Process Reliability Analysis of Gas District Cooling by Using Production Chilled Water Data

by

Nursyazwani binti Ramli

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Ainul Akmar binti Mokhtar)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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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.

NURSYAZWANI BINTI RAMLI

ABSTRACT

This paper presents the process reliability analysis of Gas District Cooling plant by using production chilled water data. Variation in the production process occurs when there is a difference between the quantity of supply chilled water from the plant to the customer and the customer's demand itself. So, the study aims to demonstrate the variation in the daily output of production chilled water and then been compared with the daily demand from the customer in order to analyze the process reliability of the system. In this study, the production chilled water data is analyzed based on the quantity that is supplied from the plant and the demand from the customer.

Process reliability is a helpful tool for testing either the system meets its requirement under assumed conditions over a certain period of time. The result of process reliability analysis will help the maintenance manager and staff to develop the proper maintenance strategy to increase future system availability, anticipate maintenance resource needs and provide long term savings in operations and maintenance costs.

Hence, Weibull analysis technique is introduced where the technique can clearly analyze the process reliability of chilled water and show the comparison between the supply and demand chilled water.

ACKNOWLEDGEMENT

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CHAPTER 1

INTPRODUCTION

1.1 BACKGROUND OF STUDY

Nowadays, reliability of a system or process becomes the main target for many companies, as the implementation of process reliability into the system may reduce production output and improve productivity. The companies who ignore this matter may have high possibility to face the losses in term of profit and production output, also consume much money to maintain the available process [1].

Resolving process reliability issue is also within the Six Sigma concept. In 1987, Motorola developed and organized Six Sigma process improvement methodology to achieve world class performance, quality and total customer satisfaction. Since that time, at least 25% of the Fortune 200, including Motorola, General Electric (GE), Ford, Boeing, Allied Signal, Toyota, Honeywell, Kodak and Bank of America have implemented the Six Sigma program. These companies claim that Six Sigma has significantly improved their profitability. For example, the concept enabled Motorola to save more than $17 billion since its commencement until 2006. In 1998, GE claimed benefits of $1.2 billion and costs of $450 million, for a net benefit of $750 million. The company’s 1999 annual report further claimed a net benefit of more than $2 billion through the elimination of all non–value added activities in all business processes within the company. Similarly, Allied Signal reported that Six Sigma was a major factor in the company’s $1.5 billion in estimated savings [2].

Dealing with high variation of production output each day, the study is carried out on the process reliability analysis of Gas District Cooling (GDC) plant by using chilled water data. GDC system is essentially a centralized energy plant generating thermal media, which is chilled water for air-conditioning requirements and/or electrical power of several buildings within a district. The chilled water produced from the plant is then distributed to the respective buildings via a network or distribution pipeline [3].

The ability of GDC plant to produce the chilled water in order to meet the demand of customer depends on its reliability. Calculating the reliability of GDC system plays an important role in economic and technical feasibility studies, operating expenses and optimal maintenance scheduling of the system. The concept of GDC reliability denotes the probability of satisfactorily operating a system under operational conditions encountered in a specific period of time [4].

The data is collected from the GDC plant at Universiti Tekologi Petronas (UTP), which is developed to support the chilled water requirement of the university, which act as a customer. The quantity of supply chilled water depends on the daily demand, which vary throughout the year, due to the seasonal nature of the activities at the university. The requirement increases considerably during peak academic activities [5]. The study is only focus on the daily production of chilled water that is supplied to UTP by the plant and the daily demand from the UTP.

1.2 PROBLEM STATEMENT

Unreliable production process may cause waste of money and is considered as corporate failure. Without measuring the process losses, the plant and customer do not have a careful measure of how much money they are missing each month due to the same continuous problem [6]. Currently, not many companies adopt this methodology to assess their process. Therefore, how do the company know for sure how much daily variability is acceptable?

For this study, the main aim of measuring the process reliability is to reduce the variability in the production output, that occur when the quantity of supply chilled water is not consistent with the demand. Frequently, the plant supply more than what the university needs and this will cause the losses to UTP to pay the bill for each month.

1.3 OBJECTIVES AND SCOPE OF STUDY

Since UTP chilled water depends solely from the GDC plant, it is important for UTP to know the operating performance of the plant in meeting the demand from the university. With this objective, a study on the process reliability of the GDC plant is undertaken by using production output data of chilled water. The analysis demonstrates the variation of daily production output of chilled water, as the difference between the supply and demand chilled water is been calculated and analyzed.

GDC plant is built to generate electricity and chilled water, which supplied to the customer, as well as for in-plant use [7]. However, as the title suggest, the study is focused on analysis of chilled water data, which is the main product of the plant. Weibull analysis technique is applied to perform the process reliability by using Weibull++, software of reliability and life data analysis. Analysis scope covers daily sets of data of chilled water from 1st January until 30th November 2011. The data of supply chilled water from the plant to UTP and the demand from the university are collected for process reliability analysis.

1.4 RELEVANCY OF PROJECT

The project is relevant, as the analysis later, will give information about the operation and performance of GDC plant in term of process reliability, in producing the chilled water that equivalent with the UTP's demand. The aim of both supplier and customer is to minimize the cost. To conduct the study, the following data are needed, which are:

1. Daily data set of supply chilled water from the GDC plant to UTP.
2. Daily data set of demand chilled water from UTP.

Secondly, to analyze the data, Weibull++ software is used to generate reliability plot by implementing Mixed Weibull Distribution parameter. Since UTP has registered Weibull++ software available for use, this would not be an issue anymore.

The next step in this is to analyze the results after run them on Weibull++ and finalize the findings. From this explanation, it is assured that this study is possible to be completed within two semesters of study as long as the right data is obtained with the right tools to begin with.

1.5 FEASIBILITY OF PROJECT

Feasibility can be defined as the state or degree of being easily or conveniently done. In this case, is how convenient can this study being conducted. The project commences with study and research work in four months of the first semester (FYP 1), following by the modelling and analysis work in the next four month of second semester (FYP 2). So, the author believes that this project can be conducted and finished within the scope and time frame as plan in the Gantt chart.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 PROCESS RELIABILITY ANALYSIS

Process reliability is a method for identifying problems, which has significant cost reduction opportunities for improvements [8]. It combines new techniques from the field of reliability and Six Sigma methodology to help identify areas for improvement and reduce variability in the production output [9].

As defined by Barringer and Roberts [9], process reliability represents the percentage of product produced with small variability in output (a desirable attribute).

The concept of Six Sigma is evolved while trying to solve a reliability problem. It is important to understand that a manufacturer cannot satisfy customers by providing defect free production output alone. One of the important design characteristics of any system is the reliability of that system, as it affects the utility of the production output later [1].

The primary goal for an organization in any business is customer satisfaction, but the customer requirements are likely to change every day. Six Sigma quality means designing the process with a defect of 3.4 defects per million opportunities, however, achieving that quality at the production stage alone cannot guarantee success Without any doubt, process reliability is one of the most important requirements of the customers. [1].

To achieve market effectiveness, it is important to ensure the manufacturing process is effective in term of reliability and ability to meet the customer requirements such as performance, maintainability, supportability and others which can be measured using Six Sigma. So, it is important to consider the concepts of reliability and Six

Sigma together instead of two isolated concept that fulfill the definition of process reliability analysis.

2.1.1 Reliability

There are many verses used to define reliability. Based on the Oxford Dictionaries Online [34], reliable can be defined as consistently good in quality or performance. In the book of 'Life Cycle Reliability Engineering' [10], reliability is defined as the probability that a product performs its intended function without failure under specified conditions for a specified period of time.

The reliability definition for a specific product or system should be operational. In other words, the reliability, intended function, specified condition and time must be quantitative and measurable. To achieve this, qualitative and uninformative terms should be avoided. If the product is a component to be installed in a system, the definition should be based on the system's requirements [10].

The basis of mathematical function for reliability is probability density function (pdf). pdf, denoted *f(x)*, indicates the failure distribution over the entire time range and represents the absolute failure speed. The larger the value of *f(x)*, the more failures that occur in a small interval of time around *x*. Although *f(x)* is rarely used to measure reliability, it is the basic tool for deriving other metrics and for conducting in-depth analytical studies. The formal mathematical equation of pdf is given by:

$$P(a \leq X \leq b) = \int_a^b f(x)dx \quad \text{and} \quad f(x) \geq 0 \; for \; all \; x \tag{2.1}$$

In other words, pdf defines the probability that *X* takes on a value in the interval *[a,b]* is the area under the density function from *a* to *b*. This is presented graphically in Figure 2.1.

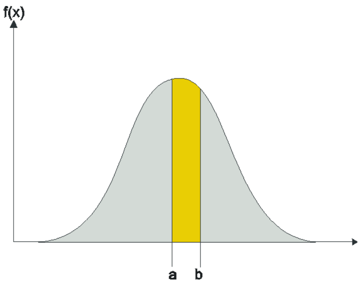

Figure 2.1: Graph of pdf in the interval *[a,b]*

However, this sort of information is required infrequently at best, as greater interest would be probability of a failure occurring before or after a certain time. If *a* is equal to zero, the above equation would return the probability of a failure occurring before time *b*. This introduces the concept of cumulative distribution function (cdf). cdf, denotes *F(x)* is the probability that a product will fall by a specified time *t*. The equation for cdf is given by:

$$F(x) = P(X \leq x) = \int_{0,-\infty}^{x} f(s)ds \tag{2.2}$$

Note that the lower limit is given as zero or negative infinity. The value of the lower limit varies from distribution to distribution. For example, the normal or Gaussian distribution has a lower limit of negative infinity, while the Weibull distribution has a lower limit of zero. Note that the value of cdf always approaches 1 as time approaches infinity. This is because the area under the curve of pdf is always equal to 1, and cdf is essentially measuring the area under pdf curve from zero to the point of interest. Figure 2.2 shows the graphical representation of the relationship between the pdf and the cdf.

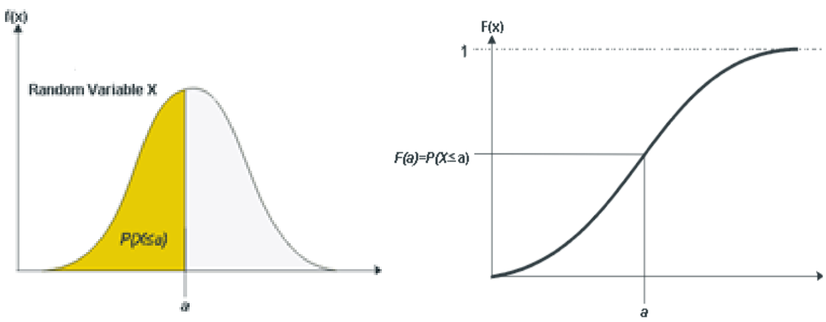

Figure 2.2: The relationship between pdf and cdf

cdf is also known as the unreliability function, and is represented by the function *Q(x)*. The reliability function, denoted *R(x)*, also called the survival function, is often interpreted as the population fraction surviving time. *R(x)* is the probability of success, which is the complement of *F(x)*.

$$F(x) = Q(x) = 1 - R(x) \tag{2.3}$$

The following Figure 2.3 illustrates the relationship between the reliability function and cdf.

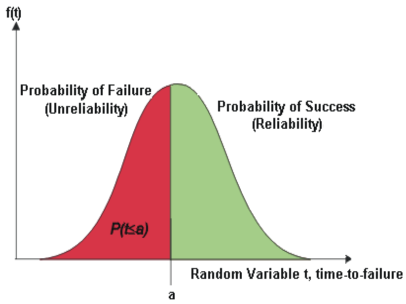

Figure 2.3: The relationship between reliability function and cdf

The reliability function can then be related to the cdf in the following manner:

$$Q(x) + R(x) = 1 \tag{2.4}$$

$$R(x) = 1 - Q(x) = 1 - \int_{0,\gamma}^{x} f(s)ds = \int_{x}^{\infty} f(s)ds \tag{2.5}$$

Another function that can be derived from pdf is the failure rate function. The failure rate function, or also known as the hazard rate function, denoted *h(x)* measures the rate of change in the probability that a surviving product will fail in the next small interval of time. Note that the failure rate is constant only for the exponential distribution, in most cases the failure rate changes with time. The failure rate function is defined by:

$$h(t) = \frac{f(t)}{1 - \int_{0,\gamma}^{t} f(s)ds} = \frac{f(t)}{R(t)} \tag{2.6}$$

Thus, the failure rate function is simply the pdf function divided by the reliability function, and has the units of failure per unit time among surviving parts, for example one failure per month. Note that the gamma, γ symbol that appears in the lower bound of some of the previous equations represents the location parameter that is found in some distributions. This is a parameter that effectively shifts the entire distribution by a value equal to the parameter value. This can be visualized as sliding the pdf curve along the x-axis of the plot [10, 11, 12].

2.1.2 Six Sigma

Developed by Bill Smith, a reliability engineer at Motorola, Six Sigma is a management philosophy that ‘emphasizes setting extremely high objectives, collecting data, and analyzing results to a fine degree as a way to reduce defects in products and services.’ [13]

Six Sigma is the top agenda for many companies which try to reduce cost and improve productivity. Many of the big manufacturing companies implement thousands of Six Sigma projects every year and this implementation demands a significant investment of capital that requires a careful analysis to make sure that the benefits obtained are much higher than the actual investment [14].

Six Sigma was introduced more than 20 years back as a method to reduce manufacturing defects. Smith proposed Six Sigma as a tool to improve the reliability and the quality of products and thus, focused it at reducing defects by improving manufacturing processes. Initially developed as an operational strategy, Six Sigma has evolved into a competitive corporate strategy used extensively throughout the corporate world. Reducing process variations is the core objective of Six Sigma project, since process variations result in higher quality loss [1].

Six Sigma quality level only has chances of having 3.4 defects per million opportunities. The main difference between other quality initiatives and Six Sigma is the disciplined quantitative approach used for the process improvement. Six Sigma uses five macros phases for improvement: Define, Measure, Analyze, Improve and Control, as standardized methodology [1].

2.2 WEIBULL ANALYSIS TECHNIQUE

2.2.1 Introduction

In carrying out this project, Weibull analysis technique is applied by the author to simulate the production data of chilled water to analyze the process reliability. Waloddi Weibull invented the Weibull distributions in 1937 and delivered his hallmark American paper on this subject in 1951. He claimed that his distribution applied to a wide range of problems [15].

In Weibull analysis, the practitioner attempts to make predictions about the life of all products in the population by fitting a statistical distribution to life data from a representative sample of units. The parameterized distribution for the data set can then be used to estimate important life characteristics of the product such as reliability or probability of failure at a specific time, the mean life and the failure rate [16]. Life data analysis requires the practitioner to [16]:

- Gather life data for the product.
- Select a lifetime distribution that will fit the data and model the life of the product.
- Estimate the parameters that will fit the distribution to the data.
- Generate plots and results that estimate the life characteristics of the product, such as the reliability or mean life.

Traditional Weibull analysis is a bottom-up approach, often in a data-starved environment, with only a few age-to-failure data points for components. Mentioned by Dr. Abernethy in his book 'The New Weibull Handbook', the component analysis tells about Weibull failure modes (beta values) and characteristic life (eta value). Today, Weibull analysis is a top-down approach in a data-rich environment. Every production facility jealously gathers daily output of prime product as proprietary information because daily output is a precursor for money. Weibull analysis tells about reliability of the moneymaking process including consistency of production output (beta values), also provides characteristic output values (eta value), which give single point estimate for demonstrated daily output from the process [17].

To give more understanding about top-down approach, consider the process as viewed from say 65, 000 feet elevation and see the process as a black box. Look at the production output using Weibull techniques for analyzing both output and reliability from the black box. This top-down view produces specific patterns on Weibull plots for understanding process reliability and other features important to manufacturing operations. Most production data will produce a straight line or series of straight-line segments on a Weibull plot [8].

2.2.2 Mathematical function of Weibull distribution [18, 19]

The equations below show the Weibull pdf for three-parameter, two-parameter and one-parameter Weibull distribution [18]:

Three-parameter Weibull pdf is defined by:

$$f(t) = \frac{\beta}{\eta}(\frac{t-\gamma}{\eta})^{\beta-1}e^{-(\frac{t-\gamma}{\eta})^{\beta}} \quad (2.7)$$

Where $f(t) \geq 0,\ t \geq 0\ or\ \gamma, \beta > 0, \eta > 0, -\infty < \gamma < \infty$

And
- β = Shape parameter / Weibull slope
- γ = Location parameter
- η = Scale parameter

Two-parameter Weibull pdf is obtained by setting γ = 0, and is defined by:

$$f(t) = \frac{\beta}{\eta}(\frac{t}{\eta})^{\beta-1}e^{-(\frac{t}{\eta})^{\beta}} \quad (2.8)$$

One-parameter Weibull pdf is obtained by setting γ = 0 and assuming β = C = constant = assumed value, and is defined by:

$$f(t) = \frac{C}{\eta}(\frac{t}{\eta})^{C-1}e^{-(\frac{t}{\eta})^{C}} \quad (2.9)$$

Where the only unknown parameter is the scale parameter, η. Note that in the formulation of one-parameter Weibull pdf, shape parameter, β, is assumed known *a* priori from past experience on identical or similar products. The advantage of doing this is that data sets with few or no failures can be analyzed.

For the characteristic effects of the shape parameter, β for the Weibull distribution, the β is also known as the slope. This is because the value of β is equal to the slope of the regressed line in a probability plot. Different values of β can have marked effects on the behaviour of the distribution. In fact, some values of β will cause the distribution equations to reduce to those of other distributions. For example, when β = 1, three-parameter Weibull pdf reduces to two-parameter exponential distribution or:

$$f(t) = \frac{1}{\eta} e^{-(\frac{t-\gamma}{\eta})} \tag{2.10}$$

Where $\frac{1}{\eta} = h(t)$ = failure rate, and the parameter β is a pure number, it is dimensionless. Figure 2.4 below shows the effect of different values of β on the shape of the pdf denoted as *f(t)*. One can see that the shape of the pdf can take on a variety of forms based on the value of β.

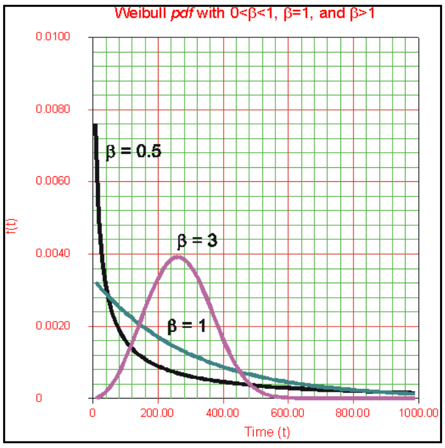

Figure 2.4: The effect of β on the pdf

For $0 < \beta \leq 1$:

- As $t \to 0\ (or\ \gamma), f(t) \to \infty$ and as $t \to \infty, f(t) \to 0$
- *f(t)* decreases monotonically and is convex as *t* increases beyond the value of γ

For $\beta > 1$:

- $f(t) = 0\ at\ t = 0\ (or\ \gamma)$
- For β < 2.6, the Weibull pdf is positively skewed (right tail), for 2.6 < β < 3.7, its coefficient of skewness approaches zero (no tail). Consequently, it may approximate the normal pdf, and for β > 3.7, it is negatively skewed (left tail).

Figure 2.5 below shows the effect of the value of β on cdf or unrealibility function denoted as *F(t)*, as manifested in the Weibull probability plot. It is easy to see why this parameter is sometimes referred as a slope. Note that the models represented by the three lines all have the same value of η.

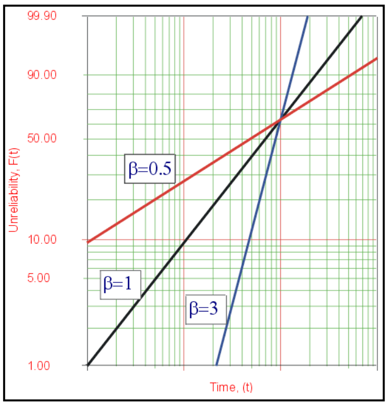

Figure 2.5: The effect of β on the cdf with a fixed value of η

Figure 2.8 below shows the effects of the varied values of β on the reliability function denoted as *R(t)*, which is a linear analog of the probability plot.

- $R(t)$ decreases sharply and monotonically for $0 < \beta < 1$ and is convex.
- For $\beta = 1$, $R(t)$ decreases monotonically but less sharply than for $0 < \beta < 1$ and is convex.
- For $\beta > 1$, $R(t)$ decreases as t increases. As wear-out sets in, the curve goes through an inflection point and decreases sharply.

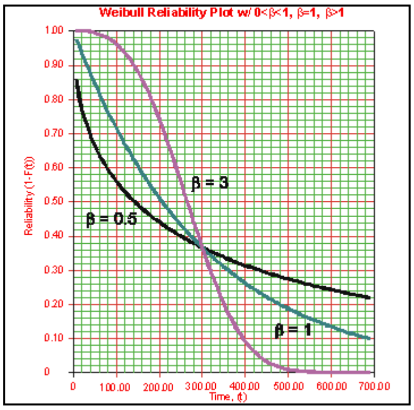

Figure 2.6: The effect of β on the *reliability function, R(t)*

For the characteristic effects of the scale parameter, η for the Weibull distribution, a change in the η has the same effect on the distribution as a change of the abscissa scale. Increasing the value of η while holding β constant has the effect of stretching out the pdf. Since the area under a pdf curve is a constant value of one, the "peak" of the pdf curve will also decrease with the increase of η, as indicated in the following Figure 2.7.

- If η is increased, while β and γ are kept the same, the distribution gets stretched out to the right and its height decreases, while maintaining its shape and location.
- η has the same unit as t, such as hours, miles, cycles, actuations, etc.

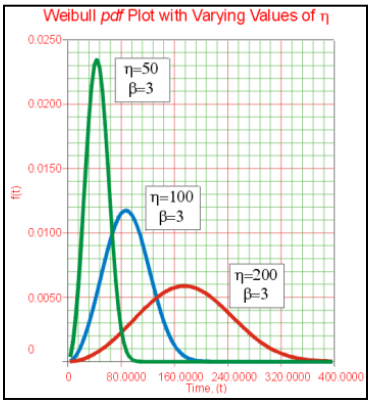

Figure 2.7: The effect of η on the pdf for a common β

For the characteristic effects of the location parameter, γ for the Weibull distribution, as the name implies, γ locates the distribution along the abscissa. Changing the value of γ has the effect of "sliding" the distribution and its associated function either to the right (if $\gamma > 0$) or to the left (if $\gamma < 0$). Figure 2.8 below shows the effects of the varied values of γ on the *pdf*.

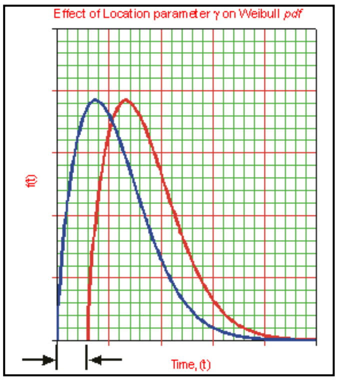

Figure 2.8: The effect of γ on the *pdf*

- When $\gamma = 0$, the distribution starts at $T = 0$ or at the origin.
- If $\gamma > 0$, the distribution starts at the location γ to the right of the origin.
- If $\gamma < 0$, the distribution starts at the location γ to the left of the origin.
- γ provides an estimate of the earliest time-to-failure of such units.
- The life period 0 to $+\gamma$ is a failure free operating period of such units.
- The parameter γ may assume all values and provides an estimate of the earliest time a failure may be observed. A negative γ may indicate that failures have occurred prior to the beginning of the test, namely during production, in storage, in transit, during checkout prior to the start of a mission, or prior to actual use.
- γ has the same units as t, such as hours, miles, cycles, actuations, etc.

2.2.3 Mixed Weibull Distribution

For the study, Mixed Weibull Distribution parameter in Weibull++ software is used. A mixed distribution comprises two or more distributions. Mixture arises when the population of interest contains two or more non-homogeneous subpopulations. A common example is that a good subpopulation is mixed with a substandard subpopulation due to manufacturing process variation and material flaws. When a homogeneous population of products is operated at different conditions, the life of products usually has multiple modes [10]. In term of daily production output data, there will be n subpopulations in the process of N_1, N_2, N_3... N_n daily data, due to variation of process and mode. The mixed Weibull methodology accomplishes this segregation based on the data given [20].

As written in [20], reliability function is defined by:

$$R_{1,2,....,n}(T) = \frac{N_{1,2,...,n_S}(T)}{N} \tag{2.11}$$

The total number surviving by age T in the mixed population is the sum of the number surviving in all subpopulations or:

$$N_{1,2,...,n_S}(T) = N\left[R_{1,2,....,n}(T)\right] = N_{1_S}(T) + N_{2_S}(T) + \cdots + N_{n_S}(T) \tag{2.12}$$

$$N_{1S}(T) = N_1 R_1(T),\ N_{2S}(T) = N_2 R_2(T),\ N_{n_S}(T) = N_n R_n(T) \tag{2.13}$$

Substituting Equation (2.15) into Equation (2.14) and (2.13) yields:

$$R_{1,2,....,n}(T) = \frac{N_1}{N} R_1(T) + \frac{N_2}{N} R_2(T) + \cdots + \frac{N_n}{N} R_n(T) \tag{2.14}$$

While, pdf is defined as:

$$f_{1,2,....,n}(T) = \frac{N_1}{N} f_1(T) + \frac{N_2}{N} f_2(T) + \cdots + \frac{N_n}{N} f_n(T) \tag{2.15}$$

Depending on the number of subpopulations chosen, Weibull++ uses the following equations for the reliability function and pdf:

$$R_{1,...,S}(T) = \sum_{i=1}^{S} \frac{N_i}{N} e^{-\left(\frac{T}{\eta_i}\right)^{\beta_i}} \tag{2.16}$$

$$f_{1,...,S}(T) = \sum_{i=1}^{S} \frac{N_i \beta_i}{N \eta_i} \left(\frac{T}{\eta_i}\right)^{\beta_i - 1} e^{-\left(\frac{T}{\eta_i}\right)^{\beta_i}} \tag{2.17}$$

Where S = 2, S = 3, and S = 4 for 2, 3 and 4 subpopulations respectively. Weibull++ uses a non-linear regression method or direct maximum likelihood methods to estimate the parameters.

2.3 SIMILAR CASE STUDY

Based on the conducted literature review, there are no published papers or projects performed yet on the process reliability analysis of GDC plant by using production chilled water with applying Mixed Weibull Distribution tool. However, there are a few projects had been done related to this project.

Two Mixed Weibull Distribution was used by Coroller, Leguerinel, Mettler, Savy and Mafart in their research [21]. Cells of *Listeria monocytogenes* or *Salmonella enterica* serovar Typhimurium taken from six characteristic stages of growth were subjected to an acidic stress (pH 3.3). As expected, the bacterial resistance increased from the end of the exponential phase to the late stationary phase. Moreover, the shapes of the survival curves gradually evolved as the physiological states of the cells changed. A new primary model, based on two mixed Weibull distributions of cell resistance, is proposed to describe the survival curves and the change in the pattern with the modifications of resistance of two assumed subpopulations. This model resulted from simplification of the first model proposed. These models were compared to the Whiting's model. The parameters of the proposed model were stable and showed consistent evolution according to the initial physiological state of the bacterial population. Compared to the Whiting's model, the proposed model allowed a better fit and more accurate estimation of the parameters. Finally, the parameters of the simplified model had biological significance, which facilitated their interpretation.

Khaled, Hordur and Mohamed [22] reported that a statistical approach, Weibull analysis is used to evaluate stochastically the schedule performance of construction or design projects. The approach can be used in conjunction with the earned value method to enhance the evaluation and control of schedule performance. Traditionally, the earned value method is used to control and monitor schedule performance using the schedule and cost performance indices which compare the budgeted cost of work performed to what was originally scheduled or what is actually expended. In the paper, the applicability of Weibull analysis for evaluating and comparing the reliability of the schedule performance of multiple projects is presented. The various steps in the analysis are discussed along: (1) Collection of percent-complete data of the project and calculation of the cost and performance schedule indices. (2) Fit the schedule performance indices data to the Weibull *cdf*. (3) Determine the probability of attaining certain index values, and if the probability of achieving a schedule performance indices value close-to or more than 1 is high, this indicates that there is strong chance of the project finishing within the budgeted hours. (4) The two projects are compared in terms of reliability using a performance graph. The authors conclude that Weibull analysis has several advantages and provides a relatively robust and effective method for construction managers to better control and monitor their projects.

In Availability and Reliability Modelling of Steam Absorption System of a Cogeneration Power Plant [23], the proposed steam absorption system availability and reliability model is based on the state space and the Markov method. The transition rates of the system are assumed to be constant and states of the system are defined using performance data clustering. State space diagram representing the operational behaviour is drawn and then problem formulation is done using Markov approach. The result indicates that availability of the system reaches at a steady state value of 95.4% after some operation days and the reliability of the system decreased rapidly through time.

In [7], Rangkuti, Amin and Gilani had done a study on the operation and performance of two units SAC of a GDC plant. However, the study did not involve any analysis by using software. Analysis of data was done to evaluate hourly, daily and monthly coefficient of performance (COP) of the chillers. Months of April and May 2005 was selected for the study because of the maximum academic activities by using the operating data obtained from GDC. Analysis of the operating data of the SAC on hourly, daily and monthly basis shown that the average COP of both chillers is around 1.2, and the load factor of 75 – 80 %. Both SAC used in the GDC plant was operating in a good condition with COP within the range were for Li-Br refrigerant, but still operating in the lower side of their installed capacity.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

The project flow for this particular study can be defined as below:

i. Problem statement

- Identify issues that lead to the need of doing the research and significant of the research towards the issues. For example, process reliability of production data.
- Set up the objectives and scope of study of the research.

ii. Literature review

- Understand the concept of process reliability, which is the combination of reliability and Six Sigma.
- Understand the method will be taken to analyze the process reliability, which is Weibull analysis technique, by using Mixed Weibull Distribution parameter.
- Review the existing related research done by the others.

iii. Software skills

- The software will be used to simulate the data is Weibull++.
- Getting familiarize with the software, to know how it will work and its applications.

iv. Collection of data

- Collect the daily production data of chilled water from the GDC plant.
- Compile the data in Microsoft Excel, to be transfer into the software later.

v. Result analysis

- Insert all data into Weibull++ software and run the software to produce the plots by using Mixed Weibull Distribution parameter.
- Analyze the plots produced and identify the trend of data distribution.

vi. Conclusion and recommendations

- Conclude the findings of the research and provide recommendations to improve the project in future studies.

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3.2 MODEL DEVELOPMENT FLOW

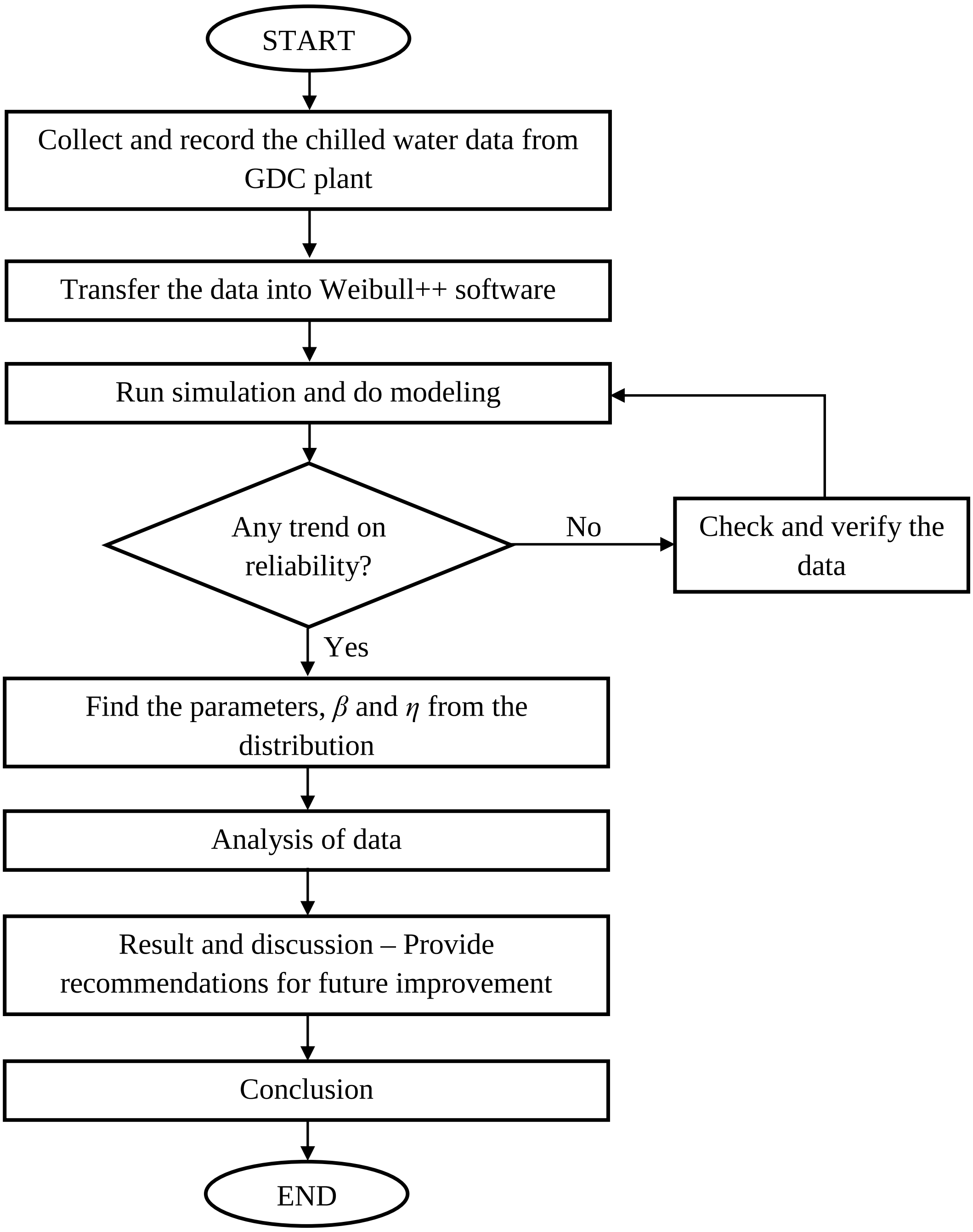

Figure 3.1: The model development flow

3.3 GANTT CHART & KEY MILESTONE

Table 3.1: Gantt chart and key milestone of the project

Task / Month	June	July	Aug	Sept	Oct	Nov	Dec	Jan
1. Background study and literature review								
2. Submission of extended proposal defence								
Due date: 1st July 2011		▲						
3. Proposal defence								
4. Learn and familiarize with Weibull++ software								
5. Submission of interim report								
Due data: 26th August 2011			▲					
6. Collection of chilled water data								
Due data: 14th November 2011						▲		
7. Submission of progress report								
Due data: 18th November 2011						▲		
8. Analysis of data								
9. Pre-EDX								
Due date: 5-9th December 2011							▲	
10. Submission of draft report								
Due date: 16th December 2011							▲	
11. Dissertation and technical paper preparation								
Due data: 23rd December 2011							▲	
12. Oral presentation								
Due date: 26-30th December 2011							▲	
13. Submission of project dissertation (Hard Bound)								
Due date: 13th January								▲

Process

▲ Milestone

3.4 DATA COLLECTION

As the title of the project, "Process Reliability Analysis of Gas District Cooling Using Production Chilled Water Data", the data needed is the daily production output data of chilled water from GDC plant. The data are taken from UTP GDC plant as the location of the plant is shown in Figure 3.2 below. While, Figure 3.3 below shows the views of the plant from the outside.

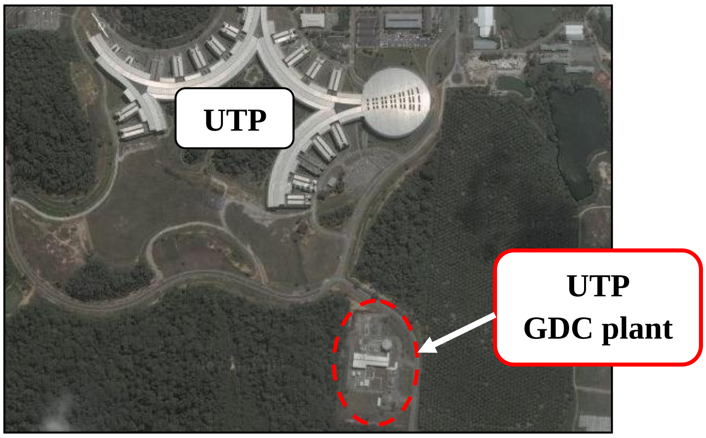

Figure 3.2: The location of UTP GDC plant [24]

Figure 3.3: The outside view of UTP GDC plant [25]

Process reliability is analysed from the production chilled water data collected from the GDC plant, which are daily set of data for quantity of chilled water supply to UTP and the demand from UTP. The date of data is from 1st January until 30th November 2011 or for 334 days.

For the case under study, the supply chilled water come is discharged from thermal energy storage (TES) system, which consists of two units of steam absorption chillers (SAC) and four units of electric chillers (EC) with unit capacity 1250 RT and 325 RT respectively, also a 10000 RTh thermal storage tank to supplement the SAC during the on-peak period. Chillers used to produce chilled water, however SAC are operated during the day only and EC are operated during the night to charge the storage tank. Sometimes, the chilled water from SAC and storage tank are not capable to fulfill the high requirement from UTP, so EC will be on and the chilled water will then directly supplied to the university [7].

Basically, the chilled water is supplied to the distribution pipe (customer building) which is UTP with outlet supply of certain temperature 5°C to 6°C. Then, the chilled water return at 13°C from distribution pipe is sent back to the plant by pump [26]. Figure 3.4 below shows the schematic diagram of GDC plant at UTP.

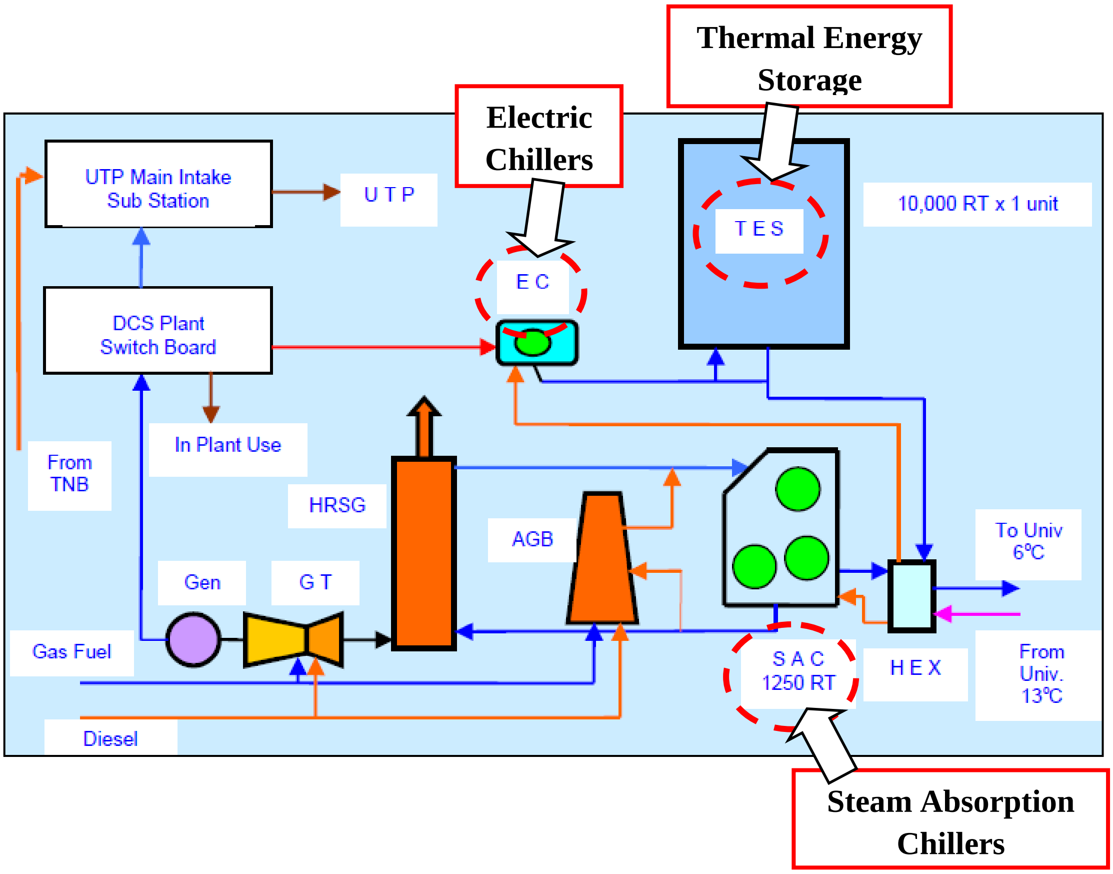

Figure 3.4: Schematic diagram of UTP GDC plant [27]

Figure 3.5 below shows the example of data sheet received from the plant, which is monthly logging data (sum) for chilled water in February 2011. The data contains full information on the quantity of chilled water for different used which are, total quantity produced by the chillers, quantity of supply to UTP, quantity for the internal plant use and quantity of demand from UTP [28]. However, for the study only data of supply and demand chilled water used, in the unit of RTh or tons of refrigeration hour.

UNIVERSITI TEKNOLOGI PETRONAS
COGENERATION/DISTRICT COOLING PLANT
MONTHLY OPERATION REPORT

GAS DISTRICT COOLING (UTP)

						MAX	MIN
DATE:	01-Feb-11	TEMP. HUMD.	27.8 *****	DEGC RH%		35.7 *****	23.1 *****

MONTHLY LOGGING DATA(SUM) FOR CHILLED WATER

	QI-SUPPLY	QI-PLANT	FQI-0440	QI-USE	QI-S011
DAY	SUM	SUM	SUM	SUM	SUM
1	26126.02	30915.47	0.20	412.22	28343.34
2	27837.60	26600.06	0.20	1587.13	29308.82
3	17921.43	27070.03	0.37	1991.00	16325.60
4	11716.00	15380.45	0.20	627.06	14214.95
5	14307.85	18000.16	0.19	94.94	16814.16
6	10217.04	15110.74	0.19	349.36	12060.86
7	30478.05	37224.62	0.63	806.28	32942.51
8	33431.04	36371.86	0.39	430.66	35604.95
9	38094.11	46557.24	0.84	2867.57	36602.68
10	35935.94	39401.68	0.42	1626.87	36106.22
11	36352.13	40291.82	0.40	1955.44	35866.11
12	14597.61	8878.67	0.20	499.87	18459.32
13	18102.46	24883.90	0.22	2177.04	16160.31
14	42162.33	51336.05	0.42	2288.29	40965.63
15	18964.10	19581.14	0.45	1932.77	17401.03
16	40442.16	47347.40	0.23	1966.86	39647.51
17	41461.68	44077.01	0.63	1075.27	42142.26
18	38098.47	43566.53	0.99	2120.58	36688.40
19	18005.38	11816.17	1.48	705.53	20665.88
20	18553.54	25265.80	0.20	2701.21	16076.99
21	38426.98	47384.72	0.20	2104.74	38120.36
22	35402.97	39028.84	0.69	1496.89	34261.13
23	40507.24	42930.81	0.41	1471.47	40131.21
24	38350.46	44368.42	0.41	2038.95	36604.28
25	38488.66	40545.79	0.64	1552.55	37687.92
26	21193.48	18104.68	0.46	793.94	20904.47
27	21315.93	22783.30	0.20	868.40	20522.26
28	40906.07	47613.59	0.65	2213.19	40142.78
29					
30					
31					
Average	28835.60	32587.03	0.45	1455.57	28956.14
Total	807396.73	912436.93	12.52	40756.08	810771.95
Maximum	42162.33	51336.05	1.48	2867.57	42142.26
Minimum	10217.04	8878.67	0.19	94.94	12060.86

Figure 3.5: Example of data sheet: The detail data for quantity of chilled water in February 2011

The data are compiled in Microsoft Excel and arranged according to the months, and then been total up. Next, all data are transferred into the Weibull++ software and simulated by using Mixed Weibull Distribution parameter for analysis.

3.5 TOOLS / EQUIPMENTS

These are the tools that will be used for the project:

i. Microsoft Excel - Data analysis
ii. Weibull++ software - Fitting the data to appropriate distribution
iii. Microsoft Word - Report writing

3.5.1 Weibull++ Software

To perform the analysis process, Weibull++ software from ReliaSoft.com is used to transfer the daily output production data into Weibull plots that will define reliability of process.

ReliaSoft's Weibull++ software tool is the industry standard in Weibull analysis for thousands of companies worldwide. Built by reliability engineers for reliability engineers, this package continues to raise the bar for statistical analysis software for reliability applications. [29]. Weibull plots help in explaining and categorizing the problems in a visual format that is understandable by engineers, process owners and management [30].

The advantage of Weibull++ is it provides the most comprehensive toolset available for reliability life data analysis, calculated results, plots and reporting, with support for all data types and all commonly used product lifetime distributions, including the Weibull model and the mixed Weibull model, as well as the Exponential, Lognormal, Normal, Generalized Gamma, Gamma, Logistic, Loglogistic, Gumbel and Weibull-Bayesian models. The software is also packed with tools for related reliability analyses, such as warranty data analysis, degradation data analysis, non-parametric data analysis and recurrent event data analysis [29].

For this study, the tool of Mixed Weibull distribution is used by the author. For the uninitiated, Weibull analysis is a method for modelling data sets containing values greater than zero [31]. In Weibull++, the zero input data will be removed from the data set automatically. Figure 3.6 below shows the interface of Weibull++ software.

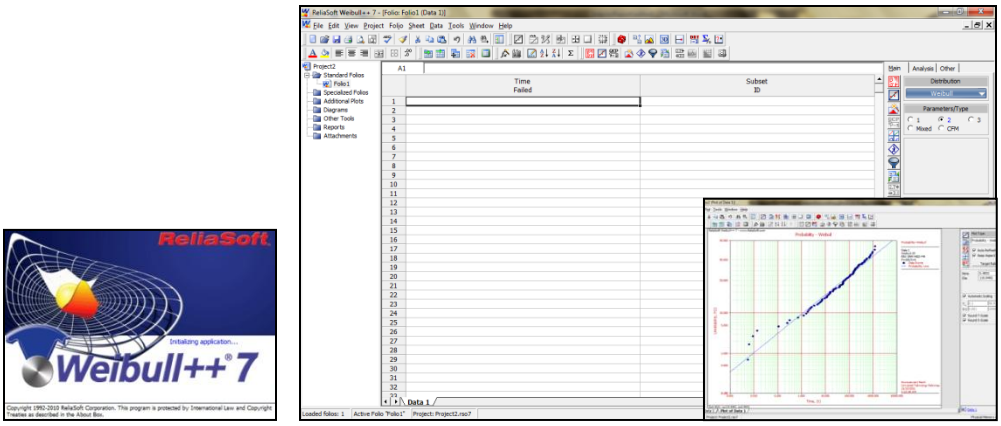

Figure 3.6: Interface of Weibull++ software

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DATA COLLECTION AND ANALYSIS

The daily data collected from the GDC plant from 1st January 2011 until 30th November 2011 are attached at the Appendices section, Table A-1 until A-6 and separated according to the month. Type of data consists of the supply chilled water from the plant to UTP and the demand from UTP itself.

As can be seen from the Table A-1 – A-6, there are high variation and substantially difference between the demands of chilled water from UTP for each single day, especially between the weekdays and weekend. As stated in District Energy [5], the chilled water demand varies throughout the year due to the seasonal nature of the activities at the university. The requirement increases considerably during peak academic activities and reduces during the semester break.

It is impossible for the plant to supply the chilled water in exact quantity as the demand from the university. In this study, it is noticed that two cases occur, which are:

1. The quantity of supply chilled water is higher than the demand.
2. The quantity of demand chilled water is higher than the supply.

However, for most of the time, quantity of supply chilled water is always higher than the demand, except for certain days, especially on January, February and April. For case 1, this condition will affect in term of cost of chilled water bill and the losses are bear by UTP. The highest difference when the quantity of supply chilled water is more than the demand occurred on 28th September 2011 or day 271, which is 11757.17 RTh. While for case 2, only 42 days out of 334 days the quantity supply chilled water do not meet the demand. The highest difference between these two data happened on 1st September 2011 or day 244, which is 67778.77 RTh.

The variations between the daily data of supply and demand chilled water are illustrated more clearly by using line chart in Figure 4.1 below. This time, the data are arranged according to the days, from day 1 until day 334. The blue line indicates the quantity of supply chilled water and the red line indicates the quantity of demand chilled water.

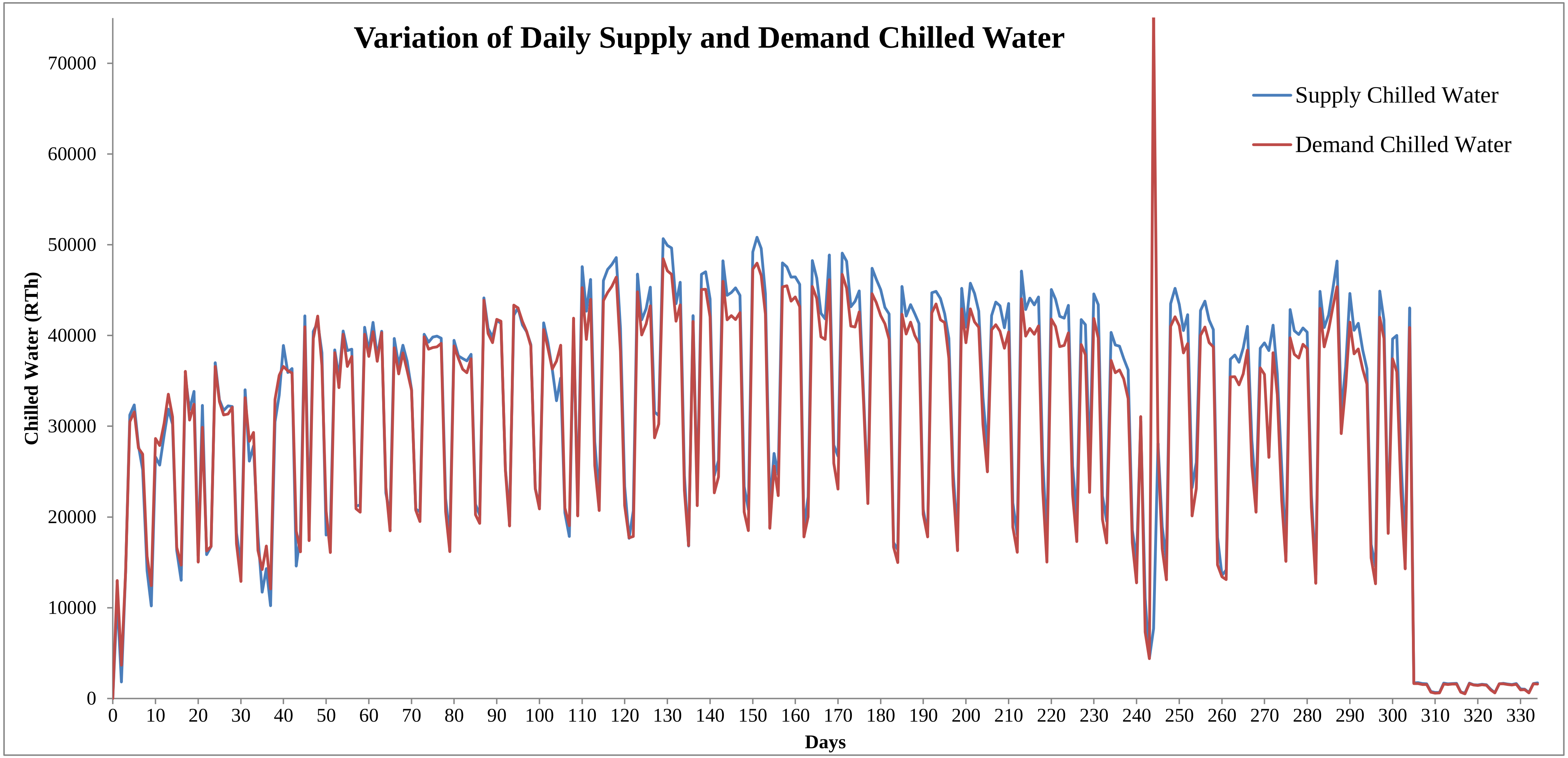

Figure 4.1: The variation of daily data of supply and demand from GDC and UTP for 334 days

4.2 CALCULATION OF LOSSES

UTP will be charged by the GDC plant for each unit of RTh of chilled water supplied to the university through the distribution pipe. So, even though the supply quantity exceeding the demand needed for the air-conditioning requirement for that day, UTP still need to pay the bill for the excess chilled water. This condition will cause the losses to the university itself, especially if the excess received in a very big amount and happen continuously.

To measure the amount of chilled water have been supplied to UTP from the GDC plant, a staff from the plant will go to check the chilled water meter, located at the UTP Control Room and record the readings every week. This Control Room is located at Undercroft, a facility at the basement of Chancellor Complex. The chilled water meter is controlled by a UTP chargeman and the readings on the meter will show the quantity of chilled water received by UTP from the GDC plant and also the daily demand of UTP.

The readings of daily demand will be key-in by the chargeman the day before, based on the requirements for the next day to notify the GDC plant about the quantity of chilled water that should be supplied to UTP. If any programs or events are conducted at UTP, the management staff such as from Student Support Services Department needs to inform the chargeman earlier with the venue, so that the quantity of supply chilled water is sufficient to fulfill the requirement of cooling load for that venue throughout the event.

For example, the event conducted at Chancellor Complex requires lots of chilled water to cool huge area of the building. Other than that, during study week, more chilled water are also needed for the use of air-conditioning at Information Resource Centre because it extends its operation from 8.00 am until 12.00 am, while during examination week, many big halls such as Main Hall, Multi Purpose Hall, Chancellor Hall and test room at Block N are used for examination purpose during the day from 9.00 am until 5.30 pm.

To calculate the bill of chilled water need to pay by UTP, the tariff is assumed based on the electricity tariff rate imposed by Tenaga Nasional Berhad (TNB), the main utility company and sole provider of power supply in Malaysia. District cooling plant is defined by TNB as a commercial consumer [32]. Table 4.1 below shows the pricing and tariff issued by TNB for their commercial customer. Tariff C1 - Medium Voltage General Commercial Tariff is used for the calculation, which is 31.2 sen/kWh or RM 0.312/kWh.

Table 4.1: The pricing and tariff issued by TNB for commercial customer [32]

TARIFF CATEGORY		UNIT	RATES
1.	Tariff B - Low Voltage Commercial Tariff		
	For Overall Monthly Consumption Between 0-200 kWh/month		
	For all kWh	sen/kWh	39.3
	The minimum monthly charge is RM7.20		
	For Overall Monthly Consumption More Than 200 kWh/month		
	For all kWh (From 1kWh onwards)	sen/kWh	43.0
	The minimum monthly charge is RM7.20		
2.	Tariff C1 - Medium Voltage General Commercial Tariff		
	For each kilowatt of maximum demand per month	RM/kW	25.9
	For all kWh	sen/kWh	31.2
	The minimum monthly charge is RM600.00		
3.	Tariff C2 - Medium Commercial Tariff Voltage Peak/Off-Peak		
	For each kilowatt of maximum demand per month during the peak period	RM/kW	38.60
	For all kWh during the peak period	sen/kWh	31.2
	For all kWh during the off-peak period	sen/kWh	19.2
	The minimum monthly charge is RM600.00		

First the total quantity of supply and demand chilled water is calculated from 1st January until 30th November 2011, for 334 days.

$$Total\ quantity\ of\ supply\ chilled\ water = 10324415.08\ RTh$$

$$Total\ quantity\ of\ demand\ chilled\ water = 9933484.53\ RTh$$

From the calculation above, it shows that the quantity of supply chilled water is exceeding the demand, which brings the losses to the university to pay for the excess chilled water.

$$
\begin{aligned}
&Excess\ chilled\ water \\
&\qquad = Total\ quantity\ of\ supply\ chilled\ water \\
&\qquad - Total\ quantity\ of\ demand\ chilled\ water \\
&\qquad = 10324415.08\ RTh - 9933484.53\ RTh = 390930.55\ RTh
\end{aligned}
$$

Now, the unit of RTh is converted into kWh.

$$0.2844\ RTh = 1\ kWh$$

$$390930.55\ RTh = \frac{1}{0.2844}(390930.55) = 1374579.993\ kWh$$

$$\text{Since, } 1\ kWh = RM\ 0.312$$

$$1374579.993\ kWh = \frac{RM\ 0.312}{kWh} x 1374579.993\ kWh = RM\ 428{,}868.96$$

The amount of RM 428,868.96 as calculated above reveals the huge losses need to bear by UTP from January to November 2011.

4.3 DATA SIMULATION

The daily data of supply and demand chilled water are simulated in the Weibull++ software by using Mixed Distribution parameter and 2-Subpopulations Mixed Weibull. The data plotted in Weibull plot are in ranked order, not in time order. The Weibull characteristic value, beta, β is the slope of the line, while eta, η represent a stretch goal for production [30].

4.3.1 Supply Chilled Water

The parameters of subpopulation 2 for supply chilled water are shown in Table 4.2 below.

Table 4.2: Parameters of subpopulation 2 for supply chilled water

Subpopulation	**Supply Chilled Water**	
	$\boldsymbol{\beta}$	$\boldsymbol{\eta}$
2	14.8244	43246

For this study, Weibull plot of supply chilled water is a demonstrated Weibull production line. Demonstrated line is a straight line trend in upper reached of the Weibull probability plot defining "normal" production when all is well, as quantities deviate from this segment, failures occur because the process losses its predictability [8].

Figure 4.2 below shows the probability plot of supply chilled water, 'Unreliability vs Quantity of Chilled Water'. The percentage of unreliability is increasing with the quantity of chilled water, or in the other word, the percentage of reliability is decreasing as the quantity of chilled water is increasing. Reliability plot is shown in Figure 4.3 below.

Probability plot allows the user to plot the data on a specially-constructed plotting paper, which differs from distribution to distribution. A distribution's plotting paper is constructed by linearizing the cdf or unreliability function of the distribution. Once this has occurred, the plotting can commence [33].

Weibull probability plots of daily process output data provide a single page view of process performance, as it disconnects process output from the time line to show unique patterns of performance [9]. Unreliability is the complement of reliability, since the mathematical equation for unreliability function is $F(t) = 1 - R(t)$, where *F(t)* is unreliability function and *R(t)* is reliability function.

Figure 4.4 below shows the probability density function plot of supply chilled water. The maximum peak of the plot is located at the value of pdf is 5.883 x 10^{-5} and the quantity of chilled water is 43063.886 RTh.

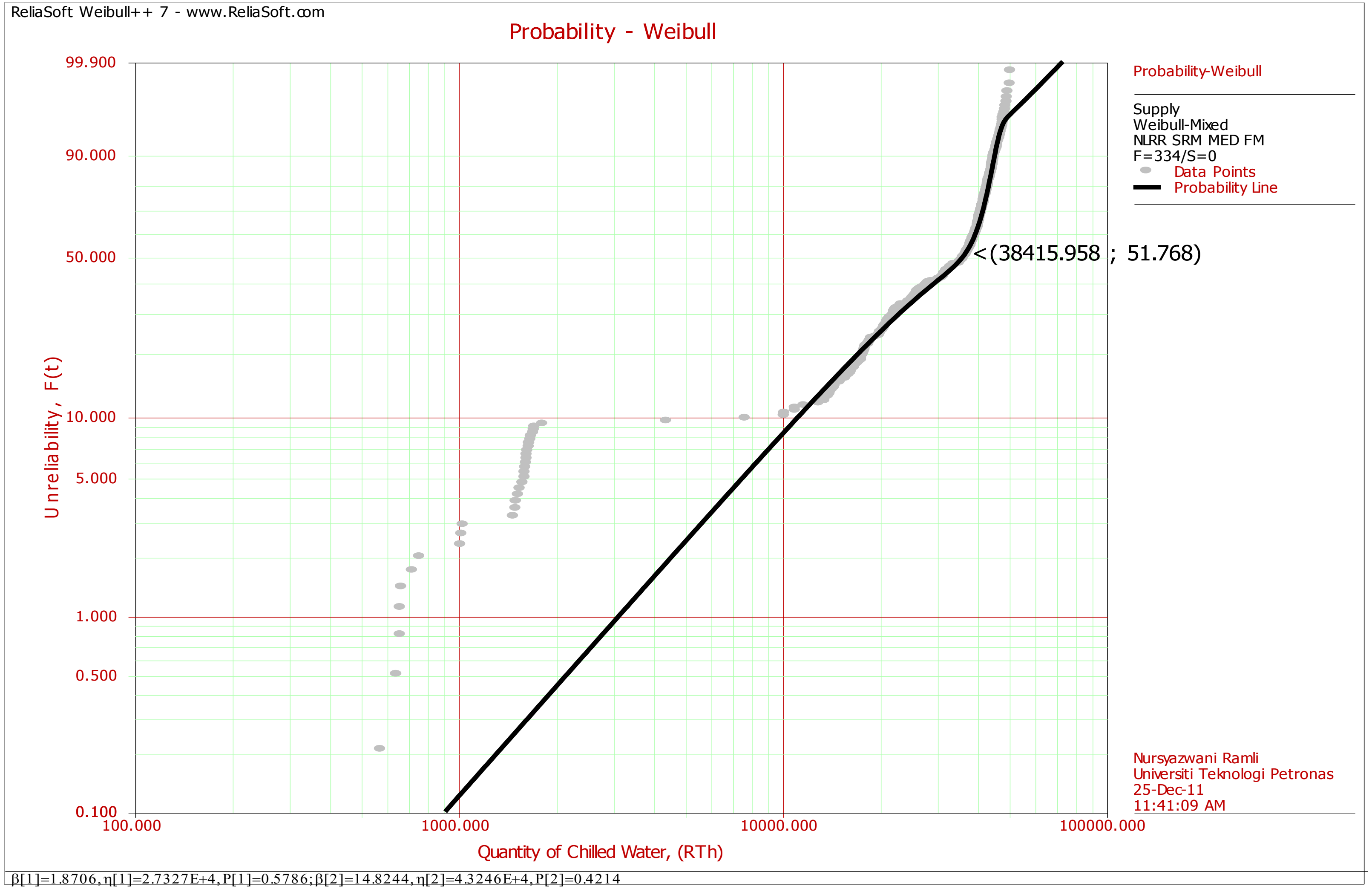

Figure 4.2: The probability plot of supply chilled water

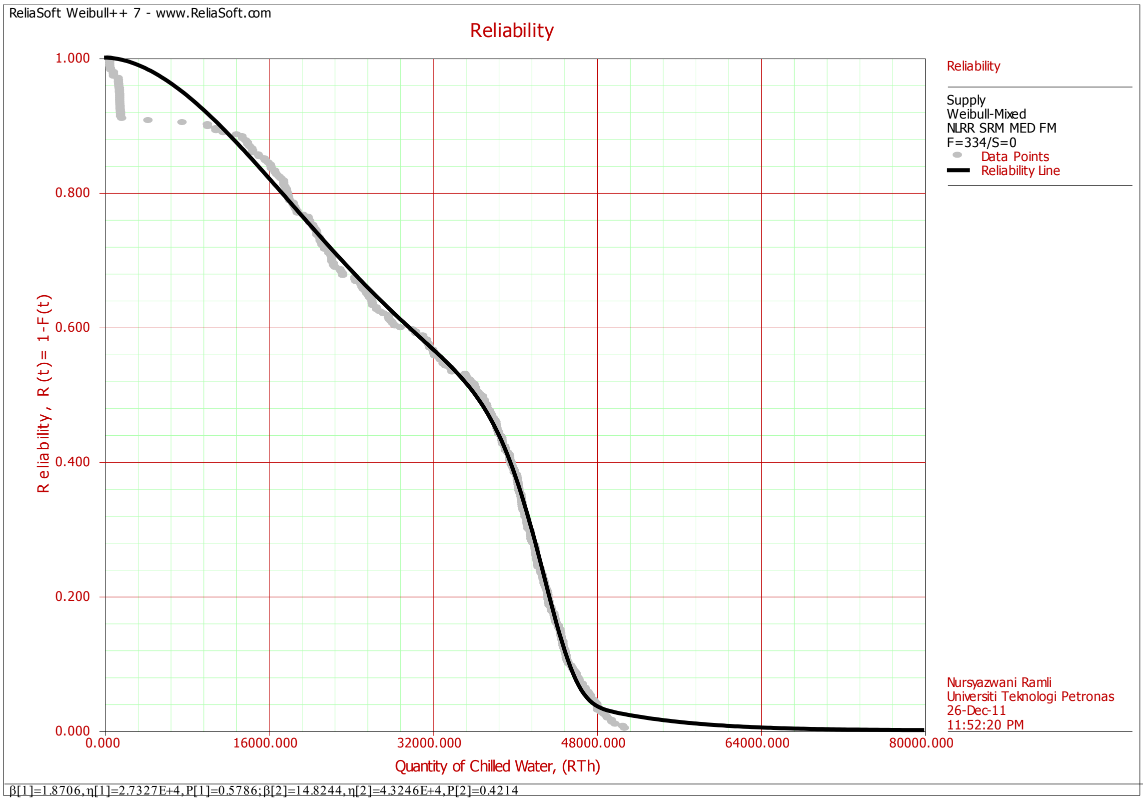

Figure 4.3: The reliability plot of supply chilled water

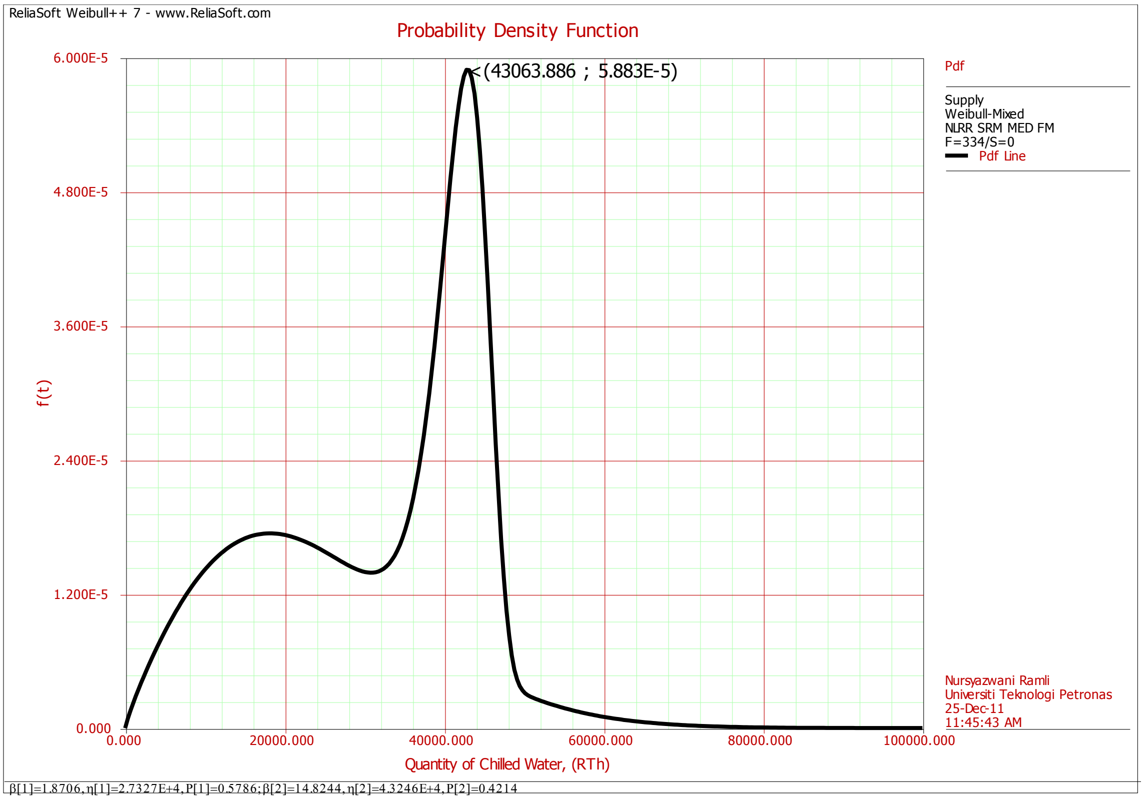

Figure 4.4: The probability density function plot of supply chilled water

4.3.2 Demand Chilled Water

The parameters of subpopulation 2 for demand chilled water are shown in Table 4.3 below.

Table 4.3: Parameters of subpopulation 2 for demand chilled water

Subpopulation	**Supply Chilled Water**	
	β	***η***
2	16.5713	41139

For this study, Weibull plot of demand chilled water is a nameplate rating line, one criterion for viewing how well the process performs. The nameplate rating is the maximum production capacity of the facility under theoretically ideal operation and control. The site contractor that designs and constructs the facility usually provides the nameplate rating. It is rarely measurable, as it is impossible to achieve ideal conditions. The slope and location of the nameplate line are fixed by the way the process is designed and operated, which both issue are controlled by management [30].

In this case, the daily demand acts as a guideline or benchmark issued by UTP, so that GDC plant knows the quantity of chilled water should be supplied to the university each day.

Figure 4.5 below shows the probability plot of demand chilled water, ‘Unreliability vs Quantity of Chilled Water’. The plot illustrates that the percentage of unreliability is increasing with the quantity of chilled water, or in term of reliability, the percentage of reliability is decreasing as the quantity of chilled water is increasing. Reliability plot is shown in Figure 4.6 below.

Figure 4.7 below shows the probability density function plot of demand chilled water. The maximum peak of the plot is located at the value of pdf is 6.879×10^{-5} and the quantity of chilled water is 41024.404 RTh.

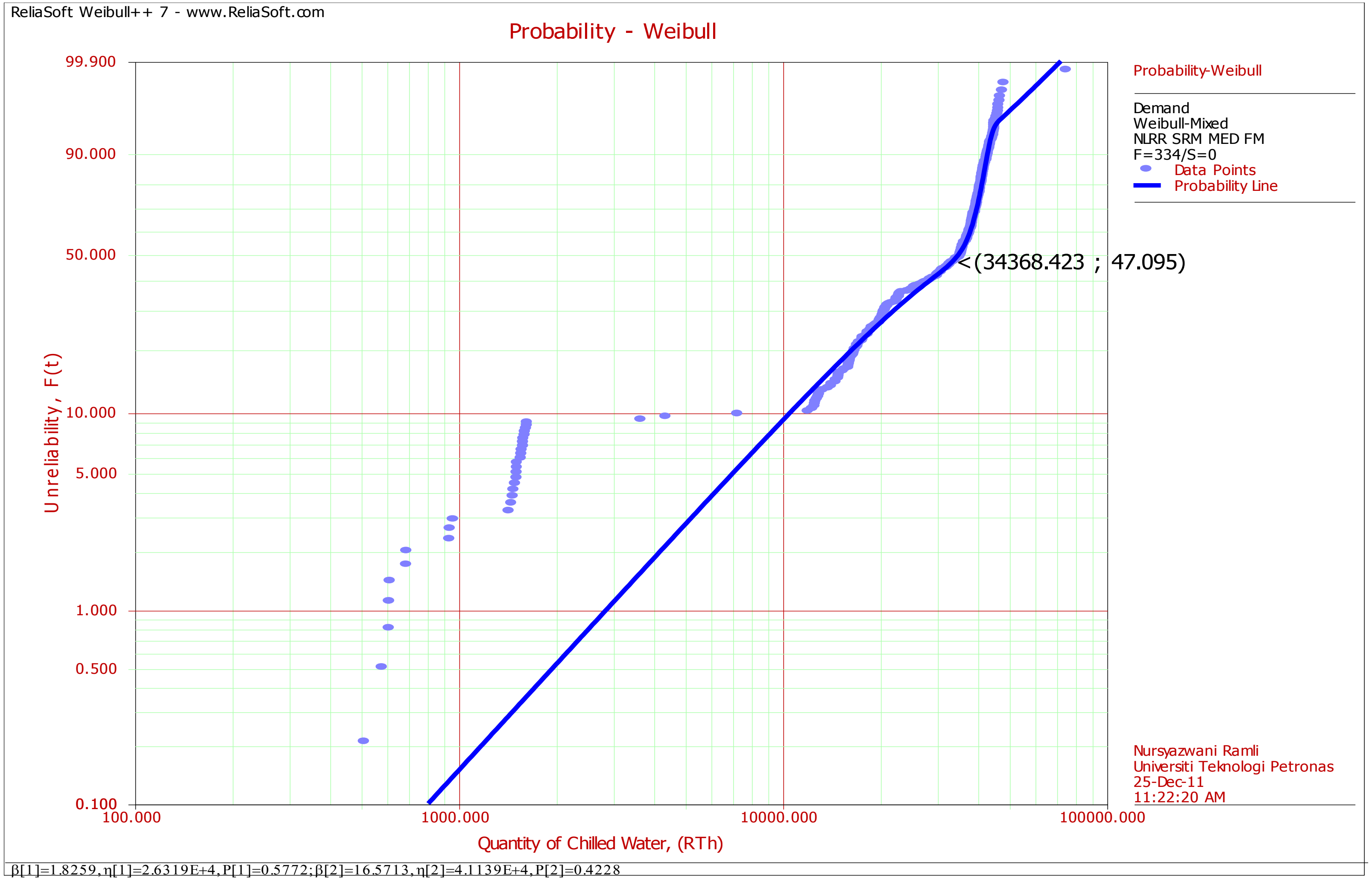

Figure 4.5: The probability plot of demand chilled water

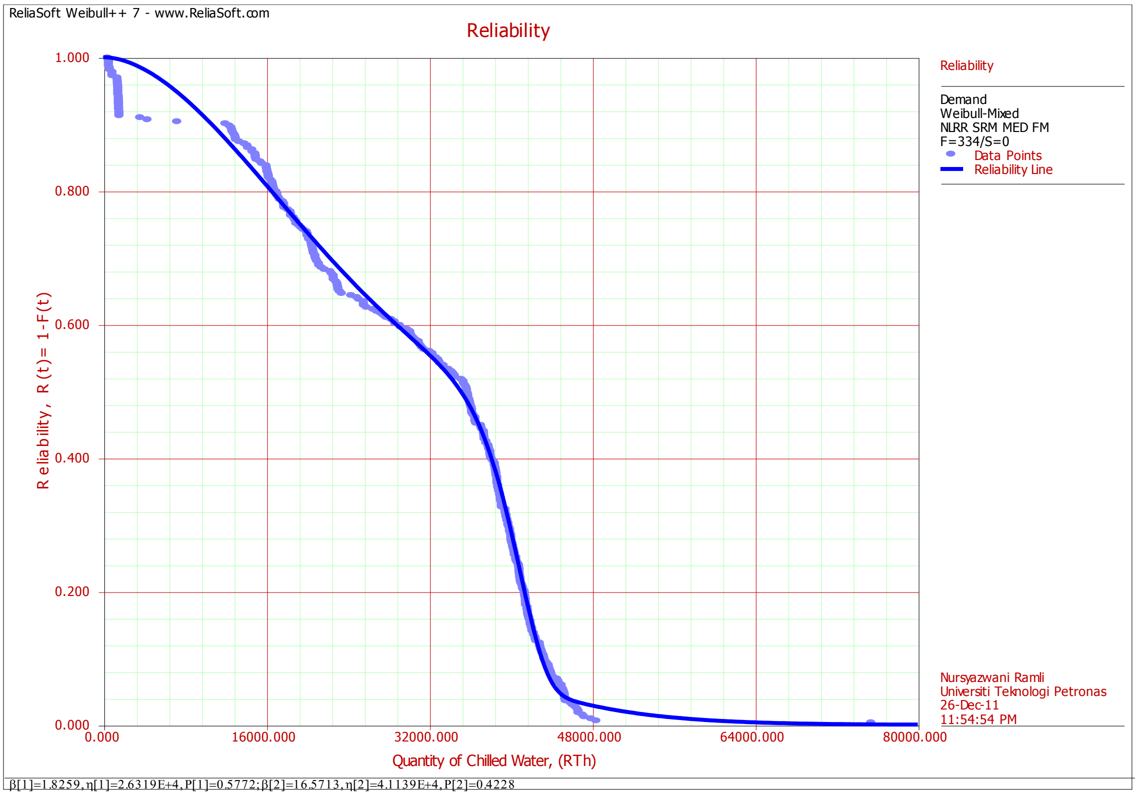

Figure 4.6: The reliability plot of demand chilled water

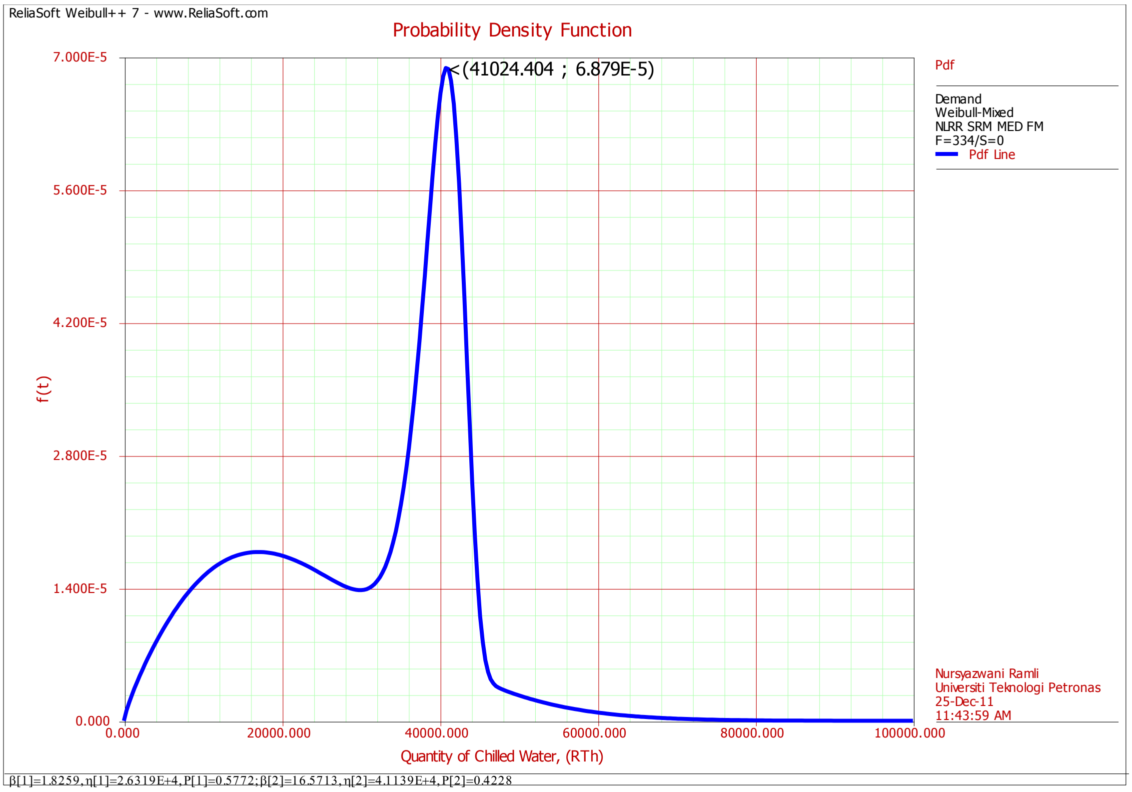

Figure 4.7: The probability density function plot of demand chilled water

4.3.3 Comparison of Supply and Demand Chilled Water

The supply and demand chilled water plots are both combined in one sheet. The Multiple Plot Sheet makes it easy to compare analyses by automatically plotting the results for multiple data sets of both data together in the same plot, rather than plotting them in different plot [35].

Figure 4.8 below shows the probability plot of supply and demand chilled water. Black line indicates the probability line of supply chilled water, while blue line indicates the probability line of demand chilled water. For both type of data, the unreliability is increasing as the quantity of chilled water is increasing. Since reliability is a compliment of unreliability, so reliability is decreasing as the quantity of chilled water is increasing.

Steep slopes on Weibull plots are desirable in the production process and display small variability in process output from small common cause variation which is built into the process. Flat slopes on Weibull plots display large variability from larger common cause variation which is built into the process or from special causes [9].

Based on the probability line in Figure 4.8, the demand chilled water line is much steeper when compared to supply chilled water line. As mentioned in Table 4.2 and Table 4.3, for the two subpopulation case, beta value of demand chilled water (β = 16.5713) is bigger than supply chilled water (β = 14.8244). It is corresponding with the statement that for production data, steeper line has larger value of beta [8]. Steep slope which is demand chilled water illustrates high grade process with small variability. While, for flat slope of supply chilled water represents low grade process with high variability.

When comparing in term of nameplate rating and demonstrated production line, demand chilled water which acts as nameplate rating has larger characteristic beta value and steeper slope than obtained by demonstrated production, which is demand chilled water.

As can be seen on the probability plot shown below, the supply chilled water line is mostly, always to the right of the demand chilled water line, which means that the quantity of supply is exceeding the demand needed by UTP.

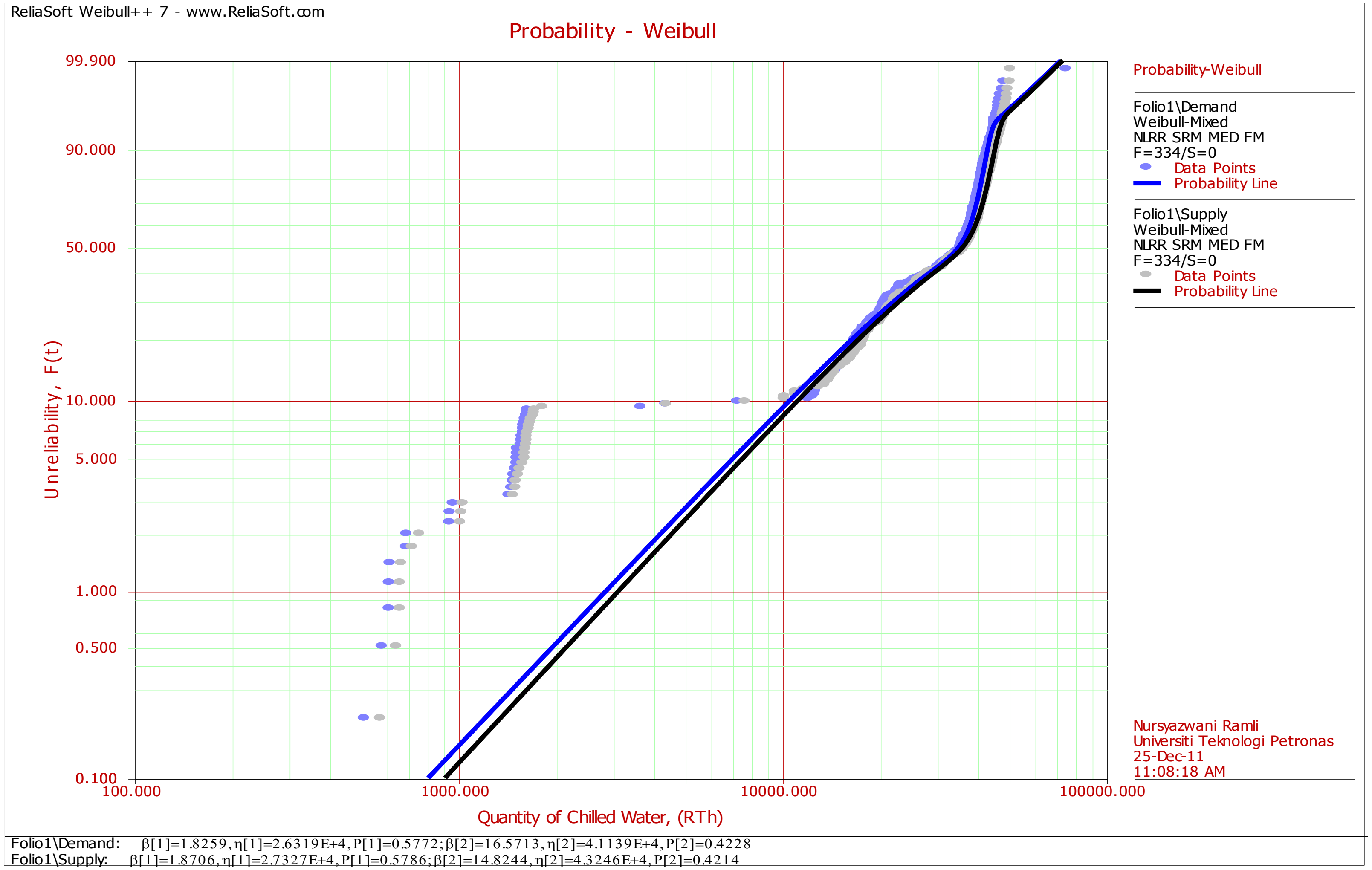

Figure 4.8: The probability plot of supply and demand chilled water

The horizontal gaps between the nameplate line and the demonstrated production line are summed to give the annual losses assigned to efficiency and utilization problems [6]. The losses occur because of the quantity of supply chilled water greater than the demand causes UTP need to pay extra money for the bill. The amount of losses is already calculated at the section 4.2.

Figure 4.9 below shows the reliability plot of supply and demand chilled water. For both type of data, the reliability is decreasing with the increasing quantity of chilled water.

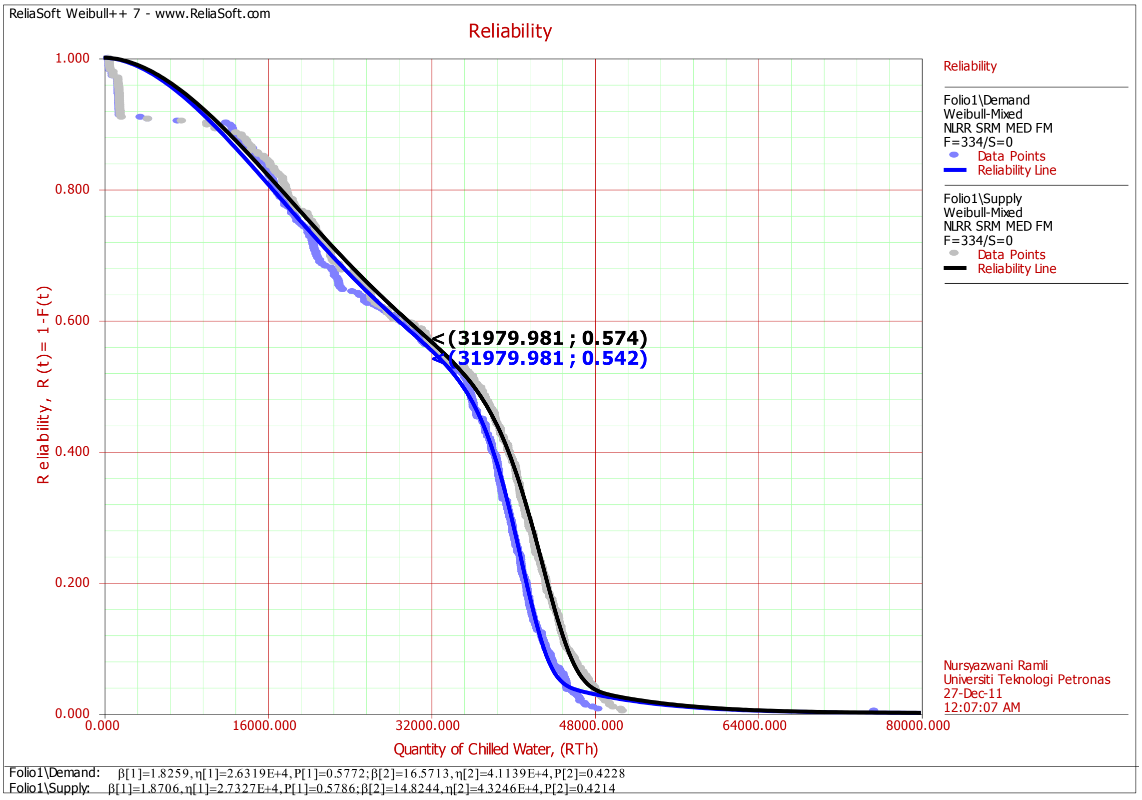

Figure 4.9: The reliability plot of supply and demand chilled water

The plot shows that in overall the reliability of supply chilled water is higher if compared to the reliability of demand chilled water. For example as labeled in Figure 4.9, at quantity of chilled water of 31979.981 RTh, the reliability is:

1. Supply chilled water (Labeled in black) – 0.574 or 57.4%
2. Demand chilled water (Labeled in blue) – 0.542 or 54.2%

Even though in other cases, production of products with reliability exceeding the expectation means that achieving a good quality of standard, but not in this case.

Figure 4.10 below shows the probability density function plot of supply and demand chilled water. Traditional distribution curves for Six Sigma process are usually bell-shaped and symmetrical. Weibull curves for production data are skewed. Weibull pdf curves, with the skew show limits to higher level of production but emphasizes greater chances for lower production, which is the case in most production facilities. [9]

Both pdf curves for supply and demand chilled water are non-symmetrical, with demand chilled water line has steeper slope, indicate higher grade process. The demand chilled water line also has maximum peak compared to supply line.

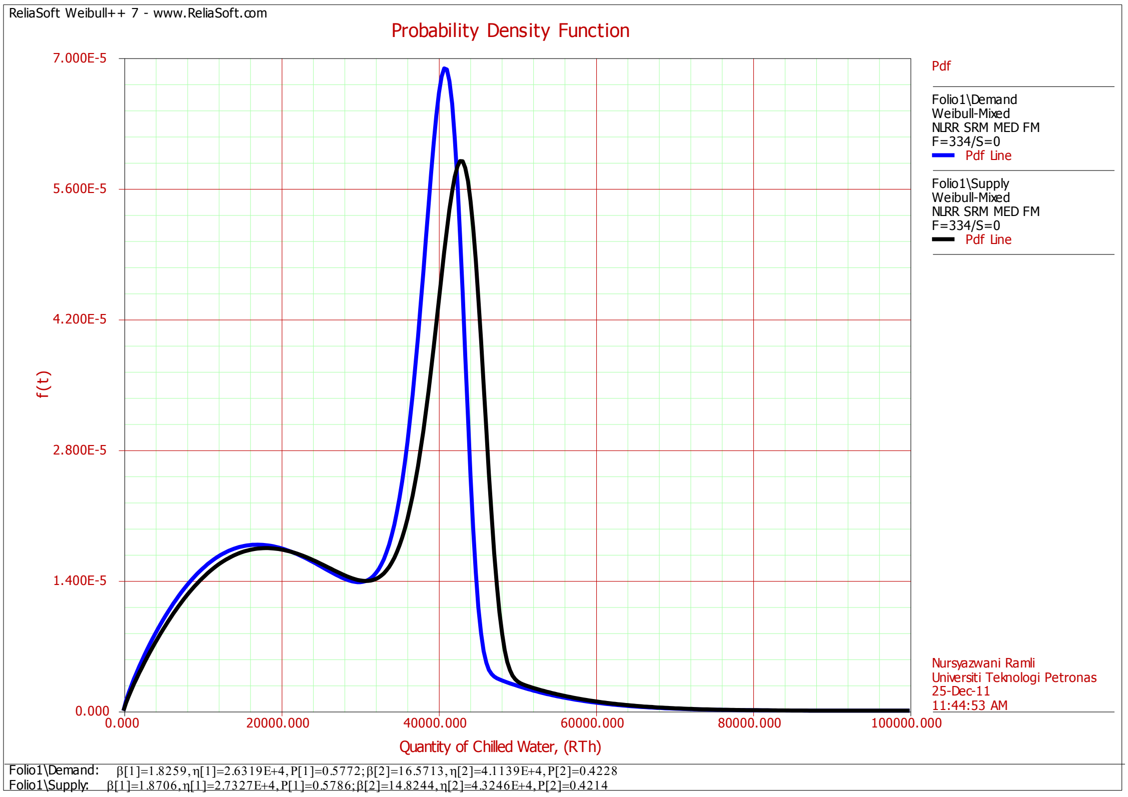

Figure 4.10: The probability density function plot of supply and demand chilled water

Weibull analysis technique does not solve the problem, but is the first step in performing a good root cause analysis by providing the cause and effects of the problem. Based on the study, we find out that the reliability of daily supply of chilled water is higher than the requirement because the supply quantity is always exceeding the demand. This condition leads to the losses, which need to pay by UTP due to the excess chilled water.

Process reliability analysis is the combination of reliability and Six Sigma. The main aim of many companies is to produce the most reliable process with high quality standard and minimum defect, as Six Sigma concept only allowed 3.4 defects per million opportunities. In connection with this study, defect can be defined as the variation that occur when the difference between the quantity of supply and demand chilled water occur, either when the supply is more or less than the demand. This defect must be eliminated, so that high grade of process can be achieved.

Table 4.4 below shows indoor design condition for air-conditioned space as defined by Malaysian Standard MS 1525:2007 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings (First Revision). The air-conditioned space should achieve normal comfort room temperature, which 23 – 26 °C [36].

Table 4.4: Indoor design condition for air-conditioned space [36]

Condition	**Condition Required Design Value**
Dry bulb temperature	23°C – 26°C
Minimum dry bulb temperature	22°C
Relative humidity	55% - 70%
Air movement	0.15 m/s – 0.50 m/s
Maximum air movement	0.7 m/s

When the quantity of chilled water supplied to UTP is less than the demand, the temperature of the buildings will increase, higher than the normal comfort room temperature. This condition will cause the occupants to feel a bit hot.

In the other way when the quantity of chilled water supplied to UTP is more than the demand, the temperature of the buildings will drop below the normal comfort room temperature, cause the occupants to feel very cool.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In the manufacturing process, no variation is desirable. Nevertheless, in the realistic and practical world this simplicity of production output does not exist and some variation will still occur even in the best process. Based on that statement, this project is been conducted.

A mentioned earlier in the objectives, the study aims at reviewing and measuring the process reliability analysis of GDC plant by using chilled water data through Weibull analysis technique. The study is important to know the performance of the plant in fulfilling the requirement of chilled water from UTP for each day.

In the results and discussion part, we can conclude that Weibull analysis technique do provide good process reliability analysis of GDC plant as effectively show the reliability of supply chilled water by comparing with the demand chilled water. The reliability of supply is higher than the demand, however it brings bad news for UTP as the university need to pay the excess chilled water, even out of the requirement. In addition, the losses need to bear by UTP from 1st January until 30th November 2011 also been calculated.

There are several recommendations that would be helpful in future studies, which are stated as below:

1. The process reliability analysis will be more reliable if the data is collected for longer period of time to see the variation between the supply and demand chilled water.
2. For this study, only Mixed Weibull Distribution parameter from Weibull analysis technique is used to analyze the data. So it is better if a further study is conducted to see if other technique may give better result of analysis.

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APPENDICES

Table A-1: The daily data of supply and demand chilled water from GDC and UTP for January and February 2011

DATE: **January 2011**

DAY	**RTh**	
	SUPPLY	**DEMAND**
1	11019.37	13005.02
2	1828.77	3676.97
3	13912.73	13921.17
4	31243.57	30500.59
5	32352.74	31574.05
6	27856.46	27603.38
7	25212.81	26931.17
8	14070.76	15661.33
9	10185.52	12442.71
10	26625.90	28656.18
11	25721.29	27867.12
12	29007.81	30320.13
13	31883.94	33546.02
14	30210.44	31043.35
15	16318.21	16646.87
16	13027.54	14681.87
17	35516.51	36051.55
18	31821.27	30691.43
19	33846.05	32416.32
20	15738.14	15028.87
21	32301.54	29894.74
22	15850.92	16258.50
23	16745.24	16742.43
24	37005.96	36595.98
25	32906.44	32706.36
26	31726.11	31234.34
27	32253.79	31341.67
28	32178.84	32088.20
29	18229.52	17070.31
30	14607.82	12885.41
31	34032.67	33139.85
Average	24362.54	24587.87
Total	755238.68	762223.89
Maximum	37005.96	36595.98
Minimum	1828.77	3676.97

DATE: **February 2011**

DAY	**RTh**	
	SUPPLY	**DEMAND**
1	26162.02	28343.34
2	27837.60	29308.82
3	17921.43	16325.60
4	11716.00	14214.95
5	14307.85	16814.16
6	10217.04	12060.86
7	30478.05	32942.51
8	33431.04	35604.95
9	38904.11	36602.68
10	35935.94	36106.22
11	36352.13	35866.11
12	14597.61	18459.32
13	18102.46	16160.31
14	42162.33	40965.63
15	18964.10	17401.03
16	40442.16	39647.51
17	41461.68	42142.26
18	38098.47	36688.40
19	18005.38	20665.88
20	18553.54	16076.99
21	38426.98	38120.36
22	35402.97	34261.13
23	40507.24	40131.21
24	38350.46	36604.28
25	38488.66	37687.92
26	21193.48	20904.47
27	21315.93	20522.26
28	40906.07	40142.78
Average	28865.81	28956.14
Total	808242.73	810771.94
Maximum	42162.33	42142.26
Minimum	10217.04	12060.86

Table A-2: The daily data of supply and demand chilled water from GDC and UTP for March and April 2011

DATE: **March 2011**

	RTh	
DAY	**SUPPLY**	**DEMAND**
1	38252.00	37699.86
2	41448.03	40424.12
3	37686.56	37152.25
4	40469.53	40320.86
5	22632.85	23284.75
6	20167.06	18484.57
7	39683.01	38656.58
8	36713.34	35781.21
9	38931.29	38078.17
10	37191.87	36147.36
11	34036.69	33969.58
12	20891.05	20757.55
13	20545.34	19496.69
14	40131.68	39846.62
15	39265.63	38501.77
16	39827.91	38683.99
17	39935.62	38760.94
18	39696.53	39132.88
19	22032.22	20608.15
20	17626.03	16181.32
21	39463.38	38852.98
22	37748.15	37476.69
23	37453.74	36276.16
24	37204.88	35887.32
25	37938.84	37446.34
26	21389.51	20239.62
27	20183.88	19288.31
28	44137.25	43890.32
29	40776.80	40224.41
30	39819.05	39220.15
31	41648.71	41781.56
Average	34352.53	33630.74
Total	1064928.43	1042553.08
Maximum	44137.25	43890.32
Minimum	17626.03	16181.32

DATE: **April 2011**

	RTh	
DAY	**SUPPLY**	**DEMAND**
1	41340.58	41578.56
2	25289.65	25170.02
3	20010.72	19002.03
4	42222.51	43348.92
5	43031.17	43050.06
6	41176.26	41554.76
7	40431.42	40471.32
8	38998.73	38848.80
9	23112.96	23154.30
10	21203.52	20883.19
11	41388.15	40663.17
12	39260.07	38641.26
13	36249.58	36302.93
14	32818.99	37187.79
15	35311.37	38942.29
16	20455.20	20982.57
17	17867.98	19025.75
18	40811.98	41917.81
19	21637.78	20122.49
20	47593.34	45284.52
21	42675.68	39585.32
22	46172.94	43987.23
23	28278.90	25669.09
24	22012.90	20700.90
25	46059.17	43827.56
26	47293.35	44747.90
27	47831.25	45414.42
28	48585.89	46440.50
29	40782.09	38233.00
30	23391.13	21266.45
Average	35443.18	34866.83
Total	1063295.26	1046004.91
Maximum	48585.89	46440.50
Minimum	17867.98	19002.03

Table A-3: The daily data of supply and demand chilled water from GDC and UTP for May and June 2011

DATE: **May 2011**

DAY	RTh	
	SUPPLY	**DEMAND**
1	17648.16	17707.25
2	20690.39	17845.84
3	46759.69	44817.04
4	41744.61	40058.42
5	42958.06	41273.45
6	45339.59	43283.43
7	31592.72	28728.62
8	31178.63	30232.84
9	50676.01	48475.84
10	49932.74	47131.42
11	49649.90	46735.00
12	43497.08	41585.22
13	45875.98	43385.20
14	24576.02	22917.03
15	16806.06	16861.20
16	42190.79	41553.36
17	22449.54	21239.71
18	46749.09	45071.90
19	47015.06	45097.44
20	44011.32	42029.07
21	24562.39	22662.46
22	26242.38	24402.51
23	48234.60	45964.51
24	44430.50	41722.47
25	44751.54	42204.58
26	45242.49	41768.89
27	44418.87	42521.95
28	23353.34	20562.22
29	20818.52	18492.72
30	49216.79	47299.14
31	50841.95	47966.60
Average	38175.96	36180.56
Total	1183454.81	1121597.33
Maximum	50841.95	48475.84
Minimum	16806.06	16861.20

DATE: **June 2011**

DAY	RTh	
	SUPPLY	**DEMAND**
1	49588.89	46623.93
2	44614.32	42378.34
3	21094.94	18758.67
4	27008.48	25620.06
5	24669.52	22356.93
6	47995.97	45352.26
7	47575.81	45480.94
8	46430.80	43793.38
9	46460.12	44241.32
10	45641.87	43178.52
11	18786.56	17816.89
12	22221.67	20022.48
13	48250.73	45400.71
14	46333.96	44068.42
15	42456.97	39859.91
16	41832.84	39572.13
17	48865.70	46158.6
18	27928.32	25925.36
19	26699.65	23075.01
20	49071.95	46742.29
21	48171.54	45205.39
22	43159.26	41035.44
23	43752.71	40936.46
24	44931.43	42593.58
25	33200.97	32376.16
26	22309.03	21488.43
27	47410.42	44607.83
28	46196.00	43643.24
29	45043.40	42188.43
30	43095.78	41303.54
Average	38412.89	36187.25
Total	1190799.61	1121804.65
Maximum	49588.89	46742.29
Minimum	18786.56	17816.89

Table A-4: The daily data of supply and demand chilled water from GDC and UTP for July and August 2011

DATE:	**July 2011**		DATE:	**August 2011**	
	RTh			**RTh**	
DAY	**SUPPLY**	**DEMAND**	**DAY**	**SUPPLY**	**DEMAND**
1	42361.72	39567.26	1	47105.05	44052.97
2	17186.95	16699.40	2	42871.50	39932.68
3	16395.70	14976.99	3	44124.22	40784.39
4	45411.79	42348.05	4	43376.95	40141.06
5	42141.26	40171.06	5	44246.84	41062.47
6	43402.72	41479.15	6	26318.68	23039.66
7	42398.11	40004.99	7	17373.94	15018.66
8	41314.77	39110.52	8	45078.46	41809.67
9	20841.50	20291.67	9	43987.36	40988.15
10	18144.61	17807.75	10	42106.34	38770.47
11	44724.41	42496.45	11	41910.66	38912.34
12	44872.44	43483.94	12	43333.60	40289.81
13	44063.44	41731.16	13	25629.04	22487.72
14	42391.60	41422.17	14	20047.15	17293.05
15	39675.55	37491.64	15	41760.00	39018.43
16	25096.68	23478.80	16	41186.65	37878.42
17	17612.29	16297.51	17	25880.50	22701.88
18	45197.71	42928.69	18	44572.28	41880.43
19	40937.13	39205.71	19	43399.39	39726.89
20	45771.21	42948.83	20	22319.91	19726.75
21	44644.84	41509.35	21	19533.74	17146.94
22	42674.01	40907.82	22	40341.23	37257.69
23	33170.73	30196.73	23	38960.33	35909.44
24	27332.11	24987.02	24	38821.52	36218.65
25	42188.41	40614.83	25	37461.48	35234.47
26	43692.30	41203.00	26	36198.90	33036.27
27	43264.45	40465.53	27	18577.29	17155.29
28	40868.75	38608.84	28	15134.09	12747.60
29	43525.14	40386.13	29	30542.23	31072.16
30	21569.27	18874.86	30	11014.15	7315.17
31	18047.01	16114.19	31	4407.17	4390.45
Average	36158.66	34122.90	Average	33471.63	30741.94
Total	1120918.61	1057810.04	Total	1037620.65	953000.03
Maximum	45771.21	43483.94	Maximum	47105.05	44052.97
Minimum	16395.70	14976.99	Minimum	4407.17	4390.45

Table A-5: The daily data of supply and demand chilled water from GDC and UTP for September and October 2011

DATE: **September 2011**

DAY	RTh SUPPLY	RTh DEMAND
1	7711.46	75490.23
2	28122.40	27338.88
3	18934.13	16481.40
4	15247.61	13073.24
5	43504.45	41016.20
6	45197.23	42064.23
7	43422.97	41094.58
8	40555.67	38089.16
9	42286.01	39120.23
10	23216.62	20126.01
11	26003.31	23135.98
12	42751.56	40005.96
13	43797.90	40933.83
14	41701.35	39206.80
15	40654.21	38761.91
16	17751.20	14715.19
17	13559.11	13412.99
18	14144.80	13102.29
19	37375.75	35434.65
20	37856.90	35471.20
21	37054.64	34573.35
22	38625.10	35760.75
23	41013.54	38381.10
24	28468.75	25669.50
25	22290.50	20517.79
26	38591.02	36437.99
27	39183.60	35717.20
28	38336.08	26578.91
29	41131.93	38104.17
30	35770.95	33469.60
Average	31750.35	31396.30
Total	984260.75	973285.32
Maximum	45197.23	75490.23

DATE: **October 2011**

DAY	RTh SUPPLY	RTh DEMAND
1	25396.56	21797.61
2	16112.16	15095.78
3	42858.14	39756.10
4	40531.44	37924.36
5	40120.51	37515.29
6	40842.60	39034.26
7	40381.60	38560.79
8	22486.21	21078.13
9	13625.10	12701.76
10	44876.13	42987.50
11	40888.24	38747.26
12	42278.83	40617.49
13	45131.31	43111.34
14	48213.26	45387.54
15	31561.58	29183.32
16	36575.50	34415.47
17	44643.65	41463.76
18	40587.23	37974.80
19	41347.19	38512.94
20	38390.16	36282.53
21	36343.66	34627.77
22	16969.88	15479.70
23	14534.53	12645.79
24	44884.05	42013.92
25	41717.69	39663.60
26	18704.67	18189.94
27	39612.20	37437.58
28	40020.49	36004.60
29	26273.68	22699.19
30	16435.45	14282.32
31	43036.85	40877.66
Average	34689.70	32453.87
Total	1075380.55	1006070.10
Maximum	48213.26	45387.54

Table A-6: The daily data of supply and demand chilled water from GDC and UTP for November 2011

DATE: **Nov-11**

DAY	**RTh**	
	SUPPLY	**DEMAND**
1	1716.00	1640.64
2	1730.00	1640.07
3	1646.00	1527.44
4	1612.00	1525.34
5	763.00	695.12
6	665.00	585.12
7	671.00	619.26
8	1682.00	1581.07
9	1614.00	1528.52
10	1637.00	1576.67
11	1663.00	1596.34
12	724.00	697.03
13	578.00	515.53
14	1690.00	1628.68
15	1511.00	1488.54
16	1486.00	1441.23
17	1558.00	1507.57
18	1516.00	1469.17
19	1022.00	947.68
20	648.00	616.09
21	1622.00	1600.31
22	1666.00	1616.54
23	1589.00	1523.42
24	1541.00	1482.58
25	1630.00	1571.06
26	1040.00	945.27
27	1029.00	970.15
28	665.00	614.91
29	1638.00	1614.59
30	1723.00	1597.30
Average	1299.19	1237.52
Total	40275.00	38363.24
Maximum	1730.00	1640.64
Minimum	578.00	515.53