Simulation of potential benefits of implementing waste water heat recovery activities at Life Little Company of Mary Hospital

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Executive Summary

This project was initiated with the aim of determining whether implementing waste water heat extraction activities at Little Company of Mary Hospital would be financially feasible. Before this could be achieved however, the current environment within the hospitals' autoclave department needed to be thoroughly understood. To achieve this, a sampling study was initiated where the outflow temperatures and flow rates would be analyzed.

The current environment analysis yielded information pertaining to the operation time of the autoclaves, the proportion of the working day they were in operation, and most importantly enabled the temperature and flow rates to be defined statistically. Using this statistical information a pseudo-population of samples was created. Using up to date tariff pricing for electricity and heat transfer equations the current financial cost of the waste was estimated using a Monte Carlo simulation technique.

The simulation showed that for the two autoclaves in the study, the heat energy lost in the discharged water cost an estimated average of ZAR 4550.00 per year. The simulation also enabled the estimated amount of grey water lost to be calculated; just less than 864 cubic meters per year for the two autoclaves under study. The model also allowed for the estimation of savings should 70% of the lost heat be recaptured and this proved to be an estimated average of ZAR 3300.00 per year. Using a predicted tariff increase of 25% for the following year, and equivalent value for the waste was calculated for the period 2012/2013.

These calculated amounts will assist hospital management in coming to a decision as to whether the waste is acceptable or unacceptable; leading to further investigation if need be.

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1 Introduction

1.1 Background of Life Healthcare

Life Healthcare as it is known today was founded in 1983 as the hospitals division of African Oxygen Limited (Afrox) with the acquisition of four hospitals. Over the following 28 years the company has grown steadily with the acquisition and building of many more hospitals and specialist healthcare centers around the country, and strategic mergers and hospital group purchases. Life Healthcare has also had phenomenal success outside of South Africa. The purchase of Gaborone Hospital in Botswana and a 50-50 partnership with a UK health services company, Care UK Plc, helped place Life Healthcare in the international healthcare market.

In 1999 the Afrox Healthcare acquired a 55% stake in Life Healthcare and established a lucrative private public partnership with the South African government. In 2005 Afrox Healthcare was delisted and sold to a private consortium led by Brimstone and the successful Mvelaphanda Group resulting in a name change from Afrox Healthcare to Life Healthcare. In 2008 Life Healthcare acquired the remaining 45% stake in Life Esidimeni and three years later achieved the company's latest milestone when it was listed on the Johannesburg Stock Exchange's (JSE) main board.

With Life Healthcare owning and operating over 56 hospitals and specialist care centers around the country with a few of these in other countries, the company was forced to be innovative in its management strategy. The company made it a priority to ensure that expenses were decreased year on year, increasing its revenue, and most importantly improving the quality of service it provides to its over 8 million customers. While the initial cost reducing actions involved the more obvious applications of energy reducing technologies such as low energy consumption lighting, the company was forced to start looking deeper within its operations for areas that could be improved thus reducing costs. The subject of this project is a result of the company looking to reduce costs while maintaining and/or improving quality.

1.2 Background of the problem

Life Little Company of Mary Hospital is situated in Groenkloof, Pretoria and with the religious Sisters of the Order, doctors and supporting staff, has served the surrounding community with the utmost attention paid to care, quality and compassion for those who have found themselves in need of care at the hospital. Having been built in 1957, Little Company of Mary is one of the oldest hospitals operated by Life Healthcare and has-since 2008, embarked on a major renovation. With Life Healthcare embarking on large capital expansion, the group-managing director has put pressure on the hospital managers to cut down on annual expenses, forcing hospital managers around the country to be innovative in their attempts to stay under budget.

With most of the hospital's expenses having been fine tuned so as to save as much money as possible, there is very little room for improvement in these areas of expenditure and a perfect example of this was cited by Little Company of Mary Hospital manager, Mr. J Joubert who said,

"Even if there are no patients in the hospital, it still needs to be cleaned and the lights still have to be on. So most of the expenses our hospital has to pay for can be looked at as core operating fixed expenses-so it is very difficult to reduce a fixed expense in this context."

When asked what he thought was a clear waste of resources which he felt would be worthwhile looking into, he immediately stated that the autoclaves in the hospital's theatre were a good place to start. The hospital makes use of five autoclaves to sterilize the instrument packages that will be used in the hospital's theatre on a daily basis. The five units consist of four Hospi Sterilizer older generation JSD400 autoclaves and one older generation JSD160 autoclave. The JSD400 models use between 200 and 250 litres of water per cycle while the JSD160 model uses between 60 and 80 litres of water per cycle.

During each cycle the water is heated to between 100 and 120 degrees Celsius, depending on the cycle, and this steam is then circulated through the chamber containing the instrument packages. The used steam is then condensed under pressure after which it is discharged into the drain. Preliminary sampling indicates that the temperature of the discharged water is between 40 and 80 degrees Celsius. Another aspect worth taking note of is that, like all steam autoclaves, the steam is condensed under pressure by use of cold tap water which is circulated through the system. This water is also discharged even though is essentially clean.

By using statistical sampling techniques to gather information about the current situation of waste, the information gathered will be summarized into probability distributions describing temperature and flow rates. The resulting probability distributions will be used as inputs into a Monte Carlo model which will simulate a pseudo-environment that closely resembles the real time environment. The simulated data will then be used to calculate a (ZAR) Rand value representative of the money that is literally going the drain. This (ZAR) Rand value can then be used as the basis to decide whether minimizing the waste can be achieved in a financially viable manner.

The remainder of this document is structured as follows: The project aim and scope define explicitly what the aim of the project is and what will be covered and excluded from the project. A literature review will assess the various techniques to be used and their appropriateness to the topic of this project. The literature review will also discuss some cases of what has already been done in the sphere of waste water heat extraction and the realized benefits. The development of supplementary methods, tools and techniques section will describe and discuss the sampling technique used to gather the data. The gathered data will then be analyzed and discussed under the data analysis section. The development of the conceptual design of the solution will also be discussed in great detail. The results of the solution will then be discussed after which the document will be concluded with further points of study and recommendations on relative action to be taken.

1.3 Project Aim

To simulate the potential benefits of installing waste water heat recovery equipment in the autoclave department of Life Little Company of Mary Hospital and the financial implications thereof. This will be achieved through the completion of the following objectives;

1. Sample study
   - This enables the current state of waste to be studied and statistically defined.
2. Environment simulation
   - Using the information from Objective 1 a pseudo-environment resembling the real world environment will be simulated.
3. Results analysis
   - The results of the simulation will be analyzed and scrutinized to ensure that they are a fair representation of the real world environment.
4. Recommendations
   - The findings of objective 3 will be the basis of whether it is financially viable to proceed with further investigations into the subject matter.

1.4 Project Scope

The scope of this project covers only the gathering of data that is representative of the current state of waste that is exhibited by two of the five autoclaves at the hospital. The scope is limited to two autoclaves due to the fact that two of the five autoclaves are offline as a result of the renovations currently taking place in the theatre. The other one is broken and is awaiting maintenance. The purpose of this will be to simulate the current situation so that a monetary figure describing the waste in ZAR can be calculated. Any estimated amount of potential savings needs to be seen as conservative, the validation of which does not fall under the scope of this project. As such the (ZAR) Rand value to be calculated is the potential amount of savings that the hospital can realize through the implementation of waste water heat recovery solutions. The exact savings is dependant on the efficiency of the equipment that will be used and as such quantifying the exact amount of money that can be saved does not fall under the scope of this project.

2 Information Gathering

2.1 Literature Review

According to the Princeton University definition of simulation, simulation is: “the act of imitating the behavior of some situation or some process by means of something suitably analogous (especially for the purpose of study or personnel training)”. Similarly, modeling is the fabrication of a model with a model being defined as the: “representation of something (sometimes on a smaller scale)”.

Put together simulation modeling is the creating of a representation of a situation that will imitate the behavior of that situation on a smaller scale. Generally speaking it is possible to simulate almost anything if the nature of the subject is thoroughly understood and the input information is known and the process by which outputs are generated is understood. Given that there are infinitely different situations that one might want to simulate there are also numerous types of simulation techniques available. Each technique has its advantages and disadvantages and has been developed for use in simulating either a specific type of situation like heat transfer, or can be used to simulate a wide variety of situations.

The specific type of simulation technique that seems most equipped to be applied in the use of this project is a method known as Monte Carlo simulation. Haarhoff (2000) says Monte Carlo simulation is best used to simulate a process where the input values are not definitive but are rather represented by a distribution of values. Monte Carlo simulation selects random values from the distribution of input values for use in the simulation. This results in the output values being a representative sample of the distribution of possible outputs. Accurate results can be achieved with a smaller than usual number of simulations by being very selective of the input data. However when selecting input data in order to minimize the number of simulations needed, one needs to test the results for bias caused by the influence of selecting the inputs.

Hammersley and Handscomb (1964) in their chapter ‘The general nature of Monte Carlo methods’ state that Monte Carlo methods comprise that branch of mathematics who’s focus is experiments based on random numbers. They go on to say that these methods have become increasingly popular for use in the fields of Operations Research and nuclear physics, but have also been used sporadically in other fields such as Chemistry, Biology, and even Medicine. Monte Carlo methods offer an alternative to major cash expenditures when studying the behavior of specific statistics (Hammersley & Handscomb, 1964).

Mooney (1997) is of the same opinion as Hammersley and Handscomb (1964) in that he said that Monte Carlo simulation offers an alternative method to understand a statistics sampling distribution when analyzing its behavior in random samples as opposed to using conventional analytical mathematics. The way in which Monte Carlo achieves this is that it makes use of random samples from known populations of simulated data to analyze a statistics behavior (Mooney, 1997). Given the above explanations of what Monte Carlo methods are, it is still not apparent as to how the random samples are used and to what end. The following example might shed some light onto how Monte Carlo simulation may be used.

Imagine a simple real world event where through random sampling, a probability density function has been created. Say the event is how long it takes a customer to use an ATM. The probability distribution contains the probabilities that a customer will take a certain amount of time when using the ATM. What Monte Carlo simulation does is it allows random samples to be simulated out of the probability distribution. Keep in mind that the samples are simulated and do not represent actual events. From the samples an accurate average time can be calculated since there are ‘more’ samples to work with. A mean value calculated from 20 samples is less accurate than an average calculated with 1000 simulated samples. The accuracy of the simulation, however, depends on the sampling techniques used to get the original probability distribution.

So far the ‘what’ is simulation has been addressed which leaves the ‘when’ to make use of simulation. Simulation techniques have been used successfully in a variety of situations; the following four examples are cited by Rubinstein (1981) as situations in which simulation techniques have been successfully used:

(1) Where it is either impossible or too expensive to gather data from certain real world processes. (2) The system to be observed cannot be adequately described in mathematical terms from which analytical equations can be formulated and solved. (3) Straight forward analytical techniques may not be able to obtain a solution even though a mathematical model describing the system of interest has been successfully created. (4) Situations where validating the experiments are either impossible or too expensive to test alternative hypotheses.

It is quite clear that in situations (1) to (4) there are two options that can be considered when one removes the simulation alternative from the situation; cancel the project in light of the fact that information is impossible to attain or go ahead and implement the desired system and run the risk of it not having the desired affect due to the lack of data during its design and implementation. It is for these reasons that Rubinstein (1981) states that for all of the above mentioned situations, simulation is the only practical method that can be used to obtain answers.

The differences between conventional simulation and the Monte Carlo method are mentioned by Rubinstein (1981) and have been summarized below;

1. Time is not as substantial in Monte Carlo methods as it is in stochastic simulations.
2. As a rule, observations in the Monte Carlo method are independent. Whereas in simulation the model is experimented with over time making each observation sequentially correlated to the preceding observation.
3. The Monte Carlo method makes it possible to express responses as a simple function of the stochastic variate inputs. The simulation response is most often very complex, usually only expressible explicitly by the computer program itself.

The above mentioned differences are according to Rubinstein (1981) the most important differences between conventional simulation and the Monte Carlo method. As a result Rubinstein (1981) firmly holds the opinion that, 'The Monte Carlo method is now the most powerful and commonly used technique for analyzing complex problems'. The term *complex problems* has come to cover a broad spectrum of applications from radiation transport modeling to river basin modeling (Rubinstein, 1981).

Hammersley and Handscomb (1964), Mooney (1997) and Rubinstein 91981) all agree that Monte Carlo simulation makes use of random samples of generated data. Hammersley and Handscomb (1964) divide the problems that can be handled by Monte Carlo methods into two categories; probabilistic and deterministic. In both categories the empirical data that represents the population is what Mooney (1997) describes as a "pseudo population". The pseudo population is the artificial world that is created using mathematical procedures for generating random numbers that resemble the samples drawn from the real population. The implication of this is that the pseudo population and how it behaves is dependant on the mathematical procedures used to describe the random numbers generated in the pseudo population.

The mathematical procedures are defined based on samples taken from the real world population. Therefore, how closely the pseudo population imitates the real population is dependant on the sampling technique used when sampling the real population. In his book 'Sampling Techniques', Cochran (1977) covers a wide variety of sampling techniques in great detail. Sampling techniques covered range from simple random sampling, stratified random sampling to systematic sampling, cluster sampling, sub sampling and double sampling techniques. Among the advantages of using the sampling method are;

1. Reduced cost
    – Since data is secured from only a small fraction of the aggregate, expenditures will be considerably smaller than if a complete census is attempted (Cochran, 1977)
2. Greater speed
    – Data can be collected and summarized in a smaller space of time if a sampling technique is used than it would in the case of a complete count (Cochran, 1977)
3. Greater scope
    – The data gathered can focus on one or more attributes of interest since the sample itself is smaller than a complete count. Complete counts can sometimes be so involved that there is only room for one attribute to be studied (Cochran, 1977)

Cochran (1977) defined simple random sampling as, 'a method of selecting n units out of the N such that every one of the ${}_NC_n$ distinct samples has an equal chance of being drawn'. He goes on to describe the manner in which simple random sampling is employed. In simple random sampling the sample is drawn unit by unit where the units in the population are numbered 1 to N. A sequence of random numbers is then generated either by a table or computer with each random number corresponding to a unit in the population. The n random numbers drawn constitute the sample which comprises of the n units drawn that correspond to the random numbers (Cochran, 1977).

Simple random sampling in which the n numbers drawn at each successive draw are eliminated from the population, excluding them from successive draws is called random sampling without replacement. Conversely, random sampling with replacement is where each sample drawn is replaced. This ensures that each and every unit in the population has an equal chance of getting drawn for each successive draw (Cochran, 1977).

Stratified random sampling as defined by Cochran (1977) is when the entire population of N units is divided into sub-populations of $N_1, N_2, \ldots, N_L$ where the sub-populations are non-overlapping and the sum of which equals the entire population N. Each of the sub-populations are called strata, and a sample is drawn from each stratum and denoted $n_1, n_2, \ldots, n_L$ respectively. Once a random sample is drawn for each of the strata it is called stratified random sampling. Four principle reasons as to why stratified random sampling is a commonly used technique according to Cochran (1977) are;

1. If data of known precision are wanted for certain sub-divisions of a population, it is advisable to treat each sub-division as a population in its own right.
2. Administrative convenience might dictate its use, like in the case of a survey agency conducting a survey having different field offices, each of which can supervise the survey for a part of the population.
3. Sampling problems may differ markedly in different parts of the population. In the case of humans, some live in hotels, hospitals, prisons etc which means the sampling approach has to differ according to which strata the population fits into.
4. Stratification may produce a gain in precision in the attributes of characteristics of the whole population.

Cochran (1977) describes systematic sampling as being quite different from simple random sampling at first sight. He describes systematic sampling as the drawing of an initial unit numbered *k* and every *k*-th unit thereafter given the fact that the units within the population are numbered 1 to some number *N*. To illustrate this technique, say *k* is chosen to be 15 and the first unit drawn is the unit numbered 13, then the next 3 draws will be the units corresponding to the numbers 28, 43, 58, and so one. The selection of the first unit determines the whole sample (Cochran, 1977).

Two advantages that this method has over the simple random sampling method are (1) it is easier to draw the samples and execution of the technique can often be carried out without mistakes, and (2) systematic sampling seems likely to be more accurate than simple random sampling. In effect systematic sampling divides the population into n strata and the samples that are drawn every *k*-th unit represent one sample per strata. This results in the samples being more uniformly spaced out in the population and is said to give a more accurate depiction of the population as a whole. The same effect cannot be attained by using simple random sampling or even stratified sampling methods as the randomness of the samples that are taken in these two methods sometimes has the effect to give a less accurate depiction of the population by virtue of the random sampling itself (Cochran, 1977).

In light of the advantages of using Monte Carlo methods and the appropriateness of certain sampling techniques a model that attempts to simulate the randomness of the autoclave use at Little Company of Mary hospital will be created.

2.2 Some Energy Recycling Applications

Internationally, the topic of waste water heat recovery systems and the benefits thereof has been a key area of interest for many years. The main stakeholders behind the interest have mainly been 'big industry' representing a variety of manufacturing and processing operations seeking to cut costs through energy recycling. This energy recycling most often makes use of thermal energy in process waste products to supplement the power needed to sustain the process. Lazzarin (1995) summarized the application of energy recycling that has been practiced to great effect in a variety of large and small industries ranging from the steel industry, distillation plants, beer brewing processes in Japan, and even fish culturing.

A case study published in 1991 documented the benefits realized by implementing a waste water heat recovery system in a hospital laundry in Royal London Hospital in Whitechapel, London. The study concluded that through effective heat recovery and water management the laundry saw a 76% reduction in energy consumption by the washer extractors (washing machines) [Case Study 60 – BRESCU 1991]. According to MIT Footprint (2002) a study done at the Massachusetts Institute of Technology (MIT) redesigned the way water was used at the institute. Regarding the autoclaves used at the institute, the results of the study showed that by modifying the path of the water used in the autoclaves MIT saved an estimated 3.36 million gallons of water annually.

3 Development of Sampling Technique

The frequency of use of the autoclaves in the hospital's theatre is entirely dependant on the scheduled surgeries to take place on any given day. The result of this is the use of the autoclaves is entirely random since there is no way one can predict for certain how many surgeries will take place on a given day since there are scheduled surgeries and unscheduled emergency surgeries. The approach chosen to gather information on the use of the autoclaves was to use a stratified random sampling technique that involved taking random samples at the discharge pipe. The random samples would serve to measure two variables of the discharge water; the temperature and the flow rate. The flow rate was measured in mass per minute with the unit of grams/minute (g/min). The temperature was measure in degrees Celsius (˚C). Before the samples could be drawn a sampling schedule needed to be formulated. The steps followed to create, define and establish the sampling technique and all supporting activities were adapted from Freivalds (2009, ch 14) and are as follows;

1. Formulation of sampling schedule
2. Determination of sample size
3. Determination of sample frequency
4. Design of the sampling form
5. Sampling and data recording procedure.

3.1 Formulation of Sampling Schedule

To formulate the sampling schedule the normal shift structure of the hospital was used. The hospital theatre usually operates from 7am to 7pm. The 12 hour period sees a random and sporadic use of the autoclaves. Due to the tediousness of having to take random samples for a continuous 12 hour period, the 12 hour shift was divided into four strata with each strata being defined as follows;

1. Strata 1: 07:00 – 10:00
2. Strata 2: 10:00 – 13:00
3. Strata 3: 13:00 – 16:00
4. Strata 4: 16:00 – 19:00

Each of the four strata is exactly same length of time, 3 hours. Figure 1 illustrates how the working day was broken down into four strata equal in length.

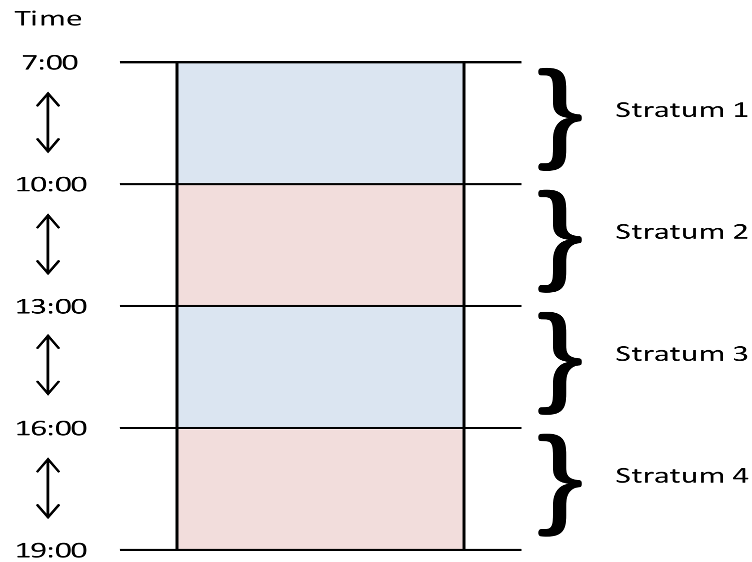


Figure 1: Visual representation of sample strata.

The approach was to take random samples during each of the strata so as to get a total sample population representing 5 week days. The way in which this will be achieved is during a 20 week day period each stratum will be randomly sampled in succession. To state this in clearer terms, on day 1 – strata 1 will be sampled, on day 2 – strata 2 will be sampled and so on until all four strata have been sampled five times. **Error! Reference source not found.** illustrates the schedule visually below.

Strata	Day																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	■				■				■				■				■			
2		■				■				■				■				■		
3			■				■				■				■				■	
4				■				■				■				■				■

Table 1: Sampling Schedule.

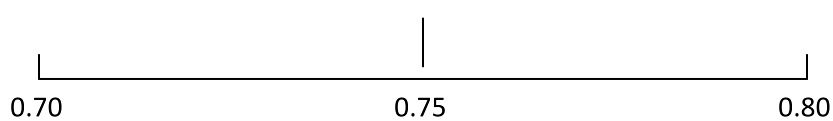
The reasoning that lead to the development of the sampling schedule in **Error! Reference source not ound.** is that the sample period needed to be as broad as possible. Given the time constraints on the project and the late stage at which sampling was determined to be required, sampling over a period of 20 working days was best. Sampling over 20 week days allowed the entire month to be sampled. This has the added advantage in that it ensures that the sample data gathered is representative of a week. However that week is a representation of all the week days of the month. Once the sampling schedule had been worked out the next step was to determine how many samples should be drawn in total and how many samples needed to be drawn per stratum.

3.2 Determination of Sample Size

Once the sampling schedule had been finalized the next step was to calculate how many samples would need to be taken in order to create a representative pseudo-population with the highest feasible degree of certainty. Freivalds (2009) describes a statistical formula that can be used to determine the number of samples to be taken. Freivalds (2009) states that, 'work sampling is based on the fundamental law of probability: at a given instant, an event can be either present or absent.' This theory is applicable to this particular project since at the time of each of the random samples the autoclave can either be on (i.e. discharging hot water), or off (i.e. discharging nothing at all). The plan is to sample both pipes simultaneously and recording the measured attribute characteristics namely, mass flow rate (grams/second) and temperature (°C).

Hospital management stated that they would not be surprised if the autoclaves ran for a total of 9 hours out every 12 hours of day shift. This ratio translates to a probability that at least one autoclave is working at any one particular time during the day shift at 75% or 0.75. Using a limit of error of 5% we get the following diagram.

So taking our mean as $\bar{o} = 0.75$ and our limit of error $\ell = 0.05$



Using $\bar{o}$ and ℓ and a 95% confidence interval we can substitute into the following equation to work out how many samples need to be taken using the following equation,

$$\mathbf{N = [(3.84)\ \bar{o}\ (1 - \bar{o})] / \ell^2} \qquad (1)$$

The resulting number of samples to be taken is 288 however when using a random number generator such as MS Excel and over so many days the result was some strata were represented more than others. This is clearly from the fact that 288 cannot be divided by 20 without leaving a remainder of 8. This lead to concern that some important data might be left out making the resulting pseudo-population of generated data less accurate. To solve the problem it was decided that each stratum should be sampled 25 times at random. The result is that each stratum will be sampled 125 times, giving each stratum equal showing in the sample data. To justify, substitute n = 500 in equation (1) above and solve for the resulting limit of error, ℓ. Solving for ℓ we attain a limit of error of approximately 3.8% which is an improvement on the originally chosen 5% limit of error.

3.3 Determination of Sample Frequency

Freivalds (2009) states that once the sample size has been determined the next step is to determine the sample frequency. The sample size was decided in section 3.2 and all that remained was to determine the actual times that the samples are to be taken. Freivalds (2009, pp 555) maintains that in order to obtain a representative sample, samples are to be taken at random times throughout the sample period. Random times can be found in the same manner when using either a random number table or software programs such as MS Excel. The approach to creating random times from random numbers is described by Freivalds (2009, pp 555) and has been adapted and summarized as follows; to find 25 sample times out of a possible 180 sample opportunities one would:

1. Select 25 numbers from a set of numbers ranging from 1 to 180 that represent each minute in the stratum.
2. Each of the numbers selected is assigned to a minute number and is translated into a time value.

As an example of the above process, say the number 28 was selected. That number 28 represents the 28^{th} minute from time zero (t = 0). Time zero is the earliest possible time in the stratum and for stratum 1 this time would be 07:00 AM. The resulting random sample time is then found at the 28^{th} minute after time zero, specifically 07:28 AM. This process was followed to determine the sample times for all the strata except MS Excel was used in place of a random number table. An example of 25 random numbers and correlating time for each sample in the stratum for the first four days are compiled in Table 2.

Random Sample Times								
Sample No.	s1d1		s2d2		s3d3		s4d4	
	Random No.	Time (hh:mm)	Random No.	Time (hh:mm)	Random No.	Time (hh:mm)	Random No.	Time (hh:mm)
1	4	7:04	7	10:07	3	13:03	1	16:01
2	11	7:11	11	10:11	15	13:15	5	16:05
3	16	7:16	19	10:19	29	13:29	12	16:12
4	27	7:27	22	10:22	35	13:35	21	16:21
5	33	7:33	25	10:25	39	13:39	24	16:24
6	42	7:42	31	10:31	43	13:43	31	16:31
7	46	7:46	38	10:38	49	13:49	40	16:40
8	51	7:51	48	10:48	53	13:53	45	16:45
9	59	7:59	55	10:55	55	13:55	56	16:56
10	67	8:07	63	11:03	59	13:59	60	17:00
11	72	8:12	70	11:10	68	14:08	66	17:06
12	79	8:19	76	11:16	72	14:12	75	17:15
13	88	8:28	84	11:24	80	14:20	79	17:19
14	91	8:31	90	11:30	87	14:27	87	17:27
15	98	8:38	97	11:37	89	14:29	89	17:29
16	106	8:46	105	11:45	97	14:37	100	17:40
17	117	8:57	118	11:58	101	14:41	115	17:55
18	121	9:01	126	12:06	115	14:55	122	18:02
19	129	9:09	133	12:13	121	15:01	132	18:12
20	137	9:17	141	12:21	131	15:11	137	18:17
21	144	9:24	149	12:29	140	15:20	147	18:27
22	151	9:31	156	12:36	151	15:31	156	18:36
23	159	9:39	161	12:41	163	15:43	164	18:44
24	164	9:44	168	12:48	167	15:47	170	18:50
25	173	9:53	176	12:56	173	15:53	172	18:52

Table 2: Random Sample Times.

Table 2 shows the random sample times for the first four days of the 20 day sample period. A new set of random sample times was calculated for each sample session. This was to ensure that an accurate representative sample population would be drawn with minimal bias. The complete set of tables containing the random sample times for the full 20 day sample period can be found in Appendix A.1.

3.4 Design of the Sampling Form

Freivalds (2009, pp 556) states that standard sampling forms are usually not acceptable for use since all sampling studies are inherently unique. As a result new sampling forms need to be designed and tailored for each study so that the required and relevant information can be recorded correctly (Freivalds, 2009). A sampling form had to be designed for this particular project. The form needed to provide space to record both of the measured variables for each sample. The form also needed to provide for the recording of relevant notes and comments that may be relevant to a particular sample. Notes and comments pertaining to the immediate study environment during a sample session also needed to be provided for.

Apart from providing a platform for the recording of sample data, the form also needed to promote and ease the process of taking samples. This was achieved by the natural sequential flow of the sample taking process into the form to ensure a smooth transition from one sample to another. Lastly, features that are not compulsory but encouraged nonetheless are integrity checks that fit in with the natural flow of the sampling process. Integrity checks are tasks that ensure that the data gathered during the next sample is accurate by means of properly prepared apparatus.

An example specifically related to this project the check that needs to be performed before subsequent samples are drawn where the scale is zeroed and the container is wiped dry. This ensures that the scale is ready for the next weighing and that the mass measurement will not be contaminated by water still adhering to the container from the previous sample or the weight of the container. These checks ensure the integrity of the data recorded from subsequent samples. An example of a sample form can be found in Appendix A.2.

3.5 Sampling and Data Recording Procedure

The final step in developing the sampling study was to clearly define the procedure by which the samples are to be drawn, analyzed (measured), recorded. A five step procedure was developed specifically for this project based on what actions were required to be performed per sample. The five step procedure is represented graphically in Figure 2. The procedure depicted in Figure 2 was developed in conjunction with the design of the sampling form discussed in section 3.4.

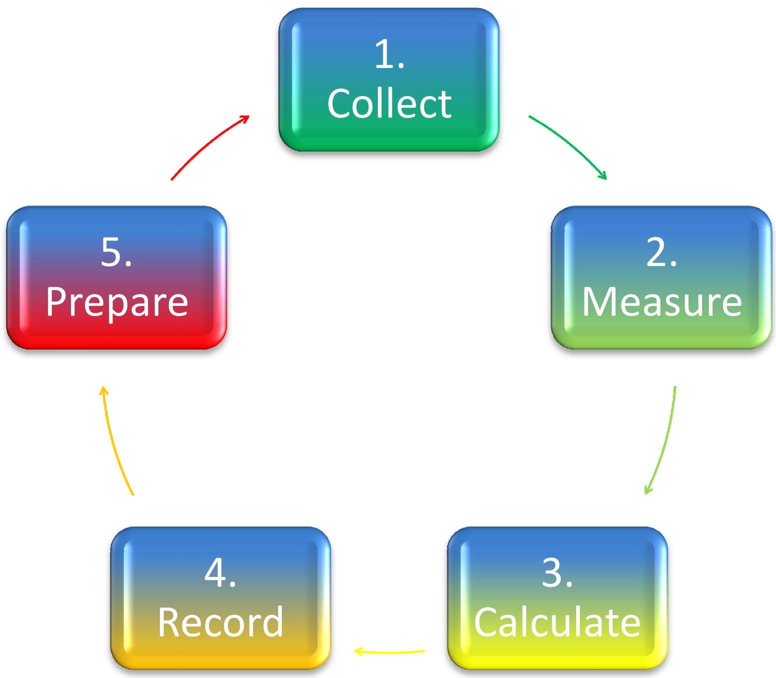


Figure 2: Five step sampling and data recording procedure.

Figure 2 shows the following five steps;

1. Collect
2. Measure
3. Calculate
4. Record
5. Prepare

3.5.1 Step 1: Collect

The first activity that needs to be performed before any other is that of collecting the sample. To collect the sample a vessel was used to collect the water discharged from the discharge pipe during a 60 second interval. The water collected represents the sample and it is from this sample that the required data will be measured. Refer to Figure 1 in Appendix B for a picture of the vessel used.

3.5.2 Step 2: Measure

The second activity to be performed is that of measuring the weight (in grams) and the temperature of the sample collected in Step 1. This activity is done as soon as possible after Step 1 so as to maintain the accuracy of the temperature readings. Refer to Figure 2 in Appendix B for pictures of the scale and thermometer used.

3.5.3 Step 3: Calculate

The third activity is to calculate the flow rate in grams per second. This is calculated by dividing the weight of the sample (in grams) by the interval length of 60 seconds.

3.5.4 Step 4: Record

The fifth step of the procedure is to record the measured temperature from Step 2 and the calculated flow rate from Step 3 onto the sample form in the appropriate space provided. It is also during this step that any other comments or notes are to be recorded.

3.5.5 Step 5: Prepare

The final step in the five step procedure is to prepare for the equipment for the next iteration of the process. By this it is meant that the collection vessel needs to be wiped dry and that the scale needs to be zeroed. Wiping the vessel eliminates the possibility of residual water contaminating successive samples while zeroing the scale ensures that the weight of the vessel is eliminated from the measured data.

3.6 Chapter 3 Summary

Chapter Three's basis has been to define and discuss one of the most important aspects of simulation modeling; data collection. As stated in Chapter Two, accurate simulations can only be created after in depth understanding of the problem and it environment has been attained. For the purpose of this project such understanding could only be achieved through sampling techniques.

The accuracy of the techniques depends not only on the applicability of the specific sampling technique but also its execution and supporting processes. In this chapter the exact method of sampling, data recording and when were defined. The defined methods and processes could then be used to carry out the sample study.

4 Data Analysis

The most important aspect to consider when analyzing gathered data is to clearly define the data. In the 3rd edition of 'Quality Management' Gitlow et al (2005) classify data into two types; attribute data and variables (measurements) data. Attribute data arise from either (1) the classification of items into categories; (2) counts or proportions of the number of items per category; and (3) counts of the number of occurrences per unit (Gitlow et al, 2005). The data gathered during the sample study is of the variables (measurement) type since it arises from a measured characteristic of a product, service or process. Variables (measurements) data can also arise from the calculation of a numerical value from two or more measurements of variables data (Gitlow et al, 2005). The data gathered during the sample study contains information. Before the information can be used the sample data needs to be sorted and analyzed. This serves to rectify any anomalies in the data before they are used. By rectifying and/or eliminating anomalies in the data, the information extracted from the data will be more credible and application accuracies will increase.

4.1 Sample Non-conformity

During the sample study there were instances when the sample could not be collected over the full 60 second period due to the flow rate of the water (see Appendix C). In these instances the water discharged from the pipe was ejected at a rate that was impossible to collect in a 2.2L container over 60 seconds. Ideally the solution was to use a container with a greater capacity however the available space could not accommodate the larger container. Instead, when the flow rate was seen to be great enough so that a full 60 second sample was impossible, the sample period was reduced accordingly. When reducing the sample period, careful judgment needed to be exercised so that the sample period was as long as possible without the container overflowing. This tactic created numerous samples that were collected over sample periods of 5, 10, 15, 20, and 30 seconds in length.

The decision to reduce the sample period time during these instances rests on the assumption that the flow rate is constant at any instant of time. To explain this more clearly take for example a sample that was gathered over a sample period of 5 seconds. To calculate the flow rate per minute one would just multiply the value by 12. However multiplying by 12 uses the assumption that the flow rate is constant and would have been constant for the 55 seconds of flow that were not recorded. Due to the fact that the pipe being sampled discharged water from, not one, but two autoclaves there is the chance that the flow rate would indeed change. The chance that the flow rate would have changed is incalculable and so the change in flow rate is also incalculable. This uncertainty makes converting the '5 second sample' into a 'minute sample' dangerous in that it could distort the data significantly reducing the accuracy by which it resembles the real world.

To avoid distorting the data the most basic unit of flow rate was used; grams per second. This ensured that the converted data inherently possessed more certainty since converting five seconds of flow to flow-per-second was more accurate than converting to flow-per-minute. It is for this reason that Step 3 of the sampling procedure discussed in Section 3.5 was included.

4.2 What the Sample Data Says

The sample data gathered during the sample study can be manipulated to extract various pieces of information regarding the autoclaves and the discharged water. The information that can be extracted from the data as it stands is;

- Representative percentage of the day the autoclaves are in use
- Frequency of temperature and flow rate occurrences within specified intervals proportionate to the sample population
- Frequency of temperature/flow rate combination occurrences within specified intervals proportionate to the sample population.

4.2.1 Estimated Autoclave running time

The sample data can be used to estimate the proportion of the day that the autoclaves are in use. Recall from Section 3.2 that the estimated time the autoclaves were expected to be in use was 75% of the 12 hour working day. To make it simpler, 75% of 12 hours is 9 hours, and so it was estimated that the autoclaves were in use 9 hours per day shift. Using the sample data, simple logic, and the built-in functions in MS Excel the validity of the estimate could be tested.

The logic used to determine the estimated usage time was based on the assumption that if the autoclave was in use the corresponding sample data would reflect non-zero measurements. Likewise, if the autoclaves were not in use then the corresponding sample data would reflect zero measurements. Simply stated, positive integers represent the "on" state and zero values represent the "off" state. Using binary operators 1 and 0 to denote the "on" and "off" states and calculating the frequency of each state proportionate to the total number of samples, percentage values were calculated for each state. The estimated figures from Section 3.2 and the new derived figures can be found in Table 3.

	Old Estimate	Derived Estimate
Hrs of use per 12 hr day shift	9 hours	11.442 (11h 26m)
Hrs not in use per 12 hr day shift	3 hours	0.558 (0h 34m)

Table 3: Estimated and Derived Figures of Use.

It would be remiss if each of the figures in Table 3 was not adequately explained in context. The estimated figure discusses in Section 3.2 was derived when all of the hospitals five autoclaves were operational. The derived figures in Table 3 were calculated from data sampled from only two autoclaves out of the five. It should also be noted that due to the renovations that are currently going on at the hospital, two autoclaves are offline and a third is offline due to repairs. Essentially, what was being done with five autoclaves is now being done with only two of them explaining the sharp difference between the estimated figure of use and the derived figure of use.

4.2.2 Frequency of Temperature and Flow Rate Occurrences

The sample data can provide information regarding the number of times the discharge water falls within a specified temperature range and can likewise provide the same information regarding the flow rate. Categorizing the information allows it to be used in ways the sample data could not. Being able to estimate the proportion of time in which a variable will be within a specified range of values can be immensely helpful when planning future projects.

4.2.2.1 Frequency of Temperature Occurrences

To determine the frequency of temperature occurrences the temperature intervals needed to be defined first. Starting at zero and increasing in increments of 10 ˚C up until greater than 100 ˚C resulted in 11 temperature intervals into which the data values could fall. Using MS Excel’s built-in FREQUENCY-array function the temperature values were sorted into their respective intervals and counted. The result of the FREQUENCY function can be found in Table 4.

Interval (˚C)	Bins	Frequency	Relative Frequency	Cumulative Frequency
>10	10	23	0.046	0.046
10 - 20	20	0	0	0.046
20 - 30	30	129	0.258	0.304
30 - 40	40	85	0.170	0.474
40 - 50	50	149	0.298	0.772
50 - 60	60	70	0.140	0.912
60 - 70	70	30	0.060	0.972
70 - 80	80	10	0.020	0.992
80 - 90	90	4	0.008	1.000
90 - 100	100	0	0	1.000
>100		0	0	1.000

Table 4: Frequency of Temperature Occurrences.

Table 4 shows the intervals that the temperature spectrum has been divided into along with the number of data values that fall within those intervals in the column labeled 'Frequency'. How the data is divided into the intervals is simple; for the temperature interval 10˚C – 20˚C, MS Excel searches for temperature values that are grater than 10˚C but less than/equal to 20˚C . It does this until all of the temperature values have been assigned to a specific temperature interval. Looking at the table it can be seen that the number of samples collected that had a temperature reading of between 10˚C and 20˚C was 0 indicating that there were no samples with a temperature value that fell into this temperature interval. However the temperature interval 40˚C - 50˚C accounts for 29.8% of all the temperature readings recorded.

The last two columns of Table 4 exhibit the relative and cumulative frequencies of the temperature occurrences. These are calculated by dividing the number of occurrences within a specific temperature interval by the total number of occurrences; 500. The cumulative frequency is calculated by adding each successive relative frequency value to each other. Cumulative frequency always stops at 1 since maximum occurrence percentage is 100%. An easier way to represent the information in Table 4 is to construct a Histogram, shown in Figure 4.

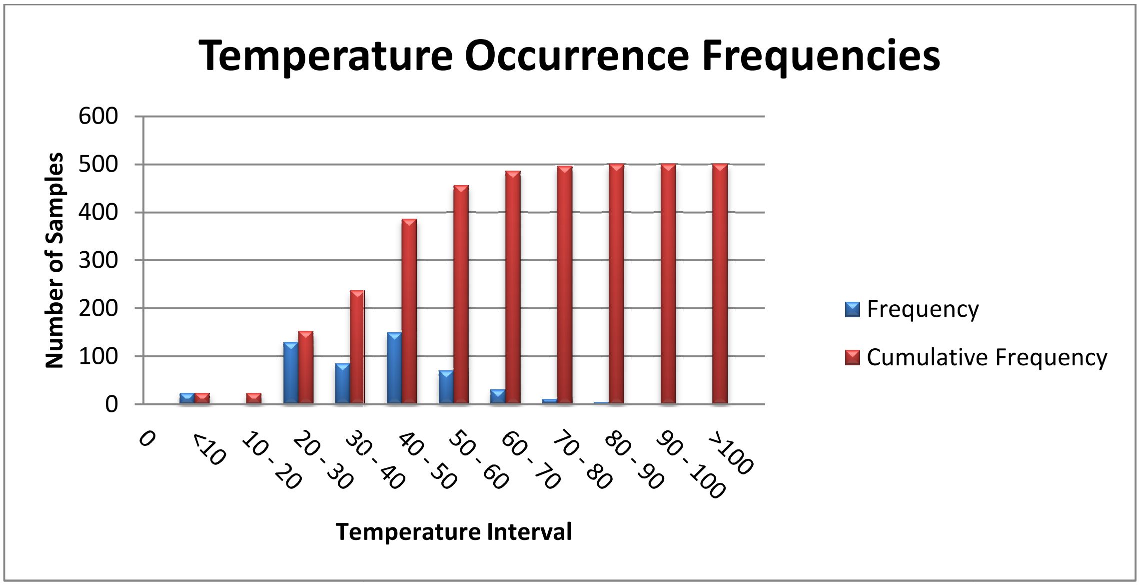


Figure 3: Graph of Temperature Occurrence Frequencies.

The histogram depicted in Figure 3 contains all the information that can be found in Table 4 only that it is easier to visualize.

4.2.2.2 Frequency of Flow Rate Occurrences

To determine the frequency of flow rate occurrences the flow rate intervals needed to be defined first. Starting at zero and increasing in increments of 100 grams/second up until greater than 500 resulted in 6 flow rate intervals into which the data values could fall. Using MS Excel's built-in FREQUENCY-array function the flow rate values were sorted into their respective intervals and counted. The result of the FREQUENCY function can be found in Table 4.

Interval (g/s)	**Bins**	**Frequency**	**Relative Frequency**	**Cumulative Frequency**
>100	100	375	0.75	0.75
100 - 200	200	10	0.02	0.77
200 - 300	300	22	0.044	0.814
300 - 400	400	93	0.186	1.000
400 - 500	500	0	0	1.000
>500		0	0	1.000

Table 5: Frequency of Flow Rate Occurrences.

Table 5 shows the intervals that the flow rate spectrum has been divided into along with the number of data values that fall within those intervals in the column labeled 'Frequency'. The data is sorted into the flow rate intervals in same manner as that explained in Section 4.2.2.1 regarding temperature. A histogram depicting the information shown in Table 5 is shown in Figure 4.

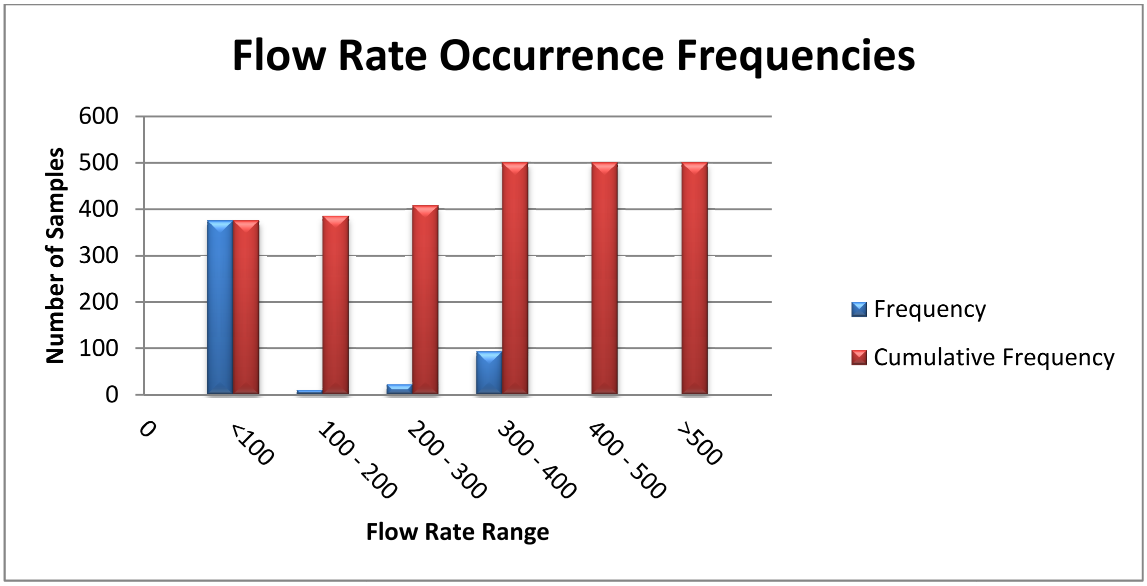


Figure 4: Graph of Flow Rate Occurrence Frequencies.

4.3 Frequencies of Temperature-Flow Rate Occurrences

In this sub-section the two frequencies discussed in the previous section will be combined to create a new and entirely different set of information. By using the same intervals as those defined in 4.2.2.1 and 4.2.2.2 we can sort the sample data into categories defined by a temperature interval AND a flow rate interval. This will allow the data to be viewed in a format where the two measurable attributes are studied simultaneously. The data was arranged in much the same way as in the individual temperature and flow rate frequency studies however the results are depicted in a table that is very different from the simple Table 4 and Table 5 shown in the previous sub-section.

For each temperature reading, the corresponding flow rate reading must fall in one of the six previously defined flow rate intervals. The same can be said about a temperature reading in that it too must fall into one of the temperature intervals. If each sample is sorted in this manner a frequency density table will start to emerge. The result is depicted in Table 6.

Intervals		<10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	>100
	Bins	10	20	30	40	50	60	70	80	90	100	More
<100	100	23	0	57	62	133	67	23	9	3	0	0
100 - 200	200	0	0	1	2	4	0	0	1	1	0	0
200 - 300	300	0	0	9	1	6	0	4	0	0	0	0
300 - 400	400	0	0	60	22	7	2	3	0	0	0	0
400 - 500	500	0	0	0	0	0	0	0	0	0	0	0
>500	More	0	0	0	0	0	0	0	0	0	0	0

Table 6: Temperature-Flow Rate Frequencies.

Table 6 shows the distribution of the number of samples that occur within a specific temperature interval that also occur within a specific flow rate interval. The column numbered 3 contains the temperature interval 20˚C - 30˚C and shows that there were 57 samples within this temperature range that fall in the flow rate interval >100. Simply put, there are 57 samples with measured temperatures between 20˚C and 30˚C that have measured flow rates of 100grams/second or less. This information is significant since it is now possible to get a visual depiction of the sample population based on BOTH temperature and flow rate. Using the information in column 3 it is possible to state that 11.4% of the samples collected had temperatures between 20˚C and 30˚C and flow rates between 0 and 100 grams per second. Figures 6 is an example of how one could visually depict the temperature occurrences for each flow interval.

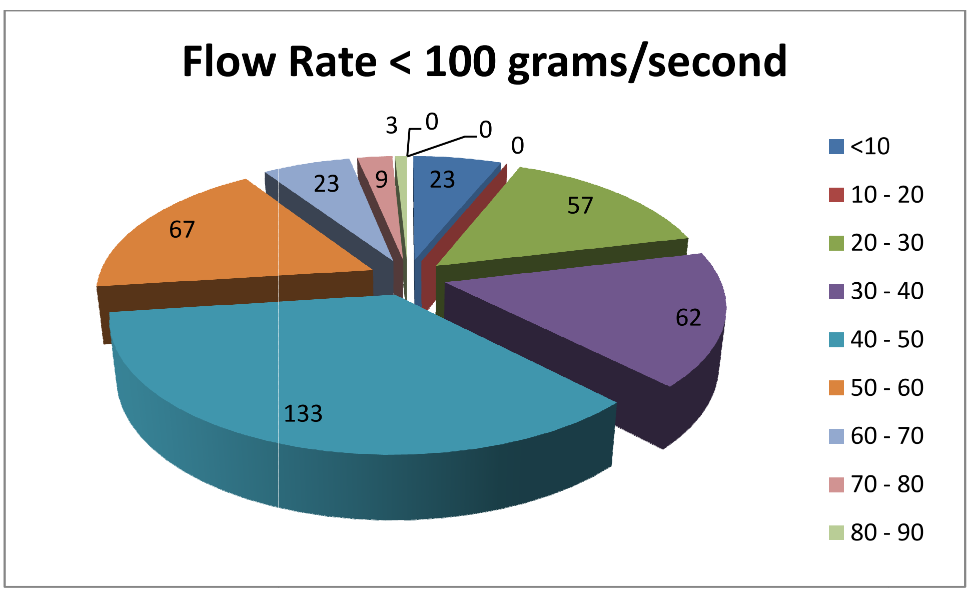
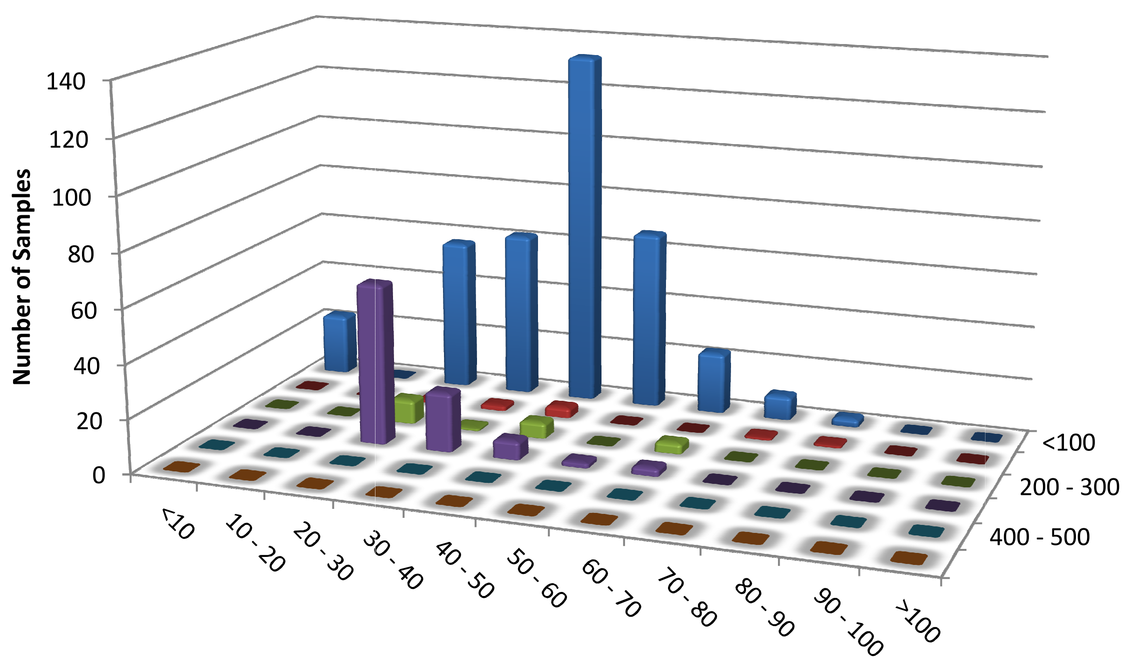


Figure 5: Temperature Frequencies for Flow rate <100 g/s.

It is also possible to visually depict the entirety of Table 6 in a 3-dimensional graph using MS Excel. Figure 6 gives a graphical representation of the sample population as a landscape with bars of differing heights representing the number of occurrences within each interval. It is now easy to see that the data is either two-sided normally distributed around a mean (blue columns) or singularly sided normally distributed around a mean (purple, green and red columns).

Frequency density of Sample occurrences within flow rate/temperature intervals.



	<10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	>100
<100	23	0	57	62	133	67	23	9	3	0	0
100 - 200	0	0	1	2	4	0	0	1	1	0	0
200 - 300	0	0	9	1	6	0	4	0	0	0	0
300 - 400	0	0	60	22	7	2	3	0	0	0	0
400 - 500	0	0	0	0	0	0	0	0	0	0	0
>500	0	0	0	0	0	0	0	0	0	0	0

Figure 6: Frequency Density of Sample Occurrences within Flow Rate/Temperature intervals.

4.4 Summary of Sample Data for use in the Project Model

The data contained in the sample forms in Appendix C cannot be used in format it was gathered in. It needed to be analyzed so that it could be defined statistically. Once the statistical information describing the sample population has been defined it can be used in the project model. Since the sample study involved the measuring of two characteristics it is difficult to discover the statistical definition that describes the sample population. Thankfully this difficulty can be circumvented owing to the type of data the sample study gathered. As mentioned at the beginning of this section, variables or measurement data arises from one of two scenarios;

1. From the measuring of a characteristic, or
2. The calculation of a variable measurement value from two or more measured variables.

Scenario 2 is how the sampled variables data for two characteristics was used to compute a third, single variables measurement value. These new values were then used to define the sample population statistically so that it could be applied to the project model.

4.4.1 Equation used to Compute Third Single Variable Data Value

The equation that was used to compute a single variables measurement value is a standard heat transfer equation taken from 'Heat Transfer – A Practical Approach' by Cengel 2006, and is shown below.

$$\mathbf{dQ/dm\ (Q) = d/dm\ (m)c_p\Delta T} \qquad (1)$$

Where: dQ/dm (Q) = rate of heat transfer (J/s)

d/dm (m) = mass flow rate (g/s)

c_p = specific heat of water (J/g.°C)

ΔT = difference in temperature between two interacting fluids ($T_2 - T_1$) (°C)

Equation 1 can be expanded further to become the expression in equation 2 below.

$$\mathbf{dQ/dm\ (Q) = [(d/dm\ (m)c_pT_2) - (d/dm\ (m)c_p\ T_1)]} \qquad (2)$$

Where: dQ/dm (Q) = rate of heat transfer (J/s)

d/dm (m) = mass flow rate (g/s)

c_p = specific heat of water (J/g.°C)

T_1 = temperature of cooler interacting liquid (°C)

T_2 = temperature of hotter interacting liquid (°C)

Looking at Equation 2 as it is now it is evident that the product, d/dm (m) x T^2, can be replaced with a new measured variable say. We will call this new variable B.

The new calculated variable, B, will be computed using the measured flow rate, d/dm(m) and the measured temperature, T_2. The new adapted equation is now;

$$\mathbf{dQ/dm\ (Q) = [(B \times c_p) - (d/dm\ (m)c_p\ T_1)]} \qquad (3)$$

Where: dQ/dm (Q) = rate of heat transfer (J/s)

d/dm (m) = mass flow rate (g/s)

c_p = specific heat of water (J/g.°C)

T_1 = temperature of cooler interacting liquid (°C)

B = d/dm (m) x T_2 - where T2 is the measured temperature (°C)

The use of the computed variable measurements value, B, allows the sample data to be used within the project model in a manner that avoids too much tampering and manipulation. A simple algebraic product enables the data to be statistically defined accurately.

4.4.2 Defining the Sample Data Statistically

Defining the sample data statistically was made easier with the computation of a new variables measurement value. Once the set of products were calculated the mean, standard deviation and variance of the distribution were calculated using MS Excel's built in statistical functions and are shown in Table 9.

Statistical Information	
Mean	2862.397
Standard Deviation	4393.013
Variance	19298559.531

Table 7: Sample Data Statistical Information.

4.5 Summary of Chapter 4

The basis of this chapter was to illustrate the value that can arise from proper data analysis. Although the above data is not specifically tied into the aim of this project it does shed more information on the study environment with the environment being the autoclaves. Being able to attain information that may help support the outcome of the project is a good incentive to properly analyze gathered data.

The computation of new variables measurement data from two or more measured variables data is useful especially when trying to statistically define a sample population where two characteristics were sampled and measured.

5 Development of Conceptual Design of Solution

5.1 Model Calculation Map

The project model was designed to be a simple calculation with the output of results being in both text and visual form. Before results could be displayed the data needed for the calculations needed to be arranged in a sequence that followed the natural flow of the calculation itself. This was to make it easier for an outside user to understand how the model worked and also aided with troubleshooting during the early stages of development. The calculation steps used by the model are illustrated by the following simple diagram.

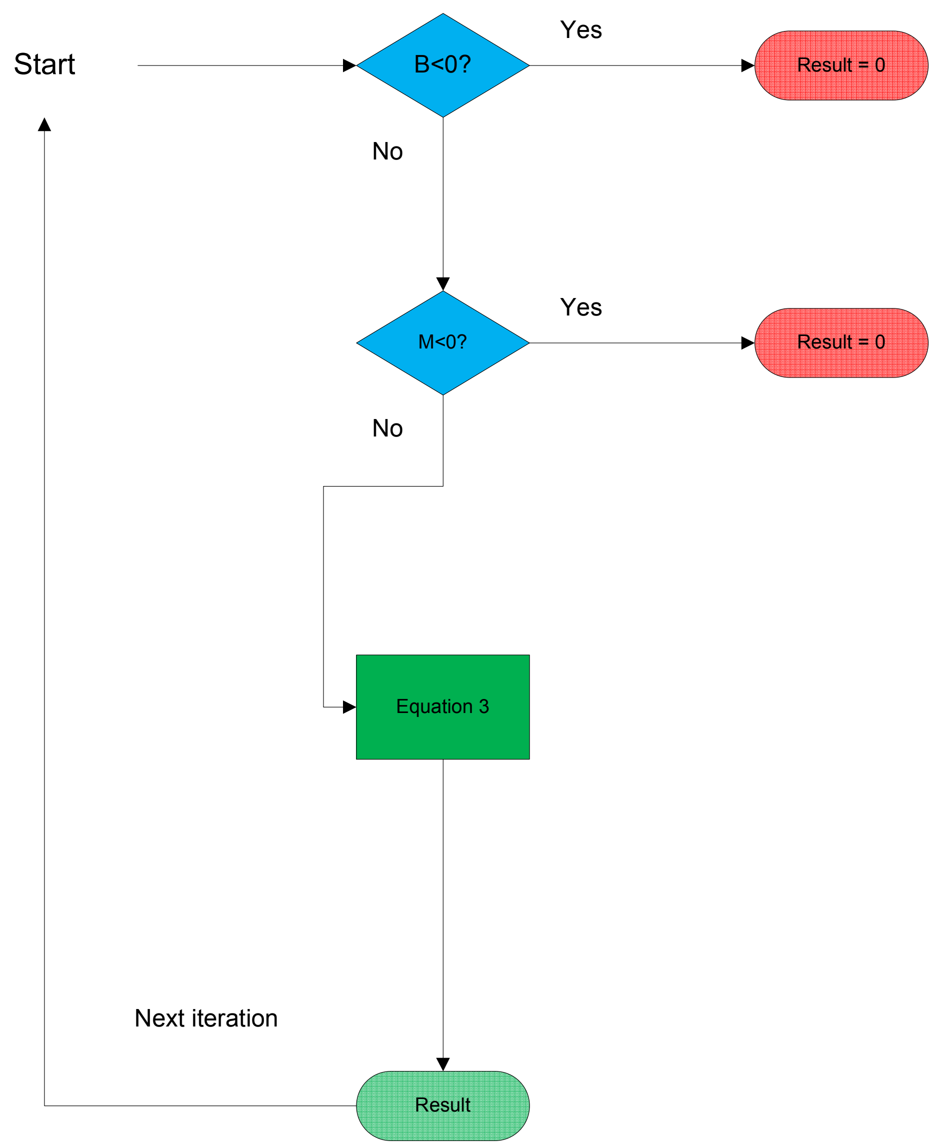


Figure 7: Model Calculation Logic.

The logic that the model uses is to ensure that negative temperature and flow rate values are omitted from the data set since a negative flow rate is impossible. Instead, if a simulated value of either variable B or variable d/dm (m) is negative, the logic in the diagram above will change it to zero. This ensures that the heat transfer rate is not under represented by including negative temperatures and negative flow rates. However should the values of both B and d/dm (m) be positive, then the model will continue to the next step of the calculation; making use of Equation 3 defined in Section 4.4.1.

Equation 3 makes use of two other values that have not yet been discussed;

1. Specific heat of water under constant pressure – c_p
2. Temperature of the interacting liquid – T_1

5.1.1 Specific Heat - c_p

The specific heat of water under constant pressure is defined as the amount of energy required to raise the temperature of 1 gram of water by 1 degree Celsius.

$$1000 \text{ J/g °C} = 1 \text{ J/kg °C}$$

The units used to describe specific heat can be generally stated as joules per mass-degree Celsius. Using the conversion example above it is easy to convert between mass units. For this project the unit joules per gram-degree Celsius was used since it had the least uncertainty as explained in Section 4.1 paragraph 2.

5.1.2 Temperature of the Interacting Liquid – T_1

For the first part of the simulation, this is the temperature of the water that goes into the autoclave boiler; the initial temperature. The model calculates the energy difference between the two temperatures if the input water and the discharge water. For the second part of the model where the presence of a grey water heat exchanger device is simulated, the efficiency of this device is set at a conservative 70%. In this second scenario, T_1 no longer represents the temperature of the water that flows into the boiler, but rather the initial temperature of the water that flows into the heat exchanger.

5.2 Model Outputs

The sample data was used in the model to determine primarily the estimated cost of the wasted heat in the discharge water from the autoclaves. However the data and the model can also be used to estimate other values of interest. The estimated values output by the model are;

1. Estimated average energy wasted per time unit (current)
2. Estimated average financial cost per time unit (current)
3. Estimated average energy wasted per time unit (potential)
4. Estimated average financial cost per time unit (potential)
5. Estimated average amount of water wasted per time unit (current)

5.2.1 Estimated Average Energy Wasted per Time Unit (current)

The output of Equation 3 is the heat transfer rate per second between the two interacting fluids. Currently there is no other interacting fluid located at the discharge pipe which was why the equation was used as is. Using the equation with no efficiency coefficient essentially calculated the heat transferred between two liquids at an efficiency of 100%. The 100% efficiency pertains to loss rather than saving since the heat in the discharge water is currently lost.

The average heat transfer rate per second calculated by the model would then be used to calculate the hourly, daily, and yearly equivalents to illustrate the impact such a small figure could possibly have over long periods of time.

5.2.2 Estimated Average Financial Cost per Time Unit (current)

To calculate the financial cost of the waste described in 5.2.1 the cost per unit of electricity was needed. The unit for the cost of electricity was ZAR cents per kilowatt-hour. The kilowatt-hour is a unit used to measure very large amounts of consumed energy and can be defined numerically as follows;

1 kilowatt-hour = 3,600,000 Joules

Once the energy figures from 5.2.1 have been calculated a simple arithmetic calculation was needed to quantify the wasted energy in financial terms.

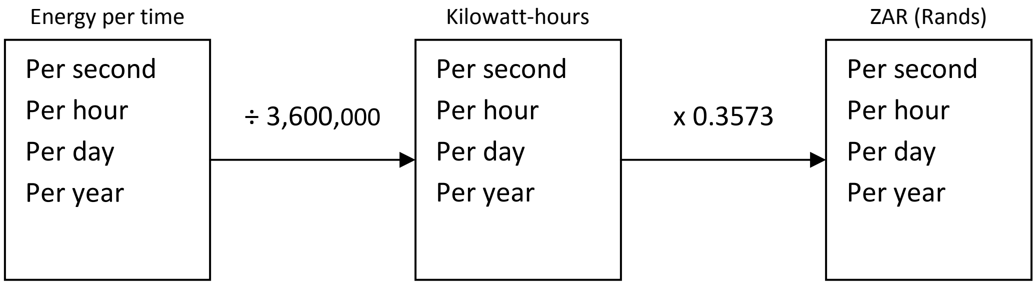


Figure 8: ZAR Rand Value Calculation Steps.

Figure 8 illustrates the calculation steps that are involved in calculating the ZAR Rand value of the current estimated average waste. The ZAR Rands value per kilowatt-hour was derived using the City of Tshwane's official price plan and was verified using the electricity bills of the hospital in Appendix D. The reduced energy charge was used since the ZAR Rand value calculated was intended to be a base line value. As such, the calculated values should be regarded as minimum costs.

5.2.3 Estimated Average Energy Wasted per Time Unit (potential)

To calculate the estimated values regarding the potential reduction in waste that can be realized an efficiency coefficient was introduced into Equation 3. An arbitrarily chosen efficiency of 70% was chosen to represent the amount of wasted energy that could potentially be recaptured and re-introduced into the system. Since the focus here was waste, we need the value that pertains to waste and if 70% pertains to savings then (1-70% = 30%) pertains to wasted heat. Running the model with this new efficiency coefficient would yield results in the same format as those discussed in Section 5.2.1.

5.2.4 Estimated Average Financial Cost per Time Unit (potential)

To calculate the potential financial loss in monetary terms the same calculation steps discussed in Section 5.2.2 were followed. The yielded results were expected to be 70% less than the current state results.

5.2.5 Estimated Average Amount of Water Wasted per Time Unit (current)

An added bonus to the model was that the sample data gathered during the sample study also yielded information that could be used to calculate the current amount of water being wasted. The measured flow rates were treated as isolated data points and using the built-in functions of MS Excel the mean flow rate was calculated using the pseudo-population of 10 000 simulated samples. The figure that was calculated was in grams per second and was used to calculate its equivalent in larger units of time; hourly, daily, and yearly. The financial cost of the wasted water that is otherwise clean did not fall under the scope of this project.

5.3 Assumptions Regarding the Model Outputs

The words 'estimated average' accompany every output that the model generates since they are calculated using all of the 10 000 simulated samples. The lowest base time unit for any output is always per second since the input data was in this format. When the outputs per second are escalated to higher orders of time like hours, days, and working years the accuracy of the resulting figures rests on the assumption that the outputs per second remain constant. However the sample data can be used as a testament to the fact that the flow rates are not constant.

When calculating flow per year using the calculated estimated average flow per second, one needs to take into account the assumption that the flow rate per second does not remain constant. Thus the resulting value can be used at best as an estimate. The arbitrarily chosen efficiency of 70% bases itself on the assumption that should heat recycling be implemented it will be implemented at the discharge nearest to the autoclave. This is to minimize the heat lost through the walls of the pipe via conduction and radiation.

6 Results

At the beginning of this document in Section 1.3 the aim of this project was discussed and divided into four objectives. The first objective was to complete a sample study of the current environment so as to assess the state of waste. The results of the sample study were discussed in Section 4. The second objective was to use the sample study data to create a simulated pseudo-population of samples. The simulated sample data would then in turn be used to calculate estimated values pertaining to the amount of heat wasted for differing periods of time and the financial cost incurred. The model and how it functions was discussed in Section 5. The third objective in keeping with those set out in Section 1.3 was to discuss the results of the model. The basis of this section is to present and discuss the model results.

6.1 The Results

The basis for the entire project was to analyze the current state of waste at the hospital so as to determine if it was financially viable to further investigate this matter. In keeping with this it was thought prudent that the project not only address how much money was being wasted, but also how much money could potentially be saved.

6.1.1 Current State

The primary objective of this project was to assess and quantify the current state of waste in the autoclave department. The results given by the model are based on information gathered on two autoclaves since the other three were not operational for the duration of the study. The two autoclaves that were studied had a shared discharge pipe and the specifications of each can be found in Appendix E.

Electricity Related Value Estimates (Current)			
Energy Wasted Down Drain	**Joules (J)**	**kW-h**	**Rand Value (ZAR)**
Per Second	4171.862	0.001	ZAR 0.00
Per Hour	15018702.875	4.172	ZAR 1.70
Per Day	171934110.510	47.759	ZAR 19.45
Per Working Year	41436120632.883	11510.034	ZAR 4,986.15

Table 8: Current State Results Summary.

Table 8 gives the minimum estimated average for the amount of heat that is lost in the discharged water. The actual model output is in Joules per second and is accompanied by the expanded amounts for different time units; per hour, per day, and per working year. The term 'working year' refers to the amount of week days in the period from July 2011 to the end of June 2012 and is relevant since the study focused on weekday use of the autoclaves only. Table 8 also shows the equivalent estimated average number of kilowatt-hours of energy that is lost in the discharged water. The definition of the kilowatt-hour was discussed in Section 5.2.2. Using the kilowatt-hour values a ZAR Rand equivalent was calculated for the different time units and displayed in the table.

From Table 8 it can be seen that the ZAR Rand value equivalent of the heat within the water discharged by the two autoclaves for the working year is estimated at around at least ZAR 4550.00. However what must also been borne in mind is that this estimate is for two out of five autoclaves; the smallest capacity and the largest capacity autoclave. Currently the hospital makes use of four JSD 400 autoclaves, each with a capacity of 400L, and one JSD 160 with a capacity of 160L. Logic would dictate that the three offline autoclaves, all JSD 400 models would cumulatively lose heat that would easily amount to almost twice that of the studied pair. Of course that figure would also depend on the assumption that all of the autoclaves are used as rigorously as the two under study.

Figure x shows the plotted values of the first 20 runs of the model accompanied by the mean and guidelines representing one, two, and three standard deviations away from the mean.

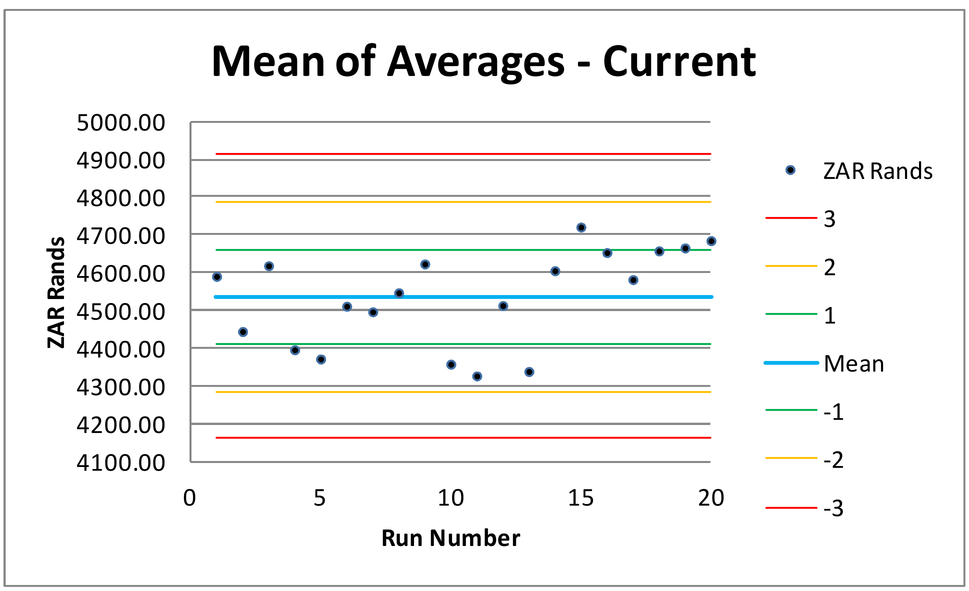


Figure 9: Mean of Averages - Current.

Figure 9 shows that the model's outputs for the first 20 runs fell between two standard deviations on either side of the mean which was ZAR 4535.95.

6.1.2 Potential State

The results discussed here are purely theoretical and serve only as an indication of the possible savings that could be realized should the hospital decide to further investigate the reclaiming of the heat from the autoclave discharge water.

Electricity Related Value Estimates (Proposed)			
Energy Wasted Down Drain	**Joules (J)**	**kW-h**	**Rand Value (ZAR)**
Per Second	1251.559	0.0003	ZAR 0.00
Per Hour	4505610.862	1.252	ZAR 0.51
Per Day	51553199.488	14.320	ZAR 5.83
Per Working Year	12424321076.558	3451.200	ZAR 1,405.75

Table 9: Potential State Results Summary.

Table 9 displays information in exactly the same format as done in Table 8 in the previous section with the only difference being that these results are reduced by 70%. Recall in Section 5.2.3 that an arbitrarily chosen efficiency of 70% was to be used to calculate the potential waste reduction and savings that could be realized. Table 9 shows that the expected ZAR Rand value of heat that will be lost should 70% of it be recaptured is around the vicinity of ZAR 1550.00.

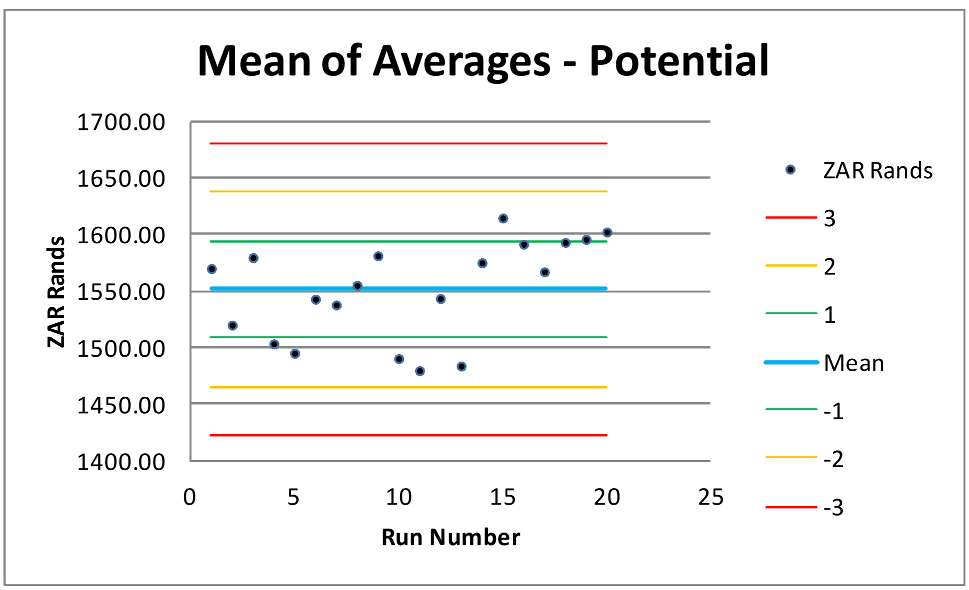


Figure 10: Mean of Averages - Potential.

Figure 10 shows that the model outputs for the potential state for the first 20 runs also fall between two standard deviations on either side of the mean which is in this case ZAR 1551.29.

6.1.3 The Water Results

In the beginning of Section 4 it was stated that the data for any project can tell more about that specific project than what the project is specifically looking for. This was the case for this project since we not only discovered what we were looking for but also other information that prove helpful at a later stage. Apart from being able to calculate the average estimated monetary loss from the throwing away of the autoclave discharge water, the model also enabled the estimation of the average amount of water that was consumed and thrown away by the same autoclaves.

Litres of Grey Water Wasted	
Per Second	0.087
Per Hour	313.323
Per Day	3585.042
Per Year	863995

Table 10: Liters of Grey Water Wasted.

Table 10 shows that the estimated average amount of water thrown down the drain is 863,995 liters. This equates to just less than 864 cubic meters of water. Considering this figure accounts for only two of the five autoclaves, the other three autoclaves could use just over twice this amount. This figure would also rest on the assumption that the other three autoclaves are used as rigorously as the two that were studied.

6.2 Results Summary

With the cost of electricity increasing year on year by a NERSA approved 25% the hospital will be paying an increasing amount for the lost heat as is indicated in Figure 11.

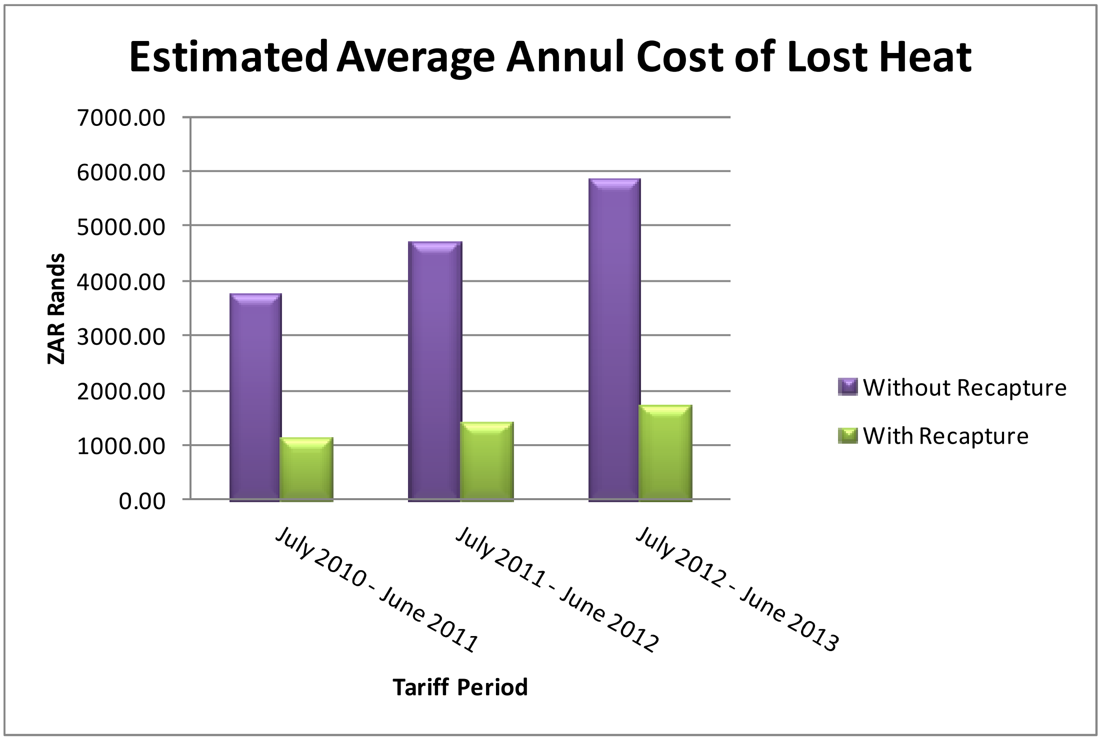


Figure 11: Estimated Annual Cost of Lost Heat.

Figure 11 depicts the estimated average annual cost of the lost heat from the two autoclaves that were studied. The estimated figures are for the period from July 2010 to June 2011, July 2011 until June 2012, and from July 2012 until June 2013. The tariffs used to calculate the estimated annual cost for the period from July 2010 to the end of June 2011 and July 2011 until the end of June 2012 were the actual tariffs used by the City of Tshwane Municipality for the same periods. The tariff used for the period beginning July 2012 until the end of June 2013 was an increase of 25% on the previous period's tariff. These figures can serve as a guide that enables the past, current, and future costs to visualized and compared. As stated throughout this section, these figures are estimated averages based on the two autoclaves that were studied. Actual annual costs can be expected to be approximately twice the stated figures assuming that all the autoclaves are used as rigorously as the two under study.

The savings, or difference between the two values compared in Figure 11 have been presented in Figure 12.

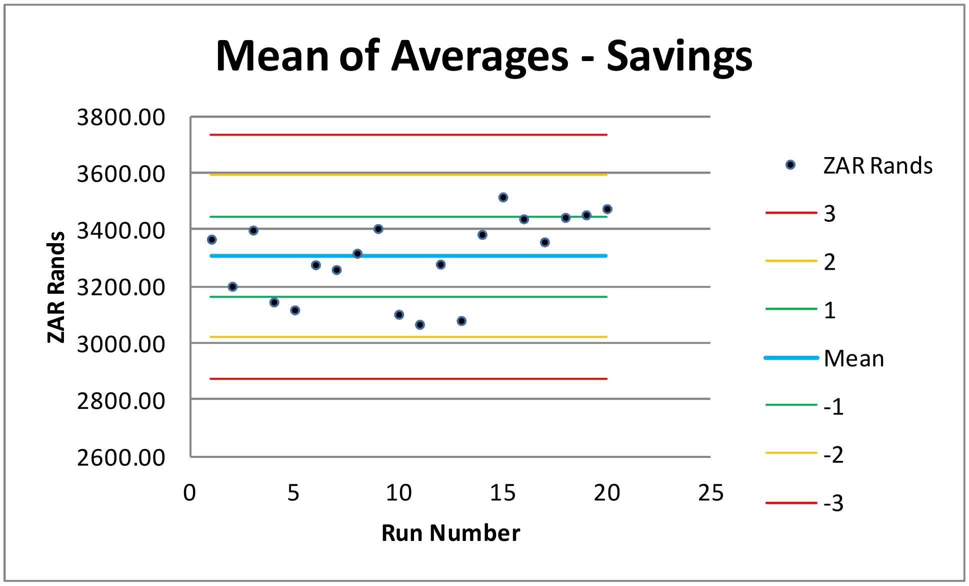


Figure 12: Mean of Averages - Savings.

Figure 12 shows that the model's outputs for the first 20 runs fall between two standard deviations on either side of the mean which is ZAR 3304.92 per annum.

7 Conclusion and Recommendations

7.1 Conclusion

The identification and management of unnecessary waste within economic enterprises is becoming increasingly important within the economic climate. Focusing on identifying possible areas of waste, managing that waste, and even redistributing recycled waste are processes that have the capacity to affect a company's bottom positively. Re-deploying resources to this end will ensure the optimal and smooth running of a company.

For Little Company of Mary Hospital where annual budgets are becoming increasingly tighter the identification of unnecessary waste is the first step towards potential realized savings. These savings can then be redistributed to areas where extra cash injection is needed.. Although the study was not done on the entire autoclave department, the results still showed promise. This project confirmed that there was cause for concern over the suspected waste, and the current state of waste was quantified in economic terms. The current state of waste for the two autoclaves studied was calculated to cost an average estimated ZAR 4000.00 for the period from July 2011 to end June 2012. This project also projected the likely annual cost of the very same waste for the next tariff period which was an average estimated ZAR 5000.00.

Another aspect of the waste was also brought to the fore; the water consumption. This project estimated the average water consumption for the two autoclaves under study to be just less than 864 cubic meters.

7.2 Recommendations

In light of the stated results of this project, hospital management are advised to consider the following recommendations;

1. Hospital management should seek to confirm the results of this project.
2. Hospital management should open dialogue with the autoclave manufacturer, Hospi Sterilizers, to see if a cooperative solution can be formulated.
3. Hospital management should consult professional agencies to discover what can be done to address the water wastage and its future feasibility.

The above mentioned recommendations should be considered with future sustainability in mind since resources are becoming scarce and proper management of them is of the utmost importance.

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A.1 Random Sample Time Tables

A.2 Sample Form Example

B Sampling Equipment

Figure 13: Boardmans Electronic Kitchen Scale.

Figure 14: Accompanying Stainless Steel 2.2L Bowl.

Figure 15: Meat Thermometer Probe.

Figure 16: Sanji Standard Stopwatch.

C Sample Forms

D.1 Tariff Unit Cost Calculations

The validation for price per kilowatt-hour used in the simulation sourced from the City of Tshwane's Tariff plan for 2011/2012. Using the hospital's electricity bill for the month of June 2011 the exact price structure that applies to the hospital was derived. The increase in the electricity price per unit was included in the simulation as the new pricing structure was implemented from July 2011. The pricing was validated as follows:

Meter reading beginning June 2011:	31747388 kWh
Meter reading end June 2011:	32275772 kWh
Difference = kilowatt-hours consumed:	528404 kWh (Actual = 528384 kWh)
Amount charged (excl. VAT):	R151 017.86
Price per kilowatt-hour:	R151 017.86/528404 kWh = R0.2857999 = R0.2858

On the off chance that the validation was coincidence, the same procedure was applied to the demand charge on the electricity bill;

Meter reading beginning June 2011:	0 kVA
Meter reading end June 2011:	1110 kVA
Difference = kilovolt-amps consumed:	1110 kVA
Amount charged (excl. VAT):	R117 704.40
Price per kilovolt-amp:	R117 704.40/1110 kVA = R106.04

As a final precautionary measure, the fixed connection charge for an 11kV connection according to the electricity bill is R822.66 excluding VAT. When studying the tariffs published by the City of Tshwane there was a category in which all of the above prices were found simultaneously. The page with highlighted values can be found in Appendix D.2. Since the samples were collected in September 2011 it means that the new price structure needs to be used. More specifically it means the new reduced energy charge per kilowatt-hour of ZAR 0.3573 needs to be used.

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Page: 1 of 2

Account for: P21	Stand no: 00000	Township: GROENKLOOF 358-JR	Days: 29
Address: ; 50 GEORGE STORRAR DRIVE		Sectional title scheme:	Unit no: V0003
Meter reading unit: 21HT14A	Group account:	Deposit date: 23/04/05	Deposit: 118937.05
Guarantee date:	Guarantee: 0.00		
SISKEY: 026800000/47/R		BP: 293957	

Date	DETAILS	(R) Amount (excl. VAT)	(R) VAT	(R) Amount (incl. VAT)
07/06/11	Balance Brought Forward	290,231.09	0.00	290,231.09
30/06/11	Payment (Thank You)	-290,230.42	0.00	-290,230.42
08/07/11	**Sub Total (A)**	**0.67**	**0.00**	**0.67**
08/07/11	Electricity	269,544.92	37,736.29	307,281.21
	VAT 14% on services of R 269544.92	0.00	37,736.29	0.00
08/07/11	**Total Current Levy (B)**	**269,544.92**	**37,736.29**	**307,281.21**
	TOTAL AMOUNT PAYABLE (A+B)	**269,545.59**	**37,736.29**	**307,281.00**

90 Days	90+ Days	Total charge (excluding VAT)	Total VAT	Total charge (including VAT)
0.00	0.00	269,545.59	37,736.29	307,281.00
	DUE DATE	29/07/11	AMOUNT PAYABLE	307,281.00

THIS STUB MUST ACCOMPANY PAYMENT

Name	Final date for payment	Account no	
L C M TRUST	29/07/11	2040715124	307,281.00

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Figure 17: Page 1 of 2 - Electricity Bill LCM July 2011.

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Account No.
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Page: 2 of 2

DATE	ICONS	DETAILS	(R) AMOUNT (excl. VAT)	(R) VAT	(R) AMOUNT (incl. VAT)
07/06/11		Balance Brought Forward	290,231.09	0.00	290,231.09
30/06/11		Payment (Thank You)	- 290,230.42	0.00	- 290,230.42
30/06/11		**Sub Total (A)**	**0.67**	**0.00**	**0.67**
08/07/11		**Electricity**			
		Reading dates: Curr 30/06/11 Prev 02/06/11 (29 days)			
		Meter: 83263362(Actual) Curr 1110 Prev 0 Cons 1110 KVA			
		Meter: 83263362(Actual) Curr 32275772 Prev 31747368 Cons 528404 KWH 349			
		Energy charge 11kV supply scale	151,017.86	21,142.50	172,160.36
		Fixed charge 11kV supply scale	822.66	115.17	937.83
		Demand charge 11kV supply scale	117,704.40	16,478.62	134,183.02
08/07/11		**VAT**			
		VAT 14% on services of R269544.92	0.00	37,736.29	0.00
		Total Current Levy (B)	**269,544.92**	**37,736.29**	**307,281.21**
		Total Amount Payable (A+B)	**269,545.59**	**37,736.29**	**307,281.00**

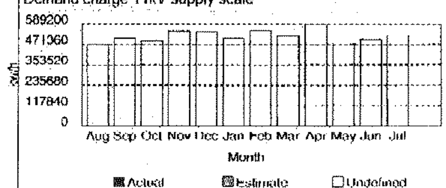

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Figure 18: Page 2 of 2 - Electricity Bill LCM July 2011.

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Page: 1 of 2

ccount for: P21	Stand no: 00000	Township: GROENKLOOF 358-JR		Days: 35	
ddress: ; 50 GEORGE STORRAR DRIVE		Sectional title scheme:		Unit no.: V0003	
eter reading unit: 21HT14A	Group account:	Deposit date: 23/04/05	Deposit: 118937.05	Guarantee date:	Guarantee: 0.00
SKEY: 026800000/47/R				BP: 293957	

D	DETAILS	(R) Amount (excl. VAT)	(R) VAT	(R) Amount (incl. VAT)
8/07/11	Balance Brought Forward	307,281.88	0.00	307,281.88
4/08/11	Payment (Thank You)	-307,281.21	0.00	-307,281.21
8/08/11	**Sub Total (A)**	**0.67**	**0.00**	**0.67**
8/08/11	Electricity	361,652.29	50,631.32	412,283.61
	VAT 14% on services of R 361652.29	0.00	50,631.32	0.00
8/08/11	**Total Current Levy (B)**	**361,652.29**	**50,631.32**	**412,283.61**
	17,691			2011 -08- 22
	TOTAL AMOUNT PAYABLE (A+B)	**361,652.96**	**50,631.32**	**412,284.00**

90 Days	90+ Days	Total charge (excluding VAT)	Total VAT	Total charge (including VAT)
0.00	0.00	**361,652.96**	**50,631.32**	**412,284.00**
	DUE DATE	29/08/11	**AMOUNT PAYABLE**	**412,284.00**

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Name	Final date for payment	Account no	
L C M TRUST	29/08/11	2040715124	**412,284.00**

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Figure 19: Page 1 of 2 - Electricity Bill LCM August 2011.

Account No.
2040715124

Page: 2 of 2

DATE	ICONS	DETAILS	(R) AMOUNT (excl. VAT)	(R) VAT	(R) AMOUNT (incl. VAT)
08/07/11		Balance Brought Forward	307,281.88	0.00	307,281.88
04/08/11		Payment (Thank You)	- 307,281.21	0.00	- 307,281.21
04/08/11		**Sub Total (A)**	**0.67**	**0.00**	**0.67**
08/08/11		**Electricity**			
		Reading dates: Curr 04/08/11 Prev 01/07/11 (35 days)			
		Meter: 83263362(Actual) Curr 1139 Prev 0 Cons 1139 KVA			
		Meter: 83263362(Actual) Curr 32825312 Prev 32275772 Cons 549540 KWH			
		Energy charge 11kV supply scale	209,649.51	29,350.93	239,000.44
		Fixed charge 11kV supply scale	1,028.33	143.97	1,172.30
		Demand charge 11kV supply scale	150,974.45	21,136.42	172,110.87
08/08/11		**VAT**			
		VAT 14% on services of R361652.29	0.00	50,631.32	0.00
		Total Current Levy (B)	**361,652.29**	**50,631.32**	**412,283.61**
		Total Amount Payable (A+B)	**361,652.96**	**50,631.32**	**412,284.00**

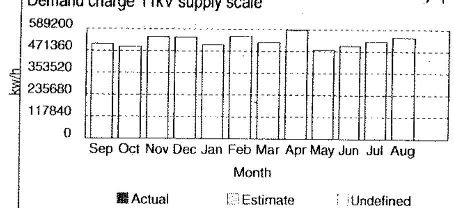

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Figure 20: Page 2 of 2 - Electricity Bill LCM August 2011.

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Page: 1 of 2

ccount for: P21	Stand no: 00000		Township: GROENKLOOF 358-JR		Days: 30
ldress: ; 50 GEORGE STORRAR DRIVE			Sectional title scheme:		Unit no.: V0003
eter reading unit: 21HT14A	Group account:	Deposit date: 23/04/05	Deposit: 118937.05	Guarantee date:	Guarantee: 0.00
SKEY: 026800000/47/R				BP:	293957

	DETAILS	(R) Amount (excl. VAT)	(R) VAT	(R) Amount (incl. VAT)
3/08/11	Balance Brought Forward	412,284.28	0.00	412,284.28
5/09/11	Payment (Thank You)	-412,284.28	0.00	-412,284.28
7/09/11	**Sub Total (A)**	**0.00**	**0.00**	**0.00**
7/09/11	Electricity	342,277.48	47,918.85	390,196.33
	VAT 14% on services of R 342277.48	0.00	47,918.85	0.00
7/09/11	**Total Current Levy (B)**	**342,277.48**	**47,918.85**	**390,196.33**
	TOTAL AMOUNT PAYABLE (A+B)	**342,277.48**	**47,918.85**	**390,196.00**

26/9/11

90 Days	90+ Days	Total charge (excluding VAT)	Total VAT	Total charge (including VAT)
0.00	0.00	**342,277.48**	**47,918.85**	**390,196.00**
	DUE DATE	28/09/11	**AMOUNT PAYABLE**	**390,196.00**

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Name	Final date for payment	Account no	
L C M TRUST	28/09/11	2040715124	**390,196.00**

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Figure 21: Page 1 of 2 - Electricity Bill LCM September 2011.

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Page: 2 of 2

DATE	ICONS	DETAILS	(R) AMOUNT (excl. VAT)	(R) VAT	(R) AMOUNT (incl. VAT)
08/08/11		Balance Brought Forward	412,284.28	0.00	412,284.28
05/09/11		Payment (Thank You)	- 412,284.28	0.00	- 412,284.28
05/09/11		**Sub Total (A)**	**0.00**	**0.00**	**0.00**
07/09/11		**Electricity**			
		Reading dates: Curr 03/09/11 Prev 05/08/11 (30 days)			
		Meter: 83263362(Actual) Curr 1074 Prev 0 Cons 1074 KVA			
		Meter: 83263362(Actual) Curr 33346650 Prev 32825312 Cons 521338 KWH			
		Energy charge 11kV supply scale	198,890.45	27,844.66	226,735.11
		Fixed charge 11kV supply scale	1,028.33	143.97	1,172.30
		Demand charge 11kV supply scale	142,358.70	19,930.22	162,288.92
07/09/11		**VAT**			
		VAT 14% on services of R342277.48	0.00	47,918.85	0.00
		Total Current Levy (B)	**342,277.48**	**47,918.85**	**390,196.33**
		Total Amount Payable (A+B)	**342,277.48**	**47,918.85**	**390,196.00**

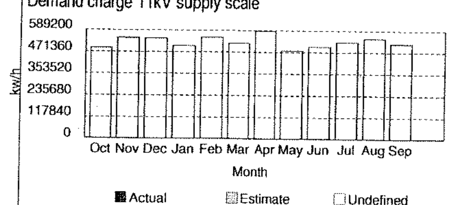


Figure 22: Page 2 of 2 - Electricity Bill LCM September 2011.

D.2 City of Tshwane Tariff Extract

E Autoclave Information

Figure 23: Autoclave No.3 - 160L.

Specifications

Model:	JSD 160
Year:	2010
Capacity:	0.160m^3
Tank Capacity:	33L
Tank Power Rating:	33kW

Figure 24: Autoclave No. 1 - JSD 400.

Specifications

Model:	JSD 400
Year:	2005
Capacity:	$0.400m^3$
Tank Capacity:	66L
Tank Power Rating:	36kW

F The Model

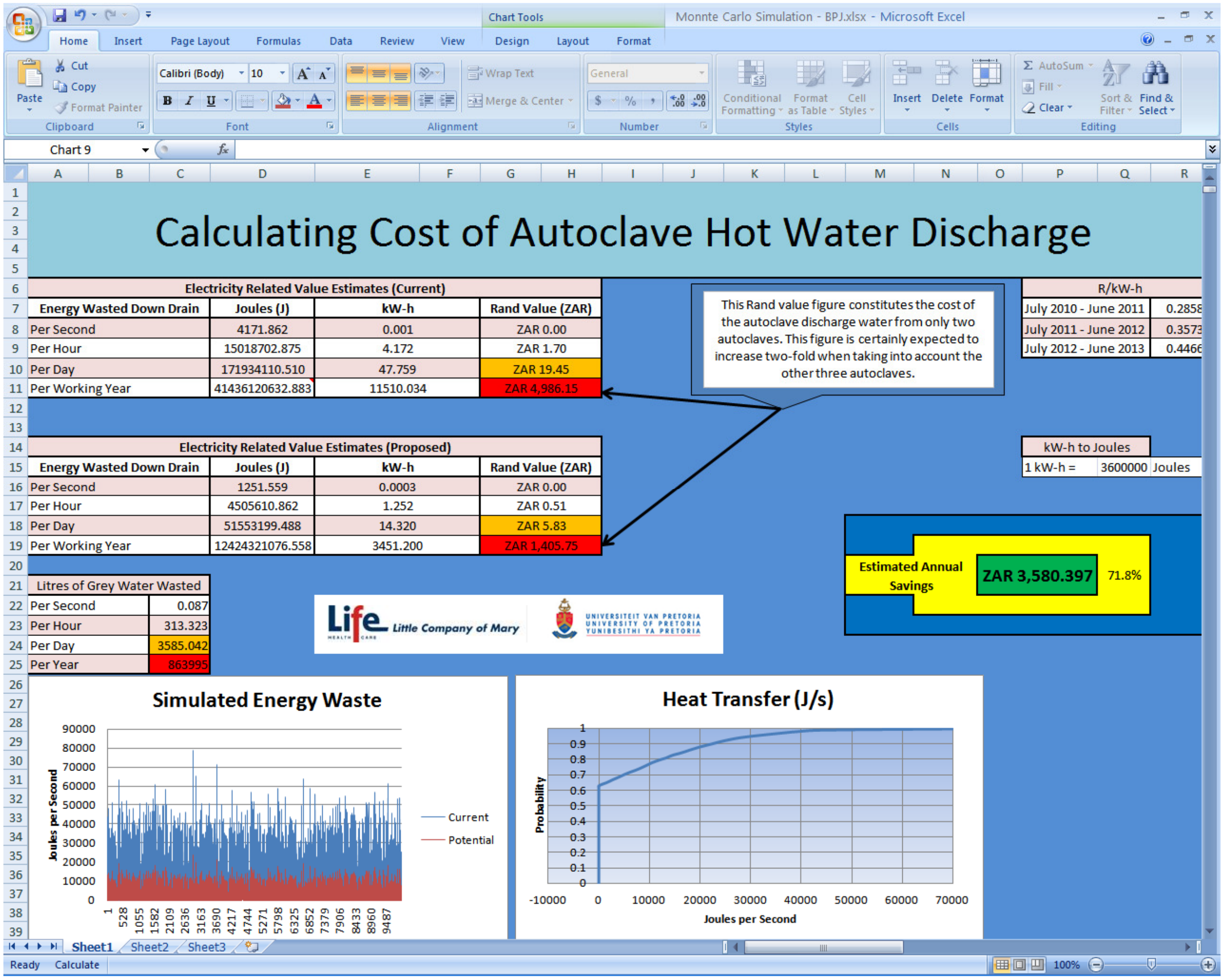


Figure 25: Model Dashboard 1.

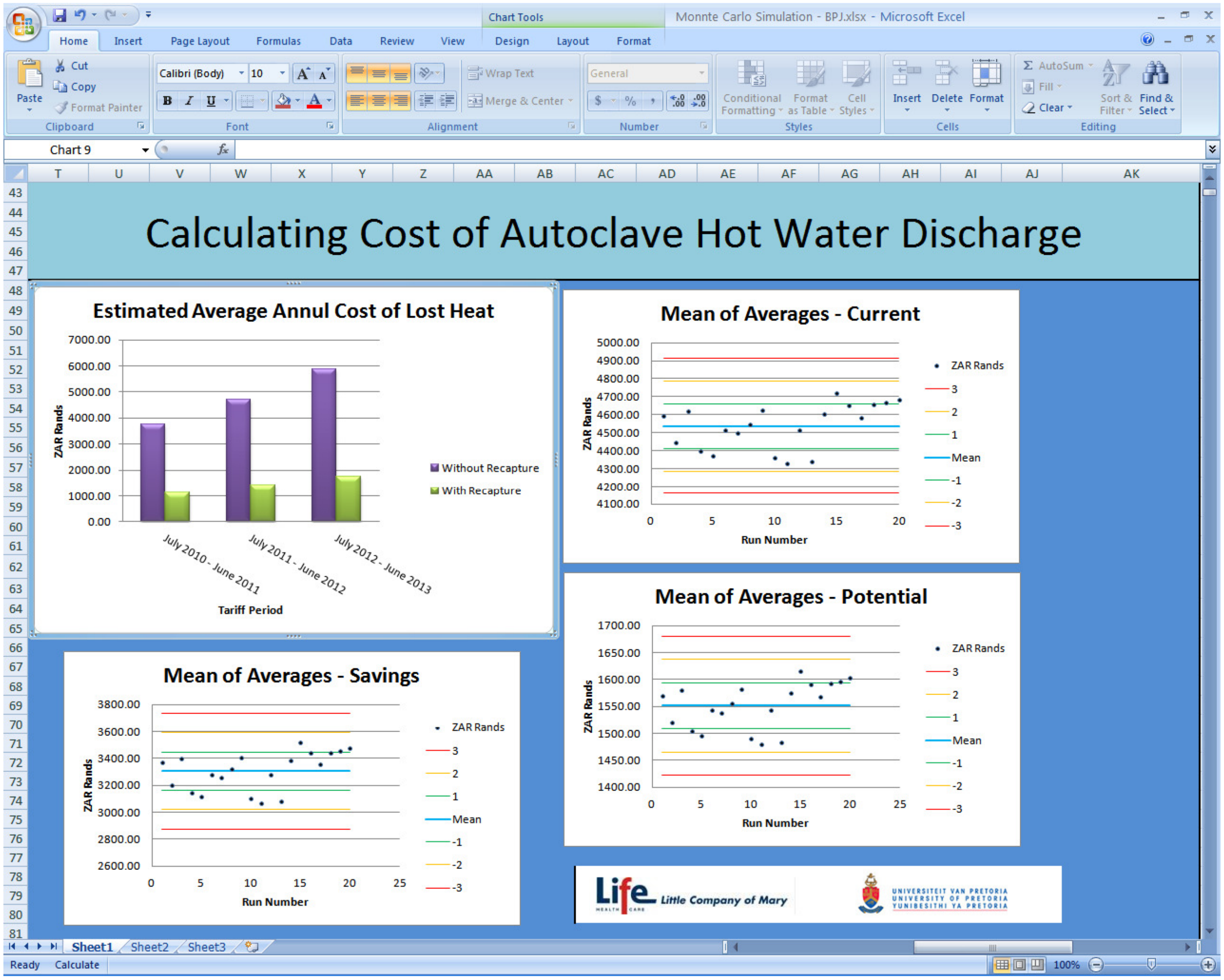
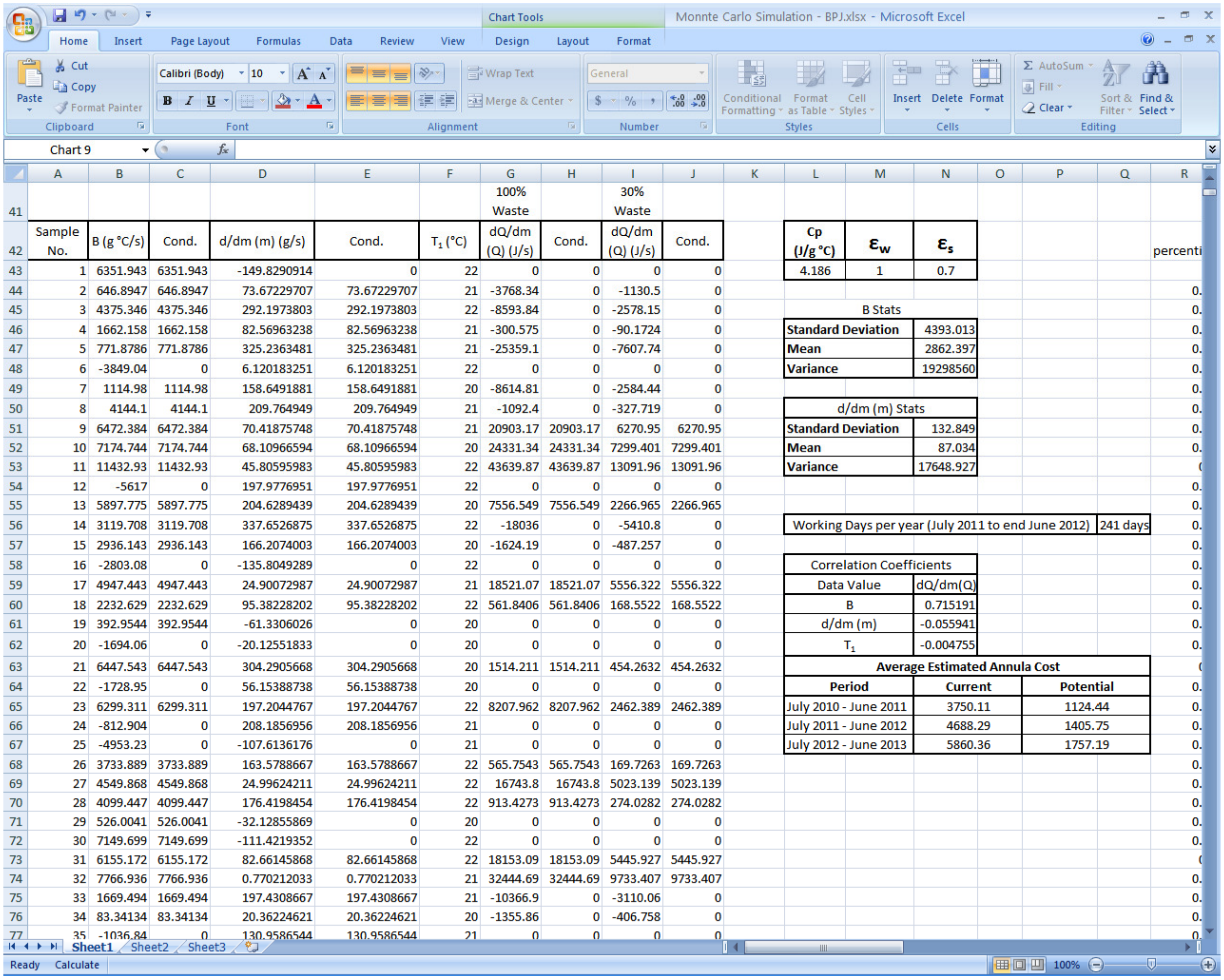


Figure 26: Model Dashboard 2.



	100% Waste		30% Waste						
Sample No.	B (g °C/s)	Cond.	d/dm (m) (g/s)	Cond.	T_1 (°C)	dQ/dm (Q) (J/s)	Cond.	dQ/dm (Q) (J/s)	Cond.
1	6351.943	6351.943	-149.8290914	0	22	0	0	0	0
2	646.8947	646.8947	73.67229707	73.67229707	21	-3768.34	0	-1130.5	0
3	4375.346	4375.346	292.1973803	292.1973803	22	-8593.84	0	-2578.15	0
4	1662.158	1662.158	82.56963238	82.56963238	21	-300.575	0	-90.1724	0
5	771.8786	771.8786	325.2363481	325.2363481	21	-25359.1	0	-7607.74	0
6	-3849.04	0	6.120183251	6.120183251	22	0	0	0	0
7	1114.98	1114.98	158.6491881	158.6491881	20	-8614.81	0	-2584.44	0
8	4144.1	4144.1	209.764949	209.764949	21	-1092.4	0	-327.719	0
9	6472.384	6472.384	70.41875748	70.41875748	21	20903.17	20903.17	6270.95	6270.95
10	7174.744	7174.744	68.10966594	68.10966594	20	24331.34	24331.34	7299.401	7299.401
11	11432.93	11432.93	45.80595983	45.80595983	22	43639.87	43639.87	13091.96	13091.96
12	-5617	0	197.9776951	197.9776951	22	0	0	0	0
13	5897.775	5897.775	204.6289439	204.6289439	20	7556.549	7556.549	2266.965	2266.965
14	3119.708	3119.708	337.6526875	337.6526875	22	-18036	0	-5410.8	0
15	2936.143	2936.143	166.2074003	166.2074003	20	-1624.19	0	-487.257	0
16	-2803.08	0	-135.8049289	0	22	0	0	0	0
17	4947.443	4947.443	24.90072987	24.90072987	21	18521.07	18521.07	5556.322	5556.322
18	2232.629	2232.629	95.38228202	95.38228202	22	561.8406	561.8406	168.5522	168.5522
19	392.9544	392.9544	-61.3306026	0	20	0	0	0	0
20	-1694.06	0	-20.12551833	0	20	0	0	0	0
21	6447.543	6447.543	304.2905668	304.2905668	20	1514.211	1514.211	454.2632	454.2632
22	-1728.95	0	56.15388738	56.15388738	20	0	0	0	0
23	6299.311	6299.311	197.2044767	197.2044767	22	8207.962	8207.962	2462.389	2462.389
24	-812.904	0	208.1856956	208.1856956	21	0	0	0	0
25	-4953.23	0	-107.6136176	0	21	0	0	0	0
26	3733.889	3733.889	163.5788667	163.5788667	22	565.7543	565.7543	169.7263	169.7263
27	4549.868	4549.868	24.99624211	24.99624211	22	16743.8	16743.8	5023.139	5023.139
28	4099.447	4099.447	176.4198454	176.4198454	22	913.4273	913.4273	274.0282	274.0282
29	526.0041	526.0041	-32.12855869	0	20	0	0	0	0
30	7149.699	7149.699	-111.4219352	0	22	0	0	0	0
31	6155.172	6155.172	82.66145868	82.66145868	22	18153.09	18153.09	5445.927	5445.927
32	7766.936	7766.936	0.770212033	0.770212033	21	32444.69	32444.69	9733.407	9733.407
33	1669.494	1669.494	197.4308667	197.4308667	21	-10366.9	0	-3110.06	0
34	83.34134	83.34134	20.36224621	20.36224621	20	-1355.86	0	-406.758	0
35	-1036.84	0	130.9586544	130.9586544	21	0	0	0	0

Cp (J/g °C)	ε_w	ε_s
4.186	1	0.7

B Stats	
Standard Deviation	4393.013
Mean	2862.397
Variance	19298560

d/dm (m) Stats	
Standard Deviation	132.849
Mean	87.034
Variance	17648.927

Working Days per year (July 2011 to end June 2012)	241 days

Correlation Coefficients	
Data Value	dQ/dm(Q)
B	0.715191
d/dm (m)	-0.055941
T_1	-0.004755

Average Estimated Annula Cost		
Period	**Current**	**Potential**
July 2010 - June 2011	3750.11	1124.44
July 2011 - June 2012	4688.29	1405.75
July 2012 - June 2013	5860.36	1757.19

Figure 27: Model Background Calculations.