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A Simulation Program for Forecasts of Production at Tetra Pak Packaging Material AB in Lund

Master Thesis by
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Preface

This master thesis was carried out as the final project of our Master of Science education in Mechanical Engineering at Lund Institute of Technology. The project was performed in cooperation with Tetra Pak Packaging Material AB in Lund.

We would like to express our sincere thanks to our supervisor at the Institute of Packaging Logistics, Mats Johnsson, and our supervisors at Tetra Pak, Christine Therén, Ulf Johnsson and Ulf Lindberg for support during this project. We would also like to thank Ola Johansson and Daniel Hellström at the Institute of Packaging Logistics for helpful information, and Jeanette Hansen at Tetra Pak for bringing us data files needed for this project. Thanks also to all the employees at Tetra Pak for helping us with our questions.

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Abstract

Tetra Pak Packaging Material AB (TPPM) is the division within the Tetra Pak concern that produces the packaging material that later on will be used for liquid products. There are 63 TPPM plants in the world, and the factory in Lund is one of the largest with its 325 employees. It is also the TPPM factory that manufactures the most varied set of packages. There are nine producing machines, divided into three machine groups: printing machines, laminating machines and slitting machines. The department of planning at TPPM plans the orders with the help of a program called ProPlanner. What they lack is a tool to predict the lead times of the planned orders and the capacity of every machine during a specific period of time. This tool should complement the ProPlanner.

To solve the problem we decided to make a simulation program. The reason we did so is that there are so many random events that affect the production so it is hard to calculate forecasts by using a deterministic method. The software we used is called AutoMod and it is a simulation program especially made for simulations of production and materials handling. After having studied the processes of production at TPPM, we structured the simulation program and collected the data needed for the program. The parameters used were:

- Set Up times for the machines
- MTTR (Mean Time To Repair)
- MTBF (Mean Time Between Failure)
- Run speed for the different orders in the different machine groups
- Planned stops in the machines
- Stops during weekends in the different machines

An important thing for this project was that the user interface of the simulation program must be user-friendly. All parameters must be possible to change and to do this we have created an easy-to-use Excel interface integrated with the simulation program. The output from the simulation is also displayed in this interface. The reliability of the output gets higher if more than one run for every simulation is made. It is possible to do 1-100 runs, and tests of the program showed that at least 30 runs should be made to get an accurate result.

The simulation program will help the personnel at the department of planning at TPPM. They can control if the lead times of the orders, as they are planned, will exceed the predetermined due date and if the capacity of the machines are enough. As all results from the simulation program are forecasts, there are no guarantees that the future will look exactly as the forecasts. If no dramatic events will occur in the production line, though, the program will give a good general view of the production in the near future.

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1 Introduction

In this chapter we present the background and problem for our project.

1.1 Background

In all factories with more or less complex manufacturing, there has to be a planning process. The planning process should deal with questions like:

- In what machines should the different orders be placed?
- What orders should have the highest priority?
- Is there enough capacity to fulfill the orders in the right time?
- When is there time to plan a stop for maintenance, for example?

The planning process depends on the different machines and what they can produce. Some machines might only produce one kind of product, while other machines might produce several different products. The activities for the different machines might also differ in time and cost. It is important to consider critical factors, which can be done with the planning process.

A well-founded planning process might facilitate the processes in a factory and also save money for the company. If the planning department knows when the utilization of the different machines is high or low, it's easier to plan maintenance for the machines, and if there is need for extra working time during weekends.

1.2 Problem

Often the planning of production is difficult because of the many factors that affect it. Some of these are events that are impossible to exactly predict, unplanned stops, for example, and in this master thesis we will investigate if it is possible to build a model that could facilitate the planning process in a dynamic way.

1.3 Objectives

The objectives of this report correspond to the problem definition and are as follows:

- Analyse the manufacturing process and stops in the machines.
- Build a short termed model that resembles the reality as much as possible. The output from the model should be the forecasted lead times for the already planned orders and the forecasted utilization on each individual machine during a specific period of time.
- Integrate the model with a tool that is easy to use.

1.4 Delimitations

- We limit this report to include the operations in the machines. The processes before and after the operations will not be included, and the processes between the machines will not be deeply analysed.
- We will not analyse the reasons for the stops in the machines. In the model we use generally accepted distributions so the model shouldn't be too complicated to upgrade.
- We will not try to optimise in what machines different orders should be put. We will just make a tool that will facilitate the order planning process for the department of planning at TPPM in Lund.

1.5 Target group

The main target groups for this report are students at Lund Institute of Technology with a major in logistics, and employees at TPPM in Lund who are involved in the order planning.

1.6 Company description

Tetra Pak is a world leading company within the packaging industry, and a part of the Tetra Laval concern. It was established in 1951 in Lund, Sweden, by Ruben Rausing and Erik Wallenberg. Tetra Pak is today represented in 165 markets worldwide and the total number of employees is 20 900 people. Tetra Pak is striving to be a single-source supplier for their costumers. This means that they supply their customers with packaging machines, packaging material and service.[1]

Tetra Pak Packaging Materials AB (TPPM) is the division within the Tetra Pak concern that makes the packaging material that will be used for liquid products. There a 63 TPPM plants in the world, and four of them are situated in Sweden. The factory in Lund is one of the largest in the world and has 325 employees.[2] It is also the factory that manufactures the most varied set of packages[3], see figure 1.1.

Figure 1.1 Examples of different packaging types manufactured by TPPM[4]

[1] http://www.tetrapak.com/, 2003-10-14
[2] http://www.siemens.se/industriteknik/ae/lopsedel/pdf/Automation_2002-09-30/AN023_s10-11_TP.pdf, 2003-10-14
[3] Ulf Lindberg, Chief of Planning, 2003-09-16
[4] http://www.tetrapak.com/, 2003-12-15

2 Description of the production planning process at TPPM

In this chapter the current production and planning process at TPPM are described.

2.1 The production

The manufacturing process of packaging materials is similar in all TPPM plants and has three sub processes: *printing, laminating* and *slitting*.

The printing process works as in a printing house. Designers at TPPM and the customer jointly decide how the package should be designed, and then TPPM makes clichés out of an original. In this process folder marks and punching are made as well, depending on which alternatives the customer has chosen. TPPM uses the printing techniques *flexo* and *flexoprocess*. The manufacturing machines in the printing group are called *10 Uteco*, *12 VT Flex 165* and *16 W & H Econoflex*. In general machine 10 and 12 print the flexoprocess, and machine 16 prints the flexo, even though different qualities and sizes of the material might suit one of the machines better than the others.

Thereafter the packaging material is sent to the laminating machines. The packaging from Tetra Pak consists of a laminate of paper, polyethylene, and, if the package should be aseptic, aluminum. The combination of the different materials is varying for different qualities. The paper makes the packages stiff, the plastic makes the packages resistible to liquid and aluminum keeps oxygen and light out. The machines in the laminating group are called *21 Erwepa* and *22 Erwepa,* and both of them can handle the flexo and flexoprocess.

In the third step the big roles are slit into a number of smaller roles which sizes depends on how many packages are printed in breadth on the role. These roles are thereafter coated by plastic and sent to the customers. The slitting group includes the machines *53 Kampf*, *54 IMS*, *55 Kampf* and *58 IMS*. In these machines the printing type doesn't matter that much, it is the size that decides in what machine the order should be put. There are two kinds of roles, *jumbo* and *standard*. Jumbo types are slittered in machines 53, 54 and 58 and standard types in machines 55 and 58. Machine 55 is only manned daytime, never at nights and weekends.[5] See figure 2.1 for a schematic picture of all the machines.

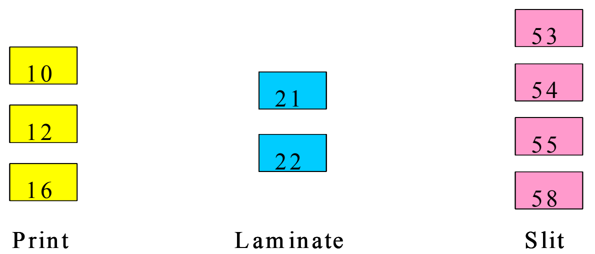

Figure 2.1 A schematic picture of the machines at TPPM in Lund.

[5] Christine Therén, Planner of Production

2.2 The planning process

The orders come from Tetra Pak's marketing companies, and the sales department of TPPM handles them. Thereafter the planning process starts. The planner receives the orders from a database, and can immediately place the order in suitable machines and sequences so that the order will be ready for delivery on due date.

Every morning there is a meeting with the shift managers, the planner and personnel from sales department. Problems in the production are discussed, as well as future maintenance work, incoming orders and other questions that might influence the manufacturing. The planner has to face problems such as when planned stops should be scheduled without disturbing the production and if the work force has to work overtime to manage the production demands. To get a good general view over the production situation, the planner puts all orders in a program called ProPlanner. Even if the planner is skilled and experienced, wrong decisions are made sometimes.

TPPM doesn't make simulations of the production today, but they are planning to start doing so.

2.3 ProPlanner

TPPM uses the program ProPlanner to plan the incoming orders into the machines. The program is designed as a Gantt diagram where the planner places the incoming orders in the chart. The estimated time of the production is based on the average speed and the length of the order. The program is easy to use and gives a fairly good approximation of the production time, but as all Gantt charts it is quite static and needs to be updated often.

ProPlanner receives all of its information from a database, and it is easy for the planner to retrieve the data that has been collected. The data for every specific order, that is order length, quality and in what order the orders have been planned, is to be found in ProPlanner.

3 Methodology

This chapter presents some theories about making a project like ours. We describe what methods we have chosen to follow and why we have done so.

3.1 Collecting information

There are different ways of collecting information and the choices depend on what kind of information that is required. One method is simply to *observe* the events you want information about. This method is expensive and time consuming but you don’t have to depend on other people’s observations, and you could therefore interpret the observations in your own way. One problem may be that it is not sure that what you observe is representative for the events in the long run. This could be hard to know if you don’t have knowledge of the events. One important question is if the observer’s presence should be known or not. If it is known that there is an observer collecting information on some events it is possible that the people dealing with the events don’t act as usual, and this could be a problem. On the other hand, if the observer’s presence is unknown, there could be problems with questions on integrity.

Another way of collecting information is to *interview* people or to make *case studies*. These methods are time saving as you don’t have to do the observations by yourself. One disadvantage, though, could be that it is not sure that the participating persons interpret their observations in the same way, as you would do.

The best way of getting statistical facts is to collect information from *documents* (from databases, for example). This may give a lot of necessary information in a short time. It is important, though, to be critical to the information and ask why the documents were done, when they were made and who made them. This is important because of the credibility of the used information.

Reading *literature* often is the best way to collect more general information on a subject. Often there are a number of books and articles on the needed information. Once again it is important to be critical to the sources.[6]

[6] Patel R, Davidsson B, *Forskningsmetodikens grunder – Att planera, genomföra och rapportera en undersökning,* 1994

3.2 Measurements

3.2.1 Validity and reliability

Validity is about measuring the right thing. High validity means that no irrelevant things are measured, but just things that are of importance of the investigation.[7]

The *reliability* is how trustworthy the measurements are.[8] If the measurements have high reliability it means that the reality really looks like the results show.[9]

It is important to secure both high validity and high reliability. If the information has low reliability it cannot answer the problem satisfactorily even if the validity is high. It is equally important that the validity is high. If there are problems with the measures it doesn't matter if the reliability is high.[10]

3.2.2 Inductive / Deductive studies

Collecting empirical facts and afterwards trying to create theories around the discoveries of the subject, is called to make an *inductive* study. If you instead try to match the empirical facts with current theory, you make a *deductive* study.[11] The strongest criticism to inductive studies is that you cannot make observations without having preconceived illusions and this affects the results.[12] Some people mean that you cannot make research on something you have deep knowledge of. Maybe that case is the best but the research gets very hard if you don't take anything for granted.[13]

3.2.3 Quantitative and Qualitative Studies

There are both similarities and differences between the *quantitative* and *qualitative* methods and there are no conflicts of principle between them. The fundamental similarity is that the purpose with both methods is to process and analyse information. The differences are more obvious, see table 3.1. When transforming the information to numbers and then analyse the information statistically, the quantitative method is used. The information that is collected makes it possible to generalise the result. With the qualitative method it is the researchers own interpretation of the information that is fundamental. The qualitative method gives a more global approach than the quantitative method.[14]

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[7] Patel R, Tebelius U, *Grundbok i forskningsmetodik*, 1987
[8] Ibid
[9] Wallén G, *Vetenskapsteori och forskningsmetodik*, 1993
[10] Holme I M, Solvang K B, *Forskningsmetodik - Om kvalitativa och kvantitativa metoder*, 1997
[11] Patel R, Davidsson B, *Forskningsmetodikens grunder – Att planera, genomföra och rapportera en undersökning,* 1994
[12] Wallén G, *Vetenskapsteori och forskningsmetodik*, 1993
[13] Patel R, Davidsson B, *Forskningsmetodikens grunder – Att planera, genomföra och rapportera en undersökning,* 1994
[14] Holme I M, Solvang K B, *Forskningsmetodik - Om kvalitativa och kvantitativa metoder*, 1997

	Quantitative methods		Qualitative methods
1	Precision.	1	Flexibility.
2	Few measures and many objects.	2	Few objects and many measures.
3	Systematic and structured observations, for example an inquiry.	3	Unsystematic and unstructured observations, for example an interview.
4	You interest in what objects have in common and average numbers.	4	You interest in the deviant and uniqueness of objects.
5	Collection of information occurs under conditions that differ from the investigated reality.	5	Collection of information occurs under conditions that are similar to the investigated reality.
6	You study various variables.	6	You study structures and connections.
7	Description and explanation.	7	Description and understanding.
8	The researcher strives to be an observer.	8	The researcher strives to be a participant.
9	I-it-relation between the researcher and the object.	9	I-you-relation between the researcher and the object.

Table 3.1 Differences between quantitative and qualitative methods[15]

3.3 Simulation as a tool

In this master thesis we will create an order-based planning-tool. To do this we will have a number of variables that will affect the time an order is being handled in the factory. Some of these variables are the same for every simulation and some are mean values of cycle times for different events. The reason why we chose to make a simulation program is that there are so many random events that affect the production so it is hard to calculate forecasts by using a deterministic method only.

3.4 Our working process

In the beginning of our project we planned the working process to come, see model in figure 3.2. Even if the process wasn't that static as shown below, we followed the model quite well.

[15] Holme I M, Solvang K B, *Forskningsmetodik - Om kvalitativa och kvantitativa metoder*, 1997

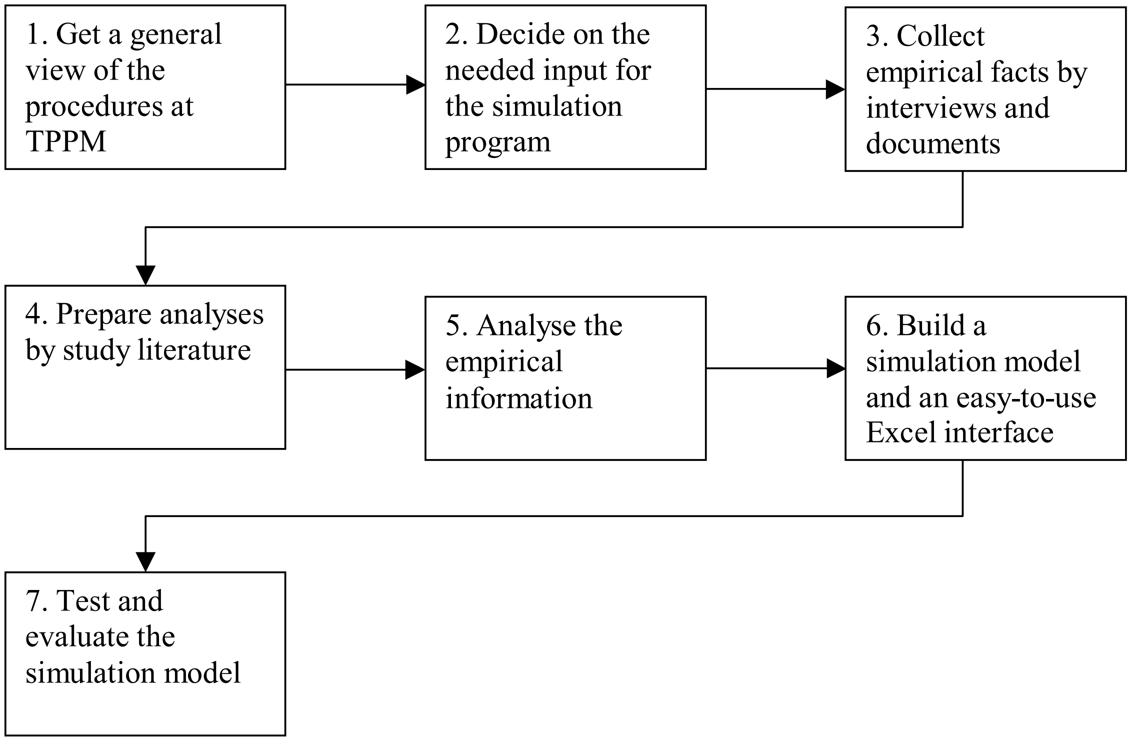

Figure 3.2 Model over our procedure during this project

1. **Get a general view of the procedures at TPPM**
   At first we got general information about the order planning process and the manufacturing procedure by Ulf Johnsson, Owner of printing processes at TPPM and Christine Therén, Planner of production at TPPM. Then we got a more profound insight about the different steps in the process from incoming order to delivery of the products by talking to personnel in different positions at the plant, both clerks and labourers. We also made several observations on our own while visiting the plant.

2. **Decide on the needed input for the simulation program**
   When we had a good understanding of the procedures at TPPM, we planned how the simulation program should be built and what parameters were needed. It was necessary to specify what kind of information we needed from TPPM.

3. **Collect empirical facts by interviews and documents**
   We collected information about the different machines both by interviewing personnel and by getting documents that showed statistical facts. By interviewing persons that are well acquainted with the processes we studied, our intention was to get qualitative information about the routines in the factory. By interviewing we could get deep answers to our questions and ask more questions when needed. We estimate that the reliability of the interviews is high as our project is about helping the people we interviewed.

   We wanted the statistical facts for our project to be quantitative. By collecting statistics over a long period of time for our simulation model, the risk of getting not characteristic values would be reduced than if only a short period of time were analysed. We think that the validity of the statistics is high, as we knew well what statistical facts we needed to create a good model. Tetra Pak provided us with statistics that is to be regarded as reliable as it was the data coming directly from every machine. The data collected was Set up times and unplanned stops. We also collected run speeds for the different qualities and sizes.

4. **Prepare analyses by studying literature**
   To get necessary knowledge to do a reliable empirical study some literature studying was made. We studied topics like production planning, mathematical statistics, simulation and methodology.

5. **Analyse the empirical information**
   To get the right variables for our simulation program we analysed mean times and distributions for Set up times and unplanned stops for the different machines. We didn't consider the reasons for the unplanned stops, as it then would be very hard and time-consuming for the personnel at Tetra Pak to upgrade the variables. When analysing the data we made a deductive study. We tried to match the empirical facts with existing theories. The reason for this is that the input to the simulation program would be much easier to define, and the upgrading process will be much easier if distributions for different stops are easy to define in the simulation software.

6. **Build a simulation model and an easy-to-use Excel interface**
   This step was the biggest and most important part of our project. We built the simulation model in the software AutoMod. This program is adapted to simulations within production, which is why we chose to use this program. The model represents the production at TPPM and is built up by the three printing machines, the two laminating machines and the four slitting machines. The temporarily warehousing between the different machine groups was also built in the model. The incoming orders to the simulation program will be the same as the ones planned in the ProPlanner at TPPM. The orders will be simulated in the same machines and in the same order as intended. The right run speed for the different qualities and sizes will be used and there will be simulated, unplanned stops in the machines.

To make the simulation process as easy as possible we built an easy-to-use Excel interface. From this interface it is easy to see the results from the simulation and to change the different inputs to the simulation. The times when the machines are shut down (weekends and planned stops) are also easy to change. To get more reliable output from the simulation there should be more than one run so it is also possible to choose 1-100 runs before the simulation is done.

7. **Test and evaluate the simulation model**
   When the program was finished it was tested with real values from ProPlanner. It is impossible to know for sure if the program works faultlessly without a longer period of use, but the results seemed reasonable as the orders were finished around due date, and the capacity of the machines were around real values. The more runs that are made, the more time the simulation takes, but the probability that the real values will match the simulated values increases. To investigate where the divergence starts to flatten out for different number of runs, tests were made to decide how many runs should be done during every simulation. To further test if the simulation program was working satisfactorily we invited Christine Therén from TPPM to test the program.

4 Theory

In this chapter we present some theories about simulation and some statistical theories that could be useful for the understanding of the simulation program we have made. Abbreviations that are used are explained in appendix K.

4.1 Simulation

Simulation is a method where you by computer or manually can imitate an operation of a real-world process or system over time. This model should resemble the real system as much as possible, and the model usually takes the form of a set of assumptions, which often are the relationships between the entities of a system. The entities are the objects of interest in the system and the relationships between them are expressed in mathematical, logical and symbolic terms. Once a simulation model is built, it can be used to investigate a lot of "What if-questions" to a system. It could be useful when a change in an existing system is planned or when a new system is to be created. By predicting the behaviour of a real system, simulation therefore can be used as an analysis tool as well as a design tool. One might wonder why simulation should be used at all, couldn't mathematical methods be used instead? Well, in some cases, using mathematical methods only could develop a model of a simple system, but often the real systems are so complex that models of these systems are virtually impossible to solve mathematically. Instead computer-based simulation is to prefer when wanting to imitate the behaviour of most real systems.[16]

4.2 When simulation is a good tool

It could be hard to decide whether simulation is the best tool to analyse a system or not. Many authors have been discussing when the circumstances for simulation are suitable and in the book *Discrete-event system simulation* the authors list following events when simulation could be an appropriate tool.[17]

- Simulation enables the study of, and experimentation with, the internal interactions of a complex system, or of a subsystem within a complex system.
- Informational, organisational and environmental changes can be simulated and the effect of these alterations on the model's behaviour can be observed.
- The knowledge gained in designing a simulation model may be of great value toward suggesting improvement in the system under investigation.
- Changing simulation inputs and observing the resulting outputs may obtain valuable insight into which variables are most important and how variables interact.
- Simulation can be used as a pedagogical device to reinforce analytic solution methodologies.
- Simulation can be used to experiment with new designs or policies prior to implementation, so as to prepare for what may happen.

[16] Banks J, Carson II J S, Nelson B L, *Discrete-Event System Simulation*, 1996
[17] Ibid

4.3 An example of simulation

An easy example of why simulation could be a good tool is if you have a store with one cashier. If it takes exactly 59 seconds to serve a customer and the customers arrive with an interval with exact one minute, an analysis would show that no queue would appear during the whole day. In reality, though, the intervals seldom are so exact, instead the interval differs in a way that could be difficult to forecast. If we in the example instead say that the customers arrive with an interval of one minute, exponentially distributed, and it takes exponentially 59 seconds to serve a customer, we will discover that queues will occur during the day, see figure 4.1. This course of events is more likely to reflect the reality, as the customers don't arrive with the same interval.

Figure 4.1 The queue length over time in the example in chapter 4.3

4.4 Where simulation could be a good tool

The different areas where simulation could be used are extensive. Some of these areas are discussed below.[18]

4.4.1 Manufacturing systems

- When finding bottlenecks in manufacturing systems, simulation could be a good tool. In the real systems it could be hard to discover where in the production line more capacity could be needed. By building a model of the system and simulate, it may be easier to find the bottlenecks.
- Could the profitability be improved by buying more machines for the production? By simulating the difference in efficiency between the old situation and the new one with more machines, an analysis can tell if the savings will be more than the costs.

[18] Banks J, Carson II J S, Nelson B L, *Discrete-Event System Simulation*, 1996

4.4.2 Service systems

- Banks, for instance, can have problems with optimising the amount of tellers who serve the customers. A simulation of the arrival frequency during different times of the day could help an analysis.
- Service that is provided by telephone calls are often analysed after having simulated different scenarios. If the waiting queue of customers shouldn't exceed a certain number, the amount of service stations could be adapted for different periods of time.

4.4.3 Transportation systems

- What kind of transportation is best to use when delivering our products? Should we use a cheap transportation, which might have a low grade of delivery reliability, or an expensive one, which has a higher grade of deliver reliability? How much money can we save by deliver our products faster? These questions might be answered after having simulated different alternatives.

4.5 Terms used within simulation

A *system* is defined as "a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose"[19] For instance, when considering manufacturing, the system can consist of the machines, the components that are put together and the workers operating. Events outside the system can affect the system and these events are said to occur in the *system environment*. When modelling systems it is important to decide on the *boundary* between the system and the system environment.

The objects that are of interest in a system are called *entities*, and could be, for example, the products that are manufactured in the factory. An *attribute* is a property of an entity and could be the colour of the entity, for example. The *activity* represents the period of time where the entities are being handled. This period of time can differ between the entities due to the attributes set to them. Variables that describe a system show the *state* of the system at any time. These could be, for example, how many machines that are occupied and how many products that have been manufactured during the day so far. *Endogenous* is a term used when describing events and activities within the system and *exogenous* when describing events and activities outside the system.

A system can be categorised either as a *discrete system* or a *continuous system*.[20] "Few systems in practice are wholly discrete or continuous, but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous".[21] A system, which, within the changes of state variables only changes at a discrete set of point in time, is called a discrete system. An example of this is in a factory where the products that are waiting for being manufactured over time could be, for example, 1, 2, 3. If the state variables change continuously over time, we're

[19] Banks J, Carson II J S, Nelson B L, *Discrete-Event System Simulation*, 1996
[20] Ibid
[21] Law A M, Kelton W D, *Simulation modeling and analysis*, 2000

dealing with a continuous system. The head of water behind a dam is a good example. When it is raining, and for some time after that, water flows into the lake behind the dam. Water then is drawn from the dam for flood control and to produce electricity. In a diagram the head of water behind the dam over time can be read. Simulation models can be also be classified as either static or dynamic. A *static* simulation model, or a Monte Carlo simulation, as it is also called, represents a system at a specific point in time. A *dynamic* simulation model represents a system that change over time. If a simulation model contains one or more random variables it is classified as a *stochastic* simulation model, and if there are no random variables it is classified as a *deterministic* simulation model. Stochastic simulation models are most common as the reality seldom is deterministic, and if it is, you often can solve the problem without simulation.[22]

4.6 Advantages and disadvantages of simulation

4.6.1 Advantages

- **Making correct choices** – Instead of committing resources for proposed changes, the changes can be simulated and a good view of the affects of the changes will be shown to a much less price.
- **Why-questions** – By reconstruct different parameters in a simulation model you can see why certain phenomena occur. These changes often are too complex in the real-world situation.
- **Preparing for change** – No one knows exactly what will happen in the future. By simulating a number of different scenarios a company can be better prepared for what might happen.
- **Training for the team** – Pilots, for example, often simulate different kinds of flights before they actually fly for real. These simulation models are designed for the specific purpose and saves both lives and money!
- **Developing understanding** – Simulation studies help you design a system as it is going to operate, instead of how someone supposes it will, which often is the case. Decisions will be made from an analysis instead of just a "feeling".
- **Specifying requirements** – If you don't know the specifications for a particular type of machine to achieve a goal for the whole system, for instance, a simulation with different capabilities for the machine may indicate the requirements needed.[23]

4.6.2 Disadvantages

- **Model building requires special training** – Simulation is often seen as an art and if two competent individuals build a model of the same system it is not likely they will be exactly the same, even though the models may have similarities.
- **Results may be hard to interpret** – Most simulations are based on random numbers and it may therefore be difficult to determine if the observations are the result of interrelationship or randomness.

[22] Banks J, Carson II J S, Nelson B L, *Discrete-Event System Simulation*, 1996
[23] Banks J, *Getting Started With AutoMod*, 2000

- **Input must be accurate –** The outputs from a simulation depend on the inputs so if the inputs aren't accurate an analysis of the outputs may be meaningless. It is therefore important that the inputs are thoroughly collected, which sometimes is hard to do.[24]

4.7 Phases in a Simulation Project

The process of getting a simulation model passes a few phases that are necessary to get a successful result. According to Jerry Banks there are four phases with 12 steps that have to be done until the work is completed.[25] See figure 4.2.

4.7.1 First phase

The first phase is a period of discovery and orientation. Its elements are *problem formulation* and *setting of objective and overall design.*

1. In the beginning of a simulation project there should be a problem statement. It is important that the problem formulation is clearly understood and agreed at by all persons involved in the project.

2. The objectives are the questions that should be answered by the simulation project. In this step there should be decided if a simulation model is the best way of solving the problem, or if a different method should be used.

This phase is usually muddled and the original objectives and problem formulation will sometimes have to be redefined.

4.7.2 Second phase

In the second phase the simulation model starts to take form. The steps in this phase are *model conceptualisation, data collection, model translation*, *verification* and *validation*.

3. The design of a model of a system is a mixture of art and science. It is important for the model constructor to have the ability to sort out and abstract the essential parts of a problem, to make correct assumptions and then to develop the model into a useful approximation of the real system. It is not recommended to build a model that is more complex than necessarily to accomplish the purpose for which the simulation project was intended.

4. The data input in a model is essential to get the correct answers based on the objectives. If the input data is wrongly analysed, the output also will be incorrect. The required data is dependent of the complexity of the model. The data collection takes a large portion of the time in a simulation project, so it is important to begin as soon as possible.

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[24] Banks J, *Getting Started With AutoMod*, 2000
[25] Banks J, Carson II J S, Nelson B L, *Discrete-Event System Simulation*, 1996

5. When the conceptualisation is ready and all the necessary data has been collected, the building of the model in a simulation program can start. There are several different programs designed for different purposes. For manufacturing and material handling system simulations there are numerous programs: Arena, AutoMod or Extend, for example. The amount of flexibility varies greatly from program to program.

6. With complex systems it is difficult to translate a model successfully without doing some debugging of the model. It is important to verify that the input and logical structure is correctly represented in the computer.

7. After building the model it is essential to confirm that it is an accurate representation of the real system. This is usually achieved by comparing the model with the actual system. By observing the differences of the systems the model builder can improve the model and then repeat the comparison so that the model can get an acceptable accuracy.

4.7.3 Third phase

When the model is built and validated it is time to start with the experiments and analysis. This phase includes *experimental design*, *production runs and analysis* and *additional runs*.

8. When the model is built it is necessary to decide which parameters that are to be changed later on. The length of the simulation and the number of runs are also important to decide wisely, so that the results become reliable. Another important factor is the initialisation period, the time it takes before the model starts to behave like the real system.

9. Production runs and analysis are used to measure the performance for the system that is being simulated.

10. When the production runs have been made, the analyst need to determine if the results are reliable, or if more runs need to be done and, if so, what design the additional experimental runs should have.

4.7.4 Fourth phase

In the fourth and final phase the model will be *implemented*. For the model builders this phase means that they have to present their *documentation and the reporting.*

11. There are two types of documentation: program and progress. The program documentation is essential if the program is going to be modified or used more than one time. If there is no documentation it will take time for the analyst to familiarise himself with the program. It is also possible to misinterpret the output if there isn't a proper documentation. If the program documentation is well done it is easier for model users to change a parameter in the model if they need to.

Progress documentation is important so that even those not involved in the daily work with the project can be update. In the progress, reports show the chronology and the decisions made in the project. This helps the project to stay in the right course.

12. The success of the implementation step depends on how well the previous eleven steps have been performed. If the model user has been involved in the process and understands how to use the model and the outputs, it is more likely that the implementation will succeed.

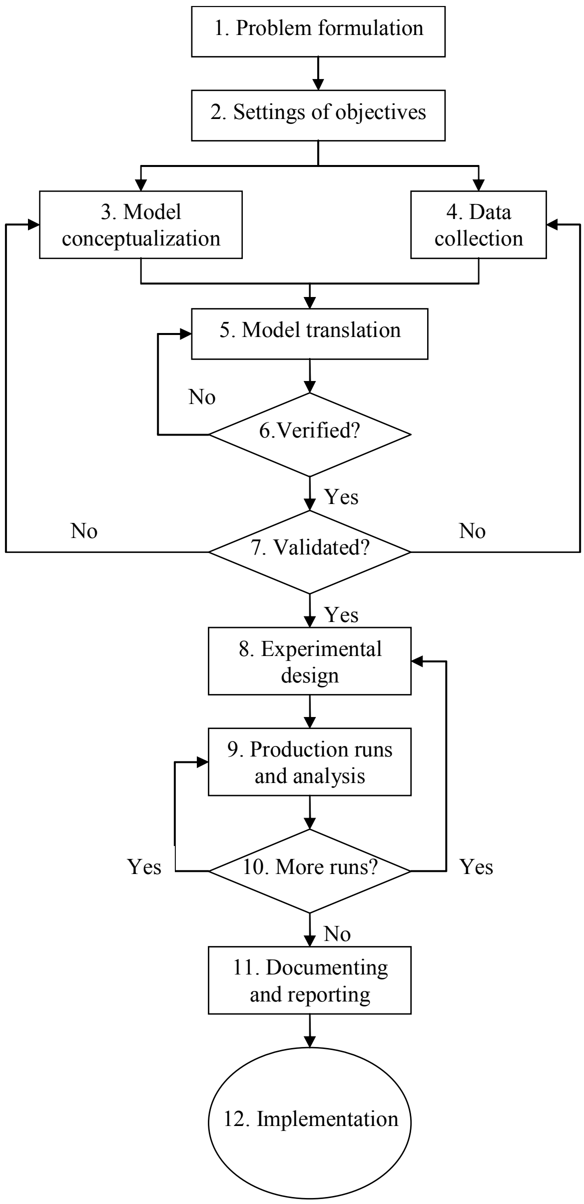

Figure 4.2 The different steps in a simulation project

4.8 Statistical models

4.8.1 Identifying distributions

When to identify what distribution a series of data could belong to, it is often a good idea to create a histogram of the data. The process of creating a histogram includes two main parts:

1. Divide the range of data into intervals
2. Determine the frequency of occurrences within each interval

It is important to set the number of class intervals so that the characteristic of the data is shown properly. If the intervals are too wide the distribution will be too blocky, and if there are too many classes the figure will be ragged.[26] There are a number of different methods of deciding how many classes there should be, all of them are based on how many observations there have been done. Ralph B. D'Agostino and Michael A. Stephens recommend that the following should be used:

$$M = 2 * n^{2/5}$$

where M is the number of classes and n is the number of observations. When the distributions are to be decided it is most common to make the intervals of equal width.[27]

4.9 Distributions

Continuous distributions can adopt every value in a given interval. There are several hundred different types of distributions, of which some have been created for very specific usage.[28] The distributions presented in this chapter are the ones that are possible to use when simulating random numbers in the software AutoMod. The program can also create random numbers from a collection of data, if none of the distributions is suitable. That is not always a good alternative, though, as the simulations take more time, and it is hard to update the values.[29]

4.9.1 Exponential distribution

This type of distribution is used for modelling completely random events that have high variability. Examples of use are a process time or independent events. The exponential probability density function is:

$$f_X(x) = \frac{1}{m} e^{-\left(\frac{x}{m}\right)} \qquad \text{if } x \geq 0$$

where m is the mean value of the distribution. The shape of the exponential probability density function is shown in figure 4.3. The fact that it is easy to calculate the parameter has contributed to make the distribution often used.

[26] Banks J, Carson II J S, Nelson B L, *Discrete-Event System Simulation*, 1996
[27] D'Agostino R B, Stephens M A, *Goodness-of-fit techniques,* 1986
[28] Blom G, *Sannolikhetsteori och statistikteori med tillämpningar*, 1989
[29] Banks J, *Getting Started With AutoMod*, 2000

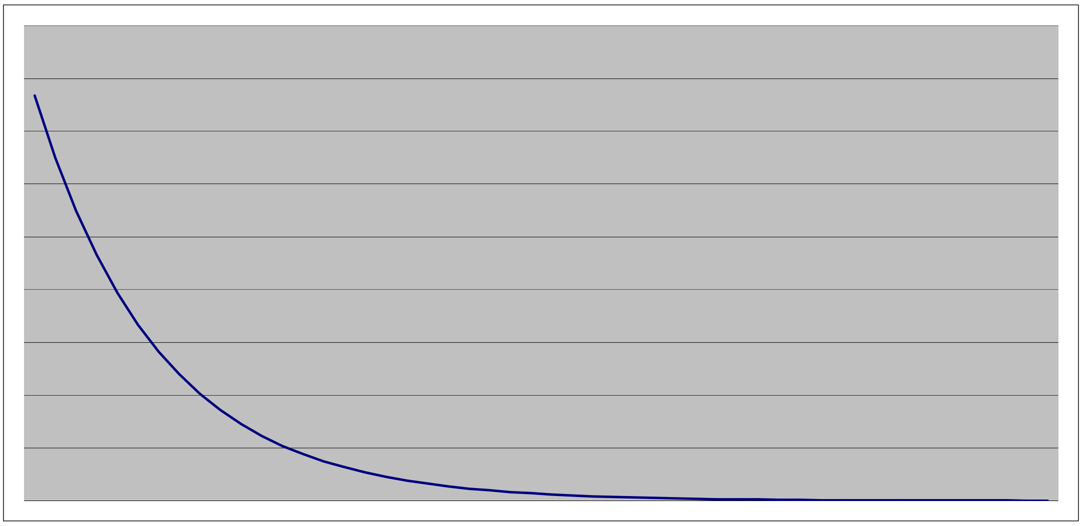

Figure 4.3 The Exponential distribution

4.9.2 Weibull distribution

This is a distribution with high flexibility and is often used for modelling TTR for components. The probability density function for Weibull, which is shown in figure 4.4, is:

$$f_X(x) = \frac{c}{a}\left(\frac{x}{a}\right)^{(c-1)} * e^{-\left(\frac{x}{a}\right)^c} \qquad \text{if } x \geq 0$$

where a and c are positive numbers. The exponential distribution is a special case of Weibull, which means that it is possible to adjust this distribution more accurately than the exponential. However, as the Weibull parameters are difficult to optimise, the exponential distribution often is preferred.

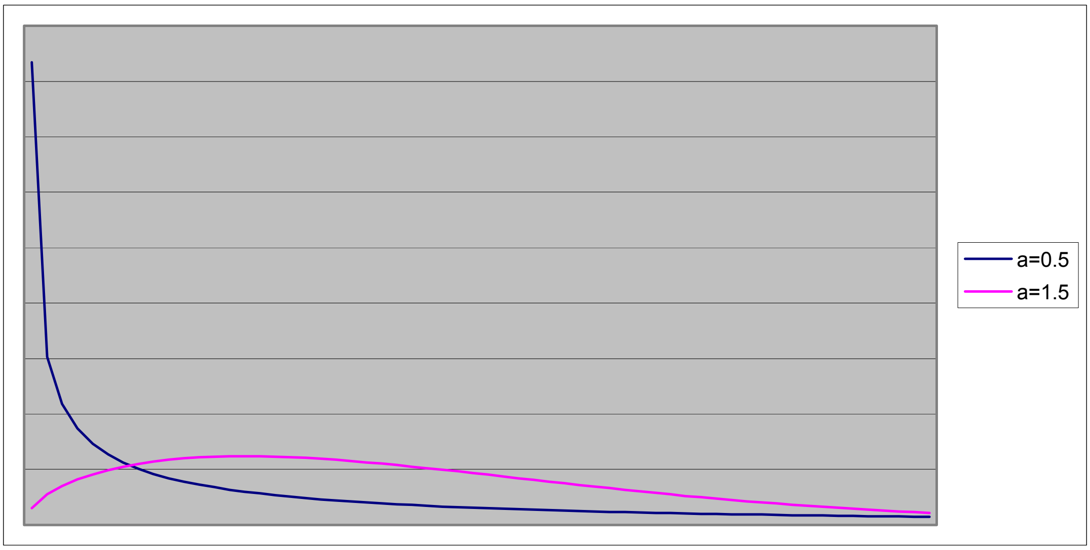

Figure 4.4 The Weibull distribution

4.9.3 Gamma distribution

Gamma is similar to the Weibull distribution regarding that both are highly flexible and can be shaped into an exponential distribution. Another similarity is that they both are difficult to adjust to the data collected from the real system. The shape of the probability density function for the Gamma distribution is shown in figure 4.5, and the equation is:

$$f_X(x) = \frac{1}{a^p \int_0^\infty x^{p-1} e^{-x} dx} x^{p-1} e^{\frac{-x}{a}} \qquad \text{if } x \geq 0$$

where p and a are constants.

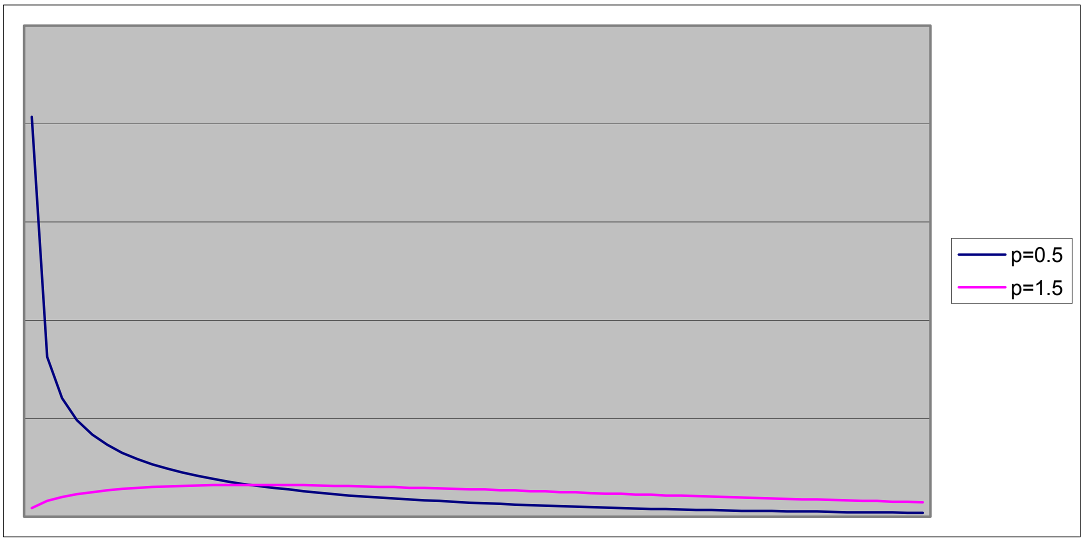

Figure 4.5 The Gamma distribution

4.9.4 Normal distribution

The normal distribution is often used when multiple activities are added, for example the time to assembly a product that require more than one operation. The probability density function has a bell formed shape, see figure 4.6, and is formulated as:

$$f_X(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-m)^2/2\sigma^2} \qquad (-\infty < x < \infty)$$

The σ is the standard deviation and m is the mean value of the distribution.

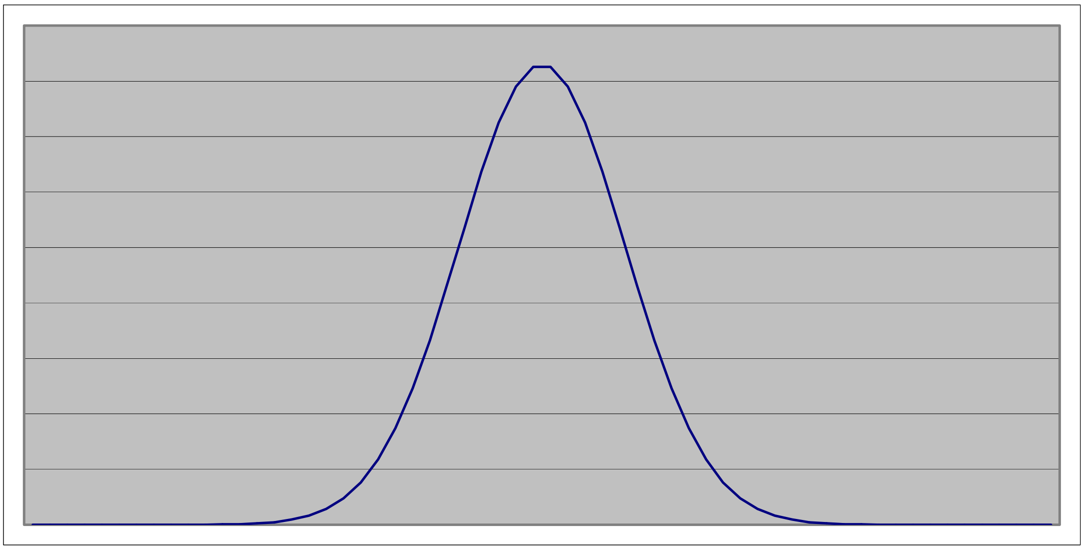

Figure 4.6 The Normal distribution

4.9.5 Lognormal distribution

The lognormal distribution is a useful distribution when to simulate the time it takes to perform several tasks. The lognormal probability density function is unlike the gamma and Weibull distributions always starting in the (0,0) point. The shape of the function is shown in figure 4.7, and the equation is:

$$f_X(x) = \frac{1}{x\sqrt{2\pi\sigma^2}} \exp\frac{-(\ln x - m)^2}{2\sigma^2} \qquad \text{if } x \geq 0$$

where σ is the standard deviation and *m* is the mean value.[30]

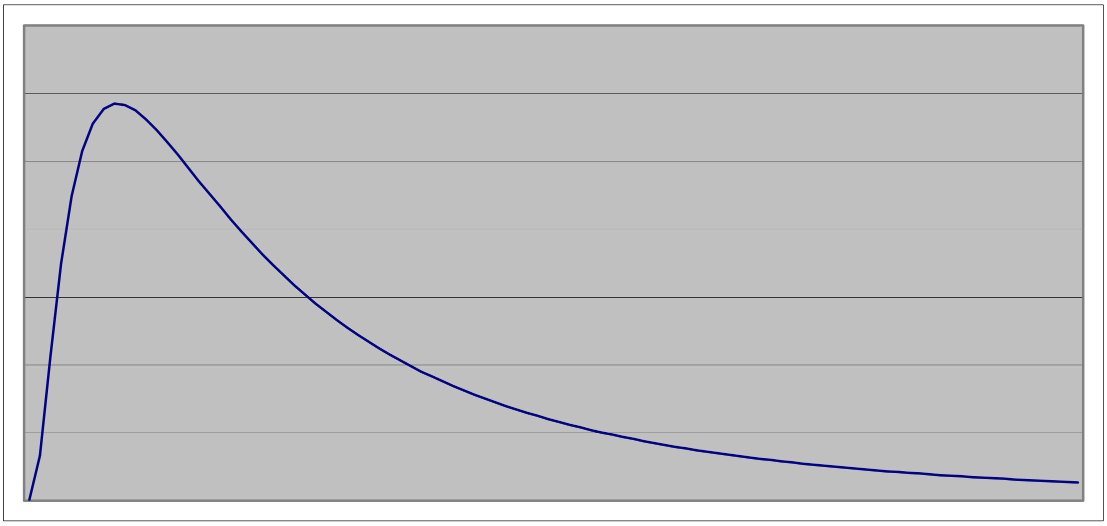

Figure 4.7 The Lognormal distribution

[30] Law A M, Kelton W D, *Simulation modeling and analysis*, 2000

4.9.6 Triangular distribution

When only minimum, most-likely and maximum values of the distribution are known, the triangular distribution is a good alternative. The probability density function for this distribution is

$$f_X(x) = \frac{2(x-a)}{(b-a)(c-a)} \qquad a \le x \le b$$

$$f_X(x) = \frac{2(c-x)}{(c-b)(c-a)} \qquad b \le x \le c$$

The *a* parameter is the lower bound, the *b* is the most-likely value and *c* is the higher bound, see figure 4.8.

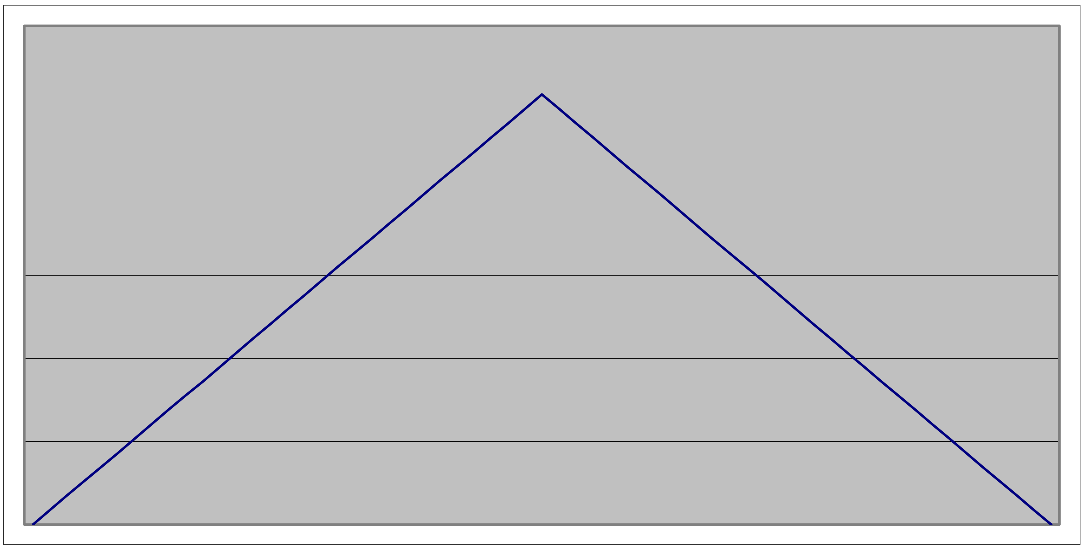

Figure 4.8 The Triangular distribution

4.9.7 Uniform distribution

This distribution is used when all the values within the range of distribution are equally probable. It is often used, uncalled for, when there is no data available. It has the probability density function:

$$f_X(x) = \frac{1}{b-a} \qquad \text{if } a < x < b.$$

The *a* parameter is the lower bound and *b* is the higher bound of the distribution, see figure 4.9.

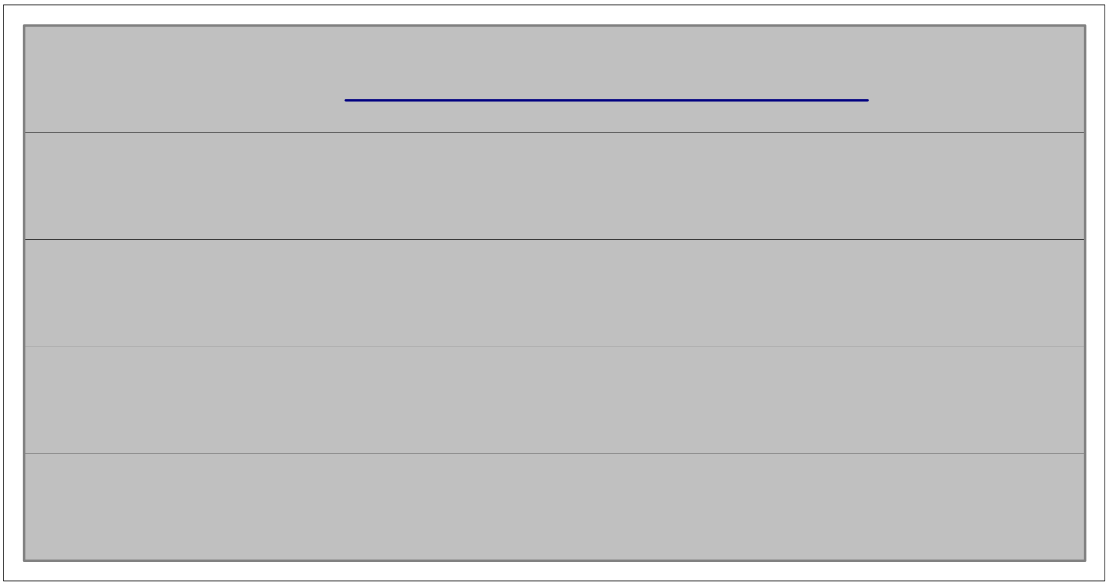

Figure 4.9 The Uniform distribution

4.10 Statistical tests

4.10.1 Chi-square test

The Chi-square test is a goodness-of-fit test that is a useful help when to evaluate if the chosen distribution is suitable for the input data into a model. Since there is no single correct distribution in a real application the Chi-square test should only be considered as guidance. Especially when there are a large amount of observations, the test is likely to reject any distribution. On the other hand, if there are few observations, the Chi-square test could accept almost any distribution.

The procedure of testing a distribution with the Chi-square method starts with deciding the number of classes. Thereafter the frequency is calculated for each class interval. The equation used by the test is

$$\chi_0^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where k is the number of classes, O_i is the number of observed events in the specific interval and E_i is the expected frequency in the specific interval. The hypotheses are:

> H_0: conforms the distributional assumption to the estimates parameters.
> H_1: the distributional assumption does not conform.

H_0 is rejected if $\chi_0^2 > \chi_{\alpha,k-s-1}^2$ where s is the number of estimated parameters in the distribution and α is the significance level, which is the probability that H_0 is rejected if H_0 is true.[31]

[31] Banks J, Carson II J S, Nelson B L, *Discrete-Event System Simulation*, 1996

4.10.2 T-test

The T-test was created by W S Gosset and is sometimes called the student's T-test. It is used to determine if differences of the mean value of two test samples is a coincident or if the two samples have different mean values. The test has good power, which means that the result is reliable. The first step in the procedure is to decide the null hypothesis, H_0, and the significance level, α. If H_0 is not rejected on the decided significance level, there is no reason to believe that the difference between the mean values isn't a coincidence. Then the counting process begins. The formula used is $t = \frac{M_1 - M_2}{\sqrt{\frac{SS_1 + SS_2}{n(n-1)}}}$, where M is the mean values and SS is the sum of all squares. Often a computer program is used to perform the calculations.[32]

4.10.3 F-test

The F-test can also be called ANOVA, which is short for Analysis of variance. The connection between the F-test and the T-test is $t^2 = F$. The difference is that the F-test isn't limited to two samples. If the null hypothesis of the F-test, which is that the standard deviation of the samples is the same, is not rejected the factor shouldn't have any statistically significant effect on the output values standard deviation. If H_0 is rejected there is reason to believe that the factor that has been changed have some effect on the result.[33]

4.11 Planning and scheduling

All manufacturing companies need to make activity plans. The plans are developed in different ways depending on if they are long termed or short termed. The different planning types are shown in figure 4.10.[34]

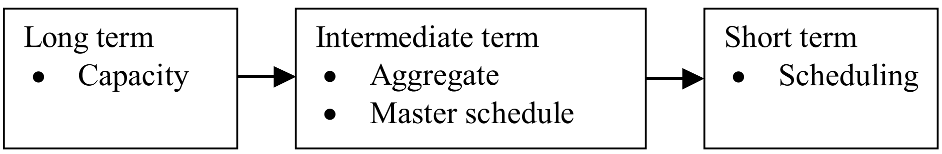

Figure 4.10 Different types of production planning

[32] http://fc.hkr.se/~lars.benthorn/statistik/ 2003-12-18
[33] Ibid
[34] Heizer J H, Render B, *Production and operations management: strategic and tactical decisions,* 1996

The planning process starts with the Capacity planning, which is a long termed planning. In this stage the factory size and equipment level is decided. Then comes planning on intermediate termed, the planning process on a 3 to 18 month basis. This stage consists of the aggregate planning and master schedule. In the short termed scheduling process, among other things, specific dates for specific jobs are decided.

In this master thesis only aggregate and short termed planning are dealt with, so those are the subjects that will be more deeply described.[35]

4.11.1 Aggregate planning

The aggregate planning means to anticipate the future facility utilization and to decide the size of the personnel or if there is any need for subcontracting. This is necessary because in most businesses the demand varies over time. Most often the companies have forecasts to foresee any change of demand and also have strategies to handle those variations. The two main options for the industries are either to change their capacity or to influence the demand. The demand option consists in for example advertising, or making different products during the seasons. The capacity changing option means to absorb the fluctuations on the market.

There are several ways to make aggregate plans. The most widely used is graphical and charting methods. Those methods require limited computations, with means that they are simple to understand and easy to use for most of the personnel. In short those methods allow the planners to compare the forecasts with the existing capacity using only a few variables. Often the planner gets several solutions with the graphical and charting methods, and the chosen alternative may not be the optimal.

When to consider all cost and evaluating new strategies, the graphical and charting methods aren't sufficient, a mathematical method is needed. The mathematical methods are more complex, but often they give a more reliable solution. A short description of the most used methods is presented below.

Transportation method of linear programming can be used to allocate operating capacity to meet the forecasted demands. The method is flexible and there is available software on the market, but the disadvantage is that the linear functions may not be realistic.

Linear decision rule is a method that attempts to minimize all costs through a series of quadratic cost curves. The downsides are that it takes a long time to develop and it doesn't always produce a feasible solution.

Management coefficient model is based on the planners previously experiences, a so-called heuristic method. A demand is that the planner or manager has fairly well past experience, but if that is the case the method is simple and easy to use.

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[35] Heizer J H, Render B, *Production and operations management: strategic and tactical decisions,* 1996

Simulation planning methods use a computer model to find, for example, the minimum-cost combination of values for the different variables in the production.

Search decision rule is a computer-based method that makes thousands systematic searches to find the minimum cost combinations of different variables. The method is widely used, but the downside is that it takes a long time to develop.[36]

4.11.2 Short Term Scheduling

The short termed scheduling has four main criteria that should be fulfilled.

1. Minimize completion time
2. Maximize utilization
3. Minimize Work-In-Progress inventory
4. Minimize costumer waiting time

The importance of those criteria varies from company to company and depends on among other things the volume of orders and the complexity of jobs. The best technique to fulfil the criteria also varies between different companies. We will make a brief presentation of two of the methods.[37]

Gantt Chart is a visual aid that is useful when the planner schedules the production. The chart can show the future utilization of several departments, machines or facilities, see figure 4.11. The chart does have some major limitations. The most serious is that it doesn't account for unexpected breakdowns or other variations in the production. It also has to be updated regularly.

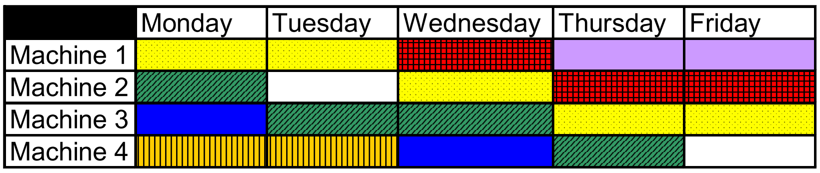

Figure 4.11 A Gantt chart where the different colours represent different orders.

The Assignment method assigns a special task or job to resources. The objective is often to minimize the cost or time required to perform the tasks at hand. This means that the tasks will be assigned to the resource that will meet the demands best.

[36] Heizer J H, Render B, *Production and operations management: strategic and tactical decisions,* 1996
[37] Ibid

5 Compilation of Data

This chapter presents the compilation of data that was needed to analyse. Unfortunately, it is impossible to show the data file in this report, due to its extent.

5.1 Collection of Data

We got a file from TPPM that contained a list over all activities in the machines from 2003-01-01 to 2003-08-27. In the list we could see the total running time for every machine and how long they were broken-down. The reasons for the breakdowns were also listed. All kinds of stops were listed, both the planned and the unplanned. All stops were listed by a code, see table 5.1. The stops are classified in three categories: *Set Up* (code 12), *Unplanned Stops* (code 10, 21, 23, 24, 25, 26, 27, 31 and 44) and *Planned Stops* (code 17, 28, 29 and 30). The status of every machine is always one of the stops or *Running*. This means that the total time of the reported breakdowns and runnings for every day always should be 24 hours. Another list received from TPPM contained the run speeds and the average speeds in the machines for every quality and size. It also contained the breakdown percentage related to the speeds, see appendix A. The run speed is defined as the maximum speed in the machines and the average speed includes set up times and unplanned stops.

Code	**Reason**
10	Meal break
12	Set Up
17	Non working time
21	Repairing
23	Lack of Material-Person
24	Doctor stop
25	Waiting for Approval
26	Short Stop
27	Cleaning
28	Maintenance
29	Lack of Orders
30	Education
31	Force Majeure
44	Run up Change
	Running

Table 5.1 The codes for the status of every machine

The categories compiled for further analyses were:

- Set Up
- Unplanned Stops

5.2 Set Up

We collected all set up times for the different machines and put them together. To get the distributions we classified the set up times in different periods of time, see appendix B. The classification was made according to D´Agostino and Stephens (M=2*n^(2/5)), see table 5.2.

Machine	**Number of Set Ups (n)**	**Number of classes (M)**
Printer 10	1215	35
Printer 12	1104	33
Printer 16	1228	35
Laminator 21	527	25
Laminator 22	466	24
Slitter 53	161	16
Slitter 54	336	21
Slitter 55	52	10
Slitter 58	361	22

Table 5.2 The number of classes for Set Up for the different machines

5.3 Unplanned Stops

We collected all unplanned stops for the machines and put them together. To get the distributions, we classified the unplanned stops in different periods of time, see appendix C. The classification was made according to D´Agostino and Stephens (M=2*n^(2/5)), see table 5.3.

Machine	**Number of Unplanned Stops (n)**	**Number of classes (M)**
Printer 10	908	31
Printer 12	1639	39
Printer 16	1248	35
Laminator 21	1049	33
Laminator 22	872	31
Slitter 53	2014	42
Slitter 54	2362	45
Slitter 55	349	21
Slitter 58	2208	44

Table 5.3 The number of classes for unplanned stops for the different machines

6 Analysis of Data

In this chapter we analyse the data compiled in the previous chapter. At the end we have a discussion around the analysis.

6.1 Set Up

6.1.1 MTT Set Up

To get the MTT Set Up we divided the Total Time to Set Up with the Number of Set Ups for each machine. The result can be seen in table 6.1.

Machine	Total TT Set Up (h)	Number of Set Ups (n)	MTT Set Up (h)
Printer 10	1205	1207	1,00
Printer 12	944	1094	0,86
Printer 16	868	1218	0,71
Laminator 21	446	505	0,88
Laminator 22	377	458	0,82
Slitter 53	140	159	0,88
Slitter 54	201	335	0,60
Slitter 55	36	49	0,73
Slitter 58	177	358	0,49

Table 6.1 The MTT Set Up for each machine

6.1.2 Distribution Set Up

When looking at the distributions for the set up times for the different machines (appendix B) we think that most of the distributions tend to look like the exponential or the Weibull distribution. See appendix D to compare the empirical values with the exponential and the Weibull distributions.

6.1.3 Chi-square test Set Up

To see if any of the two distributions is to be regarded as the same as the empirical distribution we made a Chi-square test. This shows that for the most machines the distributions could be discarded at the 0,01 significance level, see table 6.2. For a more detailed analysis, see appendix G (and F).

Machine	EXP	WEI	CHI2
10	520,13	267,60	56,06
12	158,19	96,65	53,49
16	200,69	73,33	56,06
21	95,84	71,29	42,98
22	36,15	36,15	41,64
53	25,45	21,03	30,58
54	242,43	92,76	37,57
55	16,10	5,49	21,67
58	156,96	48,98	38,93

Table 6.2 The Chi-square tests for the Set Up distributions at a significance level of 0,01

6.2 Unplanned Stops

6.2.1 MTTR (Mean Time To Repair)

When analysing the different times for Unplanned Stops, we could get the MTTR for the machines by dividing the total break-down time with the total number of stops as seen in Table 6.3.

Machine	Number of Stops	Total Break-Down Time (h)	MTTR (h)
Printer 10	908	433	0.48
Printer 12	1639	794	0.48
Printer 16	1248	537	0.43
Laminator 21	1049	588	0.56
Laminator 22	872	457	0.52
Slitter 53	2014	1899	0.94
Slitter 54	2362	1382	0.58
Slitter 55	348	708	1.62
Slitter 58	2208	1580	0.72

Table 6.3 The different MTTR for the different machines

6.2.2 Distribution TTR (Time To Repair)

When comparing the distributions for TTR for the different machines in chapter 5.3.2 we once again think that most of the distributions tend to look like the exponential or the Weibull distribution. See appendix E to compare the empirical values with the exponential and the Weibull distributions.

6.2.3 Chi-square test TTR

To see if any of the two distributions is to be regarded as the same as the empirical distribution we once again made a Chi-square test. This shows that for all machines the distributions could be discarded at the 0,01 significance level, see table 6.4. For a more detailed analysis see appendix H (and F).

Machine	EXP	WEI	CHI2
10	208,75	169,97	48,28
12	247,54	247,54	58,62
16	232,94	208,09	53,49
21	512,82	245,17	50,89
22	377,24	279,98	48,28
53	691,08	490,86	62,43
54	458,51	458,51	66,21
55	53,90	40,14	34,81
58	439,09	439,09	64,95

Table 6.4 The Chi-square tests for TTR distributions at a significance level of 0,01

6.3 Running times

6.3.1 MTBF (Mean Time Between Failure)

To find the MTBF for the different machines we first tried to do as we did with TT Set Up and TTR. Unfortunately, the *Running* times in the file we got weren't reliable as they sometimes were put together for the whole day. We asked TPPM for more detailed *Running* times but they couldn't bring it out. To bring the MTBF out we instead used the stop percentages that were available at the same file as the run speeds, see appendix A. These percentages are calculated by TPPM and upgraded every year. These values are the same as MTTR transformed into percent. This transformation is defined by the following equation:

$$\% = \frac{MTTR}{MTBF + MTTR} * 100$$

To get the MTBF we took the mean value of the stops for each machine group. The stop percentages are shown in table 6.5.

Printing machines	15,5 %
Laminating machines	12,8 %
Slitting machines	10,4 %

Table 6.5. The average percentage the machines are down

Then, in order to calculate the MTBF the following formula was used on each individually machine:

$$MTBF = \frac{MTTR * 100}{\%} - MTTR$$

The result of these calculations can be seen in table 6.6.

Machine	MTBF (h)
Printer 10	3,04
Printer 12	3,04
Printer 16	2,72
Laminator 21	3,82
Laminator 22	3,55
Slitter 53	8,37
Slitter 54	5,16
Slitter 55	4,27
Slitter 58	6,41

Table 6.6.The calculated MTBF for the machines

6.4 Discussion around the analysis

The MTT Set Up and MTTR were not that hard to bring out. The distributions were harder to define. The reason why it was so hard to define the distributions is that there were so many observations. This makes it very difficult to pass the Chi-square test. Even though no distribution exactly fits the empirical distribution, the Weibull distribution seems to match the empirical distributions better than the exponential. Yet we decided to use the exponential distribution for all random numbers in the simulation program. The reason for this is that it makes the upgrading of all input much easier, because the only value that has to be changed in that case is the mean time. If the Weibull distribution had been used, two parameters would have to been changed whenever upgrading, and this could be difficult and time consuming for the people who will use the simulation program. There is another way of creating random numbers in AutoMod, and that is to create random numbers based on collected data. This isn't a good alternative, though, as the upgrading process gets very hard and the simulations takes much more time to carry through.

To see if the choice of distribution would affect the output from the simulation we ran the simulation 100 times with exponential distributed random numbers and 100 times with Weibull distributed random numbers and compared the output. The test showed that the choice of distribution didn't affect the output worth mentioning, see appendix I.

To investigate how many runs that should be made during every simulation we ran the simulation program a number of times. Up until about 30 runs the difference between the longest and shortest result in general gets higher, but after 30 runs the divergence starts to flatten out.

7 Description of the Simulation Program

This chapter describes the simulation program, both how it was built-up and how it works.

7.1 The construction of the simulation program

The *system* in our simulation program contains all the machines, the workers and the orders. Unplanned stops are stops that occur in the system while planned stops and weekends are events in the *system environment* that affect the system.

The *entities* in the system are the orders that are handled in the machines. The *attributes* of the entities are the length of the order, the speed it can be handled in the machines and in what machines the order should be handled. The *activity* in the machines depends on the attributes of the entities and the Set Up times, MTBF and MTTR that are specific for every machine. The *state* of the machines could be either working, down or idle.

We categorise the system as *discrete* as the machines only handle one order at the time and the number of queuing orders always is discrete. The simulation is *dynamic* as the system change over time and the simulation model is *stochastic* as there are random events affecting the system.

7.2 Variables

The variables for the simulation program are the input to the simulation and it is important that they reflect the reality as much as possible.

7.2.1 Set Up Time

The Set Up time could be either order dependent or machine dependent and in our program we made it machine dependent because we couldn't get the data for making it order dependent.

7.2.2 MTTR

The MTTR is machine dependent and was brought out from the data files we got from TPPM.

7.2.3 MTBF

MTBF was calculated by using MTTR and frequency of stops for every machine group.

7.2.4 Speeds

We got the speeds for every quality and size from TPPM. The speeds are both order dependent and machine group dependent.

7.2.5 Planned Stops

The planned stops are specific for every simulation and should reflect when the machines are down because of maintenance, for example.

7.2.6 Stops during Weekends

Weekends are also specific for every simulation and reflect when the machines are shut down during the weekends.

7.2.7 Start Times

The date for the first order to start must be read, and the start times for the different machines tell the simulation program the planned start time for the first order in every machine.

7.3 The program

At first all variables are read into the program. The orders are matched with the right attributes and are put into a queue before the machine it shall be handled in. The orders are put in the same order as it is planned in ProPlanner. When an order has been handled in all the machines it is supposed to, the lead time for the order is calculated and the order leaves the system. The machines are down when planned stops, weekend times or unplanned stops are simulated. The planned stops and weekend times are predetermined, while the unplanned stops are stochastic. Different variables in the program register how long it takes for all the machines to handle all orders. These variables are later on used to calculate the utilization for every machine during a certain period of time. It is possible to run every simulation more than once, and if that is the case, all variables are reset after every run and new random numbers will be used for the next run. See figure 7.1 for a still of the simulation, and see figure 7.2 for a visual description of the program.

To make it easy to change the input, and to read the output from the simulation, an interface has been created in Excel. To facilitate transmission of information between the simulation program and the Excel interface, Visual Basic is used.[38] See appendix J for the user manual for the Excel interface.

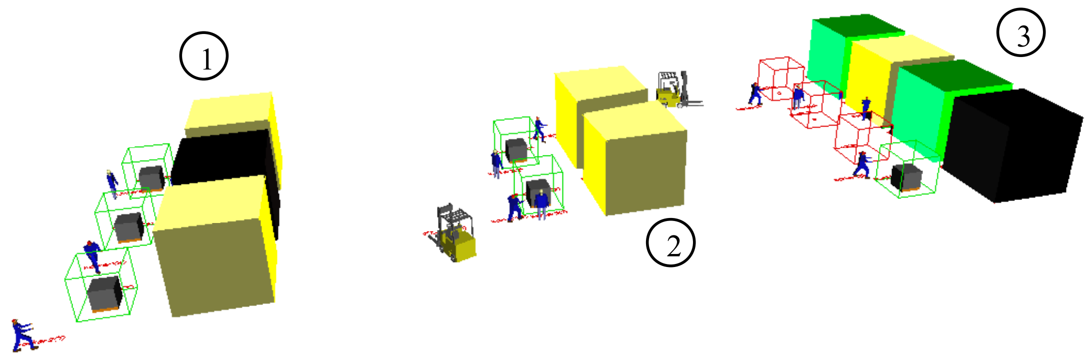

Figure 7.1 A still of the simulation model. 1 represents the printing machines, 2 the laminating machines and 3 the slitting machines. If the machine is idle it is dark gray, if it is down it is black and if it is working it is light gray. Every machine has a queue in front of it.

[38] Autoflash, Carson J, vol 12 No 1, 1999

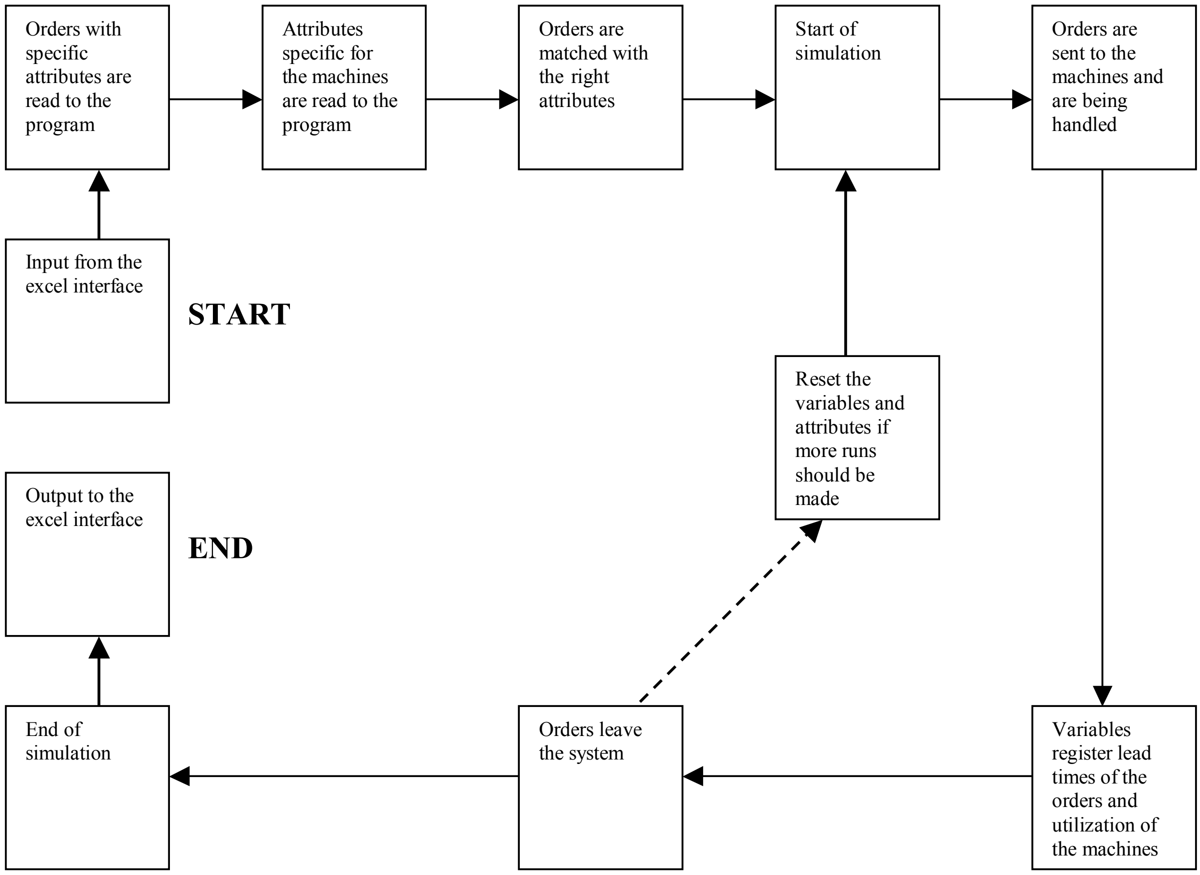

Figure 7.2 A visual description of the program.

8 Conclusions

This chapter presents the conclusions that have been drawn on the simulation program we have built for TPPM.

The purpose of the simulation program is to calculate forecasts for the lead times of the planned orders and the utilization of every machine for a specific period of time. As with all forecasts it is impossible to exactly predict the future, but with the program TPPM can get more accurate and “living” forecasts than today.

The prerequisite for the simulation program is that the parameters of input for the program are as accurate as possible. The MTT Set Up, MTTR, MTBF and the speeds in the machines should be upgraded as soon as there are premonitions of changes within these parameters. As with almost all simulations, the results also depend on how many runs are made during the simulation. In our program it is possible to do 1-100 runs and the result gets more accurate if more runs are made. Up until about 30 runs the difference between the longest and shortest result in general gets higher, but after 30 runs the divergence starts to flatten out. We therefore recommend that at least 30 runs should be made during every simulation.

When making a simulation program, or any program at all, the constructors of the program affect the construction of the program a lot. If two different project groups should solve the same problem by making a program, the program codes wouldn’t likely be the same, even if the results may be very similar. In this simulation project our main focus was to make the usage of the program as user-friendly as possible, and this has permeated the construction of the program.

The simulation program helps the personnel at TPPM to see if the lead times of the orders, as they are planned, will manage the due date of every order and if the capacity of the machines will be sufficient. As all results are forecasts, there are no guarantees that the future will look exactly as the results show, but if no dramatic events will occur in the production line, the program gives a good general view of the production in the near future.

9 References

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9.3 Interviews

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Johnsson, Ulf, Owner of Printing Processes at TPPM, Lund, continually 2003-09-01 – 2004-02-12

Lindberg, Ulf, Chief of Planning at TPPM, Lund, continually 2003-09-01 – 2004-02-12

Persson, Bo, Vicarious Shift Manager at TPPM, Lund, 2003-10-13

Therén, Christine, Planner of Production at TPPM, Lund, continually 2003-09-01 – 2004-02-12

9.4 Publications

Autoflash, Carson, Jonna, 1999-01-15, *Creating an Easy-to-use Interface for AutoMod Models using Excel*, Vol 12, No 1

Appendix A

1.	2.	3.	4.	5.	6.	7.	8.
		Printers		Laminator		Slitter	
Qual-size	Denomination	Run speed m/hour	Stops %	Run speed m/hour	Stops %	Run speed m/hour	Stops %

1. The quality and size code for the different packages.
2. Description of the packages.
3. The maximum speed for the specific quality/size in the printing machines.
4. The times in percent that the printing machines are broken for the specific quality/size.
5. The maximum speed for the specific quality/size in the laminating machines.
6. The times in percent that the laminating machines are broken for the specific quality/size.
7. The maximum speed for the specific quality/size in the slitting machines.
8. The times in percent that the slitting machines are broken for the specific quality/size.

Qual-size	Denomination	Printers		Laminator		Slitter	
		Run speed m/hour	Stops %	Run speed m/hour	Stops %	Run speed m/hour	Stops %
5202-461	TC/m F B	18 700	20,0%	22 000	12,0%	10 000	15,0%
5263-120	TCA/j F B	18 700	20,0%	22 000	12,0%	4 500	15,0%
5263-130	TCA/j F B	18 700	20,0%	22 000	12,0%	4 500	15,0%
5263-461	TCA/j F B	18 700	20,0%	22 000	12,0%	10 000	15,0%
5304-130	TCA/m F B	18 700	20,0%	22 000	12,0%	10 000	15,0%
5407-130	TCA/lk FP CB-H	20 000	20,0%	22 000	12,0%	4 500	15,0%
5408-130	TCA/lk F B	18 700	20,0%	22 000	12,0%	4 500	15,0%
5440-130	TCA/j FP CB	20 000	20,0%	22 000	12,0%	4 500	15,0%
5440-461	TCA/j FP CB	20 000	20,0%	22 000	12,0%	4 500	15,0%
5442-580	TCA/m F CD	18 700	20,0%	22 000	12,0%	10 000	15,0%
5443-580	TCA/j F CD HAL	18 700	20,0%	22 000	12,0%	10 000	15,0%
6042-560	TB/m FP CD	17 500	13,3%	23 000	13,0%	14 900	10,0%
6048-810	TB/m FP CD-H FX	22 300	10,6%	22 500	12,0%	14 500	10,0%
6100-460	TB/m F D	19 800	15,0%	23 000	13,0%	14 900	10,0%
6100-560	TB/m F D	19 800	15,0%	23 000	13,0%	14 900	10,0%
6100-580	TB/m F D	19 800	15,0%	23 000	13,0%	14 900	10,0%
6100-705	TB/m F D	19 800	15,0%	23 000	13,0%	14 900	10,0%
6104-810	TB/m F D-H	19 800	15,0%	23 000	13,0%	14 900	10,0%
6114-810	TB/m F D-H FX	22 300	10,6%	22 500	12,0%	14 500	10,0%
6114-812	TB/m F D-H FX	22 300	10,6%	22 500	12,0%	14 500	10,0%
6150-810	TB/m F CD	18 500	16,5%	23 000	13,0%	14 900	10,0%
6164-810	TB/m F CD-H FX	19 800	15,0%	23 000	13,0%	14 900	10,0%
6200-460	TBA/m F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6200-560	TBA/m F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6200-565	TBA/m F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6200-705	TBA/m F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6200-810	TBA/m F D	18 500	15,0%	22 500	12,0%	14 900	10,0%
6200-812	TBA/m F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-460	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-465	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-560	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-565	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-705	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-810	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-812	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6201-813	TBA/j F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6206-810	TBA/w F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6206-813	TBA/w F D	19 800	15,0%	23 000	13,5%	14 900	10,0%
6211-810	TBA/j F D-H	19 800	15,0%	23 000	13,5%	14 900	10,0%
6218-810	TBA/tk F CD	18 500	16,5%	20 400	12,0%	14 900	10,0%
6221-460	TBA/tk F D	18 500	16,5%	20 400	12,0%	14 900	10,0%
6250-460	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6250-465	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6250-560	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6250-565	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6250-630	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6250-705	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6250-810	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6250-813	TBA/m F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6251-460	TBA/j F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6251-465	TBA/j F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6251-560	TBA/j F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6251-565	TBA/j F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6251-810	TBA/j F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6251-813	TBA/j F CD	18 500	16,5%	23 000	13,5%	14 900	10,0%
6254-810	TBA/m F CD-H	18 500	16,5%	23 000	13,5%	14 900	10,0%
6254-812	TBA/m F CD-H	18 500	16,5%	23 000	13,5%	14 900	10,0%
6254-813	TBA/m F CD-H	18 500	16,5%	23 000	13,5%	14 900	10,0%

6255-810	TBA/j F CD-H	18 500	16,5%	23 000	13,5%	14 900	10,0%
6255-812	TBA/j F CD-H	18 500	16,5%	23 000	13,5%	14 900	10,0%
6255-813	TBA/j F CD-H	18 500	16,5%	23 000	13,5%	14 900	10,0%
6277-810	TBA/w FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6277-813	TBA/w FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6291-810	TBA/w F CD-H	18 500	16,5%	23 000	13,5%	14 900	10,0%
6295-460	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-465	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-560	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-565	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-630	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-705	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-810	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-812	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6295-813	TBA/m FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-460	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-465	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-560	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-565	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-630	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-705	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-810	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6296-813	TBA/j FP CD	17 500	13,3%	23 000	13,5%	14 900	10,0%
6356-460	TBA/tk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6356-560	TBA/tk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6356-630	TBA/tk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6356-810	TBA/tk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6356-813	TBA/tk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
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6368-813	TBA/m FP CD-H	17 500	13,3%	23 000	13,5%	14 900	10,0%
6369-810	TBA/j FP CD-H	17 500	13,3%	23 000	13,5%	14 900	10,0%
6369-812	TBA/j FP CD-H	17 500	13,3%	23 000	13,5%	14 900	10,0%
6369-813	TBA/j FP CD-H	17 500	13,3%	23 000	13,5%	14 900	10,0%
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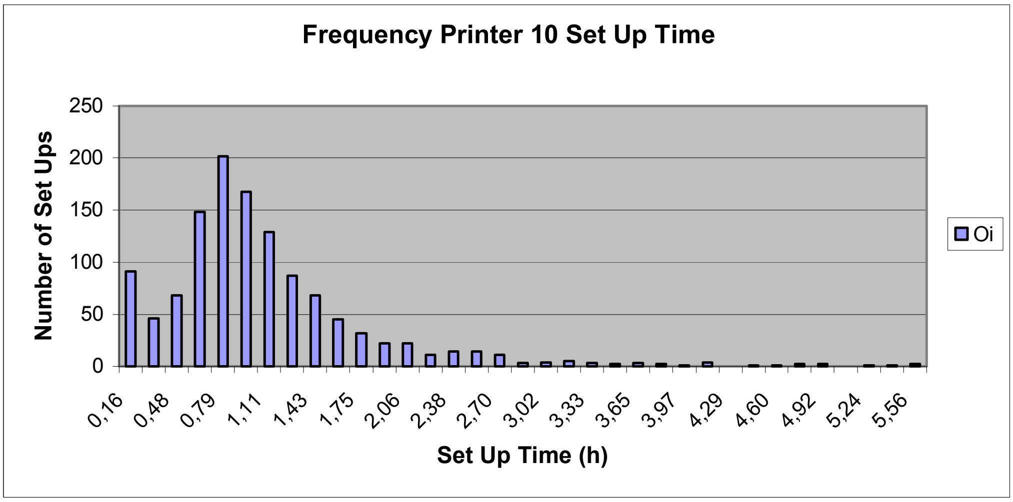
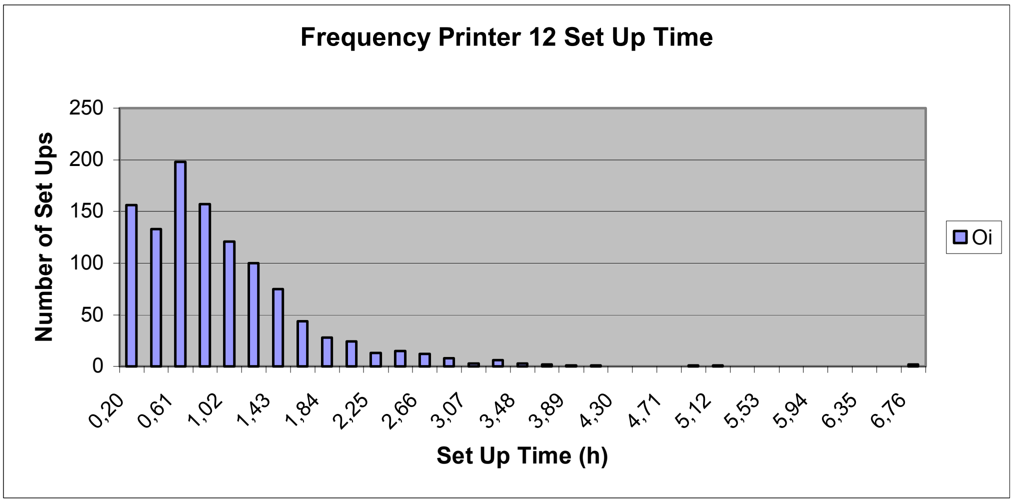
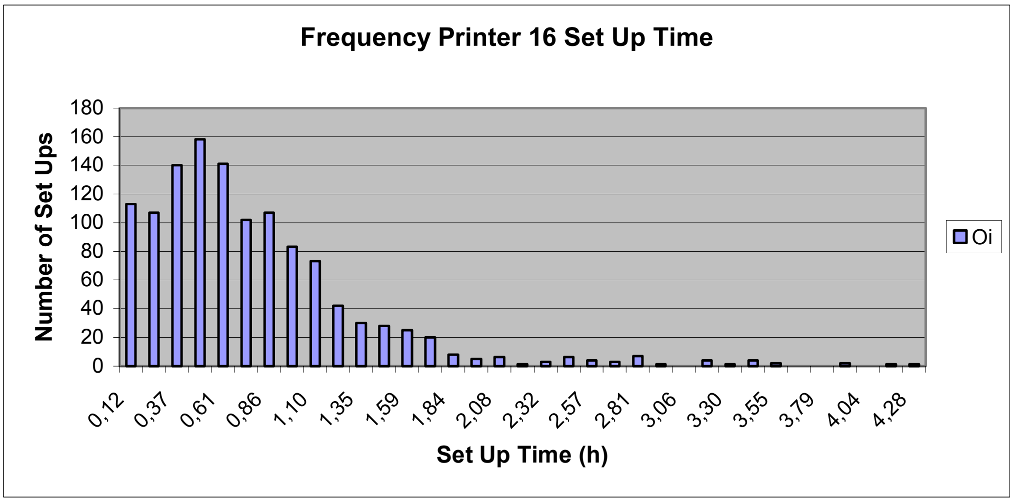
6377-810	TBA/wk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6409-810	TBA/tk FP CD-H	19 800	15,0%	20 400	12,0%	14 900	10,0%
6409-813	TBA/tk FP CD-H	19 800	15,0%	20 400	12,0%	14 900	10,0%
6411-460	TBA/jk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6453-813	TBA/j FP CD-H HAL	17 500	13,3%	23 000	13,5%	14 900	10,0%
6456-810	TBA/m F CD-H FX	22 300	10,6%	22 500	12,0%	14 500	10,0%
6480-813	TBA/aqk F CD	18 500	16,5%	20 700	11,8%	14 900	10,0%
6485-560	TBA/aqk F D	19 800	15,0%	20 700	11,8%	14 900	10,0%
6485-810	TBA/aqk F D	19 800	15,0%	20 700	11,8%	14 900	10,0%
6486-560	TBA/aqk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6492-705	TBA/j-H FP CB	17 500	13,3%	23 000	13,5%	14 900	10,0%
6539-460	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6539-465	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6539-560	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6539-630	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6539-705	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6539-810	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6539-813	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6539-835	TBA/lk FP CD	17 500	13,3%	20 700	11,8%	14 900	10,0%
6559-630	TBA/lk F CD	18 500	16,5%	20 700	11,8%	14 900	10,0%
6559-810	TBA/lk F CD	18 500	16,5%	20 700	11,8%	14 900	10,0%
6559-835	TBA/lk F CD	18 500	16,5%	20 700	11,8%	14 900	10,0%
6572-560	TBA/olk F OB	18 500	16,5%	20 700	11,8%	14 900	10,0%
6592-813	TBA/aqk FP CD-H	18 500	16,5%	20 700	11,8%	14 900	10,0%
6628-465	TWA/j FP CD-H	17 500	13,3%	23 000	13,5%	14 900	10,0%
6681-835	TBA/jk FP CB	17 500	13,3%	20 700	11,8%	14 900	10,0%
6866-835	TBA/lk FP CB	17 500	13,3%	20 700	11,8%	14 900	10,0%
6876-705	TBA/lk F CB	18 500	16,5%	20 700	11,8%	14 900	10,0%
6876-810	TBA/lk F CB	18 500	16,5%	20 700	11,8%	14 900	10,0%
6909-465	TWA/m F D-H	19 800	15,0%	23 000	13,5%	14 900	10,0%
6921-811	TPA/lk FP CB TF HAL	15 500	20,0%	20 700	11,8%	14 900	10,0%

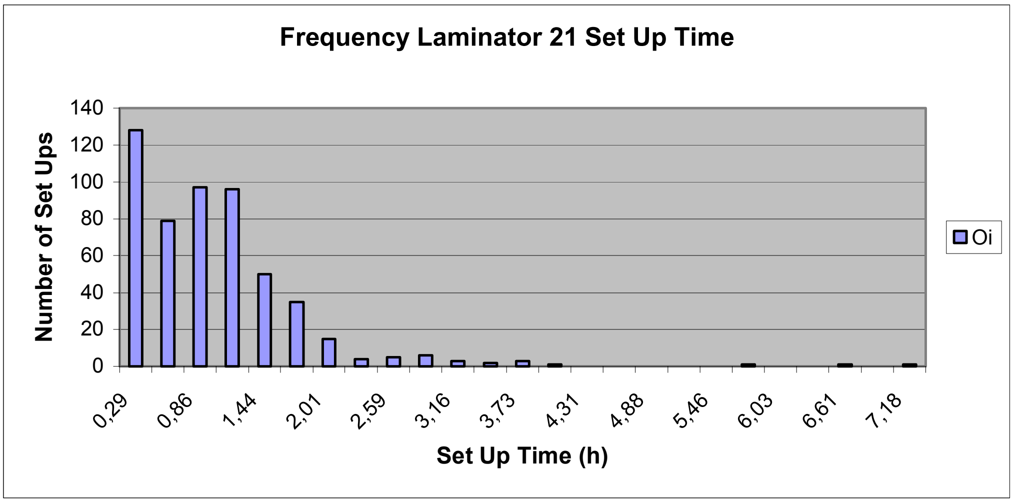
6944-811	TPA/jk FP CB TF HAL	15 500	20,0%	20 700	11,8%	14 900	10,0%
6948-811	TPA/jk FP CB TF HAL	15 500	20,0%	20 700	11,8%	14 900	10,0%
6970-701	TPA/lk FP CD MF	15 500	20,0%	20 700	11,8%	14 900	10,0%
6975-836	TB/m	18 500	16,5%	23 000	13,0%	14 900	10,0%
7379-811	TPA/jk FP CB TF HAL Stream	15 500	20,0%	20 700	11,8%	14 900	10,0%
7396-811	TPA/jk FP CB MF HAL Stream	15 500	20,0%	20 700	11,8%	14 900	10,0%
7423-811	TPA/jk FP CB TF HAL	15 500	20,0%	20 700	11,8%	14 900	10,0%
7438-701	TPA/jl-H FP CD MF HAL HPE	15 500	20,0%				
9690-811	Print TPA	15 500	20,0%				
9691-811	Print TPA	15 500	20,0%				
	Average value		**15,5%**		**12,8%**		**10,4%**

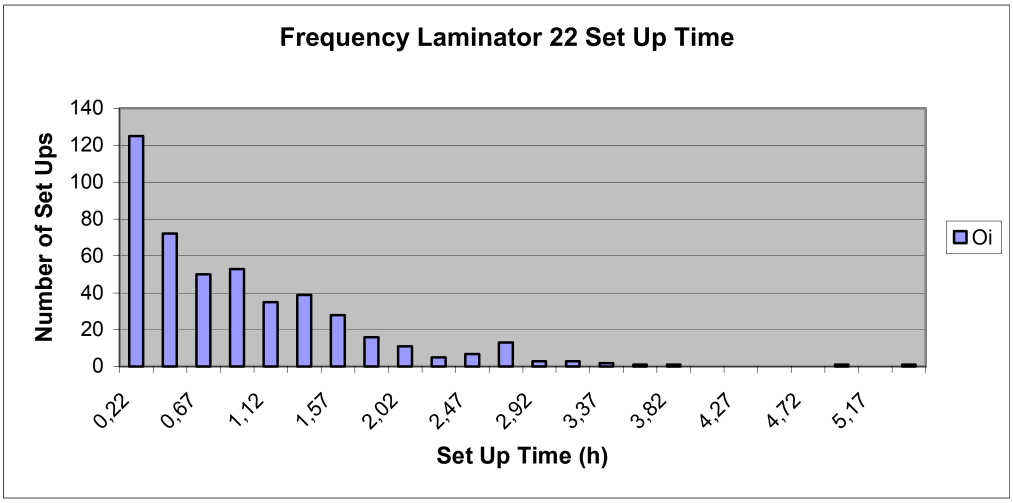
Appendix B

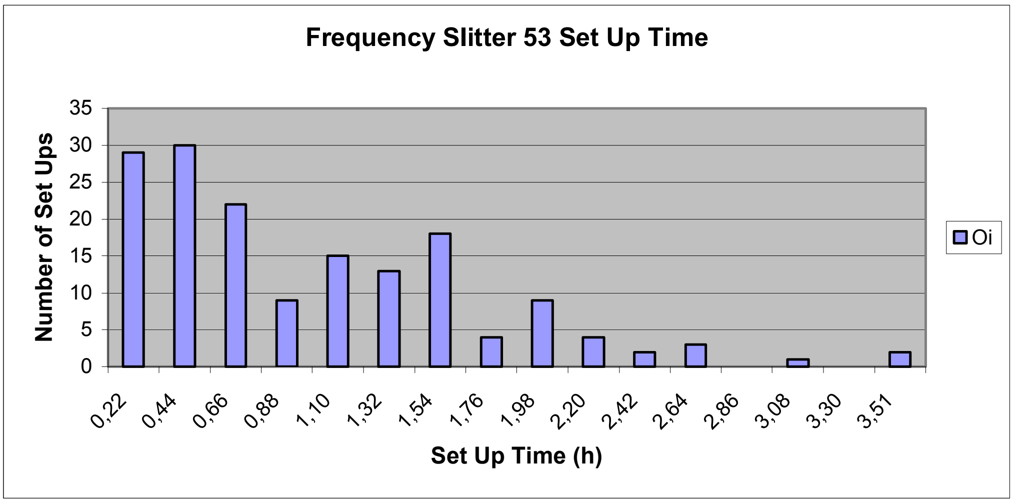

Frequency Printer 10 Set Up Time
Number of Set Ups
Set Up Time (h)
Oi
0
50
100
150
200
250
0,16 0,48 0,79 1,11 1,43 1,75 2,06 2,38 2,70 3,02 3,33 3,65 3,97 4,29 4,60 4,92 5,24 5,56

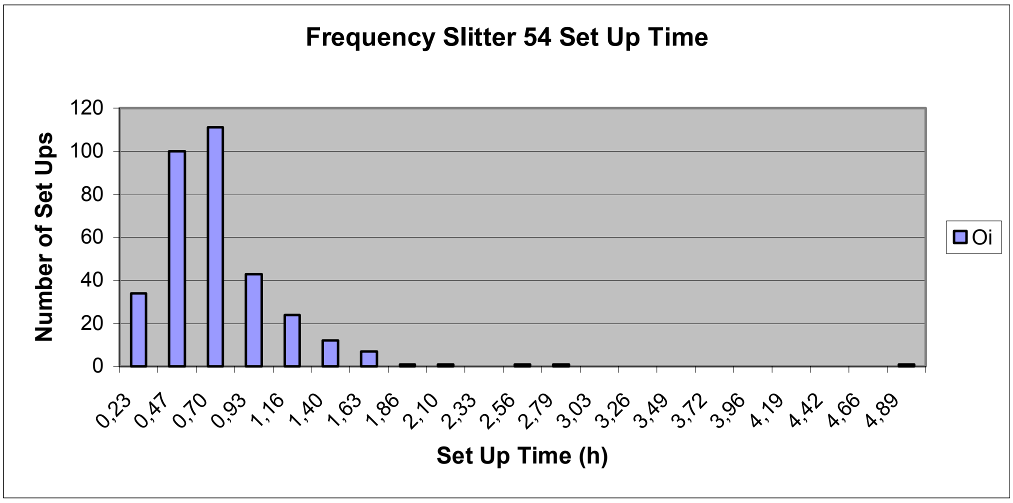

Frequency Printer 12 Set Up Time
Number of Set Ups
Set Up Time (h)
Oi
0
50
100
150
200
250
0,20 0,61 1,02 1,43 1,84 2,25 2,66 3,07 3,48 3,89 4,30 4,71 5,12 5,53 5,94 6,35 6,76

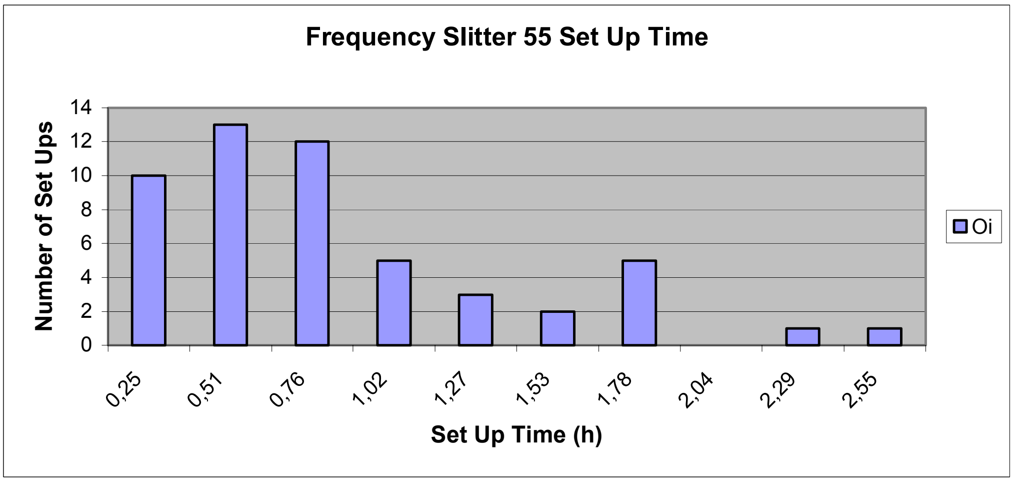

Frequency Printer 16 Set Up Time
Number of Set Ups
Set Up Time (h)
Oi
0
20
40
60
80
100
120
140
160
180
0,12 0,37 0,61 0,86 1,10 1,35 1,59 1,84 2,08 2,32 2,57 2,81 3,06 3,30 3,55 3,79 4,04 4,28

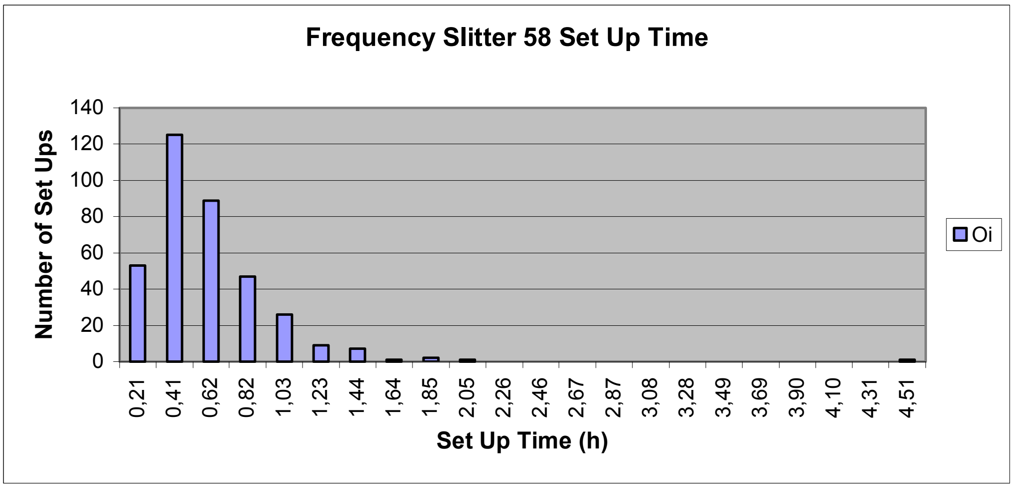

Frequency Laminator 21 Set Up Time
Number of Set Ups
140
120
100
80
60
40
20
0
0,29
0,86
1,44
2,01
2,59
3,16
3,73
4,31
4,88
5,46
6,03
6,61
7,18
Set Up Time (h)
Oi


Frequency Laminator 22 Set Up Time
Number of Set Ups
140
120
100
80
60
40
20
0
0,22
0,67
1,12
1,57
2,02
2,47
2,92
3,37
3,82
4,27
4,72
5,17
Set Up Time (h)
Oi

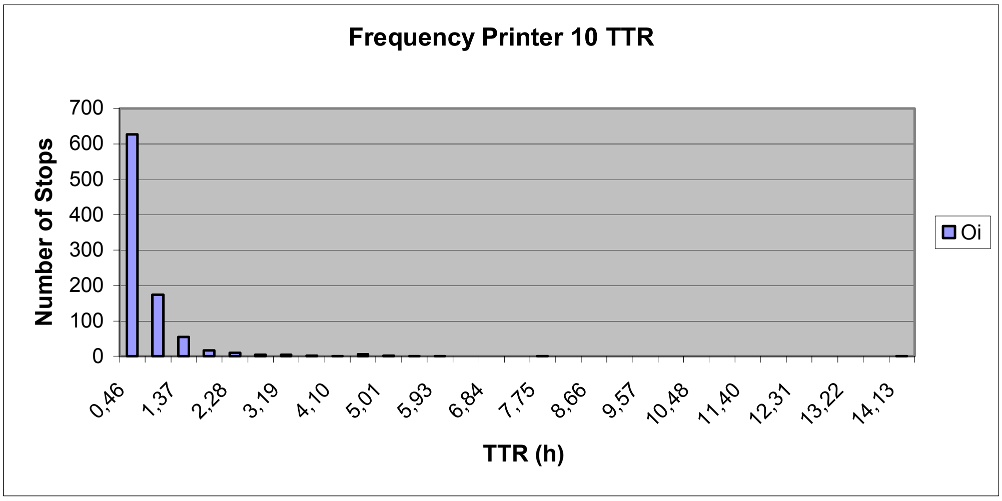

Frequency Slitter 53 Set Up Time
Number of Set Ups
35
30
25
20
15
10
5
0
0,22
0,44
0,66
0,88
1,10
1,32
1,54
1,76
1,98
2,20
2,42
2,64
2,86
3,08
3,30
3,51
Set Up Time (h)
Oi

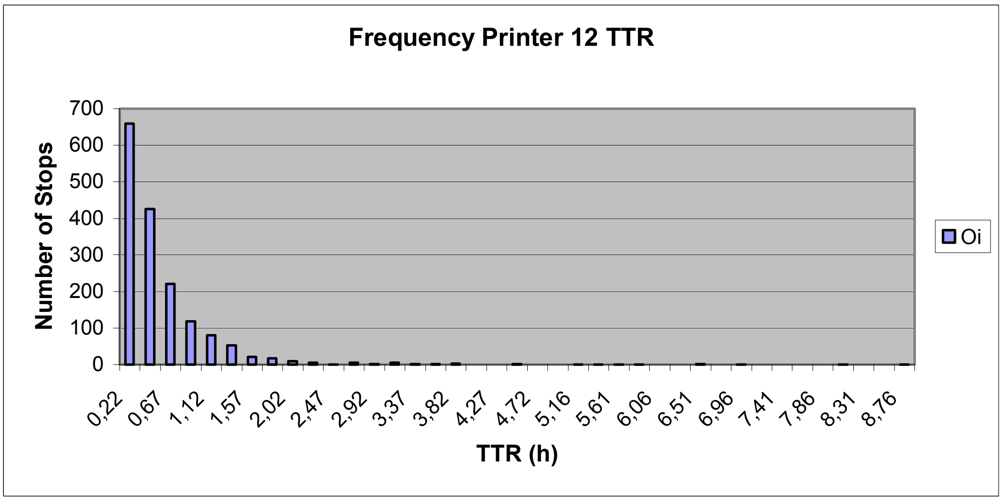

Frequency Slitter 54 Set Up Time
Number of Set Ups
Set Up Time (h)
Oi
0
20
40
60
80
100
120
0,23
0,47
0,70
0,93
1,16
1,40
1,63
1,86
2,10
2,33
2,56
2,79
3,03
3,26
3,49
3,72
3,96
4,19
4,42
4,66
4,89

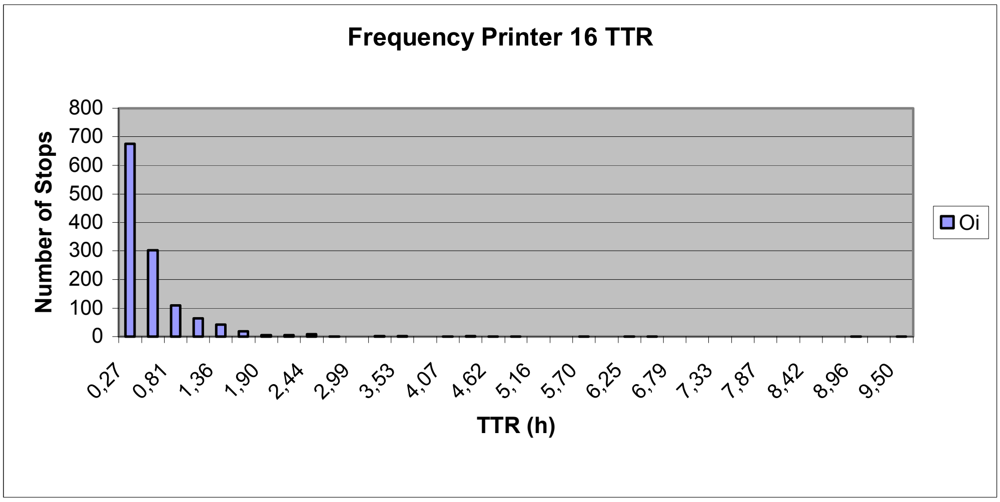

Frequency Slitter 55 Set Up Time
Number of Set Ups
Set Up Time (h)
Oi
0
2
4
6
8
10
12
14
0,25
0,51
0,76
1,02
1,27
1,53
1,78
2,04
2,29
2,55

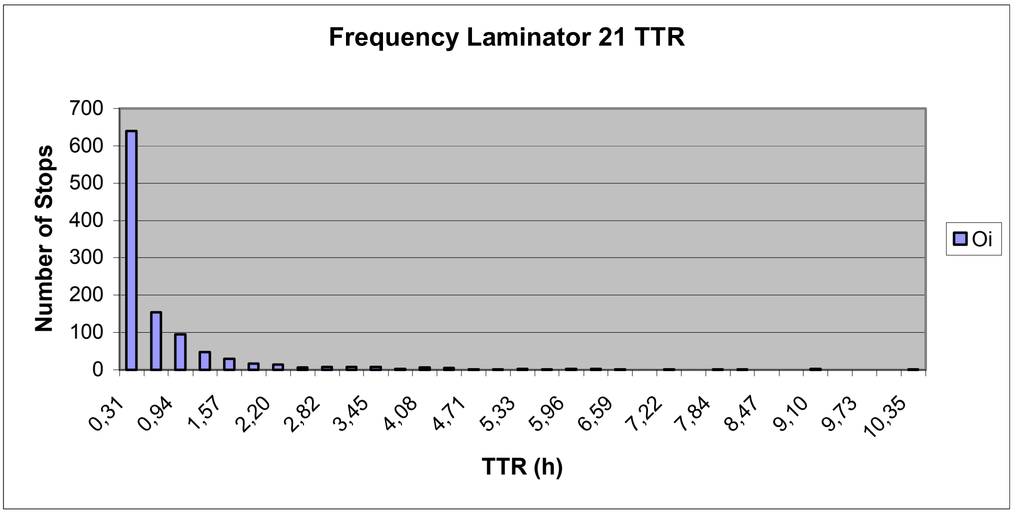

Frequency Slitter 58 Set Up Time
Number of Set Ups
Set Up Time (h)
Oi
0
20
40
60
80
100
120
140
0,21
0,41
0,62
0,82
1,03
1,23
1,44
1,64
1,85
2,05
2,26
2,46
2,67
2,87
3,08
3,28
3,49
3,69
3,90
4,10
4,31
4,51

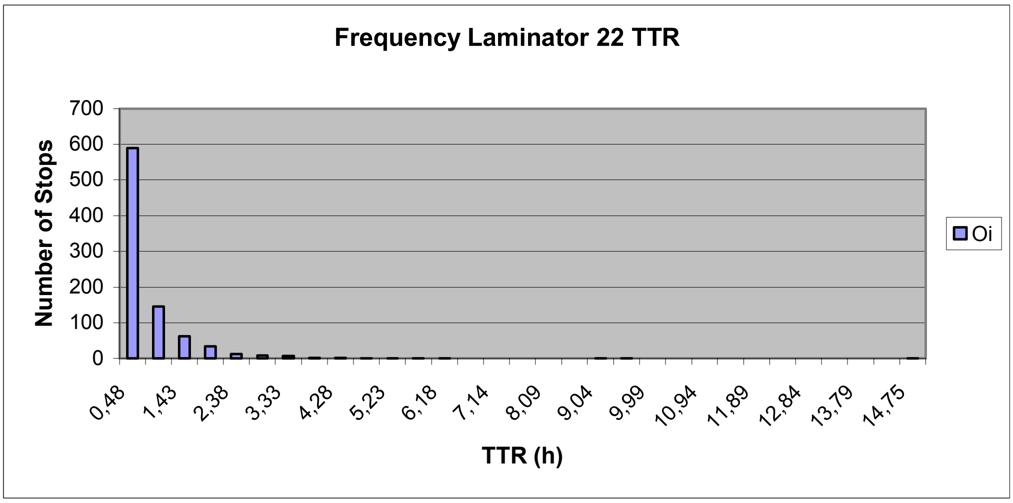
Appendix C

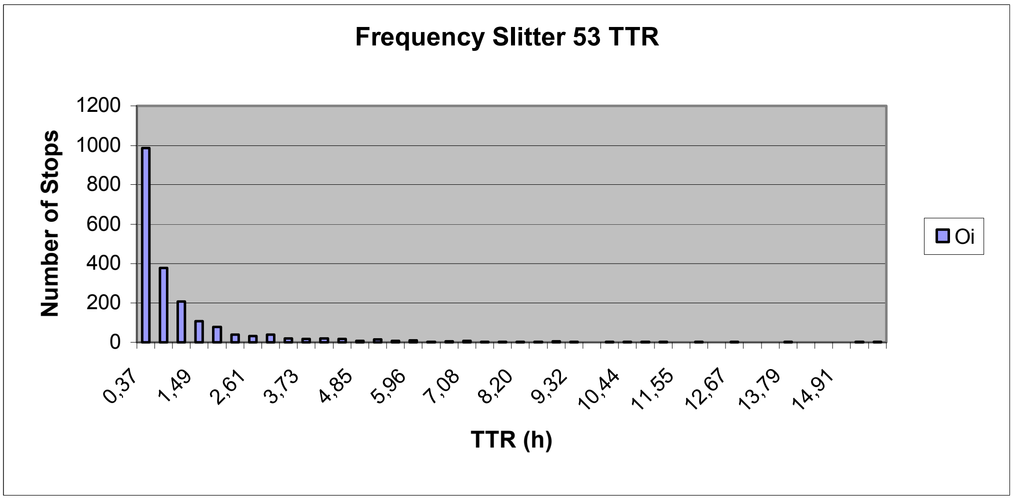

Frequency Printer 10 TTR
Number of Stops
700
600
500
400
300
200
100
0
0,46
1,37
2,28
3,19
4,10
5,01
5,93
6,84
7,75
8,66
9,57
10,48
11,40
12,31
13,22
14,13
TTR (h)
Oi

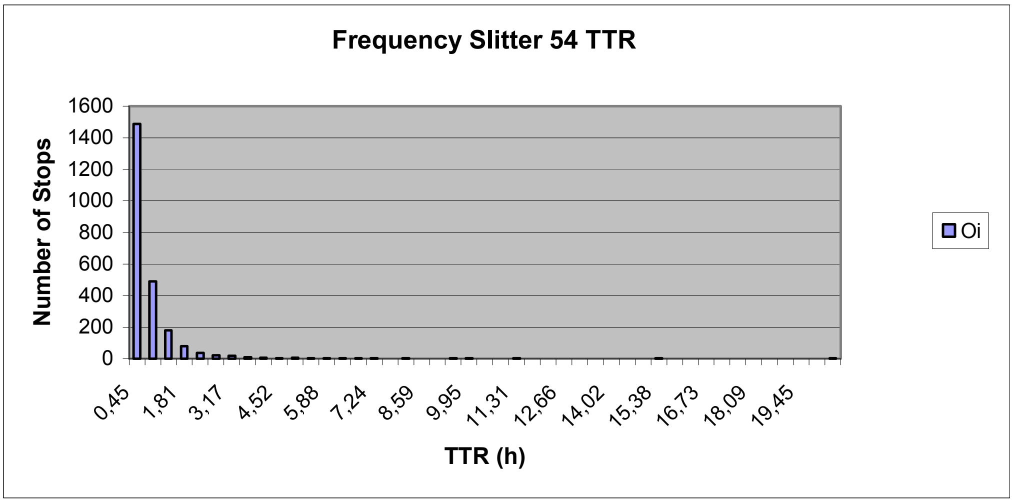

Frequency Printer 12 TTR
Number of Stops
700
600
500
400
300
200
100
0
0,22
0,67
1,12
1,57
2,02
2,47
2,92
3,37
3,82
4,27
4,72
5,16
5,61
6,06
6,51
6,96
7,41
7,86
8,31
8,76
TTR (h)
Oi

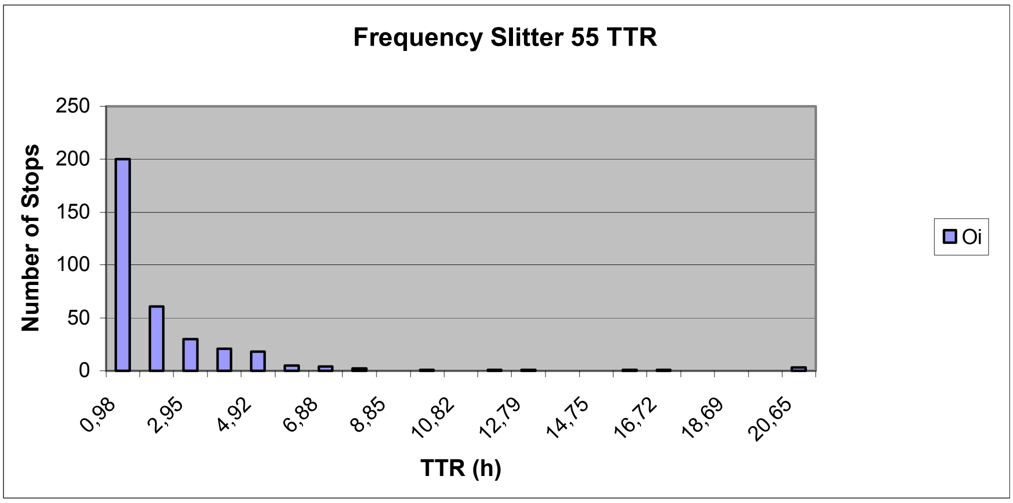

Frequency Printer 16 TTR
Number of Stops
800
700
600
500
400
300
200
100
0
0,27
0,81
1,36
1,90
2,44
2,99
3,53
4,07
4,62
5,16
5,70
6,25
6,79
7,33
7,87
8,42
8,96
9,50
TTR (h)
Oi

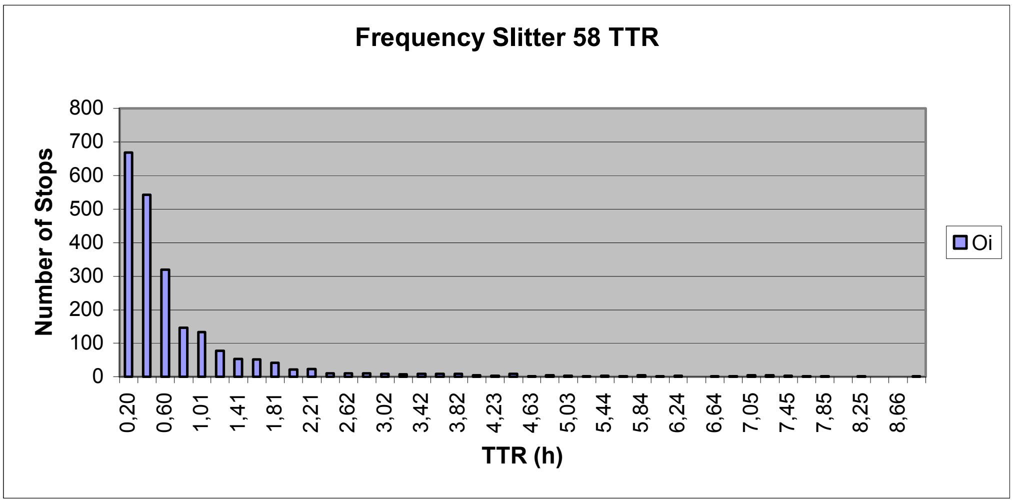

Frequency Laminator 21 TTR
Number of Stops
700
600
500
400
300
200
100
0
0,31
0,94
1,57
2,20
2,82
3,45
4,08
4,71
5,33
5,96
6,59
7,22
7,84
8,47
9,10
9,73
10,35
TTR (h)
Oi


Frequency Laminator 22 TTR
Number of Stops
700
600
500
400
300
200
100
0
0,48
1,43
2,38
3,33
4,28
5,23
6,18
7,14
8,09
9,04
9,99
10,94
11,89
12,84
13,79
14,75
TTR (h)
Oi

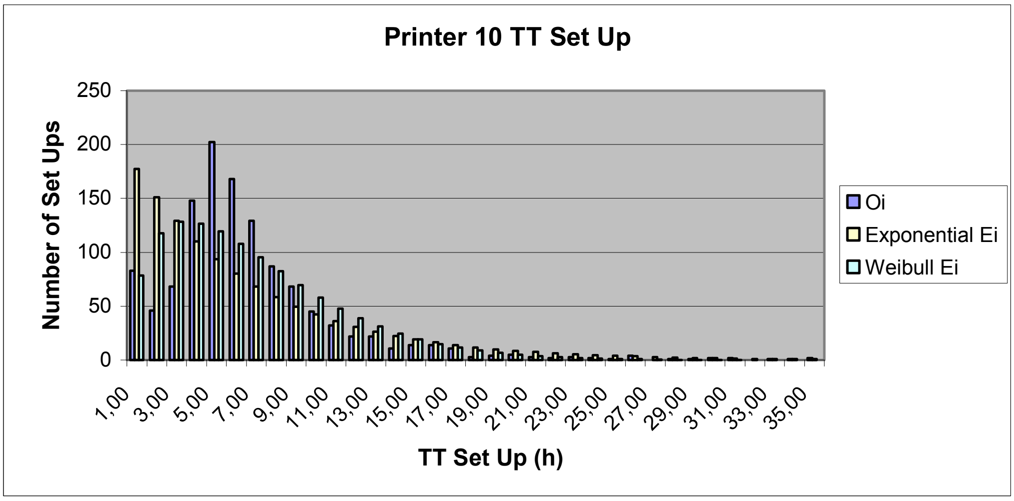

Frequency Slitter 53 TTR
Number of Stops
1200
1000
800
600
400
200
0
0,37
1,49
2,61
3,73
4,85
5,96
7,08
8,20
9,32
10,44
11,55
12,67
13,79
14,91
TTR (h)
Oi

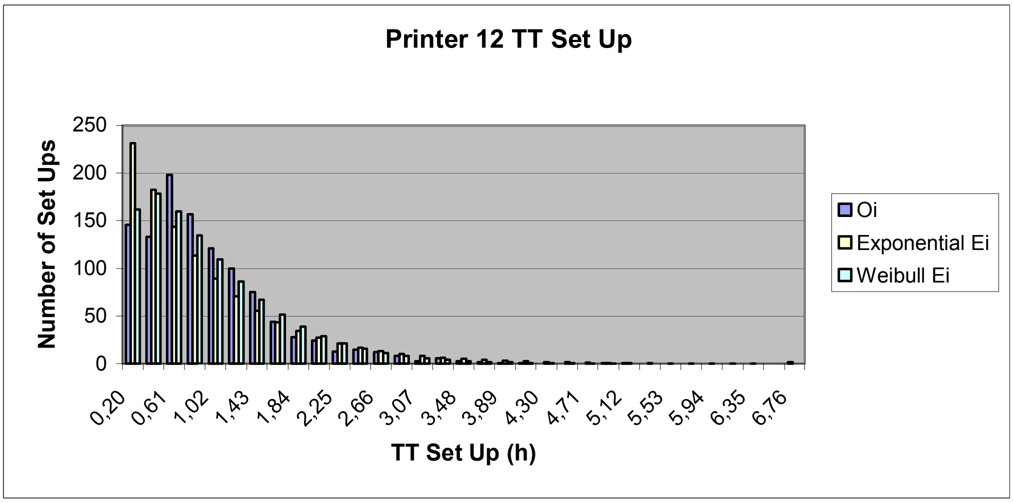

Frequency Slitter 54 TTR
Number of Stops
1600
1400
1200
1000
800
600
400
200
0
0,45
1,81
3,17
4,52
5,88
7,24
8,59
9,95
11,31
12,66
14,02
15,38
16,73
18,09
19,45
TTR (h)
Oi

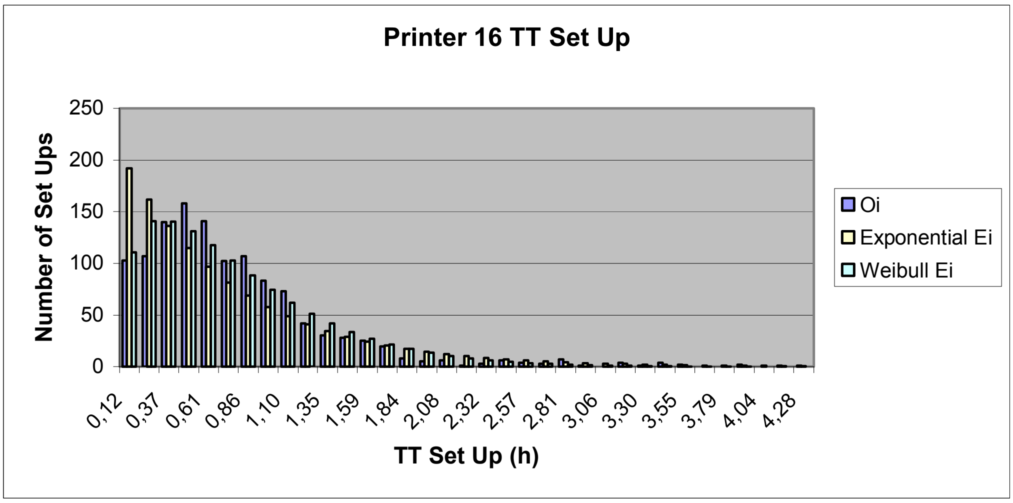

Frequency Slitter 55 TTR
Number of Stops
250
200
150
100
50
0
0,98
2,95
4,92
6,88
8,85
10,82
12,79
14,75
16,72
18,69
20,65
TTR (h)
Oi

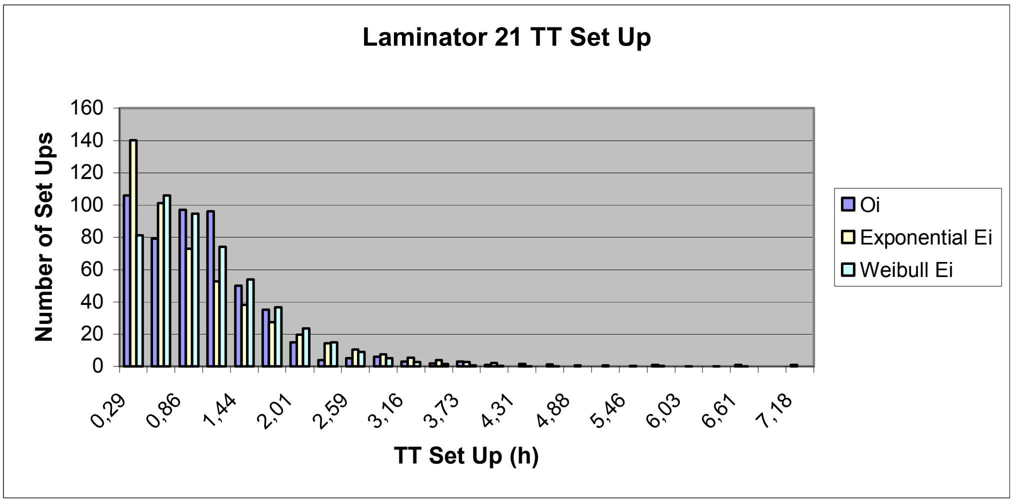

Frequency Slitter 58 TTR
Number of Stops
800
700
600
500
400
300
200
100
0
0,20
0,60
1,01
1,41
1,81
2,21
2,62
3,02
3,42
3,82
4,23
4,63
5,03
5,44
5,84
6,24
6,64
7,05
7,45
7,85
8,25
8,66
TTR (h)
Oi

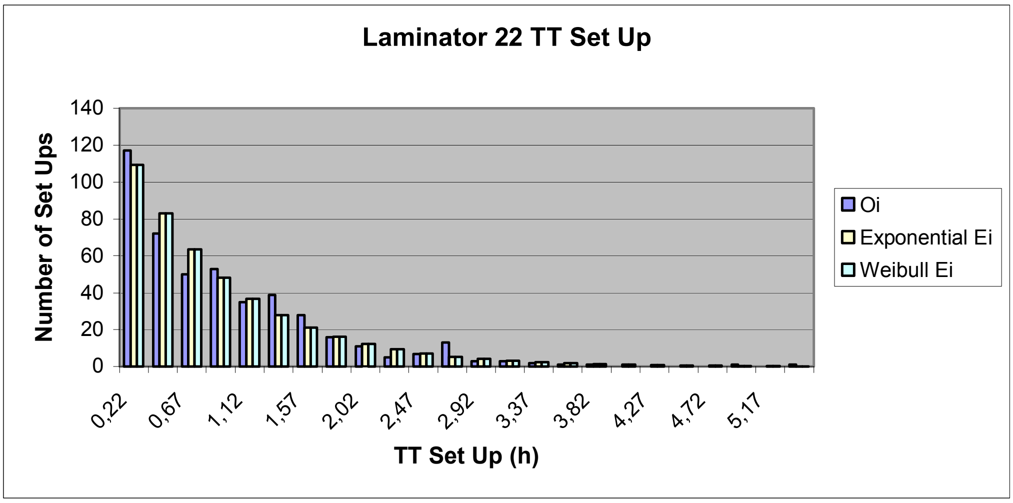
Appendix D

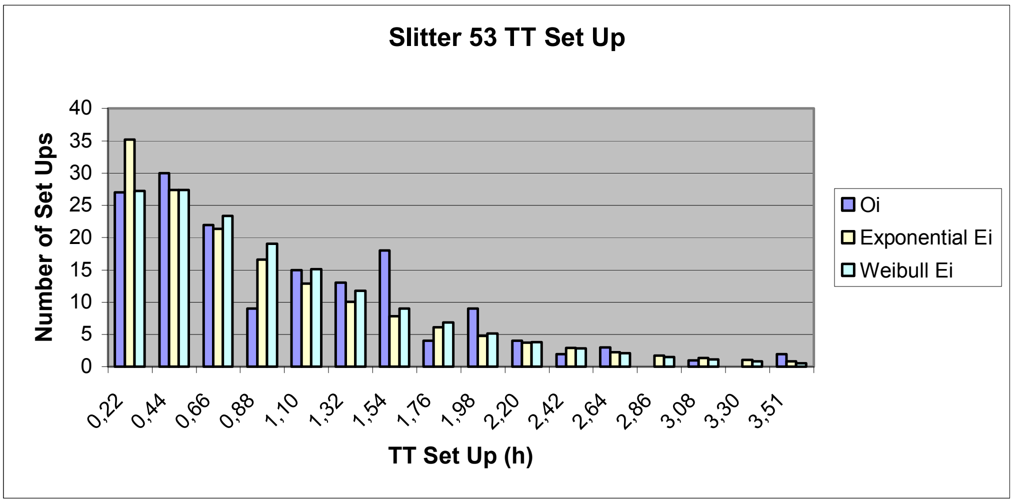

Printer 10 TT Set Up
Number of Set Ups
250
200
150
100
50
0
1,00
3,00
5,00
7,00
9,00
11,00
13,00
15,00
17,00
19,00
21,00
23,00
25,00
27,00
29,00
31,00
33,00
35,00
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei

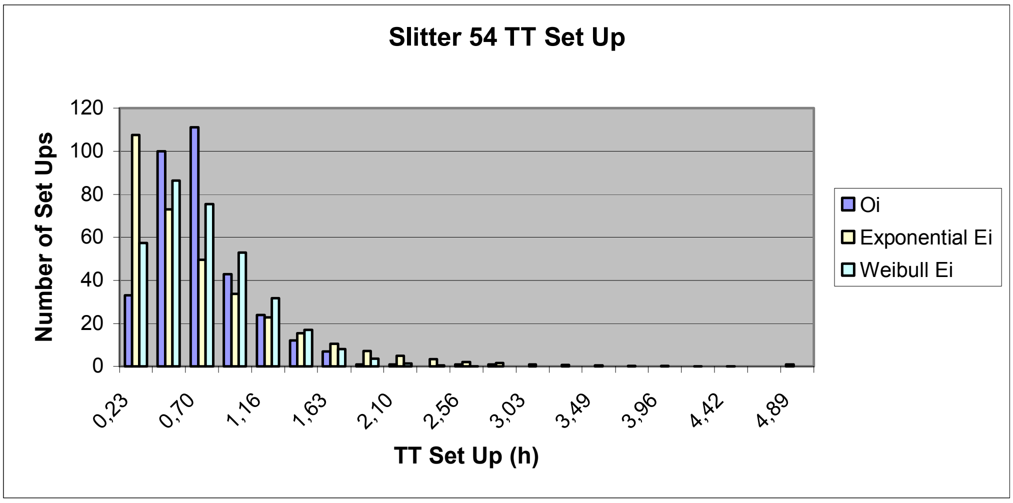

Printer 12 TT Set Up
Number of Set Ups
250
200
150
100
50
0
0,20
0,61
1,02
1,43
1,84
2,25
2,66
3,07
3,48
3,89
4,30
4,71
5,12
5,53
5,94
6,35
6,76
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei


Printer 16 TT Set Up
Number of Set Ups
250
200
150
100
50
0
0,12
0,37
0,61
0,86
1,10
1,35
1,59
1,84
2,08
2,32
2,57
2,81
3,06
3,30
3,55
3,79
4,04
4,28
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei

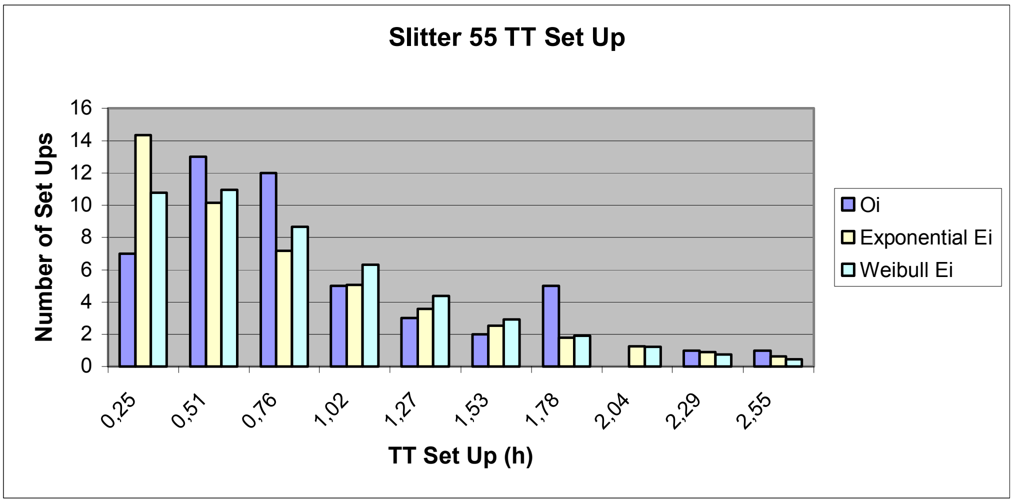

Laminator 21 TT Set Up
Number of Set Ups
160
140
120
100
80
60
40
20
0
0,29
0,86
1,44
2,01
2,59
3,16
3,73
4,31
4,88
5,46
6,03
6,61
7,18
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei


Laminator 22 TT Set Up
Number of Set Ups
140
120
100
80
60
40
20
0
0,22
0,67
1,12
1,57
2,02
2,47
2,92
3,37
3,82
4,27
4,72
5,17
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei

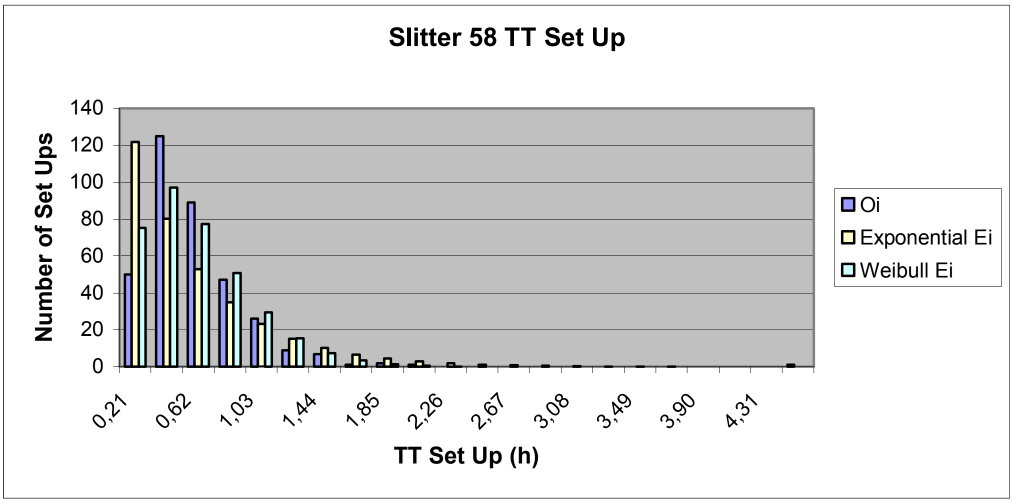

Slitter 53 TT Set Up
Number of Set Ups
40
35
30
25
20
15
10
5
0
0,22
0,44
0,66
0,88
1,10
1,32
1,54
1,76
1,98
2,20
2,42
2,64
2,86
3,08
3,30
3,51
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei



Slitter 54 TT Set Up
Number of Set Ups
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei
120
100
80
60
40
20
0
0,23
0,70
1,16
1,63
2,10
2,56
3,03
3,49
3,96
4,42
4,89

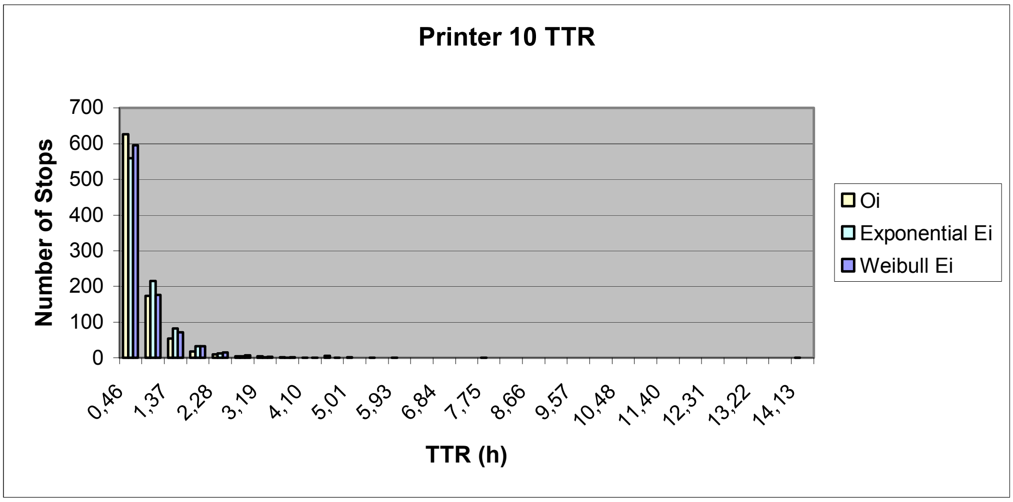


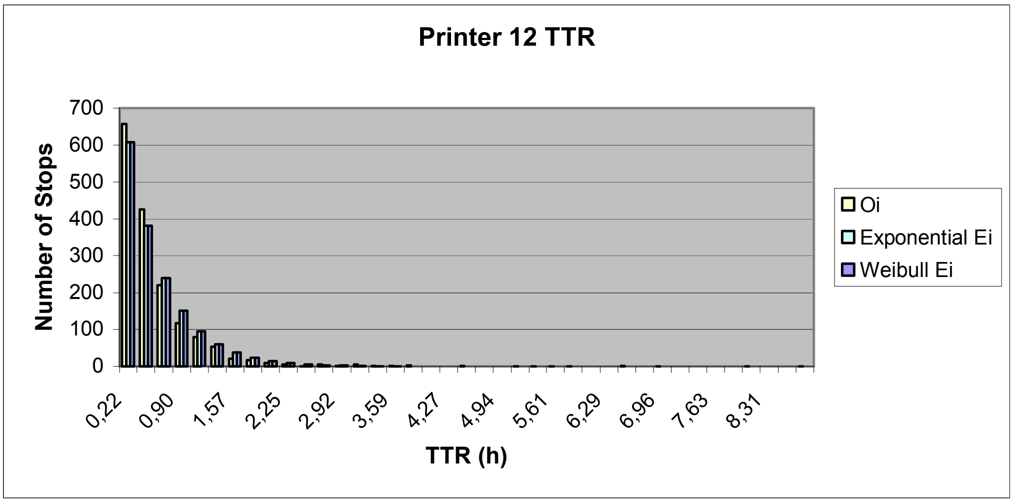
Slitter 55 TT Set Up
Number of Set Ups
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei
16
14
12
10
8
6
4
2
0
0,25
0,51
0,76
1,02
1,27
1,53
1,78
2,04
2,29
2,55

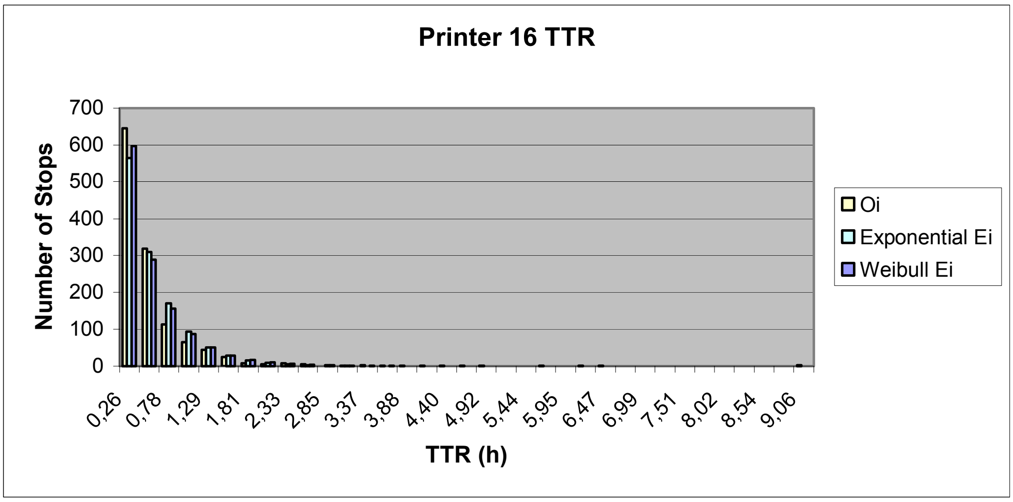


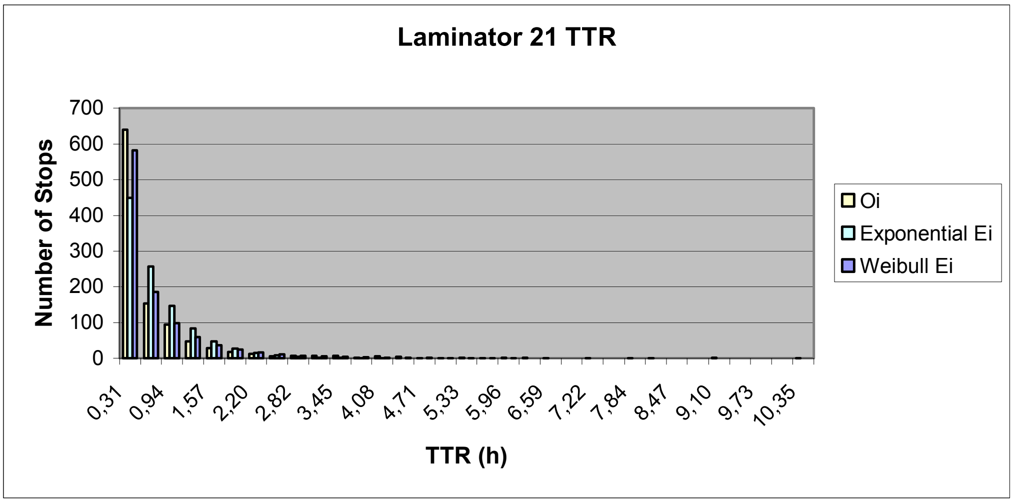
Slitter 58 TT Set Up
Number of Set Ups
TT Set Up (h)
Oi
Exponential Ei
Weibull Ei
140
120
100
80
60
40
20
0
0,21
0,62
1,03
1,44
1,85
2,26
2,67
3,08
3,49
3,90
4,31

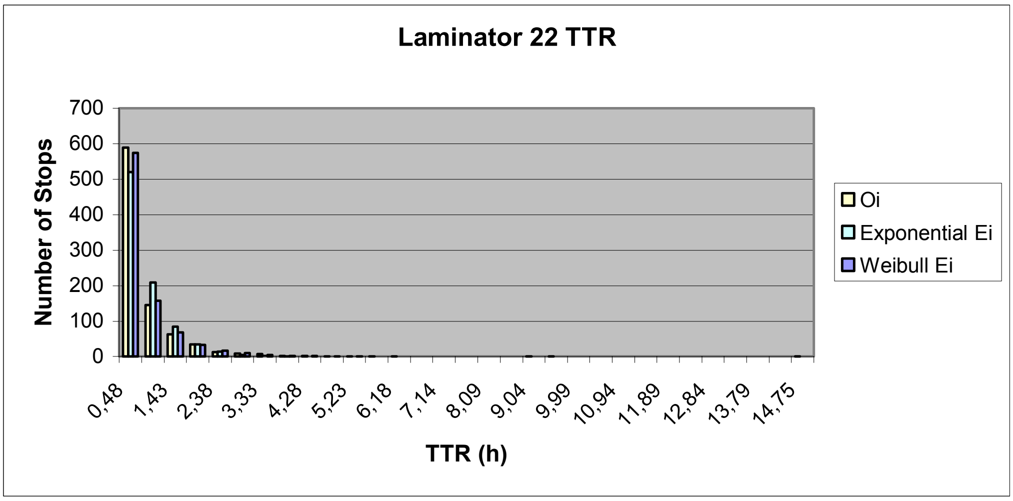
Appendix E

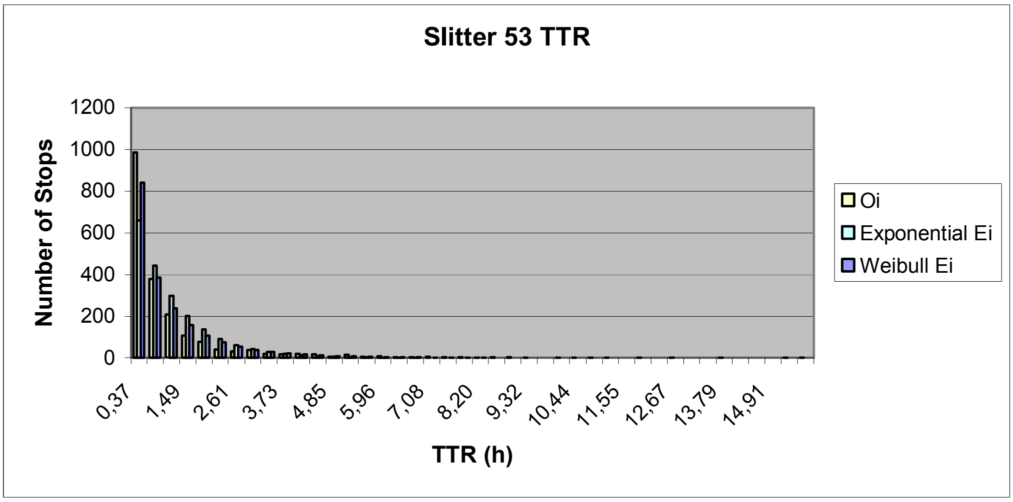

Printer 10 TTR
Number of Stops
0
100
200
300
400
500
600
700
0,46
1,37
2,28
3,19
4,10
5,01
5,93
6,84
7,75
8,66
9,57
10,48
11,40
12,31
13,22
14,13
TTR (h)
Oi
Exponential Ei
Weibull Ei

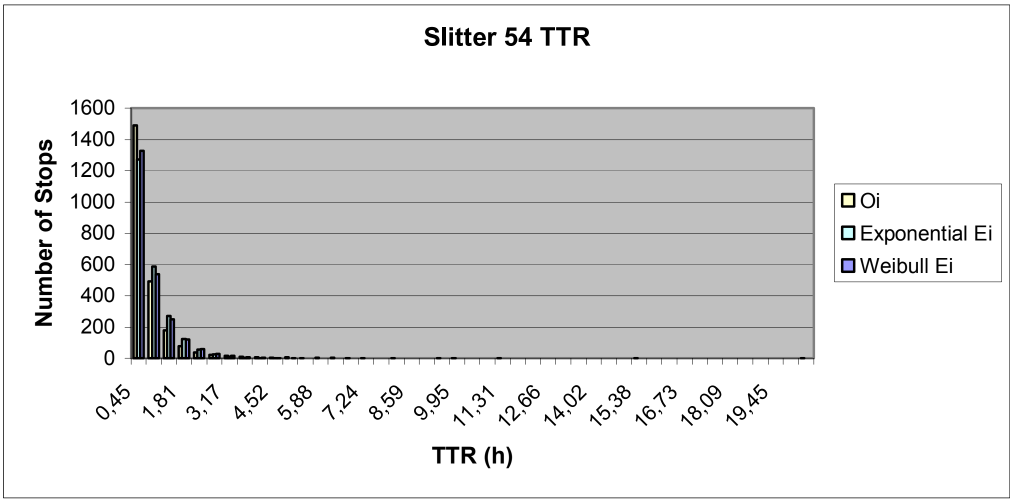

Printer 12 TTR
Number of Stops
0
100
200
300
400
500
600
700
0,22
0,90
1,57
2,25
2,92
3,59
4,27
4,94
5,61
6,29
6,96
7,63
8,31
TTR (h)
Oi
Exponential Ei
Weibull Ei

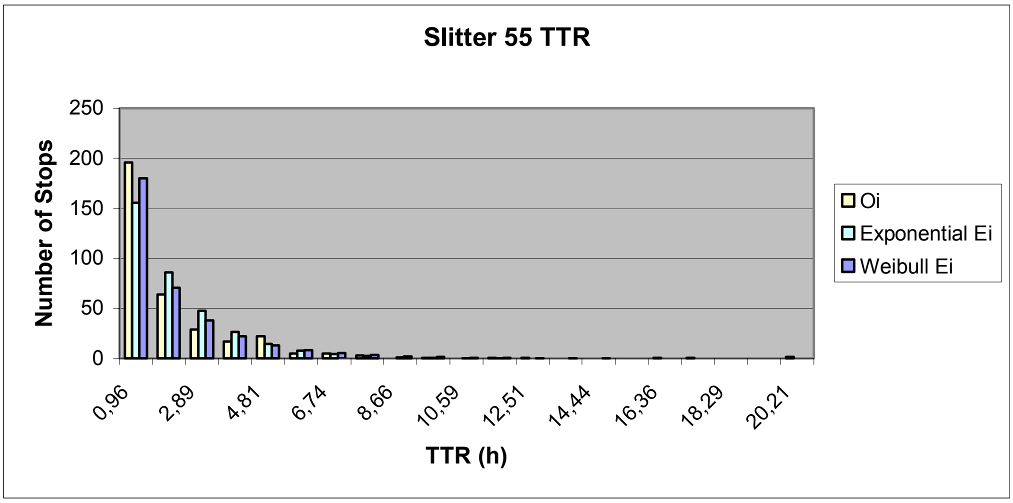

Printer 16 TTR
Number of Stops
0
100
200
300
400
500
600
700
0,26
0,78
1,29
1,81
2,33
2,85
3,37
3,88
4,40
4,92
5,44
5,95
6,47
6,99
7,51
8,02
8,54
9,06
TTR (h)
Oi
Exponential Ei
Weibull Ei

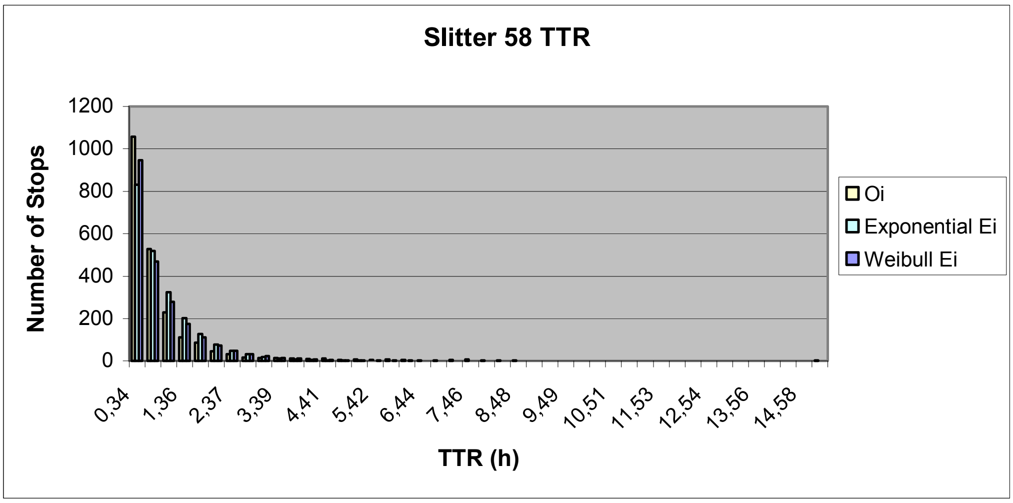

Laminator 21 TTR
Number of Stops
700
600
500
400
300
200
100
0
0,31
0,94
1,57
2,20
2,82
3,45
4,08
4,71
5,33
5,96
6,59
7,22
7,84
8,47
9,10
9,73
10,35
TTR (h)
Oi
Exponential Ei
Weibull Ei


Laminator 22 TTR
Number of Stops
700
600
500
400
300
200
100
0
0,48
1,43
2,38
3,33
4,28
5,23
6,18
7,14
8,09
9,04
9,99
10,94
11,89
12,84
13,79
14,75
TTR (h)
Oi
Exponential Ei
Weibull Ei


Slitter 53 TTR
Number of Stops
1200
1000
800
600
400
200
0
0,37
1,49
2,61
3,73
4,85
5,96
7,08
8,20
9,32
10,44
11,55
12,67
13,79
14,91
TTR (h)
Oi
Exponential Ei
Weibull Ei


Slitter 54 TTR
Number of Stops
1600
1400
1200
1000
800
600
400
200
0
0,45
1,81
3,17
4,52
5,88
7,24
8,59
9,95
11,31
12,66
14,02
15,38
16,73
18,09
19,45
TTR (h)
Oi
Exponential Ei
Weibull Ei


Slitter 55 TTR
Number of Stops
250
200
150
100
50
0
0,96
2,89
4,81
6,74
8,66
10,59
12,51
14,44
16,36
18,29
20,21
TTR (h)
Oi
Exponential Ei
Weibull Ei


Slitter 58 TTR
Number of Stops
1200
1000
800
600
400
200
0
0,34
1,36
2,37
3,39
4,41
5,42
6,44
7,46
8,48
9,49
10,51
11,53
12,54
13,56
14,58
TTR (h)
Oi
Exponential Ei
Weibull Ei

Appendix F

This appendix shows how the analyses of MTT Set Up and MTTR have been done. The analyses can be found in appendices G and H.

1.	Number of observations, n
2.	Mean value
3.	Standard Deviation
4.	Highest Value*1.01
5.	Number of classes, M=2*n^(2/5)

1. The number of observations, either the number of stops or set ups.
2. The mean value of the observations (h).
3. The standard deviation value of the observations.
4. The longest stop or set up time multiplied with 1,01(used in diagrams).
5. Number of classes, using D´Agostino and Stephens formula.

6.	wa
7.	wb
8.	Chi2 (0.01)

6. The *a* parameter for the Weibull distribution (see chapter 4.9.2)
7. The *b* parameter for the Weibull distribution (see chapter 4.9.2)
8. The chi-square test with a significance level α = 0,01 (see chapter 4.10.1)

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei

These values are used to create an illustrative diagram. The diagrams can be found in Appendix B to E.

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei

These values are used to do a Chi-square test. The sums are compared to value in cell number 8.

Appendix G

Printer 10 TT Set Up

Number of Set Ups, n	1207
MTT Set Up	1,00
Standard Deviation	1,00
Highest Value*1.01	5,56
Number of classes, M=2*n^(2/5)	35

wa	1,09
wb	1,40
Chi2 (0.01)	56,06

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,16	83	177,39	78,50
2	0,32	46	151,32	117,71
3	0,48	68	129,08	128,08
4	0,63	148	110,11	126,83
5	0,79	202	93,93	119,16
6	0,95	168	80,12	108,02
7	1,11	129	68,35	95,30
8	1,27	87	58,30	82,25
9	1,43	68	49,73	69,70
10	1,59	45	42,43	58,12
11	1,75	32	36,19	47,79
12	1,90	22	30,87	38,79
13	2,06	22	26,33	31,11
14	2,22	11	22,46	24,69
15	2,38	14	19,16	19,40
16	2,54	14	16,35	15,09
17	2,70	11	13,94	11,64
18	2,86	3	11,89	8,90
19	3,02	4	10,15	6,75
20	3,17	5	8,66	5,08
21	3,33	3	7,38	3,80
22	3,49	2	6,30	2,82
23	3,65	3	5,37	2,08
24	3,81	2	4,58	1,52
25	3,97	1	3,91	1,11
26	4,13	4	3,33	0,80
27	4,29	0	2,84	0,58
28	4,44	1	2,43	0,41
29	4,60	1	2,07	0,29
30	4,76	2	1,77	0,21
31	4,92	2	1,51	0,14
32	5,08	0	1,28	0,10
33	5,24	1	1,10	0,07
34	5,40	1	0,94	0,05
35	5,56	2	0,80	0,03

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,03	28	34,49	1,22
0,06	21	34,49	5,27
0,09	12	34,49	14,66
0,12	15	34,49	11,01
0,15	7	34,49	21,91
0,19	10	34,49	17,39
0,22	8	34,49	20,34
0,26	9	34,49	18,83
0,30	12	34,49	14,66
0,34	15	34,49	11,01
0,38	17	34,49	8,87
0,42	18	34,49	7,88
0,46	18	34,49	7,88
0,51	35	34,49	0,01
0,56	35	34,49	0,01
0,61	53	34,49	9,94
0,66	76	34,49	49,98
0,72	77	34,49	52,41
0,78	75	34,49	47,60
0,85	65	34,49	27,00
0,91	75	34,49	47,60
0,99	62	34,49	21,95
1,07	74	34,49	45,28
1,16	53	34,49	9,94
1,25	55	34,49	12,20
1,36	46	34,49	3,84
1,47	45	34,49	3,21
1,61	32	34,49	0,18
1,76	32	34,49	0,18
1,94	22	34,49	4,52
2,17	29	34,49	0,87
2,45	20	34,49	6,08
2,86	22	34,49	4,52
3,55	15	34,49	11,01
10^307	19	34,49	0,87
		Sum	520,13

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,09	61	34,49	20,39
0,14	21	34,49	5,27
0,19	13	34,49	13,39
0,24	13	34,49	13,39
0,29	10	34,49	17,39
0,33	19	34,49	6,95
0,37	17	34,49	8,87
0,42	18	34,49	7,88
0,46	13	34,49	13,39
0,50	35	34,49	0,01
0,54	28	34,49	1,22
0,59	45	34,49	3,21
0,63	52	34,49	8,89
0,68	55	34,49	12,20
0,72	66	34,49	28,80
0,77	58	34,49	16,03
0,82	43	34,49	2,10
0,87	59	34,49	17,43
0,92	55	34,49	12,20
0,97	54	34,49	11,04
1,03	54	34,49	11,04
1,08	38	34,49	0,36
1,15	36	34,49	0,07
1,21	38	34,49	0,36
1,28	43	34,49	2,10
1,36	27	34,49	1,62
1,44	34	34,49	0,01
1,53	24	34,49	3,19
1,64	27	34,49	1,62
1,76	22	34,49	4,52
1,90	20	34,49	6,08
2,08	23	34,49	3,83
2,32	20	34,49	6,08
2,70	30	34,49	0,58
10^307	36	34,49	6,08
		Sum	267,60

Printer 12 TT Set Up

Number of Set Ups, n	1094
MTT Set Up	0,86
Standard Deviation	1,12
Highest Value*1.01	6,76
Number of classes, M=2*n^(2/5)	33

wa	0,92
wb	1,22
Chi2 (0.01)	53,49

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,20	146	231,13	161,90
2	0,41	133	182,30	178,67
3	0,61	198	143,78	159,91
4	0,82	157	113,41	134,51
5	1,02	121	89,45	109,18
6	1,23	100	70,55	86,46
7	1,43	75	55,65	67,19
8	1,64	44	43,89	51,42
9	1,84	28	34,62	38,84
10	2,05	24	27,30	29,02
11	2,25	13	21,54	21,46
12	2,46	15	16,99	15,74
13	2,66	12	13,40	11,44
14	2,87	8	10,57	8,26
15	3,07	3	8,33	5,92
16	3,28	6	6,57	4,22
17	3,48	3	5,18	2,99
18	3,69	2	4,09	2,10
19	3,89	1	3,23	1,47
20	4,10	1	2,54	1,03
21	4,30	0	2,01	0,71
22	4,50	0	1,58	0,49
23	4,71	0	1,25	0,34
24	4,91	1	0,98	0,23
25	5,12	1	0,78	0,16
26	5,32	0	0,61	0,11
27	5,53	0	0,48	0,07
28	5,73	0	0,38	0,05
29	5,94	0	0,30	0,03
30	6,14	0	0,24	0,02
31	6,35	0	0,19	0,01
32	6,55	0	0,15	0,01
33	6,76	2	0,12	0,01

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,03	32	33,15	0,04
0,05	25	33,15	2,00
0,08	21	33,15	4,45
0,11	9	33,15	17,59
0,14	19	33,15	6,04
0,17	20	33,15	5,22
0,21	20	33,15	5,22
0,24	12	33,15	13,50
0,27	27	33,15	1,14
0,31	31	33,15	0,14
0,35	15	33,15	9,94
0,39	35	33,15	0,10
0,43	36	33,15	0,24
0,48	46	33,15	4,98
0,52	48	33,15	6,65
0,57	47	33,15	5,78
0,62	44	33,15	3,55
0,68	39	33,15	1,03
0,74	50	33,15	8,56
0,80	56	33,15	15,75
0,87	40	33,15	1,41
0,95	36	33,15	0,24
1,03	53	33,15	11,88
1,12	54	33,15	13,11
1,22	40	33,15	1,41
1,34	45	33,15	4,23
1,47	39	33,15	1,03
1,63	32	33,15	0,04
1,82	27	33,15	1,14
2,07	28	33,15	0,80
2,42	25	33,15	2,00
3,02	25	33,15	2,00
10^307	18	33,15	6,92
		Sum	158,19

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,05	57	33,15	17,16
0,09	26	33,15	1,54
0,13	17	33,15	7,87
0,17	26	33,15	1,54
0,21	20	33,15	5,22
0,25	21	33,15	4,45
0,28	27	33,15	1,14
0,32	27	33,15	1,14
0,36	21	33,15	4,45
0,40	28	33,15	0,80
0,44	32	33,15	0,04
0,48	46	33,15	4,98
0,52	48	33,15	6,65
0,56	40	33,15	1,41
0,61	31	33,15	0,14
0,66	47	33,15	5,78
0,71	26	33,15	1,54
0,76	46	33,15	4,98
0,81	48	33,15	6,65
0,87	38	33,15	0,71
0,93	23	33,15	3,11
0,99	45	33,15	4,23
1,06	35	33,15	0,10
1,14	43	33,15	2,93
1,22	37	33,15	0,45
1,32	38	33,15	0,71
1,42	34	33,15	0,02
1,55	24	33,15	2,53
1,70	31	33,15	0,14
1,88	26	33,15	1,54
2,14	26	33,15	1,54
2,57	27	33,15	1,14
10^307	33	33,15	0,00
		Sum	96,65

Printer 16 TT Set Up

Number of Set Ups, n	1218
MTT Set Up	0,71
Standard Deviation	0,99
Highest Value*1.01	4,28
Number of classes, M=2*n^(2/5)	35

wa	0,77
wb	1,28
Chi2 (0.01)	56,06

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,12	103	192,18	110,44
2	0,24	107	161,86	140,53
3	0,37	140	136,32	140,42
4	0,49	158	114,81	130,96
5	0,61	141	96,69	117,54
6	0,73	102	81,44	102,79
7	0,86	107	68,59	88,16
8	0,98	83	57,77	74,44
9	1,10	73	48,65	62,04
10	1,22	42	40,98	51,13
11	1,35	30	34,51	41,73
12	1,47	28	29,07	33,75
13	1,59	25	24,48	27,09
14	1,71	20	20,62	21,58
15	1,84	8	17,36	17,07
16	1,96	5	14,62	13,42
17	2,08	6	12,32	10,49
18	2,20	1	10,37	8,16
19	2,32	3	8,74	6,31
20	2,45	6	7,36	4,85
21	2,57	4	6,20	3,72
22	2,69	3	5,22	2,83
23	2,81	7	4,40	2,15
24	2,94	1	3,70	1,63
25	3,06	0	3,12	1,22
26	3,18	4	2,63	0,92
27	3,30	1	2,21	0,69
28	3,43	4	1,86	0,51
29	3,55	2	1,57	0,38
30	3,67	0	1,32	0,28
31	3,79	0	1,11	0,21
32	3,92	2	0,94	0,15
33	4,04	0	0,79	0,11
34	4,16	1	0,66	0,08
35	4,28	1	0,56	0,06

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,02	23	34,80	4,00
0,04	17	34,80	9,10
0,06	14	34,80	12,43
0,09	20	34,80	6,29
0,11	12	34,80	14,94
0,13	20	34,80	6,29
0,16	17	34,80	9,10
0,18	25	34,80	2,76
0,21	27	34,80	1,75
0,24	21	34,80	5,47
0,27	37	34,80	0,14
0,30	28	34,80	1,33
0,33	54	34,80	10,59
0,36	35	34,80	0,00
0,40	41	34,80	1,10
0,44	55	34,80	11,73
0,47	51	34,80	7,54
0,51	46	34,80	3,60
0,56	50	34,80	6,64
0,60	50	34,80	6,64
0,65	38	34,80	0,29
0,71	47	34,80	4,28
0,76	46	34,80	3,60
0,82	56	34,80	12,91
0,89	62	34,80	21,26
0,97	40	34,80	0,78
1,05	63	34,80	22,85
1,15	32	34,80	0,23
1,26	36	34,80	0,04
1,39	33	34,80	0,09
1,55	39	34,80	0,51
1,75	26	34,80	2,23
2,04	16	34,80	10,16
2,53	14	34,80	12,43
10^307	27	34,80	1,75
		Sum	200,69

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,05	40	34,80	0,78
0,08	34	34,80	0,02
0,12	22	34,80	4,71
0,15	16	34,80	10,16
0,18	27	34,80	1,75
0,21	30	34,80	0,66
0,24	27	34,80	1,75
0,27	37	34,80	0,14
0,30	28	34,80	1,33
0,33	36	34,80	0,04
0,36	46	34,80	3,60
0,39	48	34,80	5,01
0,42	44	34,80	2,43
0,46	35	34,80	0,00
0,49	38	34,80	0,29
0,52	46	34,80	3,60
0,56	39	34,80	0,51
0,60	43	34,80	1,93
0,64	33	34,80	0,09
0,68	23	34,80	4,00
0,72	43	34,80	1,93
0,76	39	34,80	0,51
0,81	47	34,80	4,28
0,86	48	34,80	5,01
0,92	41	34,80	1,10
0,98	31	34,80	0,41
1,04	50	34,80	6,64
1,12	26	34,80	2,23
1,20	23	34,80	4,00
1,30	33	34,80	0,09
1,41	29	34,80	0,97
1,55	35	34,80	0,00
1,75	24	34,80	3,35
2,07	17	34,80	9,10
10^307	40	34,80	0,78
		Sum	73,33

Laminator 21 TT Set Up

Number of Set Ups, n	505
MTT Set Up	0,88
Standard Deviation	1,14
Highest Value*1.01	7,18
Number of classes, M=2*n^(2/5)	25

wa	1,00
wb	1,40
Chi2 (0.01)	42,98

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,29	106	140,17	81,22
2	0,57	79	101,26	105,80
3	0,86	97	73,16	94,64
4	1,15	96	52,85	74,30
5	1,44	50	38,18	53,75
6	1,72	35	27,58	36,60
7	2,01	15	19,93	23,73
8	2,30	4	14,40	14,76
9	2,59	5	10,40	8,85
10	2,87	6	7,51	5,14
11	3,16	3	5,43	2,89
12	3,45	2	3,92	1,58
13	3,73	3	2,83	0,85
14	4,02	1	2,05	0,44
15	4,31	0	1,48	0,22
16	4,60	0	1,07	0,11
17	4,88	0	0,77	0,05
18	5,17	0	0,56	0,03
19	5,46	0	0,40	0,01
20	5,74	1	0,29	0,01
21	6,03	0	0,21	0,00
22	6,32	0	0,15	0,00
23	6,61	1	0,11	0,00
24	6,89	0	0,08	0,00
25	7,18	1	0,06	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,04	15	20,2	1,34
0,07	19	20,2	0,07
0,11	16	20,2	0,87
0,15	20	20,2	0,00
0,20	11	20,2	4,19
0,24	15	20,2	1,34
0,29	15	20,2	1,34
0,34	13	20,2	2,57
0,39	13	20,2	2,57
0,45	15	20,2	1,34
0,51	16	20,2	0,87
0,58	17	20,2	0,51
0,65	19	20,2	0,07
0,73	23	20,2	0,39
0,81	37	20,2	13,97
0,90	39	20,2	17,50
1,01	31	20,2	5,77
1,12	37	20,2	13,97
1,26	27	20,2	2,29
1,42	28	20,2	3,01
1,62	30	20,2	4,75
1,87	19	20,2	0,07
2,23	6	20,2	9,98
2,84	10	20,2	5,15
10^307	14	20,2	1,90
		Sum	95,84

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,10	43	20,2	25,73
0,17	30	20,2	4,75
0,23	16	20,2	0,87
0,29	17	20,2	0,51
0,34	18	20,2	0,24
0,40	13	20,2	2,57
0,45	13	20,2	2,57
0,50	18	20,2	0,24
0,56	13	20,2	2,57
0,62	11	20,2	4,19
0,68	19	20,2	0,07
0,74	18	20,2	0,24
0,80	28	20,2	3,01
0,87	25	20,2	1,14
0,94	29	20,2	3,83
1,01	24	20,2	0,71
1,09	25	20,2	1,14
1,18	28	20,2	3,01
1,28	14	20,2	1,90
1,40	20	20,2	0,00
1,54	22	20,2	0,16
1,71	18	20,2	0,24
1,93	13	20,2	2,57
2,30	7	20,2	8,63
10^307	23	20,2	0,39
		Sum	71,29

Laminator 22 TT Set Up

Number of Set Ups, n	458
MTT Set Up	0,82
Standard Deviation	1,22
Highest Value*1.01	5,39
Number of classes, M=2*n^(2/5)	24

wa	0,82
wb	1,00
Chi2 (0.01)	41,64

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,22	117	109,30	109,30
2	0,45	72	83,22	83,22
3	0,67	50	63,36	63,36
4	0,90	53	48,24	48,24
5	1,12	35	36,73	36,73
6	1,35	39	27,96	27,96
7	1,57	28	21,29	21,29
8	1,80	16	16,21	16,21
9	2,02	11	12,34	12,34
10	2,25	5	9,39	9,39
11	2,47	7	7,15	7,15
12	2,70	13	5,45	5,45
13	2,92	3	4,15	4,15
14	3,15	3	3,16	3,16
15	3,37	2	2,40	2,40
16	3,60	1	1,83	1,83
17	3,82	1	1,39	1,39
18	4,05	0	1,06	1,06
19	4,27	0	0,81	0,81
20	4,49	0	0,61	0,61
21	4,72	0	0,47	0,47
22	4,94	1	0,36	0,36
23	5,17	0	0,27	0,27
24	5,39	1	0,21	0,21

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,04	15	19,08	0,87
0,07	24	19,08	1,27
0,11	22	19,08	0,45
0,15	29	19,08	5,15
0,19	18	19,08	0,06
0,24	12	19,08	2,63
0,28	27	19,08	3,28
0,33	13	19,08	1,94
0,39	13	19,08	1,94
0,44	16	19,08	0,50
0,51	8	19,08	6,44
0,57	25	19,08	1,83
0,64	15	19,08	0,87
0,72	16	19,08	0,50
0,81	19	19,08	0,00
0,91	23	19,08	0,80
1,02	19	19,08	0,00
1,14	20	19,08	0,04
1,29	25	19,08	1,83
1,48	25	19,08	1,83
1,71	21	19,08	0,19
2,05	16	19,08	0,50
2,62	24	19,08	1,27
10^307	13	19,08	1,94
		Sum	36,15

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,04	15	19,08	0,87
0,07	24	19,08	1,27
0,11	22	19,08	0,45
0,15	29	19,08	5,15
0,19	18	19,08	0,06
0,24	12	19,08	2,63
0,28	27	19,08	3,28
0,33	13	19,08	1,94
0,39	13	19,08	1,94
0,44	16	19,08	0,50
0,51	8	19,08	6,44
0,57	25	19,08	1,83
0,64	15	19,08	0,87
0,72	16	19,08	0,50
0,81	19	19,08	0,00
0,91	23	19,08	0,80
1,02	19	19,08	0,00
1,14	20	19,08	0,04
1,29	25	19,08	1,83
1,48	25	19,08	1,83
1,71	21	19,08	0,19
2,05	16	19,08	0,50
2,62	24	19,08	1,27
10^307	13	19,08	1,94
		Sum	36,15

Slitter 53 TT Set Up

Number of Set Ups, n	159
MTT Set Up	0,88
Standard Deviation	1,11
Highest Value*1.01	3,51
Number of classes, M=2*n^(2/5)	16

wa	0,92
wb	1,16
Chi2 (0.01)	30,58

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,22	27	35,18	27,23
2	0,44	30	27,39	27,37
3	0,66	22	21,33	23,38
4	0,88	9	16,61	19,04
5	1,10	15	12,94	15,10
6	1,32	13	10,08	11,75
7	1,54	18	7,85	9,01
8	1,76	4	6,11	6,84
9	1,98	9	4,76	5,14
10	2,20	4	3,71	3,83
11	2,42	2	2,89	2,83
12	2,64	3	2,25	2,08
13	2,86	0	1,75	1,52
14	3,08	1	1,36	1,10
15	3,30	0	1,06	0,80
16	3,51	2	0,83	0,57

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,06	6	9,94	1,56
0,12	9	9,94	0,09
0,18	12	9,94	0,43
0,25	11	9,94	0,11
0,33	7	9,94	0,87
0,41	9	9,94	0,09
0,51	14	9,94	1,66
0,61	6	9,94	1,56
0,73	6	9,94	1,56
0,86	8	9,94	0,38
1,02	10	9,94	0,00
1,22	10	9,94	0,00
1,47	22	9,94	14,64
1,83	13	9,94	0,94
2,44	10	9,94	0,00
10^307	6	9,94	1,56
		Sum	25,45

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,09	10	9,94	0,00
0,16	14	9,94	1,66
0,24	10	9,94	0,00
0,32	10	9,94	0,00
0,40	9	9,94	0,09
0,48	10	9,94	0,00
0,58	10	9,94	0,00
0,67	7	9,94	0,87
0,79	4	9,94	3,55
0,91	6	9,94	1,56
1,05	11	9,94	0,11
1,22	8	9,94	0,38
1,44	20	9,94	10,19
1,74	9	9,94	0,09
2,22	14	9,94	1,66
10^307	7	9,94	0,87
		Sum	21,03

Slitter 54 TT Set Up

Number of Set Ups, n	335
MTT Set Up	0,60
Standard Deviation	0,73
Highest Value*1.01	4,89
Number of classes, M=2*n^(2/5)	21

wa	0,67
wb	1,58
Chi2 (0.01)	37,57

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,23	33	107,52	57,45
2	0,47	100	73,01	86,48
3	0,70	111	49,58	75,52
4	0,93	43	33,67	52,85
5	1,16	24	22,86	31,78
6	1,40	12	15,52	16,94
7	1,63	7	10,54	8,15
8	1,86	1	7,16	3,57
9	2,10	1	4,86	1,44
10	2,33	0	3,30	0,54
11	2,56	1	2,24	0,19
12	2,79	1	1,52	0,06
13	3,03	0	1,03	0,02
14	3,26	0	0,70	0,01
15	3,49	0	0,48	0,00
16	3,72	0	0,32	0,00
17	3,96	0	0,22	0,00
18	4,19	0	0,15	0,00
19	4,42	0	0,10	0,00
20	4,66	0	0,07	0,00
21	4,89	1	0,05	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,03	4	15,95	8,96
0,06	2	15,95	12,20
0,09	7	15,95	5,02
0,13	4	15,95	8,96
0,16	6	15,95	6,21
0,20	5	15,95	7,52
0,24	6	15,95	6,21
0,29	8	15,95	3,96
0,34	13	15,95	0,55
0,39	25	15,95	5,13
0,45	36	15,95	25,19
0,51	47	15,95	60,43
0,58	51	15,95	77,00
0,66	23	15,95	3,11
0,75	21	15,95	1,60
0,86	20	15,95	1,03
1,00	20	15,95	1,03
1,17	15	15,95	0,06
1,41	10	15,95	2,22
1,83	7	15,95	5,02
10^307	5	15,95	1,03
		Sum	242,43

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,10	13	15,95	0,55
0,16	8	15,95	3,96
0,21	7	15,95	5,02
0,25	8	15,95	3,96
0,29	11	15,95	1,54
0,34	8	15,95	3,96
0,38	22	15,95	2,29
0,42	23	15,95	3,11
0,46	33	15,95	18,22
0,51	30	15,95	12,37
0,56	35	15,95	22,74
0,60	22	15,95	2,29
0,66	16	15,95	0,00
0,71	13	15,95	0,55
0,77	17	15,95	0,07
0,84	9	15,95	3,03
0,92	11	15,95	1,54
1,02	16	15,95	0,00
1,15	8	15,95	3,96
1,36	13	15,95	0,55
10^307	12	15,95	3,03
		Sum	92,76

Slitter 55 TT Set Up

Number of Set Ups, n	49
MTT Set Up	0,73
Standard Deviation	1,17
Highest Value*1.01	2,55
Number of classes, M=2*n^(2/5)	10

wa	0,78
wb	1,24
Chi2 (0.01)	21,67

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,25	7	14,35	10,78
2	0,51	13	10,15	10,96
3	0,76	12	7,18	8,67
4	1,02	5	5,07	6,31
5	1,27	3	3,59	4,38
6	1,53	2	2,54	2,93
7	1,78	5	1,79	1,90
8	2,04	0	1,27	1,21
9	2,29	1	0,90	0,75
10	2,55	1	0,63	0,46

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,08	5	4,90	0,00
0,16	0	4,90	4,90
0,26	2	4,90	1,72
0,38	7	4,90	0,90
0,51	6	4,90	0,25
0,67	11	4,90	7,59
0,88	4	4,90	0,17
1,18	4	4,90	0,17
1,69	6	4,90	0,25
10^307	4	4,90	0,17
		Sum	16,10

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,13	5	4,90	0,00
0,23	2	4,90	1,72
0,34	5	4,90	0,00
0,46	7	4,90	0,90
0,58	5	4,90	0,00
0,73	7	4,90	0,90
0,91	5	4,90	0,00
1,15	2	4,90	1,72
1,54	5	4,90	0,00
10^307	6	4,90	0,25
		Sum	5,49

Slitter 58 TT Set Up

Number of Set Ups, n	358,00
MTT Set Up	0,49
Standard Deviation	0,83
Highest Value*1.01	4,51
Number of classes, M=2*n^(2/5)	22,00

wa	0,55
wb	1,48
Chi2 (0.01)	38,93

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,21	50	121,78	75,22
2	0,41	125	80,35	96,98
3	0,62	89	53,02	77,21
4	0,82	47	34,98	50,80
5	1,03	26	23,08	29,41
6	1,23	9	15,23	15,40
7	1,44	7	10,05	7,41
8	1,64	1	6,63	3,32
9	1,85	2	4,38	1,39
10	2,05	1	2,89	0,55
11	2,26	0	1,91	0,20
12	2,46	0	1,26	0,07
13	2,67	0	0,83	0,02
14	2,87	0	0,55	0,01
15	3,08	0	0,36	0,00
16	3,28	0	0,24	0,00
17	3,49	0	0,16	0,00
18	3,69	0	0,10	0,00
19	3,90	0	0,07	0,00
20	4,10	0	0,05	0,00
21	4,31	0	0,03	0,00
22	4,51	1	0,02	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,02	7	16,27	5,28
0,05	6	16,27	6,49
0,07	5	16,27	7,81
0,10	2	16,27	12,52
0,13	8	16,27	4,21
0,16	5	16,27	7,81
0,19	8	16,27	4,21
0,22	18	16,27	0,18
0,26	11	16,27	1,71
0,30	22	16,27	2,02
0,34	42	16,27	40,67
0,39	24	16,27	3,67
0,44	35	16,27	21,55
0,50	25	16,27	4,68
0,57	32	16,27	15,20
0,64	24	16,27	3,67
0,73	19	16,27	0,46
0,84	26	16,27	5,81
0,98	16	16,27	0,00
1,18	11	16,27	1,71
1,53	7	16,27	5,28
10^307	5	16,27	2,02
		Sum	156,96

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,07	15	16,27	0,10
0,11	9	16,27	3,25
0,15	8	16,27	4,21
0,18	9	16,27	3,25
0,22	12	16,27	1,12
0,25	17	16,27	0,03
0,29	15	16,27	0,10
0,32	24	16,27	3,67
0,35	31	16,27	13,33
0,39	18	16,27	0,18
0,43	24	16,27	3,67
0,46	22	16,27	2,02
0,51	20	16,27	0,85
0,55	22	16,27	2,02
0,60	13	16,27	0,66
0,65	18	16,27	0,18
0,71	16	16,27	0,00
0,78	9	16,27	3,25
0,87	23	16,27	2,78
0,99	10	16,27	2,42
1,17	11	16,27	1,71
10^307	12	16,27	0,18
		Sum	48,98

Appendix H

Printer 10 TTR

Number of Break-Downs, n	908
MTTR	0,48
Standard Deviation	1,22
Highest Value*1.01	14,13
Number of classes, M=2*n^(2/5)	31

wa	0,42
wb	0,83
Chi2 (0.01)	48,28

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,46	626	558,68	595,22
2	0,91	174	214,93	176,14
3	1,37	55	82,69	72,56
4	1,82	18	31,81	32,72
5	2,28	10	12,24	15,54
6	2,73	4	4,71	7,65
7	3,19	5	1,81	3,87
8	3,65	3	0,70	2,00
9	4,10	1	0,27	1,05
10	4,56	6	0,10	0,56
11	5,01	2	0,04	0,30
12	5,47	1	0,02	0,17
13	5,93	1	0,01	0,09
14	6,38	0	0,00	0,05
15	6,84	0	0,00	0,03
16	7,29	0	0,00	0,02
17	7,75	1	0,00	0,01
18	8,20	0	0,00	0,01
19	8,66	0	0,00	0,00
20	9,12	0	0,00	0,00
21	9,57	0	0,00	0,00
22	10,03	0	0,00	0,00
23	10,48	0	0,00	0,00
24	10,94	0	0,00	0,00
25	11,40	0	0,00	0,00
26	11,85	0	0,00	0,00
27	12,31	0	0,00	0,00
28	12,76	0	0,00	0,00
29	13,22	0	0,00	0,00
30	13,67	0	0,00	0,00
31	14,13	1	0,00	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,02	9	29,29	14,06
0,03	42	29,29	5,51
0,05	24	29,29	0,96
0,07	56	29,29	24,36
0,08	69	29,29	53,84
0,10	66	29,29	46,01
0,12	40	29,29	3,92
0,14	43	29,29	6,42
0,16	25	29,29	0,63
0,19	28	29,29	0,06
0,21	21	29,29	2,35
0,23	29	29,29	0,00
0,26	17	29,29	5,16
0,29	28	29,29	0,06
0,32	22	29,29	1,81
0,35	21	29,29	2,35
0,38	33	29,29	0,47
0,41	29	29,29	0,00
0,45	24	29,29	0,96
0,49	19	29,29	3,62
0,54	16	29,29	6,03
0,59	30	29,29	0,02
0,65	16	29,29	6,03
0,71	34	29,29	0,76
0,78	28	29,29	0,06
0,87	26	29,29	0,37
0,98	20	29,29	2,95
1,11	21	29,29	2,35
1,31	15	29,29	6,97
1,64	16	29,29	6,03
10^307	41	29,29	4,68
		Sum	208,75

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	0	29,29	29,29
0,02	9	29,29	14,06
0,03	25	29,29	0,63
0,04	17	29,29	5,16
0,05	51	29,29	16,09
0,07	29	29,29	0,00
0,08	69	29,29	53,84
0,10	38	29,29	2,59
0,12	49	29,29	13,26
0,14	41	29,29	4,68
0,16	30	29,29	0,02
0,18	30	29,29	0,02
0,20	35	29,29	1,11
0,23	19	29,29	3,62
0,26	27	29,29	0,18
0,29	28	29,29	0,06
0,32	32	29,29	0,25
0,36	28	29,29	0,06
0,40	28	29,29	0,06
0,44	35	29,29	1,11
0,49	20	29,29	2,95
0,55	24	29,29	0,96
0,61	30	29,29	0,02
0,68	38	29,29	2,59
0,77	28	29,29	0,06
0,87	35	29,29	1,11
1,00	30	29,29	0,02
1,17	14	29,29	7,98
1,42	19	29,29	3,62
1,87	18	29,29	4,35
10^307	32	29,29	0,25
		Sum	169,97

Printer 12 TTR

Number of Break-Downs, n	1639
MTTR	0,48
Standard Deviation	1,00
Highest Value*1.01	8,76
Number of classes, M=2*n^(2/5)	39

wa	0,48
wb	1,00
Chi2 (0.01)	58,62

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,22	658	607,82	607,82
2	0,45	425	382,41	382,41
3	0,67	220	240,59	240,59
4	0,90	118	151,37	151,37
5	1,12	80	95,23	95,23
6	1,35	53	59,92	59,92
7	1,57	21	37,70	37,70
8	1,80	18	23,72	23,72
9	2,02	10	14,92	14,92
10	2,25	5	9,39	9,39
11	2,47	1	5,91	5,91
12	2,69	5	3,72	3,72
13	2,92	2	2,34	2,34
14	3,14	5	1,47	1,47
15	3,37	2	0,93	0,93
16	3,59	2	0,58	0,58
17	3,82	3	0,37	0,37
18	4,04	0	0,23	0,23
19	4,27	0	0,14	0,14
20	4,49	2	0,09	0,09
21	4,72	0	0,06	0,06
22	4,94	0	0,04	0,04
23	5,16	1	0,02	0,02
24	5,39	1	0,01	0,01
25	5,61	1	0,01	0,01
26	5,84	1	0,01	0,01
27	6,06	0	0,00	0,00
28	6,29	0	0,00	0,00
29	6,51	2	0,00	0,00
30	6,74	0	0,00	0,00
31	6,96	1	0,00	0,00
32	7,18	0	0,00	0,00
33	7,41	0	0,00	0,00
34	7,63	0	0,00	0,00
35	7,86	0	0,00	0,00
36	8,08	1	0,00	0,00
37	8,31	0	0,00	0,00
38	8,53	0	0,00	0,00
39	8,76	1	0,00	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	4	42,03	34,41
0,03	7	42,03	29,19
0,04	13	42,03	20,05
0,05	47	42,03	0,59
0,07	37	42,03	0,60
0,08	76	42,03	27,47
0,10	38	42,03	0,39
0,11	71	42,03	19,98
0,13	41	42,03	0,03
0,14	60	42,03	7,69
0,16	72	42,03	21,38
0,18	36	42,03	0,86
0,20	55	42,03	4,01
0,22	66	42,03	13,68
0,24	63	42,03	10,47
0,26	49	42,03	1,16
0,28	41	42,03	0,03
0,30	35	42,03	1,17
0,32	65	42,03	12,56
0,35	36	42,03	0,86
0,37	63	42,03	10,47
0,40	47	42,03	0,59
0,43	50	42,03	1,51
0,46	40	42,03	0,10
0,50	28	42,03	4,68
0,53	48	42,03	0,85
0,57	38	42,03	0,39
0,61	33	42,03	1,94
0,66	32	42,03	2,39
0,71	37	42,03	0,60
0,77	31	42,03	2,89
0,83	39	42,03	0,22
0,91	33	42,03	1,94
1,00	36	42,03	0,86
1,10	30	42,03	3,44
1,24	36	42,03	0,86
1,44	30	42,03	3,44
1,78	30	42,03	3,44
10^307	46	42,03	0,38
		Sum	247,54

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	4	42,03	34,41
0,03	7	42,03	29,19
0,04	13	42,03	20,05
0,05	47	42,03	0,59
0,07	37	42,03	0,60
0,08	76	42,03	27,47
0,10	38	42,03	0,39
0,11	71	42,03	19,98
0,13	41	42,03	0,03
0,14	60	42,03	7,69
0,16	72	42,03	21,38
0,18	36	42,03	0,86
0,20	55	42,03	4,01
0,22	66	42,03	13,68
0,24	63	42,03	10,47
0,26	49	42,03	1,16
0,28	41	42,03	0,03
0,30	35	42,03	1,17
0,32	65	42,03	12,56
0,35	36	42,03	0,86
0,37	63	42,03	10,47
0,40	47	42,03	0,59
0,43	50	42,03	1,51
0,46	40	42,03	0,10
0,50	28	42,03	4,68
0,53	48	42,03	0,85
0,57	38	42,03	0,39
0,61	33	42,03	1,94
0,66	32	42,03	2,39
0,71	37	42,03	0,60
0,77	31	42,03	2,89
0,83	39	42,03	0,22
0,91	33	42,03	1,94
1,00	36	42,03	0,86
1,10	30	42,03	3,44
1,24	36	42,03	0,86
1,44	30	42,03	3,44
1,78	30	42,03	3,44
10^307	46	42,03	0,38
		Sum	247,54

Printer 16 TTR

Number of Break-Downs, n	1248
MTTR	0,43
Standard Deviation	1,03
Highest Value*1.01	9,06
Number of classes, M=2*n^(2/5)	35

wa	0,41
wb	0,92
Chi2 (0.01)	53,49

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,26	645	564,14	596,76
2	0,52	318	309,13	288,19
3	0,78	113	169,39	156,04
4	1,04	65	92,82	87,29
5	1,29	44	50,86	49,76
6	1,55	24	27,87	29
7	1,81	8	15,27	17
8	2,07	5	8,37	10
9	2,33	8	4,59	5,84
10	2,59	4	2,51	3,48
11	2,85	0	1,38	2,08
12	3,11	1	0,75	1,25
13	3,37	2	0,41	0,75
14	3,62	1	0,23	0,46
15	3,88	1	0,12	0,28
16	4,14	1	0,07	0,17
17	4,40	1	0,04	0,10
18	4,66	1	0,02	0,06
19	4,92	1	0,01	0,04
20	5,18	0	0,01	0,02
21	5,44	0	0,00	0,01
22	5,69	1	0,00	0,01
23	5,95	0	0,00	0,01
24	6,21	1	0,00	0,00
25	6,47	1	0,00	0,00
26	6,73	0	0,00	0,00
27	6,99	0	0,00	0,00
28	7,25	0	0,00	0,00
29	7,51	0	0,00	0,00
30	7,77	0	0,00	0,00
31	8,02	0	0,00	0,00
32	8,28	0	0,00	0,00
33	8,54	0	0,00	0,00
34	8,80	0	0,00	0,00
35	9,06	2	0,00	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	5	35,66	26,36
0,03	10	35,66	18,46
0,04	15	35,66	11,97
0,05	63	35,66	20,97
0,07	28	35,66	1,64
0,08	56	35,66	11,61
0,10	39	35,66	0,31
0,11	59	35,66	15,28
0,13	35	35,66	0,01
0,14	54	35,66	9,44
0,16	52	35,66	7,49
0,18	60	35,66	16,62
0,20	26	35,66	2,62
0,22	54	35,66	9,44
0,24	70	35,66	33,08
0,26	36	35,66	0,00
0,29	29	35,66	1,24
0,31	52	35,66	7,49
0,34	31	35,66	0,61
0,36	37	35,66	0,05
0,39	40	35,66	0,53
0,43	23	35,66	4,49
0,46	37	35,66	0,05
0,50	36	35,66	0,00
0,54	26	35,66	2,62
0,58	25	35,66	3,19
0,64	28	35,66	1,64
0,69	28	35,66	1,64
0,76	16	35,66	10,84
0,84	27	35,66	2,10
0,93	28	35,66	1,64
1,06	20	35,66	6,88
1,23	30	35,66	0,90
1,53	31	35,66	0,61
10^307	42	35,66	1,13
		Sum	232,94

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	0	35,66	35,66
0,02	5	35,66	26,36
0,03	25	35,66	3,19
0,04	32	35,66	0,38
0,05	31	35,66	0,61
0,07	28	35,66	1,64
0,08	56	35,66	11,61
0,10	39	35,66	0,31
0,11	59	35,66	15,28
0,13	35	35,66	0,01
0,14	54	35,66	9,44
0,16	52	35,66	7,49
0,18	33	35,66	0,20
0,20	53	35,66	8,44
0,22	78	35,66	50,28
0,24	46	35,66	3,00
0,27	36	35,66	0,00
0,29	29	35,66	1,24
0,32	52	35,66	7,49
0,34	43	35,66	1,51
0,37	40	35,66	0,53
0,41	30	35,66	0,90
0,44	35	35,66	0,01
0,48	40	35,66	0,53
0,53	36	35,66	0,00
0,57	20	35,66	6,88
0,63	33	35,66	0,20
0,69	31	35,66	0,61
0,76	21	35,66	6,02
0,85	27	35,66	2,10
0,95	28	35,66	1,64
1,09	25	35,66	3,19
1,28	32	35,66	0,38
1,62	30	35,66	0,90
10^307	34	35,66	0,08
		Sum	208,09

Laminator 22 TTR

Number of Break-Downs, n	872
MTTR	0,52
Standard Deviation	1,34
Highest Value*1.01	14,75
Number of classes, M=2*n^(2/5)	31

wa	0,43
wb	0,76
Chi2 (0.01)	48,28

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,48	589	519,87	574,55
2	0,95	146	209,93	156,76
3	1,43	63	84,78	68,02
4	1,90	34	34,23	33,15
5	2,38	13	13,82	17,25
6	2,85	9	5,58	9,38
7	3,33	7	2,25	5,27
8	3,81	2	0,91	3,03
9	4,28	2	0,37	1,78
10	4,76	1	0,15	1,07
11	5,23	1	0,06	0,65
12	5,71	1	0,02	0,40
13	6,18	1	0,01	0,25
14	6,66	0	0,00	0,16
15	7,14	0	0,00	0,10
16	7,61	0	0,00	0,06
17	8,09	0	0,00	0,04
18	8,56	0	0,00	0,03
19	9,04	1	0,00	0,02
20	9,51	1	0,00	0,01
21	9,99	0	0,00	0,01
22	10,46	0	0,00	0,00
23	10,94	0	0,00	0,00
24	11,42	0	0,00	0,00
25	11,89	0	0,00	0,00
26	12,37	0	0,00	0,00
27	12,84	0	0,00	0,00
28	13,32	0	0,00	0,00
29	13,79	0	0,00	0,00
30	14,27	0	0,00	0,00
31	14,75	1	0,00	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,02	13	28,13	8,14
0,03	46	28,13	11,35
0,05	51	28,13	18,60
0,07	88	28,13	127,43
0,09	78	28,13	88,42
0,11	56	28,13	27,62
0,13	34	28,13	1,23
0,16	33	28,13	0,84
0,18	26	28,13	0,16
0,20	25	28,13	0,35
0,23	13	28,13	8,14
0,26	19	28,13	2,96
0,29	15	28,13	6,13
0,32	24	28,13	0,61
0,35	13	28,13	8,14
0,38	18	28,13	3,65
0,42	9	28,13	13,01
0,46	19	28,13	2,96
0,50	13	28,13	8,14
0,54	23	28,13	0,94
0,59	13	28,13	8,14
0,65	21	28,13	1,81
0,71	25	28,13	0,35
0,78	22	28,13	1,34
0,86	16	28,13	5,23
0,96	22	28,13	1,34
1,07	18	28,13	3,65
1,23	21	28,13	1,81
1,44	24	28,13	0,61
1,80	26	28,13	0,16
10^307	48	28,13	14,04
		Sum	377,24

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,00	0	28,13	28,13
0,01	13	28,13	8,14
0,02	30	28,13	0,12
0,03	16	28,13	5,23
0,04	21	28,13	1,81
0,06	30	28,13	0,12
0,07	88	28,13	127,43
0,09	42	28,13	6,84
0,11	71	28,13	65,34
0,13	44	28,13	8,95
0,15	31	28,13	0,29
0,17	30	28,13	0,12
0,19	26	28,13	0,16
0,22	21	28,13	1,81
0,25	19	28,13	2,96
0,28	15	28,13	6,13
0,32	24	28,13	0,61
0,36	15	28,13	6,13
0,40	23	28,13	0,94
0,45	21	28,13	1,81
0,51	17	28,13	4,40
0,57	29	28,13	0,03
0,64	24	28,13	0,61
0,73	28	28,13	0,00
0,83	28	28,13	0,00
0,95	29	28,13	0,03
1,11	25	28,13	0,35
1,32	27	28,13	0,05
1,62	28	28,13	0,00
2,18	24	28,13	0,61
10^307	33	28,13	0,84
		Sum	279,98

Laminator 21 TTR

Number of Break-Downs, n	1049
MTTR	0,56
Standard Deviation	1,42
Highest Value*1.01	10,35
Number of classes, M=2*n^(2/5)	33

wa	0,42
wb	0,70
Chi2 (0.01)	50,89

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,31	640	449,68	582,33
2	0,63	154	256,91	186,38
3	0,94	94	146,78	99,09
4	1,25	47	83,86	59,06
5	1,57	29	47,91	37,43
6	1,88	17	27,37	25
7	2,20	13	15,64	17
8	2,51	6	8,93	12
9	2,82	7	5,10	8,25
10	3,14	7	2,92	5,92
11	3,45	7	1,67	4,31
12	3,76	2	0,95	3,16
13	4,08	6	0,54	2,35
14	4,39	4	0,31	1,76
15	4,71	1	0,18	1,32
16	5,02	1	0,10	1,00
17	5,33	2	0,06	0,77
18	5,65	1	0,03	0,59
19	5,96	2	0,02	0,45
20	6,27	2	0,01	0,35
21	6,59	1	0,01	0,27
22	6,90	0	0,00	0,21
23	7,22	1	0,00	0,17
24	7,53	0	0,00	0,13
25	7,84	1	0,00	0,10
26	8,16	1	0,00	0,08
27	8,47	0	0,00	0,07
28	8,78	0	0,00	0,05
29	9,10	2	0,00	0,04
30	9,41	0	0,00	0,03
31	9,73	0	0,00	0,03
32	10,04	0	0,00	0,02
33	10,35	1	0,00	0,02

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,02	19	31,79	5,14
0,04	92	31,79	114,05
0,05	79	31,79	70,12
0,07	87	31,79	95,90
0,09	69	31,79	43,56
0,11	62	31,79	28,71
0,13	51	31,79	11,61
0,16	31	31,79	0,02
0,18	25	31,79	1,45
0,20	34	31,79	0,15
0,23	25	31,79	1,45
0,25	26	31,79	1,05
0,28	23	31,79	2,43
0,31	13	31,79	11,10
0,34	14	31,79	9,95
0,37	14	31,79	9,95
0,41	19	31,79	5,14
0,44	24	31,79	1,91
0,48	19	31,79	5,14
0,52	24	31,79	1,91
0,57	21	31,79	3,66
0,62	19	31,79	5,14
0,67	23	31,79	2,43
0,73	20	31,79	4,37
0,79	23	31,79	2,43
0,87	14	31,79	9,95
0,96	18	31,79	5,98
1,06	22	31,79	3,01
1,18	21	31,79	3,66
1,34	14	31,79	9,95
1,57	19	31,79	5,14
1,96	21	31,79	3,66
10^307	64	31,79	32,64
		Sum	512,82

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,00	0	31,79	31,79
0,01	0	31,79	31,79
0,02	19	31,79	5,14
0,02	41	31,79	2,67
0,03	51	31,79	11,61
0,04	49	31,79	9,32
0,06	30	31,79	0,10
0,07	50	31,79	10,43
0,08	75	31,79	58,74
0,10	31	31,79	0,02
0,12	62	31,79	28,71
0,14	51	31,79	11,61
0,16	31	31,79	0,02
0,18	38	31,79	1,21
0,21	21	31,79	3,66
0,24	35	31,79	0,32
0,27	25	31,79	1,45
0,30	27	31,79	0,72
0,34	17	31,79	6,88
0,38	19	31,79	5,14
0,43	30	31,79	0,10
0,48	24	31,79	1,91
0,54	34	31,79	0,15
0,61	30	31,79	0,10
0,69	34	31,79	0,15
0,79	28	31,79	0,45
0,90	29	31,79	0,24
1,04	27	31,79	0,72
1,22	26	31,79	1,05
1,46	22	31,79	3,01
1,83	25	31,79	1,45
2,50	19	31,79	5,14
10^307	49	31,79	9,32
		Sum	245,17

Slitter 53 TTR

Number of Break-Downs, n	2014
MTTR	0,94
Standard Deviation	1,22
Highest Value*1.01	15,66
Number of classes, M=2*n^(2/5)	42

wa	0,81
wb	0,80
Chi2 (0.01)	62,43

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,37	987	657,67	840,74
2	0,75	377	442,91	386,01
3	1,12	207	298,28	237,31
4	1,49	107	200,88	156,50
5	1,86	77	135,28	107,22
6	2,24	40	91,10	75,34
7	2,61	31	61,35	53,92
8	2,98	38	41,32	39,14
9	3,35	19	27,83	28,74
10	3,73	18	18,74	21,31
11	4,10	20	12,62	15,93
12	4,47	18	8,50	11,99
13	4,85	6	5,72	9,08
14	5,22	15	3,85	6,92
15	5,59	6	2,60	5,29
16	5,96	9	1,75	4,07
17	6,34	3	1,18	3,14
18	6,71	4	0,79	2,43
19	7,08	6	0,53	1,89
20	7,45	3	0,36	1,48
21	7,83	3	0,24	1,16
22	8,20	2	0,16	0,91
23	8,57	3	0,11	0,71
24	8,95	4	0,07	0,56
25	9,32	1	0,05	0,44
26	9,69	0	0,03	0,35
27	10,06	1	0,02	0,28
28	10,44	2	0,02	0,22
29	10,81	1	0,01	0,18
30	11,18	1	0,01	0,14
31	11,55	0	0,00	0,11
32	11,93	1	0,00	0,09
33	12,30	0	0,00	0,07
34	12,67	1	0,00	0,06
35	13,05	0	0,00	0,05
36	13,4186	0	0,00	0,04
37	13,7913	1	0,00	0,03
38	14,164	0	0,00	0,02
39	14,5368	0	0,00	0,02
40	14,9095	0	0,00	0,02
41	15,2823	1	0,00	0,01
42	15,655	1	0,00	0,01

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,02	8	47,95	33,29
0,05	17	47,95	19,98
0,07	51	47,95	0,19
0,09	128	47,95	133,62
0,12	67	47,95	7,57
0,15	118	47,95	102,32
0,17	112	47,95	85,55
0,20	66	47,95	6,79
0,23	96	47,95	48,14
0,26	78	47,95	18,83
0,29	72	47,95	12,06
0,32	70	47,95	10,14
0,35	49	47,95	0,02
0,38	63	47,95	4,72
0,42	49	47,95	0,02
0,45	71	47,95	11,08
0,49	40	47,95	1,32
0,53	60	47,95	3,03
0,57	36	47,95	2,98
0,61	32	47,95	5,31
0,65	29	47,95	7,49
0,70	24	47,95	11,96
0,75	28	47,95	8,30
0,80	33	47,95	4,66
0,85	40	47,95	1,32
0,91	24	47,95	11,96
0,97	53	47,95	0,53
1,04	27	47,95	9,15
1,11	27	47,95	9,15
1,18	27	47,95	9,15
1,26	28	47,95	8,30
1,35	22	47,95	14,05
1,45	26	47,95	10,05
1,56	22	47,95	14,05
1,69	25	47,95	10,99
1,83	31	47,95	5,99
2,01	18	47,95	18,71
2,22	27	47,95	9,15
2,49	21	47,95	15,15
2,87	41	47,95	1,01
3,52	36	47,95	2,98
10^307	122	47,95	114,34
		Sum	691,08

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	0	47,95	47,95
0,02	4	47,95	40,29
0,03	8	47,95	33,29
0,05	13	47,95	25,48
0,06	51	47,95	0,19
0,08	43	47,95	0,51
0,10	85	47,95	28,62
0,11	67	47,95	7,57
0,14	89	47,95	35,14
0,16	62	47,95	4,12
0,18	109	47,95	77,72
0,21	72	47,95	12,06
0,23	90	47,95	36,87
0,26	70	47,95	10,14
0,29	50	47,95	0,09
0,32	87	47,95	31,80
0,35	52	47,95	0,34
0,39	43	47,95	0,51
0,43	68	47,95	8,38
0,47	71	47,95	11,08
0,51	50	47,95	0,09
0,55	60	47,95	3,03
0,60	39	47,95	1,67
0,66	29	47,95	7,49
0,71	36	47,95	2,98
0,77	38	47,95	2,07
0,84	40	47,95	1,32
0,91	35	47,95	3,50
0,98	54	47,95	0,76
1,07	38	47,95	2,07
1,16	34	47,95	4,06
1,27	36	47,95	2,98
1,39	27	47,95	9,15
1,52	33	47,95	4,66
1,67	32	47,95	5,31
1,86	36	47,95	2,98
2,08	28	47,95	8,30
2,35	24	47,95	11,96
2,72	39	47,95	1,67
3,26	37	47,95	2,50
4,21	45	47,95	0,18
10^307	90	47,95	36,87
		Sum	490,86

Slitter 54 TTR

Number of Break-Downs, n	2362
MTTR	0,58
Standard Deviation	1,04
Highest Value*1.01	20,35
Number of classes, M=2*n^(2/5)	45

wa	0,58
wb	1,00
Chi2 (0.01)	66,21

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,45	1489	1271,82	1327,12
2	0,90	492	587,01	539,69
3	1,36	180	270,93	251,03
4	1,81	80	125,05	121,49
5	2,26	37	57,72	60,19
6	2,71	21	26,64	30,31
7	3,17	18	12,29	15,46
8	3,62	10	5,67	7,96
9	4,07	8	2,62	4,14
10	4,52	3	1,21	2,16
11	4,97	7	0,56	1,14
12	5,43	1	0,26	0,60
13	5,88	3	0,12	0,32
14	6,33	3	0,05	0,17
15	6,78	2	0,03	0,09
16	7,24	1	0,01	0,05
17	7,69	0	0,01	0,03
18	8,14	2	0,00	0,01
19	8,59	0	0,00	0,01
20	9,05	0	0,00	0,00
21	9,50	1	0,00	0,00
22	9,95	1	0,00	0,00
23	10,40	0	0,00	0,00
24	10,85	0	0,00	0,00
25	11,31	1	0,00	0,00
26	11,76	0	0,00	0,00
27	12,21	0	0,00	0,00
28	12,66	0	0,00	0,00
29	13,12	0	0,00	0,00
30	13,57	0	0,00	0,00
31	14,02	0	0,00	0,00
32	14,47	0	0,00	0,00
33	14,92	0	0,00	0,00
34	15,38	1	0,00	0,00
35	15,83	0	0,00	0,00
36	16,28	0	0,00	0,00
37	16,73	0	0,00	0,00
38	17,19	0	0,00	0,00
39	17,64	0	0,00	0,00
40	18,09	0	0,00	0,00
41	18,54	0	0,00	0,00
42	18,99	0	0,00	0,00
43	19,45	0	0,00	0,00
44	19,90	0	0,00	0,00
45	20,35	1	0,00	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	8	52,49	37,71
0,03	14	52,49	28,22
0,04	28	52,49	11,43
0,05	28	52,49	11,43
0,07	43	52,49	1,72
0,08	89	52,49	25,40
0,10	47	52,49	0,57
0,11	117	52,49	79,29
0,13	83	52,49	17,74
0,15	41	52,49	2,51
0,16	97	52,49	37,75
0,18	87	52,49	22,69
0,20	40	52,49	2,97
0,22	75	52,49	9,65
0,24	64	52,49	2,52
0,26	67	52,49	4,01
0,28	66	52,49	3,48
0,30	87	52,49	22,69
0,32	99	52,49	41,21
0,34	58	52,49	0,58
0,37	61	52,49	1,38
0,39	79	52,49	13,39
0,42	39	52,49	3,47
0,45	56	52,49	0,23
0,47	54	52,49	0,04
0,50	68	52,49	4,58
0,54	62	52,49	1,72
0,57	41	52,49	2,51
0,60	44	52,49	1,37
0,64	40	52,49	2,97
0,68	37	52,49	4,57
0,73	36	52,49	5,18
0,77	37	52,49	4,57
0,82	34	52,49	6,51
0,88	32	52,49	8,00
0,94	43	52,49	1,72
1,01	43	52,49	1,72
1,09	37	52,49	4,57
1,18	30	52,49	9,64
1,29	32	52,49	8,00
1,42	31	52,49	8,80
1,58	34	52,49	6,51
1,82	34	52,49	6,51
2,23	36	52,49	5,18
10^307	84	52,49	18,92
		Sum	458,51

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	0	52,49	37,71
0,02	8	52,49	28,22
0,03	26	52,49	11,43
0,04	16	52,49	11,43
0,05	28	52,49	1,72
0,07	43	52,49	25,40
0,08	89	52,49	0,57
0,09	47	52,49	79,29
0,11	49	52,49	17,74
0,12	108	52,49	2,51
0,14	43	52,49	37,75
0,16	80	52,49	22,69
0,17	101	52,49	2,97
0,19	84	52,49	9,65
0,21	44	52,49	2,52
0,23	63	52,49	4,01
0,25	64	52,49	3,48
0,27	65	52,49	22,69
0,29	123	52,49	41,21
0,31	69	52,49	0,58
0,34	57	52,49	1,38
0,36	92	52,49	13,39
0,39	51	52,49	3,47
0,41	67	52,49	0,23
0,44	56	52,49	0,04
0,47	54	52,49	4,58
0,51	68	52,49	1,72
0,54	75	52,49	2,51
0,58	35	52,49	1,37
0,62	44	52,49	2,97
0,66	40	52,49	4,57
0,70	50	52,49	5,18
0,75	38	52,49	4,57
0,81	38	52,49	6,51
0,87	35	52,49	8,00
0,93	46	52,49	1,72
1,01	41	52,49	1,72
1,09	47	52,49	4,57
1,19	36	52,49	9,64
1,31	26	52,49	8,00
1,45	34	52,49	8,80
1,64	41	52,49	6,51
1,91	32	52,49	6,51
2,38	32	52,49	5,18
10^307	77	52,49	18,92
		Sum	458,51

Slitter 55 TTR

Number of Break-Downs, n	348
MTTR	1,62
Standard Deviation	1,35
Highest Value*1.01	20,21
Number of classes, M=2*n^(2/5)	21

wa	1,42
wb	0,81
Chi2 (0.01)	34,81

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,96	196	155,58	180,08
2	1,92	64	86,02	70,96
3	2,89	29	47,57	37,98
4	3,85	17	26,30	21,97
5	4,81	22	14,54	13,27
6	5,77	5	8,04	8,26
7	6,74	5	4,45	5,25
8	7,70	3	2,46	3,39
9	8,66	0	1,36	2,22
10	9,62	1	0,75	1,48
11	10,59	0	0,42	0,99
12	11,55	1	0,23	0,67
13	12,51	1	0,13	0,45
14	13,47	0	0,07	0,31
15	14,44	0	0,04	0,21
16	15,40	0	0,02	0,15
17	16,36	1	0,01	0,10
18	17,32	1	0,01	0,07
19	18,29	0	0,00	0,05
20	19,25	0	0,00	0,04
21	20,21	2	0,00	0,03

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,08	15	16,57	0,15
0,16	27	16,57	6,56
0,25	25	16,57	4,29
0,34	27	16,57	6,56
0,44	22	16,57	1,78
0,55	30	16,57	10,88
0,66	12	16,57	1,26
0,78	17	16,57	0,01
0,91	15	16,57	0,15
1,05	14	16,57	0,40
1,21	14	16,57	0,40
1,38	17	16,57	0,01
1,57	10	16,57	2,61
1,78	9	16,57	3,46
2,03	11	16,57	1,87
2,33	11	16,57	1,87
2,69	8	16,57	4,43
3,16	11	16,57	1,87
3,82	11	16,57	1,87
4,95	24	16,57	3,33
10^307	18	16,57	0,12
		Sum	53,90

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,03	7	16,57	5,53
0,08	11	16,57	1,87
0,14	20	16,57	0,71
0,21	18	16,57	0,12
0,29	17	16,57	0,01
0,37	26	16,57	5,36
0,47	21	16,57	1,18
0,57	31	16,57	12,56
0,69	15	16,57	0,15
0,83	15	16,57	0,15
0,98	19	16,57	0,36
1,16	13	16,57	0,77
1,36	20	16,57	0,71
1,60	16	16,57	0,02
1,88	8	16,57	4,43
2,22	17	16,57	0,01
2,65	8	16,57	4,43
3,23	14	16,57	0,40
4,08	16	16,57	0,02
5,62	21	16,57	1,18
10^307	15	16,57	0,15
		Sum	40,14

Slitter 58 TTR

Number of Break-Downs, n	2208
MTTR	0,72
Standard Deviation	1,11
Highest Value*1.01	14,92
Number of classes, M=2*n^(2/5)	44

wa	0,72
wb	1,00
Chi2 (0.01)	64,95

Diagram

Class	Interval	Oi	Exponential Ei	Weibull Ei
1	0,34	1058	830,65	946,33
2	0,68	527	518,16	468,87
3	1,02	227	323,23	279,36
4	1,36	110	201,63	174,71
5	1,70	86	125,78	112,28
6	2,03	45	78,46	73,50
7	2,37	32	48,94	48,78
8	2,71	16	30,53	32,73
9	3,05	15	19,04	22,15
10	3,39	13	11,88	15,10
11	3,73	12	7,41	10,37
12	4,07	9	4,62	7,15
13	4,41	10	2,88	4,96
14	4,75	5	1,80	3,46
15	5,09	6	1,12	2,42
16	5,42	4	0,70	1,70
17	5,76	6	0,44	1,20
18	6,10	4	0,27	0,84
19	6,44	2	0,17	0,60
20	6,78	3	0,11	0,43
21	7,12	5	0,07	0,30
22	7,46	6	0,04	0,22
23	7,80	3	0,03	0,15
24	8,14	2	0,02	0,11
25	8,48	1	0,01	0,08
26	8,82	0	0,01	0,06
27	9,15	0	0,00	0,04
28	9,49	0	0,00	0,03
29	9,83	0	0,00	0,02
30	10,17	0	0,00	0,02
31	10,51	0	0,00	0,01
32	10,85	0	0,00	0,01
33	11,19	0	0,00	0,01
34	11,53	0	0,00	0,00
35	11,87	0	0,00	0,00
36	12,21	0	0,00	0,00
37	12,54	0	0,00	0,00
38	12,88	0	0,00	0,00
39	13,22	0	0,00	0,00
40	13,56	0	0,00	0,00
41	13,90	0	0,00	0,00
42	14,24	0	0,00	0,00
43	14,58	0	0,00	0,00
44	14,92	1	0,00	0,00

Exponential Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,02	1	50,18	48,20
0,03	34	50,18	5,22
0,05	44	50,18	0,76
0,07	28	50,18	9,81
0,09	69	50,18	7,06
0,11	79	50,18	16,55
0,12	88	50,18	28,50
0,14	76	50,18	13,28
0,16	84	50,18	22,79
0,19	72	50,18	9,49
0,21	93	50,18	36,54
0,23	65	50,18	4,38
0,25	96	50,18	41,83
0,28	62	50,18	2,78
0,30	58	50,18	1,22
0,32	75	50,18	12,27
0,35	81	50,18	18,93
0,38	42	50,18	1,33
0,41	63	50,18	3,27
0,44	68	50,18	6,33
0,47	53	50,18	0,16
0,50	42	50,18	1,33
0,53	58	50,18	1,22
0,57	37	50,18	3,46
0,60	61	50,18	2,33
0,64	34	50,18	5,22
0,68	25	50,18	12,64
0,73	31	50,18	7,33
0,77	38	50,18	2,96
0,82	32	50,18	6,59
0,88	37	50,18	3,46
0,93	40	50,18	2,07
1,00	39	50,18	2,49
1,06	29	50,18	8,94
1,14	28	50,18	9,81
1,22	30	50,18	8,12
1,32	26	50,18	11,65
1,43	25	50,18	12,64
1,56	38	50,18	2,96
1,72	32	50,18	6,59
1,93	29	50,18	8,94
2,22	34	50,18	5,22
2,72	25	50,18	12,64
10^307	107	50,18	9,81
		Sum	439,09

Weibull Chi-square

Interval	Oi	Ei	(Ei-Oi)^2/Ei
0,01	0	50,18	48,20
0,02	1	50,18	5,22
0,03	34	50,18	0,76
0,04	17	50,18	9,81
0,06	27	50,18	7,06
0,07	56	50,18	16,55
0,09	41	50,18	28,50
0,10	79	50,18	13,28
0,12	88	50,18	22,79
0,14	42	50,18	9,49
0,16	72	50,18	36,54
0,18	79	50,18	4,38
0,20	86	50,18	41,83
0,22	84	50,18	2,78
0,24	87	50,18	1,22
0,27	66	50,18	12,27
0,29	56	50,18	18,93
0,32	83	50,18	1,33
0,34	86	50,18	3,27
0,37	63	50,18	6,33
0,40	63	50,18	0,16
0,43	68	50,18	1,33
0,47	53	50,18	1,22
0,50	65	50,18	3,46
0,54	35	50,18	2,33
0,58	66	50,18	5,22
0,62	48	50,18	12,64
0,67	31	50,18	7,33
0,72	36	50,18	2,96
0,77	45	50,18	6,59
0,83	32	50,18	3,46
0,89	53	50,18	2,07
0,96	39	50,18	2,49
1,04	38	50,18	8,94
1,12	34	50,18	9,81
1,22	33	50,18	8,12
1,33	32	50,18	11,65
1,45	35	50,18	12,64
1,61	34	50,18	2,96
1,80	43	50,18	6,59
2,05	24	50,18	8,94
2,41	32	50,18	5,22
3,03	29	50,18	12,64
10^307	93	50,18	9,81
		Sum	439,09

Appendix I

The comparison between the exponential and the Weibull distribution is made by a T-test and an F-test for each machine. The T-test is made to determine whether two samples are likely to have come from populations that have the same mean. The F-test gives probability that the variances of the two samples are not significantly different. The P-values show on what significance level the null hypothesis can't be discarded at. If the number is greater than 0,05 there is reason to believe that the two samples have the same mean value and variance. The number of observations, that is runs, is in all cases 100. The tests are made in Excel.

Machine 10	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	116,02	117,18
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,37	

F-test	*Variable 1*	*Variable 2*
Variance	69,88	91,46
Observations	100	100
P(F<=f) one-tail	0,09	

Machine 12	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	156,43	156,68
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,82	

F-test	*Variable 1*	*Variable 2*
Variance	75,96	53,68
Observations	100	100
P(F<=f) one-tail	0,05	

Machine 16	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	176,50	174,90
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,14	

F-test	*Variable 1*	*Variable 2*
Variance	54,61	55,63
Observations	100	100
P(F<=f) one-tail	0,46	

Machine 21	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	174,84	175,119
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,82	

F-test	*Variable 1*	*Variable 2*
Variance	68,09	87,74
Observations	100	100
P(F<=f) one-tail	0,10	

Machine 22	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	252,514	251,87
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,65	

F-test	*Variable 1*	*Variable 2*
Variance	96,69	101,33
Observations	100	100
P(F<=f) one-tail	0,41	

Machine 53	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	143,18	145,08
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,06	

F-test	*Variable 1*	*Variable 2*
Variance	50,73	68,79
Observations	100	100
P(F<=f) one-tail	0,07	

Machine 54	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	136,05	136,09
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,96	

F-test	*Variable 1*	*Variable 2*
Variance	33,95	36,32
Observations	100	100
P(F<=f) one-tail	0,37	

Machine 55	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	11,54	11,32
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,46	

F-test	*Variable 1*	*Variable 2*
Variance	3,74	3,75
Observations	100	100
P(F<=f) one-tail	0,49	

Machine 58	**Exp**	**Wei**
T-test	*Variable 1*	*Variable 2*
Mean	195,14	195,34
Observations	100	100
Hypothesized Mean Difference	0	
P(T<=t) two-tail	0,85	

F-test	*Variable 1*	*Variable 2*
Variance	38,48	57,30
Observations	100	100
P(F<=f) one-tail	0,05	

Appendix J

Introduction

This is a user manual for a simulation program made by Dan Lennartsson and Peter Månsson. The program was made in 2004 as a master thesis at Lund Institute of Technology. The program is designed to facilitate the order planning process at TPPM in Lund.

The program gives forecasts for the lead times of the planned orders, and the capacity utilization for the different machines. For further information about the program read the report *A Simulation Program for Forecasts of Production at Tetra Pak Packaging Material AB in Lund*.

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1. SAVING DATA FROM PROPLANNER

Order Number	Order Due Date	Planned Start Time	Quality	Size	Variant	Machine Name	Planned Run Length
458352	2003-11-06	2003-11-05 01:44	7042	810	28	53 Kampf	20 705
452650	2003-11-07	2003-11-05 03:59	6200	812	8	53 Kampf	15 768
0457917-C	2003-11-05	2003-11-05 05:29	6296	810	38	53 Kampf	50 500
457918	457918		6296	810	38		
0457795-C	2003-11-10	2003-11-05 10:20	6277	810	38	53 Kampf	25 250
457796	457796		6277	810	38		
0458292-C	2003-11-12	2003-11-05 12:45	6201	810	38	53 Kampf	25 250
458293	458293		6201	810	38		
0458023-C	2003-11-06	2003-11-05 13:52	6296	813	61	54 IMS	38 957
458024	458024		6296	813	61		
458026	458026		6296	813	61		
458027	458027		6296	813	61		
458031	458031		6296	813	61		
0458368-C	2003-11-11	2003-11-05 15:10	6296	810	38	53 Kampf	25 250
458367	458367		6296	810	38		
458369	458369		6296	810	38		
458370	458370		6296	810	38		
0458045-C	2003-11-07	2003-11-05 16:29	6296	813	61	54 IMS	27 826
458046	458046		6296	813	61		
458048	458048		6296	813	61		
458050	458050		6296	813	61		
458054	458054		6296	813	61		
0458013-C	2003-11-07	2003-11-05 17:36	6250	810	38	53 Kampf	10 100
458011	458011		6250	810	38		
0458297-C	2003-11-06	2003-11-05 18:21	6296	813	61	54 IMS	32 000
458296	458296		6296	813	61		
458298	458298		6296	813	61		
458157	2003-11-07	2003-11-05 18:34	6250	810	38	53 Kampf	25 250
0457656-C	2003-11-07	2003-11-05 18:35	6539	835	61	58 IMS	85 025
457658	457658		6539	835	61		
457151	2003-11-06	2003-11-05 20:30	7017	813	61	54 IMS	8 348
458899	2003-11-07	2003-11-05 20:59	7018	810	38	53 Kampf	5 050
0457924-S2	2003-11-06	2003-11-05 21:03	6295	813	51	54 IMS	27 826
0458014-S2	2003-11-06	2003-11-05 22:55	6295	813	51	54 IMS	38 957
457472	2003-11-10	2003-11-05 23:31	5263	130	1	55 Kampf	11 512
0457651-C-S1	2003-11-10	2003-11-06 00:18	6539	835	51	58 IMS	42 513
457652	457652		6539	835	51		
457653	457653		6539	835	51		
457654	457654		6539	835	51		
0458047-C	2003-11-07	2003-11-06 01:32	6296	813	61	54 IMS	27 826

1. To execute the simulation the program needs the following parameters from ProPlanner: *Order number*, *Order due date*, *Planned start time*, *Quality, Size*, *Variant*, *Machine name* and *Planned run length*. The parameters should be placed in the order they were mentioned. This process is needed for all the three machine groups individually. Only orders with planned start times during the period the simulation will last, should be included.

2. Save the files as c:/printing.xls, c:/laminating.xls and c:/slitting.xls.

2. INPUT START TIMES

5 4 1 6 2 3 7

Year-Month-Day (YYYY-MM-DD)	Number of Simulations
2003-11-05	37

Start Time	Day	Hour	Min
	2	10	0

Time until Start Machine	Hour	Min	Weeks
10	3		2
12	2	20	2
16			2
21		45	2
22	2	15	2
53	1		2
54	3	20	2
55		30	2
58	1	45	2

Day Code						
Sun	Mon	Tue	Wed	Thu	Fri	Sat
0	1	2	3	4	5	6
7	8	9	10	11	12	13
7	8	9	10	11	12	13
14	15	16	17	18	19	20
14	15	16	17	18	19	20
21	22	23	24	25	26	27
21	22	23	24	25	26	27
28	29	30	31	32	33	34

10 Weekend Time	Day	Hour	Min
1st Weekend Start	5	18	
1st Weekend End	7	22	
2nd Weekend Start	12	22	
2nd Weekend End	14	22	
3rd Weekend Start	19	14	
3rd Weekend End	21	22	
4th Weekend Start	26	14	
4th Weekend End	28	22	

55 Week Time	Hour	Min
1st Week Day Start	7	
1st Week Day End	15	36
2nd Week Day Start	7	
2nd Week Day End	15	36
3rd Week Day Start	7	
3rd Week Day End	15	36
4th Week Day Start	7	
4th Week Day End	15	36

1. Write the date of the beginning of the simulation.

2. Write the number of runs you want to do. The number must be between 1 and 100. If you write a big number, the simulation will take more time, but the output gets more reliable.

3. This is a day code for boxes 4 and 7.

4. Write the start time for the machine that will start first in the simulation. Day 2, Hour 10 means for example that the simulation will start at 10 o'clock on Tuesday.

5. Write how long time the other machines will wait after the first one has started. Machine 12, for example, will start 2 hours and 20 minutes after the first machine. This means it will start Tuesday at 12.20.

6. Write how many weeks the capacity utilization shall be based on. The number of weeks must be an integer number between 1 and 4, but can be different for different machines.

7. Write the weekend time, where the machine is not used, in this box. There is one box for each machine. For machine 55, write the manned hours Monday-Friday instead of the weekend time.

3. INPUT PLANNED STOPS

1 2

Machine	Stop number 1						Stop number 2					
	Stop Start			Stop Length			Stop Start			Stop Length		
	Date	Hour	Min	Days	Hour	Min	Date	Hour	Min	Days	Hour	Min
10	2003-11-06	12	30		5							
12												
16												
21	2003-11-07	8		1	10		2003-11-13	16	30		4	30
22												
53												
54	2003-11-06	10			5	45						
55												
58	2003-11-08	15			2							

1. Write the date and time for the beginning of the first planned stop in the *Stop Start* column, and how long the machine will be down in the *Stop Length* column.

2. Write the date and time for the beginning of the second planned stop in the *Stop Start* column, and how long the machine will be down in the *Stop Length* column. The number of stops for each machine is limited to 7.

4. INPUT FREQUENCY OF STOPS

5 1 4 3 2

Machine	Set Up (hr)	MTBF (hr)	MTTR (hr)	Stops (%)
10	1,00	3,04	0,48	14%
12	0,86	3,04	0,48	14%
16	0,71	2,72	0,43	14%
21	0,88	3,82	0,56	13%
22	0,82	3,55	0,52	13%
53	0,88	8,37	0,94	10%
54	0,60	5,16	0,58	10%
55	0,73	4,27	0,48	10%
58	0,49	6,41	0,72	10%

Default values

Machine	Set Up (hr)	MTBF (hr)	MTTR (hr)	Stops (%)
10	1,00	3,04	0,48	14%
12	0,86	3,04	0,48	14%
16	0,71	2,72	0,43	14%
21	0,88	3,82	0,56	13%
22	0,82	3,55	0,52	13%
53	0,88	8,37	0,94	10%
54	0,60	5,16	0,58	10%
55	0,73	4,27	0,48	10%
58	0,49	6,41	0,72	10%

1. Write the average Set up time for each machine.

2. Write how many percent of the running time the machine in average is down due to unplanned stops.

3. Write the MTTR (Mean Time To Repair), which is the average time a machine is down during an unplanned stop, for each machine.

4. MTBF (Mean Time Between Failure) is automatically calculated from *MTTR* and *Stops (%)* so you don't have to write anything in this column.

5. The Default values are the average times that were brought forth from the analysis made during the creation of this simulation program. These values can be used as long as no drastic changes occur or as long as no further analyses have been made.

5. INPUT SPEEDS

5 1 2 3 4

Quality-Size	Run speed print	Run speed laminate	Run speed slit
If Missing	**21000**	**24000**	**16000**
2441-137		20 400	
2459-325		20 400	
2463-325		20 400	
5202-130	18 700	23 400	4 000
5202-461	18 700	23 400	10 000
5263-120	18 700	23 400	4 000
5263-130	18 700	23 400	4 000
5263-461	18 700	23 400	10 000
5304-461	18 700	23 400	10 000
5407-130	18 700	23 400	4 000
5440-130	18 700	23 400	4 000
5440-461	18 700	23 400	10 000
5442-580	18 700	23 400	10 000
5443-580	18 700	23 400	10 000
5468-130	18 700	23 400	4 000
6042-460	21 000	24 000	16 000
6042-560	21 000	24 000	16 000
6042-701	21 000	24 000	16 000
6044-560	21 000	24 000	16 000
6044-810	21 000	24 000	16 000
6048-810	23 000	24 000	16 000
6064-701	21 000	24 000	16 000
6065-701	21 000	24 000	16 000
6075-836	21 000	24 000	16 000
6100-460	23 000	24 000	16 000
6100-560	23 000	24 000	16 000
6100-580	23 000	24 000	16 000
6100-705	23 000	24 000	16 000
6104-810	23 000	24 000	16 000
6114-810	23 000	24 000	16 000
6114-812	23 000	24 000	16 000
6131-701	23 000	24 000	16 000

1. Write the different Quality-Size numbers for the products.

2. Write the Run speed (m/hr) for the print machines for the specific Quality-Size.

3. Write the Run speed (m/hr) for the laminate machines for the specific Quality-Size.

4. Write the Run speed (m/hr) for the slit machines for the specific Quality-Size.

5. Write the Run speeds that should be used if there's an order that doesn't match with the Run speeds in this table.

6. OUTPUT LEAD TIME

1	2	3	4	5	6
Order nr	Lead Time Min	Lead Time Max	Due Date	Difference Min	Difference Max
458352	2,3	7,7	2003-11-06	13,3	18,7
452650	3,4	9,9	2003-11-07	35,1	41,6
0457917-C	7,2	15,8	2003-11-05	-18,8	-10,2
0457795-C	9,5	18,1	2003-11-10	98,9	107,5
0458292-C	11,7	21,9	2003-11-12	143,1	153,3
0458023-C	6,1	11,5	2003-11-06	9,5	14,9
0458368-C	13,6	25,3	2003-11-11	115,7	127,4
0458045-C	7,9	14,3	2003-11-07	30,7	37,1
0458013-C	14,9	48,1	2003-11-07	-3,1	30,1
0458297-C	10,1	17,8	2003-11-06	3,2	10,9
458157	16,6	50,6	2003-11-07	-5,6	28,4
0457656-C	17,4	29,2	2003-11-07	15,8	27,6
457151	11,3	19,1	2003-11-06	1,9	9,7
458899	17,0	51,5	2003-11-07	-6,5	28,0
0457924-S	13,5	20,9	2003-11-06	0,1	7,5
0458014-S	16,6	23,8	2003-11-06	-2,8	4,4
457472	1,3	5,0	2003-11-10	112,0	115,7
0457651-C-S	20,1	32,5	2003-11-10	84,5	96,9
0458047-C	18,6	26,8	2003-11-07	18,2	26,4
0458388-C	26,6	40,3	2003-11-11	100,7	114,4
458016	22,5	29,9	2003-11-07	15,1	22,5
457473	27,2	35,1	2003-11-10	-14,1	-6,2
0457920-C	33,3	59,3	2003-11-06	81,7	107,7
0458411-C	33,6	42,9	2003-11-11	-69,9	-60,6
457661	33,1	46,0	2003-11-04	95,0	107,9
0458390-C	40,7	50,8	2003-11-11	-77,8	-67,7
457660	56,1	68,0	2003-11-04	97,0	108,9
0458511-C	41,2	56,4	2003-11-12	156,6	171,8
0458155-C	44,4	55,9	2003-11-14	133,1	144,6
458616	46,0	155,6	2003-11-13	9,4	119,0
458295	50,9	168,6	2003-11-12	-51,6	66,1
457197	47,2	156,2	2003-11-10	19,8	128,8
458497	66,6	205,3	2003-11-12	20,9	159,7

1. Here you see the specific orders as they are planned in ProPlanner.

2. Here you see the *shortest* lead time of the simulations that have been run. The lead time is shown in hours.

3. Here you see the *longest* lead time of the simulations that have been run. The lead time is shown in hours.

4. Here the Due date of the order is shown.

5. Here you see the "worst case" of the simulations. The number shows how many hours before or after due date the order was finished in the simulation. If the number is negative, it's shown in red.

6. Here you see the "best case" of the simulations. The number shows how many hours before or after due date the order was finished in the simulation. If the number is negative, it's shown in red.

7. OUTPUT CAPACITY

	4	5	2	3	1
Machine	**"Best Case"**	**"Worst Case"**	**Min Time (hr)**	**Max Time (hr)**	**Available Time (hr)**
10	94%	100%	312	332	333
12	90%	98%	303	330	336
16	86%	95%	211	233	245
21	85%	86%	206	208	242
22	107%	115%	261	280	244
53	60%	65%	147	158	244
54	81%	90%	206	229	253
55	29%	44%	25	38	86
58	109%	119%	136	148	124

1. Here you see the available time in hours for the machines during the number of weeks the utilization is based on. The times for weekends and planned stops are subtracted.

2. Here you see the “best case” of the simulations. The time is in hours and shows how long it took for the machines to finish all the orders.

3. Here you see the “worst case” of the simulations. The time is in hours and shows how long it took for the machines to finish all the orders.

4. Here you see the capacity utilization for the “best case”. If the number is less than 100 % the machine finished all the orders within the number of weeks the utilization is based on. If it’s more than 100 % the machine didn’t make it.

5. Here you see the capacity utilization for the “worst case”. If the number is less than 100 % the machine finished all the orders within the number of weeks the utilization is based on. If it’s more than 100 % the machine didn’t make it.

Appendix K

Vocabulary

In this report some abbreviations are used. These are explained on this side.

TT Set Up
Time To Set Up. This is the time it takes to prepare a machine for an order.

MTT Set Up
Mean Time To Set Up. The average time it takes to do the Set Up.

TTR
Time To Repair. When a machine is down, this is the time it takes to bring it up again.

MTTR
Mean Time To Repair. The average time a machine is down.

TBF
Time Between Failures. The time a machine is running before a stop.

MTBF
The average time a machine is running before a stop.

Oi
Oi represent the observed values in a study.

Ei
Ei represent the expected values for a certain theory.