Muller Strydom
26035104

Process analyzing and improvement at De Graaf Exhaust Systems

Executive Summary:

De Graaf Exhaust Systems is a factory stationed in Hermanstad Pretoria. They produce exhausts for other De Graaf Exhaust Systems outlets as well as other businesses both in South Africa and overseas. The process at De Graaf Exhaust Systems is not working to its full capacity and thus losing profit. The process and flow of the products will be analyzed and improved with the necessary engineering principles. After analysis the process's throughput and efficiency will increase hand in hand with the increase of products and thus the profit will increase. But this will only be possible if the capability of the system is known and which processes are diminishing the throughput of the system.

The simulation model that will be based on the process will clearly show the bottlenecks and the capability of the system. The layout or flow of the process can then be changed to enhance the throughput of the system. Extra workers can also be employed to help man the machines. With the current process raw sheets of metal enter the process and go through a number of processes to obtain the final product. The scope of the investigation will be on the production of the exhaust bases and not on any other workstations. In this particular section there is a significant amount of possibility for improvement and change.

The bottlenecks in the system can be as a result of a few factors:

- Workstations that are not working to their full capacity and decreasing the whole system's flow;
- Machines that are giving problems and producing errors;
- Processes are repeated;
- Workers are not doing work right;
- The right process flow is not followed;
- Optimal batches are not transported to the next workstation;
- Machines are idling and decreasing the whole system's flow;
- A lack of communication or management between workers and section manager or workers and owner or section manager and owner;
- Material not on standard;
- Strenuous or bad work conditions.

Table of contents

List of figures

List of tables

Chapter 1 - Introduction

1.1 Background

The owner Freek De Graaf started De Graaf Exhaust Systems in the 1960's, producing their own brand of exhausts. Their products were such a success that they later started to also produce for other fitments centres. With the growing demand, Freek De Graaf's son, Bert De Graaf, opened the factory stationed in Hermanstad in the 1980s - at that stage the first of the current three De Graaf exhaust fitment centres. They evolved into one of the biggest exhaust manufacturers in South Africa and now manufacture exhausts for performance, commercial, industrial, agricultural and aeronautical use. They grew over the last three years from the fifth largest to the second largest exhaust manufacturer in South Africa.

De Graaf Exhaust Systems distribute different types of exhausts to more than 450 local exhaust fitment centres and also to other countries. They have a work force of more than 60 permanent staff members.

De Graaf also has centres where other products besides exhausts are fitted. A few activities at these centres are fitment of:

- Shocks;
- Tow bars;
- Bush bars;
- Roll bars;
- Batteries;
- Tyres;
- Cv-joints;
- Services (i.e. fitments) etc.

And to distinguish between these centres and the De Graaf Exhaust centres, it was decided in 1999 to call these centres De Graaf Under-Car.

1.2 Current process

The current process for producing different exhausts at the centre, which will be investigated, is as follows:

- Raw metal sheets are cut into smaller pieces depending on the type of exhaust that will be manufactured;
- The corners are then cut out approximately a centimetre by a centimetre;
- The De Graaf Exhaust Systems logo is imprinted onto the metal by means of a press;
- Next, two sides of the smaller pieces of metal are bent over approximately 1 cm from the end;
- It is bent slightly so that the metal can easily go into the next machine;
- Next, the metal is bent into a round spherical form;
- The ends of the spherical form that are touching are then welded or flared together depending on the type of exhaust that is made;
- The top ends of the spherical form are now bent over 90 degrees;
- Depending on the end form of the product the exhaust is then left spherical or bent into the desired form;
- The silencer of the exhaust is welded onto the end caps and put into the exhaust cover;
- Fibre is weighed depending on the different type of exhaust manufactured and put into the exhaust cover for the damping of sound and minimizing of pollution;
- The other end cap is put onto the cover and both end caps are lastly bent to complete the exhaust.

1.3 Problem statement

With the current economic conditions the factory does not want to work ineffectively. The workers are currently repeating processes and taking longer to finish a product to ensure they can work overtime. This means that the factory must also work on Fridays to meet demand, which results in a waste of resources. The analysis of their process line indicates that there were a few problems that might possibly reduce the throughput time of the process. This is a huge problem since the process is not working to full capacity and thus money is wasted. The analysis of the process will identify the bottlenecks and the number of products that should be produced as well as the number of work days needed to meet the demand.

The owner of the factory wants to know what the current throughput is and where bottlenecks are and what can be done to increase profit. He would like to test alternative scenarios to try and increase the efficiency of the process. The aim is not to retrench workers but to better the process and increase productivity and production, which will result in an increase of products produced and profit. With the enhanced process there can then be catered for additional fitment centres.

1.4 Project aim

The aim of the project is to improve efficiency and throughput of the production line.

1.5 Project scope

The project will only be done at the franchise of De Graaf Exhaust Systems stationed in Hermanstad. Only the section where the base of the exhaust is manufactured will be earmarked for analysis and possible improvement. A simulation model will be constructed for this area. Both the manual and automatic machine processes will be included. The transportation of the products between the different machines will also be included in the study. A lot of improvement that can be made on this area because of the manual processes that are currently in place and it will have a significant impact on the business itself. After the bottlenecks and processes that are dampening the throughput of the process are established with the simulation model, ways will be looked at to help and improve the flow of the system. This will help determine the time needed to meet demand. The layout will be investigated to see where the possible problems originated. Construction of new layouts will be undertaken to finally obtain the optimal layout to help relief processes that are under severe pressure. There will also be investigated whether additional workers must be hired. The above will establish a benchmark for process capability reporting.

The other section where the pipes and branches are manufactured as well as the storage of the exhausts will not be investigated. Some of the processes at the section where the pipes and branches are made are done by other businesses and thus will not be investigated, for example laser cutting of the pipes. These processes can be investigated later on to see whether it will be feasible to buy a laser cutting machine and doing it in-house.

The production of the silencer is also done on another production line. It is then send to the production line that will be analysed in this study. So it will be assumed that that product is always available and is not responsible for decreasing the throughput of the process that will be investigated.

All the different types of exhausts and sizes are manufactured on this process line, but only the normal size, box exhaust type will be looked at when analysing the process line. The simulation model will be constructed from the data collected for this specific exhaust type and size.

Chapter 2 – Literature review

2.1 History of simulation modelling

Simulation modelling evolved with the progression of the development of the computer. In the earlier days mathematical models were constructed to model problems analytical but simulation modelling was often used as an adjunct to, or substitution where closed form analytic solutions were not possible as discussed in 'Computer simulation.' Initially, simulation models were used to complement mathematical models but their use became widespread later on. The first large-scale project was developed in World War II (Computer simulation). A Monte Carlo algorithm was constructed on the nuclear detonation. There is a wide variety of computer simulation available. The common feature is that they model the specific system and attempt to generate alternative scenarios to the problem. As quoted by Marc I Kellner et el (1999:91): '*software process simulation modelling is gaining increasing interest among academic researchers and practitioners alike as an approach for analysing complex business and policy questions. Although simulation modelling has been applied in a variety of disciplines for a number of years, it has only recently been applied to the area of software development and evolution processes. Currently, software process simulation modelling is beginning to be used to address a variety of issues from the strategic management of software development to supporting process improvement, to software project management training*.' Andrew Greasley (2008:979) quotes from (Law and Kelton, 2000), '*Simulation modelling is arguably more widely applied to manufacturing systems in general than any other application area*.' Andrew Greasley (2008:979) furthermore states that this is because of the complexity of automated systems, which is a result of improved productivity and quality. Another factor that Andrew Greasley (2008:979) mentions is the cost of simulation modelling is fairly small and it offers a divers number of advantages, in comparison to the cost of equipment and facilities of automated systems that can be quite large.

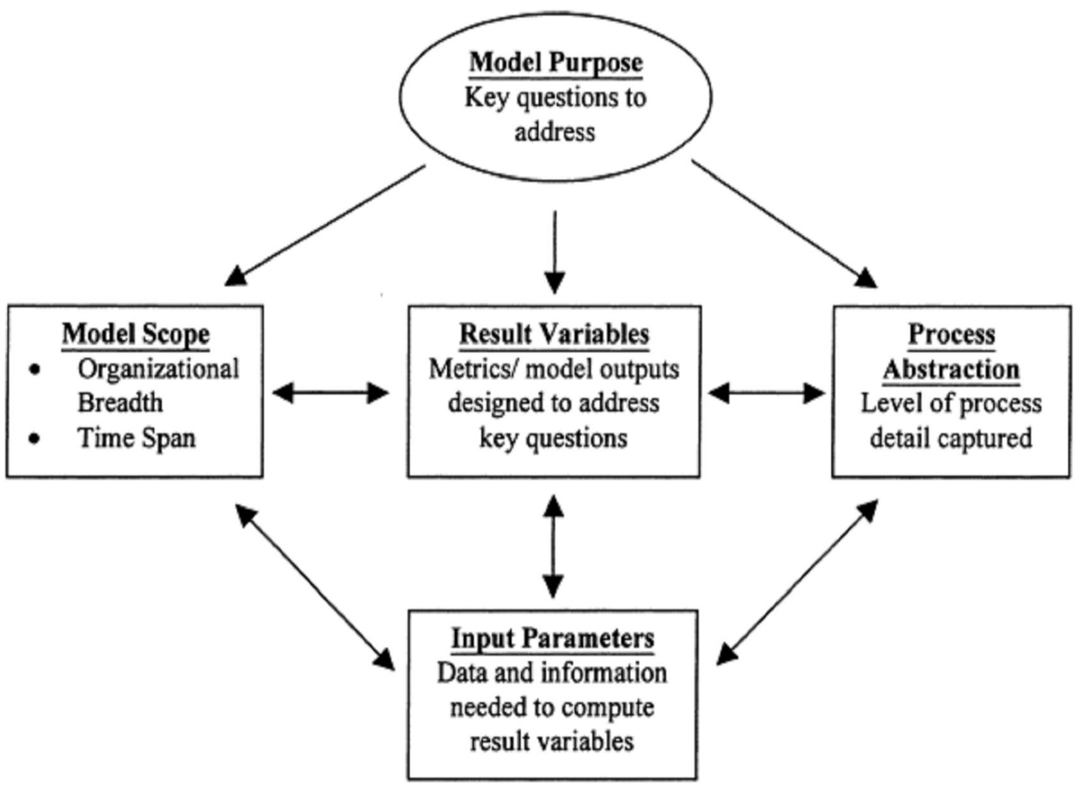
2.2 Why simulation modelling

Zahir Irani et el (2000:7) quotes Dasgupta et el (1999), Love et el (1998), '*Those organisations that have failed to rise to the challenge of using information technology*

(IT) to increase their competitiveness are running into serious performance and competitiveness problems.' Felix T.S Chan and Bing Jiang (1999:283) claim simulation modelling is one of the biggest and most rewarding tools at the planning stages for different layout configurations of the production line and for improving of existing systems by testing alternative scenarios. The model is constructed over time by observing the system's patterns. Simulation can also be defined as stated by Felix T.S Chan and Bing Jiang (1999:276) '*the process of designing a model of a system and conducting experiments with this model for the purpose of either understanding the behaviour of the system and/or evaluating various strategies for the operation of the system*' (Carrie, 1988). It has become a frequently used tool because of the encouraging results that are obtained from the use of it.

Figure 1 from Marc I. Kellner (1999:95) shows the relationships between critical questions that should be asked like 'why' and 'what'.

Figure 1: Relationships among 'why' and 'what' aspects.



Simulation modelling usually refers to visual representation of the system using appropriate software. Spreadsheet simulation is usually developed with Microsoft Excel and using the Microsoft Visual Basic Applications language. It is a low cost way of simulating problems where numeric analysis, tabulation and graphing are needed (Andrew Greasley 2004:565). He also claims computer simulation modelling can take many forms, but generally the technique is applied by developing a computer model using a simulation language, package, tool or integrated environment system. A model of a business process or systems allows rapid analysis and experimentation to be performed. Simulating the effects of redesigned processes before implementation can lead to improved efficiency and effectiveness, thereby leading to reduced expenditure and investment (Irani er al., 2000; O'Kane el al., 1999, 2000).

Simulation modelling has a diverse range of advantages. According to Felix T.S Chan and Bing Jiang (1999:276), the biggest advantage is the saving of resources and time because of the 'fictional' model that is constructed. Felix T.S Chan and Bing Jiang (1999:276) also state, by modelling the process no production must be stopped to change the line and try and improve the process by physically changing the system. This increases profit tremendously as a result of the information that is obtained from the model. As extracted from Zahir Irani et el (2000:11), 'Simulation models can provide quantitative information that can be used for decision making and may be regarded as problem understanding, rather than problem-solving, tools.' Marc I. Kellner et el (1999:93), lists different results that can be identified from the simulation model:

- Bottlenecks (which station is the bottleneck);
- Areas where improvement can be made;
- Product's flow;
- Utilisation of machines and processes;
- Waiting time of machines and processes;
- Working time of machines and processes;
- Number of the specific product moving through machines and processes;
- Number of products that can be produced with current system;
- Capacity of process;
- Alternative scenarios can be tested;
- Forecast cost and product quality;

- Forecast service-level provided;
- Forecast staffing levels across time;
- Analyse risk.

Another aspect that makes simulation modelling so popular is the fact that it can clearly mimic variation and randomness of the real world system as discussed by Felix T.S Chan and Bing Jiang (1999:276). It can also model different scenarios to help obtain the optimal scenario. One of the main advantages is also discussed by Andrew Greasley (2004:564), namely that simulation modelling reduces risk. '*Uncertainty is removed and replaced with certainty about the expected operation of a new system or about the effects of changes to an existing system*' (McHaney, 1991). Felix T.S Chan and Bing Jiang (1999:276) suggest, before trying to mimic a system and building a simulation model the processes must be understood thoroughly. The graphical representation of simulation modelling also makes it easy to use and to understand (Andrew Greasley 2004:565). It is advisable not to solely rely on just the animation but to also use other reporting and analysis tools. M Erasmus (2005:12) explains from D.K. Myers' studies that the use of visual communication is much more promising in remembering the information than just hearing something. In the past the output data from simulation models took the form of tables or matrixes. This made analysing the data difficult because of the enormous amount of data presented. 'Computer simulation states that the use of graphs and moving images were much more promising. Furthermore the process trend could be swiftly recognized and events can be predicted.

Marc I Kellner et el (1999:93), lists six reasons for using simulation modelling (quoted):

- 'Strategic management;
- Planning;
- Control and operational management;
- Process improvement and technology adoption;
- Understanding;
- Training and learning'.

Before a new business is started there are a few decisions that must be made, for example the capital investment and whether the process will meet expected demand. It is very expensive to test the new system especially if there is not yet certainty about the process (Zahir Irani 2000:11). Zahir describes that simulation modelling can help with insight into these problems and help decision makers make the right choice.

2.3 Different types of simulation

According to Kelton (2007:7), simulation models can be classified according to the following dimensions:

- Static vs. dynamic

  Static models can also be called steady-state models. They try to find a system that is in equilibrium by applying equations to define the relationships between elements of the modelled system. They are used to simulate physical systems as a simpler case before trying to simulate them with dynamic models. Time also plays a role in dynamic models where the opposite is not true from static models. Raymond C. Shreckengost (1985:1) states when using dynamic models in a practical sense, we are concerned with usefulness rather validity. The personal view of the user will state the validity and usefulness of the model. The selection of an appropriate level of detail, problem boundaries, and similar considerations constitute the "art" aspect of dynamic simulation model development.

- Continuous vs. discrete

  Discrete models simulate events on a time scale. It is not important to execute the events on real time. Time is only used as a way to see when what event happens and as events are processed the simulator reads the data. The data derived from the simulation model are usually more important than the input. Results obtained are used to find logic defects in the design. These should be looked at to try and reduce the complexity of the model to make the sustainability of the model easier. Change can only occur at separate points in time with discrete models where with continuous models the state of the system can change continuously over time as stated by Kelton et el (2007:7). A disadvantage of continuous simulation modelling is that information can be lost if the timescale of the model is too large.

- Deterministic vs. stochastic

  Deterministic models use no random inputs and parameters are specified as single values where as with stochastic models there is some kind of randomness in the inputs. Random number generators are used to model stochastic models due to the random events that are present. Uncertainty is recognized in many parameters and correlation between parameters. Monte Carlo simulation models are used when working with stochastic models. Result variables are obtained from numerous batches that are performed on the specific problem.

- Local vs. distributed

  Distributed models are discrete models performed on multiple computers. One simulation model is run over multiple computers that can be composed of several simulation programs. They are usually interconnected through the Internet or some kind of network. Local models are models executed on a single computer. As assured by Richard M. Fujimoto (2001:147): '*distributed simulation is concerned with the execution of simulations on loosely coupled systems where interactions take much more time, and occur less often.*' Also quoted from Fujimoto (2001:153), '*each simulator sends messages, called protocol data unit (PDUs), whenever its state changes in a way that might affect another simulator. Typical PDUs include movement to a new location, firing at another simulated entity, changes in its appearance to other simulators (such as rotating the turret of a tank) etc*.'

Raymond C. Shreckengost (1985, 3) claims '*model boundaries must match the purpose for which the model is designed, if the model is to be used with confidence', that is, the model must include all of the important factors affecting the behaviour of interest. In practice, boundaries tend to shift as the developers' and users' understanding of a problem evolves with the model's development. As model purpose shifts, changes in the model's boundaries may be required.*'

2.4 Different types of simulation software

Marc I. Kellner et el (1999:91) discusses the fact that simulation software has evolved over the past few decades into better, faster, cheaper and more reliable software. This makes the job of software developers much more difficult to improve the performance and the creation of superior simulation software.

Andrew Greasley (2004:565) reports that there is a variety of different simulation modelling software that can be used. For this investigation I used Arena since it is user friendly and easily understood due to its graphical representation of the system as stated by Adrew Greasley (2004:565). Furthermore Marc I. Kellner et el (1999:93) declares that the model also gives feedback information about possible bottlenecks in the system, utilisation of the system and so forth. It can also interact with most of the Microsoft tools, like Excel, Visio, and Access. Importing of spreadsheets from Excel, which helps with statistical and graphical analysis, can also be done.

According to Felix T.S. Chan and Bing Jiang (1999:279) if only random input is available, probability distributions can be used to obtain confidence intervals to represent the reality of the system. By then using triangular and exponential distributions in the simulation process and by repeating this a number of times, confidence intervals can be achieved which will help to find expected values. Felix T.S. Chan and Bing Jiang (1999:279) also state that if random or stochastic input are used the output will also be random.

2.5 Gathering of data

As discussed by Felix T.S. Chan and Bing Jiang (1999:279), the collection of the right information for the construction of the simulation model is of great importance. Additionally if the wrong or insufficient amounts of data are used the results obtained will not be credible and most possibly the wrong conclusions will be drawn. Time studies can be performed on the machines and processes to obtain standard times. This must be repeated a number of times to achieve an accurate average time. A process transforms inputs into outputs towards the common endeavour (Howard S. Gitlow 2005:3). In addition a feedback loop can be implemented on the whole process to report the strengths and weaknesses that are obtained from the outputs back to the decision-makers.

Howard S. Gitlow (2005:5) discusses that in any process there are a number of things that can cause problems. According to him these problems can be identified as either special causes of variation or common causes of variation. He explains these variations as follows: Common causes of variation are events depicting the process itself like day-to-day changes and are because of design of products or services. Employees should not be held liable for common causes of variation. The only way they can be controlled is if a change to the process is made. On the other hand, special causes of variation are things external to the process but still have an impact on the process. Common and special causes of variation should be examined and resolved to stabilise the process. There will always be common causes of variation present to a certain extend in the process but there should be strived towards eliminating special causes of variation from the process. Control limits and an arithmetic average should be calculated to help with the examining of the control chart and data. By using the appropriate rules for identifying out-of-control points a stable process can be achieved. Some cases will demand the calculation of boundaries between the upper and lower control limits to help with the stabilising of the process. After this is done, the process will most probably be stable. Once a process is stable the following are a few advantages as stated by Howard S. Gitlow (2005:155) that will be visible for management:

- Process capability will be known and performance, cost and quality levels can be predicted;
- Productivity will be at a maximum, and costs will be minimised;
- If management wants to alter specification limits, it will have the data to back up its decision;
- With no causes of variation or out-of-control points, changes in the system can be done quicker, easier and with greater reliability.

A stable process is a prerequisite for process improvement. Howard S. Gitlow et el (2005:17) stipulates, '*in the past, quality meant "conformance to valid customer requirements" - that is, as long as an output fell within acceptable limits, called specification limits, around a desired value, called the nominal value (denoted by m) or* *target value, it was deemed conforming, good, or acceptable and we refer to this as the goalpost definition of quality. The nominal value and specification limits are based on perceived needs and wants of customers.*' This definition has changed as quality has emerged. Dr. Genichi Taguchi stipulated as quoted from Howard S. Gitlow er el (2005:18), '*Quality is a predictable degree of uniformity and dependability, at low cost and suited to the market*.' Furthermore Howard S. Gitlow er el (2005:18) explains that requirements should be exceeded and not only met. This is because of the fact that even if products conform to the requirements but deviate from the nominal value, there is a loss associated with these products. Quality should be employed into the design of the product (Howard S. Gitlow er el 2005:21). This is the given characteristic that makes it suited for the given needs and wants of the market at a given cost.

2.6 Constructing of a simulation model

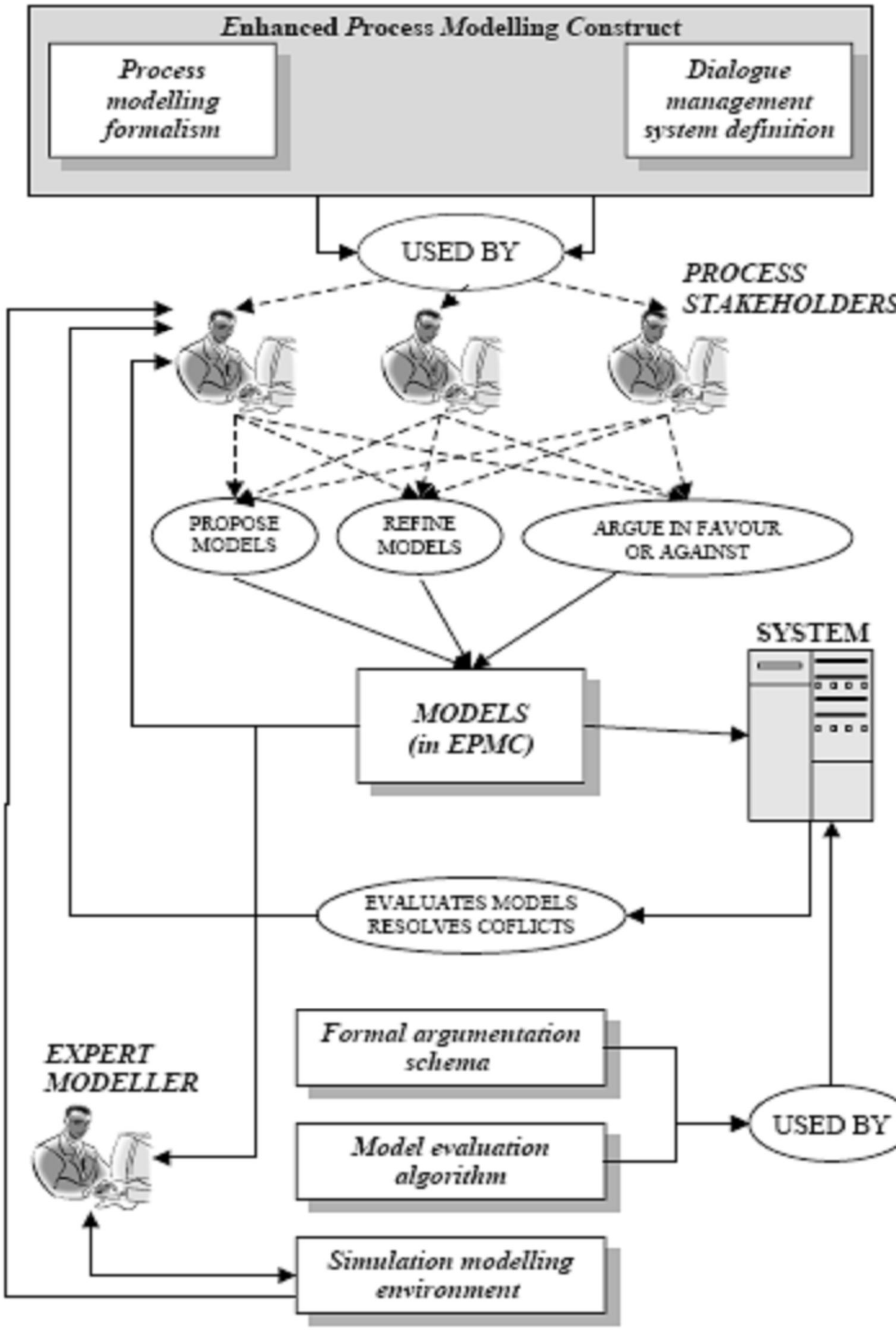
The following are the steps needed to construct a simulation model in any simulation language as identified by Marc I. Kellner (1999:97):

- Define the system to be used and state the objectives;
- Collect credible data and if necessary analyse the data to specify the input parameters and distributions;
- Specify the problem to be modelled;
- Identify key activities and tasks;
- Separate the model into pieces so that each entity represents a part that will be modelled;
- Categorise dependencies between activities and tasks and the flow of the process;
- Determine decision points in model;
- Built the model;
- Run the created model;
- Store run outputs;
- Change certain key variables and re-run the model;
- Analyse the results obtained from the model.

Line balancing will be established when analysing the simulation model and trying to reduce the cycle time and maximising the output (Adrew Greasley 2004:562). In addition when testing alternative scenarios, the simulation model can, for example run with the target cycle time and demand to assess the performance of the system. Also reduction in key factors like fabrication set-up times can help and achieve the required overall cycle time. This new improved process can then result in a more balanced line and increase the utilisation capacity.

The following figure from Emmanuel D. Adamides and Nikos Karacapilidis (2006:564) shows the complete process of simulation modelling in a business context.

Figure 2: Methodology of simulation modelling in the business context



2.7 Conclusion – Literature review

Simulation modelling has developed into one of the most used tools for analysing processes. Simulation modelling is used at the design phase of a project and if a process is not operating at its full capacity and must be improved. Performance and utilisation can be predicted and processes that will most possible cause problems can be detected. The use of simulation modelling has increased enormously, because of the numerous advantages that it offers. Different scenarios can also be tested to obtain an improved process. The output is represented by way of visual and graphical models that make the results easily understandable and useable. As *quoted* by 'Computer simulation', '*The reliability and the trust people put in computer simulations depends on the validity of the simulation model, therefore verification and validation are of crucial importance in the development of computer simulation. Another important aspect of computer simulations is that of reproducibility of the results, meaning that a simulation model should not provide a different answer for each execution.*' Sensitivity analysis should also be performed on the answers established from the model to certify the accuracy of the answers and that they are understood correctly. The results obtained from the simulation model depend on accuracy of the values of the parameters. According to Marc I. Kellner (1999:98), '*Actual data should be used to validate the model empirically and to calibrate it against real-world results*.'

The model that is constructed should be revised to check if the behaviour of the model is similar to that of the system that is observed. If this is not the case the system will generate little or no confidence. Data used should also be stable and randomness should try to be avoided, since random input will generate random output. According to Raymond C. Shreckengost (1985, 4), if the model is not tested to extreme conditions it may impact the performance of the model when operating under normal conditions and when questions are asked that fall outside the operating regions.

Simulation modelling is often seen only as a tool for analysing different scenarios at an operational level. When major investment decisions are made the success of these strategic decisions is dependant on the subsequent operational effectiveness of the investment (Adrew Greasley 2008:983).

Chapter 3 – Conceptual design

The following will be the steps of the project and ways in which the process will be analysed and improved:

- The process flow will be examined and time studies will be done on the different workstations of the process;
- Quality management will be introduced if out-of control points are discovered with the implementation of standard times for the different workstations;
- After analysis of the process a simulation model will be built to obtain which of the workstations is decreasing the throughput of the system as well as to see whether they are performing at full capacity and efficiency;
- The bottlenecks from the original process will be eliminated and the improved layout will be simulated to see at which station new bottlenecks exist as well as the improvement in throughput and efficiency.
- The improved layout and flow will be given over to the owner to implement the improved processes and layout.

Each step of the project cannot commence before the previous step has been finished. Time studies will be performed on each separate machine and process to obtain standard times. This will be repeated a number of times to achieve accurate average times. Quality management will be performed and control charts will be created from the standard times obtained. Out-of-control points will be identified and analysed to stabilize the process. A stabile process is a prerequisite for an accurate simulation model. The simulation model will be based on the data collected from the process and constructed only on the specified section. With the concluding of the project it will be handed offer to management for implementations and improvement of the process.

Chapter 4 – Work Study

Data had to be gathered and analysed to generate the necessary solutions to the problems. Work-study is a diverse number of techniques aimed to examine machine and human output, used to help and improve the efficiency of the process. This will help to utilise the available resources to their full potential.

4.1 Time Study

Time studies were performed a number of times on the process line under examination, including the workstations and transportation between machines. As stated only the normal size, box exhaust type was used for analyses. The bottleneck for this specific type and size of exhaust will also be the bottleneck for all the other types and sizes of exhausts. The time to manufacture different types and sizes of exhausts is proportional to each other. Time studies were done to establish standard times and standard deviation times for each workstation. Standard time is the time that a specific machine or operator requires performing a task, working at normal speed and pace.

Time studies should be repeated a number of times to achieve more accurate standard times. Samples where fatigue and delays played a role should be eliminated out of the study to achieve more precise times. The following is the time studies that were done on the process being analysed.

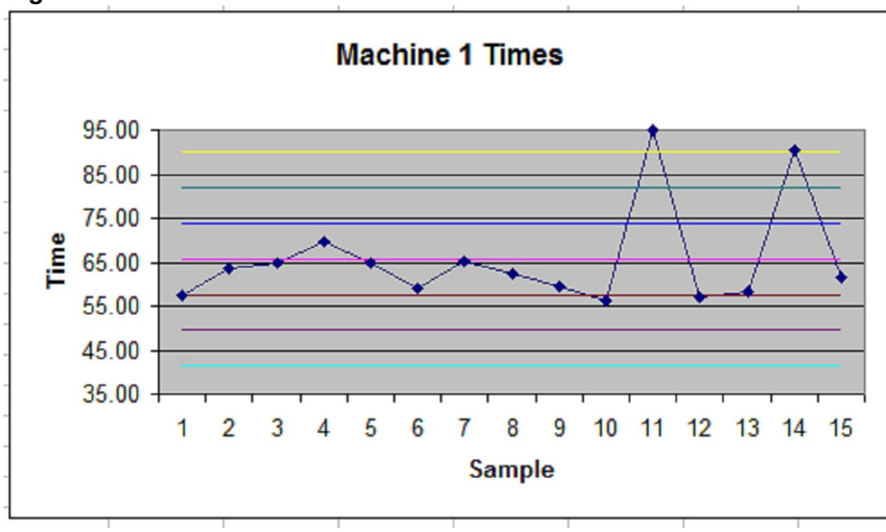
Table 1: Time study

	Times										
Machine		1	2	3	4	5	6	7	8	11	12
	1	57.57	6.73	11.10	24.45	11.19	19.58	20.10	14.44	53.80	59.07
	2	63.70	5.51	8.00	26.28	12.84	26.05	24.20	13.10	50.51	56.13
	3	64.93	5.40	7.53	24.47	12.32	21.72	18.24	13.53	57.86	62.84
	4	69.88	5.47	8.16	25.01	12.96	20.93	21.68	14.58	118.51	55.42
	5	64.84	6.68	8.67	25.56	12.66	22.44	19.37	23.76	62.62	59.81
	6	59.23	5.49	8.53	25.31	13.80	23.61	23.79	14.77	53.16	63.42
	7	65.31	5.99	7.97	26.87	12.31	20.30	22.06	12.83	58.30	89.83
	8	62.39	5.59	8.34	25.19	13.28	19.89	20.61	13.83	59.79	60.13
	9	59.32	5.92	8.49	24.41	12.60	21.37	23.29	11.98	68.97	58.80
	10	56.10	5.00	10.14	24.84	12.91	24.85	19.46	13.04	64.09	62.49
	11	94.82	6.34	9.20	27.60	11.54	21.86	21.16	14.30	59.11	59.21
	12	57.17	5.06	8.88	26.12	11.89	22.37	21.46	18.61	55.84	61.37
	13	58.32	6.30	8.73	24.81	13.64	23.79	22.99	16.28	124.05	58.38
	14	90.65	5.84	8.65	24.90	13.10	20.14	21.71	12.09	63.09	83.29
	15	61.36	5.43	9.18	25.63	12.63	20.37	19.73	14.52	58.76	62.49
	Average	65.71	5.78	8.77	25.43	12.64	21.95	21.32	14.78	67.23	63.51
	Stdev	11.62	0.54	0.89	0.93	0.72	1.92	1.76	2.99	22.45	9.72
	Max	94.82	6.73	11.10	27.60	13.80	26.05	24.20	23.76	124.05	89.83
	Min	56.10	5.00	7.53	24.41	11.19	19.58	18.24	11.98	50.51	55.42

4.2 Quality Management

Control charts are used to stabilise data. C- charts were used to analyse the times recorded and to exam whether times have stabilised or not. A C- chart was used because of the sample size and data series. During the time studies, machines 1, 11 and 12 already showed signs of times that were large and hence, possibly out-of-control points. The times recorded for each machine must first be examined and stabilised, before using them for the creation of the simulation model.

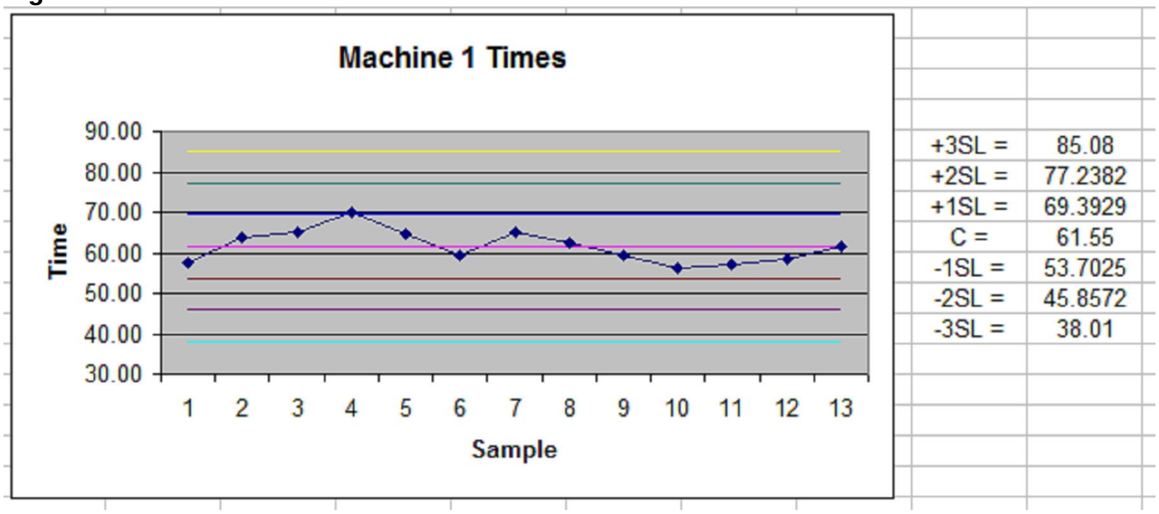
Figure 3: Unstable times of machine 1



+3SL =	90.02
+2SL =	81.9178
+1SL =	73.8119
C =	65.71
-1SL =	57.6001
-2SL =	49.4942
-3SL =	41.39

Point 11 and 14 were larger than average due to workers struggling to retrieve the raw material and cutting it in the desired measurements for the specific exhaust that will be manufactured. After eliminating these points the chart was under statistical control.

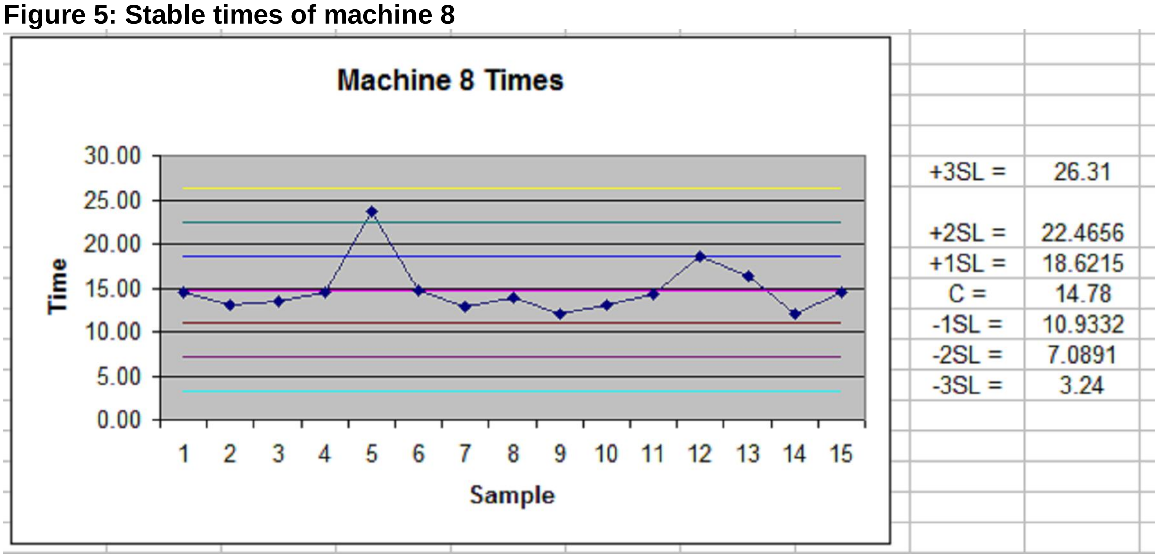
Figure 4: Stable times of machine 1



Using these stable times, the mean and standard deviation can be calculated and used in constructing the simulation model. The times used will now be more exact after the out-of-control points were eliminated.

The next machine that showed signs of instability was machine 8. After the necessary calculation was done, it showed that the process was stable and all the points varied between the upper and lower control limits. None of the rules for out-of-control points were valid and could be applied.

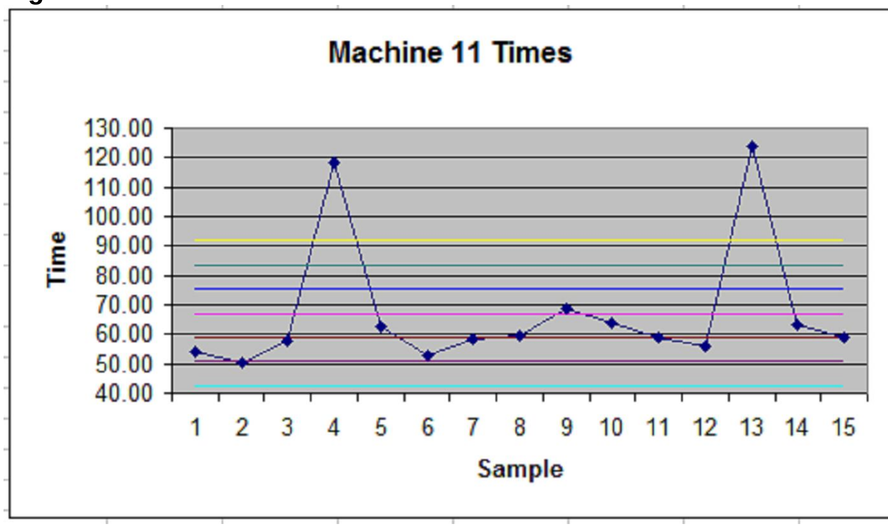
Figure 5: Stable times of machine 8



Point 5 was as a result of the worker looking for the part and then struggling to perform the required activity.

Out-of-control points were established at points 4 and 13.

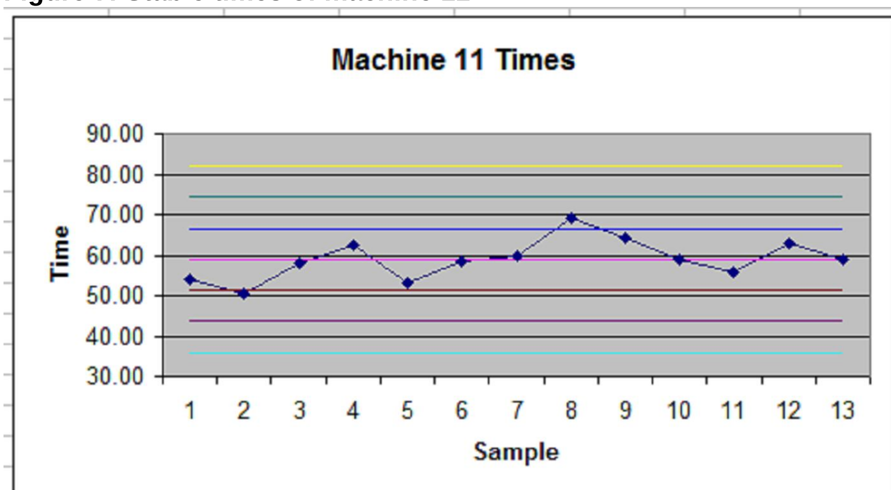
Figure 6: Unstable times of machine 11



+3SL =	91.83
+2SL =	83.6295
+1SL =	75.4301
C =	67.23
-1SL =	59.0312
-2SL =	50.8318
-3SL =	42.63

After eliminating points 4 and 13 - which was as a result of fibre that was finished and the worker that had to get more fibre before continuing his work - the process was then stable and the data collected from the time studies could be used in the construction of the simulation model.

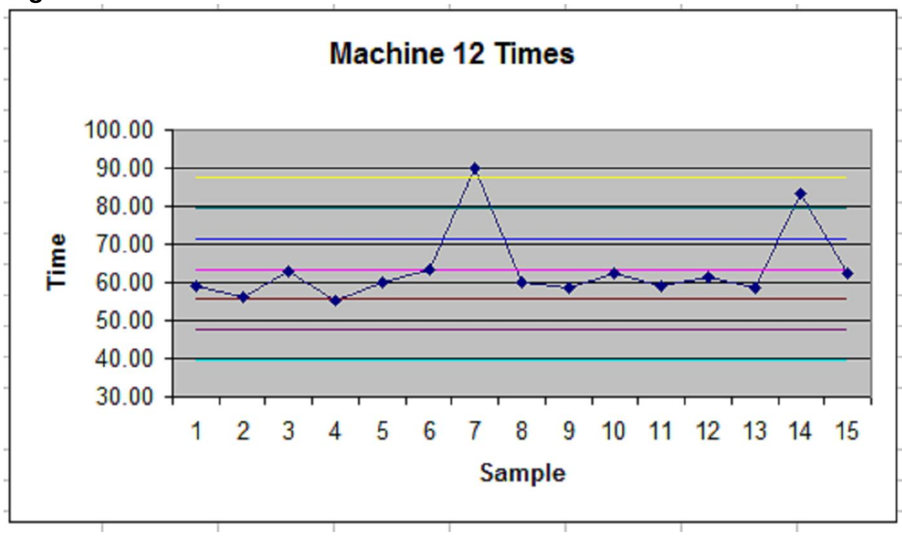
Figure 7: Stable times of machine 11



+3SL =	81.94
+2SL =	74.2667
+1SL =	66.5910
C =	58.92
-1SL =	51.2397
-2SL =	43.5641
-3SL =	35.89

The last process showed 2 points that was quite large. Only point 7 though was eligible for removal. Point 14 was within the control limits.

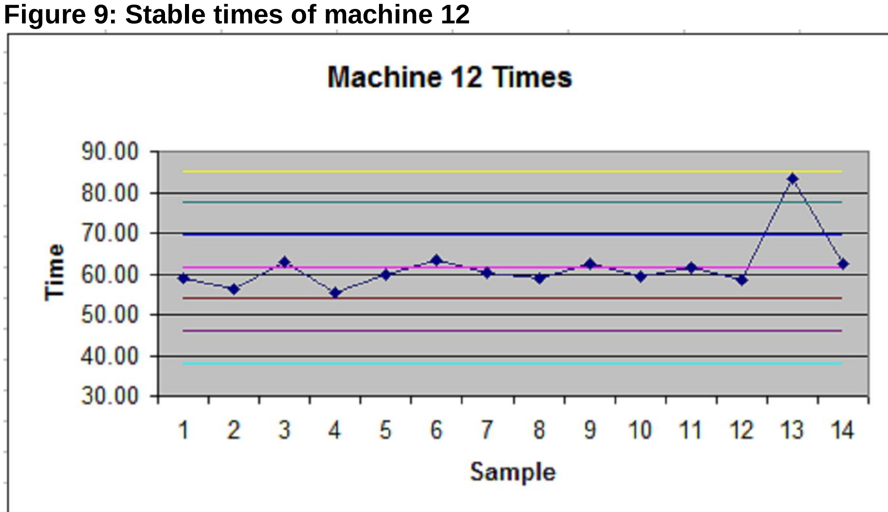
Figure 8: Unstable times of machine 12



+3SL =	87.42
+2SL =	79.4509
+1SL =	71.4814
C =	63.51
-1SL =	55.5426
-2SL =	47.5731
-3SL =	39.60

After eliminating point 7, which was as a result of a problem between worker and machine, the process was stabilise. Point 13, although very large, is still within the control limits.

Figure 9: Stable times of machine 12



+3SL =	85.18
+2SL =	77.3334
+1SL =	69.4828
C =	61.63
-1SL =	53.7815
-2SL =	45.9309
-3SL =	38.08

All the processes are now stable and the data collected can now be used to construct a simulation model for further analyses.

Chapter 5 – Design and Problem Solving

5.1 Simulation modelling

The first step of building a simulation model is identifying your entities, variables, attributes, resources and statistical accumulators. Every facet of the process, be it human or machine that interacts with the process, must be addressed to give a clear suggestion for the modeller on the problem.

5.1.1 Entities

As quoted by Kelton (2007:20): '*Entities move around, change status, affect and are affected by other entities and the state of the system. They usually are created, move around for a while, and then are disposed of as they leave*.' In the model there will be the following entities:

- Raw metal sheets.

5.1.2 Variables

As extracted from Kelton (2007:21): '*A variable is a piece of information that reflects some characteristic of your system, regardless of how many of what kinds of entities might be around.*' The variable of the model includes:

- Time part spends in system.

5.1.3 Attributes

Referencing Kelton (2007:21): '*An attribute is a common characteristic of all entities, but with a specific value that can differ from one entity to another.'* The attributes identified are:

- Entity picture;
- Destination of parts.

5.1.4 Resources

Kelton (2007:22) states '*An entity seizes a resource when available and releases it when finished.'* Resources will include the following:

- Workers available to bring raw material to cutting machine;
- Different machines;
- Workers performing the sorting of the different exhausts manufactured;
- Workers storing sorted exhausts.

5.1.5 Queues

As discussed by Kelton (2007:22): '*When an entity can not move on, perhaps because it needs to seize a unit of a resource that is tied up by another entity, it needs a place to wait, which is the purpose of a queue.'* Queues will develop where there are bottlenecks and at workstations where the utilisation is very high.

5.1.6 Statistical Accumulators

To get output performance measures, various intermediate statistical-accumulators variables must be followed. The following statistical accumulators will be followed through the system:

- The number of parts produced;
- The longest time spent in queue so far;
- The total time spent in system by all parts;
- The longest time in system.

5.2 Building of the Simulation Model

5.2.1 Model Logic

The simulation model has a number of processes that represents the machines and workstations. Raw metal sheets are retrieved from the storage area and cut into smaller pieces depending on the size and type of exhaust manufactured. It then enters the process moving through the different workstations. All the workstations only have one worker. The process where fibre is weight and put into the exhaust cover has two workers. Products are sent to the worker with the least amount of products waiting in line. The factory works from 7 am to 4 pm, Monday to Friday. Machines are then shutdown and cleaned.

The following are the mean and standard deviation times used in the simulation model. These were derived from the times collected from the time studies and stabilised with the quality management techniques.

Table 2: Machine times

Machine	Old Average	New Average	Old Stdev	New Stdev
1	65.71	61.55	11.62	4.05
2	5.78	5.78	0.54	0.54
3	8.79	8.79	0.89	0.89
4	25.43	25.43	0.93	0.93
5	12.64	12.64	0.72	0.72
6	21.95	21.95	1.92	1.92
7	21.32	21.32	1.76	1.76
8	14.78	14.78	2.99	2.99
11	67.23	58.92	22.45	5.01
12	63.51	61.63	9.72	6.68

To distinguish which of the machines is the bottleneck 33 raw metal sheets are used with the simulation model created. The raw metal sheets are then cut into 9 smaller pieces and enter the process. Raw metal sheets enter the process every 340 seconds. This is sufficient, because entities are already stacking up at certain stations. A number of process modules that depict each machine and its corresponding mean and standard deviation were used to simulate the problem. A separate module was also used were the raw metal sheets are cut into 9 smaller pieces. A decide module was also used to decide to which filling machine products would be sent. Products are sent to the filling machine with the smallest amount of products in the queue. The Arena layout for the process can be seen in the figure below.

Figure 10: Simulation model of current process

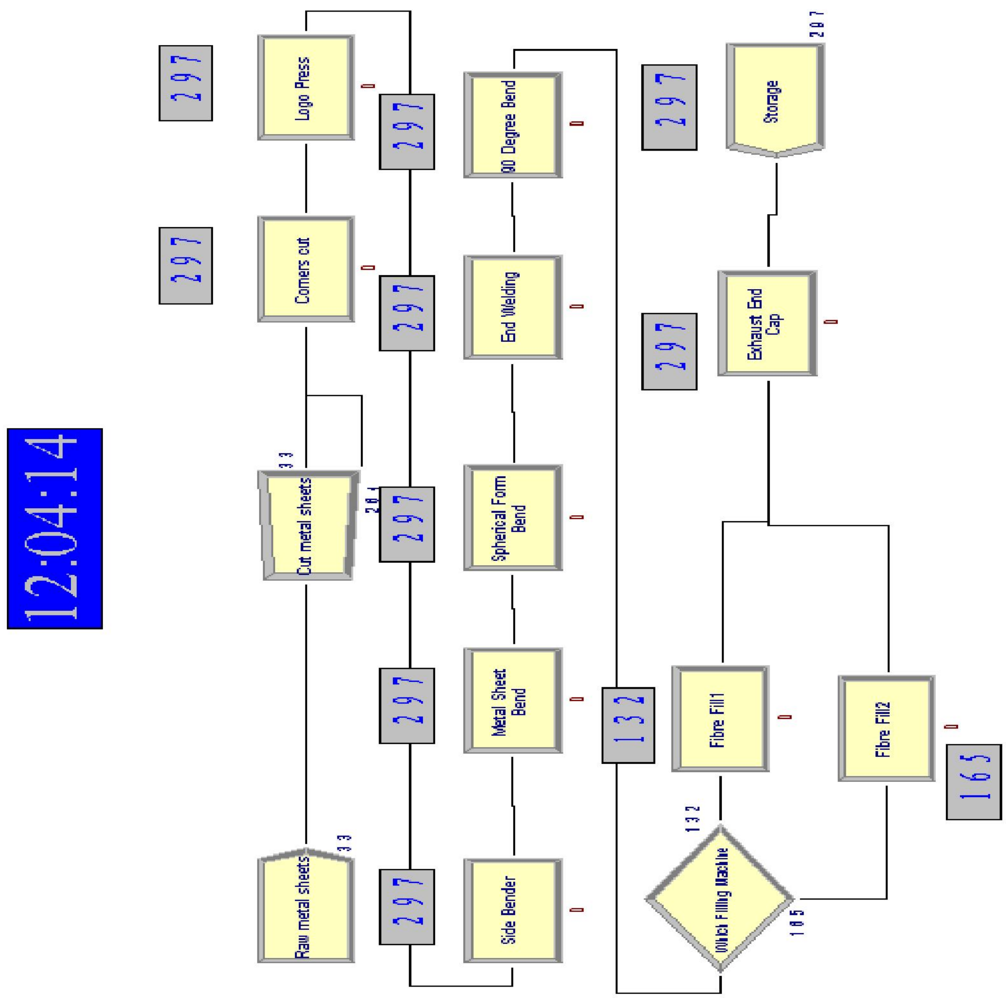


Table 3: Current process results

	Utilization	Avg Wait sec.
Corners cut	0.09	22.94
Logo Press	0.14	12.08
Side Bender	0.41	66.73
Metal Sheet Bend	0.21	0.00
Spherical Form Bend	0.35	0.04
End Welding	0.35	0.16
90 Degree Bend	0.24	0.76
Fibre Fill machine 1	0.42	15.90
Fibre Fill machine 2	0.53	33.60
Exhaust End Cap machine 1	0.99	3448.44

Chapter 6 – Design / Solution evaluation

33 metal sheets were modelled to establish the bottlenecks of the system. With the current process as seen from the results obtained from Arena, the bottleneck is at the machine where the exhaust end caps are put onto the exhaust. The average waiting time at the exhaust end cap machine is 3448.44 seconds. If workers start to work at 7 am they must work approximately to 12 pm to finish 297 exhausts with the current process layout.

After investigation it was established that there is another exhaust end cap machine. In the improved process layout both machines are used and another decide module is used to send products to the machine with the smallest amount of products in the queue. Raw metal sheets enter the process every 155 seconds, a big improvement on the original arrival time of 340 seconds. The average waiting time of the exhaust end cap machines has decreased significantly. As seen from the new average waiting times, the side bender machine is now the bottleneck of the process.

The new improved layout can be stream lined even more by adding another side bender machine. This will increase the throughput time even more which will lead to more exhausts being manufactured.

It takes the new improved process approximately two and a half hours to finish 297 exhausts. Approximately double the amount of exhausts can now be manufactured with the improved process, in the same amount time as before.

The cost analyses of the current and improved process are as follows, where only the normal size, box exhaust type (UMC3318502) is used as stated.

Table 4: Cost analysis

	Current process	Improved process
Price of exhaust (UMC3318502)	R 125.00	R 125.00
Manufacturing cost	R 57.90	R 57.90
Profit per exhaust (UMC3318502)	R 67.10	R 67.10
Products produced per month	9504	19008
Additional electricity per month	-	R 192.00
Maintenance on additional machine per month	-	R 25.00
Additional worker salary per month	-	R 4,000.00
Profit per month	**R 637,718.40**	**R 1,271,219.80**

The improved process will increase monthly income by R 633 501,40. Thus the change in process is financially supported.

The Arena layout for the improved process can be seen in the figure below:

Figure 11: Simulation model of improved process

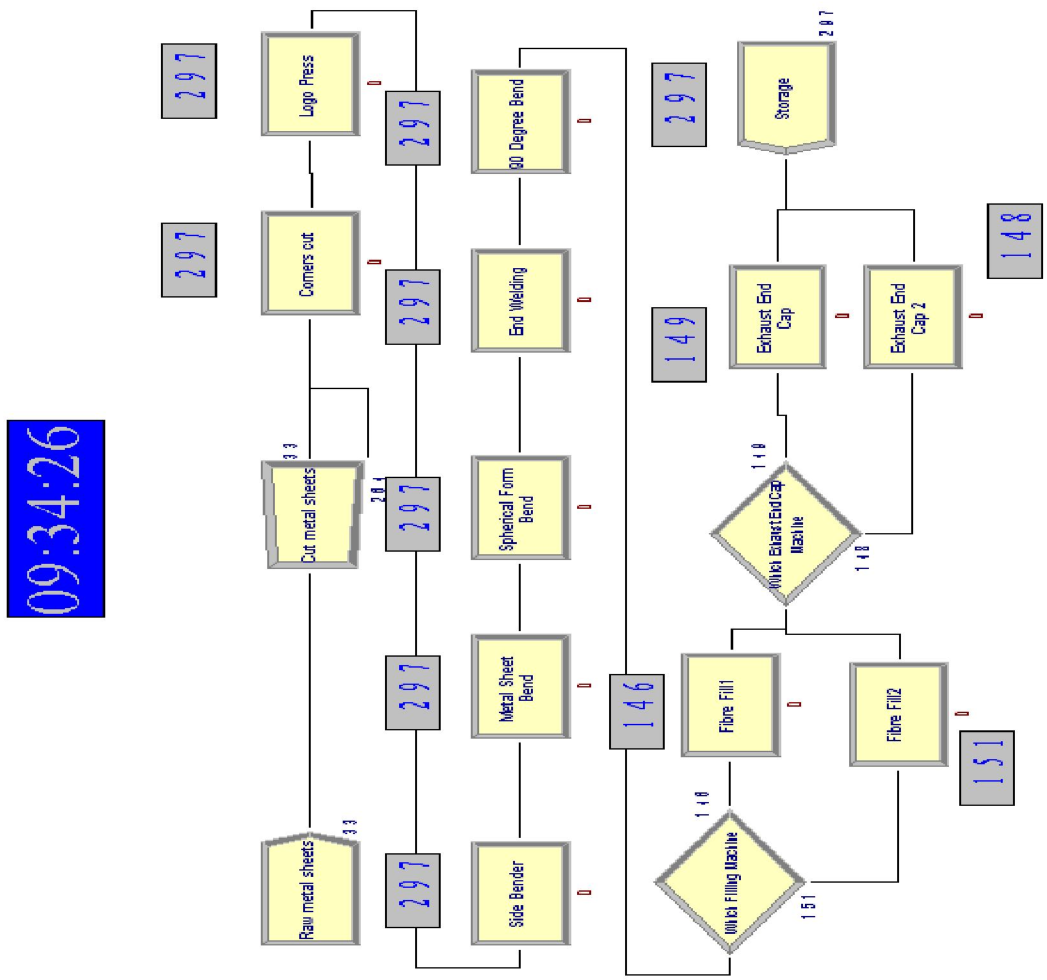


Table 5: Improved process results

	Utilization	Avg Wait sec.
Corners cut	0.18	22.85
Logo Press	0.28	12.20
Side Bender	0.81	1247.52
Metal Sheet Bend	0.40	0.00
Spherical Form Bend	0.70	0.06
End Welding	0.68	0.21
90 Degree Bend	0.48	0.00
Fibre Fill machine 1	0.93	552.34
Fibre Fill machine 2	0.94	563.16
Exhaust End Cap machine 1	0.97	202.80
Exhaust End Cap machine 2	0.98	232.10

Chapter 6 – Conclusion

The project increased the throughput and efficiency of the current process and established better ways of utilising recourses and manpower. The performance of the current layout was tested and alternative layouts were established to increase the productivity and thus profit. It also assisted management in predicting whether additional lines or machines or the replacement of machines are required. Simulation modelling was applied on the standard times that were achieved from time studies and quality management. Quality management techniques were applied to stabilise the process by eliminating out-of-control points. Possible conclusions can also be drawn from the control charts that were created from the data.

The simulation model also made workers more accountable for their contributions and actions. The model informed the workers about the process and will help them interact better with each other and the process analysed. Best and worst case scenarios can also be tested with the simulation model to determine the maximum and minimum rate of product flow through the system. Extreme conditions can also be tested, like machine breakdown events. This will illustrate the robustness of the system. Other important decisions that can also be made with the results obtained from the simulation model are capacity planning, material management and ordering policy.

Simulation modelling helped to understand the process and increase the throughput time. Although a very powerful tool, no tool or man can predict the future; it should only be used to aid decision-making.

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Appendix A

Appendices A.1

1.) c = Total nuber of events obeserved / Number of areas of opporunity

= 985.59 / 15.00

= 65.71

standard error = √(62.36)

= 8.11

UCL(c) = c + 3√c

= 62.36 + 3√62.36

= 90.02

LCL(c) = c - 3√c

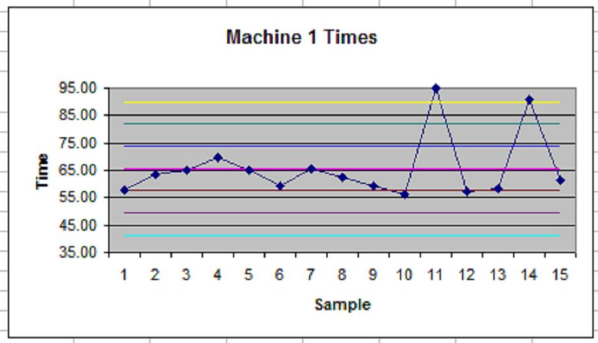
= 62.36 3√62.36

= 41.39

Boundry between lower zones A and B = c - 2√(c) = 49.4942

Boundry between lower zones B and C = c - √(c) = 57.6001

Boundry between upper zones A and B = c + 2√(c) = 81.9178



+3SL =	90.02
+2SL =	81.9178
+1SL =	73.8119
C =	65.71
-1SL =	57.6001
-2SL =	49.4942
-3SL =	41.39

B

	Times	
Machine		1
	1	57.57
	2	63.70
	3	64.93
	4	69.88
	5	64.84
	6	59.23
	7	65.31
	8	62.39
	9	59.32
	10	56.10
	12	57.17
	13	58.32
	15	61.36
	Average	61.55
	Stdev	4.05
	Max	69.88
	Min	56.10

c = Total nuber of events obeserved / Number of areas of opporunity

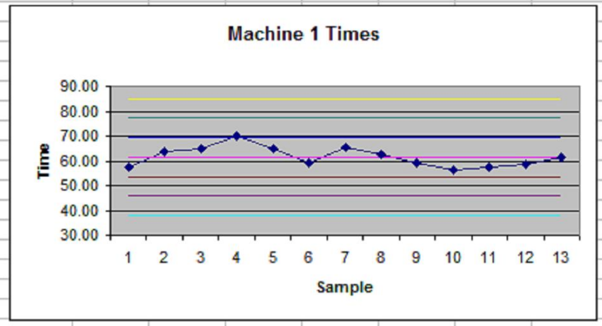
= 800.12 / 13.00

= 61.55

standard error = √(61.55)

= 7.85

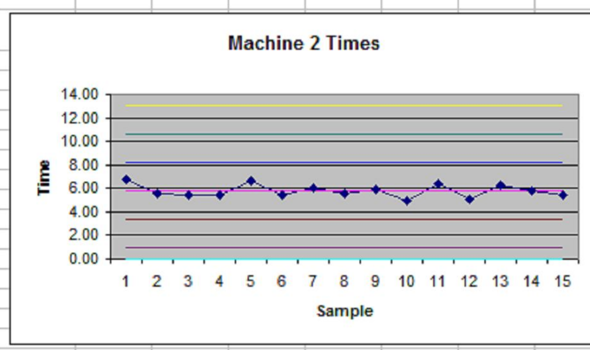
	UCL(c) =	c + 3√c	
	=	61.55 + 3√61.55	
	=	85.08	
	LCL(c) =	c - 3√c	
	=	61.55 3√61.55	
	=	38.01	
Boundry between lower zones A and B		=	c - 2√(c)
		=	45.8572
Boundry between lower zones B and C		=	c - √(c)
		=	53.7025
Boundry between upper zones A and B		=	c + 2√(c)
		=	77.2382
Boundry between upper zones A and B		=	c + √(c)
		=	69.3929



+3SL =	85.08
+2SL =	77.2382
+1SL =	69.3929
C =	61.55
-1SL =	53.7025
-2SL =	45.8572
-3SL =	38.01

Appendices A.2

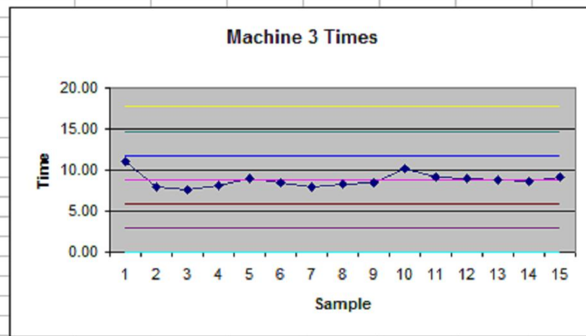
2.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	86.75	
		15.00	
	=	5.78	
			√(5.78)
	standard error =		
		=	2.40
	UCL(c) =	c + 3√c	
	=	5.78 + 3√5.78	
	=	13.00	
	LCL(c) =	c - 3√c	
	=	5.78 - 3√5.78	
	=	-1.43	
	=	0.00	
Boundry between lower zones A and B		=	c - 2√(c)
		=	0.9736
Boundry between lower zones B and C		=	c - √(c)
		=	3.3785
Boundry between upper zones A and B		=	c + 2√(c)
		=	10.5930
Boundry between upper zones A and B		=	c + √(c)
		=	8.1882



+3SL =	13.00
+2SL =	10.5930
+1SL =	8.1882
C =	5.78
-1SL =	3.3785
-2SL =	0.9736
-3SL =	0.00

Appendices A.3

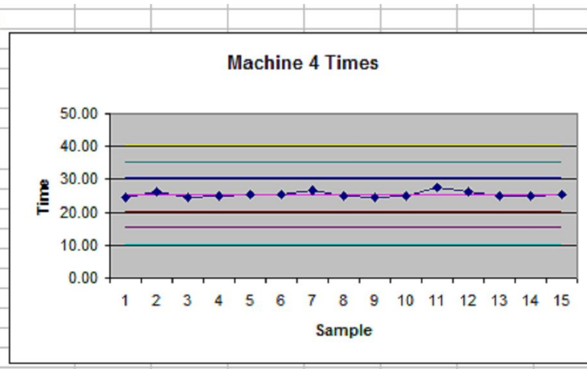
3.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	131.83	
		15.00	
	=	8.79	
			√(8.77)
	standard error =		
		=	2.96
	UCL(c) =	c + 3√c	
	=	8.77 + 3√8.77	
	=	17.68	
	LCL(c) =	c - 3√c	
	=	8.77 - 3√8.77	
	=	-0.11	
	=	0.00	
Boundry between lower zones A and B		=	c - 2√(c)
		=	2.8595
Boundry between lower zones B and C		=	c - √(c)
		=	5.8241
Boundry between upper zones A and B		=	c + 2√(c)
		=	14.7178
Boundry between upper zones A and B		=	c + √(c)
		=	11.7532



+3SL =	17.68
+2SL =	14.7178
+1SL =	11.7532
C =	8.79
-1SL =	5.8241
-2SL =	2.8595
-3SL =	0.00

Appendices A.4

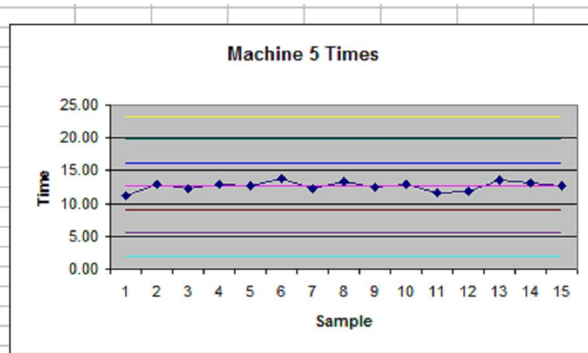
4.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	381.45	
		15.00	
	=	25.43	
			√(25.43)
	standard error =		
		=	5.04
	UCL(c) =	c + 3√c	
	=	25.43 + 3√25.43	
	=	40.56	
	LCL(c) =	c - 3√c	
	=	25.43 - 3√25.43	
	=	10.30	
Boundry between lower zones A and B		=	c - 2√(c)
		=	15.3444
Boundry between lower zones B and C		=	c - √(c)
		=	20.3872
Boundry between upper zones A and B		=	c + 2√(c)
		=	35.5156
Boundry between upper zones A and B		=	c + √(c)
		=	30.4728



+3SL =	40.56
+2SL =	35.5156
+1SL =	30.4728
C =	25.4300
-1SL =	20.3872
-2SL =	15.3444
-3SL =	10.30

Appendices A.5

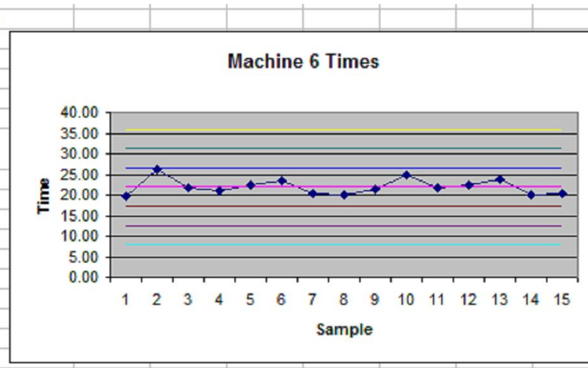
5.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	189.67	
		15.00	
	=	12.64	
			√(12.64)
	standard error =		
		=	3.56
	UCL(c) =	c + 3√c	
	=	12.64 + 3√12.64	
	=	23.31	
	LCL(c) =	c - 3√c	
	=	12.64 - 3√12.64	
	=	1.98	
Boundry between		=	c - 2√(c)
lower zones A and		=	5.5328
B			
Boundry between		=	c - √(c)
lower zones B and		=	9.0887
C			
Boundry between		=	c + 2√(c)
upper zones A and		=	19.7565
B			
Boundry between		=	c + √(c)
upper zones A and		=	16.2006
B			



+3SL =	23.31
+2SL =	19.7565
+1SL =	16.2006
C =	12.64
-1SL =	9.0887
-2SL =	5.5328
-3SL =	1.98

Appendices A.6

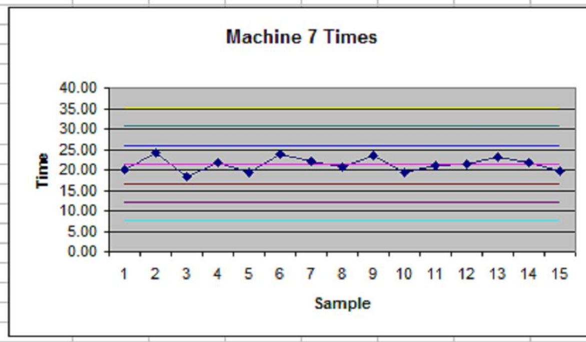
6.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	329.27	
		15.00	
	=	21.95	
			√(21.95)
	standard error =		
		=	4.69
	UCL(c) =	c + 3√c	
	=	21.95 + 3√21.95	
	=	36.01	
	LCL(c) =	c - 3√c	
	=	21.95 - 3√21.95	
	=	7.90	
Boundry between		=	c - 2√(c)
lower zones A and		=	12.5809
B			
Boundry between		=	c - √(c)
lower zones B and		=	17.2661
C			
Boundry between		=	c + 2√(c)
upper zones A and		=	31.3218
B			
Boundry between		=	c + √(c)
upper zones A and		=	26.6366
B			



+3SL =	36.01
+2SL =	31.3218
+1SL =	26.6366
C =	21.95
-1SL =	17.2661
-2SL =	12.5809
-3SL =	7.90

Appendices A.7

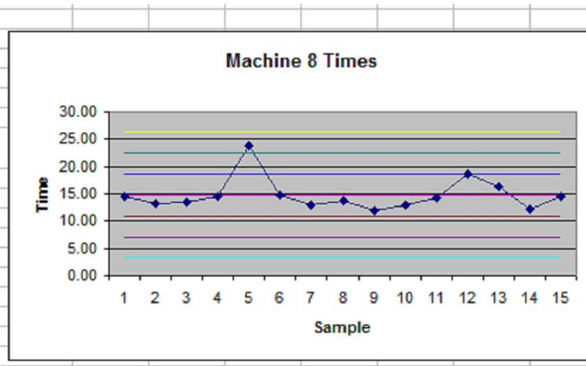
7.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	319.85	
		15.00	
	=	21.32	
			√(21.32)
	standard error =		
		=	4.62
	UCL(c) =	c + 3√c	
	=	21.32 + 3√21.32	
	=	35.18	
	LCL(c) =	c - 3√c	
	=	21.32 - 3√21.32	
	=	7.47	
Boundry between lower zones A and B		=	c - 2√(c)
		=	12.0879
Boundry between lower zones B and C		=	c - √(c)
		=	16.7056
Boundry between upper zones A and B		=	c + 2√(c)
		=	30.5588
Boundry between upper zones A and B		=	c + √(c)
		=	25.9411



+3SL =	35.18
+2SL =	30.5588
+1SL =	25.9411
C =	21.32
-1SL =	16.7056
-2SL =	12.0879
-3SL =	7.47

Appendices A.8

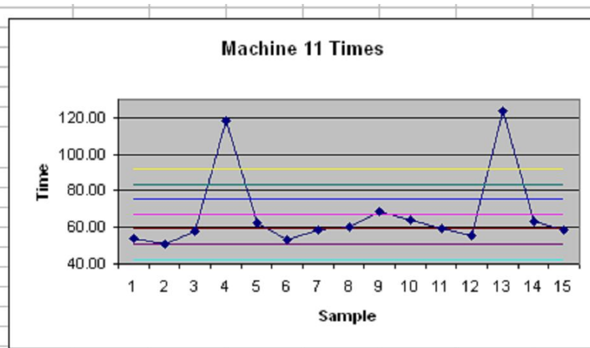
8.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	221.66	
		15.00	
	=	14.78	
			√(14.78)
	standard error =		
		=	3.84
	UCL(c) =	c + 3√c	
	=	14.78 + 3√14.78	
	=	26.31	
	LCL(c) =	c - 3√c	
	=	14.78 - 3√14.78	
	=	3.24	
Boundry between lower zones A and B		=	c - 2√(c)
		=	7.0891
Boundry between lower zones B and C		=	c - √(c)
		=	10.9332
Boundry between upper zones A and B		=	c + 2√(c)
		=	22.4656
Boundry between upper zones A and B		=	c + √(c)
		=	18.6215



+3SL =	26.31
+2SL =	22.4656
+1SL =	18.6215
C =	14.78
-1SL =	10.9332
-2SL =	7.0891
-3SL =	3.24

Appendices A.9

11.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	1008.46	
		15.00	
	=	67.23	
			√(59.52)
	standard error =		
		=	8.20
	UCL(c) =	c + 3√c	
	=	59.52 + 3√59.52	
	=	91.83	
	LCL(c) =	c - 3√c	
	=	59.52 - 3√59.52	
	=	42.63	
Boundry between lower zones A and B	=	c - 2√(c)	
	=	50.8318	
Boundry between lower zones B and C	=	c - √(c)	
	=	59.0312	
Boundry between upper zones A and B	=	c + 2√(c)	
	=	83.6295	
Boundry between upper zones A and B	=	c + √(c)	
	=	75.4301	

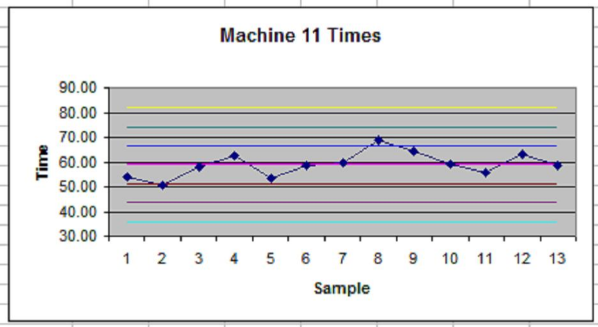


+3SL =	91.83
+2SL =	83.6295
+1SL =	75.4301
C =	67.23
-1SL =	59.0312
-2SL =	50.8318
-3SL =	42.63

	Times	
Machine		11
	1	53.80
	2	50.51
	3	57.86
	5	62.62
	6	53.16
	7	58.30
	8	59.79
	9	68.97
	10	64.09
	11	59.11
	12	55.84
	14	63.09
	15	58.76
	Average	58.92
	Stdev	5.01
	Max	68.97
	Min	50.51

	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	765.90	
		13.00	
	=	58.92	
			√(58.92)
	standard error =		
		=	7.68

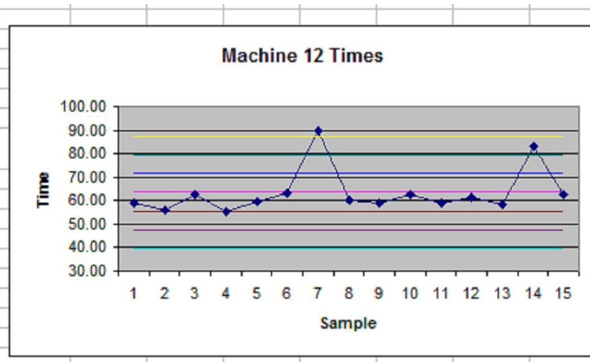
	UCL(c) =	c + 3√c	
	=	58.92 + 3√58.92	
	=	81.94	
	LCL(c) =	c - 3√c	
	=	58.92 - 3√58.92	
	=	35.89	
Boundry between lower zones A and B	=	c - 2√(c)	
	=	43.5641	
Boundry between lower zones B and C	=	c - √(c)	
	=	51.2397	
Boundry between upper zones A and B	=	c + 2√(c)	
	=	74.2667	
Boundry between upper zones A and B	=	c + √(c)	
	=	66.5910	



+3SL =	81.94
+2SL =	74.2667
+1SL =	66.5910
C =	58.92
-1SL =	51.2397
-2SL =	43.5641
-3SL =	35.89

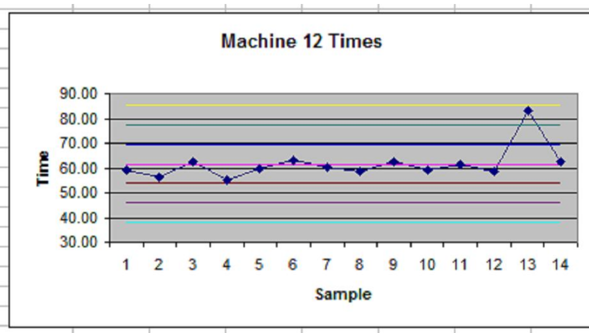
Appendices A.10

12.)	c =	Total nuber of events obeserved	
		Number of areas of opporunity	
	=	952.68	
		15.00	
	=	63.51	
			√(60.39)
	standard error =		
		=	7.97
	UCL(c) =	c + 3√c	
	=	60.39 + 3√60.39	
	=	87.42	
	LCL(c) =	c - 3√c	
	=	60.39 - 3√60.39	
	=	39.60	
Boundry between lower zones A and B	=	c - 2√(c)	
	=	47.5731	
Boundry between lower zones B and C	=	c - √(c)	
	=	55.5426	
Boundry between upper zones A and B	=	c + 2√(c)	
	=	79.4509	
Boundry between upper zones A and B	=	c + √(c)	
	=	71.4814	



+3SL =	87.42
+2SL =	79.4509
+1SL =	71.4814
C =	63.51
-1SL =	55.5426
-2SL =	47.5731
-3SL =	39.60

	Times	
Machine		12
	1	59.07
	2	56.13
	3	62.84
	4	55.42
	5	59.81
	6	63.42
	8	60.13
	9	58.80
	10	62.49
	11	59.21
	12	61.37
	13	58.38
	14	83.29
	15	62.49
	Average	61.63
	Stdev	6.68
	Max	83.29
	Min	55.42



+3SL =	85.18
+2SL =	77.3334
+1SL =	69.4828
C =	61.63
-1SL =	53.7815
-2SL =	45.9309
-3SL =	38.08

c = Total nuber of events obeserved / Number of areas of opporunity

= 862.85 / 14.00

= 61.63

standard error = √(61.63)

= 7.85

UCL(c) = c + 3√c

= 61.63 + 3√61.63

= 85.18

LCL(c) = c - 3√c

= 61.63 - 3√61.63

= 38.08

Boundry between lower zones A and B	=	c - 2√(c)
	=	45.9309
Boundry between lower zones B and C	=	c - √(c)
	=	53.7815
Boundry between upper zones A and B	=	c + 2√(c)
	=	77.3334
Boundry between upper zones A and B	=	c + √(c)
	=	69.4828

Appendix B

Category Overview

Current process

Replications: 1 Time Units: Seconds

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
90 Degree Bend.Queue	0.01272218	(Insufficient)	0.00	3.3903
Corners cut.Queue	22.9366	(Insufficient)	0.00	48.4843
End Welding.Queue	0.1592	(Insufficient)	0.00	5.3892
Exhaust End Cap.Queue	3448.44	(Insufficient)	0.00	6911.20
Fibre Fill1.Queue	15.8978	(Insufficient)	0.00	58.7936
Fibre Fill2.Queue	33.6007	(Insufficient)	0.00	73.0197
Logo Press.Queue	12.0754	(Insufficient)	0.00	30.2225
Metal Sheet Bend.Queue	0.00	(Insufficient)	0.00	0.00
Side Bender.Queue	66.7281	(Insufficient)	0.00	142.71
Spherical Form Bend.Queue	0.04491242	(Insufficient)	0.00	2.1873

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
90 Degree Bend.Queue	0.00020699	(Insufficient)	0.00	1.0000
Corners cut.Queue	0.3732	(Insufficient)	0.00	8.0000
End Welding.Queue	0.00258955	(Insufficient)	0.00	1.0000
Exhaust End Cap.Queue	56.1059	(Correlated)	0.00	114.00
Fibre Fill1.Queue	0.1150	(Insufficient)	0.00	1.0000
Fibre Fill2.Queue	0.3037	(Insufficient)	0.00	2.0000
Logo Press.Queue	0.1965	(Correlated)	0.00	4.0000
Metal Sheet Bend.Queue	0.00	(Insufficient)	0.00	0.00
Side Bender.Queue	1.0857	(Correlated)	0.00	6.0000
Spherical Form Bend.Queue	0.00073072	(Insufficient)	0.00	1.0000

Current process

Replications: 1 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
90 degree bend machine	0.2377	(Correlated)	0.00	1.0000
Bend machine	0.2069	(Correlated)	0.00	1.0000
Corners cut machine	0.0934	(Correlated)	0.00	1.0000
End welding machine	0.3463	(Correlated)	0.00	1.0000
Exhaust end cap machine	0.9908	(Insufficient)	0.00	1.0000
Fibre fill machine	0.4184	(Insufficient)	0.00	1.0000
Fibre fill machine2	0.5304	(Insufficient)	0.00	1.0000
Logo press machine	0.1427	(Correlated)	0.00	1.0000
Side bender machine	0.4140	(Correlated)	0.00	1.0000
Spherical form bend machine	0.3549	(Correlated)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
90 degree bend machine	0.2377	(Correlated)	0.00	1.0000
Bend machine	0.2069	(Correlated)	0.00	1.0000
Corners cut machine	0.0934	(Correlated)	0.00	1.0000
End welding machine	0.3463	(Correlated)	0.00	1.0000
Exhaust end cap machine	0.9908	(Correlated)	0.00	1.0000
Fibre fill machine	0.4184	(Correlated)	0.00	1.0000
Fibre fill machine2	0.5304	(Correlated)	0.00	1.0000
Logo press machine	0.1427	(Correlated)	0.00	1.0000
Side bender machine	0.4140	(Correlated)	0.00	1.0000
Spherical form bend machine	0.3549	(Correlated)	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
90 degree bend machine	1.0000	(Insufficient)	1.0000	1.0000
Bend machine	1.0000	(Insufficient)	1.0000	1.0000
Corners cut machine	1.0000	(Insufficient)	1.0000	1.0000
End welding machine	1.0000	(Insufficient)	1.0000	1.0000
Exhaust end cap machine	1.0000	(Insufficient)	1.0000	1.0000
Fibre fill machine	1.0000	(Insufficient)	1.0000	1.0000
Fibre fill machine2	1.0000	(Insufficient)	1.0000	1.0000
Logo press machine	1.0000	(Insufficient)	1.0000	1.0000
Side bender machine	1.0000	(Insufficient)	1.0000	1.0000
Spherical form bend machine	1.0000	(Insufficient)	1.0000	1.0000

Current process

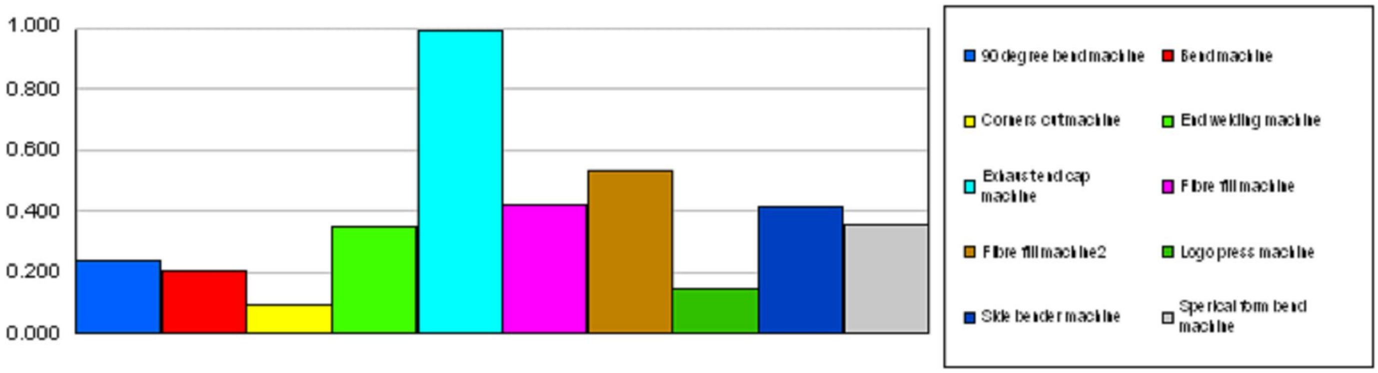
Replications: 1 Time Units: Seconds

Resource

Usage

Scheduled Utilization

	Value
90 degree bend machine	0.2377
Bend machine	0.2069
Corners cut machine	0.0934
End welding machine	0.3463
Exhaust end cap machine	0.9908
Fibre fill machine	0.4184
Fibre fill machine2	0.5304
Logo press machine	0.1427
Side bender machine	0.4140
Spherical form bend machine	0.3549



Current process

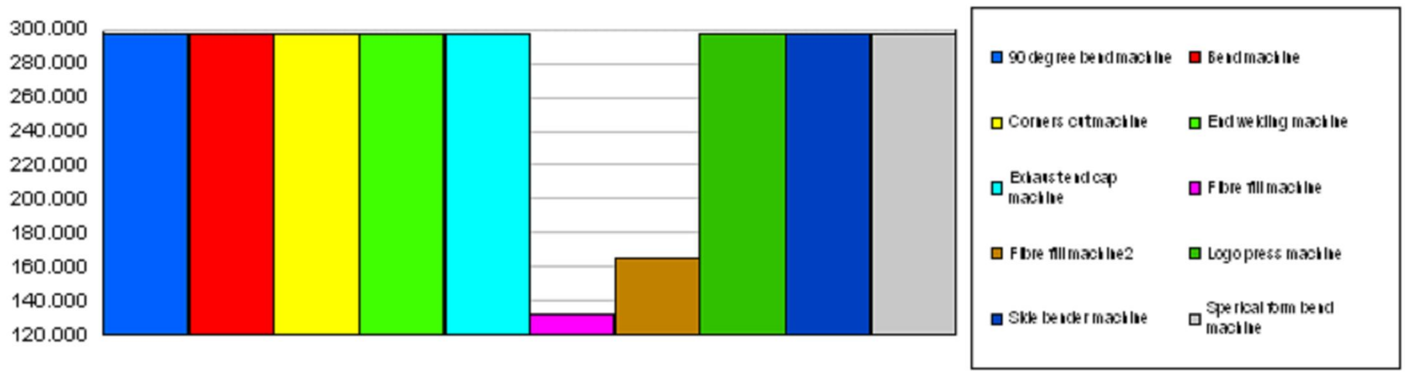
Replications: 1 Time Units: Seconds

Resource

Usage

Total Number Seized

	Value
90 degree bend machine	297.00
Bend machine	297.00
Corners cut machine	297.00
End welding machine	297.00
Exhaust end cap machine	297.00
Fibre fill machine	132.00
Fibre fill machine2	165.00
Logo press machine	297.00
Side bender machine	297.00
Spherical form bend machine	297.00



Improved process

Replications: 1 Time Units: Seconds

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
90 Degree Bend.Queue	0.00	(Insufficient)	0.00	0.00
Corners cut.Queue	22.8520	(Insufficient)	0.00	48.6171
End Welding.Queue	0.2105	(Insufficient)	0.00	5.7621
Exhaust End Cap 2.Queue	232.10	(Insufficient)	0.00	430.39
Exhaust End Cap.Queue	202.80	(Insufficient)	0.00	381.14
Fibre Fill1.Queue	552.34	(Insufficient)	0.00	1125.26
Fibre Fill2.Queue	563.16	(Insufficient)	0.00	1165.16
Logo Press.Queue	12.2015	(Insufficient)	0.00	29.9988
Metal Sheet Bend.Queue	0.00	(Insufficient)	0.00	0.00
Side Bender.Queue	1247.52	(Insufficient)	0.00	2491.49
Spherical Form Bend.Queue	0.06096988	(Insufficient)	0.00	1.3584

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
90 Degree Bend.Queue	0.00	(Insufficient)	0.00	0.00
Corners cut.Queue	0.7324	(Insufficient)	0.00	8.0000
End Welding.Queue	0.00674594	(Insufficient)	0.00	1.0000
Exhaust End Cap 2.Queue	3.7071	(Insufficient)	0.00	7.0000
Exhaust End Cap.Queue	3.2610	(Insufficient)	0.00	7.0000
Fibre Fill1.Queue	8.7028	(Insufficient)	0.00	19.0000
Fibre Fill2.Queue	9.1771	(Insufficient)	0.00	20.0000
Logo Press.Queue	0.3911	(Correlated)	0.00	4.0000
Metal Sheet Bend.Queue	0.00	(Insufficient)	0.00	0.00
Side Bender.Queue	39.9854	(Correlated)	0.00	99.00
Spherical Form Bend.Queue	0.00195420	(Insufficient)	0.00	1.0000

Improved process

Replications: 1 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
90 degree bend machine	0.4756	(Correlated)	0.00	1.0000
Bend machine	0.4034	(Correlated)	0.00	1.0000
Corners cut machine	0.1836	(Correlated)	0.00	1.0000
End welding machine	0.6846	(Correlated)	0.00	1.0000
Exhaust end cap machine	0.9750	(Insufficient)	0.00	1.0000
Exhaust end cap machine 2	0.9781	(Insufficient)	0.00	1.0000
Fibre fill machine	0.9318	(Insufficient)	0.00	1.0000
Fibre fill machine2	0.9415	(Insufficient)	0.00	1.0000
Logo press machine	0.2816	(Correlated)	0.00	1.0000
Side bender machine	0.8146	(Insufficient)	0.00	1.0000
Spherical form bend machine	0.7038	(Correlated)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
90 degree bend machine	0.4756	(Correlated)	0.00	1.0000
Bend machine	0.4034	(Correlated)	0.00	1.0000
Corners cut machine	0.1836	(Correlated)	0.00	1.0000
End welding machine	0.6846	(Correlated)	0.00	1.0000
Exhaust end cap machine	0.9750	(Correlated)	0.00	1.0000
Exhaust end cap machine 2	0.9781	(Correlated)	0.00	1.0000
Fibre fill machine	0.9318	(Correlated)	0.00	1.0000
Fibre fill machine2	0.9415	(Correlated)	0.00	1.0000
Logo press machine	0.2816	(Correlated)	0.00	1.0000
Side bender machine	0.8146	(Correlated)	0.00	1.0000
Spherical form bend machine	0.7038	(Correlated)	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
90 degree bend machine	1.0000	(Insufficient)	1.0000	1.0000
Bend machine	1.0000	(Insufficient)	1.0000	1.0000
Corners cut machine	1.0000	(Insufficient)	1.0000	1.0000
End welding machine	1.0000	(Insufficient)	1.0000	1.0000
Exhaust end cap machine	1.0000	(Insufficient)	1.0000	1.0000
Exhaust end cap machine 2	1.0000	(Insufficient)	1.0000	1.0000
Fibre fill machine	1.0000	(Insufficient)	1.0000	1.0000
Fibre fill machine2	1.0000	(Insufficient)	1.0000	1.0000
Logo press machine	1.0000	(Insufficient)	1.0000	1.0000
Side bender machine	1.0000	(Insufficient)	1.0000	1.0000
Spherical form bend machine	1.0000	(Insufficient)	1.0000	1.0000

Improved process

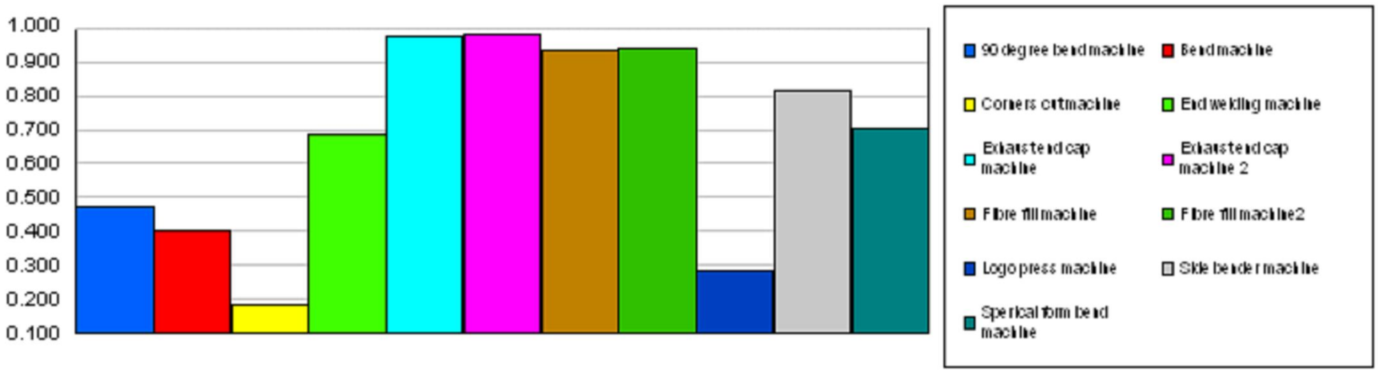
Replications: 1 Time Units: Seconds

Resource

Usage

Scheduled Utilization

	Value
90 degree bend machine	0.4756
Bend machine	0.4034
Corners cut machine	0.1836
End welding machine	0.6846
Exhaust end cap machine	0.9750
Exhaust end cap machine 2	0.9781
Fibre fill machine	0.9318
Fibre fill machine2	0.9415
Logo press machine	0.2816
Side bender machine	0.8146
Spherical form bend machine	0.7038



Improved process

Replications: 1 Time Units: Seconds

Resource

Usage

Total Number Seized

	Value
90 degree bend machine	297.00
Bend machine	297.00
Corners cut machine	297.00
End welding machine	297.00
Exhaust end cap machine	149.00
Exhaust end cap machine 2	148.00
Fibre fill machine	146.00
Fibre fill machine2	151.00
Logo press machine	297.00
Side bender machine	297.00
Spherical form bend machine	297.00