CHAPTER 1
INTRODUCTION

1.1 Background study

Hoyland and Rausad (1994) stated that reliability is the ability of an item to perform a required function, under given environmental and operational conditions and for a stated period of time. The term "item" is used here to denote any component, subsystem or system that can be considered as an entity. A "required function" may be a single function or a combination of functions that is necessary to provide a specified service. All technical items (components, subsystems, systems) are designed to perform one or more (required) functions. Some of these functions are active and some functions are passive. Containment of fluid in a pipeline is an example of a passive function. Complex system (e.g., an automobile) usually has a wide range of required functions. To assess the reliability (e.g., of an automobile), we must first specify the required function(s) that we are considering. For a hardware item to be reliable, it must do more than meet an initial factory performance or quality specification. Therefore, it must operate satisfactorily for a specified period of time in the actual application for which it is intended.

The study is very important to estimate the useful life of every equipment that operates in the system. Hence, the study for perforamnce measure to forecast the probability of failure would be very beneficial for the company in order to sustain the production or services without any sudden failure which would affect the company in the future. With the perforamnce measure of SAC system, it actually can improve the performance of the system and also give output performance analysis for critical equipment for that particular system.

1.2 Problem statement

Without reliability and availability assessment, the maintenance for the overall system can be costly because the people did not know when the right time to do the maintenance for the equipment is and this could lead to poor performance of the equipment. Therefore, the desired output from the system would be not being very efficient. Besides that, it is difficult to predict the failure of equipment since there is no reliability and availability analysis. This could lead to the sudden failure of the equipment and affect the overall performance of plant so it is crucial for the author to do the performance measure for the equipment in plant.

1.3 Objective

To evaluate performance measure for Steam Absorption Chiller (SAC) of a District Cooling Plant.

1.4 Scope of study

The scope of study will be narrowed down to the UTP GDC plant system which covers the performance data for SAC in 2009 and 2010 historical data. The study adopted Pareto analysis , Markov Model and the probability of each state determine by using the Differential Equation method that applicable on ODE45 in Matlab software. The reliability and availability graphs were shown by using Microsoft Excel. The comparison between the results obtained by methematical model from Matlab software with the results form the Block Sim software are also undertaken.

1.5 The relevance of the project

The requirement to study the plant system in order to increase the reliability of the system and enhance the performance for every subsystem involved with cooling system. Therefore; this project is very relevance since it is related to the reliability and maintenance. It also gives an additional knowledge for the future career especially for mechanical engineer, reliability of energy plant system.

1.6 The feasibility of the project

The project is feasible to be completed within the time frame as the final year project.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

According to Juan et al (2009), the reliability of a structural system may be estimated at two levels: component level and system level. At the component level, limit state formulations and efficient analytical and simulation procedures have been developed for reliability estimation. In particular, if a new structure will have some components that have been used in other structural designs, chances are that there are available data; on the other hand, if a new structure uses components about which no historical data exists, then survival analysis methods, such as accelerated life testing, can be used to obtain information about component reliability behavior.

Juan and Monteforte (2011) also mentioned that system level analysis also addresses two types of issues: the multiple performance criteria or multiple structural states, and the multiple paths or sequences of individual component failures leading to overall structural failure. Notice that, in any case, it could be necessary to consider possible interactions among structural components, i.e. to study possible dependences among components failure-times.

2.1.2 Bathtub Curve

The failure rate of components and systems follow the classical "bathtub" curve. This curve is shown in Figure 1.1 and has three distinctive phases:

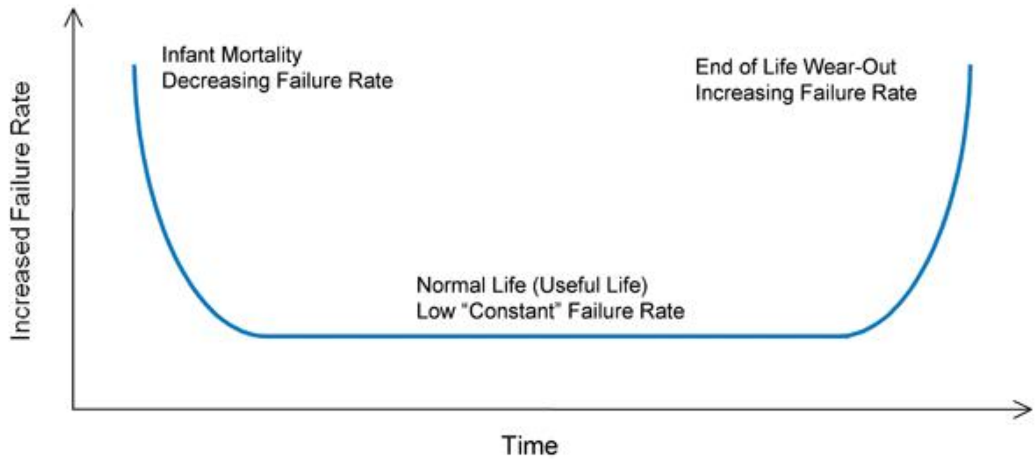

Figure 1.1: The Bathtub Curve (Criterion, 2004)

1. An "infant mortality" early life phase characterized by a decreasing failure. Failure occurrence during this period is not random in time but rather the result of substandard components with gross defects and the lack of adequate controls in the manufacturing process. Parts fail at a high but decreasing rate.
2. A "useful life" period where electronics have a relatively constant failure rate caused by randomly occurring defects and stresses. This corresponds to a normal wear and tear period where failures are caused by unexpected and sudden over stress conditions. Most reliability analyses pertaining to electronic systems are concerned with lowering the failure frequency during this period.
3. A "wear out" period where the failure rate increases due to critical parts wearing out .As they wear out, it takes less stress to cause failure and the overall system failure rate increases, accordingly failures do not occur randomly in time.

2.2 Brief Description of Gas District Cooling (GDC)

Majid and Sulaiman (2011) say that the GDC system is a district cooling system which uses natural gas (NG) as the primary source of energy in the production of the chilled water. GDC system can be achieved by numerous methods which are simplified to the following three:

a. The first method is to burn the natural gas in a direct – fired absorption chiller, which in turn produces the chilled water.

b. The second method is by using the natural gas as fuel to a boiler to produced steam. The steam is then used as the source of energy in an indirect-fired absorption chiller or also known as steam absorption chiller (SAC) for the chilled water production. Other type of chiller that uses steam as the source of energy is the steam turbine centrifugal chiller. In most cases, the steam produced by the boiler is primarily used in the steam turbine plant for power generation, while some of the steam is used for heating process as shown in figure: . this type of system is called a cogeneration system or combined heat and power (CHP) system. However, when the steam is also used in the SAC for chilled water production, then the integrated energy system is referred to as a trigeneration plant, for example generation of electricity (power), steam (heat) and chilled water (cold). This type of plant is shown in figure 2.1 and figure 2.2:

:

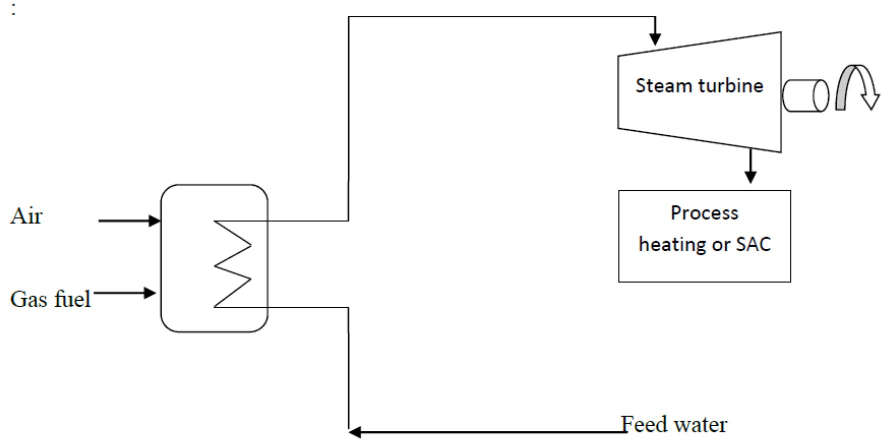

Figure 2.1: Combined heat and power (CHP) plant (Majid and Sulaiman, 2011)

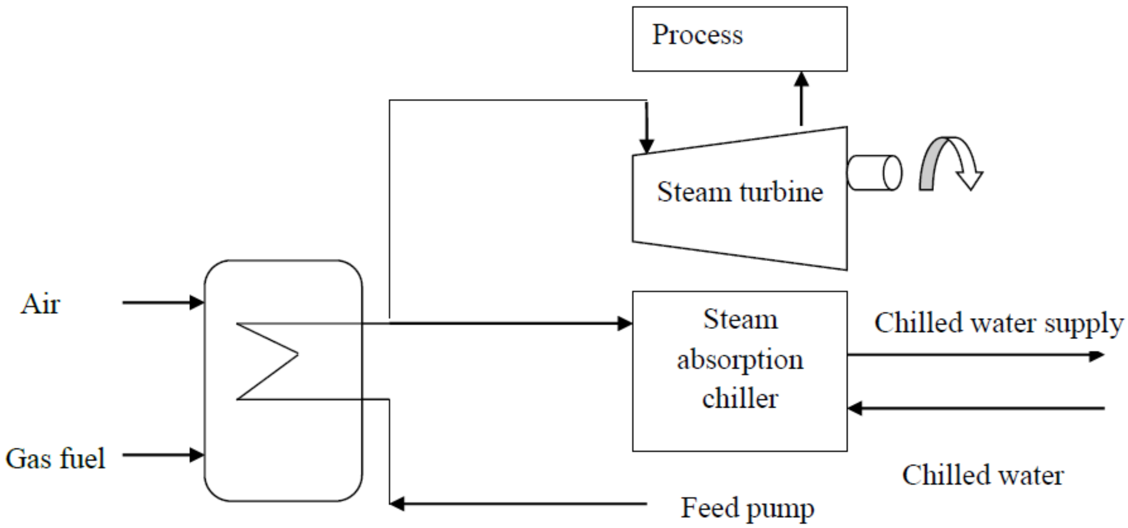

Figure 2.2: An example of a tri-regeneration plant (Majid and Sulaiman, 2011)

c. Majid and Sulaiman (2011) also point out that the third method is when the gas fuel is used in the gas turbine as prime mover for the electrical generator and the surplus thermal energy from the turbine exhaust gases is harnessed (or recovered) to produce steam in a waste heat steam generator or commonly known as heat recovery steam generator (HRSG). The steam from the HRSG is then used in the SAC for chilled water production. If the steam is also utilized in the steam turbine as another prime mover for the electrical generation, the system can be referred to as a combined cycle plant, i.e. Brayton cycle for the gas turbine plant and Rankine cycle for the steam turbine plant.

2.3 Main Equipment of GDC in UTP

Table 1.1 shows the main equipment of GDC plant at Universiti Teknologi PETRONAS and the capacity of the equipment.

Table 1.1: Major equipment of the GDC plant at Universiti Teknologi PETRONAS (Majid and Sulaiman, 2011)

Universiti Teknologi PETRONAS GDC Plant System
Plant's Installed Capacity Electricity : 8.4 MW Chilled Water: 4000 RT
Gas Turbine Generators: 2 x 4.2 MW Solar Taurus 60S Steam Generators: 2 x 12 ton/hr Vickers Heat Recovery Steam Generator 1 x 6 ton/hr Vickers Auxiliary Gas boiler Chilled Water Systems 4x 325 RT Dunham Bush Electric Air-Cooled Chillers 2 x 1250 RT Ebara Steam Absorption Chillers Thermal Storage 10 000 RTh thermal storage tank

The figure 2.3 shows the arrangement for the block diagram of the equipment GDC system in UTP. As can be seen, the SAC will produce the chilled water for the consumer.

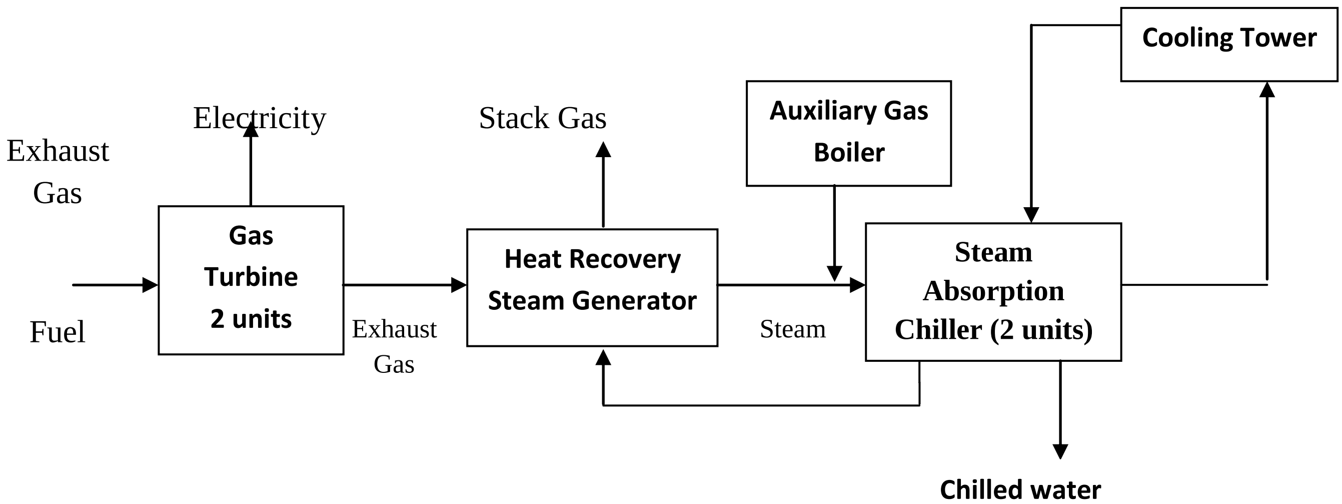

Figure 2.3: Block diagram of the equipment GDC system in UTP (Majid and Sulaiman, 2011)

According to Gilani et al (2006), the plant is a combination of a cogeneration and GDC plant. It is equipped with two 4.2 MW gas turbines, two heat recovery steam generators (HRSG), two boilers, two 1250 tons of refrigeration (RT) absorption chillers (ACs) and a 10000 tons of refrigeration hours (RTh) thermal storage tank. Electricity generated by the two gas turbines was supplied to the client as well as for in-plant use. Similarly for the chilled water produced it was supplied to the client and for in-plant use. The plant was operated on 24 hour basis and was designed to have the two turbines operating during the day and one turbine during the night. The operating schedule for the chillers was designed to have the ACs to be operated during the day and the electric chillers (ECs) to be operated during the night for charging the thermal storage tank. The ECs were designed to operate using the electricity supplied from Tenaga Nasional Berhad (TNB) when the turbines are down. The storage tank was designed to supplement the chilled water requirements during the day.

Tamiru et al (2007) also mentioned that a cogeneration and cooling plant delivers three outputs from a single source of energy. The first output is electric power. It is generated in the gas turbine generator (GTG) part of the cogeneration system. The second output is steam that is produced in the heat recovery steam generator (HRSG), which is also part of cogeneration system. The third output is chilled water. It can be produced using the steam from the HRSG in the SACs or employing electric chillers (ECs) that are driven by the electricity generated by the GTG. The GTG is featured by an air-compressor, combustor, and gas turbine. UTP cogeneration and cooling plant is characterized by two GTG, two units of HRSG, two units of SACs and four units of ECs. The plant is designed and put in service to produce electric power and deliver it to the customers (UTP) and inplant usage. HRSG produced steam is supplied to the SACs making the chillers produce chilled water. The plant has a capacity of 8.4 MW electric power, 12 ton/hr of steam and 3800RT of chilled water (2500 RT from SACs and 1300RT from ECs).

Operating strategy that has put in place is such that the GTGs would run during peak hours (8:00- 21:00) and one GTG operates during off-peak hours (0:00-8:00 and 21:00 – 23:00). To keep high reliability of electricity supply, replacement electricity would be obtained from Tenaga Nasional Berhad (TNB). The two HRSG would be used to recover the waste heat. During peak hours or in normal operation mode, both SACs would run concurrently with the HRSGs while one would be run during off-peak hours by Tamiru et al (2007).

According to Ambri and Yongo (2011), the cogeneration plant located on a site called the GDC produces both electric power and chilled water for space cooling in Universiti Teknologi PETRONAS (UTP). The GDC plant consists of gas turbine engine, heat recovery steam generator, steam absorption chiller, air cooled chiller, cooling tower, and thermal energy storage. The waste heat from the exhaust of the gas turbine is utilized for steam production that is used for heating in the steam absorption chiller. The chilled water produced from the steam absorption chiller is used for air conditioning of the building in UTP. Cogeneration is considered as a form of energy recovery that would have been lost from the gas turbine exhaust.

2.4 Steam Absorption Chillers (SACs)

Absorption chillers use heat instead of mechanical energy to provide cooling. A thermal compressor consists of an absorber, a generator, a pump, and a throttling device, and replaces the mechanical vapor compressor.In the chiller, refrigerant vapor from the evaporator is absorbed by a solution mixture in the absorber. This solution is then pumped to the generator. There the refrigerant re-vaporizes using a waste steam heat source. The refrigerant-depleted solution then returns to the absorber via a throttling device. The two most common refrigerant/ absorbent mixtures used in absorption chillers are water/lithium bromide and ammonia/water by (Solair,2009).

Majid and Sulaiman (2011) say that the Lithium Bromide-Water absorption cycle uses water as the refrigerant and lithium bromide as the absorbent. It is the strong affinity that these two substances have for one another that makes the cycle work. A single-effect steam absorption chiller process is summarised below;

2.4.1 Generator

Steam is supplied to the dilute solution of LiBr-H_20 in the generator at comparatively high temperature. The high temperature and pressure of water in the solution is boiled out and the water vapour (refrigerant) goes to the condenser. The concentrated LiBr solution left in the generator flows down to the absorber, passing through a heat exchanger where it is cooled.

2.4.2 Condenser

The refrigerant vapour condenses on the tubes of the circulating cooling water. The liquid refrigerant is then collected at the bottom of the condenser.

2.4.3 Evaporator

The high pressure liquid refrigerant then passes through a throttling valve that reduces it pressure. The low pressure liquid refrigerant then passes into the evaporator. Due to the extreme vacuum of the evaporator and low boiling point temperature, the liquid refrigerant boils by transferring heat from the water. Hence, the water is chilled.

2.4.4 Absorber

The refrigerant vapour migrates to the absorber from the evaporator where it returns to a liquid state. The concentrated LiBr solution pulls the refrigerant vapour into solution (the absorption process), creating the extreme vacuum in the evaporator. The absorption of the refrigerant vapour into the lithium bromide soltuion also generates heat which is removed by the cooling water. The diluted $LiBr\text{-}H_20$ solution is pumped back to the generator. The absorption cooling cycle is now completed and the process repeats.

Wu and Wang(2006) also mentioned that the steam absorption chiller can be considered as a simple equipment due the absence of moving parts, requiring no lubrication and hence, low maintenance. Since the chiller uses only low thermal energy, such as waste heat or solar,potential energy savings is significant. A single effect absorption chiller, driven by a heat source ranging from 80^o C to 110^oC, could provide chilled water between 5^oC to 10^oC, with cooling capacity up to 1500 refrigerant tonne (RT).

The figure 2.4 shows the diagram for main components for the absorption chiller that consist of four major components for absorption cooling cycle.

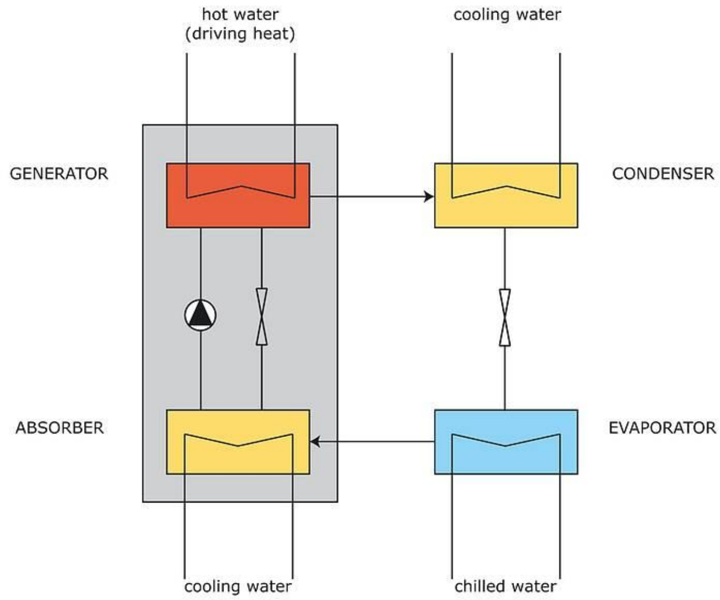

Figure 2.4: The main components of an absorption chiller are the generator, the condenser, the evaporator and the absorber (Solair, 2009)

2.5 System reliability

The figure 2.5 shows the major branches for repairable system for the reliability of the system.

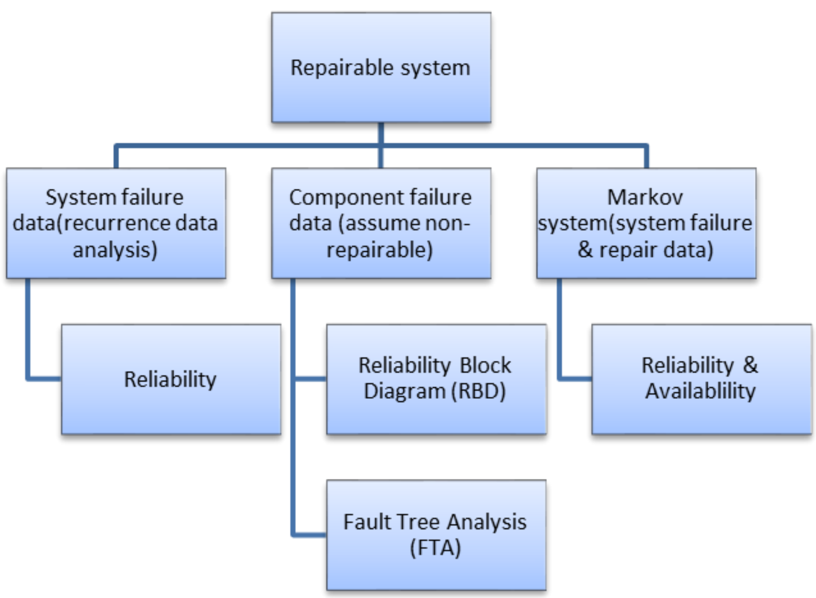

Figure 2.5: System reliability for repairable system (Dieter and Schmidt, 2009)

The figure 2.6 shows the five types of assumptions that used in estimating the condition of the repairable system after repair and maintenance section.

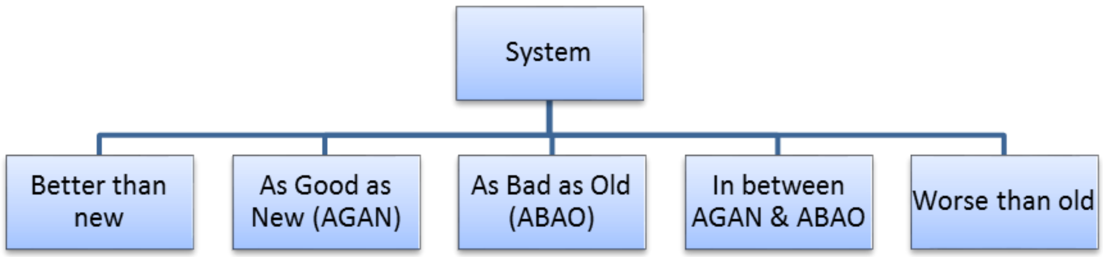

Figure 2.6: The assumptions for the condition of the system after repair stage (Dieter and Schmidt, 2009)

According to Dieter and Schmidt (2009), the overall reliability of the system depends on how the individual components with their individual failure rates are arranged. If the components are so arranged that the failure of any component causes the system to fail, it is said to be arranged in series.

$$R_{system} = R_A \times R_B \times \ldots\ldots\ldots \times R_n \qquad [2.1]$$

It is obvious that if there are many components exhibiting series reliability, the system reliability quickly becomes very low. For example, if there are 20 components each with R = 0.99, the system reliability is $0.99^{20} = 0.818$. Most consumer products exhibit series reliability. If we are dealing with a constant-failure-rate system, and the value of λ for the system is the sum of the values of λ for each component

$$R_{system} = R_A \times R_B = e^{-\lambda 1t} \times e^{-\lambda 2t} = e^{-(\lambda 1+\lambda 2)t} \qquad [2.2]$$

A much better arrangement of components is one in which it is necessary for all components in the system to fail in order for the system to fail. This is called parallel reliability.

$$R_{system} = 1-(1-R_A)(1-R_B)(1-R_C)\ldots(1-R_n) \qquad [2.3]$$

If we have a constant failure rate system,

$$R_{system} = 1-(1-R_A)(1-R_B) = 1-(1-e^{-\lambda 1t})(1-e^{-\lambda 2t}) \qquad [2.4]$$

Dieter and Schmidt (2009) also say that since it is not in the form $e^{-constant}$, the parallel system has a variable failure rate. A system in which the components are arranged to give parallel reliability is said to be redundant; there is more than one mechanism for the system functions to be carried out. In a system with full active redundancy, all but one component may fail before the system fails. Other systems have partial active redundancy, in which certain components can fail without causing system failure, but more than one component must remain operating to keep the system operating. A simple example would be a four-engine aircraft that can fly on two engines but would lose stability and control if only one engine were operating. This type of situation is known as an n-out-of-m unit network. At least n units must function normally for the system to succeed rather than only one unit in the parallel case and all units in the series case. The reliability of an n-out –of-m system is given by a binomial distribution, on the assumption that each of the m units is independent and identical.

$$R_{nlm} = = \sum_{i=n}^{m} \binom{m}{i} R^{i}(1-R)^{m-i} \quad . \quad . \quad . \quad . \quad . \quad . \qquad [2.5]$$

where $\binom{m}{i} = \frac{m!}{i!(m-i)!}$ . . . . [2.6]

2.6 Maintenance and Repair.

Repairing a failed component in a series system will not improve the reliability, since the system is not operating. However, decreasing the repair time will shorten the period during which the system is out of service, and thus the maintainability and availability will be improved by (Dieter and Schmidt, 2009).

A redundant system continues to operate when a component has failed, but it may become vulnerable to shutdown unless the component is repaired and placed back in service. To consider this fact we define some additional terms.

MTBF = MTTF + MTTR . . . . [2.7]

where MTBF = mean time between failures = $1/\lambda$ for constant failure rate.

MTTF= mean time to failure.

MTTR=mean time to repair.

If the repair rate r = 1/ MTTR, then for an active redundant system.

$$MTTF = \frac{3\lambda + r}{2\lambda^2} \qquad [2.8]$$

Availability is the concept that combines both reliability and maintainability; it is the proportion of time the system is working "on line" to the total time, when that is determined over a long working period.

If MTTF = $1/\lambda$, then

$$\text{Availability} = \frac{MTTF}{MTTF + MTTR} \qquad [2.9]$$

2.7 Pareto analysis

According to John (2011), in the very early 1900's, an Italian economist by the name of Vilfredo Pareto created a mathematical formula describing the unequal distribution of wealth he observed and measured in his country: Pareto observed that roughly twenty percent of the people controlled or owned eighty percent of the wealth. In the late 1940s, Dr. Joseph M. Juran, a Quality Management pioneer, attributed the 80/20 Rule to Pareto, calling it Pareto's Principle. While some may claim that Juran's broad attribution of this scientific observation to Pareto is inaccurate, Pareto's Principle or "Pareto's Law" as it is sometimes called, can be very effective business tools that can help people manage more effectively.

John (2011) also stated that the 80/20 Rule means that in any set of things such as workers, customers, etc. a few (20 percent) are vital and many (80 percent) are considered trivial. In Pareto's case, he found that roughly 20 percent of the people in his country dominated with 80 percent of the wealth. In Juran's initial work, he identified 20 percent of product defects causing 80 percent of product problems. It's well known by Project Managers that 20 percent of work (usually the first 10 percent and the last 10 percent) consume 80 percent of the time and resources. It can be apply the 80/20 Rule to almost anything, from the science of management to the sciences of the physical world around us.

2.8 Markov model

According to Billiton and Allan (1983), the Markov approach can be applied to the random behavior of systems that vary discretely or continuously with respect to time and space. This discrete or continuous variation is known as a stochastic process. Not all stochastic processes can be modeled using the basic Markov approach although there are techniques available for modeling some additional stochastic processes using extensions of this basic method.

Billiton and Allan (1983) say in order for the basic Markov approach to be applicable, the behavior of the systems must be characterized by a lack of memory, that is, the future states of a system are independent of all past states except the immediately preceding one. Therefore the future random behavior of a system only depends on where it is at present, not on where it has been in the past or how it arrived at its present position. In addition, the process must be stationary, sometimes called homogenous, for the approach to be applicable. This means that the behavior of the system must be the same at all points of time irrespective of the point of time being considered, i.e., the probability of making a transition from one given state to another is the same (stationary) at all times in the past and future. It is evident from these two aspects, lack of memory and being stationary, that the Markov approach is applicable to those systems whose behavior can be described by a probability distribution that is characterized by a constant hazard rate such as Poisson and exponential distributions, since only if the hazard rate is constant does the probability of making a transition between two states remain constant at all points of time. If this probability is a function of time or the number of discrete steps, then the process is non-stationary and designated as non- Markovian.

Billiton and Allan (1983) also say in the general case of Markov model, both time and space may either be discrete or continuous. It only considers these two cases. The discrete case, generally known as Markov Chain while the continuous case, generally known as a Markov process. The only requirements needed for the technique to be applicable are that the system must be stationary , the process must lack memory and the states of the system must be identifiable. For the transient behavior or time-dependent values of the state probabilities, as the number of time intervals is increased, the values of state probabilities tend to a constant or limiting value. This is characteristic of most systems which satisfy the conditions of the Markov approach, and these limiting values of probability are known as the limiting-state or time-independent values of the state probabilities.

Billiton and Allan (1983) point out that it was assumed that the system started in state 1 and the transient behavior was evaluated as time increased. The state of the system at step 0 or zero time is known as the initial conditions. In most reliability evaluation problems these initial conditions are known, and the problem centers on evaluating the system reliability as time extends into the future. The transient behavior is very dependent on the initial conditions and the reader is left to evaluate a similar graph for the case when the system initially resides in state 2 rather than state 1.

CHAPTER 3
METHODOLOGY

3. 1 Project planning:

The figure 3.1 shows the project planning throughout the FYP timeline for performance measure for SAC of district cooling plant.

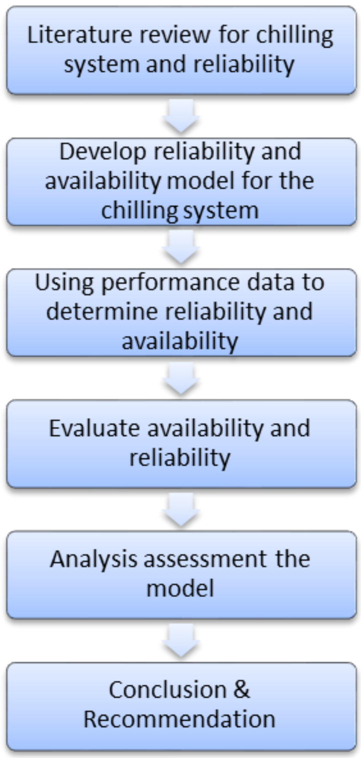

Figure 3.1: Project planning throughout the FYP timeline

3.2 Research methodology

Throughout the project planning, the development of reliability and availability model for the SAC system is very crucial in order to determine the result. The proposed model is based on the performance data which can be measured in the form of hourly flow rates, hourly refrigeration tonnage or other some forms that can be used to measure equipment's health by (Muhammad, Mokhtar and Majid, 2011). Firstly, the Pareto analysis is used to group the performance data. Next, development of the model by using the multi-state repairable system based on Continuous Time Markov Chain (CTMC). For CMTC, the probability of each state with respect to time, P_i (t), can be determined by solving the differential equations by (Muhammad, Moktar and Majid, 2011). In addition, the analysis and comparison between the result using Matlab software and Block Sim software also have been discuss for the reliability and availability graph that have obtained. Lastly, the conclusion and recommendation would be done for the model system. Figure 3.2 shows the details for the analysis assessment for the SAC.

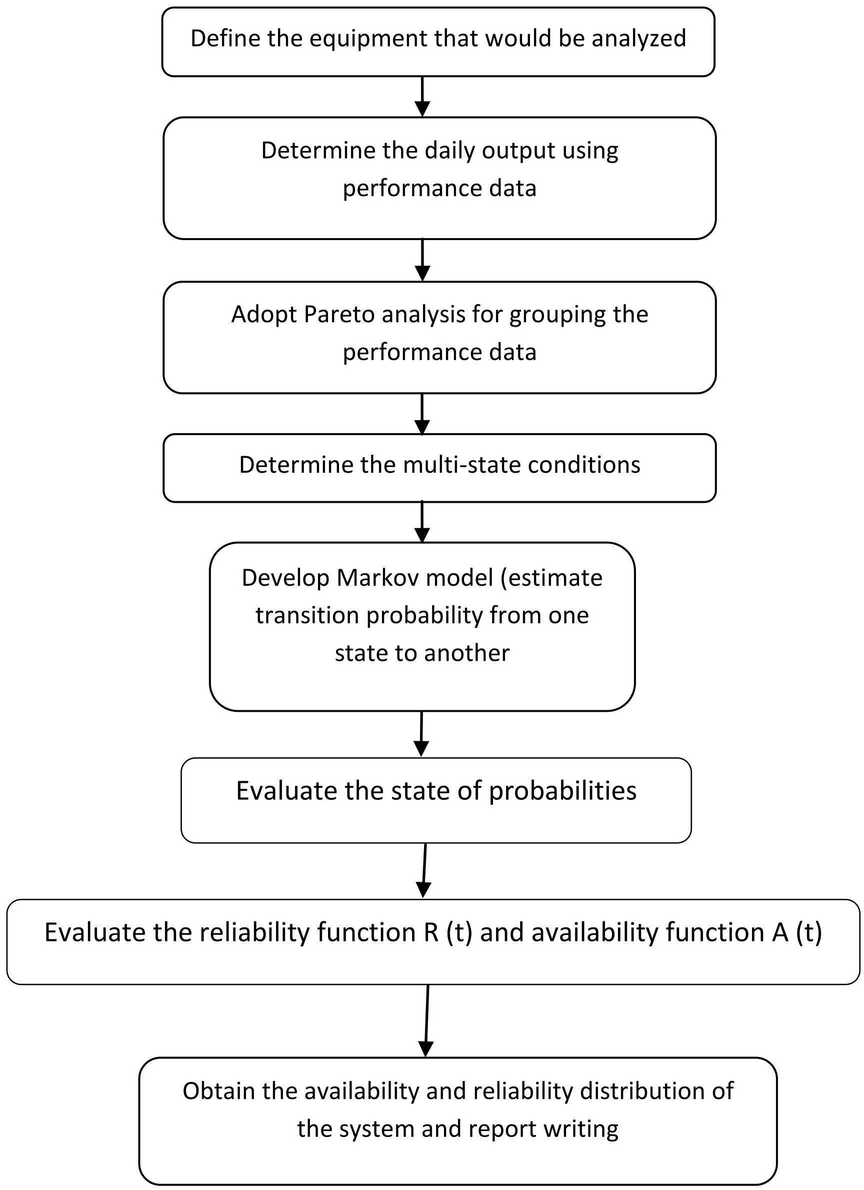

Figure 3.2: Flowchart of performance measure of Steam Absorption Chiller

3.3 Proposed model

The figure 3.3 shows the two units of SAC that are connected in parallel connection for SAC system.

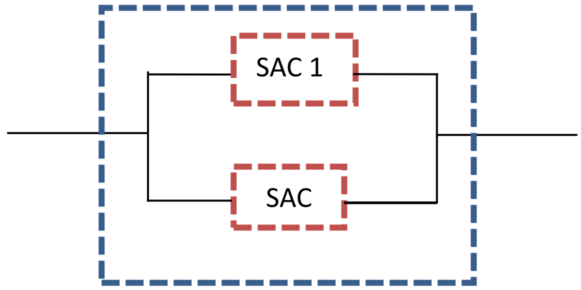

Figure 3.3: The parallel configuration for component SAC

3.4 Model assumptions

- SAC is a repairable system
- It has the repair and maintenance section
- The operating capacity would not exceed the full capacity operation, 1250 RTh.
- Both SAC 1 and SAC 2 were operated at the same design capacity, 1250 RTh and same temperature condition.

3.5 Pareto analysis

The Pareto analysis is used to form groups for the performance data before continues with the multi-state model. The table 3.1 has shown the number of bins that represent the number of state for single chiller.

Table 3.1: The bin used to calculate the frequency of group performance data

Single chiller state	Generating capacity
State 2	Nominal capacity, 850 RTh – 1250 RTh
State 1	Reduced capacity, 450 RTh – 850 RTh
State 0	Failed state, 0 RTh – 450 RTh

3.6 Estimation Methods for transition rate from one unit of SAC

In order to find the transition rate from one state to another, equation (1) and (2) are used. In this study, two level approximation method by Lisnianski (2003) is used to estimate the arrival and departure from each state.

$$\mu = \frac{1}{Tc - tp} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad [3.1]$$

$$\lambda = \frac{1}{tp} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad [3.2]$$

Where:

μ is arrival rate from failed or partial operating to the up state, i

λ is departure rate from up state, i to partial operating and failed state

T_c is cycle time

t_p is the mean duration of the peak

3.7 State space modeling in the availability assessment of steam absorption chiller system

A state space method using Markov model is used for multi-state system availability analysis. This method can include common cause failures, multiple failures, different repair times, and variable failure rates. The state space method is not limited to two states only, such as 'up' and 'down'. Furthermore, components can have different states such as operational, partial, down, and /or under maintenance by Majid (2011) Therefore, the Markov model of two parallel steam absorption chillers is developed as shown in Figure 4.4 and 4.5.

3.8 Comparison with the Block Sim software

After obtaining the plot graphs for both evaluations, the comparison between the Markov model's results with traditional binary system would be analyze in detail. The traditional binary system, which is BlockSim software, will only use one parameter for exponential distribution. The reason why the exponential distribution was chosen due to the operating equipment usually in the constant failure rate which in this case, it is exponential distribution. The simulation time is 1000 days.

Using 1-parameter for exponential distribution, key in the value of λ= 0.051. Therefore, using this equation

$$\lambda = \frac{1}{\text{MTBF}} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad [3.3]$$

$$\text{MTBF} = 196 \text{ days}$$

The value of Mean Time between Failure (MTBF) is used to evaluate the reliability. For availability evaluation, the value of Mean Downtime (MDT) obtained from this equation

$$(1 - A) = \frac{\text{MDT}}{\text{Total time}} \qquad . \quad . \quad . \quad . \quad . \quad . \qquad [3.4]$$

$$(1 - A) = \frac{\text{MDT}}{1000 \text{ days}}$$

$$\text{MDT} = 2.67 \text{ days}$$

3.9 Key Milestone on FYP 2

The table 3.2 shows the key milestone for final year project (FYP) 2 about the due date for every submission of the report for this semester May 2012.

Table 3.2: The key milestone for FYP 2

Detail	Week
Progress report	8
Pre-EDX	11
Submission of Draft Report	12
Submission of Technical Paper	13
Submission of Dissertation(Soft cover)	13
Oral presentation	14
Submission of Final Dissertation Report	15

3.10 Gantt chart

The table 3.3 shows the Gantt chart of FYP 1 and FYP 2 timeline which consist the overall durations for completing the FYP project.

Table 3.3: Gantt chart of FYP 1 and FYP 2

Activity	**FYP 1**			**FYP 2**		
	February	March	April	June	July	August
Title Awarded						
Literature review for chilling system and Pareto chart						
Develop reliability and availability model						
Determine reliability and availability using performance data						
Evaluate availability and reliability						
Analysis assessment the model						
Report Completion						

3.11 Tool / software required.

Throughout the project completion, the grouping of historical performance data of Steam Absorption Chiller for 2009 and 2010 using Pareto chart, the **Matlab software** and **Microsoft Excel 2007** were used to solve the differential equation method, obtained the state probabilities for availability and reliability evaluation. The model was compared to the traditional binary system using the **Block sim software.**

CHAPTER 4
RESULT AND DISCUSSIONS

4.1 Data collection

The data for Steam Absorption Chiller, SAC 1 and SAC 2 were taken from 2009 and 2010. Some of the data were attached on the Appendix. The analysis data were taken from the 12 hours daily data recorded by the technician starting from 7 a.m. until 7 p.m at Gas District Cooling plant in Universiti Teknologi PETRONAS (UTP).

Daily performance data (RTh) versus Operating time (7 a.m. until 7 p.m.)

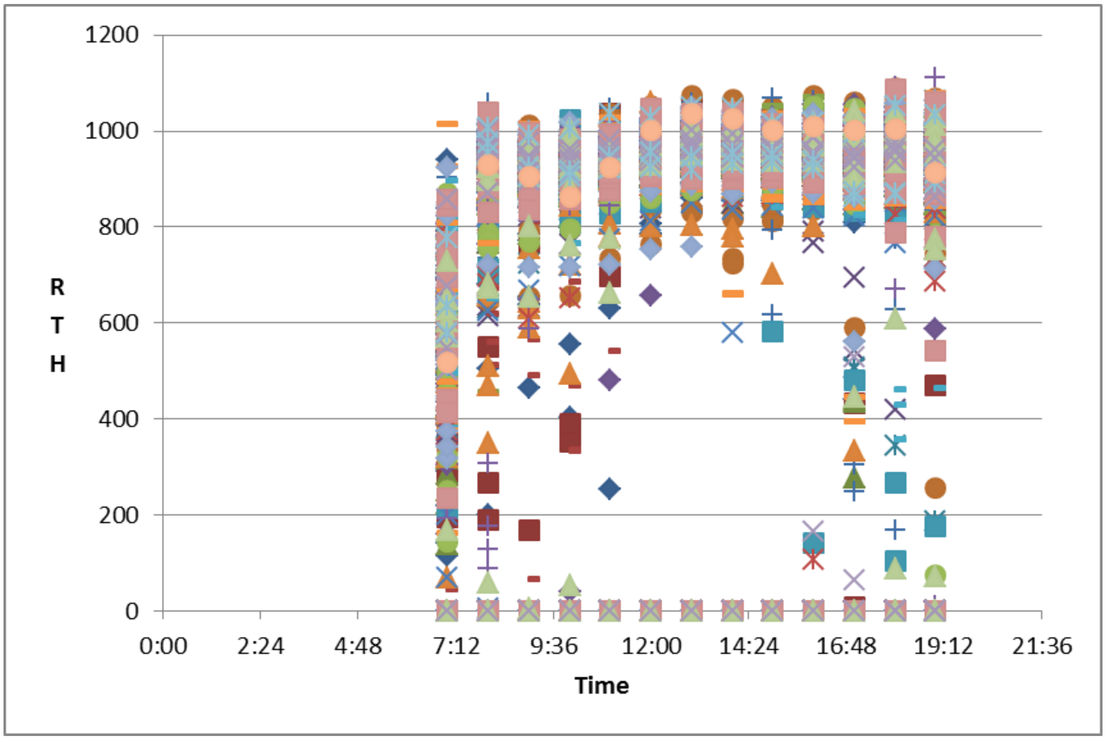

Figure 4.1: The daily performance data for Steam Absorption Chiller

Based on the scatter plot in figure 4.1, it can be seen that most of the time, the Steam Absorption Chiller can be operating at nominal capacity which is between 850 RTh to 1250 RTh. Only at certain time, the SAC operate at reduced capacity and failed state.

4.2 Pareto chart

Based on Table 3.1, there would be three groups for this performance data. State 2 with 850 ~1250 RTh, State 1 with 450 ~ 850 RTh, and State 0 with 0~450 RTh. State 2 is known as upstate which operate at nominal capacity that nearly to the design capacity but did not exceed from the design capacity, 1250 RTh. State 1 is known as reduced capacity due to performance of equipment degrade and below the nominal capacity. Using the boundaries of each state, the frequency and accumulated duration of the state were determined as shown in Figure 4.2. The frequency is shown how many times the system resides with the particular states. The accumulated duration is the time how long the system stays in that particular state. However, in this study the number of frequency and the accumulated duration are the same because the data is taken in hourly base. One data entering in those particular states which means the system can stay for one hour in that particular state.

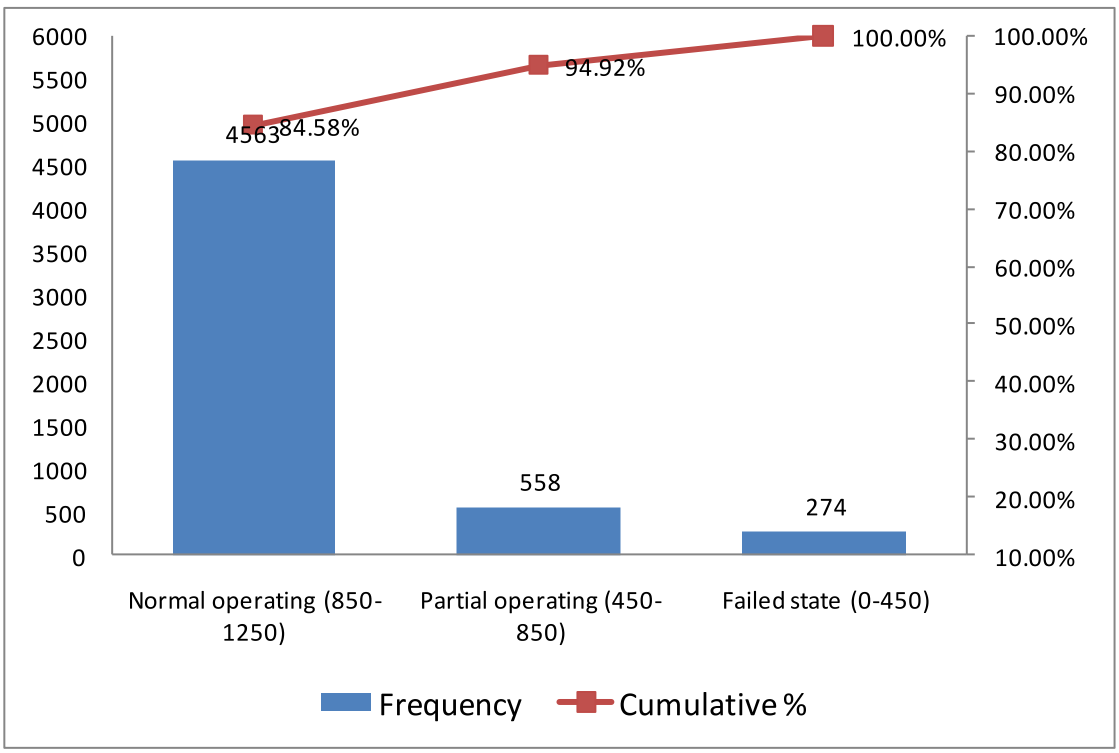

Figure 4.2: The Pareto Chart for performance data grouping of SAC 1 and SAC 2

From Figure 4.2, out of the total observation or cycle time the system resides with up state for 4563 hours which 84.58% of the cycle time, 10.34% resides with the reducing state which is 558 hours and 5.08% resides with failed states. Once we got the accumulated hours for each state, we can estimate the transition rate using two level approximation methods.

4.3 Estimation of transition rate

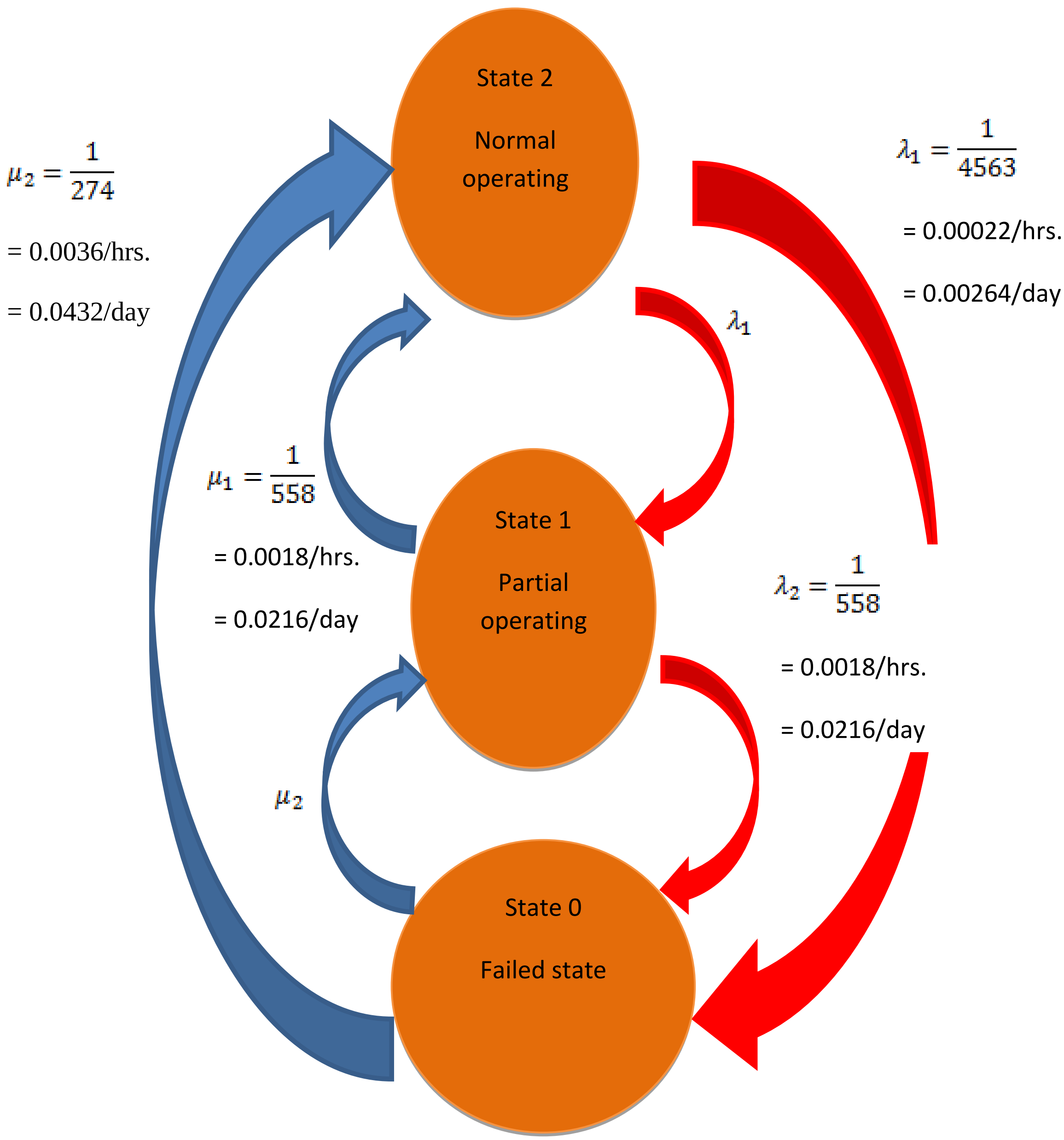

Figure 4.3: The state space diagram for one chiller of the SACs

Once the individual SAC transition rate is determined, the system transition rates can be found based on Figure 4.4 and 4.5 as shown in Table 4.3.

4.4 State Space Modeling In the Availability Assessment of SAC System

The state space diagram of SAC system for availability and reliability are shown in Figure 4.4 and Figure 4.5. Figure 4.4 presents nine states that can occur in District Cooling Plant operation. State 1 is the best state of the system; both SACs are working with nominal capacity/normal operating. State 2 and 3 are working partial operating due to either one of SACs working at less than nominal capacity which is at reduced capacity while state 5 is working at reduced capacity for both SACs. Meanwhile, the state 4, 6, 7, 8 and 9 were down due to the failure of one of the SACs.

Based on Figure 4.4, failure rates can be determined by departure rate, λ when the SAC system fails from nominal and partial state due to degradation and other relevant factors. It is also can be seen that system will back to nominal state after corrective and preventive maintenance action is taken.

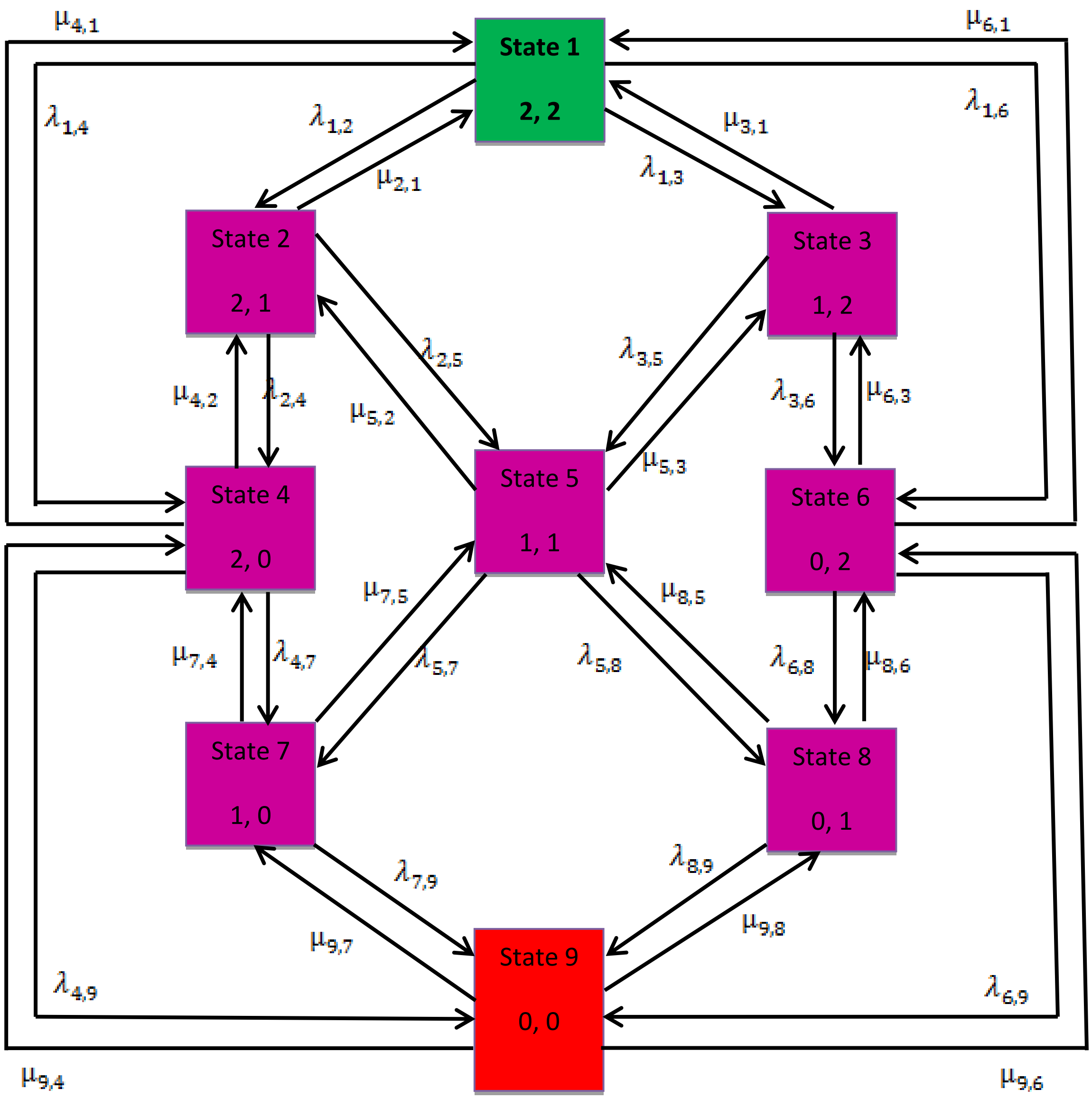

Figure 4.4: Transition diagram of two units SAC for availability evaluation

The description of each operation states are shown in Table 4.1.

Table 4.1: The system state description for the SAC

System state	State of SAC 1	State of SAC 2	Description
1	2	2	Both SACs are working at nominal capacity
2	2	1	SAC 1 is working at nominal capacity SAC 2 is working at reduced capacity
3	1	2	SAC 2 is working at nominal capacity SAC 1 is working at reduced capacity
4	2	0	SAC 1 is working at nominal capacity SAC 2 is at failed state
5	0	2	SAC 2 is working at nominal capacity SAC 1 is at failed state
6	1	1	Both SACs are working at reduced capacity
7	1	0	SAC 1 is working at reduced capacity SAC 2 is at failed state
8	0	1	SAC 2 is working at reduced capacity SAC 1 is at failed state
9	0	0	Both SACs are at failed state

4.5 Mathematical equation method for SAC system availability

Mathematical equation related with the transition based on state space diagram is developed and probability of supplying the chilled water can be evaluated.

$$\frac{dP_1}{dt} = (\mu_{4,1}.P_4 + \mu_{6,1}.\ P_6 + \mu_{2,1}.P_2 + \mu_{3,1}.\ P_3) - (\lambda_{1,4} + \lambda_{1,2} + \lambda_{1,3} + \lambda_{1,6})P_1 \quad [4.1]$$

$$\frac{dP_2}{dt} = (\mu_{5,2}.P_5 + \mu_{4,2}.\ P_4 + \lambda_{4,2}.\ P_4) - (\mu_{2,1} + \lambda_{2,5} + \lambda_{2,4})P_2 \quad . \quad . \quad [4.2]$$

$$\frac{dP_3}{dt} = (\lambda_{1,3}.P_1 + \mu_{5,3}.\ P_5 + \mu_{6,3}.\ P_6) - (\lambda_{3,5} + \mu_{3,1} + \lambda_{3,6})P_3 \quad . \quad . \quad [4.3]$$

$$\frac{dP_4}{dt} = (\lambda_{2,4}.P_2 + \mu_{7,4}.\ P_7 + \lambda_{1,4}.P_1 + \mu_{9,4}.\ P_9) - (\lambda_{4,9} + \lambda_{4,7} + \mu_{4,2} + \mu_{4,1})P_4 \quad [4.4]$$

$$\frac{dP_5}{dt} = (\lambda_{3,5}.P_3 + \lambda_{2,5}.P_2 + \mu_{7,5}.\ P_7 + \ \mu_{8,5}.\ P_8) - (\ \mu_{5,3} + \ \mu_{5,2} + \lambda_{5,7}\ + \lambda_{5,8}\ )P_5 \quad [4.5]$$

$$\frac{dP_6}{dt} = (\lambda_{1,6}.P_1 + \lambda_{3,6}.\ P_3 + \mu_{8,6}.P_8 + \ \mu_{9,6}.P_9) - (\ \mu_{6,3} + \ \mu_{6,1} + \lambda_{6,8}\ + \lambda_{6,9})P_6 \quad [4.6]$$

$$\frac{dP_7}{dt} = (\lambda_{4,7}.P_4 + \lambda_{5,7}.P_5 + \mu_{9,7}.\ P_9) - (\ \lambda_{7,9} + \ \mu_{7,4} + \ \mu_{7,5})P_7 \quad . \quad . \quad [4.7]$$

$$\frac{dP_8}{dt} = (\lambda_{6,8}.P_6 + \lambda_{5,8}.P_5 + \mu_{9,8}.\ P_9) - (\ \mu_{8,6} + \ \mu_{8,5} + \lambda_{8,9}\ )P_8 \quad . \quad . \quad [4.8]$$

$$\frac{dP_9}{dt} = (\lambda_{7,9}.P_7 + \lambda_{8,9}.\ P_8 + \lambda_{6,9}.P_6 + \ \lambda_{4,9}.P_4) - (\ \mu_{9,7} + \ \mu_{9,8} + \mu_{9,6}\ + \mu_{9,4})P_9 \quad [4.9]$$

By using Ordinary Differential Equations (ODE45) function in **Matlab software**, the equations can be solved to obtain the state probabilities for each state. Then once defined the state probabilities, the availability equation can be determine using Equation (12) or (13)

Availability, $A = 1 - P_9$ . . . . . . [4.10]

$$\Sigma A = P_1 + P_2 + P_3 + \ P_4 + P_5 + P_6 + P_7 + P_8 \quad . \quad . \quad . \quad [4.11]$$

4.6 State Space Modeling In the Reliability Assessment of SAC System

Using absorbing state concept, the state space model for reliability analysis can be modeled as shown in Figure 4.5. From Figure 4.4, all states which cannot satisfy the required demand were uniting as one state in Figure 4.5. State 5 at Figure 4.5 is absorbing state of the system that means once the system entered to this state; it will never have arrival rate from partial or failed state to the up state, i. Therefore, no repair action required once it fails. From Figure 4.5, the reliability of SAC system can be evaluated.

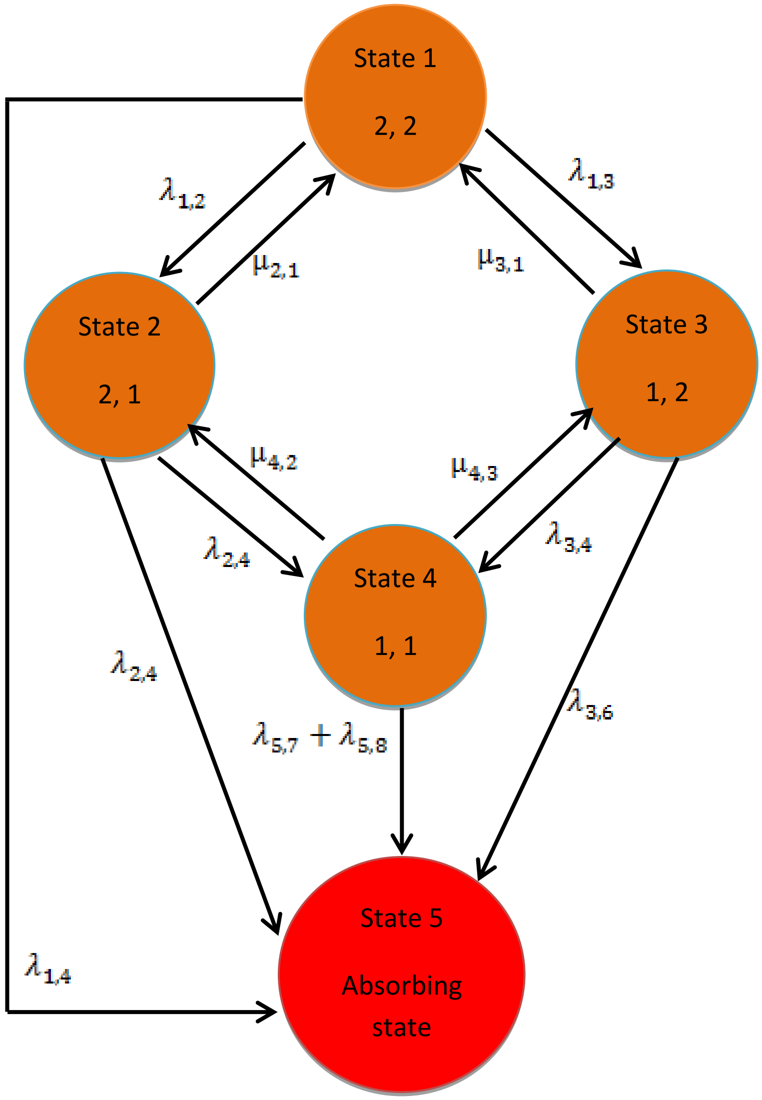

Figure 4.5: Transition diagram of two units SAC for reliability evaluation

4.7 Mathematical equation method for SACs system reliability

Mathematical equation related with the transition based on state space diagram is developed and probability of supplying the chilled water can be evaluated

$$\frac{dP_1}{dt} = \left(\mu_{2,1}.P_2 + \mu_{3,1}.\ P_3\right) - \left(\lambda_{1,2} + \lambda_{1,4} + \lambda_{1,3}\right)P_1 \quad . \quad . \quad [4.12]$$

$$\frac{dP_2}{dt} = \left(\lambda_{1,2}.P_1 + \mu_{4,2}.\ P_4\right) - \left(\mu_{2,1} + \lambda_{2,4} + \lambda_{2,4}\right)P_2 \quad . \quad . \quad [4.13]$$

$$\frac{dP_3}{dt} = (\lambda_{1,3}.P_1 + \mu_{4,3}.\ P_4) - (\mu_{3,1} + \lambda_{3,4} + \lambda_{3,6})P_3 \quad . \quad . \quad . \qquad [4.14]$$

$$\frac{dP_4}{dt} = (\lambda_{2,4}.P_2 + \lambda_{3,4}.P_3) - (\mu_{4,2} + \mu_{4,3} + \lambda_{5,7} + \lambda_{5,8})P_4 \quad . \quad . \qquad [4.15]$$

$$\frac{dP_5}{dt} = (\lambda_{1,4}.P_1 + \lambda_{2,4}.P_2 + \lambda_{3,6}.P_3 + (\lambda_{5,7} + \lambda_{5,8})P_4) \quad . \quad . \qquad [4.16]$$

Therefore, the reliability is a measure of the probability for non-failure operation during a given interval. The reliability of the system is deducting the probability of absorbing state for a unit.

$$R_{SAC} = 1 - P_4(t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad [4.17]$$

The table 4.2 below shows the system transition rates for SAC system

Table 4.2: The transition rate of the SAC system

Transition of departure rate	Quantitative value	Transition of return rate	Quantitative value
$\lambda_{1,6}$	0.00022/hour 0.00264/day	$\mu_{4,1}$	0.0036/hour 0.0432/day
$\lambda_{1,4}$		$\mu_{6,1}$	
$\lambda_{1,2}$		$\mu_{6,3}$	
$\lambda_{1,3}$		$\mu_{9,6}$	
$\lambda_{2,5}$		$\mu_{9,8}$	
$\lambda_{4,7}$		$\mu_{9,7}$	
$\lambda_{4,9}$		$\mu_{4,2}$	
$\lambda_{6,9}$		$\mu_{7,5}$	
$\lambda_{6,8}$		$\mu_{8,5}$	
$\lambda_{3,5}$		$\mu_{9,4}$	
$\lambda_{2,4}$	0.0018/hour 0.0216/day	$\mu_{2,1}$	0.0018/hour 0.0216/day
$\lambda_{5,7}$		$\mu_{3,1}$	
$\lambda_{7,9}$		$\mu_{5,3}$	
$\lambda_{8,9}$		$\mu_{8,6}$	
$\lambda_{5,8}$		$\mu_{7,4}$	
$\lambda_{3,6}$		$\mu_{5,2}$	

4.8 Estimation state probabilities, availability and reliability

In order to estimate the availability and reliability of the entire system, it is necessary to determine the probability of each system using differential equation method with initial condition P_1= 1, which is the best state of the system. Availability of steam absorption chiller is given by the sum of probability of functional state. States probabilities as function of time are evaluated as shown.

Table 4.3: The state probabilities of SAC for availability evaluation

		State Probability								
Time (Day)	Availability	P1	P2	P3	P4	P5	P6	P7	P8	P9
0	1	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.9992	0.8553	0.0423	0.0423	0.0278	0.0018	0.0278	0.0009	0.0009	0.0008
40	0.9985	0.7867	0.0649	0.0649	0.0363	0.0047	0.0363	0.0023	0.0023	0.0015
60	0.9980	0.7523	0.0760	0.0760	0.0400	0.0070	0.0400	0.0034	0.0034	0.0020
80	0.9977	0.7345	0.0815	0.0815	0.0417	0.0085	0.0417	0.0042	0.0042	0.0023
100	0.9976	0.7252	0.0842	0.0842	0.0426	0.0094	0.0426	0.0047	0.0047	0.0024
120	0.9975	0.7202	0.0857	0.0857	0.0431	0.0099	0.0431	0.0049	0.0049	0.0025
140	0.9974	0.7174	0.0864	0.0864	0.0433	0.0103	0.0433	0.0051	0.0051	0.0026
160	0.9974	0.7160	0.0868	0.0868	0.0435	0.0104	0.0435	0.0052	0.0052	0.0026
180	0.9974	0.7151	0.0870	0.0870	0.0436	0.0105	0.0436	0.0053	0.0053	0.0026
200	0.9973	0.7147	0.0871	0.0871	0.0436	0.0106	0.0436	0.0053	0.0053	0.0027
220	0.9973	0.7145	0.0872	0.0872	0.0436	0.0106	0.0436	0.0053	0.0053	0.0027
240	0.9973	0.7143	0.0872	0.0872	0.0436	0.0106	0.0436	0.0053	0.0053	0.0027
260	0.9973	0.7142	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
280	0.9973	0.7142	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
300	0.9973	0.7142	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
320	0.9973	0.7142	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
340	0.9973	0.7142	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
360	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
380	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
400	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
420	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
440	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
460	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
480	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
500	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
520	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
540	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
560	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
580	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
600	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
620	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027

640	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
660	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
680	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
700	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
720	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
740	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
760	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
780	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
800	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
820	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
840	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
860	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
880	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
900	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
920	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
940	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
960	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
980	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027
1000	0.9973	0.7141	0.0873	0.0873	0.0436	0.0107	0.0436	0.0053	0.0053	0.0027

Based on table 4.3, the upstate which is normal operating has decreased for the first 360 operation days and become steady state for the remaining operation days. However, the probabilities of other state had increased gradually throughout the time. For the long term period, the state one had reached the limiting value that is 71.41% whereas the availability value has become steady state at 200 operation days and for the remaining operation days at 99.73%.

The figure 4.6 has shown the state probabilities for nine states in availability model which include the state 1 as the best state with the probabilities of one.

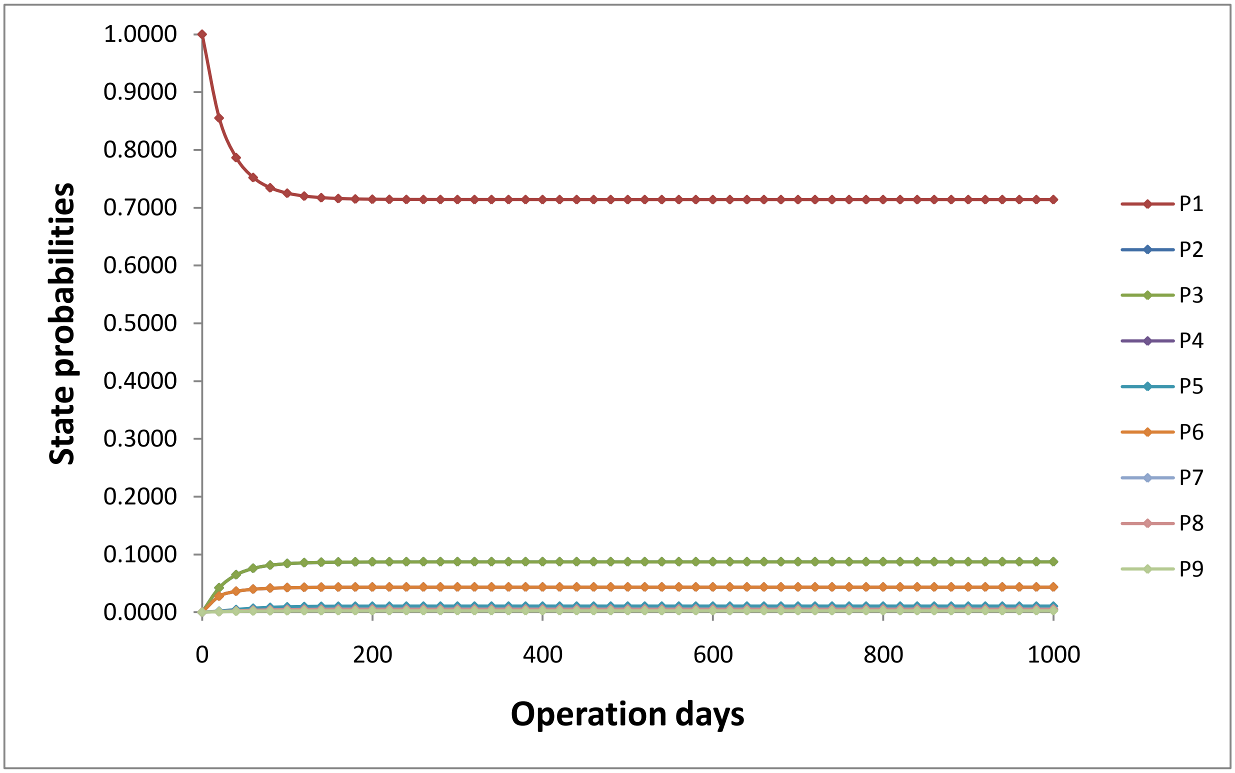

Figure 4.6: The state probabilities of SAC system for availability evaluation

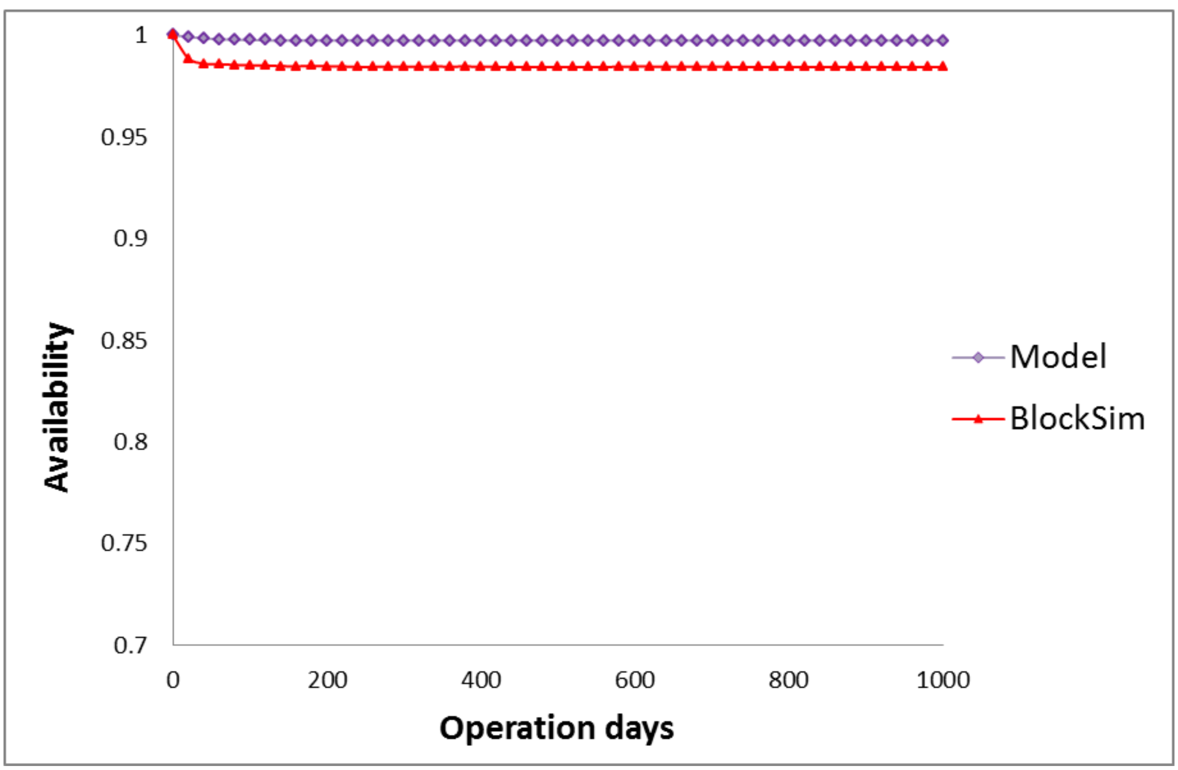

Figure 4.7: The comparison of availability for SAC system

Availability of Steam Absorption Chiller system is known as the total of probability of states that defined in equation (1). The result for availability had shown in Figure 4.7 that includes the comparison with the traditional binary system using Block Sim software. The model availability with respect to time has decreased rapidly from 0 to 200 days and become stable after 200 operation days. The limiting value for model availability is 99.75%.The model result shown high value of availability due to the parallel configuration system for Steam Absorption Chiller (SAC). After long operation time, the system availability reaches the limit value that shown the system is depends on the transition rate of the system.

The model result was compared graphically with the Block Sim software shown in figure 4.7. The traditional binary availability achieved the steady state at limit value of 98.43% which is lower than the model availability limit value of 99.73%. The percentage different for the model and the Block Sim model is 1.31%. It is only slightly small different from both models.

Table 4.4: State probabilities of SAC system for reliability evaluation

		State Probability					Failure rate, λ
Time(Day)	Reliability	P1	P2	P3	P4	P5	$\lambda = \frac{\text{Ln (R)}}{\text{Operation days}}$
0	1	1	0	0	0	0	0
20	0.9335	0.8684	0.0283	0.0325	0.0044	0.0665	0.003441
40	0.8544	0.7697	0.0347	0.0427	0.0073	0.1456	0.003934
60	0.7752	0.6884	0.0346	0.0442	0.0080	0.2248	0.004244
80	0.7007	0.6183	0.0324	0.0423	0.0077	0.2993	0.004447
100	0.6323	0.5564	0.0296	0.0391	0.0072	0.3677	0.004585
120	0.5701	0.5010	0.0268	0.0357	0.0065	0.4299	0.004683
140	0.5139	0.4514	0.0242	0.0323	0.0059	0.4861	0.004755
160	0.4632	0.4067	0.0219	0.0292	0.0053	0.5368	0.004811
180	0.4174	0.3665	0.0197	0.0263	0.0048	0.5826	0.004854

200	0.3762	0.3303	0.0178	0.0238	0.0043	0.6238	0.004889
220	0.3390	0.2976	0.0160	0.0214	0.0039	0.6610	0.004917
240	0.3055	0.2682	0.0144	0.0193	0.0035	0.6945	0.004941
260	0.2753	0.2417	0.0130	0.0174	0.0032	0.7247	0.004961
280	0.2481	0.2178	0.0117	0.0157	0.0029	0.7519	0.004978
300	0.2236	0.1963	0.0106	0.0141	0.0026	0.7764	0.004993
320	0.2015	0.1769	0.0095	0.0127	0.0023	0.7985	0.005006
340	0.1816	0.1594	0.0086	0.0115	0.0021	0.8184	0.005018
360	0.1636	0.1437	0.0077	0.0103	0.0019	0.8364	0.005028
380	0.1475	0.1295	0.0070	0.0093	0.0017	0.8525	0.005037
400	0.1329	0.1167	0.0063	0.0084	0.0015	0.8671	0.005046
420	0.1198	0.1051	0.0057	0.0076	0.0014	0.8802	0.005053
440	0.1079	0.0948	0.0051	0.0068	0.0012	0.8921	0.00506
460	0.0973	0.0854	0.0046	0.0061	0.0011	0.9027	0.005066
480	0.0876	0.0769	0.0041	0.0055	0.0010	0.9124	0.005072
500	0.0790	0.0693	0.0037	0.0050	0.0009	0.9210	0.005077
520	0.0712	0.0625	0.0034	0.0045	0.0008	0.9288	0.005082
540	0.0641	0.0563	0.0030	0.0041	0.0007	0.9359	0.005086
560	0.0578	0.0508	0.0027	0.0037	0.0007	0.9422	0.005091
580	0.0521	0.0457	0.0025	0.0033	0.0006	0.9479	0.005094
600	0.0469	0.0412	0.0022	0.0030	0.0005	0.9531	0.005098
620	0.0423	0.0371	0.0020	0.0027	0.0005	0.9577	0.005101
640	0.0381	0.0335	0.0018	0.0024	0.0004	0.9619	0.005105
660	0.0344	0.0302	0.0016	0.0022	0.0004	0.9656	0.005108
680	0.0310	0.0272	0.0015	0.0020	0.0004	0.9690	0.00511

700	0.0279	0.0245	0.0013	0.0018	0.0003	0.9721	0.005113
720	0.0251	0.0221	0.0012	0.0016	0.0003	0.9749	0.005115
740	0.0227	0.0199	0.0011	0.0014	0.0003	0.9773	0.005118
760	0.0204	0.0179	0.0010	0.0013	0.0002	0.9796	0.00512
780	0.0184	0.0162	0.0009	0.0012	0.0002	0.9816	0.005122
800	0.0166	0.0146	0.0008	0.0010	0.0002	0.9834	0.005124
820	0.0149	0.0131	0.0007	0.0009	0.0002	0.9851	0.005126
840	0.0135	0.0118	0.0006	0.0009	0.0002	0.9865	0.005128
860	0.0121	0.0107	0.0006	0.0008	0.0001	0.9879	0.00513
880	0.0109	0.0096	0.0005	0.0007	0.0001	0.9891	0.005131
900	0.0099	0.0087	0.0005	0.0006	0.0001	0.9901	0.005133
920	0.0089	0.0078	0.0004	0.0006	0.0001	0.9911	0.005134
940	0.0080	0.0070	0.0004	0.0005	0.0001	0.9920	0.005136
960	0.0072	0.0063	0.0003	0.0005	0.0001	0.9928	0.005137
980	0.0065	0.0057	0.0003	0.0004	0.0001	0.9935	0.005139
1000	0.0059	0.0051	0.0003	0.0004	0.0001	0.9941	0.00514

Based on table 4.4, it has shown that the probability of state one had decreased fast over the period of time while state two and state three were increased until 60 operation days and then start to decreased throughout the time. On the other hand, state four and state five have increment during operation days.

Figure 4.8 shows the state probabilities of SAC system that occurred when assuming the best state is state 1 which has the value of probability state one equal to one at the beginning. The five state probabilities occurred based on transition diagram for the reliability evaluation of SAC system in the figure 4.5

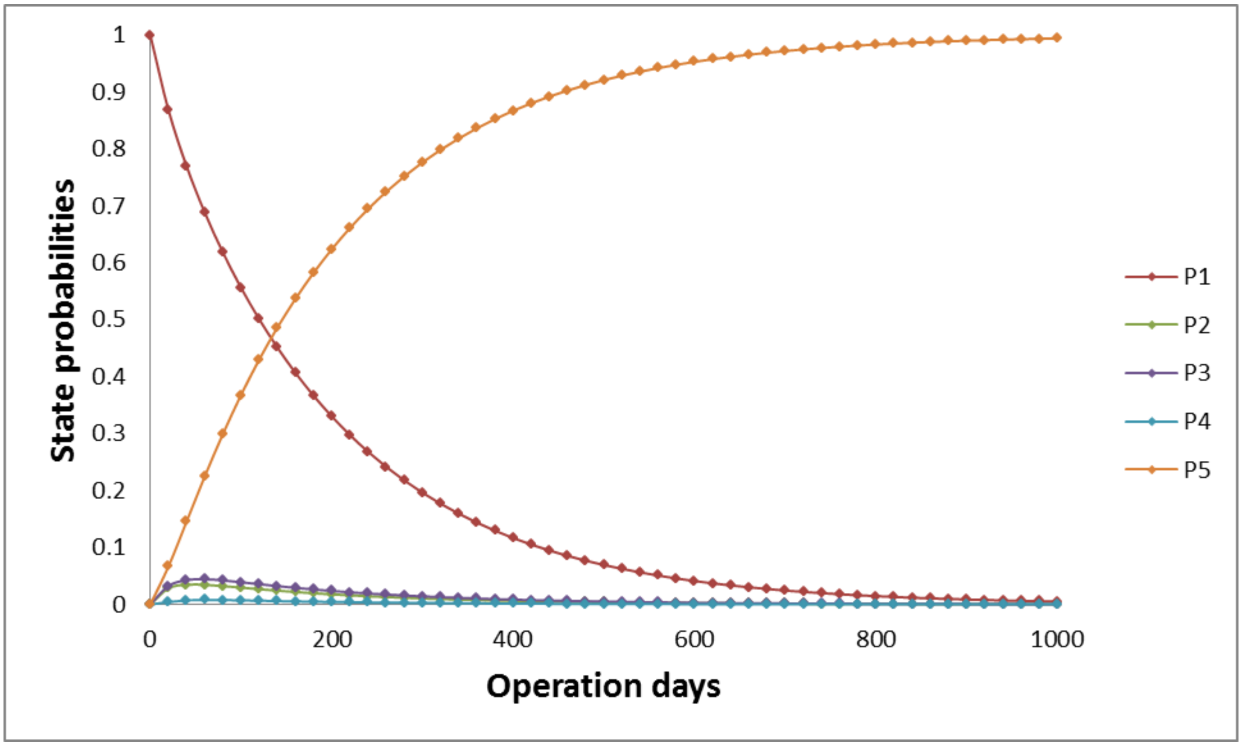

Figure 4.8: The state probabilities of SAC system for reliability evaluation

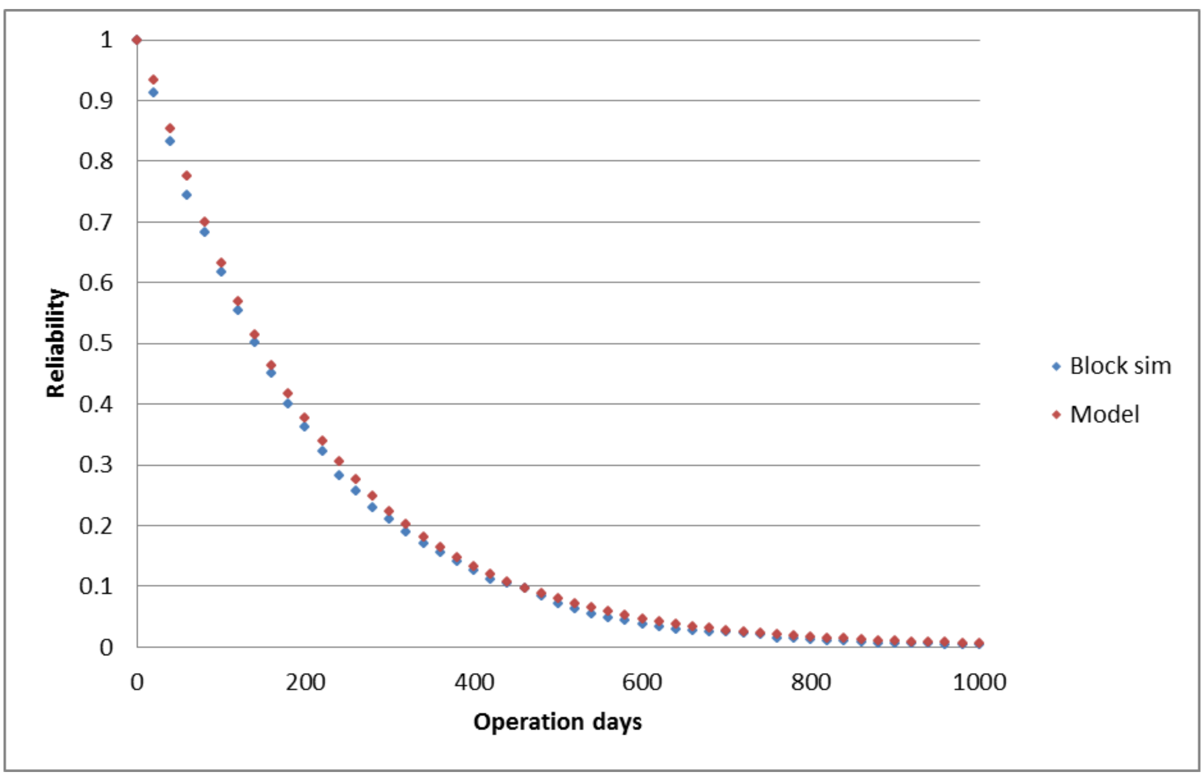

Figure 4.9: The comparison of reliability for SAC system

From figure 4.9, the reliability of system is decreasing throughout the time. The failure has high probability to occur throughout the period of operating time. The Block Sim reliability achieved the final value of 0.004 which is lower than the model reliability value of 0.0058. The percentage different between the model and the Block Sim model is 31.03%.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

Results have shown that the availability evaluated using multi-state model achieved the limit value of 99.73% that is higher than the availability obtained using the Block Sim software which is 98.43%. This difference between these two methods is based on the number of state involved. One of the reasons that give the high availability for the system is the parallel configuration for two units of steam absorption chiller. This would ensure if either one of the steam absorption chiller failed or degraded, the other one could support the system to meet the required demand for consumer.

On the other hand, the reliability value for the mathematical model had achieved the value of 0.0058 while the reliability value from the Block Sim software is 0.004. This is due to the number of state involved in both methods. For Block Sim software, it only involved two states which are upstate and downstate whereas the multi-state model have three states consists of upstate, downstate and partial operating state. The percentage difference from these two methods is 31.03% which is high percentage compared to the differences between availability. It can be concluded that the results obtained for the Markov model nearly similar with the Block Sim software. Therefore, the model could be applicable for the system

In a nutshell, the accuracy of results needs to be validating by using the other method so that the data interpretation would be beneficial to analyze the performance of equipment in the plant. For future works of this project, the performance data clustering would be more applicable to estimate the number of state for the system that need to be analyzed in order to assess the behavior of the performance data. The validation of the Markov model with data values from various years of historical data would give the accurate and precise value of the transition rate from one state to another state. It would be advantages for the project to compare the actual operating system behavior, traditional binary system and multi-state system to achieve accurate result for research development. A Markov model is very essential to be applied for repairable system like in this case, Gas District Cooling which provides the real condition for the system. By obtaining the number of failure for every period of time, it can utilize the equipment as well as reduce the operating and maintenance cost since we could predict the probability failure of the system. Hence, the performance data of the equipment is also beneficial for future maintenance planning instead of depending on the maintenance data only.

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APPENDICES

Appendix 1: Steps in Matlab Software

a. Key in the coding, the value of transition rate, and the time span for the model

b. Call up the Ordinary Differential Equation (ODE 45) function to solve the mathematical equations that have constructed.

c. Run the coding to determine the state probabilities data and reliability and availability graphs.

d. Re-construct the model and differential equation if the result is not sufficient for The Equipment.

Appendix 2: Matlab Code

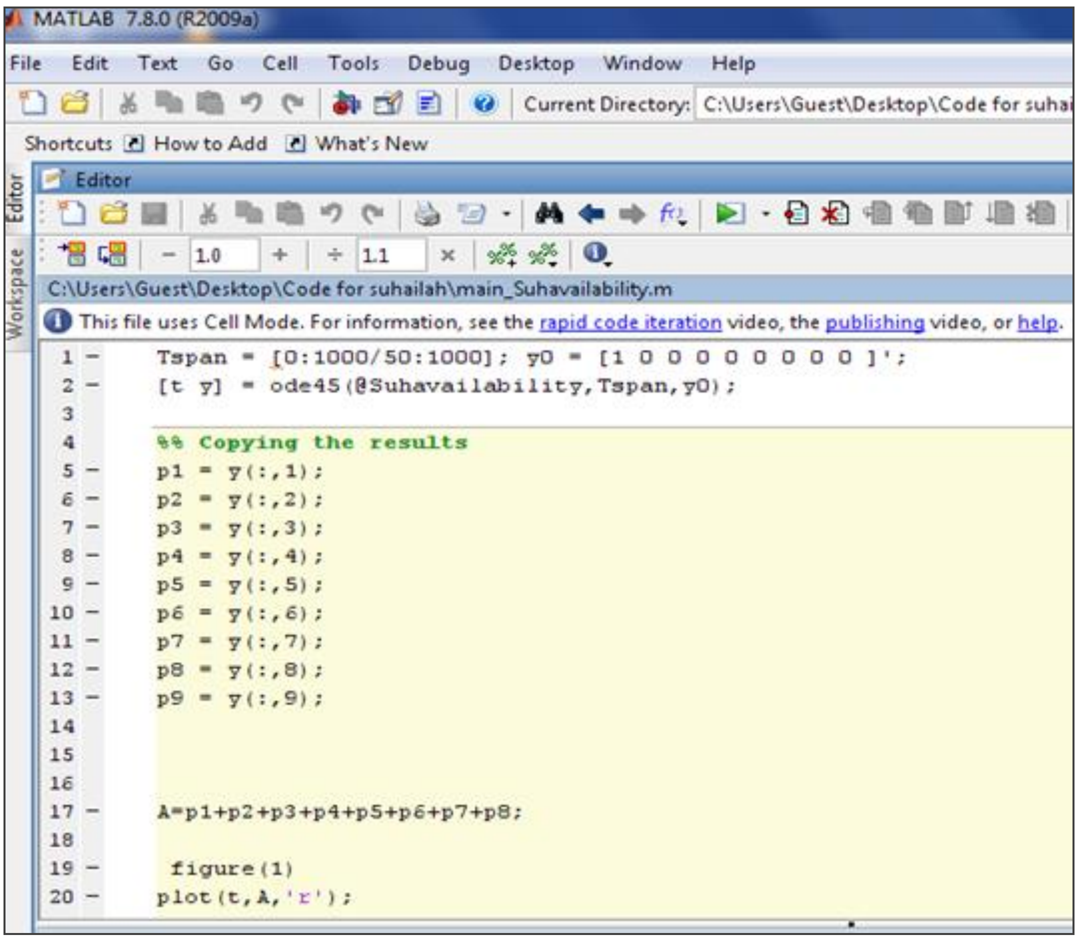
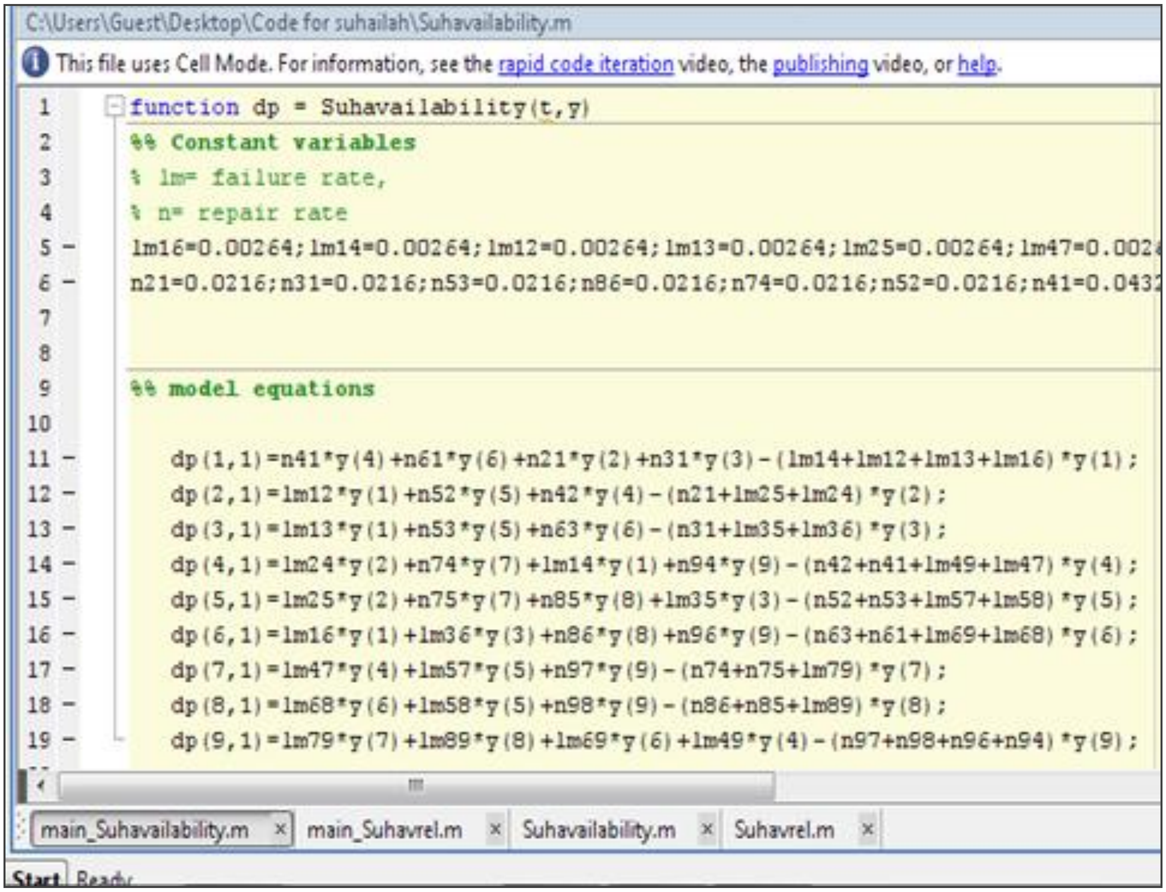


Figure 1: The part of coding for availability evaluation




```
function dp = Suhavailability(t,y)
%% Constant variables
% lm= failure rate,
% n= repair rate
lm16=0.00264;lm14=0.00264;lm12=0.00264;lm13=0.00264;lm25=0.00264;lm47=0.002
n21=0.0216;n31=0.0216;n53=0.0216;n86=0.0216;n74=0.0216;n52=0.0216;n41=0.043


%% model equations

    dp(1,1)=n41*y(4)+n61*y(6)+n21*y(2)+n31*y(3)-(lm14+lm12+lm13+lm16)*y(1);
    dp(2,1)=lm12*y(1)+n52*y(5)+n42*y(4)-(n21+lm25+lm24)*y(2);
    dp(3,1)=lm13*y(1)+n53*y(5)+n63*y(6)-(n31+lm35+lm36)*y(3);
    dp(4,1)=lm24*y(2)+n74*y(7)+lm14*y(1)+n94*y(9)-(n42+n41+lm49+lm47)*y(4);
    dp(5,1)=lm25*y(2)+n75*y(7)+n85*y(8)+lm35*y(3)-(n52+n53+lm57+lm58)*y(5);
    dp(6,1)=lm16*y(1)+lm36*y(3)+n86*y(8)+n96*y(9)-(n63+n61+lm69+lm68)*y(6);
    dp(7,1)=lm47*y(4)+lm57*y(5)+n97*y(9)-(n74+n75+lm79)*y(7);
    dp(8,1)=lm68*y(6)+lm58*y(5)+n98*y(9)-(n86+n85+lm89)*y(8);
    dp(9,1)=lm79*y(7)+lm89*y(8)+lm69*y(6)+lm49*y(4)-(n97+n98+n96+n94)*y(9);
```

Figure 2: The differential equation using ODE 45 function for availability evaluation of SAC

C:\Users\Guest\Desktop\Code for suhailah\main_Suhavrel.m

This file uses Cell Mode. For information, see the rapid code iteration video, the publishing video, or help.

```
Tspan = [0:1000/50:1000]; y0 = [1 0 0 0 0 ]';
[t y] = ode45(@Suhavrel,Tspan,y0);

%% Copying the results
p1 = y(:,1);
p2 = y(:,2);
p3 = y(:,3);
p4 = y(:,4);
p5 = y(:,5);



R=p1+p2+p3+p4;

 figure(3)
plot(t,R,'r');
figure(4)
plot(t,y);
```

Figure 3: The coding for reliability evaluation of SAC

C:\Users\Guest\Desktop\Code for suhailah\Suhavrel.m

This file uses Cell Mode. For information, see the rapid code iteration video, the publishing video, or help.

```
    function dp = Suhavrel(t,y)
%% Constant variables
% lm= failure rate,
% n= repair rate
lm16=0.00264;lm14=0.00264;lm12=0.00264;lm13=0.00264;lm25=0.00264;lm47=0.0
n21=0.0216;n31=0.0216;n53=0.0216;n86=0.0216;n74=0.0216;n52=0.0216;n41=0.0


%% model equations

   dp(1,1)=n21*y(2)+n31*y(3)-(lm14+lm12+lm13)*y(1);
   dp(2,1)=lm12*y(1)+n42*y(4)-(n21+lm24+lm24)*y(2);
   dp(3,1)=lm13*y(1)+n43*y(4)-(n31+lm34+lm36)*y(3);
   dp(4,1)=lm24*y(2)+lm34*y(3)-(n42+n43+lm57+lm58)*y(4);
   dp(5,1)=lm14*y(1)+lm24*y(2)+(lm57+lm58)*y(4)+lm36*y(3);
```

Appendix 3: **Steps in Block Sim Software.**

1. Create the Reliability Block Diagram (RBD) for the Steam Absorption Chiller system
2. Name the block diagram as Chilled Water System
3. Select 1P-Exponential distribution
4. Key in the value of MTBF for reliability graph and MDT for availability graph
5. Simulate the result in 1000 days and obtain the reliability and availability graphs.

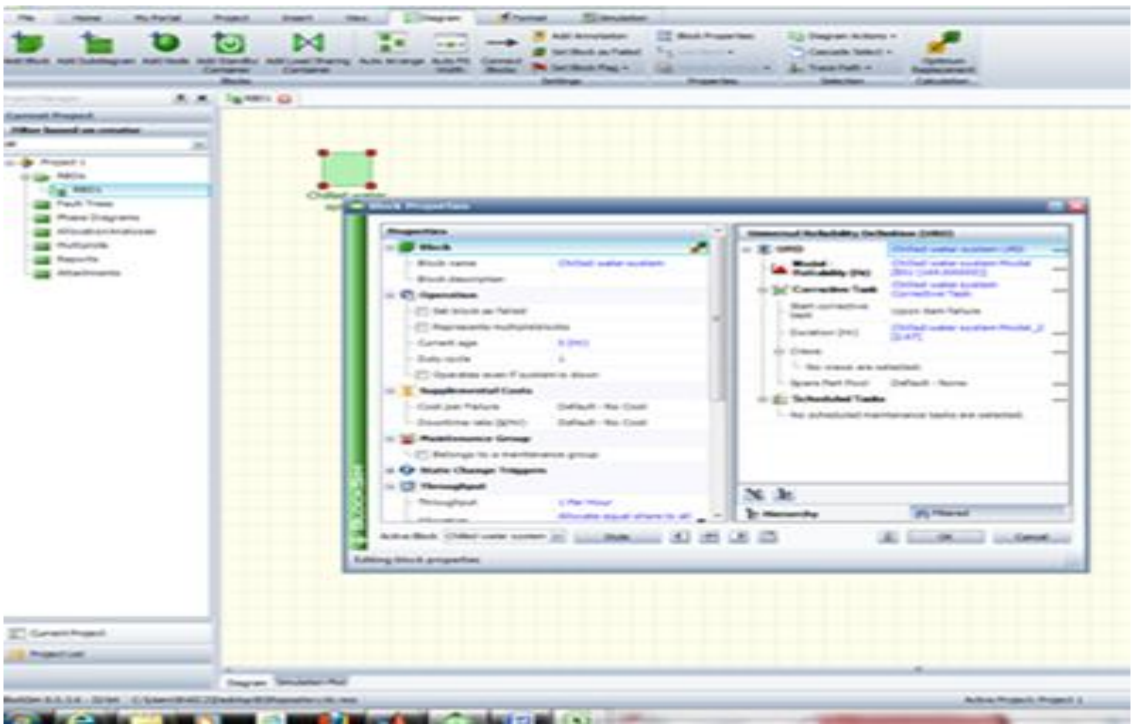


Figure 5: The parameters used to obtain reliability and availability graphs for Steam Absorption Chiller (SAC)

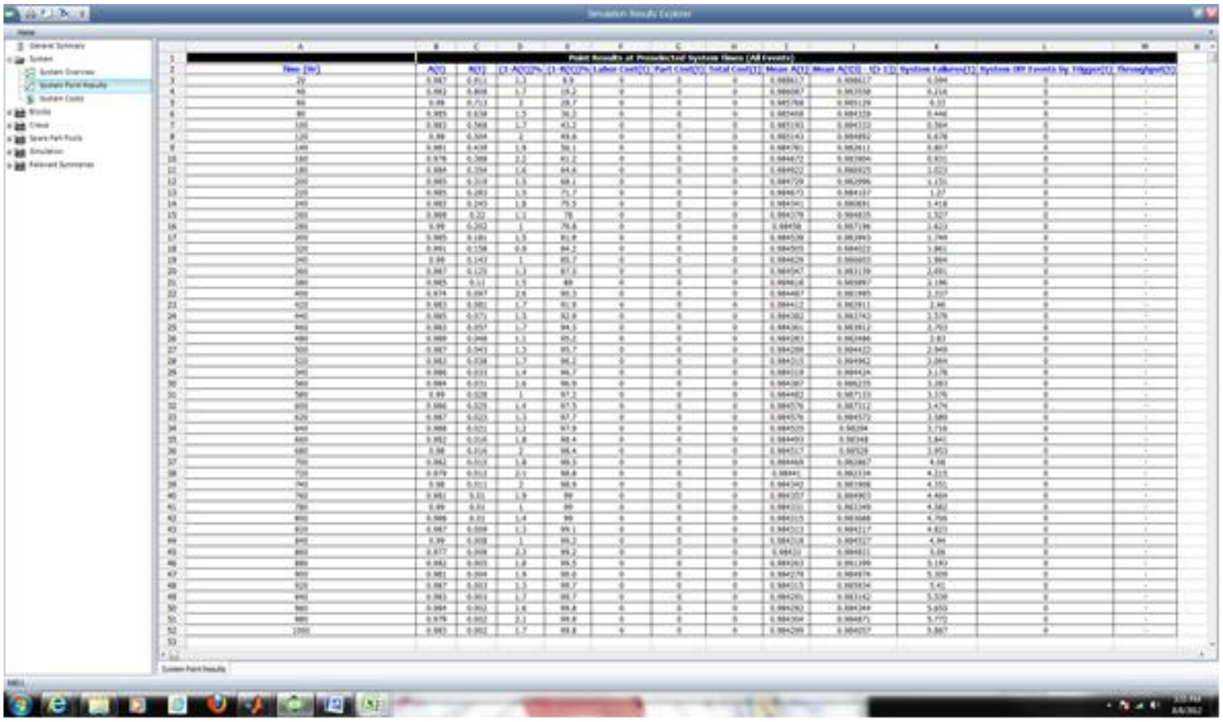


Figure 6: The simulation result summary for Steam Absorption Chiller (SAC)

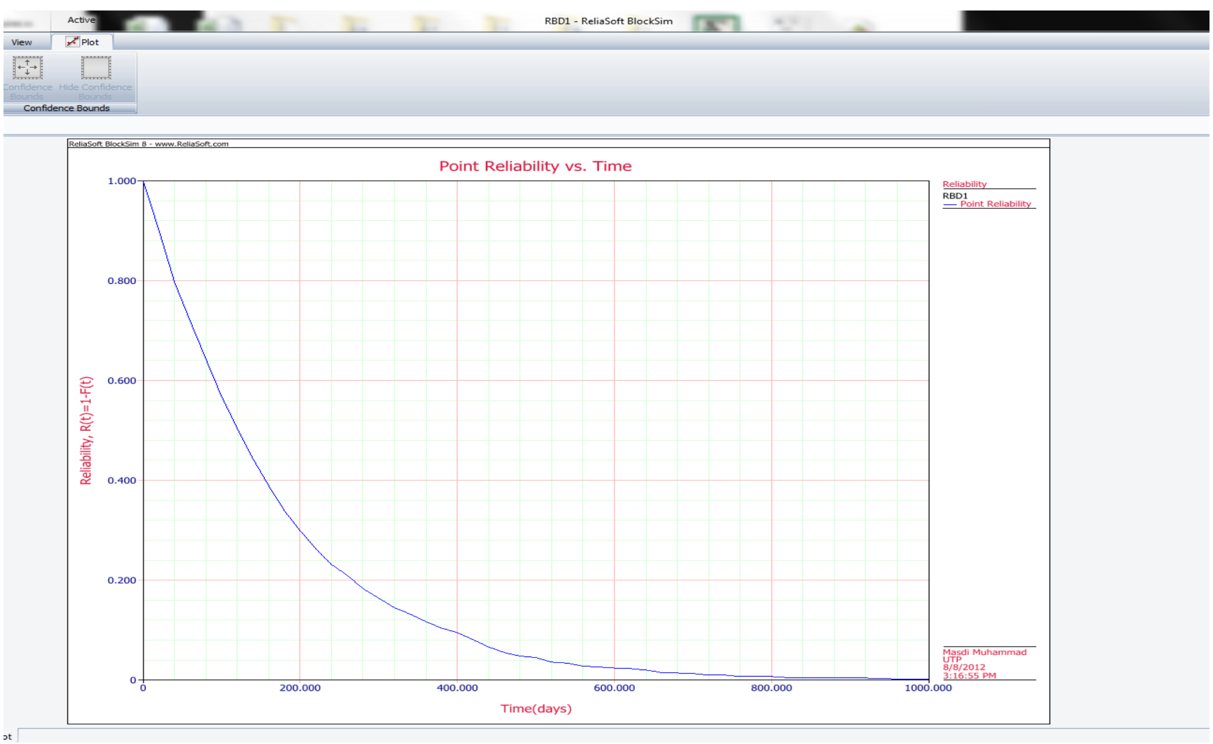


Figure 7: The reliability graph using Block Sim software for Steam Absorption Chiller (SAC)

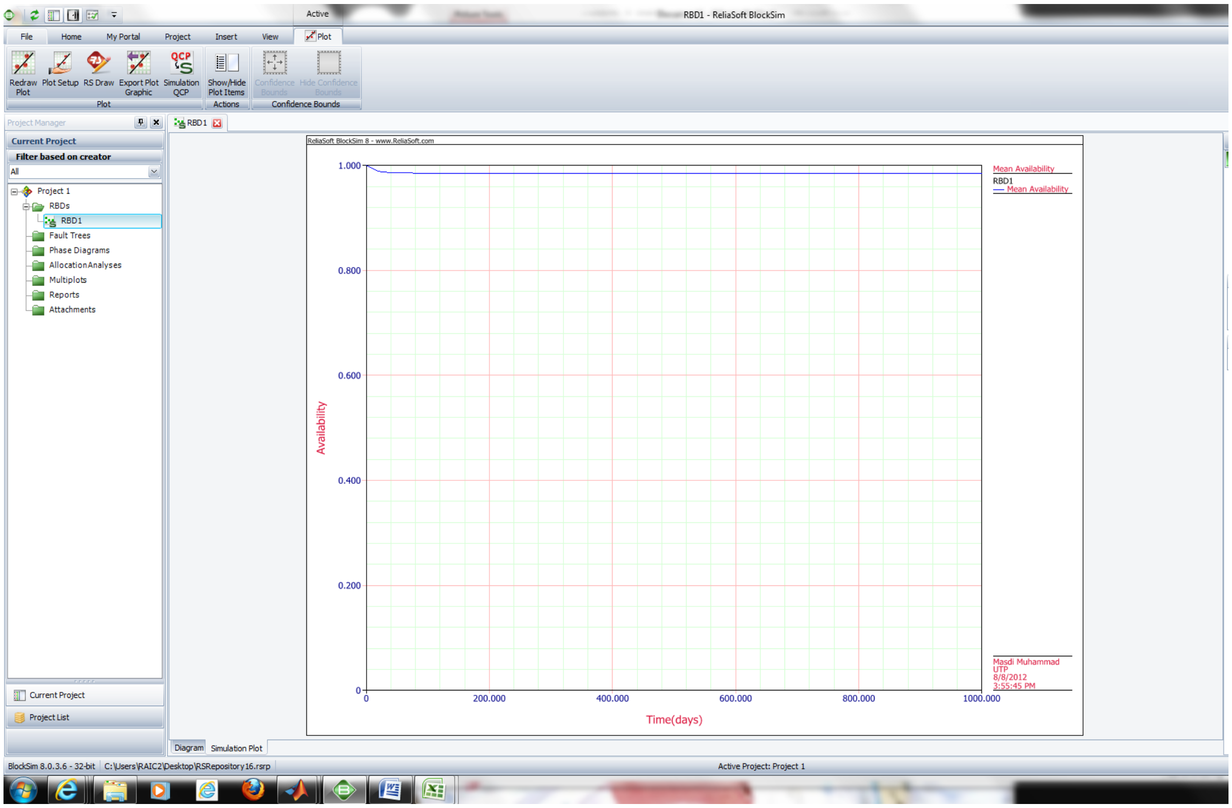


Figure 8: The availability graph using Block Sim software for Steam Absorption Chiller (SAC)