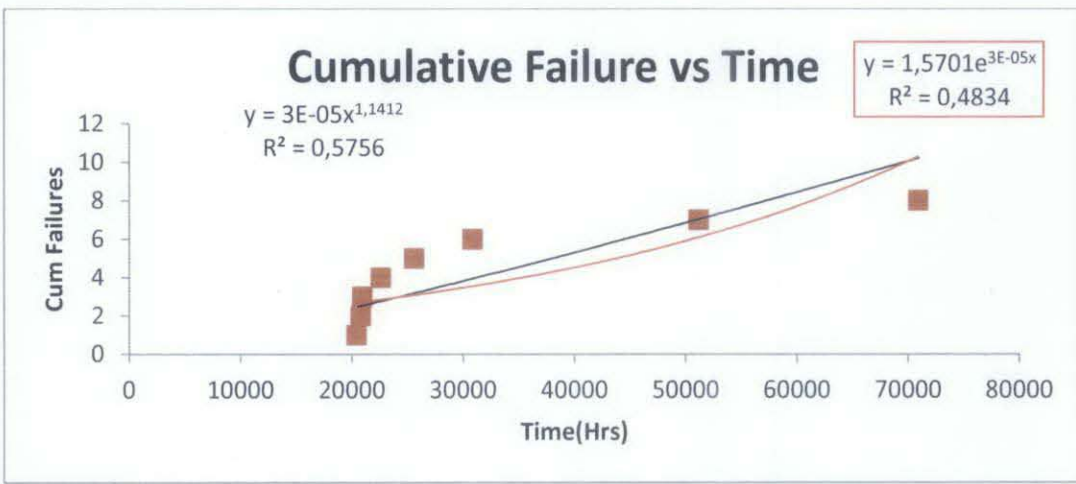

Figure 4.6 G104 trend test plot with exponential fitting

Figure 4.5 and 4.6 shows the trend test plot that was used to determine the R^2 of the data.

4.1.2.4 Pump G105

First analysis: Calculating time to failure and cumulative time to failure, table 4.10 shows the result of the calculations.

Table 4.10 G105 data

Pump	TIME TO FAILURE (HOURS)	CUMULATIVE TIME TO FAILURE	NO OF FAILURE
1/13/1999	2712	2712	1
5/6/1999	21576	24288	2
10/21/2001	16152	40440	3
8/25/2003	4680	45120	4
3/7/2004	3744	48864	5
8/10/2004	20112	68976	6
11/26/2006	13656	82632	7

Second analysis: Trend tests, table 4.11 shows the result of the Mann test and the result of the trend tests.

Table 4.11 Trend test G105

No of Failure	Mann Test	Cum MTBF
1	6	2712.00
2	0	12144.00
3	1	13480.00
4	2	11280.00
5	2	9772.80
6	0	11496.00
7	0	11804.57

Mann test
M (sum of mann test) = 11
M_e = 10.5
Result of mann test = no trending

Laplace test
Failure truncated = -0.299
Time truncated = 0.377
Confidence interval = -1.282/1.282
Result = no trending

Figure 4.7 showed the plot for trend test of pump G105 fitted with linear fitting, while figure 4.8 shows the same graph with exponential fitting.

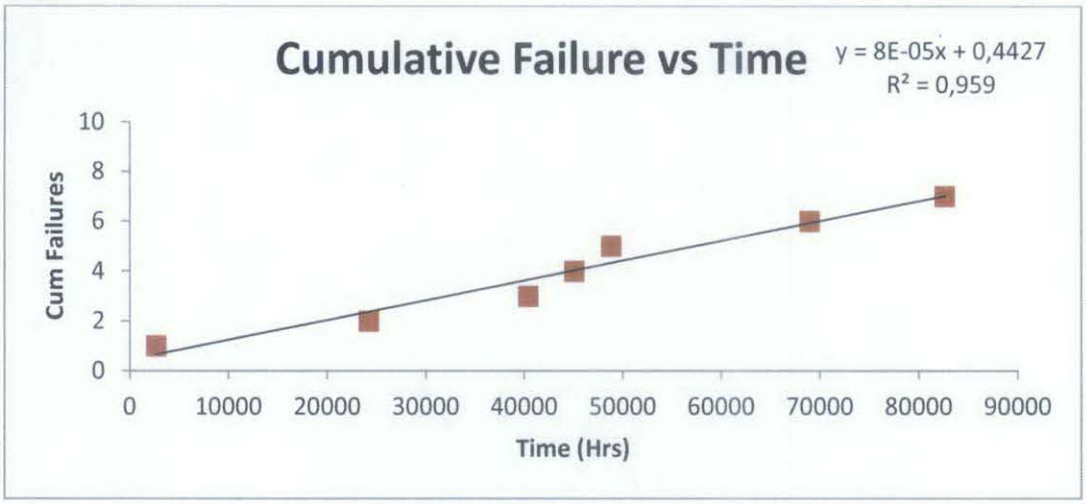

Figure 4.7 G105 trend test plot with linear fitting

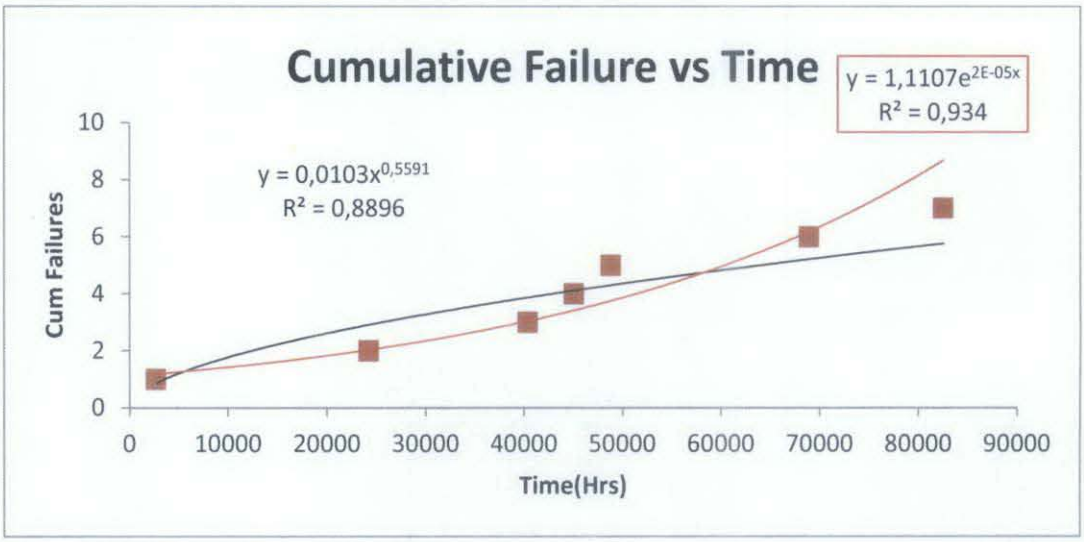

Figure 4.8 G105 trend test with exponential fitting

4.1.2.5 Pump G110

First analysis: Calculating of time to failure and cumulative time to failure, table 4.12 shows the calculation done on the data.

Table 4.12 G110 data

Pump	TIME TO FAILURE (HOURS)	CUMULATIVE TIME TO FAILURE	NO OF FAILURE
10/22/2000	336	336	1
11/5/2000	8496	8832	2
10/25/2001	384	9216	3
11/10/2001	720	9936	4
12/10/2001	7248	17184	5
10/8/2002	2208	19392	6
1/8/2003	9456	28848	7
2/6/2004	7632	36480	8
12/20/2004	6192	42672	9

Second analysis: Trend test, table 4.13 shows the result of the Mann test and the Laplace test.

Table 4.13 Trend test G110

No of Failure	Mann Test	Cum MTBF
1	8	336.00
2	1	4416.00
3	6	3072.00
4	5	2484.00
5	2	3436.80
6	3	3232.00
7	0	4121.14
8	0	4560.00
9	0	4741.33

Mann test
M (sum of mann test) = 25
M_e = 18
Result of mann test = trending

Laplace test
Failure truncated = -1.161
Time truncated = -0.518
Confidence interval = -1.282/1.282
Result = no trending

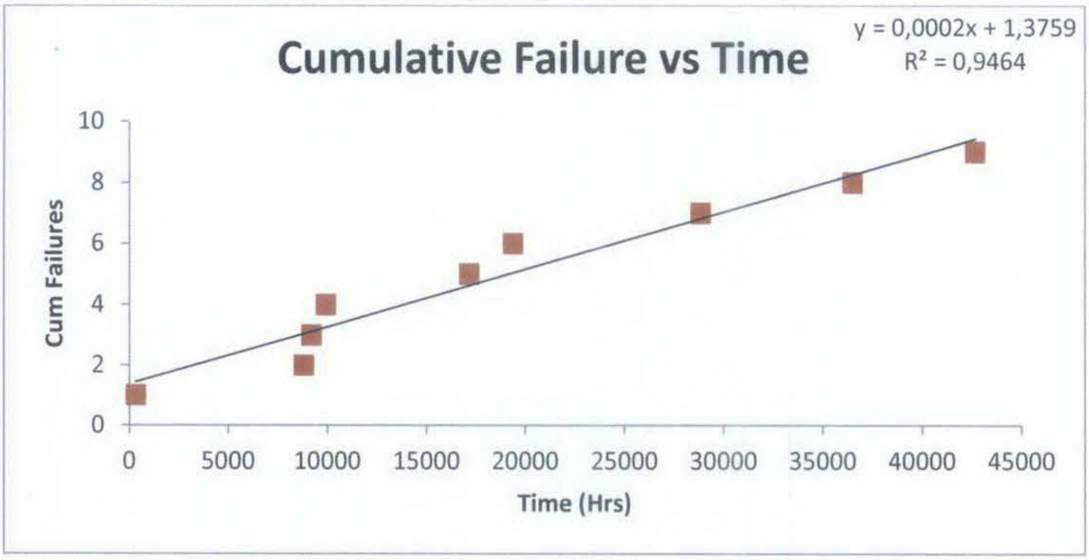

Figure 4.9 G110 trend test result with linear fitting

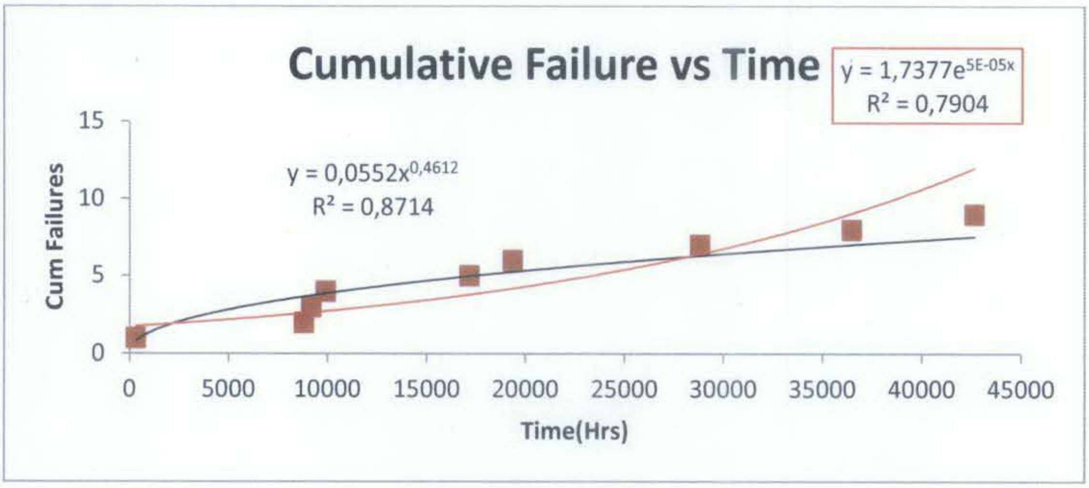

Figure 4.10 G110 trend test result with exponential fitting

Figure 4.9 and 4.10 shows the cumulative failure vs time plot for pump G110, with differing line fitting with figure 16 shows the plot fitted with linear fitting and figure 17 shows the plot with exponential fitting.

Third analysis: Crow-AMSAA, table 4.14 listed the parameter involves in the Crow-AMSAA analysis and its conversion to log and ln value.

Table 4.14 Crow-AMSAA G110

Time to Failure (chronological)	Cum. Time to Failure	Cum MTBF	ln(cum MTBF)	log(cum MTBF)
336	336	336.00	5.817	2.526
8496	8832	4416.00	9.086	3.645
384	9216	3072.00	9.129	3.487
720	9936	2484.00	9.204	3.395
7248	17184	3436.80	9.752	3.536
2208	19392	3232.00	9.873	3.509
9456	28848	4121.14	10.270	3.615
7632	36480	4560.00	10.505	3.659
6192	42672	4741.33	10.661	3.676

Table 4.15 shows the result of the Crow-AMSAA analysis, highlighting the cumulative failure N(t) and next failure occurrence.

Table 4. 15 Results G110

Parameters		
No of failure	r =	9
End of observation time	T=	42672
Slope (MLE)	Beta =	0.77214402
Lambda		0.0023939
1-beta	b =	0.22785598
Cum. Mean time between failures	MTBF	4741.33333
Instantaneous MTBF		6140.47793
Cumulative failure N(t), t=	2500	1.00647811
Next failure occurrence, N=	10	48190.324

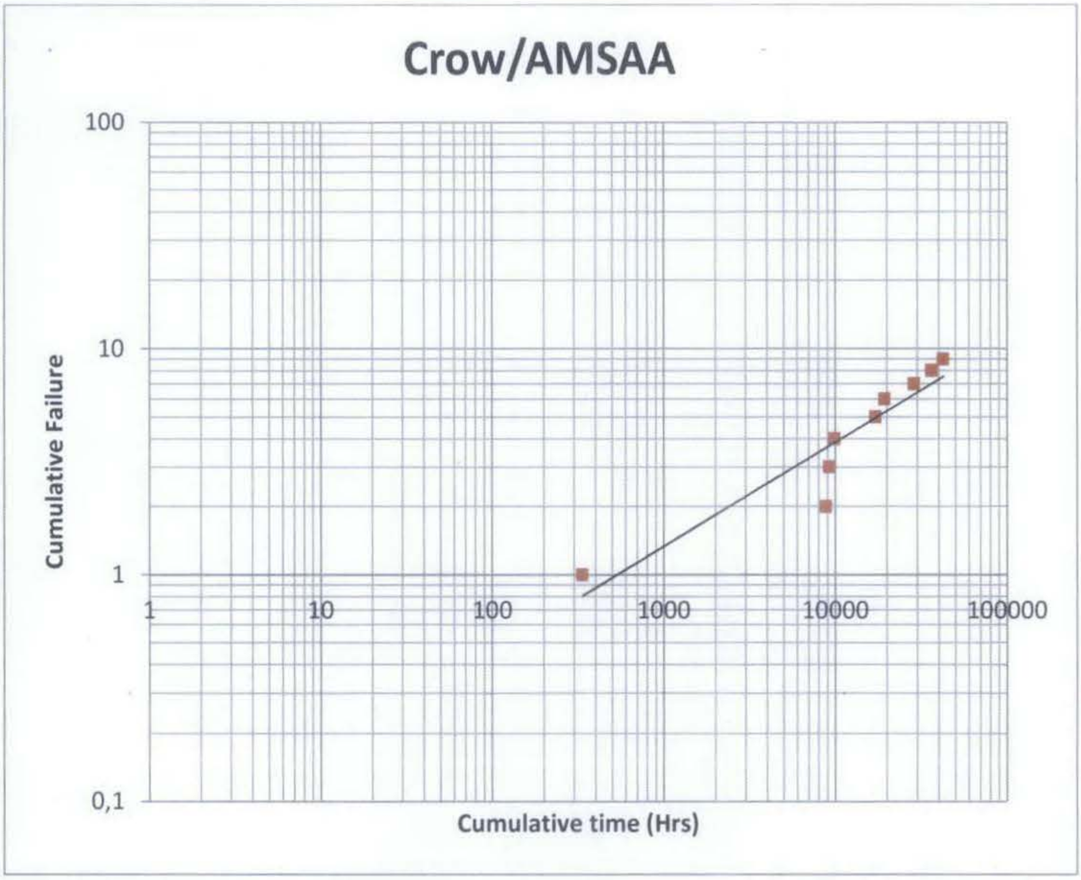

Figure 4.11 G110 Crow-AMSAA plot

Figure 4.11 shows the Crow-AMSAA graph on a log-log scale, the graph have a increasing slope.

Fourth analysis: Validation of results

The actual 11^{th} failure occurrence (date): 20/7/2006 – 319 days from failure 14th

The predicted 15^{th} failure occurrence: 48910.64 hours from the first failure occurrence

The predicted 15^{th} failure occurrence (date): 21/5/2006 – 259.94days from failure 14th

Error in prediction: (319 – 259.94)/319 = 0.1810 ~ 18%

4.1.2.6 Pump G151

First analysis: Calculating time to failure and cumulative time to failure, table 4.16 shows the calculation if the cumulative time to failure.

Table 4.16 G151 data

Pump	TIME TO FAILURE (HOURS)	CUMULATIVE TIME TO FAILURE	NO OF FAILURE
10/5/1999	12096	12096	1
2/20/2001	1584	13680	2
4/27/2001	4320	18000	3
10/24/2001	29352	47352	4
2/28/2005	4368	51720	5
8/29/2005	10752	62472	6

Second analysis: Trend test, table 4.17 shows the result of the trend tests both Mann and Laplace.

Table 4.17 Trend test G151

No of Failure	Mann Test	Cum MTBF
1	1	12096.00
2	4	6840.00
3	3	6000.00
4	0	11838.00
5	1	10344.00
6	0	10412.00

Mann test
M (sum of mann test) =9
M_e = 7.5
Result of mann test = no trending

Laplace test
Failure truncated = -0.331
Time truncated = 0.405
Confidence interval = -1.282/1.282
Result = no trending

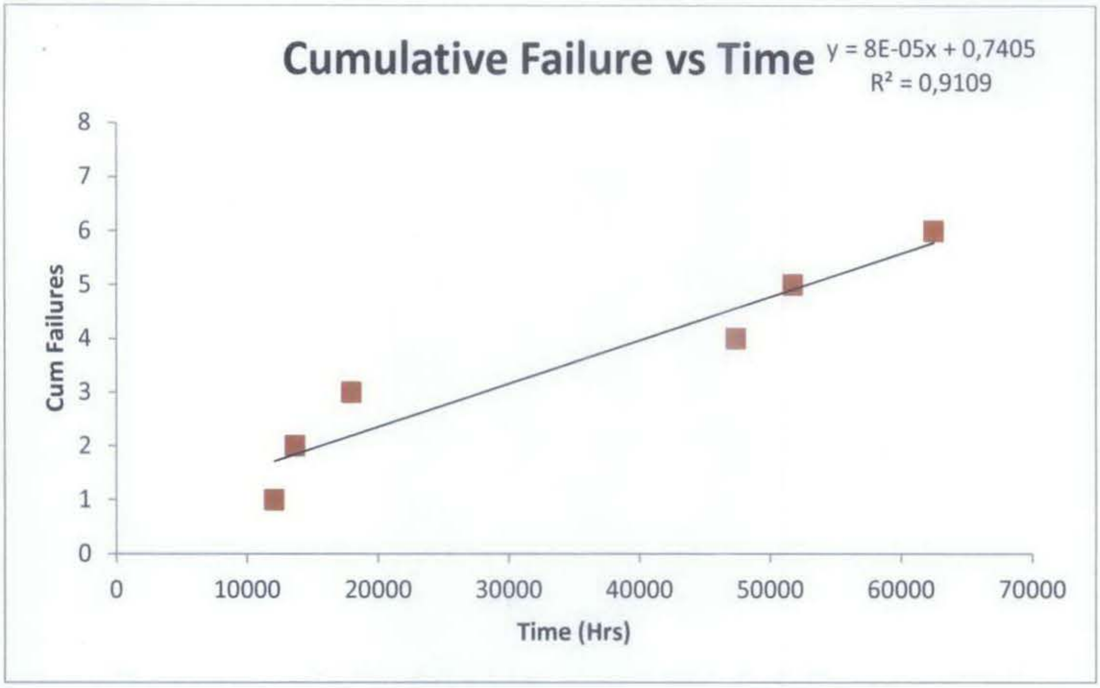

Figure 4.12 G110 trend test plot with linear fitting

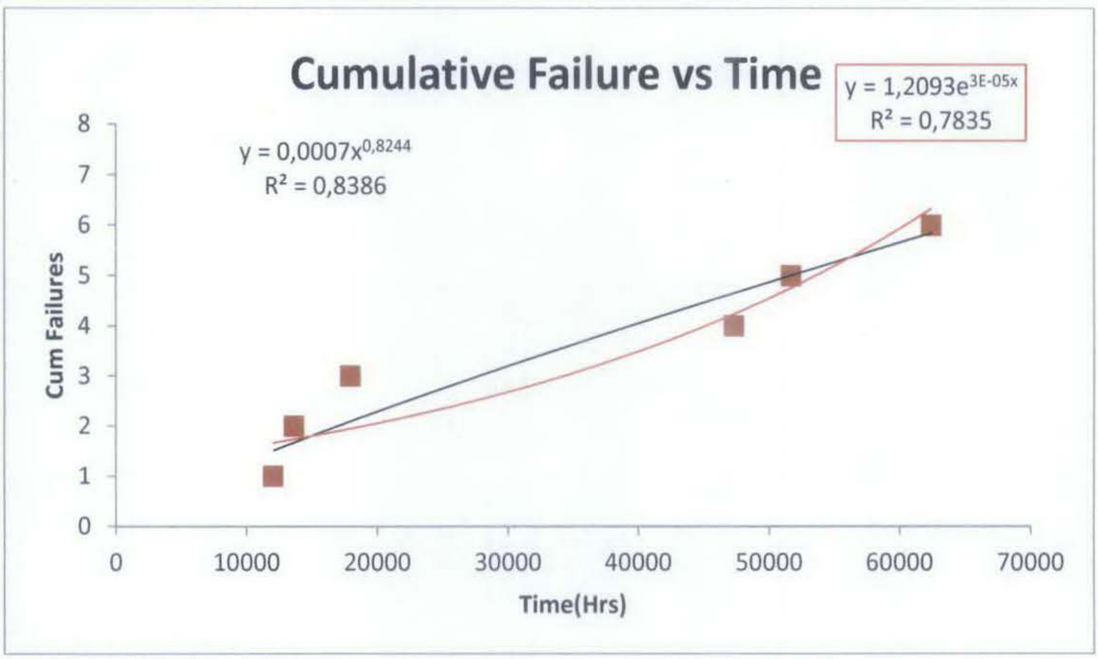

Figure 4.13 G151 trend test plot with exponential fitting

Figure 4.12 and 4.13 both shows data for cumulative failure versus time for pump G151, with linear and exponential fitting respectively.

4.2 Discussion

The importance of determinig whether the data is trending before applying the Crow-AMSAA failure analysis model, lies in the fact that Crow-AMSAA model can only be use on non-homogeneous Poisson process data sets. One of the characteristic of NHPP data set is the present of trending, whether the trend is increasing or decreasing. Referring back to section 4.1 only 2 out of 6 pumps analysed show trending.

The Crow-AMSAA prediction on the next failure occurance of the pumps, have an error precentage of 16% and 18% . In the industrial application of this, the pumps could be better maintain and suprise shutdowns could be reduce. With this tool in hand engineer could confidently set an alocatted time to prepare and take steps to minimize the loses when those shutdowns happened. Also by predicting when failure would occur engineer could be more efficient in handling the maintaince of the pumps.

Both pumps that qualify to undergoe Crow-AMSAA analysis shows an increasing slope, pump G801 slope was more pronounce than that of G110. This increasing slope shows that the failure rate for both centrifugal pump increases respective to time. For the trend test plot two fitting is applied, linear fitting and exponential fitting. The best of fit is taken as the data to use for the analysis. The reasoning behind using this two fitting is that both fitting are the most common for trend analysis.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The failure analysis model Crow-AMSAA was used to predict the next failure occurance of a centrifugal pump system. From the data that have been acquired, only 2 pumps showed the correct criteria that for the analysis. The requirement that was needed for Crow-AMSAA to be applicable was the data have to have a trend, because of this all the eligible data were put through a trend test, data with trending are identified. From the Crow-AMSAA analysis the next failure occurance of the pump is predicted. The two pumps that underwent Crow-AMSAA analyse were pump G801 and G110. As for pump G801 the next failure occurance is expected to be at 89450 hours after the first failure while for G110 is at 48190 after the first failure. These results were then compared with the actual last failure occurance that was recorded in the original data set. From the comparison the error of each prediction is 16% and 18% respectively for G801 and G110. With this range the conclusion is drawn that Crow-AMSAA analysis based prediction have a error range of 20%.

5.2 Recommendation

The result of this project could be improved by increasing the number of pumps for Crow-AMSAA analysis. Since for this project only 2 pumps were discovered to have trending the number of analysis that were done are limited to these 2 pumps. By acquiring more data of pumps that have trending more Crow-AMSAA analysis could be done. With more analysis on Crow-AMSAA the error range could be refined and this could lead to more confident results in Crow-AMSAA analysis as a tool in predicting centrifugal pump failure is the preferable method.

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APPENDIX

A. FAILURE DATA OF CENTRIFUGAL PUMPS

Unit	No	Equipt No	No and Categories of Repairs																			
			1st		2nd		3rd		4th		5th		6th		7th		8th		9th		10th	
			Date	Code	Date	Code	Date	Code	Date	Code	Date	Code	Date	Code	Date	Code	Date	Code	Date	Code	Date	Code
CDU	1	G 102 A	11/10/1999	7h	14/10/1999	3a	11/04/2000	7h	13/08/2000	7h	20/08/2000	3a	21/01/2003	3a	14/12/2006	2a,3a	02/12/2008	2a,3a				
	2	G 102 B	14/03/2000	3a	02/07/2000	2a	28/05/2003	3a	18/09/2006	3a,2a	20/11/2007	3a										
	3	G 103 A	01/11/2001	3a	01/03/2005	3a	24/04/2006	3a,2b	04/06/2008	3a												
	4	G 103 B	21/06/2000	2a,3a	18/04/2001	7h	19/08/2002	7h	07/08/2002	6	01/03/2004	6	27/06/2005	3a	27/11/2005	3a	09/07/2006	3a,2b,9				
	5	G 104 A	14/02/2000	3a	03/07/2002	2a	09/07/2002	6	18/12/2005	2a	19/03/2008	3a,7c										
	6	G 104 B	18/06/2002	3a	16/09/2002	2a	19/01/2003	2a	25/08/2003	2a												
	7	G 105 A	06/05/1999	2a,3a	21/10/2001	3a	07/03/2004	3a,2a														
	8	G 105 B	13/01/1999	2a	25/08/2003	2b	10/08/2004	3a	26/11/2006	3a,2a,7c	17/06/2008	2a,3a										
	9	G 106 A	12/04/2003	2a	14/08/2003	3a,7c,2b	02/10/2006	3a,7k														
	10	G 106 B	06/11/2000	2a,3a	07/09/2005	3a,2a																
	11	G 107 A	11/11/2004	2a,5																		
	12	G 107 B																				
	13	G 108 A	26/11/2000	3a																		
	14	G 108 B	23/09/2002	3a	09/02/2003	7f																
	15	G 109 A	26/04/2001	3b	30/11/2004	3b																
	16	G 109 B																				
	17	G 110 A	08/10/2002	2a,3a	08/01/2003	2a	06/02/2004	5														
	18	G 110 B	25/10/2001	2a,3a	10/11/2001	2a	20/12/2004	2a,7a														
	19	G 110 C	22/10/2000	2a	05/11/2000	2a	10/12/2001	3a	04/09/2005	2b												
	20	G 111 A	22/11/2000	2a																		
	21	G 111 B																				
	22	G 120 A																				
	23	G 120 B	10/11/1999	2a	04/09/2002	6	25/03/2007	4,7a,b,c,j,l	21/04/2008	2a(both)												
	24	G 121 A	18/12/2000	2a,3a																		
	25	G 121 B	25/10/1999	2a	11/09/2000	3a	11/12/2000	3a	25/06/2002	2a	25/05/2003	2a	21/01/2008	2a,3a	27/05/2008	7b,3a	04/06/2008	2a,3a,6b				
	26	G 122 A																				
	27	G 122 B	22/01/2006	3a																		
	28	G 123 A	10/08/2000	2a,3a																		
	29	G 123 B	10/01/2001	3a																		
	30	G 124 A	09/01/2002	3a																		
	31	G 124 B	22/10/2007	2a																		
	32	G 151 A	05/10/1999	2a	20/02/2001	2a,3a	27/04/2001	5	28/02/2005	2a,2b	29/08/2005	5										
	33	G 151 B	24/10/2001	5	20/11/2006	2a,2b,7a																
	34	G 161 A	17/02/2004	3a	12/04/2004	2a																
	35	G 161 B	18/08/2003	2a																		
	36	G 162 A	08/08/2000	2a	30/09/2002	3a	17/06/2003	2a														
	37	G 162 B																				
	38	G 450 A	02/08/2009	2a,3a																		
	39	G 450 B																				
	40	G 450 C																				
	41	G 455 A																				
	42	G 455 B	09/02/1999	2a	24/04/2000	2a	08/08/2000	2a	07/09/2000	2a	07/04/2002	2a										
	43	G 460 A	21/01/1999	3a	08/11/1999	3a	03/07/2006	3a														
	44	G 460 B	05/02/2001	3a																		
	45	G 460 C																				
	46	G 461 A																				
	47	G 461 B																				
	48	G 465 A	24/01/2001	3b																		
	49	G 465 B	07/02/2006	2b,3a																		
	50	G 469	18/07/2005	5																		
	51	G 470	18/09/2006	3a,3b																		
	52	G 476	22/01/2002	3a																		
	53	G 481	07/01/1999	2a	20/05/2001	2a,3a	18/08/2002	2a	29/07/2003	5	13/10/2004	3a	12/05/2004	2a,3a	09/06/2005	3a,2a	01/08/2005	2b				
	54	G 701 A	02/10/2002	3a																		
	55	G 701 B	03/01/1999	5	21/02/2000	3a																
	56	G 801 A	27/05/1999	3a,7d,2a	18/12/2000	2a	27/07/2003	2a	04/11/2003	2a	14/04/2004	2a	17/01/2006	2a	30/10/2008	2a						
	57	G 801 B	18/12/2000	2a	06/09/2001	2a	09/10/2007	2a	09/11/2008	2a												
	58	G 801 C	19/07/1999	2a	24/02/2000	5	12/07/2004	2a	05/02/2006	2a	17/02/2007	5,7c,2a	26/02/2008	2a	25/11/2008	7c						