Assessment of Process Capability Using Weibull Analysis

by

Nurul Atiqah Binti Roszopor

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

____
(Dr. Ainul Akmar Mokhtar)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2012

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.

NURUL ATIQAH BINTI ROSZOPOR

ABSTRACT

For a production process, meeting the customer's specification is important. Thus process capability should assist the company to overview their manufacturing processes. In order to maintain the satisfaction of the customer, production has to achieve a normal distribution for their production output, where the production itself has to be in between the limit that the customer set. With this pattern, process capability can be find using normal process capability indices. These normal process capability indices however cannot be applied to non-normal distribution production data. Thus, in a normal approach assessing a non-normal distribution production data is to convert the distribution to be a normal distribution using specific variables as stated by Peter J. Sherman. With this method, process capability indices for normal distribution now can be use for the non-normal distribution of production data.

Besides using the method of transforming the non-normal distribution, a new process capability index S_{pmk} is established, this process capability index can straight away finding the process capability for non-normal distribution without having to convert it first. This study will use Weibull distribution to find a process capability on one set of production data. Process capability able to identify whether the manufacturing process is at the top of the games or some improvement can be done to improve the production rate. After knowing the process capability, further step can be taking for example applying Six Sigma into the manufacturing processes. Six sigma help company to improve the quality of process output by eliminate the causes of production error or defects and minimizing the variable in manufacturing process to deliver near-perfect products to the customer. Finding a process capability is essential for the company to maximize profit by increasing the process capability. Without careful measurement of process capability, company will end up losing more money unwittingly

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The special thanks go to my supervisor, Dr Ainul Akmar Mokhtar. With her expertise and wide knowledge I can finish up this final year project smoothly. The cooperation is highly appreciated. This project can be devastated without her guidance. She is a very strict supervisor and she gives the directions where to go very clearly. With the generosity sharing her knowledge, I can see do the project with ease. I am very thankful with my supervisor because her attitude of always open for discussion helps me every time I'm face a big stumble in completing my project.

I'm also wanted to express my gratitude to Mr Meseret, a postgraduate student doing master in reliability. With his value time, he taught me how to use Weibull ++ software and make sure I'm really understand my project. His friendliness give me courage to ask everything related to Weibull ++ software. Last but now least I wish to avail myself of this opportunity to express a sense of gratitude to my friends and my family for their support, strength and motivation as for me to continue to do this project.

I'm hoping that this project can beneficiary all in future. With that thank you again for those who are contribute whether I'm realize about it or may not.

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ABBREVIATIONS AND NOMENCLATURES

1.	PCI	Process capability index
2.	$C_p, C_{pl}, C_{pu}, C_{pk}$	Process capability
3.	USL	Upper specification limit
4.	LSL	Lower specification limit
5.	*Pdf*	Probability density functions
6.	*Cdf* (Φ)	Cumulative density functions
7.	B	Weibull shape parameter
8.	η	Weibull scale parameter
9.	μ	Mean for data
10.	σ	Standard deviation for data

CHAPTER 1

INTRODUCTION

1.1 Background

The efficiency of the manufacturing process can be identifying by the process capability. Every manufacturing company has an aiming to hit their production target, different company will come out with different solution on how they can achieve their target as suggested by Caruana and Einav (2005). With process capability, company will be able to examine the area that they can improve and compete with other company or increase their own productivity and annual income. This implementation will also reduce maintenance time and reducing cost for available system. In most practice, assuming the production data is in normal distribution allowing finding the process capability indices (PCIs).

But in worst case scenario, production data can be skewed from normal distribution or not meet the target of the production process. In this case, the non-normal distribution needs to be convert into normal distribution before able to find the process capability. There are ways on how converting a non-normal distribution based on what is the non-normal distribution type. According to Peter J. Sherman, the box-cox method can be use to transform the non-normal distribution such as Weibull, Binomial, Exponential and Poisson, by using the power transformation for the data by raising the original measurements to a power lambda (λ). Once non-normal distribution change into normal distribution the usual calculations can be use easily.

Changing the distribution type may be a tedious job, thus several methods have proposed to help finding the process capability for non-normal distribution as stated by Chen and Pearn(1997), Tong and Chen (1998). Chen and Ding (2000) also proposed a new process capability index S_{pmk}. With these new process capability indices, company can find the process capability in any kind of distribution of the production data they have. Ensuring the process capability is in good shape will eventually help to raise the production rate in the manufacturing company.

1.2 Problem statement

Process capability can be measured by using a process capability formula, with all the parameter can be gain from the normal distribution graph and the production data. Besides using normal distribution, Weibull distribution can be use to find the process capability. Normal distribution can be related to Weibull distribution because the shape parameter in the Weibull distribution can be considered as standard deviation from the normal distribution. To find the process capability in normal distribution is easy considered the process capability indices are available, but when it come to non-normal distribution example such as Weibull distribution. Other type of process capability indices have to be use.

If the production data is in non-normal distribution, it will skew positively or negatively from the target. When facing this type of distribution, Weibull distribution can be use because it can take on the characteristic of others type of distributions just on the value of the shape parameter, β based on The Weibull Distribution (2006)

In this matter, identifying the shape parameter in Weibull distribution is important. Production data is needed to build up the Weibull distribution. Weibull analysis not only helps to find the process capability but Weibull analysis can help company to assist with their reliability. Importance of finding the process capability may give the company overview on their level for production process. With that company can adopted different type of management solution to increase their profit.

1.3 Objectives and Scope of Study

1.3.1 Objectives of the study are to assess the process capability using Weibull analysis of daily production data and to find the deviations of the production process from Weibull distribution.

1.3.2 The scope of study is to find the process capability of manufacturing process by using production data in Weibull distribution. The process capability will be discovered using new process capability index proposed by Chen and Ding (2000). In this first semester of final year project, being able to come out with the methodology to find the process capability is essential to help smoothen out the process of calculation and modeling of the production data.

CHAPTER 2

LITERATURE REVIEW

2.1 Process Capability

Process capability is a method to compares the output of a production to be in the specification limits counted according to Jack Prins in Engineering Statistic Handbook. (n.d.) The production data will be presented on a normal distribution graph, where the standard deviations can be found.

Company should know whether their production is in the specification limits set by the customer or not. This will help in the production team work principles. If the production is not in good shape, some modifications need to be done. There are some other reasons why company shall find their process capability;

1 It will help the company to predict until what extends that they can go and be able to hold tolerance or customer requires.

2 Overview to make changes in the system, redesigning and implementation a new process.

3 Knowing the process capability, company can specify better their quality performance requirements for machine and manufacturing process.

Based on articles written by Tushar Mehtar (2011) the normal distribution graph from a set of production data, the shape of the distribution can be called bell curve where both side of the distribution have an even size. It will show the mean and the standard deviation of the production data. For example, below graph represent a normal distribution with mean is zero and standard deviation is one ($\mu=0$, $\sigma=1$).

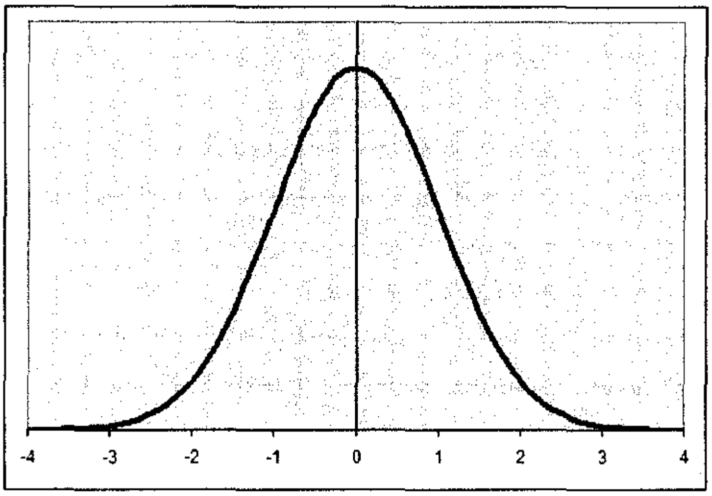

Figure 1: Example of normal distribution

With these two parameters finding process capability can be found using process capability indices. Process capability indices can show if the process is capable to produce products on target and still maintain the production inside the specific limit. For normal distribution, process capability will be estimated by using Cp, Cpl, Cpu, and Cpk as stated in Measuring Your Process Capability by Mehernosh (n.d.).

Process capability indices	Usage
$C_p = \dfrac{USL - LSL}{6\sigma}$	Process capability for both sides of the specification limit.
$C_{pu} = \dfrac{USL - \mu}{3\sigma}$	Process capability for upper specification limit.
$C_{pl} = \dfrac{\mu - LSL}{3\sigma}$	Process capability for lower specification limit
$C_{pk} = min\left(\dfrac{USL - \mu}{3\sigma}\right), \left(\dfrac{\mu - LSL}{3\sigma}\right)$	Process capability for both sides accounting for process centering.

Table 1: Process capability indices for normal distribution

Where μ is the mean of the production data and σ is the standard deviation of the production data, USL is the upper specification limit and LSL is the lower specification limit. The target is to get the process capability index C_p greater value bringing the meaning of the manufacturing process is in good shape.

This research however only applicable if the distribution is normal if the distribution is non-normal, other process capability indices have to be use. Some other process capability indices have been proposed by Pearn an Chen(1995), Chen and Pern (1997), Tong and Chen(1998). Chen and Ding (2000) also proposed a process capability index that can apply to any kind of distribution called S_{pmk},

$$S_{pmk} = \frac{\Phi^{-1}\left(\frac{1 + F(USL) - F(LSL)}{2}\right)}{\sqrt[3]{1 + \left(\frac{\mu - T}{\sigma}\right)^2}}$$

Parameter	Usage
Φ	- Cumulative density functions, *cdf* for Weibull distribution
F(USL), F(LSL)	- Sample proportion from production data.
μ	- Mean for production data of Weibull distribution
T	- Target for production process set by the customer
σ	- Standard deviation for Weibull distribution

Table 2: Parameters in new PCI and the functions.

This study will use S_{pmk} to find the process capability on production data that having a Weibull distribution.

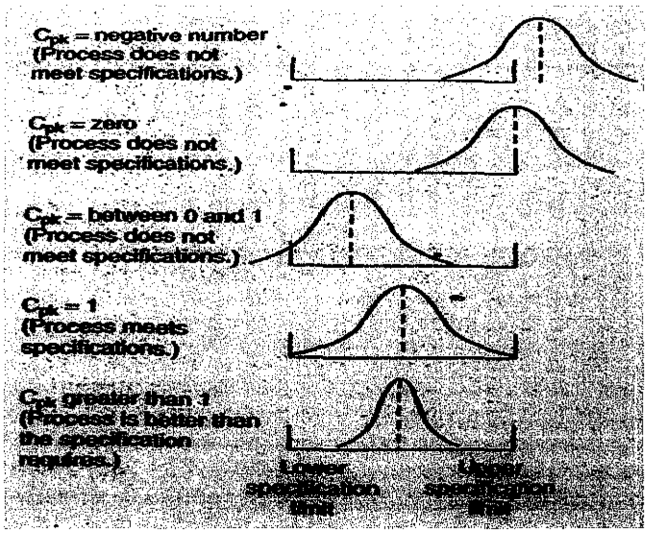

Figure 2: Meaning of PCI measures

In this study, the aim to find the process capability index to see if the process capability stay in the specification limit because according to J. Heizer and B. Render (2011) process that have PCI as 1 is a capable process. Capable process here mean that the overall process data stay in between the specification limit and the process is capable to produce within ±3 standard deviation (fewer than 2700 defects per million). When the process having PCI greater than 1 it's mean that the process able to produce fewer than 3.4 defects per million which is follow the Six Sigma concept but if the PCI is 0 to 1 its show that the process slide away from the centre between the specification limit.

2.2 Six Sigma Management

The Six Sigma is a management methodology that uses data and statistical analysis to measure and improve a company performance by located and eliminating defects. Article what is Six Sigma (n.d.) said to achieve Six Sigma, manufacturing process must not produce more than 3.4 defects per million productions. Six Sigma implementation focus on customer expectation and concentrate to the company resources to improve and contribute to the high profitability for the company. In All About Six Sigma (2006), Warren declared the main goal of Six Sigma methodology is to use specific problem-solving approach and selected six sigma tools to improve processes and quality of products. Using data collected, unacceptable products quantity can be reduced.

Six Sigma objective is to implement a measurement-based strategy that focus on process improvement and variation reduction through the application of Six Sigma methodology. Arazi, Shaharin and M. Faris (2010) underline several methods of improving manufacturing process using Six Sigma method. The first method is DMAIC process (define, measure, analyze, improve, control) this method is suitable for process which fall below the specification limit and looking for incremental improvement. Another method called DMADV process (define, measure, analyze, design, verify) is an improvement system to be used for new proves or product.

According to Warren (2006) this methodology of Six Sigma has been proves to be a good tools to increase profitability of the company, in fact the Motorola has been implement Six Sigma in the 1980s. They realize that an old traditional used defect per thousand is not sensitive and they need to measure defects per million parts. Motorola also came up with standard implementation method to use Six Sigma; they worked hard to prove that quality of the project will show positive effect on the bottom line. In 1991, Allied Signal put their own spin to implement Six Sigma and come out with the training manual to be used in their company. Impressed by successful of Allied Signal, Jack Welch the CEO of General Electric eager to implement Six Sigma to his company after got out from the hospital. Big savings have been tasted by Motorola by saving up to \$16million, \$800million by the Allied Signal and \$12billion for General Electric for only five years of use. Thus implementation of Six Sigma bring a lot of advantage to the company, since by saving up that much will help company to grow and gain name in the marketplace. Different stage of Six Sigma can be achieved by company where training plays a big role in helping the workers to move to higher belts as stated by R.B. Coronado (2002). Refer appendix 1 to see the training belts for Six Sigma method.

2.3 Weibull Distribution and Analysis

Weibull distribution is a distribution that can take the characteristic of other type of distribution based on the value of the shape parameter β based on The Weibull Distribution (2006). Waloddi Weibull who was invented Weibull distribution in 1936;

he claimed that this distribution method can be applied to all kind of problems as stated by Robert (2006). Nowadays, Weibull analysis has become the leading method in the world to plot data production in the same time complements the Six Sigma methodology. They both have the same objectives to control and reduce the variation. Daily production output when plotted into Weibull probability plot will produce straight lines. When the inconsistency happen in the manufacturing processes, indicate that trend line significantly loss the process reliability. When unreliability happens, it will affect the company paycheck. Few company are able to identified the problem and amend it but few other lack of courage to make process reliability improvements.

Yang (2007) stated the Weibull distribution is consider a general purpose reliability distribution to model time to failure of manufacturing processes, few parameters have to be reflect on to defined Weibull distribution;

- The *pdf* of the Weibull distribution

$$f(t) = \frac{\beta}{\eta^{\beta}} t^{\beta-1} \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right], t > 0 \text{ -- (1)}$$

- The Weibull *cdf*

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right], t > 0 \text{ -- (2)}$$

Where β and α is the distribution parameter:

- o β = Shape parameter
- o η = Scale parameter

The β = shape parameter indicates the prevalent failure modes.

- β < 1 indicates 'infant mortality' due to poor production quality or insufficient burn-in
- β = 1 indicates random failures which are independent of time. Human errors, natural events etc.
- β = 1 to 4 indicates early wear out i.e. erosion, corrosion, early fatigue 1
- β > 4 indicates old age and rapid wear out. Bearing failures, corrosion, erosion, fatigue etc.

Above indicator will provide overview on area that can be improved in the manufacturing process. For process capability, finding the shape parameter and substitute it inside the process capability formula will give the value to estimate the manufacturing process. To relate the Weibull distribution analysis with normal distribution, in Weibull shape parameter, β is the standard deviation from the normal distribution.

CHAPTER 3

METHODOLOGY

3.1 Project flow chart

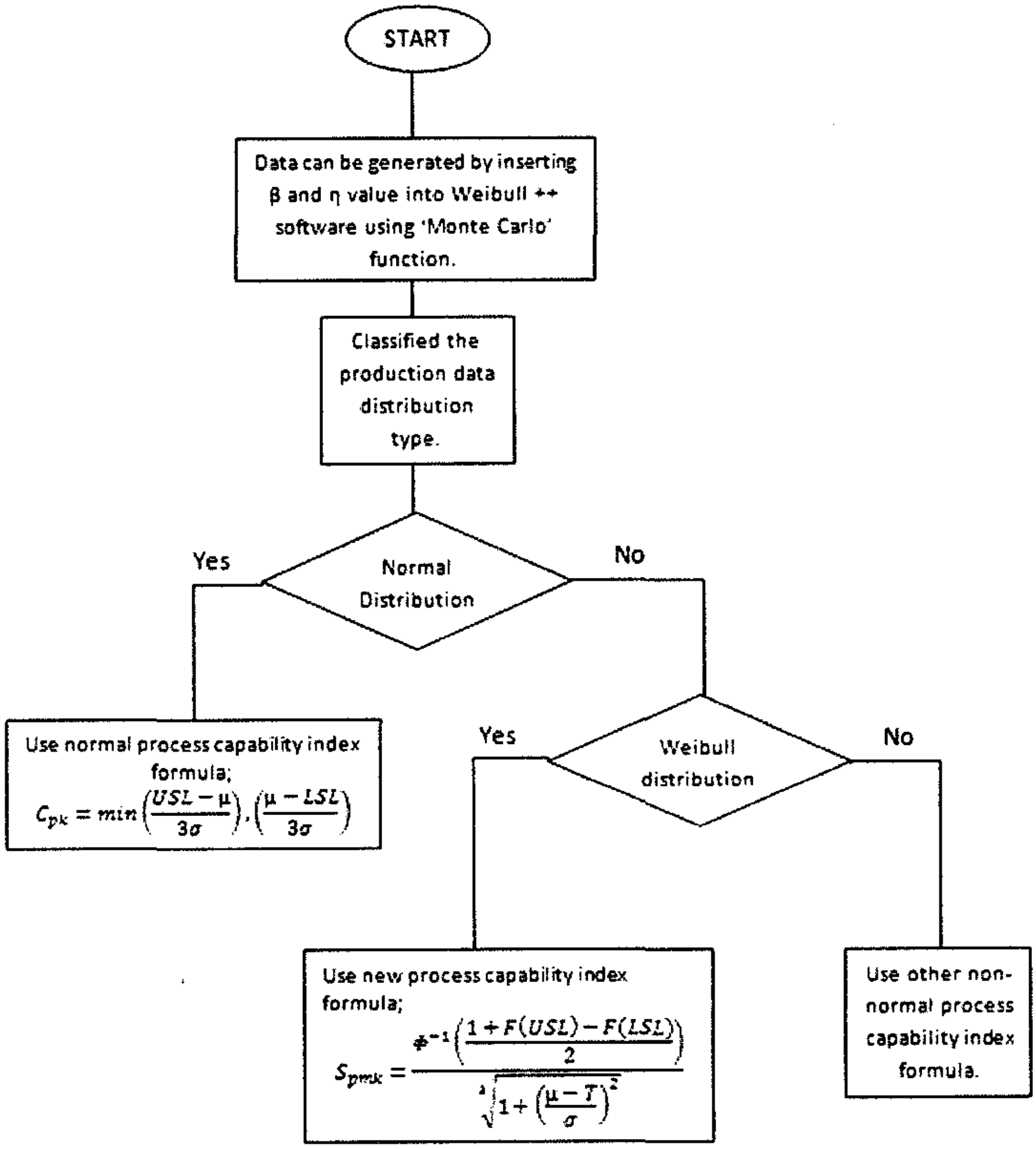

Figure 3: Flow chart of the methodology

3.2 Tools and Equipment

a. Microsoft Excel - data collection and analysis

b. Weibull++ - plotting data into Weibull distribution graph

c. Microsoft Word - report writing.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result

The theory is if the process capability is high, thus the production is in a good state. But when the process capability is low, finding the main causes contribute to inefficiency of the manufacturing process is important. In this study, a case study will be examine to see how other researcher find the process capability using Weibull analysis. In the case example in Process Variation and Capability Assessment (2006), production data are collected from a chemical manufacturer. Customer required the production to be at least 975 tons and no more than 1025 tons with the target of 1000 tons. Thus data are collected in one year time. Below show the F/S histograms in the article.

Specification/ customer request	Value
Target	1000 tons
Lower specification limit	975 tons
Upper specification limit	1025 tons

Table 3: Specification set by the customer

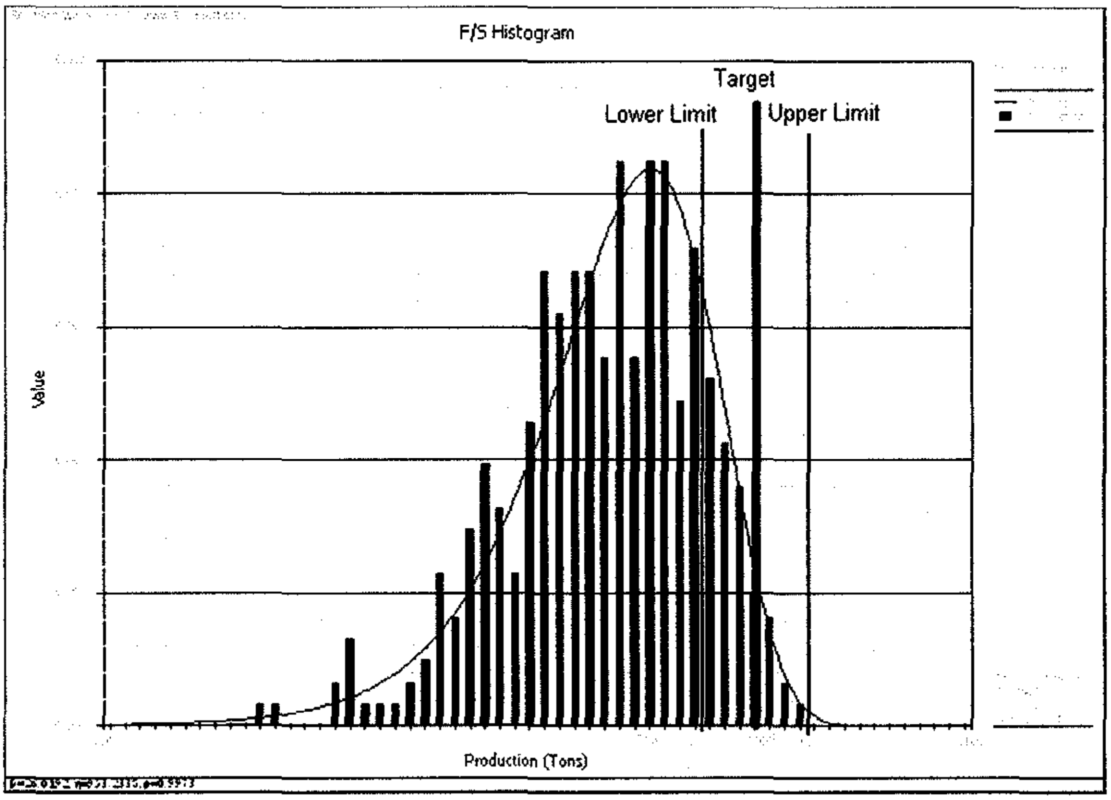

Figure 4: F/S histograms

To replicate the production data from a histogram given in the article, 'monte carlo' function in Weibull ++ software was used.'Monte carlo' is a data generator in Weibull ++ thus five sets of production data are generated using 'monte carlo' with the same β and η value. Below the 'monte carlo' function work in Weibull ++, by inserting the parameters then it can generate the data base on the parameters given. The goal is to get the most similar F/S histogram chart with the case study F/S histogram chart

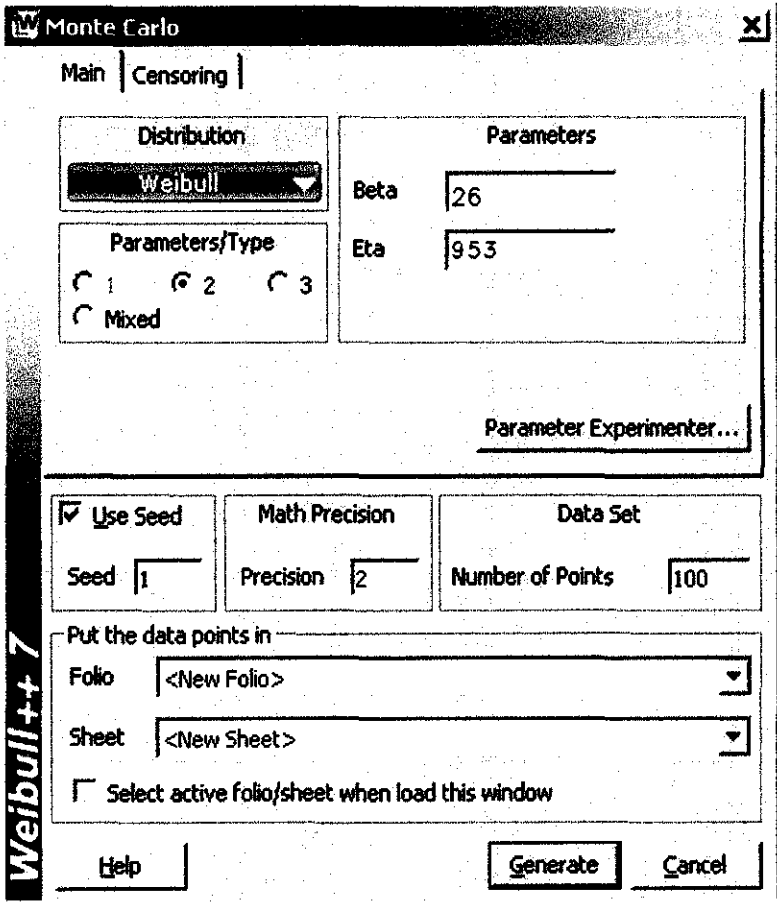

Figure 5: Monte carlo function to generate data

Monte carlo wont give the exact value as value requested, it will generate data that most slightly closer to the value requested. Thus, three set of data was generated that may be close to the value requested. Below are the three set of data Monte carlo generated with data points of 100 data.

1. $\beta = 26$ and $\eta = 953$

763	874	902	919	929	943	949	961	970	986
842	883	903	920	929	943	952	961	973	988
843	887	907	921	930	943	952	963	975	989
854	890	907	924	933	944	954	963	976	990
855	891	908	924	934	946	956	964	977	990
857	893	908	925	935	946	956	965	978	990
862	894	916	925	938	946	958	965	981	995
864	894	917	926	941	947	959	966	982	996
869	900	917	927	941	949	959	966	984	998
873	900	918	928	942	949	960	969	984	1002

Table 4:Data generated by 'monte carlo' for $\beta = 26$ and $\eta = 953$

2. $\beta = 26.9$ and $\eta = 953.5$

815	875	900	915	923	938	954	963	972	986
830	880	902	915	923	940	954	966	975	988
843	883	902	917	926	941	956	967	976	990
857	884	902	917	927	941	956	967	977	991
858	888	902	918	934	943	957	969	979	991
861	889	909	919	935	946	960	969	980	994
863	889	909	920	936	947	960	969	980	1004
866	892	910	920	936	949	961	970	982	1007
869	898	914	922	937	951	962	971	983	1009
869	898	914	923	938	952	963	972	985	1024

Table 5:Data generated by 'monte carlo' for $\beta = 26.9$ and $\eta = 953.5$

$\beta = 26.55$ and $\eta = 955$

776	876	902	917	929	939	948	956	962	965	987
804	877	907	918	932	939	950	957	986	966	988
845	878	907	920	933	942	951	957	963	971	993
855	880	908	921	935	943	951	957	963	974	995
860	880	910	923	935	943	954	958	963	975	1000
862	883	911	924	936	943	954	959	964	976	1003
867	888	911	926	939	944	955	960	964	981	1008
867	898	912	927	939	944	956	960	964	982	1011
869	899	912	929	939	945	956	961	964	984	1015

Table 6: Data generated by 'monte carlo' for $\beta = 26.55$ and $\eta = 955$

With this three sets of data generated, choosing the most suitable data that resemble the example in the article have to be done. Thus, deciding which data to choose can be done by plotting the data in the F/S histograms to find the most similar patterns same as the case study.

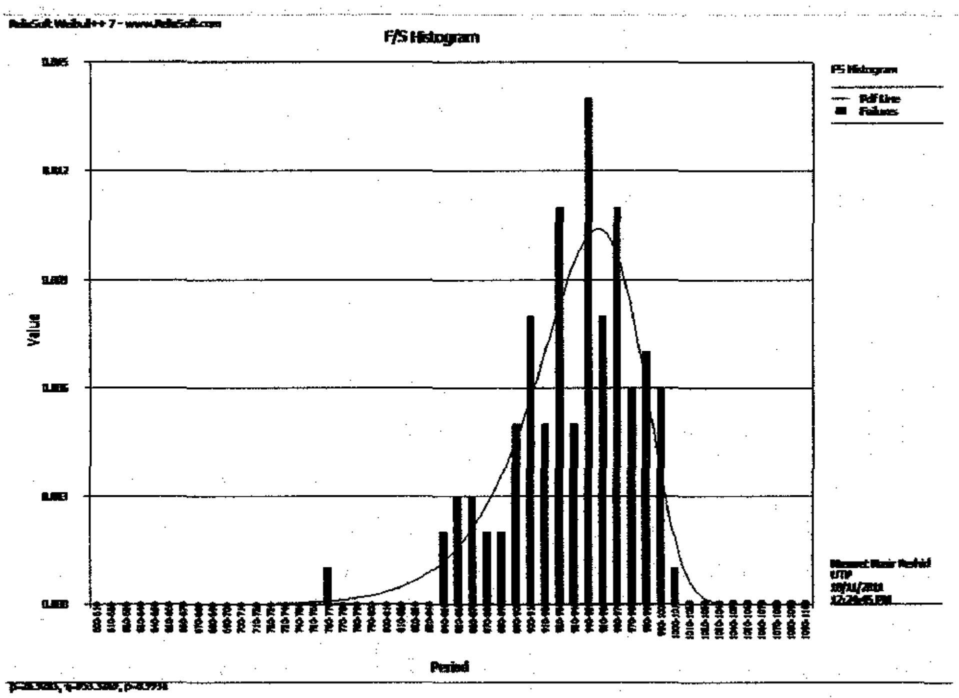

Figure 6: F/S histograms for $\beta = 26$ and $\eta = 953$

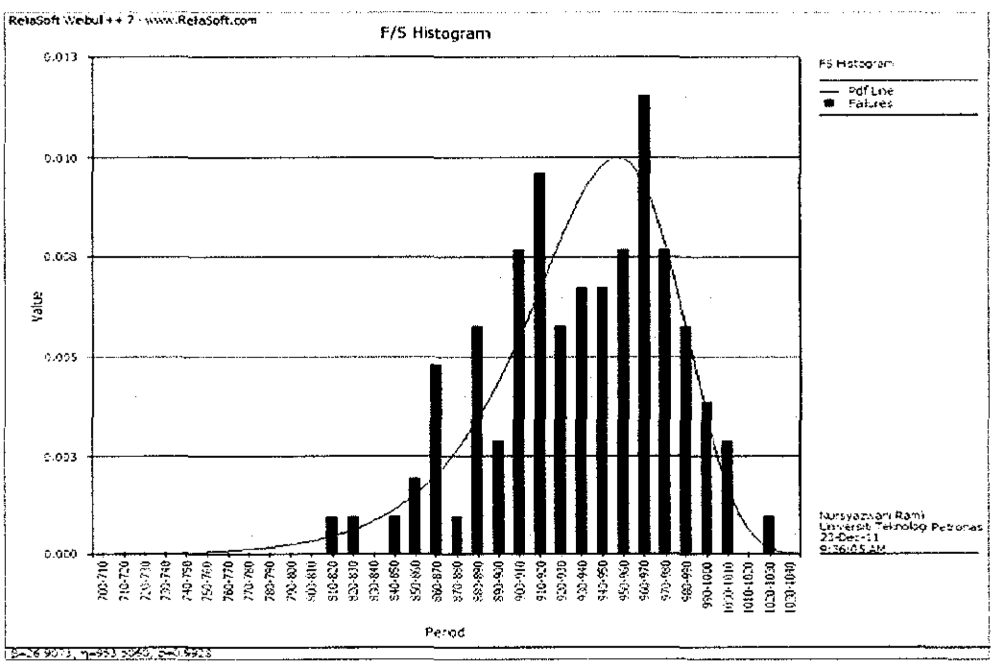

Figure 7: F/S histograms for $\beta = 26.9$ and $\eta = 953.5$

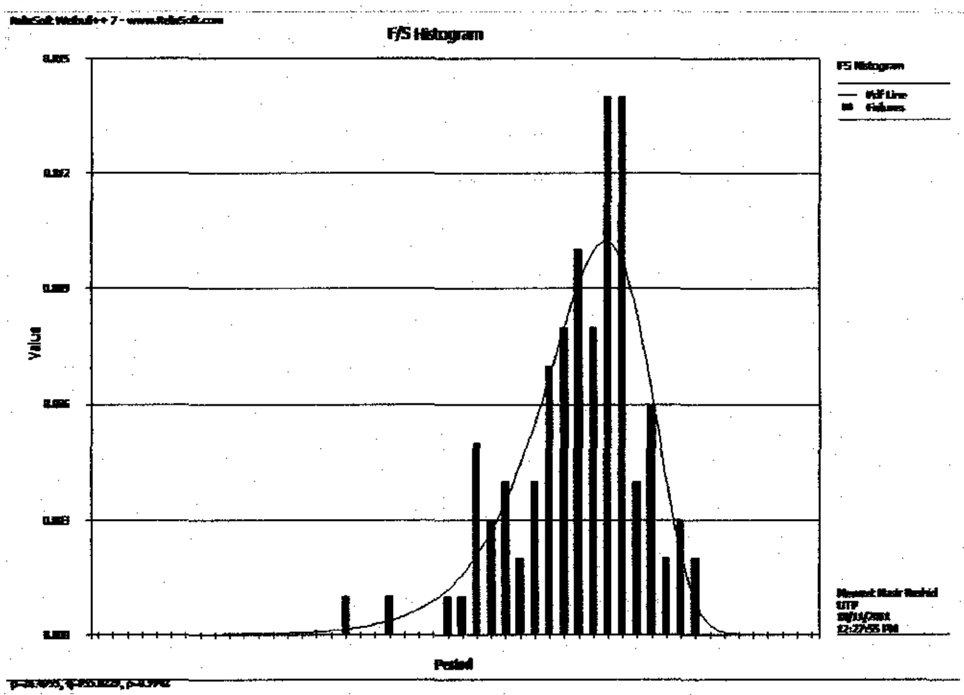

Figure 8: F/S histograms for $\beta = 26.55$ and $\eta = 955$

After comparisons are made, second generated data is mostly close to the real case study F/S histogram chart.

But in the case study paper, it's doesn't mention how many data are used. Thus, inspecting every variable is important. The next step is to use 'monte carlo' function again to generate data with different number of point. Number of points will be a variable; in this case 100 points, 200 points and 300 points will test to see if this variables effecting the trend of the histograms.

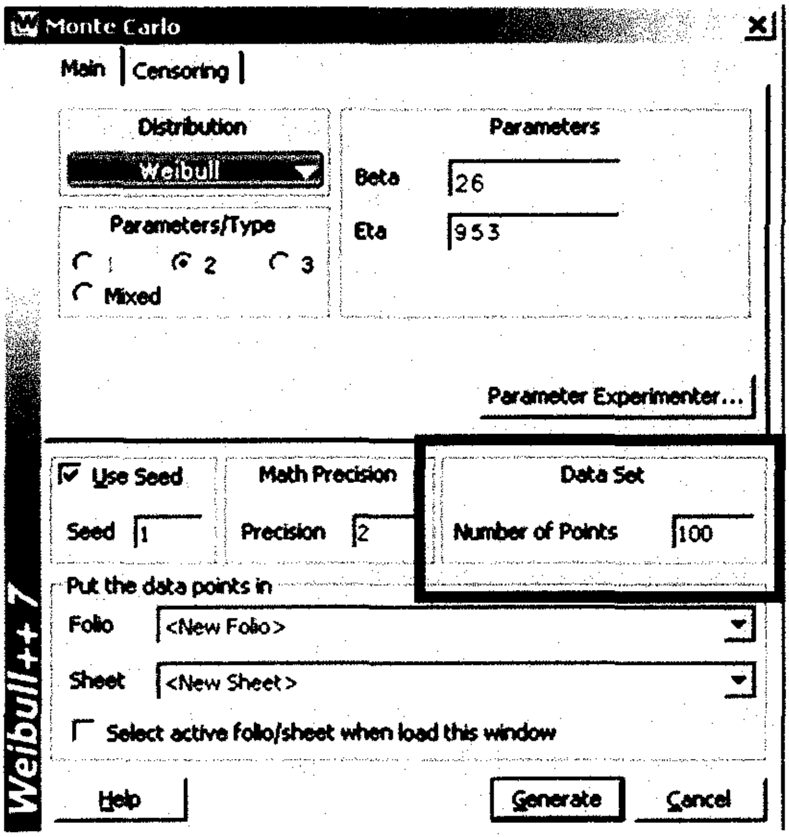

Figure 9: Monte carlo function to generate data with different number of points

Below are the results for using number of points as the variables.

1. $\beta = 26.9$ and $\eta = 953.5$ with 100 data.

815	875	900	915	923	938	954	963	972	986
830	880	902	915	923	940	954	966	975	988
843	883	902	917	926	941	956	967	976	990
857	884	902	917	927	941	956	967	977	991
858	888	902	918	934	943	957	969	979	991
861	889	909	919	935	946	960	969	980	994
863	889	909	920	936	947	960	969	980	1004
866	892	910	920	936	949	961	970	982	1007
869	898	914	922	937	951	962	971	983	1009
869	898	914	923	938	952	963	972	985	1024

Table 7: Data generated by 'monte carlo' for $\beta = 26.9$ and $\eta = 953.5$

2. $\beta = 26$ and $\eta = 953.7$ with 200 data.

795	870	897	912	928	936	949	962	975	988
811	872	899	913	928	937	949	962	975	988
825	873	899	913	928	937	951	963	975	991
829	877	899	913	928	937	951	963	976	991
835	880	900	916	928	940	951	964	977	991
838	881	900	916	929	941	952	965	977	995
842	881	900	918	929	941	953	965	979	997
847	882	902	918	929	942	954	966	979	999
848	882	903	918	930	942	954	966	979	999
855	883	905	919	930	943	955	967	981	1000
856	884	905	919	931	943	957	967	982	1002
858	884	907	922	932	943	957	968	982	1005
859	884	907	923	933	943	958	969	983	1007
864	891	907	923	933	944	960	971	983	1009
864	892	908	925	933	944	961	971	984	1011
864	894	909	925	934	945	961	971	985	1014
865	895	910	925	934	945	961	971	985	1014
867	895	911	926	935	945	961	971	986	1026
868	896	911	927	935	947	961	972	986	1030
870	896	912	927	936	948	962	974	988	1030

Table 8: Data generated by 'monte carlo' for $\beta = 26.3$ and $\eta = 953.2$

3. $\beta = 26.1$ and $\eta = 953.2$ with 300 data.

727	874	898	911	930	942	952	959	968	984
779	875	898	911	931	942	952	959	969	984
823	875	898	912	931	942	953	959	969	985
828	875	898	913	931	943	953	960	969	986
834	876	899	913	932	943	953	960	970	988
834	878	899	915	932	944	953	960	970	989
836	879	899	915	932	945	953	960	970	990
838	880	900	917	933	946	953	961	971	991
838	880	900	917	933	947	954	961	971	992
844	883	900	919	935	947	954	961	971	993
845	883	901	919	935	947	955	961	973	995
845	886	901	919	936	947	955	962	973	995
848	887	902	920	936	948	955	962	974	995
848	887	902	920	937	949	955	963	974	997
853	889	902	920	937	949	955	963	974	997

856	890	903	920	938	949	956	963	975	1000
857	892	903	920	939	949	956	964	977	1001
857	892	904	920	939	949	956	964	977	1001
858	893	904	921	940	950	956	964	977	1003
858	893	904	921	940	950	956	965	978	1004
861	893	904	921	940	950	956	966	978	1005
861	893	906	923	940	950	957	966	979	1006
864	894	906	925	940	950	957	966	979	1007
865	894	907	926	940	951	957	967	980	1007
868	895	907	928	940	951	957	967	980	1011
871	895	908	928	941	951	957	967	980	1013
872	896	908	928	941	951	958	968	982	1013
873	896	908	929	941	951	958	968	982	1014
873	897	910	929	941	952	959	968	982	1018
873	897	910	930	942	952	959	968	983	1037

Table 9: Data generated by 'monte carlo' for $\beta = 26.1$ and $\eta = 953.2$

The next step is to generate the F/S histogram charts for each data. With the histogram charts, the comparisons of histograms with the real case study histograms will be done. Below are the histograms for different number of points variable.

1. $\beta = 26.9$ and $\eta = 953.5$ with 100 data.

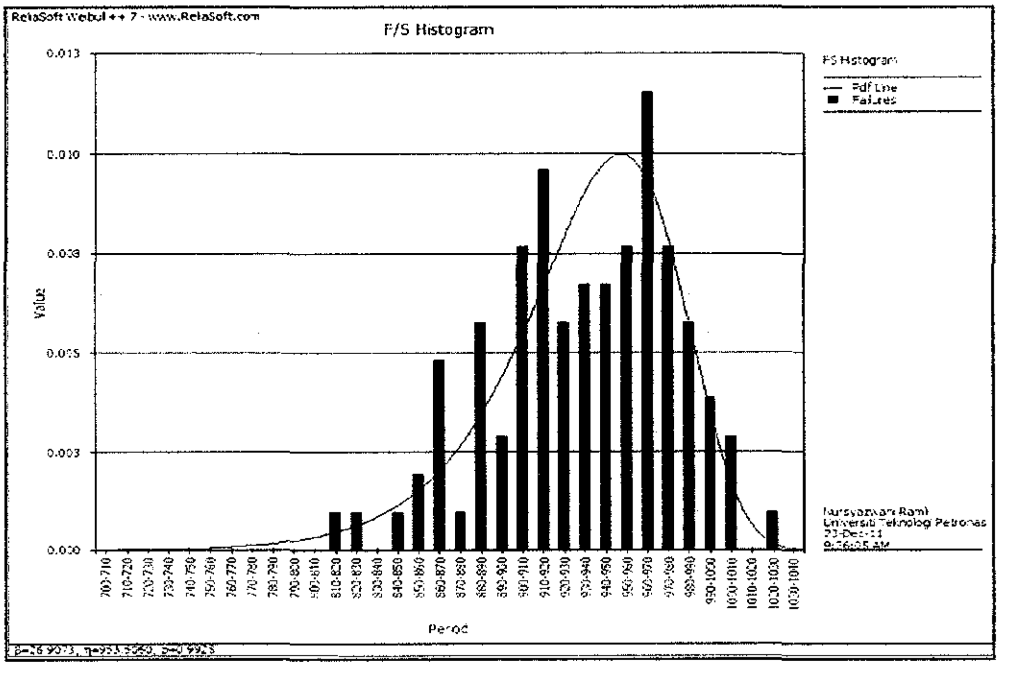

Figure 10: F/S histograms for $\beta = 26.9$ and $\eta = 953.5$

2. $\beta = 26$ and $\eta = 953.6$ with 200 data.

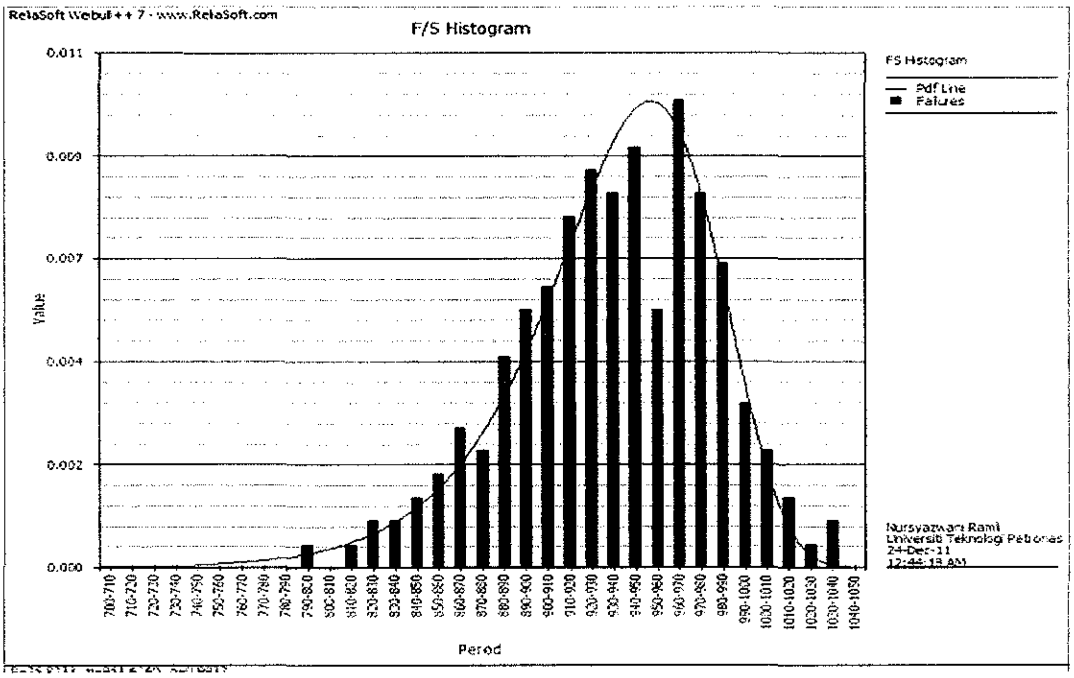

Figure 11: F/S histograms for $\beta = 26$ and $\eta = 953.6$

3. $\beta = 26.1$ and $\eta = 953.2$ with 300 data.

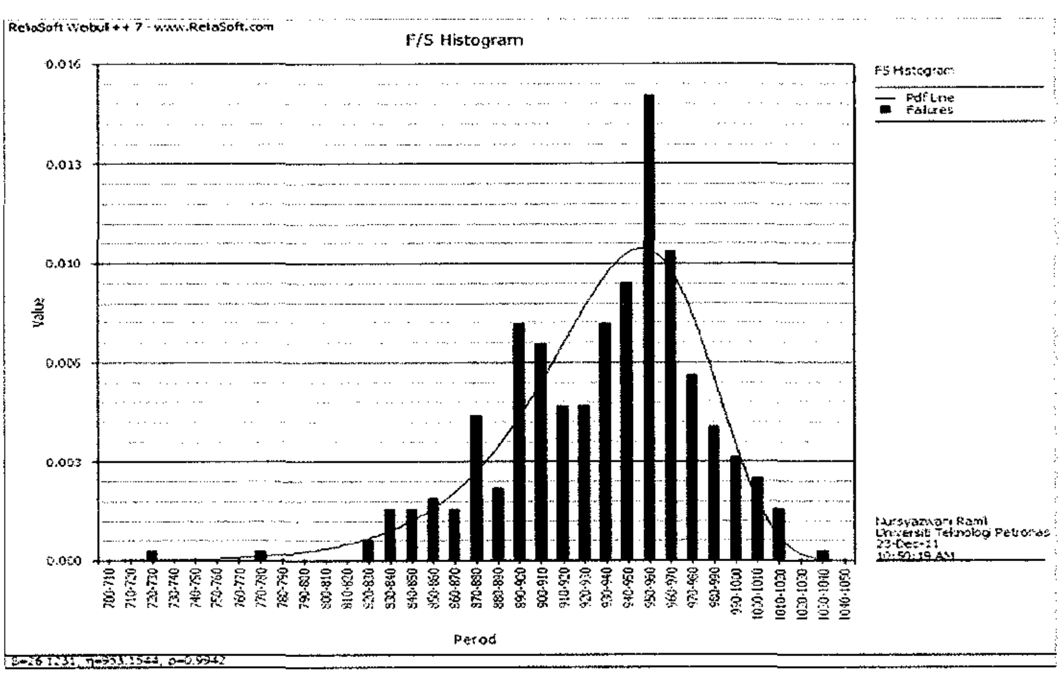

Figure 12: F/S histograms for $\beta = 26.1$ and $\eta = 953.2$

Different number of points generated different type of histogram trend. To find the best suitable data to be use in finding the process capability it must match with histogram in the case study. After examine the variables, the data with 200 points of data is the most suitable to match with the case study.

To find the process capability some parameters need to be calculated before using the final new PCI. The formula for the new PCI, S_{pmk};

$$S_{pmk} = \frac{\Phi^{-1}\left(\frac{1 + F(USL) - F(LSL)}{2}\right)}{\sqrt[3]{1 + \left(\frac{\mu - T}{\sigma}\right)^2}}$$

- Where Φ is cumulative density functions, *cdf;*

$$\Phi = 1 - e^{-(T/\eta)^{\beta}}$$

$$\Phi = 1 - e^{-(1000/953.2)^{26.3}}$$

$$\Phi = 0.9679$$

- F(USL) is the upper proportion of the data. The upper specification limit is 1025 tons. All data below 1025 is counted from the data table.

$$F(USL) = \frac{197}{200}$$

$$F(USL) = 0.985$$

- F(LSL) is the lower proportion of the data. The lower specification limit is 975 tons. All data below 975 is counted from the data table.

$$F(LSL) = \frac{160}{200}$$

$$L(LSL) = 0.8$$

- μ and σ is mean and standard deviation for 200 data.

$$\mu = \eta \times \Gamma\left(1 + \frac{1}{\beta}\right)$$

$$\mu = 933.17$$

$$\sigma = \eta^2 \times \Gamma\left(1 + \frac{2}{\beta}\right) - \mu^2$$

$$\sigma = 59.1$$

Parameter	Value
Φ^{-1}	0.9679
F(USL)	0.985
F(LSL)	0.8
μ	933.17
T	1000
σ	59.1

Table 10: Parameters with value for new PCI

With all parameter counted, the next step is to calculate the PCI of the process.

$$S_{pmk} = \frac{0.9679\left(\frac{1 + 0.985 - 0.8}{2}\right)}{\sqrt[3]{1 + \left(\frac{933.17 - 1000}{59.1}\right)^2}}$$

$$S_{pmk} = 0.43$$

Thus the process capability is 0.43; it is far from a good process because according to J. Heizer and B. Render (2010) good process will give PCI as 1 where the process able to produce within ± 3 standard deviation. By looking at the data itself, its already show a red alert in the process because the customer target it between 975 tons and 1025 tons but the manufacturer produce average of 934 tons.

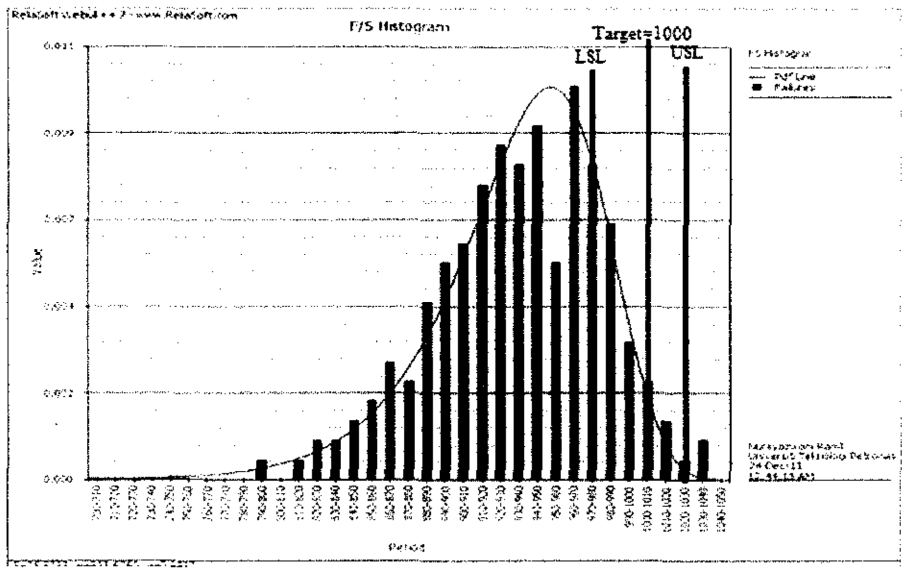

Figure 13: Production histogram with customer limit

4.2 Discussion

With the above result of PCI for the process is 0.43 its show that the company needs to re-evaluate their manufacturing process. This may cause by several factors from the manufacturer. Incapable process may cause from;

1. Unreliable machine

   Every machine have specific life span, where increasing the years of usage it will definitely decreasing the reliability. Low machine reliability will increase the rate of failures when machine always having failures the production will be affected. Old machine need to be replaced to make sure the reliability and the availability are good.

2. Inappropriate maintenance scheduling

   When the machine is unreliable, the close to care about is the machine maintenance. Aged machine should be taken care of frequently to ensure the availability. Thus, company has to identify machine that need more attention for example rather than do monthly maintenance the machine should be check twice a month. To rescheduling the maintenance table, company should get a closer look on the machine reliability. With the machine reliability is known manufacturer will be aware which machine need more attention compare to the other machine.

3. Machine efficiency

   Machine efficiency can be calculated by dividing the work output energy with work input energy. Lack of machine efficiency is because of high energy loss in the machine which making the machine giving out the small output. Manufacturer has to investigated why the machine having so high energy loss.
4. Unprofessional workers

   Human error can be one of the factors why the company can produce up to the customer specifications. Human can sometimes be lazy or forgetful. In manufacturing company all workers need to give full alert to the process because process machine need to be set up before the process start and this need human assistant.

As shown in the result where the process is incapable thus company need be re-evaluate from start until the end. Once the manufacturer able to keep the production data between the specifications limits, manufacturer now can implement Six Sigma to decrease the defects rate. Therefore Six Sigma implementation method can be used to reduce the variations of the production. In this case DMAIC method can be suitable method since this method can be used to established process like so. Below is the diagram on how company can used DMAIC method to improve the process based on research done by Tushar N. Desai and Dr. R. L. Shrivastava (2008).

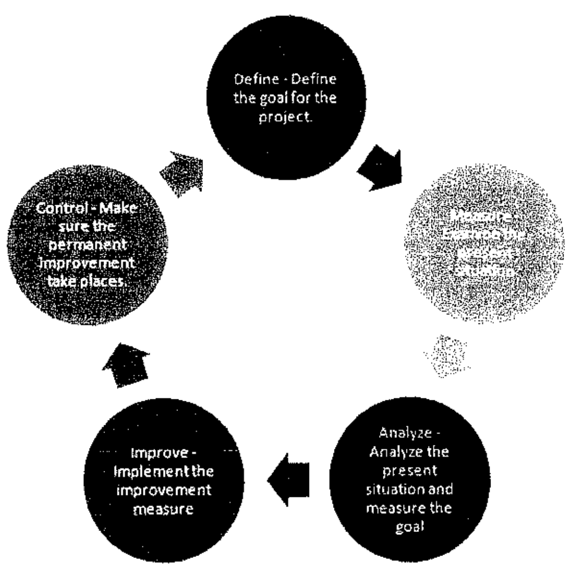

Figure 14: DMAIC method

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study we examine the case study for the process capability using new PCI, S_{pmk} proposed by Chen and Ding (2000). The case study is analyzed using Weibull analysis where the value of *cdf* is needed in the PCI formula. Analysis where done with several assumptions for example, data is collected for 200 points. This is in order to replicate the case study histograms, where the β and η are 26.8 and 953.2 respectively.

Calculations show that the case study process having a low PCI where it proves that the process needs major improvement to satisfied the customer need. This study prove that the new PCI, S_{pmk} can be used to find process capability index for Weibull distribution and analysis.

5.2 Recommendations

Problem of incapable process can be solved by several methods. Here are some suggestions on how the problem can be tackle.

1. Purchased new equipment

   The machine can be the major problem in the manufacturing processes. It may be an old machine where the reliability is low. Company has to spend for new machine to replace the old machine. For some this method may be financial wrecker but as in long term this can help in increasing the production thus decreasing the rejects from the customers that eventually bringing more profit.

   What company can do is to conduct a machine reliability assessment to investigate the machine reliability. If the machine having low reliability or it reach the end of life (wear out region) thus it may need to be replace but if the machine still in the good condition or in normal life (low constant failure rate) it need observe and keep it maintain in good shape. Appendix one will show the bathtub curve and the meaning of every region from the article written by Dennis J. Wilkins (2002)

2. Updating new maintenance scheduling

   After finding out which machine need more care, the maintenance department should rescheduling the maintenance schedule to make sure that the machine with less reliability is always in good condition and will always be available. Maintenance need to be done before the machine break down and always keep a track on what changing in the machine. With this, company can assess the machine failure rate.

3. Increasing the machine efficiency

   Machine efficiency depends on the energy flow inside the machine to be used to help in adding value to the product. But when the machine having low efficiency, energy may be use to overcome any resistance in the machine and block the high maximum energy to be use to add more value to the product. Machine engineer should be able to detect if the machine having high resistance and overcome the problem by changing the machine circuit to use less input energy. This will reduce the energy losses and give maximum energy to the process.

4. Unprofessional workers

   Human error can be a factor why the production is low. There are many causes can be related back to human error such as workers forget to updated the process instructions, they sometime missing from their workstation and may be they just too lazy to do their work properly. This is a called for supervisor and management department to always make sure that the workers always deliver a high quality job. Other method can be done is to utilize computer worker or in other wood to apply robot technology to replace human workers but robotic technology will cost a lot of money. Thus other way is to develop training to the workers and keep track on their performance every month.

With these recommendations, company able to increase the production and therefore increasing the process capability. Once the process becomes a capable process, company can focus on how to reduce more variations in the production. With less variations and the production always meet the target.

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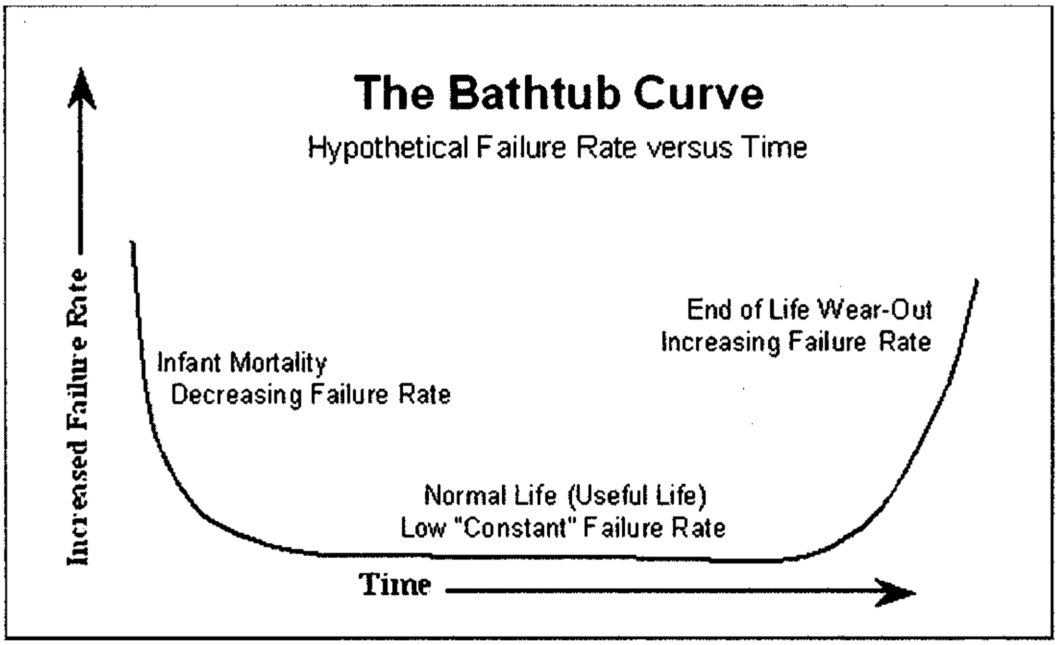
APPENDIX

1. Appendix 1

Table I Comparison of role, profile and training in six sigma belt system			
	Green belts	**Black belts**	**Champions**
Profile	Technical background Respected by peers Proficiency in basic and advanced tools	Technical degree Respected by peers and management Master of basic and advanced tools	Senior manager Respected leader and mentor of business issues Strong proponent of six sigma who asks the right questions
Role	Leads important process improvement teams Leads, trains and coaches on tools and analysis Assists black belts Typically part-time on a project	Leads strategic, high impact process improvement projects Change agent Teaches and mentors cross-functional team members Full-time project leader Cover gains into £	Provides resources and strong leadership for projects Inspires a shared vision Establishes plan and creates infrastructure Develops metrics Converts gain into £
Training	Two three-day sessions with one month in-between to apply Project review in second session	Four one-week sessions with three weeks in-between to apply Project review in sessions two, three and four	One week champion training Six sigma develop and implementation plan
Numbers	One per 20 employees (5 per cent)	One per 50 to 100 employees (1-2 per cent)	One per business group or major manufacturing site
Source: Air Academy Associates (1998)			

Appendix 1: Six Sigma belt system

2. Appendix 2



Appendix 2: The bathtub curve