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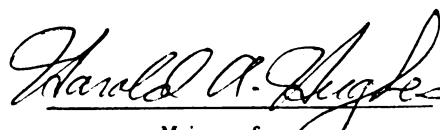
SIMULATION OF A DAIRY PLANT PACKAGING

presented by

JAEMIN CHOI

has been accepted towards fulfillment
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SIMULATION OF A DAIRY PLANT PACKAGING LINE

By

Jaemin Choi

A THESIS

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ABSTRACT

SIMULATION OF A DAIRY PLANT PACKAGING LINE

By

Jaemin Choi

Simulation is a powerful problem-solving technique. The optimization process for a packaging line often can not be solved by an analytical method. The proper selection of optimization method will result in higher productivity of the packaging line. A simulation model for increasing the productivity of dairy plant packaging lines was developed based on statistical analysis, using the simulation software "Taylor II". The computer simulation model was run for a variety of system parameters and was found to accurately predict the performance of the system.

There has been no implementation of the simulation to date. However, for limiting cases, the simulation model of the current line agreed very well with actual performance.

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INTRODUCTION

There are several useful tools that are finding increasing application for improving packaging line efficiency. Among them, simulation, which addresses the dynamic interactions of line components and measures overall system efficiency and control stability, is the most useful.

A packaging line simulation study consists of four basic steps: building a model of a packaging line, simulating the model, analyzing the simulation results, and making recommendations.

Building a packaging line model involves describing the line machinery and the logic of its operations. Collection and interpreting data are critical steps in the process of making a useful and accurate simulation model.

Simulation does not necessarily provide accurate answers. However, the technique does allow a simulation practitioner (and a client) to develop and test various approaches to a problem and to quantify the efficiency gains for each.

Packaging lines can be evaluated under varying conditions and operating characteristics without actually modifying the lines or building them if they do not exist. Another advantage of simulation modeling is that it forces the user to gain a full understanding of the process. Valuable insights can be gained even before the model is built. In this study, a simulation model of a dairy plant was built based on the data from real dairy plant¹ in southeast Michigan and evaluated by using the discrete simulation software "Taylor II".

¹ Specific plant not identified at request of management

The overall goal for this study was to find the “best possible” solution to increase the productivity of current system.

The specific objectives of this research were:

- 1. To collect and analyze data for the simulation study**
- 2. To develop a model to identify bottlenecks in the system**
- 3. To provide alternative solutions to increase production rate**
- 4. To provide answers to ‘what if’ questions such as ‘what if one more filling machine is added into the system’, ‘what if the repair time of the blowmolding machines is reduced’, etc.**

CHAPTER 1

LITERATURE REVIEW

1.1. COMPUTER SIMULATION OF A MANUFACTURING/PACKAGING LINE

1.1.1. Definition

Simulation is the process of designing a model of a real system and conducting experiments with the model for the purpose of obtaining a better understanding of the behavior of the system or of evaluating various strategies and alternatives for the operation of the system (Shannon 1975). In other words, simulation is an experimental technique and an applied methodology which seeks to describe and to understand the behavior of systems, to construct theories or hypotheses that account for the observed behavior, and to use these theories to predict future behavior or the effect produced by changes in the operational input set (Pidd 1984; F&H Simulations, 1995).

Simulation is a tool used within a problem-solving process. Problem solving processes are numerous and evolving. Examples include designing a new packaging line, choosing a right sized buffer, right sizing and many other popular processes. Often there is no pre-configured problem solving process, but simulation is a tool which can process the decision making criteria in a timely and cost efficient manner. Simulation may not provide all of the answers. It is a tool to help understand the system under study (Mott, 1996).

Many manufacturing/packaging systems are good examples of "collections of interdependent elements portraying random but statistically

predictable behavior.” These systems are often of such size and complexity that traditional design techniques are inadequate to guarantee that the resulting design will have the desired cost and performance attributes. Simulation of a proposed system design or designs can be thought of as a foretelling technique that lets a system be tested before it has been built. Also when using simulation, one can make mistakes and correct them ahead of time in a relatively easy and inexpensive way. Over the years, simulation has become a technique of high practicality. Many studies show it is one of the most effective tools which can be used to help solve problems (Sahnnon et al 1980; Ledbetter and Fox 1977; Cook and Russell 1976).

The actual process of simulation is simple and straightforward. A model of the system's operations is built on a personal computer or main-frame computer. Once built, the simulation model serves as a tool in which proposed changes to that system can be tested and studied. To give structure to this model building process, a general purpose simulation language or manufacturing oriented simulation package is usually used (Banks 1996). Examples of these languages include SIMSCRIPT II, GPSS, SLAM II, AWESIM and MAP/1. Examples of the software packages include TaylorII, Witness, Arena, Promodel and BPSimulator.

1.1.2. Classification

Simulation is classified according to the type of system under study. Hence, simulation can be either continuous or discrete. If all changes in the state of a system occur at specific points in time, the system is of the discrete event

type. For example, a unit of work-in-process arrives at a machine. When all changes in system state occur continuously over time the system is of the continuous type. For example, the level of oil in a storage tank rises continuously as oil is pumped into the tank.

Hybrid systems involve both discrete and continuous changes in system state. Continuous changes in system state can often be represented by a series of discrete approximations. Discrete-event techniques have been highly successful in modeling a large number of systems (Law 1986).

Simulation is classified as either static or dynamic depending on whether or not the model variables change over time. The checkout system in a retail store is an example of a dynamic system. The number of customers in the queue changes as new ones arrive and others complete the checkout process. All queuing models are considered to be dynamic models. A financial model in a spreadsheet is generally a static model. One changes a variable, for example the tax percentage, and studies the effect on the net profit. In such a model, time has no influence on the result. A static simulation model is called a Monte Carlo simulation. (F&H Simulations 1995; Law 1986; Hoover and Perry 1989)

1.1.3. Advantages and disadvantages of simulation

The general benefit of simulation is that it allows a simulation practitioner to obtain a system wide view of the effect of changes on the system, whether it exists or not. For example the effect of adding an additional accumulator to a work station may be predicted by using simple queuing theory. However, the

technique probably is not robust enough to determine the effect the change will have on the entire system. Increasing the throughput at one workstation might cause bottlenecks to develop at one or more other workstations. Specific benefits of simulation in manufacturing are increased throughput, reduced in-process inventories, improved utilization of machines and workers, increased on-time deliveries and reduced capital requirements (Law 1986; Filmer 1994).

The simulation yields information on machine utilization, bottlenecks, throughput and queue sizes along with the effects of unplanned occurrences, such as machine breakdowns. A simulation model may be used to perform experiments. A proposed system can be evaluated before actually implementing it into a real system. Also an existing system can be “experimented on” without disturbing it (Law 1986).

On the negative side, simulation is, innately, an imperfect technique. Simulation produces statistical estimates, rather than exact results. Simulation is not an optimization technique. It involves only a comparison of alternatives, as contrasted with identification of the optimal design. Models tend to become unwieldy, involving many combinations of independent variables. Simulation may be costly, requiring trained simulation model specialists. And, the building of models is only part of a simulation project. Long modeling lead times can be involved. The gathering of system details, collection and estimation of data, building the computer model, verifying, and validating the model, and drawing appropriate inferences from simulation runs, can consume months of time. Large amounts of computer time may be needed even though the introduction of high

capacity computer hardware has shortened the simulation runtime. However new manufacturing-oriented simulation languages and software systems are on the market and their capabilities are improving. Software includes modeling languages and includes other tools needed for a balanced simulation study, e.g., preparation of input data; graphical support for describing system layouts; statistical analysis of output; data presentation. Personal computers have contributed to reducing the cost of computing and shortened modeling lead times by putting the computing resource under the control of the simulation practitioner (Law 1986; Filmer 1994; Musselman 1984).

1.1.4. Requirements of simulation software

Software is of considerable importance in simulation and the following requirements should be met.

- 1. Must be flexible enough to model the most common characteristics of a manufacturing system line without the need of a simulation language expert.**
- 2. Must automatically generate detailed simulation output reports with the statistics required to make design decisions.**

The software should support the use of computer graphics to produce animated, screen-based displays of the movement of entities through the simulated system to make verification and presentation easy. Among its several advantages, simulation animation greatly enhances communication between the simulation model builder and second parties responsible for the system being simulated, for example, manufacturing engineers, managers, clients, etc.

Animation may help the simulation practitioners establish credibility for themselves in the eyes of the second parties. The second parties can become more involved in the modeling process, can more easily judge whether the model simulates reality properly, and can more easily suggest modifications which might be made in the system design to improve system performance (Swientek 1993; Carson 1986). Another advantage of watching the animated simulated system at work is that this may trigger creative ideas about how the system might be modified to improve system performance. However, simulation animation is not a substitute for rigorous model verification, model validation, and statistical analysis of simulation output.

1.2. SETTING UP A SIMULATION STUDY

It has been proposed that there are six steps in a typical simulation study (Martha 1996; Law 1986; Hoover and Perry 1989). These are listed below.

Commentary on various aspects of these elements follows throughout the rest of this study.

- 1. Formulate problem and plan the study**
- 2. Data collection and analysis**
- 3. Model building**
- 4. Model verification and validation**
- 5. Experiments and output analysis**
- 6. Documentation, presentation, and implementation of results**

A simulation study usually starts when there is a problem with an existing system, when it is not possible to experiment with an existing system, or when a system is under design, that is, the system does not exist yet. After clearly understanding and evaluating management needs and expectations, the simulation practitioner should determine whether or not simulation is a proper tool for the analysis of the system under observation. In some instances, an analytical technique may provide a solution (F&H Simulations 1995).

If simulation modeling is the right technique, the practitioner should begin by stating objectives clearly and describing the system to be studied.

1.2.1. FORMULATE PROBLEM AND PLAN THE STUDY

Problem formulation can have a significant impact on the ultimate success of the analysis and the implement of the results. Appropriate solutions to inappropriately formulated problems can not be achieved (Urban 1974). In this stage, the simulation practitioner definitively states the study's overall objectives, how much detail should be included in the system and the specific issues to be addressed based on preliminary data from the client, since the client or manager may not know precisely. Also, the system configurations to be studied are described. At this stage the modeler should decide whether to use a general purpose language (C++, FORTRAN, BASIC), a simulation specific language (SIMSCRIPT II, GPSS, SLAM II, Arena, or MAP/1), or a manufacturing oriented simulation package (TaylorII, Witness, HighSpeedSim, Promodel, or BPSimulator). Manufacturing oriented simulation software usually has convenient

features like statistical distribution tools, data analysis tools and pre-configured model entities (Banks 1996). Project goals should be set at this stage and checks should be made to be sure that all agendas are understood completely by all of the parties involved. (Law 1997)

1.2.2. DATA COLLECTION AND ANALYSIS

During this step, the bulk of the data is collected, reduced, and analyzed to make the model more explicit. Information on the system layout, operating procedures and routing is collected. Information should be acquired from multiple sources. No single person or document is sufficient. Some people may provide inaccurate information so true subsystem “experts” must be identified.

Data are collected to specify model parameters and input probability distributions. Examples of the types of needed data are arrival times, processing times, expected time between failures of machines, repair times, travel times, and setup times (F&H Simulations 1995).

Data can be collected in many ways. Typical sources of data are (Carson 1986);

(1) If the system exists, properly designed **time studies** usually provide the most accurate data.

(2) **Historical records** from earlier studies can be obtained from digital forms or the production and downtime reports. Information from these sources should be used carefully, because historical records are usually not designed to be used for time studies, and because reports may show aggregated information

in such a way as to be misleading rather than the specific data needed for simulation studies.

(3) The equipment **vendor** may be able to supply specifications and projected performance characteristics (e.g., processing time, time to failure). Such information can provide a useful starting point but should be used with caution. Vendor claims are often based on ideal conditions, not the actual production conditions.

(4) The **client** can provide estimates of data in some cases, such as machine capacity, line speed, etc

(5) Based on experience, the **simulation practitioner** may be in a position to estimate the statistical distribution form which data of various types are likely to follow.

If possible, data should be collected on the performance of the existing system. These data can be used to test the model. The level of model detail depends on project objectives, performance measures, data availability, credibility concerns, computer constraints, opinions of system "experts", and time/money constraints. Data should be collected to suit the study's objectives. (Law 1986).

The data may be available in many places and in different formats. For example, data may be on a production log, production order sheets, and or found in a computerized data accumulation system. When there is no data available or collected data are of poor quality, the modeler must measure, estimate and assume (F&H Simulations, 1995). The modeler should consult with experts in the

plant or system before assuming or predicting. A client, management personnel or decision-maker must participate during the data acquisition period. Usually, they know the system better than anybody else. Throughout the study, interaction with plant personnel or system experts is crucial for a successful simulation project (Law 1997).

Some of the data used to define a model is deterministic, that is, known with certainty, but much of it is probabilistic. In simulation, probability distributions are introduced to describe the stochastic character of a system. Examples of stochastic events are arrival of parts in a system, size of orders, breakdown behavior of systems, etc. Often, the use of an appropriate theoretical distribution is both revealing in the understanding of the system behavior and efficient in the running of the model (Law 1982; Centeno 1996; F&H Simulations 1995).

Determining the theoretical distribution will be discussed in chapter 2.3.

Discoveries found while collecting and analyzing data may prompt a return to the problem formulation stage to recast the original problem (Hoover and Perry 1989).

1.2.3. MODEL BUILDING

After the conceptual model has been established and verified, and data has been collected and analyzed, a computer-based model must be developed. Computer program flow charts can be used to define the flow of the conceptual logic of the simulation model (F&H Simulations 1995; Hoover and Perry 1989). Usually it is useful to break the model into several small blocks and combine those together into one big model later.

Too much detail can make a model bigger than necessary make simulation runtime longer, and make the verification and validation processes more complex and difficult.

1.2.4. MODEL VERIFICATION AND VALIDATION

Modelers, users of the information derived from the results of the simulation experiments, and people affected by decisions based on such model information, are all concerned with whether a model and its results are “correct”. This concern is addressed through the processes of model verification and validation. Converting a conceptual model into a digital model is meaningless, unless the digital model is thoroughly verified and validated. The reliability of the digital model is directly affected by the quality of the verification and validation processes.

Verification (or debugging) is the process a modeler uses to determine if a conceptual model has been correctly translated into a computer program: Does the model act as it was designed? Is the computer code correctly representing the process flow diagram? Validation is the process ensuring that the model behaves the same as the real system and evaluating how much reliance can be placed on the predictions made by the model. A valid model can be used to answer certain “what if” questions (Carson 1989; Sadowski 1989). A decision on model validity is based on the degree to which the performance measures predicted by the model and those observed in the real system are similar. In

reality, verification is often regarded as a part of the validation. (F&H Simulations 1995)

Conceptually, if a simulation model is "valid," it can be used to make decisions about the system similar to those that would be made if it were feasible and cost-effective to experiment with the system itself. The ease or difficulty of the validation process depends on the complexity of the system being modeled and on whether the system currently exists. A simulation model of a complex system can only be an approximation of the actual system. There is no absolute model validity. Furthermore, the most valid model is not necessarily the most cost-effective.

There are three basic approaches used in the validation process (Sargent 1994, 1996). The most common approach is to make a subjective decision based on the results of various tests and evaluations conducted as part of the model development process. Another approach is to use a third party to decide whether the model is valid. The third party should be independent of the model development team and client. The last approach is to use a scoring model. The scoring technique is infrequently used.

Validation techniques include animation, comparison with other models, extreme-condition tests, historical data validation, structured walkthroughs, historical methods, and traces (Balci and Sargent 1982). Breaking down a big model into several small sub-units can greatly improve the verification and validation quality. The final verification has to be performed on a complete model and the ultimate test of the model's validity must be how well the model

accurately predicts future events. Simulation programs with animation capabilities can make the verification task much easier. Animation allows the modeler to display all significant model elements on the screen to be observed, show important interactions within the model and explain the nature of the simulation model to management. Also, it can be used to debug a simulation computer program. Animation, however, is not a substitute for a statistical analysis of the simulation output and a "correct" animation is no guarantee of a valid or debugged model (Law 1997). Validation can be difficult and in some cases impossible to perform. If the system currently exists, comparisons can be made to ensure that the model represents the real world. If the system does not exist, but similar ones do, the simulation results can be compared to similar systems and, at least, a partial validation performed. If there is no real system to be compared with the simulation, then validation cannot be performed. If this is the case, it is recommended that the Turing Test be used, as suggested by Alan Turing. The Turing test is based on principles of artificial intelligence. Those who are familiar with the system design are asked to verify and validate simulation output. (Schruben 1980; Carson 1989; Hoover and Perry 1989)

Validation and verification should not be regarded as steps that can be tacked onto the end of a project. They are an important part of a process that starts at the beginning of the project and evolve throughout model building and into the period of implementing the experiments. Involving the client in a team effort makes it more likely that the model will be efficient and will be accepted and used in the decision-making process.

1.2.5. EXPERIMENTS AND OUTPUT ANALYSIS

In this phase, a simulation model can provide answers to the questions asked when the problem was originally formulated. The system configurations that are to be simulated are selected. Experimenting is divided into three steps; setting experiment conditions, carrying out the simulation runs and registering results (Law 1997). Output analysis is a statistical process that is aimed at estimating a simulation model's (not necessarily the system's) measures of performance. Topics of interest are length of each simulation run, warm-up - period duration, and number of independent simulation runs.

The analysis of the data provided by the simulation model will depend on the initial objectives of the study and on the type of system being modeled (Sadowski 1993). There are two types of systems: terminating and non-terminating. Statistical experiments are designed to meet the objectives of the study. Observing a model under one or two experiments usually provides incomplete information. Therefore, a set of experiments must be analyzed within the practical range of multiple experimental conditions. Objectives of a simulation output analysis are determining performance of system configurations and comparing alternative system configurations (Hoover and Perry 1989). Details will be discussed in chapter 2.4.

By evaluating alternative system designs according to the measures of performance produced by simulation output analysis, the best, or at least a very good system design can be selected.

1.2.6. DOCUMENTATION, PRESENTATION, AND IMPLEMENTATION OF RESULTS

Assumptions, computer programs, and results of projects should be documented. No matter how good the results of the model experiments, if they can not be communicated convincingly, they are essentially useless. The documentation and presentation should be done to ensure that the client or manager understands the results of the study, or at least has the impression that the study has been carried out well. Usually, for a good presentation of results, animation, graphics and a discussion of model building/validation process should be included (Law 1997; F&H Simulations 1995).

All that remains is the implementation of the selected solution. It is obvious that the users, clients, and manager will not realize the benefits of a lengthy and costly analysis without proper implementation and acceptance. Since implementation appears at the end of any sequential list of elements in a simulation study, it is often the case that implementation is not thought about, or dealt with until the final model or solution has been developed. However, research suggests that this approach will almost assure failure (Perry et al 1986). Reasons for unsuccessful implementation include the following: a communication gap between modeler and user, the inability of users and managers to understand the technical terminology of the modeler, the undertaking of implementation too late in the analysis procedure, and resistance to change, or a lack of coincidence of personal and organizational objectives. In dealing with these potential obstructions, the general approach is adapted from techniques used in developing and implementing information systems, namely treating the

entire project as a process of change and viewing the analyst as a change agent (Lucas 1974). This approach requires full involvement of users and modelers from the beginning of the simulation project. Lucas (1974) suggests the following elements for Information Systems. These can be adapted as a change plan for the simulation study:

- A design team consisting of users and analysts
- An active role for users in the modeling process
- User-initiated simulation study requests
- Support of high level management
- Development of favorable attitudes toward study goals
- Careful planning for implementation from the outset
- Appropriate attention to training and user manuals.

Advances in personal computer hardware and software for simulation study may narrow the traditional gap between users and modelers. The newly found ease with which models can be constructed and experiments run may help users to understand the simulation process but it may also cause users to draw statistically toward the wrong conclusion.

1.3. PROBABILITY DISTRIBUTION

1.3.1. STOCHASTIC BEHAVIOR OF THE SYSTEM

Most manufacturing systems contain one or more stochastic components (random variables). Inter-arrival times of parts in a system, machine breakdown

time, machine repair times and the outcomes of inspecting jobs (e.g., good, rework, or scrap) are examples of random factors in a manufacturing system. A probability distribution indicates how the chances are divided. A simulation engine generates random samples from these input probability distributions as required throughout the simulation run. The output data from a simulation (e.g., daily throughputs, average queue in the system) are also random samples from probability distributions. Therefore, it is important to correctly model the random inputs to a simulation model and also to analyze simulation outputs in a proper manner. (Law 1986)

1.3.2. THEORETICAL DISTRIBUTION AND EMPIRICAL DISTRIBUTION

A probability distribution is a theoretical set of values defined by a set of probabilities. The frequency with which a value occurs in a simulation depends upon the probability distribution chosen for that variable. A probability distribution is characterized by three quantities: the average, the standard deviation, and the form of the distribution. In a simulation model, the correctness of the average is the most important, followed by the correctness of the standard deviation and the form of the distribution (Law 1997). That is, a 10 % error margin in the average is worse than a 10 % error margin in the standard deviation. An error in the standard deviation is worse than choosing the wrong distribution.

There are two approaches to determining distributions from data (F&H Simulations 1995):

- Use a theoretical probability distribution
- Use an empirical distribution

Usually a theoretical probability distribution is the preferred method for selecting an input probability distribution. It is often the case that historic data is not available and an empirical distribution may give an incorrect description without a fairly large amount of data. Determining an empirical distribution is difficult, especially when confronted with a large range of possible values. If a theoretical distribution fits the data adequately, it will represent the parent population better than an empirical distribution. For example, an empirical distribution may give a poor fit to the parent distribution in one or both tails of the distribution. On the other hand, the tails of distributions can not be estimated accurately from a limited amount of data, whether a theoretical or an empirical approach is being used to determine the distribution (F&H Simulations 1995). There is considerable debate, however, about whether using theoretical distribution is better than an empirical distribution (Fox 1981).

1.3.3. CHOOSING A DISTRIBUTION

The following methods are used in fitting a theoretical distribution to the data (Schriber 1974):

- 1) Select a distribution form (e.g., uniform, lognormal, exponential, Weibull):**

The selection can be accomplished by plotting a histogram of the acquired data and visually comparing its form with the forms of known theoretical distributions.

- 2) Estimate values for the parameters in the distribution:**

Parameters can be estimated from the data. One or more parameters might alternatively be provided in the form of estimates based on knowledge of the process which gives source to the data.

3) Goodness-of-fit test :

Goodness-of-fit tests are designed to test whether a data set can be considered to be a sample from a specified probability distribution. The two most frequently used tests are the Pearson's Chi-square goodness-of-fit test and the Kolmogorov-Smirnov (K-S) goodness-of-fit test. If the proposed fit is unacceptable, the modeler can try one or more other distribution forms, or can use an empirical distribution for the data (Hoover and Perry 1989).

When no data are available, the following procedures can be used (Law 1997):

1. Choose a typical distribution for the application
2. Use a Triangular distribution as a "first cut"
3. Choose a distribution from based on knowledge or intuition.

Schriber (1974) suggested several useful methods of quantifying probabilistic data based on estimates, since there are still a number of possibilities for getting probabilistic estimates supplied by people (e.g.. vendors, clients):

(1) Mean Only. If only the mean value (e.g.. mean time to failure) can be estimated, then just the mean itself might be used: or a distribution centered on the mean with a range taken as some percentage of the mean might be used: or in some cases, an exponential distribution might be used.

(2) Range Only (Pessimistic and Optimistic Values). If only the range of values (e.g., minimum time to failure: maximum time to failure) can be estimated, then a uniform distribution spanning the range might be used: or a normal

distribution can be determined, centered on the midpoint and with a standard deviation estimated by dividing the range by 6.

(3) Most Likely Value and Range. If these three values can be estimated, then a triangular distribution can be used or, if the most likely value is at the midpoint of the range, a normal distribution can be used.

(4) Most likely Value. 10th Percentile and 90th Percentile. If these three values can be estimated, then a 10-90 triangular distribution can be used; or a uniform distribution (extending appropriately beyond the 10th and 90th percentiles) can be used: or, if the most likely value is at the midpoint of the 10-90 range, a normal distribution (with standard deviation determined appropriately) can be used.

(5) Mean Value Most Likely Value and Range. If these four values can be estimated, then a Beta distribution can be used.

Statistical software packages are also commercially available to support the process of fitting distributions to data, e.g., UNIFIT, ExpertFit, and SIMSTAT (Banks 1996).

1.3.4. COMMON THEORETICAL DISTRIBUTION

The following are selected descriptions and areas of application of common theoretical distribution (Law 1997; Hoover and Perry 1989; Centeno 1996).

1. Uniform distribution

The uniform distribution is symmetrical and is used when lower and upper limits are known, but very little is known about the distribution between these limits. Intervals that fall outside the limits have a zero probability of occurring. Within a lower and upper limit each value has an equal chance of occurring.

This distribution is often used in the early stages of a simulation analysis until information is developed to construct some other distribution, as a convenient and well understood source of random variation.

Parameters are lower limit a and upper limit b .

2. Normal distribution

The normal distribution is usually symmetrical (may be skewed) and 95% of values are within 1.96 times the standard deviation.

It is used when the average is known and when most values occur near the average. Numbers, weights, sizes, measurements, and deviations are often assumed to be normally distributed. Processing times are sometimes normally distributed, especially if they are manual actions with little variation in the required time.

Parameters are mean and standard deviation.

3. Exponential distribution

This distribution is used for processes where intervals between events are independent. The greater the value the less often an event occurs. Values less than the mean occur more often. Values range from 0 to around 10 times the mean. The standard deviation of the negative exponential distribution is equal to the average. In practice, the exponential distribution is often the greatest form of randomness. The exponential distribution has no memory.

The most important application for the distribution is its use for arrival processes; customers placing orders, parts arriving at a system. If they are independent events, the arrival process is exponential. For example, arrival of customers at a post office are independent of each other. Besides arrival

processes, there are many other processes that can be described with the exponential distribution: time between two breakdowns (MTBF), order sizes, processing times, etc.

Parameter is a mean.

4. Erlang distribution

The erlang distribution involves two parameters; a mean and a K factor. With $K=1$ the distribution is a negative exponential. With large K values (about 10) or as K approaches infinity, the distribution approaches a normal distribution.

Applications are processing times, repair times, manual tasks, handling times and, sometimes, inter-arrival times.

5. Lognormal distribution

This distribution has a taller “spike” than the erlang distribution. Standard deviations larger than the mean are allowed.

The lognormal is often used as a model of the time to perform manual tasks such as assembly, inspection, or repair, and has also been used as a model of the time until failure.

The lognormal distribution involves two parameters; a mean and a standard deviation.

6. Empirical Distribution

The empirical distribution allows the possibility of defining multiple “peaks.” For each possible value, the modeler must specify the chance that the event will occur. Historical data is needed to create an accurate empirical distribution.

7. Gamma distribution

Examples of the gamma distribution are the time to perform a manual task, the monthly sales of an item, the seconds of CPU time a job will require, and the deviation of a trajectory from its intended target.

It is characterized by two parameters: shape and scale.

8. Weibull distribution

The weibull distribution is used in reliability theory to model the distribution of time until failure, particularly for devices where wear or usage is a factor such as vacuum tubes, ball bearings, and springs.

It is characterized by two parameters: shape and scale.

9. Beta distribution

Common application of the beta distribution is the time to complete an activity in a project consisting of multiple activities.

It is characterized by two parameters: shape and scale.

10. Logistic distribution

It is used for random variables which are constrained to be greater or equal to 0.

The logistic distribution involves two parameters; a mean and a standard deviation.

1.4. Statistical Analysis of results

After getting results from several simulation runs, statistical techniques are used to analyze the results. Statistical analysis is used to estimate a simulation model's true measures of performance. Many simulation practitioners make a single simulation run of somewhat arbitrary length and then treat the resulting estimates as the true answer for the model (Law 1997). A result that comes from one simulation run is usually different than the result from another simulation run. These results are random variables themselves that may have large variances, and differ greatly from the corresponding real answers. From a simple experiment of throwing a die, one can not tell that each result has an equal theoretical probability of 0.17 without a large number of replications. An infinite number of observations are needed to get exact results. However executing an infinite number of replications is impossible. Some simulation models of manufacturing operations take a very long time to execute. The number of observations in a simulation should large enough to result in the required accuracy.

To get a number of observations, which is enough to provide required accuracy, a simple method, "making a number of runs", can be used (F&H

Simulations 1995). If four simulations are run and four outputs are obtained, the average of the four outputs can be taken as the simulation results. However, often more accurate methods are required.

A confidence interval in the form of “the average output can be found between 5,288 and 5,420 with a reliability of 95%” can be used to describe the output of the simulation results. A large number of observations are needed to produce a confidence interval. These observations are acquired by repeating the experiment or by dividing a long experiment into a number of subruns. Choosing a proper method depends on the objectives of the simulation study and whether the experiment involves a terminating or non-terminating system. Also warm-up conditions and the subrun length play an important role in the gathering of observations. (F&H Simulation 1995; Law and Kelton 1982)

1.4.1. Terminating simulation and non-terminating simulation

“A terminating simulation is one for which there is a natural event E that specifies the length of each run (Law and Kelton 1982; Law 1997)”. The event E often occurs at a time point that has one of the following properties:

- System is “cleaned out”
- Beyond which no useful information is obtained.

There may be reoccurring epochs, sometimes called points of regeneration, but each epoch starts off fresh. In a terminating system, the ending state of the previous epoch does not affect the starting state of the current epoch (Hoover and Perry 1989). An example of a terminating system is a post office.

When the office opens in the morning, the queues are empty. At closing time, the queues are being emptied.

A non-terminating system is one for which there is no natural event E to specify the length (end) of a run. The discrete events driving the system continue to occur indefinitely. A single epoch of the system continues indefinitely and there is no terminating event. An example of a non-terminating simulation is a manufacturing plant that never stops. Another example is a manufacturing plant starts at 8 a.m. and closes 5 p.m. But the products are not emptied. The plant continues the following morning as it stopped the previous evening.

Closely related to the issues of terminating or non-terminating systems are the transient and steady-state properties of systems (Sadowski 1993). The steady state is the situation in which the system is 'behaving normally'. In steady-state, the probabilities of possible situations in the system are not influenced by the time at which one measures. In terminating simulations, it is generally the case that, the simulation practitioner is interested in transient behavior, but the terminating event may occur when the system is behaving as it would in steady state. In non-terminating simulations, the modeler is usually interested in the steady-state behavior. Often, however, non-terminating systems never achieve a steady-state behavior (Hoover and Perry 1989).

Almost every paper and book written on the analysis of simulation output data deals with the non-terminating, steady state case. However, according to Law and Kelton (1991), by surveying a large number of simulation practitioners it

was discovered that significant proportions of simulations in the real world are actually of the terminating type.

1.4.2. Statistical analysis for terminating simulations

Terminating systems are relatively easy to analyze. A simulation run takes as long as the “open” times of the system under observation or, if necessary, a little longer to clear out the system. In terminating simulations, each replication produces an IID (independent identically distributed) “observation” (Law 1997). Therefore constructing confidence intervals is relatively simple. Suppose that we would like to estimate the population mean μ , when the random sample size is reasonably large. Make n independent replications and let $X_1, X_2, \dots, X_n$ be the resulting IID random variables. An approximate 100(1- α) percent confidence interval for μ is given by $\bar{X} \pm z s\{\bar{X}\}$.

$$\text{Where, } z = z(1-\alpha/2), \quad s\{\bar{X}\} = \frac{s}{\sqrt{n}} \quad (\text{Neter et al 1992})$$

When n becomes infinitely large, the probability of exceeding limits becomes equal to those of the normal distribution. With more than 30 observations, one may freely use the standard normal distribution (F&H Simulation 1995).

1.4.3. Statistical analysis for non-terminating simulations

For non-terminating systems, it is necessary to bring the simulation model to steady state before model generated data is analyzed. All of the data

generated before the model reaches steady state should be thrown away. Upon reaching steady state, it is necessary to decide the length of the single replication that is to be run. Usually, the method of batching is used to analyze this data (Martha 1996). Batching refers to breaking the highly correlated, sequential observations generated by the model, into groups or batches. These batches would then be treated in the same fashion as replication in the case of terminating systems.

A batch is based on the level of correlation between observations separated by a given lag k . Statistical theory tells us that the farther apart two correlated observations are, the smaller the correlation. So, it is necessary to compute the correlation factor for various values of the lag k (20-500), graph the correlation factor, and identify the lag value at which the correlation factor ρ is approximately 0. From that process, the number of observations in the batch is established taking into account that this is a random process, so a safety factor needs to be added.

Once the batches are formed, each batch is treated as an independent replication, and an analysis similar to that for a terminating system should be done. Regardless of the type of system, the simulation practitioner should keep in mind that the reporting point estimates of the measure of performance are not particularly helpful. Confidence intervals on critical measures of performance should be constructed to add credibility and strength to the study.

When analyzing a non-terminating system, it is necessary to bring the model to steady state before the data generated from the model is used in

analysis. Simulations of manufacturing/packaging systems often begin with the system in an idle or empty state. This results in the output data from the “beginning” of the simulation not being representative of the “normal” behavior of the system. Therefore, simulations are often run for a certain amount of time, the **warm-up period**, before the output data are analyzed to acquire the desired measure of performance. This is also known as the starting run. In most cases, systems with high utilization of machines and long sequences require very long warm-up period. Including data from the long warm-up time data often results in inaccurate results (F&H Simulation 1995). In the simple case of a bank simulation, the queue starts with 0 at an early stage then grows.

There are a number of ways to determine the length of the warm up period. One method is to simply plot a key simulation parameter as the simulation repeats, and observe where the model starts repeating its output on some consistent level. Another method for determining the warm up length with fewer observations is the Welch method that is generally accepted today (Stockdale 1997). This method is similar to the above. However, by eliminating fluctuations in the average, a reasonably smooth plot can be obtained with relatively small number of observations.

The Welch graphical method is rather complex. It requires running multiple full length replications of the model. For each replication, for time periods 1, 2..., n, a key simulation parameter is averaged. Then, the data are plotted, one graph for each denominator of the moving average, and inspected for its flatness. As with any other visual method, the Welch method is subject to graphical bias from

choosing axis intervals that distort plots by under or over flattening moving average curves (Welch 1983).

While the Welch graphical method is a good academic tool, modelers can rarely invest the time required for this technique. Many simulation practitioners find that technique of determining the warm-up period is more complex and time consuming than development of the model itself. The simple plot technique is better than guessing, but visually observing output for the warm-up periods does not present one with easy decision (Stockdale 1997).

CHAPTER 2

DEVELOPMENT OF THE SIMULATION MODEL

The research project consisted of the following phases: (F&H Simulation 1995; Martha 1996; Law 1986)

- 1. Problem formulation**
- 2. Description of the system to be modeled**
- 3. Experimental alternatives**
- 4. Gathering and analyzing the data**
- 5. Computer model building with verification and validation**

2.1. Problem formulation - Defining the current problem of the dairy plant.

The dairy plant produced five kinds of milk: skim milk, low fat milk, one percent, two percent, homogenized (whole milk) and chocolate milk. Milk was bottled in one-gallon high-density polyethylene (HDPE) bottles and half gallon HDPE bottles. Gable top cartons were used to bottle small portions.

The packaging machinery set for milk products was: blow molders, wire conveyors, filling machines, casers, stackers, and case washers (Figure 1). Since all of the machine components were linked together, either directly or indirectly, it was very hard to define the cause of problems in the packaging line. If the blowmolders and filling machines were running well, there often was a shortage of cases or space for cooling storage. Of course, if the blow molders

were not working well, the rest of the line had to wait for bottles; i.e. operators had to shut down the rest of the line and wait for bottles.

People in the plant have tried to fix these problems, but the problems appeared to be related and have no clear solutions. Frequently a problem is caused by multiple factors and uncertainties which all influence one another. Even if plant personnel identified a possible solution, they could not be sure of its financial merits. People at the plant have proposed replacing or overhauling the old blowmolding machines because the blowmolders are at the start of packaging line and have had many problems. It was reported that two filling machines also had very low utilization of around 60 percent.

The following were the problems of the plant;

- Low productivity
- Low utilization of filling machines and stackers
- Alternative possibility of overhauling of existing machine or purchasing a new machine

In short, the plant wanted to find a way to increase the productivity within its financial limit.

2.2. Description of the system to be modeled

The plant produces about 8,640 gallons of milk per hour (one-gallon plastic bottles). It has an average bottled milk production of 100,000 gal/day. There are seven pasteurized milk tanks with a total capacity of approximately

70,000 gallons. The factory (Figure 1) runs six days a week with two shifts; approximately 8.5 hours per shift.

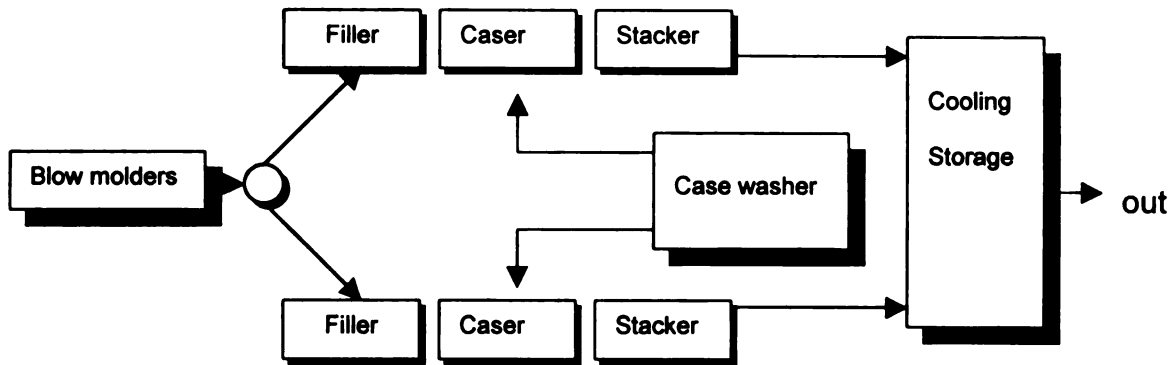


Figure 1. Dairy plant packaging line

2.2.1. Blow molding machines

Four blowmolding machines produce one-gallon high-density polyethylene bottles for milk. About every 7.5 seconds each blowmolding machine mold four bottles using the “extrusion blow molder.” The process consists of extruding a hollow tube, called a “parison,” between two halves of a mold. As the mold closes, it closes the bottom of the parison, leaving the top open for the injection of air. The warm, soft plastic stretches out under this pressure and forms the shape of the mold interior. (Hanlon 1992)

After molding, the four bottles are placed on the cooling conveyor and moved to the trimmer. After trimming, compressed air is blown into the bottle to check for leakage. If leakage is found, the bottle is rejected and moved to the grinding room for reuse. If leaks are not found, the bottles from blowmolder 1, 2,

and 3 are moved on a stainless steel conveyor to the wire conveyor. The bottles from machine 4 are transferred to the wire conveyor directly. Each blowmolder has its own reject ratio of 1 to 10 percent. Speed and capacity of the blowmolding machines are shown in Table 1.

The first, second, and third blowmolders use the same conveyor, while the fourth blowmolder uses a different conveyor. After traveling on each conveyor, the bottles are merged onto a single conveyor in front of the raw milk storage room. Line dividers are used to direct the flow from blowmolders 1, 2, 3, and machine 4. A divider blocks off the exit and allows only one line of milk bottles to flow through at a time. The back pressure on the bottles moves the bottles that are in position onto the through lane, while keeping the other containers milling around until each of them is in position (Davis 1994). Currently, the line divider is set to open for 15 seconds for bottles from the first, second, and third machines and close for 4 seconds to clear up the path, then the divider is reopened for four seconds for bottles from the fourth machine and closed for four seconds to clear up the pathway. This procedure repeats throughout the production. (Figure 2)

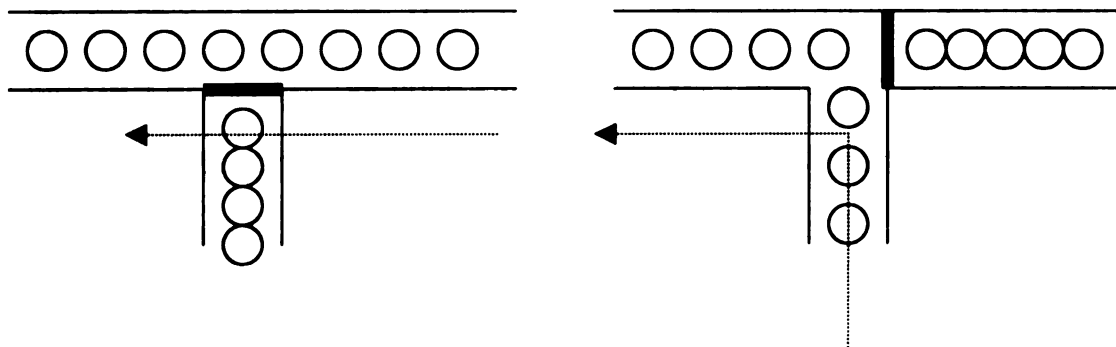


Figure 2. Line divider

Table 1. Detailed information of blowmolding machines

	Speed	Capacity	Reject ratio
Blowmolder 1	4 bottles/7.6 sec	4	1 ~ 10%
Blowmolder 2	4 bottles/7.8 sec	4	1 ~ 10%
Blowmolder 3	4 bottles/7.5 sec	4	1 ~ 10%
Blowmolder 4	4 bottles/7.4 sec	4	1 ~ 10%

Two operators run the machines and 4,000 ~ 7,000 bottles are produced in an hour.

2.2.2. Wire conveyor

The wire conveyor transfers bottles with speed of 1 meter per second and acts as an accumulator.

2.2.3. Filling machines

The filling machinery consisted of four components: labeler, date coder, filler and capper machines. The rotary fillers had 26 filling heads and ran at the speed of 4,320 bottles per hour. Filling machines 1 and 2 had the same speed and capacity but different downtimes. One operator was needed to run each machine.

2.2.4. Case washer

After trucks deliver and unload empty cases, the empty cases are cleaned in the case washer. After cleaning, the cases are moved to one of the casers. Two operators are needed for the case washer. One operator drives a forklift to move pallet-loads of empty cases while the other runs the washing machine and handles the trash in empty cases.

2.2.5. Caser

The caser loads four bottles from filling machine into each case.

2.2.6. Stacker

The stacker stacks two columns and six rows of cases into a unit (12 cases, 48 bottles).

2.2.7. Cooling Storage

The cooler can hold up to 25,000 cases (100,000 bottles). It maintains a temperature 35°F. The cooler is connected to the dock area.

2.3. Experimental alternatives

Based on the preliminary study of the system, the following possible solutions were considered.

- Changing the speed of the conveyor
- Changing the length of the conveyor (acting as an accumulator)

- Changing the speed of the filling machines
- Minimizing the downtime of the filling machines
- Minimizing the downtime of the casers
- Minimizing the downtime of the stackers

The simulation software "Taylor II" was chosen after consideration of the study objectives and availability. Taylor II is a product developed by F&H Simulations. It runs under Microsoft Windows 3.1 and Windows 95, 98, and NT. The process of using Taylor II starts with building a model. All model building is menu driven. A model in Taylor II consists of four fundamental entities: elements, jobs, routings, and products. The element types are in/out, machine, buffer, conveyor, transport, path, aid, warehouse, and reservoir. One or more operations can take place at an element. The three basic operations are processing, transport, and storage. Defining a layout is the first step when building a model. Layouts consist of elements. By selecting the elements in sequence, the product path or routing is defined. Routing descriptions may also be provided from external files.

The next step is detailing the model. In this step the parameters are provided. In addition to a number of default parameters, Taylor II uses a macro language called TLI for Taylor Language Interface. TLI is a programming language that permits modifications of model behavior in combination with simulation-specific predefined and user-definable variables. TLI can also be used

interactively during a simulation run to make queries and updates. Interfaces to different program language like C, Basic, or Pascal are also possible.

During simulation, zoom, pan, rotate, and pause are options. Modifications can be made “on-the-fly.” The time representation is fully user-definable (hours, days, seconds, and can be mixed). Output analysis possibilities include predefined graphics, user-defined graphics, predefined tabular reports, and user-defined reports. Examples of predefined graphics are queue histograms and utilization pies. User-defined outputs include bar graphs, stacked bars, and other business graphics. Predefined tables include job, element and cost reports.

Animation capabilities include both 2-D and 3-D. The 3-D animation can be shaded. Standard indicators can be shown for elements. Icon libraries for both 2-D and 3-D animation are provided. Each of these libraries contains more than 50 icons.

2.4. Gathering and analyzing the data

There are two fundamental entities in Taylor II that are needed to build a model: elements and products. Elements are the resources of the model and products are the entities that are processed by the elements. Elements fall into three categories: the element, the job, and the stage parameters. Properties that are related to the physical part of the element are categorized in the element parameters, such as the capacity, entry and exit condition and the failure rate etc. Job parameters describe how an operation is done, for example: how long it takes for the machine cycle, what the batch size is, etc. The definition of the

routing of products through the model is done with the stage parameters of an element.

The following methods were used to gather data for this study: time studies, historical records, vendors' claims, and line managers' "best guess". Some of the data was estimated, especially machine downtimes, repair times and the arrival times of some of the machine elements. Another reason for estimation was because of the machine operators' occasional work overload. Sometimes operators couldn't find enough time to measure and keep records of downtimes or repair times. It will be noted when estimated data were used later in this chapter.

Estimations of the conveyor lengths were made from scaled floor drawings, so there is a possibility of some error in the lengths of the conveyors. The model was based on a two-month span of the daily production log. Each data element is listed in Appendix A.

2.4.1. Mean Time between Failure (MTBF) and Mean Time to Repair (MTTR)

To interpret the stochastic behavior of the system, mainly for "Mean Time between Failure (MTBF)" and "Mean Time to Repair (MTTR)", an analysis of the historical data of machine down time was performed.

There are two approaches to determine the distributions from the data: fitting a theoretical distribution to the data and fitting an empirical distribution to the data. If a fairly large amount of data can be gained, an empirical distribution can be used. Since the data set in this study, however, was collected only for two

months, the alternative approach, “fitting a theoretical distribution to the data” was used.

The following three methods were used to fit a theoretical distribution to the data.

1. Curve fit actual data to a theoretical distribution form – This was done by plotting a histogram from the data and visually comparing its form with the forms of known theoretical distributions.
2. Determine the relative goodness of the fitted distribution –This was done by the statistical goodness-of-fit test e.g. Chi-Square, Kolmogorovsmirnov.
3. Comparing results from 1 and 2 and built-in fitting analysis functions in Taylor II.

Some of the data sets have a very small amount of data to fit into a theoretical distribution. In these cases, the distribution was selected based on the modeler’s knowledge or intuition. The theoretical distributions of MTBF and MTTR for each element are shown in Table 2.

The simulation engine generated random samples from these distributions as required throughout each simulation replication. Examples of raw data of machines down times, repair times, and histograms are shown in Appendix B (Table B1 and Figure B1 to B22).

Table 2. Theoretical distribution of elements.

Elements	MTBF	MTTR
Blowmolder 1	Beta (19453.45, 0.6, 1.5)	Lognormal (3234.83, 4025.16)
Blowmolder 2	Logistic (35129.47, 24120.27)	Exponential (3568.42)
Blowmolder 3	Gamma (33438.39, 0.9)	Lognormal (2184.19, 3364.75)
Blowmolder 4	Weibull (35475, 0.7)	Lognormal (3100.91, 3794.6)
Conveyor	Beta (53240.87, 0.6, 1.7)	Lognormal (1090.43, 1153.79)
Filling machine 1	Weibull (75868.97, 1.1)	Lognormal (1605.52, 2416.21)
Filling machine 2	Beta (30356.84, 0.5, 1.2)	Gamma (1654.74, 0.9)
Caser	Weibull (19546.71, 0.5)	Weibull (374.37, 0.9)
Stacker 1	Lognormal (28488,43393.04)	Lognormal (955.2, 1024.83)
Stacker 2	Gamma (4548429, 0.4)	Logistic (996.43, 513.9)
Cooling storage	Logistic (131793.5, 141889)	Exponential (2110)

2.5. Computer model building, verification and validation

The computer model building was split into three phases:

- Building a layout
- Input of parameters, control logic, etc.
- Further specification

Before building the computer model, a conceptual model was built based on the system study. It is shown on Figure 3.

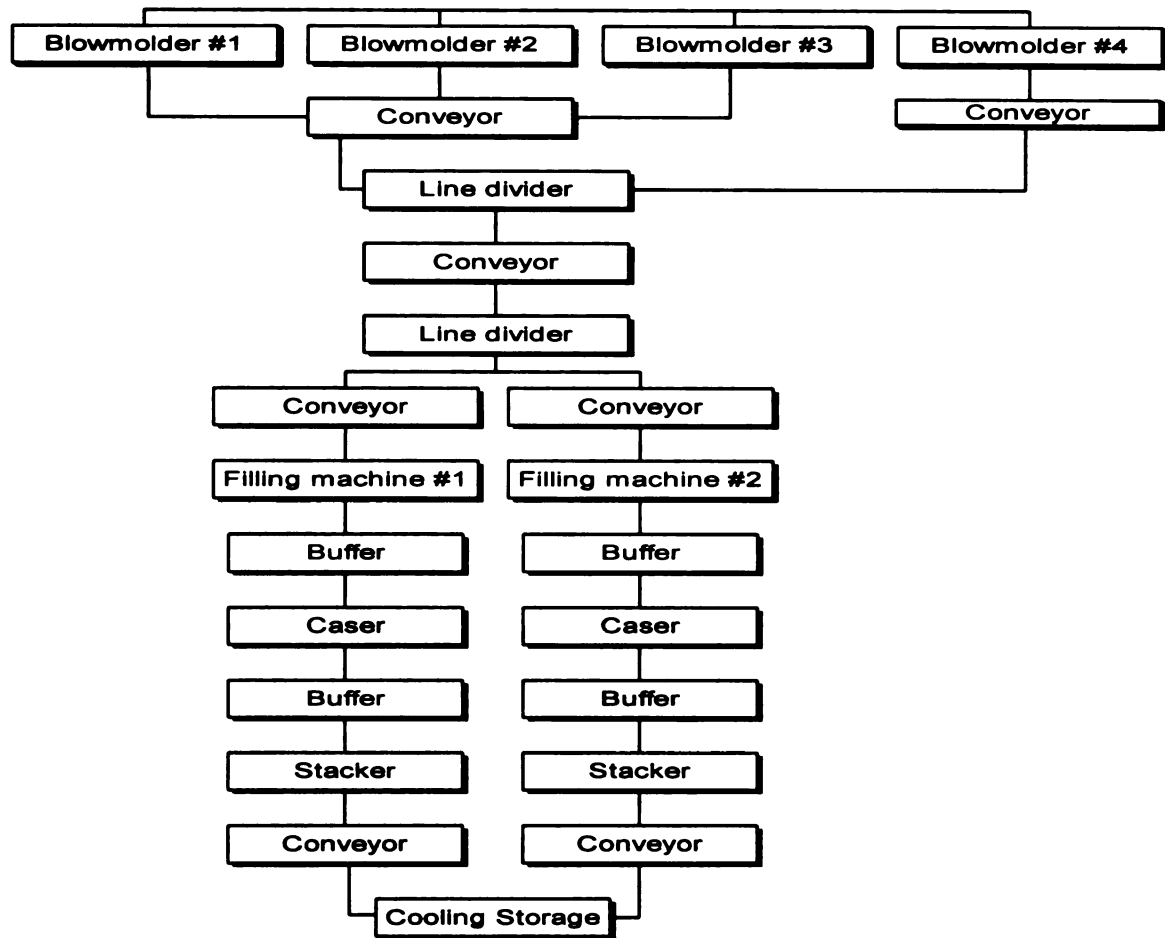


Figure 3. Simulation model layout

To make verification easier and more feasible, the model building process was divided into several stages.

1. Model of blowmolding station
2. Model of blowmolding station and wire conveyor I
3. Model of blowmolding station and wire conveyor I and II
4. Model of blowmolding station and wire conveyor I, II and filling machines
5. Further specification

2.5.1. Model 1 - Model of blowmolding station (Figure 4)

In Figure 4, element numbers 1, 5, 9, and 13, the in/out elements, represented inputs of plastic resin. The default capacity was 2 with zero job time. This means the resin will be supplied to the filling machines endlessly during the simulation run. Element numbers 1, 5, 9 and 13 were assigned product codes from 1 to 4. In reality there was no difference in bottles from each machines, however, by assigning different product codes, the verification and validation processes could be done more easily.

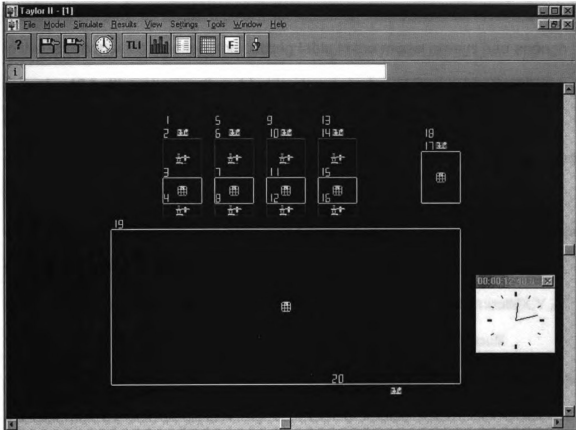


Figure 4. Model 1 - Model of blowmolding station

Element numbers 2, 6, 10 and 14 represented the extrusion blow molding machines. Each machine had the capacity of 4 with a production time of about 7 seconds per 4 bottles. Since 4 bottles were produced and sent out at the same time, “batch” and “out batch” commands were used.

Element numbers 3, 7, 11 and 15, represented the cooling tables. Each cooling table had the capacity of 20 bottles. During production, the cooling table always had a stock of 16 bottles. To simulate this behavior, the TLI (Taylor Language Interface) command of “elqueue” was used. The “elqueue[x]” means the current number of products available at element x. By adding “elqueue[3]>16” in the “exit condition” section, the cooling table in the model always had enough room for 16 bottles plus another 4 bottles to be produced from a blowmolding machine.

Element numbers 4, 8, 12 and 16 represented the trimmers. The trimmers have job times of 1.9 seconds with the capacity of 12 bottles. Again the command, “elqueue[4]>8” was used in the “Exit condition” section to simulate the stock of 8 bottles in the trimmer and the space for 4 bottles from the cooling table. To simulate the reject ratio of bottles, a TLI command of “bernoulli[X,Y,Z]” was introduced. The “bernoulli[X,Y,Z]” returns a value from a Bernoulli distribution, which is: in x% of the cases y is returned, in (100 – x)% of the cases z is returned. So “bernoulli[90,19,17]” sent 90% of bottles to element number 19 and 10% of the bottles to the element number 17, the regrinder, for reuse of the plastics. Each blowmolder had an individualized reject ratio.

Element number 17 represented the regrinder. After regrinding, resin was put back into each blowmolding machines in the real system. But, in the simulation, enough stock of resin was defined (stock of 2 with processing time of zero), so the plastic from the regrinder did not go back to the “In/Out” element for the blowmolders in the model. Element number 18 represented the “In/Out” element, a sinksource function, which is typically used at the beginning or at the end of a line. It generated and “ate” products.

Element number 19 represented the big buffer. All of the bottles, except rejected bottles, from blowmolding machines 1, 2, 3 and 4 were sent to this element. This element does not exist in the plants. For the purpose of verification, a short job time with a high capacity buffer was introduced.

Finally, element number 20 represented the “In/Out” which absorbs the products from the previous elements. HDPE bottles, size of 15 centimeters, were also defined in the “Products” sub menu in the “Model” menu.

The route listing is shown in Appendix C. To verify the computer model, a run time of five hours and replications of ten runs were executed.

From simple calculations, the production of bottles can be estimated.

Blowmolder number 1

4 bottles per 7.6 seconds = 0.52 bottles per second

0.52 bottles $\times$ 3,600 seconds = 1,894.7 bottles per hour

1,894.7 bottles per hour $\times$ 90 % = 1,705.2 bottles per hour

Blowmolder number 2

4 bottles per 7.8 seconds = 0.51 bottles per second

$0.51 \text{ bottles} \times 3,600 \text{ seconds} = 1,846.1 \text{ bottles per hour}$

$1,846.1 \text{ bottles per hour} \times 92 \% = 1,698.4 \text{ bottles per hour}$

Blowmolder number 3

$4 \text{ bottles per } 7.5 \text{ seconds} = 0.53 \text{ bottles per second}$

$0.53 \text{ bottles} \times 3,600 \text{ seconds} = 1,920 \text{ bottles per hour}$

$1,920 \text{ bottles per hour} \times 96 \% = 1,843.2 \text{ bottles per hour}$

Blowmolder number 4

$4 \text{ bottles per } 7.4 \text{ seconds} = 0.54 \text{ bottles per second}$

$0.54 \text{ bottles} \times 3,600 \text{ seconds} = 1,945.9 \text{ bottles per hour}$

$1,945.9 \text{ bottles per hour} \times 93 \% = \mathbf{1,809.7 \text{ bottles per hour}}$

Average total number of bottles produced per 5 hours;

$(1,705.263 + 1,698.462 + 1,843.2 + 1,809.7297) \times 5 = \mathbf{\text{approximately } 35,283}$

bottles.

For comparison, the results of 10, 5 hour long simulations are presented in the following section. To find the number of bottles produced, the TLI command of “produced[X]” was introduced. The TLI command, “produced[19]” returned the number of products produced in job 19.

Using the built-in analyzer in the “Experiments” sub-menu of the “Simulate” menu, an average of 34,616 bottles per 5 hours was found between 34,583.7 bottles and 34,649.2 bottles with a confidence interval of 95% (Figure 5).

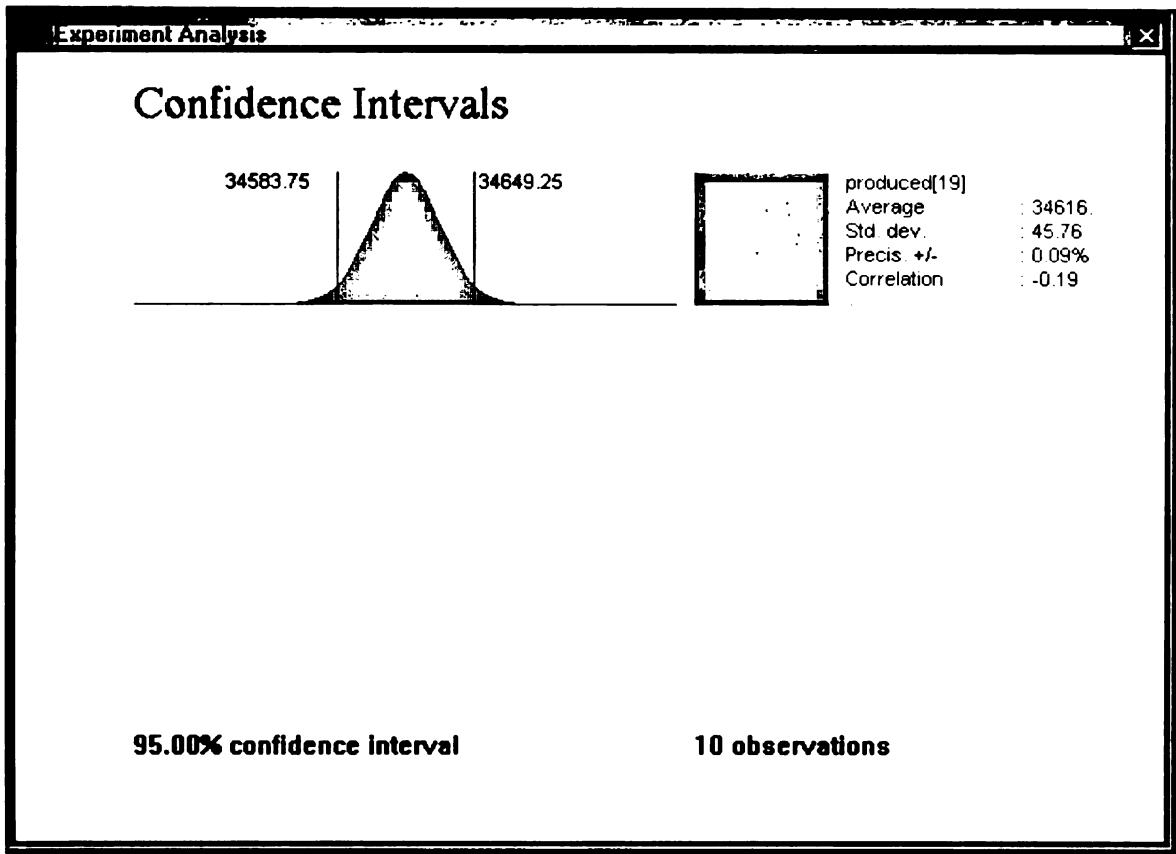


Figure 5. Experiment analysis of Model 1

To find the average queue of products at element X, the “avgqueue[X]” command was introduced. After 5 hours of running time, the average queue of each element was measured. The results are shown in Figure 6. In Figure 6, each of the blowmolding machines show 4 products in the queue and the cooling tables and the trimmers also have adequate amounts of products.

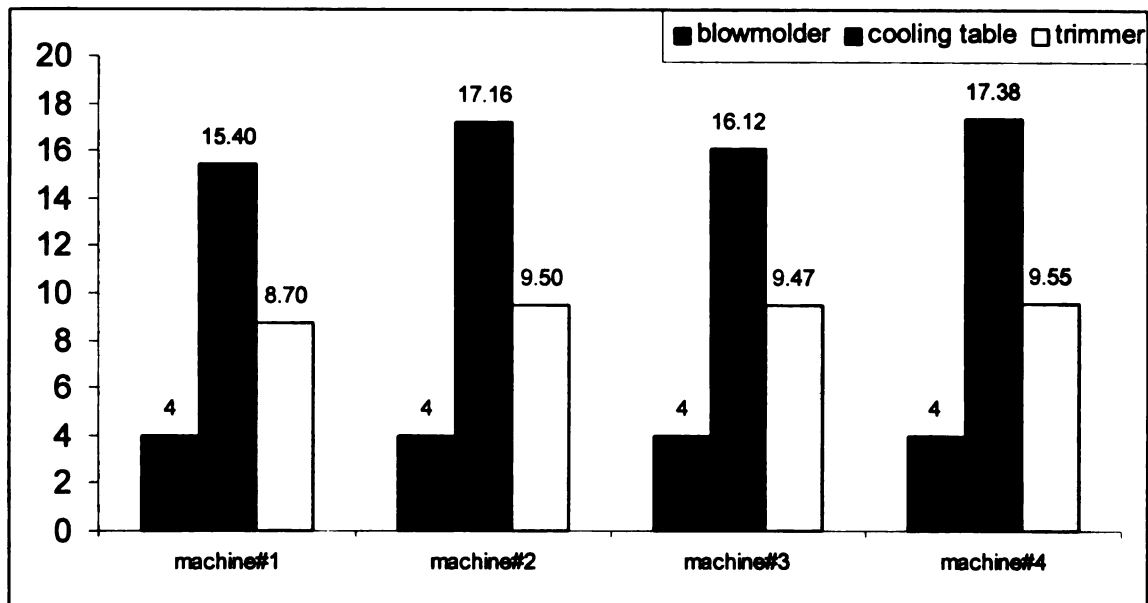


Figure 6. Average queue of each element in Model 1

After comparing the calculated results and simulated results, it was concluded that this model behaved as intended.

2.5.2. Model 2 - Model of blowmolding station and wire conveyor I

Element numbers 4, 8, and 12 sent bottles to the conveyor numbers 21, 20, and 19 respectively. To describe this behavior, modification of the “bernoulli[X,Y,Z]” was required. In model 1 (Figure 4), all accepted bottles were sent to the same buffer, but this time each machine was assigned to a different conveyor. (Figure 7)

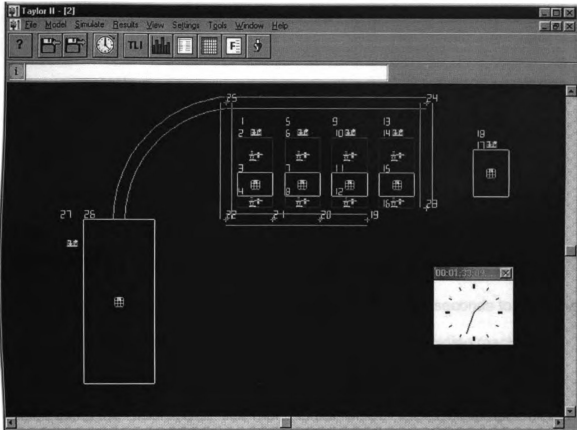


Figure 7. Model 2- blowmolding station and wire conveyor I

To describe the behavior of the line divider at the beginning of conveyor 25, User-defined function and "Userevents" were introduced. Using "function editor", four functions were defined.

```
function open22 (open conveyor 22)
```

```
  elsend[22]:=1
```

```
  elsend[24]:=0
```

```
function open24 (open conveyor 24)
```

```
  elsend[22]:=0
```

```
  elsend[24]:=1
```

```
function close22    (close conveyor 22)

elsend[22]:=0

elsend[24]:=0

function close24    (close conveyor 24)

elsend[22]:=0

elsend[24]:=0
```

These functions executed the following:

The line divider was set to open for 15 seconds for the bottles from the blowmolding machines numbers 1, 2 and 3 and closed for 4 seconds to clear the path, followed by open for 4 seconds for bottles from blowmolding machine number 4 and closed for 4 seconds to clear the pathway.

Using the “Userevents” sub-menu in the “Model” menu, each open and close time was entered. The “Userevents” repeated every 27 seconds throughout the entire run of a simulation.

Element number 26 represented the big buffer. All of the bottles from blowmolding machines were sent to this element. The element does not exist in the actual plant, however, for the purpose of verification, a short job time with a high capacity buffer was introduced.

The route listing is shown in Appendix C.

To verify the model, a visual check of the model in the screen was made and ten, one hour long, simulation runs were executed. To verify the model visually, the model was set to run in speed of 1, a full animation view and the screen was refreshed at a rate of 1 unit (second). So the screen was updated

every second. Also the TLI command of “prodqueue[x,y] (element, product)” was introduced. This command gives the current number of products with product code y at element x. After one hour of run, the number of products was counted at conveyor 25, immediately after the line divider, by TLI command “prodqueue[x,y]”

prodqueue[25,1] = 244

prodqueue[25,2] = 236

prodqueue[25,3] = 258

prodqueue[25,4] = 254

The four products maintained the same ratio in the conveyor, after the line divider. Therefore, it was concluded that the line divider used in the model acted as intended.

2.5.3. Model 3 - Model of blowmolding station and wire conveyor I and II

Elements 23 to 26 and 39 to 40 represent wire conveyor. After the first line divider, the bottles traveled through the wire conveyor and were divided at four seconds each. At the end of conveyor 32, another line divider sent the bottles to each filling machine at the same ratio of time, 4 seconds per machine. To simulate this behavior, the stage parameter of “if time|8<4 then 33 else 34” was used in the “send to” section.

To verify the model five one-hour long replications of the simulation were executed. The results (Figure 9) show that the number of bottles supplied to conveyor 36 and 39, were nearly identical.

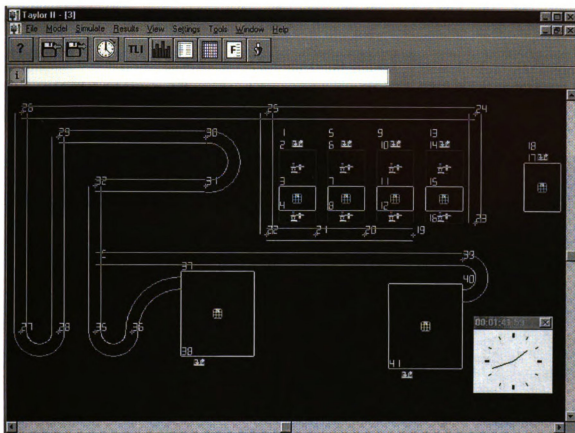


Figure 8. Model 3 - Model of blowmolding station and wire conveyor I and II

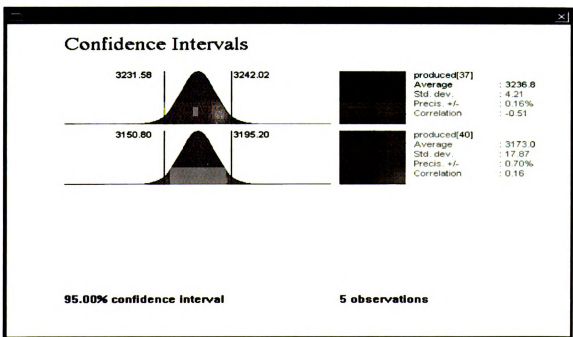


Figure 9. Experiment Analysis of Model 3

2.5.4. Model 4 - Model of blowmolding station and wire conveyor I, II and filling machines

Model 4 included the rest of the machines; filling machines, casers, stackers and cooling storage (Figure 10).

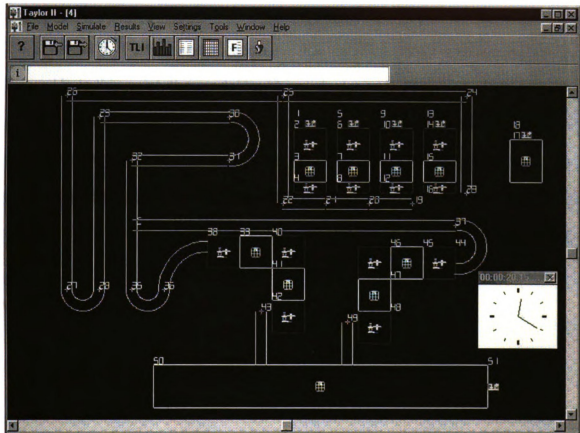


Figure 10. Model 4 - Model of blowmolding station and wire conveyor I, II and filling machines

A new product code was introduced in elements 40 and 46, casers, to generate icons representing cases by using the "product[C]:=5" command. Also, the batch size was changed from 4 to 1 so that 4 bottles become 1 case.

Again, a new product code was used in elements 42 and 48, stackers, using the "product[C]:=6" command. Batch size was changed from 12 to 1 so that 12 cases became 1 batch. The sizes of products 5 and 6 were also defined as 0.33 meters and 0.66 meters, respectively.

2.5.5. Model 5 - Further specification

Up to this point, the model had been designed to fit an unrealistic situation, no machine downtime, no unwanted waiting time and no excessive queue build up. To fine tune the model, that is, to add stochastic behavior to the elements, mean time between failure (MTBF) and mean time to repair (MTTR) were defined for all elements and the parameters for animation were introduced.

Also for visual presentation purposes, the icons representing milk bottles were changed to new bottle-look-alike icons (Figure 11).

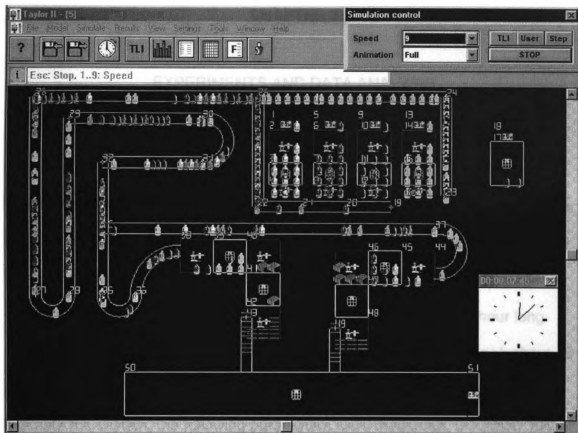


Figure 11. Model 5 - Further specification

CHAPTER 3

EXPERIMENTS AND DATA ANALYSIS

The plant starts production about seven o'clock in the morning and shuts down after eleven o'clock in the evening. So, there is a natural event E that specifies the length of each run. Every night, bottles and milk are cleaned out so that the end condition doesn't affect the start condition of the plant or the model. It can be concluded that the milk plant is a terminating system.

To analyze the simulation data, thirty replications of sixteen hour long simulation runs were executed. A sixteen hour long simulation run took about 45 minutes using 200 MHz Intel Pentium CPU based personal computer. To evaluate the system, the following parameters were measured; utilization, block time, busy time, down time, average queue in the system, idle time, and total number of filled one-gallon milk containers that were produced. Since Taylor II can write the simulation output to a spreadsheet program, data was collected and sorted using Microsoft Excel 97.

The total number of filled milk containers produced in a 16-hour run was ranged between 97,513 and 100,246 with a reliability of 95%. The other outputs of the 30 runs of simulation are shown in Appendix D.

3.1 Experiments

Based on the output of the simulation of the existing system and the questions from plant personnel, the following experiments were devised;

1. Changing the length of conveyor
2. Changing the speed of conveyor
3. Adding accumulators
4. Changing the speed of casers and stackers
5. Adding the accumulators and changing the speed of casers and stackers
6. Increasing the efficiency of filling machines
7. Increasing the efficiency of casers
8. Increasing the efficiency of stackers
9. Increasing the efficiency of blowmolding machines

There could have been other experiments, such as adding a blowmolder or replacing the current blowmolders. However, the current plant situation does not allow for new equipment or overhauling equipment because of financial and space constraints.

3.1.1. Changing the length of conveyor (experiment 1)

The length of the conveyor from the blowmolding station to the filling machines was 369.83 meters, which could hold up to 2,465 bottles, enough for 2,054 seconds of operation. During the simulation, the average number of bottles in the conveyor was 506. So, 1,595 bottles could be accumulated in the case of failure of filling machines. Also, from the Table D2 (average blocked time of elements), there is almost no blocked time at the blowmolding stations. Therefore it was concluded that the conveyors between the blowmolding station and filling

machines had enough capacity to hold the empty bottles. There was no need for an experiment to change the length of conveyor.

3.1.2. Changing the speed of conveyor (experiment 2)

Two different speeds of conveyor were tested. The default speed of 1 meter per second was changed to 1.25 meters per second and 1.5 meters per second.

3.1.3. Adding accumulators (experiment 3)

Four accumulators were added in front of the casers and the stackers, respectively. The capacities of the accumulators were calculated based on the average blocked time of casers and stackers.

The capacity for each accumulator was;

Accumulator number 1 (before caser number 1) – 380 bottles

Accumulator number 2 (before stacker number 1) – 180 bottles

Accumulator number 3 (before caser number 2) – 230 bottles

Accumulator number 4 (before stacker number 2) – 20 bottles

3.1.4. Changing the speed of casers and stackers (experiment 4)

In packaging lines, machines before and after the filling machine generally have higher capacities than the filling machine to give a “pull out” effect. The casers and stackers in the plant had the same speed as filling machines. To simulate “pull out” effect the speed of casers and stackers were changed to 7.5

seconds and 33.3 seconds (10 percent and 20 percent increases in speed), respectively.

3.1.5. Adding the accumulators and changing the speed of casers and stackers (experiment 5)

Experiment 3 and 4 were applied in one experiment model.

3.1.6. Increasing the efficiency of filling machines (experiment 6)

There are several ways to increase the efficiency of the filling machines, such as purchasing new equipment, overhauling old machines, or improving maintenance. However, the current plant situation only allows faster reaction and shorter repair time by maintenance department. So increasing machines speed or minimizing downtime of the filling machines were not feasible solutions. To increase the efficiency of the filling machines, the technique of minimizing the repair time of the filling machines was used. Mean time to repair of filling machine number 1 and 2 were changed to 802.8 and 827.37 (50 percent decreases in time), respectively.

3.1.7. Increasing the efficiency of casers (experiment 7)

To increase the efficiency of casers, the technique of minimizing the repair time of the casers was used. Mean time to repair of casers number 1 and 2 were changed to 187 (50 percent decreases in time).

3.1.8. Increasing the efficiency of stackers (experiment 8)

To increase the efficiency of the stackers, the technique of minimizing the repair time of the stackers was used. Mean time to repair of stackers number 1 and 2 were changed to 478 and 498 (50 percent decreases in time), respectively.

3.1.9. Increasing the efficiency of blowmolding machines (experiment 9)

From the basic equipment capacity study, it was concluded that the blowmolding machines were a bottleneck in the existing system. The blowmolding machines did not supply enough bottles for the rest of the line. Even before performing the experiment it was obvious that increasing the efficiency of the blowmolding stations would improve the production rate of the system.

To increase the efficiency of the blowmolding machines, the technique of minimizing the repair time of the blowmolding machines was used. Mean time to repair of blowmolding machine number 1, 2, 3 and 4 were changed to 1,617.4, 1,784.2, 1,092.1, and 1,550.4, respectively.

3.1.10. Experimental Method

All experiments were divided into three steps: adjusting experiment conditions, carrying out the simulation, and registering results. Analysis of variance (ANOVA) and multiple comparison, namely Fisher's Least Significant Difference, performed by Minitab version 11 for Windows from Minitab Inc., were employed to compare the proposed and original models.

3.2. Results and Discussion

The results of the experiments are shown in Table D1 to D8. The result of the statistical analysis is presented in Table D9.

Figure 12 the ANOVA test, shows that the average number of filled milk bottles from experiment 5, 3, 7, and 9 were different from the results of the original model. Adding the accumulators and changing the speed of casers and stackers, adding accumulators, increasing the efficiency of casers, and increasing the efficiency of blowmolding machines can be recommended to improve the production rate, respectively. The total number of filled milk containers produced in 16 hours was found to be between 103,465 and 106,135 with a confidence interval of 95 percent by reducing the repair time of blowmolding stations to half of the current repair time. About 5.98 percent improvement in production rate was obtained. Experiment 5, 3, and 7 show improved production rate about 2.14 percent, 2.44 percent, and 3.04 percent, respectively.

One additional experiment was performed, combining the experiments 7 and 9, reducing repair time of blowmolding machines and casers. The total number of filled milk containers produced in this experiment was found to be between 104,713 and 106,071 with a confidence interval of 95%. The result of statistical analysis is presented in Table D10 and it is not significantly different from that of experiment 9, increasing the efficiency of blowmolding machine.

Therefore it can be concluded that increasing the efficiency of blowmolding machines by putting more time and effort to reduce the repair time

is the most suitable solution to improve the output of the current line considering inadequate manpower, spatial, and financial limitations in the plant.

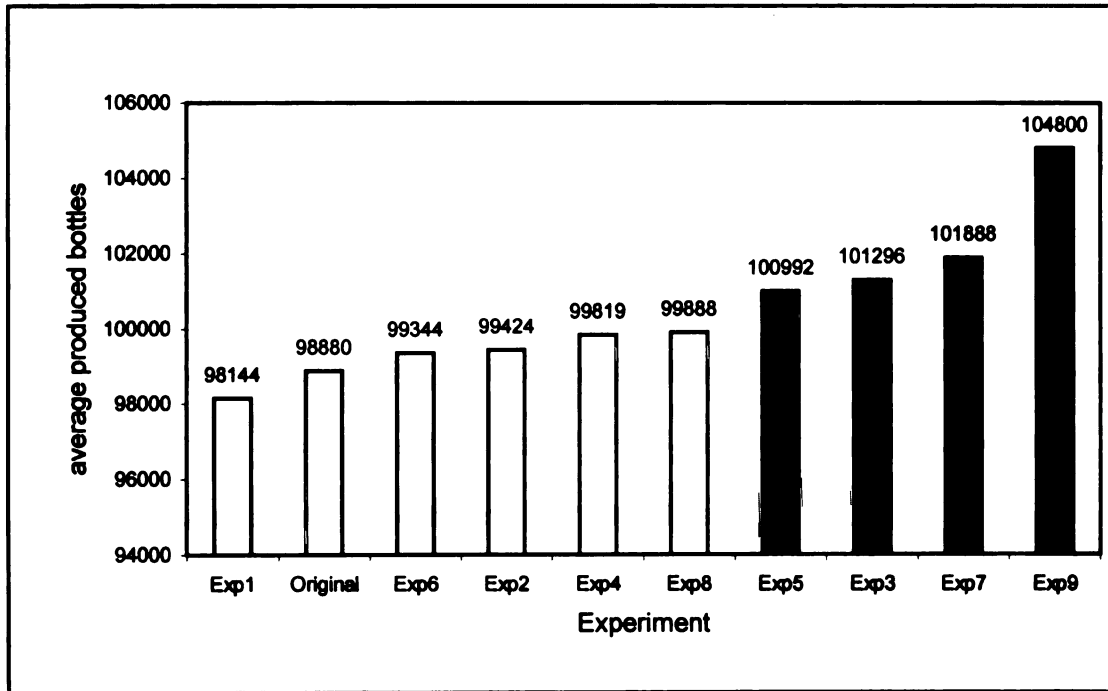


Figure 12. Average number of produced bottles for each experiment

CHAPTER 4

CONCLUSION

The simulation program is a useful tool for packaging line design and optimization. Packaging line variables including the efficiency of equipment, downtime of equipment, and blocked time can be analyzed. Another advantage is that even before actually building a simulation model, a simulation practitioner can gain understanding of the line while collecting data and studying the system.

A simulation of a dairy plant packaging line was built to optimize the line efficiency and to solve current problems on the packaging line. Data were collected and analyzed to build simulation models.

From the simulation study, it was found that the blowmolding machines were a bottleneck in the system. The blowmolding machines did not supply enough bottles for the rest of the line.

Ten experimental models have been built and run to provide alternative solutions to increase production rate and to answer 'what if' questions. From the ten experimental models, increasing the efficiency of blowmolding machines by reducing the repair time was the most beneficial approach to improving the output of the current line.

There has been no implementation of the simulation results to date. However the simulation model predictions agreed very well with actual packaging line results. The models provided a quick and inexpensive means to identify bottlenecks and critical parameters to adjust. However, still it takes long time for

an average plant packaging engineer to learn the simulation software and requires certain amount of programming skills and statistical knowledge to analyze the input data and the output from simulation model runs.

The model can be utilized to evaluate the effectiveness of new equipment to replace existing machines, in addition to being used to design new packaging line for new plant. In this case, the modeler can readily evaluate numerous equipment parameters to identify potential improvement and problems.

APPENDICES

APPENDIX A

MACHINE ELEMENT DATA

Table A1. Machine element data

Element	Speed	Capacity	Length
Blowmolder #1	7.6 seconds/4 bottles	4 bottles	
Blowmolder #2	7.8 seconds/4 bottles	4 bottles	
Blowmolder #3	7.5 seconds/4 bottles	4 bottles	
Blowmolder #4	7.4 seconds/4 bottles	4 bottles	
Stainless steel conveyor	1.9 meters/second	49 bottles	7.45 meters
Conveyor from blowmolder #4 to first line divider	1 meters/second	482 bottles	72.45 meters
Conveyor from stainless steel conveyor to first line divider	1 meters/second	119 bottles	17.85 meters
Conveyor from the first line divider to the second line divider	1 meters/second	1151 bottles	173.08 meters
Conveyor from the second line divider to the filling machine #1	1 meters/second	469 bottles	70.5 meters
Conveyor from the second line divider to the filling machine #2	1 meters/second	189 bottles	28.5 meters
Filling machine #1	0.833 seconds/bottle	26 bottles	
Filling machine #2	0.833seconds/bottle	26 bottles	
Caser #1 and #2	3.33 seconds/case	4 bottles	
Stacker #1 and #2	40 seconds/load	12 cases	
Chain conveyor from the stacker #1 to the cooling storage	0.14 meters/second	13 loads	9 meters
Chain conveyor from the stacker #2 to the cooling storage	0.14 meters/second	34 loads	23 meters
Cooling storage		2090 loads (about 25000 cases)	

* Bottle - 15 centimeter × 15 centimeter (length × width)

* Plastic case - 33 centimeter × 33 centimeter (length × width)

APPENDIX B

EXAMPLE OF RAW DATA OF TIME BETWEEN FAILURE AND TIME TO REPAIR

Table B1. Raw data of time between failure and time to repair of blowmolding machine #1

No.	Time to Repair	Time between Failure	No.	Time to Repair	Time between Failure
1	45	240	30	240	480
2	10	420	31	30	650
3	20	150	32	45	1120
4	20	405	33	60	150
5	45	355	34	60	10
6	85	50	35	35	350
7	10	300	36	10	90
8	45	10	37	45	810
9	165	450	38	15	65
10	45	240	39	360	165
11	10	60	40	10	665
12	180	90	41	30	245
13	10	30	42	45	30
14	120	60	43	10	420
15	50	120	44	10	60
16	30	90	45	90	360
17	100	30	46	30	30
18	150	350	47	10	120
19	12	60	48	20	840
20	10	540	49	10	355
21	10	570	50	10	270
22	100	100	51	45	1080
23	45	540	52	240	420
24	30	810	53	20	300
25	15	540	54	45	60
26	55	10	55	10	240
27	45	540	56	15	450
28	45	360	57	30	1130
29	30	25	58	10	295

* Unit: minute

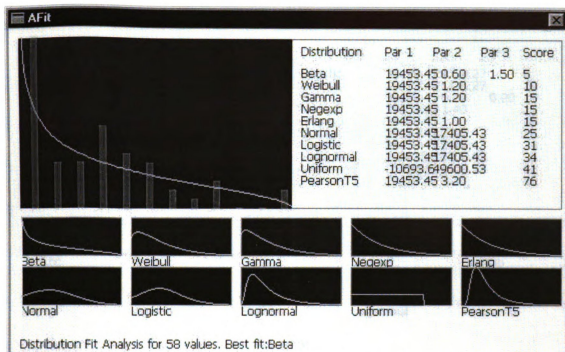


Figure B1. Theoretical distribution of mean time between failure of blowmolding machine #1

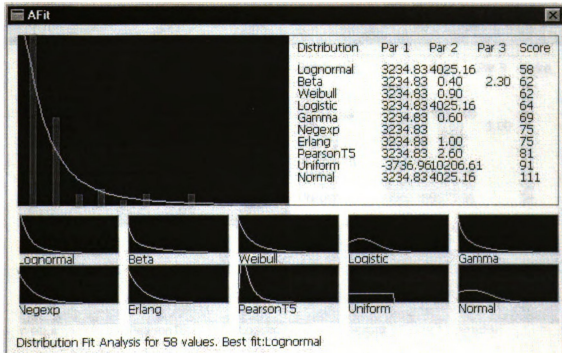


Figure B2. Theoretical distribution of mean time to repair blowmolding machine #1

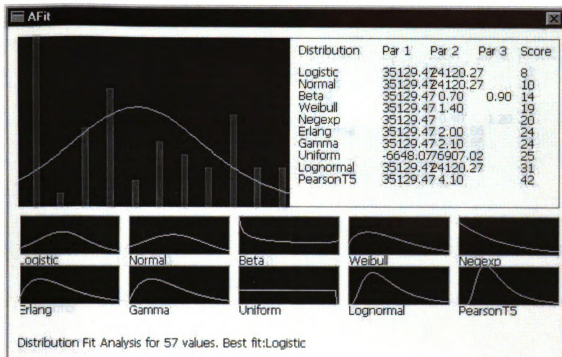


Figure B3. Theoretical distribution of mean time between failure of blowmolding machine #2

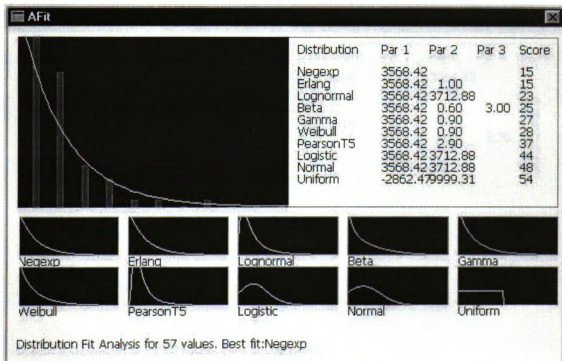


Figure B4. Theoretical distribution of mean time to repair blowmolding machine #2

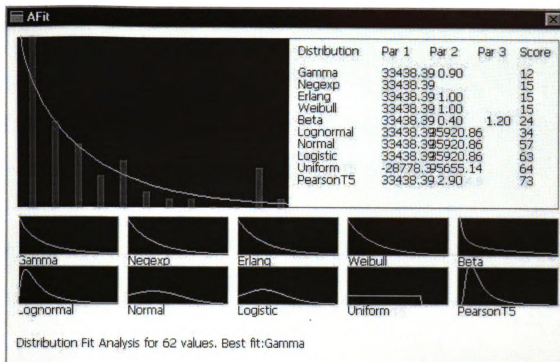


Figure B5. Theoretical distribution of mean time between failure of blowmolding machine #3

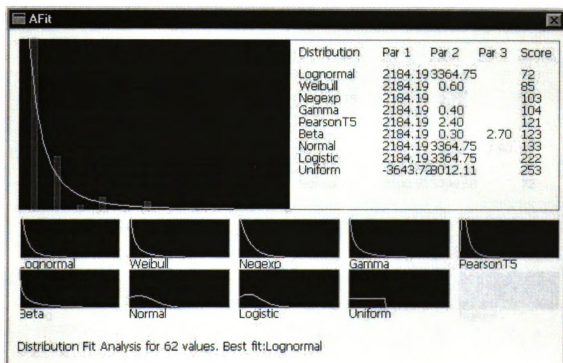


Figure B6. Theoretical distribution of mean time to repair blowmolding machine #3

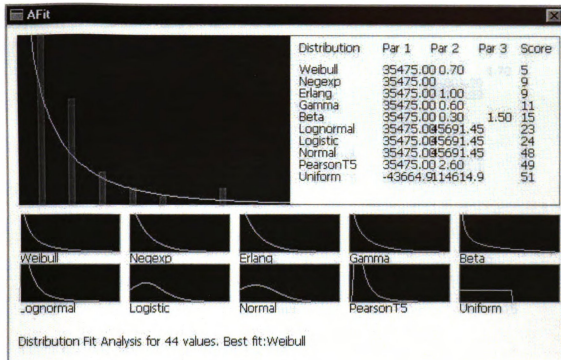


Figure B7. Theoretical distribution of mean time between failure of blowmolding machine #4

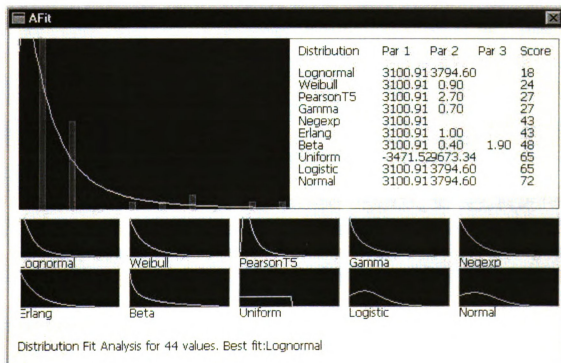


Figure B8. Theoretical distribution of mean time to repair blowmolding machine #4

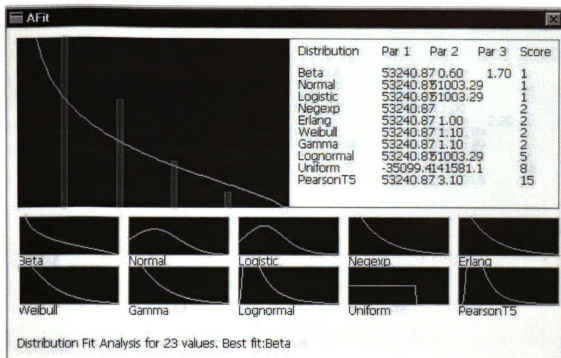


Figure B9. Theoretical distribution of mean time between failure of conveyor

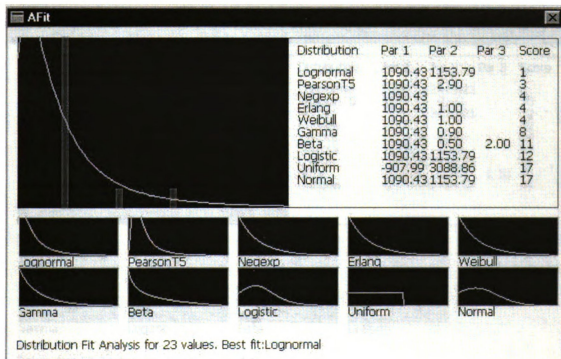


Figure B10. Theoretical distribution of mean time to repair conveyor

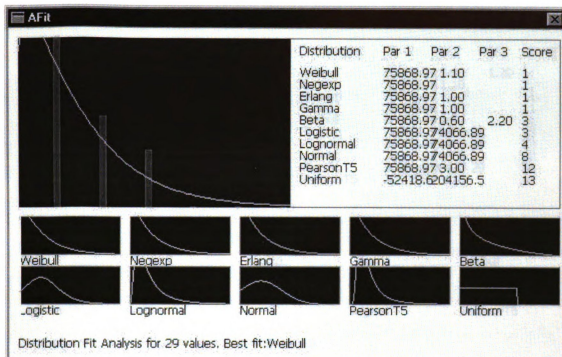


Figure B11. Theoretical distribution of mean time between failure of filling machine #1

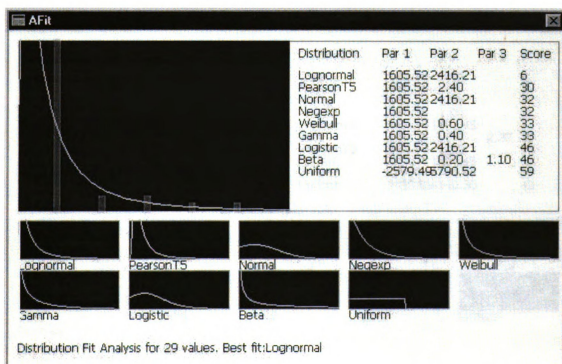


Figure B12. Theoretical distribution of mean time to repair filling machine #1

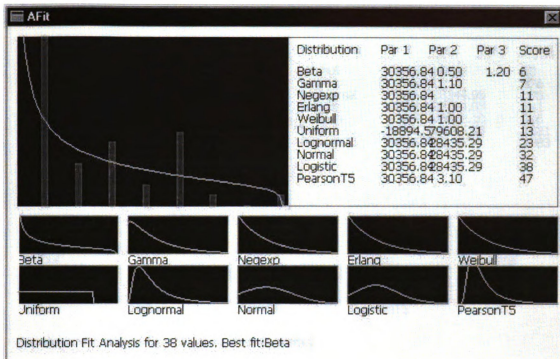


Figure B13. Theoretical distribution of mean time between failure of filling machine #2

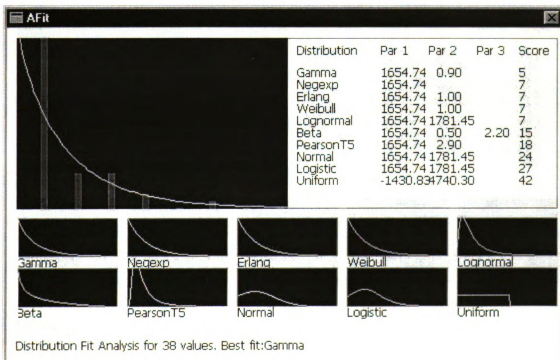


Figure B14. Theoretical distribution of mean time to repair filling machine #2

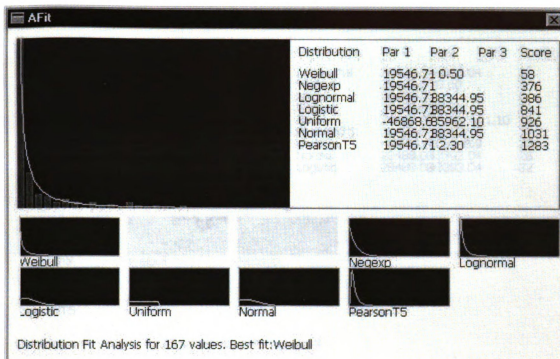


Figure B15. Theoretical distribution of mean time between failure of caser

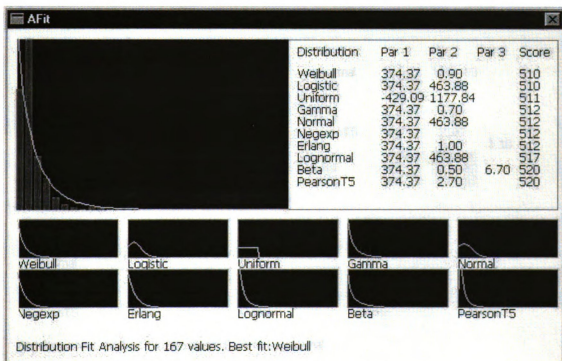


Figure B16. Theoretical distribution of mean time to repair caser

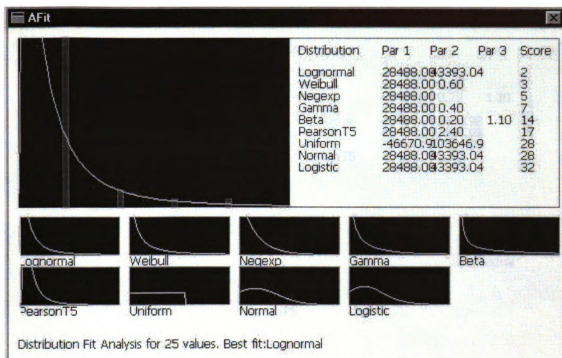


Figure B17. Theoretical distribution of mean time between failure of stacker #1

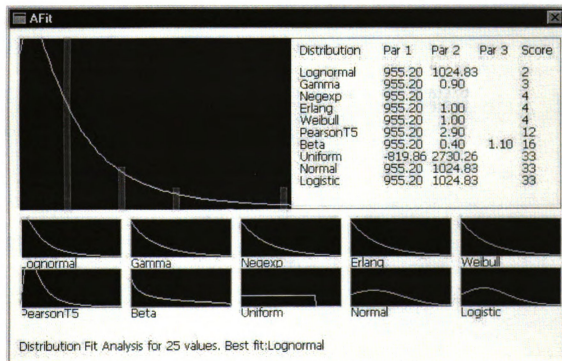


Figure B18. Theoretical distribution of mean time to repair stacker #1

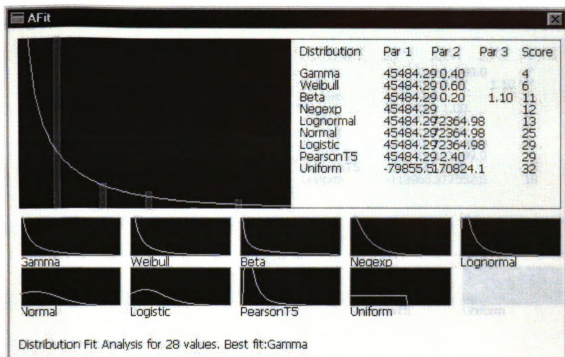


Figure B19. Theoretical distribution of mean time between failure of stacker #2

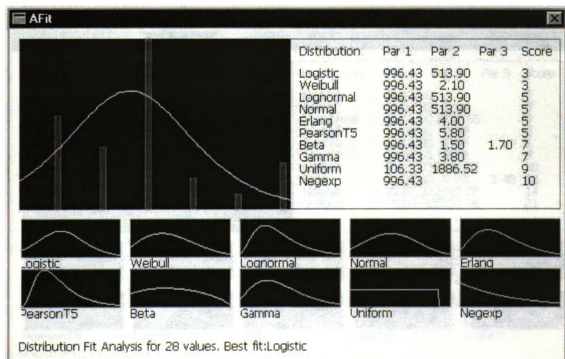


Figure B20. Theoretical distribution of mean time to repair stacker #2

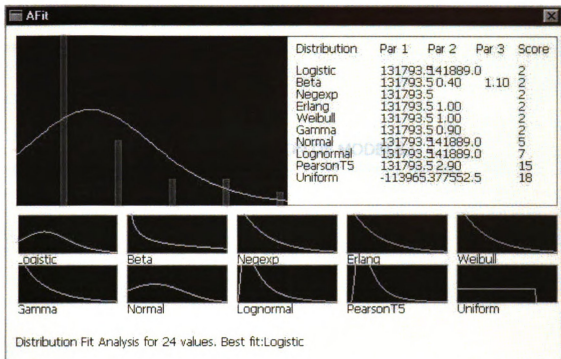


Figure B21. Theoretical distribution of mean time between failure of cooling storage

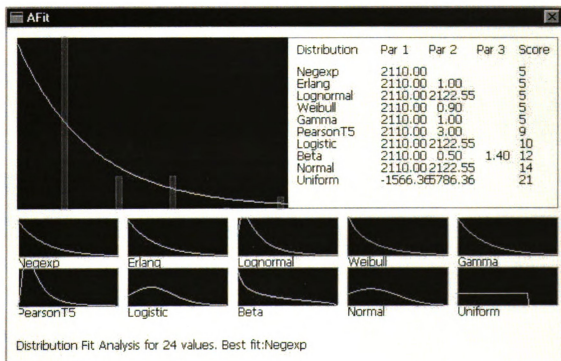


Figure B22. Theoretical distribution of mean time to repair cooling storage

APPENDIX C

DOCUMENTATION OF MODELS

Documentation of Model 1

GENERAL REMARKS

1.SIM consists of 20 elements, 20 jobs and 20 stages.

Time representation is as follows: 60 units make 1 minute,

60 minutes make 1 hour, 8 hours make 1 day.

At request usertli will be executed.

TABLE 1: Element parameters

ELEM NR	NAME	T	CAP	EXIT COND
1	Inou_1	I	2	
2	machine	M	4	
3	Buff_3	B	20	*
4	Mach_4	M	12	*
5	Inou_5	I	2	
6	Mach_6	M	4	
7	Buff_7	B	20	*
8	Mach_8	M	12	*
9	Inou_9	I	2	
10	Mach_10	M	4	
11	Buff_11	B	20	*
12	Mach_12	M	12	*
13	Inou_13	I	2	
14	Mach_14	M	4	
15	Buff_15	B	20	*
16	Mach_16	M	12	*
17	Regrinder	B	100	
18	Inou_18	I	2	
19	Buff_19	B	30000	
20	Inou_20	I	2	

TABLE 3: Job parameters

JOB NR	NAME	ELEM	JOBTIME			BATCH IN			OUTBATCH		
			par1	dis	par2	par1	dis	par2	par1	dis	par2
1	E1:J1	1				1.00			1.00		
2	E2:J1	2	7.60			4.00			4.00		

3	E3:J1	3	7.60	4.00	4.00
4	E4:J1	4	1.90	1.00	1.00
5	E5:J1	5		1.00	1.00
6	E6:J1	6	7.80	4.00	4.00
7	E7:J1	7	7.80	4.00	4.00
8	E8:J1	8	2.00	1.00	1.00
9	E9:J1	9		1.00	1.00
10	E10:J1	10	7.50	4.00	4.00
11	E11:J1	11	7.50	4.00	4.00
12	E12:J1	12	1.90	1.00	1.00
13	E13:J1	13		1.00	1.00
14	E14:J1	14	7.40	4.00	4.00
15	E15:J1	15	7.40	4.00	4.00
16	E16:J1	16	1.90	1.00	1.00
17	E17:J1	17	5.00	1.00	1.00
18	E18:J1	18		1.00	1.00
19	E19:J1	19		1.00	1.00
20	E20:J1	20		1.00	1.00

ROUTE LISTING

ROUTE NR	STAGE NR	NAME	USES JOBNR	SEND TO
1	1	R1:1	1	2
1	2	R1:2	2	3
1	3	R1:3	3	4
1	4	R1:4	4	bernoulli[90,19,17]
1	5	R1:5	5	6
1	6	R1:6	6	7
1	7	R1:7	7	8
1	8	R1:8	8	bernoulli[92,19,17]
1	9	R1:9	9	10
1	10	R1:10	10	11
1	11	R1:11	11	12
1	12	R1:12	12	bernoulli[96,19,17]
1	13	R1:13	13	14
1	14	R1:14	14	15
1	15	R1:15	15	16
1	16	R1:16	16	bernoulli[93,19,17]
1	17	R1:17	17	18
1	18	R1:18	18	0
1	19	R1:19	19	20
1	20	R1:20	20	0

PRODUCT PARAMETERS

```

prod 1      size= 0.15      icon= 10
prod 2      size= 0.15      icon= 11
prod 3      size= 0.15      icon= 12
prod 4      size= 0.15      icon= 13
All other products default (size=1 and weight=1).

```

STOCK LISTING

```
(1)  (R1:1)      --> 1    product  (code=1)
(5)  (R1:5)      --> 1    product  (code=2)
(9)  (R1:9)      --> 1    product  (code=3)
(13) (R1:13)     --> 1    product  (code=4)
```

TLI SYNTAX LISTING

```
(3)  Exit condition  = elqueue[3]>16
(4)  Exit condition  = elqueue[4]>8
(7)  Exit condition  = elqueue[7]>16
(8)  Exit condition  = elqueue[8]>8
(11) Exit condition  = elqueue[11]>16
(12) Exit condition  = elqueue[12]>8
(15) Exit condition  = elqueue[15]>16
(16) Exit condition  = elqueue[16]>8
(2)  MTBF            =
(2)  MTTR            =
(4)  Send to         = bernoulli[90,19,17]
(8)  Send to         = bernoulli[92,19,17]
(12) Send to         = bernoulli[96,19,17]
(16) Send to         = bernoulli[93,19,17]
```

EXECUTE FUNCTION AT REQUEST: usertli

End of document

Documentation of Model 2

GENERAL REMARKS

2.SIM consists of 27 elements, 27 jobs and 27 stages.
 Time representation is as follows: 60 units make 1 minute,
 60 minutes make 1 hour, 8 hours make 1 day.
 The systemsize has been changed to 10000.
 At request usertli will be executed.

TABLE 1: Element parameters

ELEM NR	NAME	T	CAP	EXIT COND	QUEU DISC
1	Inou_1	I	2000		Fifo
2	Mach_2	M	4		Fifo
3	Buff_3	B	20	*	Fifo
4	Mach_4	M	12	*	Fifo
5	Inou_5	I	2		Fifo
6	Mach_6	M	4		Fifo
7	Buff_7	B	20	*	Fifo
8	Mach_8	M	12	*	Fifo
9	Inou_9	I	2		Fifo
10	Mach_10	M	4		Fifo
11	Buff_11	B	20	*	Fifo
12	Mach_12	M	12	*	Fifo
13	Inou_13	I	2		Fifo
14	Mach_14	M	4		Fifo
15	Buff_15	B	20	*	Fifo
16	Mach_16	M	12	*	Fifo
17	Buff_17	B	100		Fifo
18	Inou_18	I	2		Fifo
19	Conv_19	C	11		Location
20	Conv_20	C	13		Location
21	Conv_21	C	25		Location
22	Conv_22	C	119		Location
23	Conv_23	C	221		Location
24	Conv_24	C	261		Location
25	Conv_25	C	3333		Location
26	Buff_26	B	900000		Fifo
27	Inou_27	I	2		Fifo

TABLE 2: Element parameters (various) --> CONVEYOR/WAREHOUSE/RESERVOIR

ELEM NR	NAME	T	CAP	PROD SPAC	ACM	SPEED	LNGTH
19	Conv_19	C	11		Y	1.90	1.65

20	Conv_20	C	13	Y	1.90	2.00
21	Conv_21	C	25	Y	1.90	3.80
22	Conv_22	C	119	Y	1.00	17.85
23	Conv_23	C	221	Y	1.00	33.22
24	Conv_24	C	261	Y	1.00	39.23
25	Conv_25	C	3333	Y	1.00	500.00

TABLE 3: Job parameters

JOB NR	NAME	ELEM	JOBTIME			BATCH IN			OUTBATCH		
			par1	dis	par2	par1	dis	par2	par1	dis	par2
1	E1:J1	1				1.00			1.00		
2	E2:J1	2	7.60			4.00			4.00		
3	E3:J1	3	7.60			4.00			4.00		
4	E4:J1	4	1.90			1.00			1.00		
5	E5:J1	5				1.00			1.00		
6	E6:J1	6	7.80			4.00			4.00		
7	E7:J1	7	7.80			4.00			4.00		
8	E8:J1	8	1.95			1.00			1.00		
9	E9:J1	9				1.00			1.00		
10	E10:J1	10	7.50			4.00			4.00		
11	E11:J1	11	7.50			4.00			4.00		
12	E12:J1	12	1.88			1.00			1.00		
13	E13:J1	13				1.00			1.00		
14	E14:J1	14	7.40			4.00			4.00		
15	E15:J1	15	7.40			4.00			4.00		
16	E16:J1	16	1.85			1.00			1.00		
17	E17:J1	17	5.00			1.00			1.00		
18	E18:J1	18				1.00			1.00		
19	E19:J1	19				1.00			1.00		
20	E20:J1	20				1.00			1.00		
21	E21:J1	21				1.00			1.00		
22	E22:J1	22				1.00			1.00		
23	E23:J1	23				1.00			1.00		
24	E24:J1	24				1.00			1.00		
25	E25:J1	25				1.00			1.00		
26	E26:J1	26	0.10			1.00			1.00		
27	E27:J1	27				1.00			1.00		

ROUTE LISTING

ROUTE NR	STAGE NR	NAME	USES JOBNR	SEND TO
1	1	R1:1	1	2
1	2	R1:2	2	3
1	3	R1:3	3	4
1	4	R1:4	4	bernoulli[90,21,17]
1	5	R1:5	5	6
1	6	R1:6	6	7
1	7	R1:7	7	8

1	8	R1:8	8	bernoulli[92,20,17]
1	9	R1:9	9	10
1	10	R1:10	10	11
1	11	R1:11	11	12
1	12	R1:12	12	bernoulli[96,19,17]
1	13	R1:13	13	14
1	14	R1:14	14	15
1	15	R1:15	15	16
1	16	R1:16	16	bernoulli[93,23,17]
1	17	R1:17	17	18
1	18	R1:18	18	19
1	19	R1:19	19	20
1	20	R1:20	20	21
1	21	R1:21	21	22
1	22	R1:22	22	25
1	23	R1:23	23	24
1	24	R1:24	24	25
1	25	R1:25	25	26
1	26	R1:26	26	27
1	27	R1:27	27	0

EVENT LIST

1. Time= 0.00 (repeated every 27.00 units)
Tli = open22
2. Time= 15.00 (repeated every 27.00 units)
Tli = close22
3. Time= 19.00 (repeated every 27.00 units)
Tli = open24
4. Time= 23.00 (repeated every 27.00 units)
Tli = close24

PRODUCT PARAMETERS

prod 1	size= 0.15	icon= 10
prod 2	size= 0.15	icon= 11
prod 3	size= 0.15	icon= 12
prod 4	size= 0.15	icon= 13

All other products default (size=1 and weight=1).

STOCK LISTING

(1)	(R1:1)	-->	1	product	(code=1)
(5)	(R1:5)	-->	1	product	(code=2)
(9)	(R1:9)	-->	1	product	(code=3)
(13)	(R1:13)	-->	1	product	(code=4)

TLI SYNTAX LISTING

```
-----
(3)  Exit condition  = elqueue[3]>16
(4)  Exit condition  = elqueue[4]>8
(7)  Exit condition  = elqueue[7]>16
(8)  Exit condition  = elqueue[8]>8
(11) Exit condition  = elqueue[11]>16
(12) Exit condition  = elqueue[12]>8
(15) Exit condition  = elqueue[15]>16
(16) Exit condition  = elqueue[16]>8
(2)  MTBF            =
(2)  MTTR            =
(4)  Send to         = bernoulli[90,21,17]
(8)  Send to         = bernoulli[92,20,17]
(12) Send to         = bernoulli[96,19,17]
(16) Send to         = bernoulli[93,23,17]
EXECUTE FUNCTION AT REQUEST: usertli
```

TLI FUNCTIONS

function open22

```
    elsend[22]:=1
    elsend[24]:=0
```

function open24

```
    elsend[22]:=0
    elsend[24]:=1
```

function close22

```
    elsend[22]:=0
    elsend[24]:=0
```

function close24

```
    elsend[22]:=0
    elsend[24]:=0
```

End of document

Documentation of Model 3

GENERAL REMARKS

3.SIM consists of 41 elements, 41 jobs and 41 stages.
 Time representation is as follows: 60 units make 1 minute,
 60 minutes make 1 hour, 8 hours make 1 day.
 The systemsize has been changed to 10000.
 At request usertli will be executed.

TABLE 1: Element parameters

ELEM NR	NAME	T	CAP	EXIT COND	QUEU DISC
1	Inou_1	I	2000		Fifo
2	Mach_2	M	4		Fifo
3	Buff_3	B	20	*	Fifo
4	Mach_4	M	12	*	Fifo
5	Inou_5	I	2		Fifo
6	Mach_6	M	4		Fifo
7	Buff_7	B	20	*	Fifo
8	Mach_8	M	12	*	Fifo
9	Inou_9	I	2		Fifo
10	Mach_10	M	4		Fifo
11	Buff_11	B	20	*	Fifo
12	Mach_12	M	12	*	Fifo
13	Inou_13	I	2		Fifo
14	Mach_14	M	4		Fifo
15	Buff_15	B	20	*	Fifo
16	Mach_16	M	12	*	Fifo
17	Buff_17	B	100		Fifo
18	Inou_18	I	2		Fifo
19	Conv_19	C	11		Location
20	Conv_20	C	13		Location
21	Conv_21	C	25		Location
22	Conv_22	C	119		Location
23	Conv_23	C	221		Location
24	Conv_24	C	261		Location
25	Conv_25	C	228		Location
26	Conv_26	C	229		Location
27	Conv_27	C	46		Location
28	Conv_28	C	186		Location
29	Conv_29	C	163		Location
30	Conv_30	C	66		Location
31	Conv_31	C	120		Location
32	Conv_32	C	113		Location
33	Conv_33	C	403		Location
34	Conv_34	C	63		Location
35	Conv_35	C	63		Location
36	Conv_36	C	63		Location

37	Buff_37	B	1000	Fifo
38	Inou_38	I	2	Fifo
39	Conv_39	C	66	Location
40	Buff_40	B	1000	Fifo
41	Inou_41	I	2	Fifo

TABLE 2: Element parameters (various) --> CONVEYOR/WAREHOUSE/RESERVOIR

ELEM NR	NAME	T	CAP	PROD SPAC	ACM	SPEED	LNTH
19	Conv_19	C	11		Y	1.90	1.65
20	Conv_20	C	13		Y	1.90	2.00
21	Conv_21	C	25		Y	1.90	3.80
22	Conv_22	C	119		Y	1.00	17.85
23	Conv_23	C	221		Y	1.00	33.22
24	Conv_24	C	261		Y	1.00	39.23
25	Conv_25	C	228		Y	1.00	34.29
26	Conv_26	C	229		Y	1.00	34.29
27	Conv_27	C	46		Y	1.00	7.00
28	Conv_28	C	186		Y	1.00	28.00
29	Conv_29	C	163		Y	1.00	24.50
30	Conv_30	C	66		Y	1.00	10.00
31	Conv_31	C	120		Y	1.00	18.00
32	Conv_32	C	113		Y	1.00	17.00
33	Conv_33	C	403		Y	1.00	60.50
34	Conv_34	C	63		Y	1.00	9.50
35	Conv_35	C	63		Y	1.00	9.50
36	Conv_36	C	63		Y	1.00	9.50
39	Conv_39	C	66		Y	1.00	10.00

TABLE 3: Job parameters

JOB NR	NAME	ELEM	JOBTIME		BATCH IN		OUTBATCH	
			par1	dis	par1	dis	par1	dis
1	E1:J1	1			1.00		1.00	
2	E2:J1	2	7.60		4.00		4.00	
3	E3:J1	3	7.60		4.00		4.00	
4	E4:J1	4	1.90		1.00		1.00	
5	E5:J1	5			1.00		1.00	
6	E6:J1	6	7.80		4.00		4.00	
7	E7:J1	7	7.80		4.00		4.00	
8	E8:J1	8	1.95		1.00		1.00	
9	E9:J1	9			1.00		1.00	
10	E10:J1	10	7.50		4.00		4.00	
11	E11:J1	11	7.50		4.00		4.00	
12	E12:J1	12	1.88		1.00		1.00	
13	E13:J1	13			1.00		1.00	
14	E14:J1	14	7.40		4.00		4.00	

15	E15:J1	15	7.40	4.00	4.00
16	E16:J1	16	1.85	1.00	1.00
17	E17:J1	17	5.00	1.00	1.00
18	E18:J1	18		1.00	1.00
19	E19:J1	19		1.00	1.00
20	E20:J1	20		1.00	1.00
21	E21:J1	21		1.00	1.00
22	E22:J1	22		1.00	1.00
23	E23:J1	23		1.00	1.00
24	E24:J1	24		1.00	1.00
25	E25:J1	25		1.00	1.00
26	E26:J1	26		1.00	1.00
27	E27:J1	27		1.00	1.00
28	E28:J1	28		1.00	1.00
29	E29:J1	29		1.00	1.00
30	E30:J1	30		1.00	1.00
31	E31:J1	31		1.00	1.00
32	E32:J1	32		1.00	1.00
33	E33:J1	33		1.00	1.00
34	E34:J1	34		1.00	1.00
35	E35:J1	35		1.00	1.00
36	E36:J1	36		1.00	1.00
37	E37:J1	37	1.00	1.00	1.00
38	E38:J1	38		1.00	1.00
39	E39:J1	39		1.00	1.00
40	E40:J1	40	1.00	1.00	1.00
41	E41:J1	41		1.00	1.00

ROUTE LISTING

ROUTE NR	STAGE NR	NAME	USES JOBNR	SEND TO
1	1	R1:1	1	2
1	2	R1:2	2	3
1	3	R1:3	3	4
1	4	R1:4	4	bernoulli[90,21,17]
1	5	R1:5	5	6
1	6	R1:6	6	7
1	7	R1:7	7	8
1	8	R1:8	8	bernoulli[92,20,17]
1	9	R1:9	9	10
1	10	R1:10	10	11
1	11	R1:11	11	12
1	12	R1:12	12	bernoulli[96,19,17]
1	13	R1:13	13	14
1	14	R1:14	14	15
1	15	R1:15	15	16
1	16	R1:16	16	bernoulli[93,23,17]
1	17	R1:17	17	18
1	18	R1:18	18	19
1	19	R1:19	19	20
1	20	R1:20	20	21
1	21	R1:21	21	22

1	22	R1:22	22	25
1	23	R1:23	23	24
1	24	R1:24	24	25
1	25	R1:25	25	26
1	26	R1:26	26	27
1	27	R1:27	27	28
1	28	R1:28	28	29
1	29	R1:29	29	30
1	30	R1:30	30	31
1	31	R1:31	31	32
1	32	R1:32	32	if time 8<4 then 33 else 34
1	33	R1:33	33	39
1	34	R1:34	34	35
1	35	R1:35	35	36
1	36	R1:36	36	37
1	37	R1:37	37	38
1	38	R1:38	38	0
1	39	R1:39	39	40
1	40	R1:40	40	41
1	41	R1:41	41	0

EVENT LIST

1. Time= 0.00 (repeated every 27.00 units)
Tli = open22
2. Time= 15.00 (repeated every 27.00 units)
Tli = close22
3. Time= 19.00 (repeated every 27.00 units)
Tli = open24
4. Time= 23.00 (repeated every 27.00 units)
Tli = close24

PRODUCT PARAMETERS

prod 1 size= 0.15 icon= 10
 prod 2 size= 0.15 icon= 11
 prod 3 size= 0.15 icon= 12
 prod 4 size= 0.15 icon= 13
 All other products default (size=1 and weight=1).

STOCK LISTING

(1)	(R1:1)	-->	1	product	(code=1)
(5)	(R1:5)	-->	1	product	(code=2)
(9)	(R1:9)	-->	1	product	(code=3)
(13)	(R1:13)	-->	1	product	(code=4)

TLI SYNTAX LISTING

```
-----
(3)  Exit condition    = elqueue[3]>16
(4)  Exit condition    = elqueue[4]>8
(7)  Exit condition    = elqueue[7]>16
(8)  Exit condition    = elqueue[8]>8
(11) Exit condition    = elqueue[11]>16
(12) Exit condition    = elqueue[12]>8
(15) Exit condition    = elqueue[15]>16
(16) Exit condition    = elqueue[16]>8
(2)  MTBF              =
(2)  MTTR              =
(4)  Send to           = bernoulli[90,21,17]
(8)  Send to           = bernoulli[92,20,17]
(12) Send to           = bernoulli[96,19,17]
(16) Send to           = bernoulli[93,23,17]
(32) Send to           = if time|8<4 then 33 else 34
EXECUTE FUNCTION AT REQUEST: usertli
```

TLI FUNCTIONS

function open22

```
    elsend[22]:=1
    elsend[24]:=0
```

function open24

```
    elsend[22]:=0
    elsend[24]:=1
```

function close22

```
    elsend[22]:=0
    elsend[24]:=0
```

function close24

```
    elsend[22]:=0
    elsend[24]:=0
```

End of document

Documentation of Model 4

GENERAL REMARKS

4.SIM consists of 51 elements, 51 jobs and 51 stages.
 Time representation is as follows: 60 units make 1 minute,
 60 minutes make 1 hour, 8 hours make 1 day.
 The systemsize has been changed to 10000.
 At request usertli will be executed.

TABLE 1: Element parameters

ELEM NR	NAME	T	CAP	EXIT COND	QUEU DISC
1	Inou_1	I	2000		Fifo
2	Mach_2	M	4		Fifo
3	Buff_3	B	20	*	Fifo
4	Mach_4	M	12	*	Fifo
5	Inou_5	I	2		Fifo
6	Mach_6	M	4		Fifo
7	Buff_7	B	20	*	Fifo
8	Mach_8	M	12	*	Fifo
9	Inou_9	I	2		Fifo
10	Mach_10	M	4		Fifo
11	Buff_11	B	20	*	Fifo
12	Mach_12	M	12	*	Fifo
13	Inou_13	I	2		Fifo
14	Mach_14	M	4		Fifo
15	Buff_15	B	20	*	Fifo
16	Mach_16	M	12	*	Fifo
17	Buff_17	B	100		Fifo
18	Inou_18	I	2		Fifo
19	Conv_19	C	11		Location
20	Conv_20	C	13		Location
21	Conv_21	C	25		Location
22	Conv_22	C	119		Location
23	Conv_23	C	221		Location
24	Conv_24	C	261		Location
25	Conv_25	C	228		Location
26	Conv_26	C	229		Location
27	Conv_27	C	46		Location
28	Conv_28	C	186		Location
29	Conv_29	C	163		Location
30	Conv_30	C	66		Location
31	Conv_31	C	120		Location
32	Conv_32	C	113		Location
33	Conv_33	C	403		Location
34	Conv_34	C	63		Location
35	Conv_35	C	63		Location

36	Conv_36	C	63	Location
37	Conv_37	C	66	Location
38	Mach_38	M	26	Fifo
39	Buff_39	B	48	Fifo
40	Mach_40	M	4	Fifo
41	Buff_41	B	5	Fifo
42	Mach_42	M	12	Fifo
43	Conv_43	C	34	Location
44	Mach_44	M	26	Fifo
45	Buff_45	B	48	Fifo
46	Mach_46	M	4	Fifo
47	Buff_47	B	5	Fifo
48	Mach_48	M	12	Fifo
49	Conv_49	C	13	Location
50	Buff_50	B	2090	Fifo
51	Inou_51	I	2	Fifo

TABLE 2: Element parameters (various) --> CONVEYOR/WAREHOUSE/RESERVOIR

ELEM NR	NAME	T	CAP	PROD SPAC	ACM	SPEED	LNTH
19	Conv_19	C	11		Y	1.90	1.65
20	Conv_20	C	13		Y	1.90	2.00
21	Conv_21	C	25		Y	1.90	3.80
22	Conv_22	C	119		Y	1.00	17.85
23	Conv_23	C	221		Y	1.00	33.22
24	Conv_24	C	261		Y	1.00	39.23
25	Conv_25	C	228		Y	1.00	34.29
26	Conv_26	C	229		Y	1.00	34.29
27	Conv_27	C	46		Y	1.00	7.00
28	Conv_28	C	186		Y	1.00	28.00
29	Conv_29	C	163		Y	1.00	24.50
30	Conv_30	C	66		Y	1.00	10.00
31	Conv_31	C	120		Y	1.00	18.00
32	Conv_32	C	113		Y	1.00	17.00
33	Conv_33	C	403		Y	1.00	60.50
34	Conv_34	C	63		Y	1.00	9.50
35	Conv_35	C	63		Y	1.00	9.50
36	Conv_36	C	63		Y	1.00	9.50
37	Conv_37	C	66		Y	1.00	10.00
43	Conv_43	C	34		Y	0.14	23.00
49	Conv_49	C	13		Y	0.14	9.00

TABLE 3: Job parameters

JOB NR	NAME	ELEM	JOBTIME par1 dis par2	BATCH IN par1 dis par2	OUTBATCH par1 dis par2	TRIG ENTR
1	E1:J1	1		1.00	1.00	
2	E2:J1	2	7.60	4.00	4.00	

3	E3:J1	3	7.60	4.00	4.00	
4	E4:J1	4	1.90	1.00	1.00	
5	E5:J1	5		1.00	1.00	
6	E6:J1	6	7.80	4.00	4.00	
7	E7:J1	7	7.80	4.00	4.00	
8	E8:J1	8	1.95	1.00	1.00	
9	E9:J1	9		1.00	1.00	
10	E10:J1	10	7.50	4.00	4.00	
11	E11:J1	11	7.50	4.00	4.00	
12	E12:J1	12	1.88	1.00	1.00	
13	E13:J1	13		1.00	1.00	
14	E14:J1	14	7.40	4.00	4.00	
15	E15:J1	15	7.40	4.00	4.00	
16	E16:J1	16	1.85	1.00	1.00	
17	E17:J1	17	5.00	1.00	1.00	
18	E18:J1	18		1.00	1.00	
19	E19:J1	19		1.00	1.00	
20	E20:J1	20		1.00	1.00	
21	E21:J1	21		1.00	1.00	
22	E22:J1	22		1.00	1.00	
23	E23:J1	23		1.00	1.00	
24	E24:J1	24		1.00	1.00	
25	E25:J1	25		1.00	1.00	
26	E26:J1	26		1.00	1.00	
27	E27:J1	27		1.00	1.00	
28	E28:J1	28		1.00	1.00	
29	E29:J1	29		1.00	1.00	
30	E30:J1	30		1.00	1.00	
31	E31:J1	31		1.00	1.00	
32	E32:J1	32		1.00	1.00	
33	E33:J1	33		1.00	1.00	
34	E34:J1	34		1.00	1.00	
35	E35:J1	35		1.00	1.00	
36	E36:J1	36		1.00	1.00	
37	E37:J1	37		1.00	1.00	
38	E38:J1	38	0.83	1.00	1.00	
39	E39:J1	39	TLI	1.00	1.00	*
40	E40:J1	40	0.83	4.00	1.00	*
41	E41:J1	41	TLI	1.00	1.00	*
42	E42:J1	42	3.33	12.00	1.00	*
43	E43:J1	43		1.00	1.00	
44	E44:J1	44	0.83	1.00	1.00	
45	E45:J1	45	TLI	1.00	1.00	*
46	E46:J1	46	0.83	4.00	1.00	*
47	E47:J1	47	TLI	1.00	1.00	*
48	E48:J1	48	3.33	12.00	1.00	*
49	E49:J1	49		1.00	1.00	
50	E50:J1	50	600.00	1.00	1.00	*
51	E51:J1	51		1.00	1.00	

ROUTE LISTING

ROUTE NR	STAGE NR	NAME	USES JOBNR	SEND TO
1	1	R1:1	1	2
1	2	R1:2	2	3
1	3	R1:3	3	4
1	4	R1:4	4	bernoulli[90,21,17]
1	5	R1:5	5	6
1	6	R1:6	6	7
1	7	R1:7	7	8
1	8	R1:8	8	bernoulli[92,20,17]
1	9	R1:9	9	10
1	10	R1:10	10	11
1	11	R1:11	11	12
1	12	R1:12	12	bernoulli[96,19,17]
1	13	R1:13	13	14
1	14	R1:14	14	15
1	15	R1:15	15	16
1	16	R1:16	16	bernoulli[93,23,17]
1	17	R1:17	17	18
1	18	R1:18	18	0
1	19	R1:19	19	20
1	20	R1:20	20	21
1	21	R1:21	21	22
1	22	R1:22	22	25
1	23	R1:23	23	24
1	24	R1:24	24	25
1	25	R1:25	25	26
1	26	R1:26	26	27
1	27	R1:27	27	28
1	28	R1:28	28	29
1	29	R1:29	29	30
1	30	R1:30	30	31
1	31	R1:31	31	32
1	32	R1:32	32	if time 8<4 then 33 else 34
1	33	R1:33	33	37
1	34	R1:34	34	35
1	35	R1:35	35	36
1	36	R1:36	36	38
1	37	R1:37	37	44
1	38	R1:38	38	39
1	39	R1:39	39	40
1	40	R1:40	40	41
1	41	R1:41	41	42
1	42	R1:42	42	43
1	43	R1:43	43	50
1	44	R1:44	44	45
1	45	R1:45	45	46
1	46	R1:46	46	47
1	47	R1:47	47	48
1	48	R1:48	48	49
1	49	R1:49	49	50
1	50	R1:50	50	51
1	51	R1:51	51	0

EVENT LIST

1. Time= 0.00 (repeated every 27.00 units)
Tli = open22
2. Time= 15.00 (repeated every 27.00 units)
Tli = close22
3. Time= 19.00 (repeated every 27.00 units)
Tli = open24
4. Time= 23.00 (repeated every 27.00 units)
Tli = close24

PRODUCT PARAMETERS

prod 1	size= 0.15	icon= 43
prod 2	size= 0.15	icon= 44
prod 3	size= 0.15	icon= 45
prod 4	size= 0.15	icon= 46
prod 5	size= 0.33	icon= 41
prod 6	size= 0.66	icon= 23
prod 7	size= 1.00	icon= 2

All other products default (size=1 and weight=1).

STOCK LISTING

(1)	(R1:1)	-->	1	product	(code=1)
(5)	(R1:5)	-->	1	product	(code=2)
(9)	(R1:9)	-->	1	product	(code=3)
(13)	(R1:13)	-->	1	product	(code=4)

TLI SYNTAX LISTING

(3)	Exit condition	=	elqueue[3]>16
(4)	Exit condition	=	elqueue[4]>8
(7)	Exit condition	=	elqueue[7]>16
(8)	Exit condition	=	elqueue[8]>8
(11)	Exit condition	=	elqueue[11]>16
(12)	Exit condition	=	elqueue[12]>8
(15)	Exit condition	=	elqueue[15]>16
(16)	Exit condition	=	elqueue[16]>8
(2)	MTBF	=	
(2)	MTTR	=	
(39)	Trig. on Entry	=	att1[C]:=time+8
(39)	Jobtime	=	att1[E,1]-time
(40)	Trig. on Entry	=	product[C]:=5

```

(41) Trig. on Entry    = att1[C]:=time+8
(41) Jobtime           = att1[E,1]-time
(42) Trig. on Entry    = product[C]:=6
(45) Trig. on Entry    = att1[C]:=time+8
(45) Jobtime           = att1[E,1]-time
(46) Trig. on Entry    = product[C]:=5
(47) Trig. on Entry    = att1[C]:=time+8
(47) Jobtime           = att1[E,1]-time
(48) Trig. on Entry    = product[C]:=6
(50) Trig. on Entry    = product[C]:=7
(4)  Send to           = bernoulli[90,21,17]
(8)  Send to           = bernoulli[92,20,17]
(12) Send to           = bernoulli[96,19,17]
(16) Send to           = bernoulli[93,23,17]
(32) Send to           = if time|8<4 then 33 else 34
EXECUTE FUNCTION AT REQUEST: usertli

```

TLI FUNCTIONS

function open22

```

    elsend[22]:=1
    elsend[24]:=0

```

function open24

```

    elsend[22]:=0
    elsend[24]:=1

```

function close22

```

    elsend[22]:=0
    elsend[24]:=0

```

function close24

```

    elsend[22]:=0
    elsend[24]:=0

```

End of document

Documentation of Model 5

GENERAL REMARKS

5.SIM consists of 51 elements, 52 jobs and 52 stages.
Time representation is as follows: 60 units make 1 minute,
60 minutes make 1 hour, 24 hours make 1 day.
The systemsize has been changed to 10000, and the number of attributes
is 2
At request usertli will be executed.

TABLE 1: Element parameters

ELEM NR	NAME	T	CAP	EXIT COND	QUEU DISC	MTBF par1	dis	par2	MTTR par1	dis	par2
1	Inou_1	I	2000		Fifo						
2	Mach_2	M	4		Fifo		TLI		3234.60	Log	4025.16
3	Buff_3	B	20	*	Fifo						
4	Mach_4	M	12	*	Fifo						
5	Inou_5	I	2		Fifo						
6	Mach_6	M	4		Fifo	100458.40	Log	145152.20	TLI		
7	Buff_7	B	20	*	Fifo						
8	Mach_8	M	12	*	Fifo						
9	Inou_9	I	2		Fifo						
10	Mach_10	M	4		Fifo		TLI		2184.00	Log	3364.80
11	Buff_11	B	20	*	Fifo						
12	Mach_12	M	12	*	Fifo						
13	Inou_13	I	2		Fifo						
14	Mach_14	M	4		Fifo		TLI		3100.80	Log	3794.40
15	Buff_15	B	20	*	Fifo						
16	Mach_16	M	12	*	Fifo						
17	Buff_17	B	100		Fifo						
18	Inou_18	I	2		Fifo						
19	Conv_19	C	11		Location						
20	Conv_20	C	13		Location						
21	Conv_21	C	25		Location						
22	Conv_22	C	119		Location						
23	Conv_23	C	221		Location						
24	Conv_24	C	261		Location						
25	Conv_25	C	228		Location						
26	Conv_26	C	229		Location						
27	Conv_27	C	46		Location						
28	Conv_28	C	186		Location						
29	Conv_29	C	163		Location	148552.20	Neg		1090.20	Log	1153.80
30	Conv_30	C	66		Location						
31	Conv_31	C	120		Location						
32	Conv_32	C	113		Location			TLI			TLI
33	Conv_33	C	403		Location						
34	Conv_34	C	63		Location						

35	Conv_35	C	63	Location				
36	Conv_36	C	63	Location				
37	Conv_37	C	66	Location				
38	Mach_38	M	26	Fifo		TLI		TLI
39	Buff_39	B	48	Fifo				
40	Mach_40	M	4	Fifo		TLI		TLI
41	Buff_41	B	5	Fifo				
42	Mach_42	M	12	Fifo	80766.00	Neg		TLI
43	Conv_43	C	34	Location				
44	Mach_44	M	26	Fifo		TLI	1605.60 Log	2416.20
45	Buff_45	B	48	Fifo				
46	Mach_46	M	4	Fifo		TLI		TLI
47	Buff_47	B	5	Fifo				
48	Mach_48	M	12	Fifo	43510.00	Neg		TLI
49	Conv_49	C	13	Location				
50	Buff_50	B	2090	Fifo	131793.60	Neg	2110.20 Log	2122.80
51	Inou_51	B	99999	Fifo				

TABLE 2: Element parameters (various) --> CONVEYOR/WAREHOUSE/RESERVOIR

ELEM NR	NAME	T	CAP	PROD SPAC	ACM	SPEED	LNTH
19	Conv_19	C	11		Y	1.90	1.65
20	Conv_20	C	13		Y	1.90	2.00
21	Conv_21	C	25		Y	1.90	3.80
22	Conv_22	C	119		Y	1.00	17.85
23	Conv_23	C	221		Y	1.00	33.22
24	Conv_24	C	261		Y	1.00	39.23
25	Conv_25	C	228		Y	1.00	34.29
26	Conv_26	C	229		Y	1.00	34.29
27	Conv_27	C	46		Y	1.00	7.00
28	Conv_28	C	186		Y	1.00	28.00
29	Conv_29	C	163		Y	1.00	24.50
30	Conv_30	C	66		Y	1.00	10.00
31	Conv_31	C	120		Y	1.00	18.00
32	Conv_32	C	113		Y	1.00	17.00
33	Conv_33	C	403		Y	1.00	60.50
34	Conv_34	C	63		Y	1.00	9.50
35	Conv_35	C	63		Y	1.00	9.50
36	Conv_36	C	63		Y	1.00	9.50
37	Conv_37	C	66		Y	1.00	10.00
43	Conv_43	C	34		Y	0.14	23.00
49	Conv_49	C	13		Y	0.14	9.00

TABLE 3: Job parameters

JOB NR	NAME	ELEM	JOBTIME			BATCH IN			OUTBATCH			TRIG ENTR
			par1	dis	par2	par1	dis	par2	par1	dis	par2	
1	E1:J1	1				1.00			1.00			
2	E2:J1	2	7.60			4.00			4.00			
3	E3:J1	3	7.60			4.00			4.00			
4	E4:J1	4	1.90			1.00			1.00			
5	E5:J1	5				1.00			1.00			
6	E6:J1	6	7.80			4.00			4.00			
7	E7:J1	7	7.80			4.00			4.00			
8	E8:J1	8	1.95			1.00			1.00			
9	E9:J1	9				1.00			1.00			
10	E10:J1	10	7.50			4.00			4.00			
11	E11:J1	11	7.50			4.00			4.00			
12	E12:J1	12	1.88			1.00			1.00			
13	E13:J1	13				1.00			1.00			
14	E14:J1	14	7.40			4.00			4.00			
15	E15:J1	15	7.40			4.00			4.00			
16	E16:J1	16	1.85			1.00			1.00			
17	E17:J1	17	5.00			1.00			1.00			
18	E18:J1	18				1.00			1.00			
19	E19:J1	19				1.00			1.00			
20	E20:J1	20				1.00			1.00			
21	E21:J1	21				1.00			1.00			
22	E22:J1	22				1.00			1.00			
23	E23:J1	23				1.00			1.00			
24	E24:J1	24				1.00			1.00			
25	E25:J1	25				1.00			1.00			
26	E26:J1	26				1.00			1.00			
27	E27:J1	27				1.00			1.00			
28	E28:J1	28				1.00			1.00			
29	E29:J1	29				1.00			1.00			
30	E30:J1	30				1.00			1.00			
31	E31:J1	31				1.00			1.00			
32	E32:J1	32				1.00			1.00			
33	E33:J1	33				1.00			1.00			
34	E34:J1	34				1.00			1.00			
35	E35:J1	35				1.00			1.00			
36	E36:J1	36				1.00			1.00			
37	E37:J1	37				1.00			1.00			
38	E38:J1	38	0.83			1.00			1.00			
39	E39:J1	39		TLI		1.00			1.00			*
40	E40:J1	40	0.83			4.00			1.00			*
41	E41:J1	41		TLI		1.00			1.00			*
42	E42:J1	42	3.33			12.00			1.00			*
43	E43:J1	43				1.00			1.00			
44	E44:J1	44	0.83			1.00			1.00			
45	E45:J1	45		TLI		1.00			1.00			*
46	E46:J1	46	0.83			4.00			1.00			*
47	E47:J1	47		TLI		1.00			1.00			*
48	E48:J1	48	3.33			12.00			1.00			*
49	E49:J1	49				1.00			1.00			
50	E50:J1	50	10.00			1.00			1.00			
51	E51:J1	51	0.50			1.00			1.00			

52 E44:J2 44 0.83 1.00 1.00 *

ROUTE LISTING

ROUTE NR	STAGE NR	NAME	USES JOBNR	SEND TO
1	1	R1:1	1	2
1	2	R1:2	2	3
1	3	R1:3	3	4
1	4	R1:4	4	bernoulli[90,21,17]
1	5	R1:5	5	6
1	6	R1:6	6	7
1	7	R1:7	7	8
1	8	R1:8	8	bernoulli[92,20,17]
1	9	R1:9	9	10
1	10	R1:10	10	11
1	11	R1:11	11	12
1	12	R1:12	12	bernoulli[96,19,17]
1	13	R1:13	13	14
1	14	R1:14	14	15
1	15	R1:15	15	16
1	16	R1:16	16	bernoulli[93,23,17]
1	17	R1:17	17	18
1	18	R1:18	18	0
1	19	R1:19	19	20
1	20	R1:20	20	21
1	21	R1:21	21	22
1	22	R1:22	22	25
1	23	R1:23	23	24
1	24	R1:24	24	25
1	25	R1:25	25	26
1	26	R1:26	26	27
1	27	R1:27	27	28
1	28	R1:28	28	29
1	29	R1:29	29	30
1	30	R1:30	30	31
1	31	R1:31	31	32
1	32	R1:32	32	if time 8<4 then 33 else 34
1	33	R1:33	33	37
1	34	R1:34	34	35
1	35	R1:35	35	36
1	36	R1:36	36	38
1	37	R1:37	37	44
1	38	R1:38	38	39
1	39	R1:39	39	40
1	40	R1:40	40	41
1	41	R1:41	41	42
1	42	R1:42	42	43
1	43	R1:43	43	50
1	44	R1:44	44	45
1	45	R1:45	45	46
1	46	R1:46	46	47

1	47	R1:47	47	48
1	48	R1:48	48	49
1	49	R1:49	49	50
1	50	R1:50	50	51
1	51	R1:51	51	0
1	52	R1:52	52	45

EVENT LIST

1. Time= 0.00 (repeated every 27.00 units)
Tli = open22
2. Time= 15.00 (repeated every 27.00 units)
Tli = close22
3. Time= 19.00 (repeated every 27.00 units)
Tli = open24
4. Time= 23.00 (repeated every 27.00 units)
Tli = close24

PRODUCT PARAMETERS

prod 1	size= 0.15	icon= 43
prod 2	size= 0.15	icon= 44
prod 3	size= 0.15	icon= 45
prod 4	size= 0.15	icon= 46
prod 5	size= 0.33	icon= 41
prod 6	size= 0.66	icon= 23
prod 7	size= 1.00	icon= 2

All other products default (size=1 and weight=1).

STOCK LISTING

(1)	(R1:1)	-->	1	product	(code=1)
(5)	(R1:5)	-->	1	product	(code=2)
(9)	(R1:9)	-->	1	product	(code=3)
(13)	(R1:13)	-->	1	product	(code=4)

TLI SYNTAX LISTING

(3)	Exit condition	=	elqueue[3]>16
(4)	Exit condition	=	elqueue[4]>8
(7)	Exit condition	=	elqueue[7]>16
(8)	Exit condition	=	elqueue[8]>8
(11)	Exit condition	=	elqueue[11]>16

```

(12) Exit condition = elqueue[12]>8
(15) Exit condition = elqueue[15]>16
(16) Exit condition = elqueue[16]>8
(2) MTBF = weibull[49364.4,0.6]
(10) MTBF = weibull[41090.4,0.8]
(14) MTBF = weibull[57736.8,0.7]
(32) MTBF =
(38) MTBF = beta[105343.4,0.4,1.1]
(40) MTBF = weibull[19546.8,0.5]
(44) MTBF = gamma[110611.2,0.8]
(46) MTBF = weibull[19546.8,0.5]
(6) MTTR = pearson5[3803.08,2.7]
(32) MTTR =
(38) MTTR = pearson5[1467,2.7]
(40) MTTR = weibull[374.4,0.9]
(42) MTTR = beta[1014,2.6,2]
(46) MTTR = weibull[374.4,0.9]
(48) MTTR = beta[900,0.1,0.3]
(39) Trig. on Entry = att1[C]:=time+8
(39) Jobtime = att1[E,1]-time
(40) Trig. on Entry = product[C]:=5
(41) Trig. on Entry = att1[C]:=time+8
(41) Jobtime = att1[E,1]-time
(42) Trig. on Entry = product[C]:=6
(45) Trig. on Entry = att1[C]:=time+8
(45) Jobtime = att1[E,1]-time
(46) Trig. on Entry = product[C]:=5
(47) Trig. on Entry = att1[C]:=time+8
(47) Jobtime = att1[E,1]-time
(48) Trig. on Entry = product[C]:=6
(52) Trigger on Entry = att3[C]:=time - att3[C]
(4) Send to = bernoulli[90,21,17]
(8) Send to = bernoulli[92,20,17]
(12) Send to = bernoulli[96,19,17]
(16) Send to = bernoulli[93,23,17]
(32) Send to = if time|8<4 then 33 else 34
EXECUTE FUNCTION AT REQUEST: usertli

```

TLI FUNCTIONS

function open22

```

    elsend[22]:=1
    elsend[24]:=0

```

function open24

```

    elsend[22]:=0
    elsend[24]:=1

```

function close22

```
    elsend[22]:=0  
    elsend[24]:=0
```

```
function close24
```

```
    elsend[22]:=0  
    elsend[24]:=0
```

```
End of document
```

APPENDIX D

OUTPUT OF SIMULATION RUNS AND ANALYSES

Table D1. Utilization of element

	Element	AVG	STDEV	95 % Confidence interval
Blowmolder #1	1			
	2	85.1	10.5	85.1 ± 3.8
	3	84.6	10.5	84.6 ± 3.8
	4	84.2	10.5	84.2 ± 3.8
Blowmolder #2	5			
	6	94.3	5.6	94.3 ± 2.0
	7	93.7	5.6	93.7 ± 2.0
Blowmolder #3	8	93.3	5.6	93.3 ± 2.0
	9			
	10	92.1	9.9	92.1 ± 3.5
Blowmolder #4	11	91.5	9.8	91.5 ± 3.5
	12	91.3	9.9	91.3 ± 3.5
	13			
	14	91.2	8.3	91.2 ± 3.0
Regrinder	15	90.7	8.3	90.7 ± 3.0
	16	90.3	8.3	90.3 ± 3.0
	17	68.0	3.3	68.0 ± 1.2
Conveyor 1	18			
	19	4.2	0.5	4.2 ± 0.2
	20	9.7	0.5	9.7 ± 0.2
	21	23.9	1.0	23.9 ± 0.3
	22	73.0	0.8	73.0 ± 0.3
	23	88.6	8.1	88.6 ± 2.9
	24	46.2	4.0	46.2 ± 1.4
Conveyor 2	25	98.7	1.0	98.7 ± 0.4
	26	98.1	1.7	98.1 ± 0.6
	27	75.2	3.4	75.2 ± 1.2
	28	96.6	3.5	96.6 ± 1.2
	29	95.4	5.3	95.4 ± 1.9
	30	84.7	6.2	84.7 ± 2.2
	31	92.9	7.9	92.9 ± 2.8
	32	91.4	9.2	91.4 ± 3.3
Conveyor to Filler #2	33	82.5	16.7	82.5 ± 6.0
	34	50.7	6.6	50.7 ± 2.4
	35	49.0	7.6	49.0 ± 2.7
Conveyor to Filler #1	36	46.5	8.7	46.5 ± 3.1
	37	44.6	11.0	44.6 ± 3.9
Filler #2	38	71.8	3.2	71.8 ± 1.2
	39	91.0	5.1	91.0 ± 1.8
caser #2	40	17.9	0.8	17.9 ± 0.3
	41	90.4	5.0	90.4 ± 1.8
stacker #2	42	5.9	0.3	5.9 ± 0.1
	43	29.3	1.4	29.3 ± 0.5
Filler #1	44	72.2	3.1	72.2 ± 1.1
	45	88.9	6.2	88.9 ± 2.2
caser #1	46	18.0	0.8	18.0 ± 0.3
	47	88.3	5.5	88.3 ± 2.0
stacker # 1	48	5.9	0.3	5.9 ± 0.1
	49	11.5	0.5	11.5 ± 0.2
cooling storage	50	35.7	1.4	35.7 ± 0.5

Table D2. Average blocked time of elements

	Element	AVG	STDEV	95% Confidence Interval
Blowmolder #1	1	57600.0	0.0	
	2	0.0	0.0	
	3	0.0	0.0	
	4	1.0	0.3	1.0 ± 0.1
Blowmolder #2	5	57600.0	0.0	
	6	13.1	71.7	13.1 ± 25.6
	7	15.7	85.9	15.7 ± 30.7
	8	17.6	89.3	17.6 ± 32.0
Blowmolder #3	9	57600.0	0.0	
	10	24.3	45.3	24.3 ± 16.2
	11	105.8	45.7	105.8 ± 16.3
	12	7.6	41.4	7.6 ± 14.8
Blowmolder #4	13	57600.0	0.0	
	14	0.0	0.0	
	15	0.0	0.0	
	16	0.0	0.0	
Regrinder	17	0.0	0.0	
	18	0.0	0.0	
Conveyor 1	19	15.7	86.0	15.7 ± 30.8
	20	20.2	110.5	20.2 ± 39.6
	21	38.6	158.3	38.6 ± 56.7
	22	58.0	315.4	58.0 ± 112.9
	23	0.0	0.0	
	24	57.6	315.5	57.6 ± 112.9
Conveyor 2	25	184.1	584.2	184.1 ± 209.0
	26	501.2	1004.1	501.2 ± 359.3
	27	594.5	1114.0	594.5 ± 398.6
	28	1328.8	2001.7	1328.8 ± 716.3
	29	1378.8	2962.5	1378.8 ± 1060.1
	30	1651.6	3435.5	1651.6 ± 1229.3
	31	2284.6	4347.2	2284.6 ± 1555.6
	32	2890.0	5097.3	2890.0 ± 1824.0
Conveyor to Filler #2	33	7877.2	8192.0	7877.2 ± 2931.4
	34	4027.9	5506.9	4027.9 ± 1970.6
	35	5828.4	6624.2	5828.4 ± 2370.4
Conveyor to Filler #1	36	8424.9	8046.8	8424.9 ± 2879.5
	37	11036.9	9356.3	11036.9 ± 3348.0
Filler #2	38	479.4	723.9	479.4 ± 259.1
	39	1783.3	1403.5	1783.3 ± 502.2
caser #2	40	252.2	251.7	252.2 ± 90.1
	41	131.7	252.4	131.7 ± 90.3
stacker #2	42	0.0	0.0	
	43	0.0	0.0	
Filler #1	44	1056.7	1569.8	1056.7 ± 561.7
	45	2998.7	2723.6	2998.7 ± 974.6
caser #1	46	1420.7	1619.7	1420.7 ± 579.6
	47	1408.1	1582.9	1408.1 ± 566.4
stacker # 1	48	0.0	0.0	
	49	0.0	0.0	
cooling storage	50	0.0	0.0	

Table D3. Average busy time of elements

	Element	AVG	STDEV	95 % Confidence Interval
Blowmolder #1	1	49023.6	6046.3	49023.6 ± 2163.6
	2	48723.5	6045.4	48723.5 ± 2163.3
	3	48514.2	6045.4	48514.2 ± 2163.3
	4	0	0	
Blowmolder #2	5	54290.5	3224.6	54290.5 ± 1153.9
	6	53982.6	3224.7	53982.6 ± 1153.9
	7	53767.6	3224.6	53767.6 ± 1153.9
	8	0	0	
Blowmolder #3	9	53025.5	5689.2	53025.5 ± 2035.8
	10	52690.6	5672.7	52690.6 ± 2029.9
	11	52608.7	5687.2	52608.7 ± 2035.1
	12	0	0	
Blowmolder #4	13	52509.5	4758.3	52509.5 ± 1702.7
	14	52215.4	4757.9	52215.4 ± 1702.6
	15	52011.9	4757.9	52011.9 ± 1702.6
	16	39146.3	1902.8	39146.3 ± 680.9
Regrinder	17	0	0	
Conveyor 1	18	2416.3	262.6	2416.3 ± 94.0
	19	5600.5	313.9	5600.5 ± 112.3
	20	13765.3	551.3	13765.3 ± 197.3
	21	42057.1	481.9	42057.1 ± 172.4
	22	51039.4	4660.3	51039.4 ± 1667.6
	23	26587.8	2330.5	26587.8 ± 833.9
	24	56864.1	582.8	56864.1 ± 208.5
Conveyor 2	25	56512.9	1001.9	56512.9 ± 358.5
	26	43340.5	1936.3	43340.5 ± 692.9
	27	55638.8	2000.8	55638.8 ± 715.9
	28	54978.7	3078.0	54978.7 ± 1101.4
	29	48811.9	3579.8	48811.9 ± 1281.0
	30	53529.1	4552.8	53529.1 ± 1629.2
	31	52661.9	5293.9	52661.9 ± 1894.4
	32	47522.1	9611.4	47522.1 ± 3439.3
Conveyor to Filler #2	33	29200.3	3782.8	29200.3 ± 1353.6
	34	28211.3	4354.9	28211.3 ± 1558.4
	35	26762.7	5003.5	26762.7 ± 1790.4
Conveyor to Filler #1	36	25685.3	6354.7	25685.3 ± 2274.0
	37	41342.1	1871.9	41342.1 ± 669.8
Filler #2	38	52388.7	2939.5	52388.7 ± 1051.9
	39	10288.1	469.6	10288.1 ± 168.0
caser #2	40	52074.5	2874.1	52074.5 ± 1028.4
	41	3422.4	158.1	3422.4 ± 56.6
stacker #2	42	16871.8	779.4	16871.8 ± 278.9
	43	41608.5	1805.0	41608.5 ± 645.9
Filler #1	44	51216.0	3593.3	51216.0 ± 1285.8
	45	10354.0	455.6	10354.0 ± 163.0
caser #1	46	50848.7	3148.9	50848.7 ± 1126.8
	47	3399.9	149.0	3399.9 ± 53.3
stacker #1	48	6650.6	289.8	6650.6 ± 103.7
	49	20550.9	811.0	20550.9 ± 290.2
cooling storage	50	0	0	

Table D4. Average down time of elements

	Element	AVG	STDEV	95% Confidence Interval
Blowmolder #1	1	0.0	0.0	
	2	8576.4	6046.3	8576.4 ± 2163.6
	3	0.0	0.0	
	4	0.0	0.0	
Blowmolder #2	5	0.0	0.0	
	6	3296.4	3230.6	3296.4 ± 1156.0
	7	0.0	0.0	
	8	0.0	0.0	
Blowmolder #3	9	0.0	0.0	
	10	4550.2	5690.7	4550.2 ± 2036.4
	11	0.0	0.0	
	12	0.0	0.0	
Blowmolder #4	13	0.0	0.0	
	14	5090.5	4758.3	5090.5 ± 1702.7
	15	0.0	0.0	
	16	0.0	0.0	
Regrinder	17	0.0	0.0	
	18	0.0	0.0	
Conveyor 1	19	0.0	0.0	
	20	0.0	0.0	
	21	0.0	0.0	
	22	0.0	0.0	
	23	0.0	0.0	
	24	0.0	0.0	
	25	0.0	0.0	
Conveyor 2	26	0.0	0.0	
	27	0.0	0.0	
	28	0.0	0.0	
	29	535.7	1070.0	535.7 ± 382.9
	30	0.0	0.0	
	31	0.0	0.0	
	32	0.0	0.0	
Conveyor to Filler #2	33	0.0	0.0	
	34	0.0	0.0	
	35	0.0	0.0	
Conveyor to Filler #1	36	0.0	0.0	
	37	0.0	0.0	
Filler #2	38	2106.1	2954.8	2106.1 ± 1057.3
	39	0.0	0.0	
Caser #2	40	1473.0	1224.3	1473.0 ± 438.1
	41	0.0	0.0	
Stacker #2	42	114.9	355.6	114.9 ± 127.3
	43	0.0	0.0	
Filler #1	44	1393.4	2568.5	1393.4 ± 919.1
	45	0.0	0.0	
Caser #1	46	1493.1	1512.9	1493.1 ± 541.4
	47	0.0	0.0	
Stacker # 1	48	1962.9	1685.4	1962.9 ± 603.1
	49	0.0	0.0	
Cooling Storage	50	618.2	1049.8	618.2 ± 375.7

Table D5. Average queue of elements

	Element	AVG	STDEV	95% Confidence Interval	
Blowmolder #1	1	1.0	0.0		
	2	4.0	0.0		
	3	15.9	0.0		
	4	9.2	0.2	9.2 ± 0.058	
Blowmolder #2	5	1.0	0.0		
	6	4.0	0.0		
	7	15.9	0.3	15.9 ± 0.108	
	8	9.3	0.2	9.3 ± 0.068	
Blowmolder #3	9	1.0	0.0		
	10	4.0	0.0		
	11	17.3	0.7	17.3 ± 0.260	
	12	10.1	0.3	10.1 ± 0.097	
Blowmolder #4	13	1.0	0.0		
	14	4.0	0.0		
	15	15.9	0.1	15.9 ± 0.026	
	16	9.3	0.1	9.3 ± 0.049	
Regrinder	17	1.5	0.2	1.5 ± 0.083	
	18	0.0	0.0		
Conveyor 1	19	0.0	0.0		
	20	0.1	0.0		
	21	0.3	0.1	0.3 ± 0.021	
	22	2.8	0.5	2.8 ± 0.189	
	23	1.5	0.1	1.5 ± 0.052	
	24	2.3	0.4	2.3 ± 0.127	
Conveyor 2	25	6.4	1.7	6.4 ± 0.620	
	26	7.2	3.1	7.2 ± 1.109	
	27	1.7	0.9	1.7 ± 0.305	
	28	7.8	4.8	7.8 ± 1.717	
	29	7.4	6.9	7.4 ± 2.462	
	30	3.5	3.7	3.5 ± 1.319	
	31	7.3	8.2	7.3 ± 2.918	
	32	8.1	9.4	8.1 ± 3.348	
	33	33.2	40.1	33.2 ± 14.350	
Conveyor to Filler #2	34	4.4	5.5	4.4 ± 1.967	
	35	6.2	6.6	6.2 ± 2.365	
	36	8.6	8.0	8.6 ± 2.858	
Conveyor to Filler #1	37	11.6	10.1	11.6 ± 3.622	
	38	5.4	3.6	5.4 ± 1.278	
Filler #2	39	7.7	0.8	7.7 ± 0.284	
	40	2.3	0.1	2.3 ± 0.033	
Caser #2	41	1.7	0.1	1.7 ± 0.029	
	42	6.2	0.2	6.2 ± 0.060	
Stacker #2	43	0.3	0.0		
	44	6.6	4.1	6.6 ± 1.472	
	45	8.4	1.7	8.4 ± 0.614	
Caser #1	46	2.3	0.1	2.3 ± 0.040	
	47	1.8	0.2	1.8 ± 0.054	
Stacker #1	48	6.2	0.2	6.2 ± 0.080	
	49	0.1	0.0	0.1 ± 0.002	
Cooling Storage	50	0.4	0.2	0.4 ± 0.062	

Table D6. Average idle time of elements

	Element	AVG	STDEV	95% Confidence Interval
Blowmolder #1	1	0.0	0.0	
	2	0.0	0.0	
	3	8876.5	6045.4	8876.5 ± 2163.3
	4	9084.8	6045.5	9084.8 ± 2163.3
Blowmolder #2	5	0.0	0.0	
	6	0.0	0.0	
	7	3601.7	3232.1	3601.7 ± 1156.6
	8	3814.7	3232.4	3814.7 ± 1156.7
Blowmolder #3	9	0.0	0.0	
	10	0.0	0.0	
	11	4803.6	5685.1	4803.6 ± 2034.3
	12	4983.8	5679.1	4983.8 ± 2032.2
Blowmolder #4	13	0.0	0.0	
	14	0.0	0.0	
	15	5384.6	4757.9	5384.6 ± 1702.6
	16	5588.1	4757.9	5588.1 ± 1702.6
Regrinder	17	18453.7	1902.8	18453.7 ± 680.9
	18	57600.0	0.0	
Conveyor 1	19	55168.0	259.8	55168.0 ± 93.0
	20	51979.3	315.3	51979.3 ± 112.8
	21	43796.1	555.5	43796.1 ± 198.8
	22	15484.8	397.5	15484.8 ± 142.2
	23	6560.6	4660.3	6560.6 ± 1667.6
	24	30954.6	2366.1	30954.6 ± 846.7
Conveyor 2	25	551.8	14.2	551.8 ± 5.1
	26	585.9	14.4	585.9 ± 5.2
	27	13665.0	1628.3	13665.0 ± 582.7
	28	632.4	18.8	632.4 ± 6.7
	29	706.8	46.3	706.8 ± 16.6
	30	7136.5	1584.7	7136.5 ± 567.1
	31	1786.3	1108.7	1786.3 ± 396.7
	32	2048.1	1127.7	2048.1 ± 403.6
Conveyor to Filler #2	33	2200.8	1928.4	2200.8 ± 690.1
	34	24371.7	2228.3	24371.7 ± 797.4
	35	23560.3	2661.2	23560.3 ± 952.3
Conveyor to Filler #1	36	22412.4	3351.0	22412.4 ± 1199.1
	37	20877.8	3496.8	20877.8 ± 1251.3
Filler #2	38	13672.4	2665.2	13672.4 ± 953.7
	39	3428.0	2888.0	3428.0 ± 1033.4
Caser #2	40	45586.7	1366.4	45586.7 ± 489.0
	41	5393.9	2927.3	5393.9 ± 1047.5
Stacker #2	42	54062.7	381.7	54062.7 ± 136.6
	43	40728.2	779.4	40728.2 ± 278.9
Filler #1	44	13541.4	2710.8	13541.4 ± 970.0
	45	3385.3	2790.6	3385.3 ± 998.6
Caser #1	46	44332.3	2509.5	44332.3 ± 898.0
	47	5343.2	2799.2	5343.2 ± 1001.6
Stacker #1	48	52237.2	1646.9	52237.2 ± 589.3
	49	50949.4	289.8	50949.4 ± 103.7
Cooling Storage	50	36430.9	1007.9	36430.9 ± 360.7

Table D7. Total number of produced of each element

	Element	AVG	STDEV	95% Confidence Interval
Blowmolder #1	1	2685.7	243.9	2685.7 ± 87.3
	2	2681.7	243.9	2681.7 ± 87.3
	3	2665.6	243.9	2665.6 ± 87.3
	4	2656.1	243.6	2656.1 ± 87.2
Blowmolder #2	5	2771.3	179.4	2771.3 ± 64.2
	6	2767.3	179.4	2767.3 ± 64.2
	7	2751.2	179.6	2751.2 ± 64.3
	8	2741.5	179.6	2741.5 ± 64.3
Blowmolder #3	9	2788.5	305.1	2788.5 ± 109.2
	10	2784.5	305.1	2784.5 ± 109.2
	11	2767.2	304.5	2767.2 ± 109.0
	12	2757.0	304.4	2757.0 ± 108.9
Blowmolder #4	13	2856.5	236.8	2856.5 ± 84.7
	14	2852.5	236.8	2852.5 ± 84.7
	15	2836.5	236.8	2836.5 ± 84.7
	16	2827.5	236.3	2827.5 ± 84.6
Regrinder	17	783.8	35.5	783.8 ± 12.7
	18	0.0	0.0	
Conveyor 1	19	2645.8	293.4	2645.8 ± 105.0
	20	5168.4	327.9	5168.4 ± 117.3
	21	7564.5	356.7	7564.5 ± 127.6
	22	7562.0	356.7	7562.0 ± 127.6
	23	2630.2	218.7	2630.2 ± 78.3
	24	2627.6	218.7	2627.6 ± 78.2
Conveyor 2	25	10181.6	392.3	10181.6 ± 140.4
	26	10167.3	403.0	10167.3 ± 144.2
	27	10164.8	405.7	10164.8 ± 145.2
	28	10154.1	418.1	10154.1 ± 149.6
	29	10144.3	430.5	10144.3 ± 154.0
	30	10140.6	435.9	10140.6 ± 156.0
	31	10133.2	446.5	10133.2 ± 159.8
	32	10126.1	457.1	10126.1 ± 163.6
Conveyor to Filler #2	33	5069.8	303.0	5069.8 ± 108.4
	34	5009.4	251.2	5009.4 ± 89.9
	35	5001.6	251.3	5001.6 ± 89.9
Conveyor to Filler #1	36	4989.1	254.1	4989.1 ± 90.9
	37	5051.6	308.3	5051.6 ± 110.3
Filler #2	38	4979.9	255.5	4979.9 ± 91.4
	39	4972.7	255.8	4972.7 ± 91.5
Caser #2	40	1242.8	63.8	1242.8 ± 22.8
	41	1240.9	64.0	1240.9 ± 22.9
Stacker #2	42	102.8	5.3	102.8 ± 1.9
	43	102.6	5.3	102.6 ± 1.9
Filler #1	44	5041.7	311.5	5041.7 ± 111.4
	45	5032.0	313.4	5032.0 ± 112.1
Caser #1	46	1257.4	78.4	1257.4 ± 28.1
	47	1255.4	78.8	1255.4 ± 28.2
Stacker #1	48	104.1	6.6	104.1 ± 2.4
	49	104.0	6.6	104.0 ± 2.3
Cooling Storage	50	206.1	10.9	206.1 ± 3.9

Table D8. Average number of produced bottles

Experiment	average	standard deviation	confidence Interval
Original Model	98880	3819	98880 ± 1366.7
Conveyor speed 1	98144	4636	98144 ± 1659
Conveyor speed 2	99424	4770	99424 ± 1706.9
Adding accumulators	101296	2834	100704 ± 1014
Speeding up stackers and casers	99819	3468	99592 ± 1241
Adding accumulators and speeding up stackers and casers	100992	3841	100992 ± 1374.5
Reducing repair time of filling machines	99344	4174	99424 ± 1493.6
Reducing repair time of casers	101888	2937	100912 ± 1051
Reducing repair time of stackers	99888	4982	99888 ± 1782.9
Reducing repair time of blowmolders	104800	3731.6	104800 ± 1335.3

Table D9. Output of ANOVA test

One-Way Analysis of Variance

Analysis of Variance for C2

Source	DF	SS	MS	F	P
C1	10	1.650E+09	164990280	11.20	0.000
Error	319	4.700E+09	14731993		
Total	329	6.349E+09			

Individual 95% CIs For Mean
Based on Pooled StDev

Level	N	Mean	StDev	
Exp1	30	98144	4636	(---*---)
Original	30	98880	3819	(---*---)
Exp6	30	99344	4174	(---*---)
Exp2	30	99424	4770	(---*---)
Exp4	30	99819	3468	(---*---)
Exp8	30	99888	4982	(---*---)
Exp5	30	100992	3841	(---*---)
Exp3	30	101296	2834	(---*---)
Exp7	30	101888	2937	(---*---)
Exp9	30	104800	3732	(---*---)
Pooled StDev = 3838				99000 102000 105000

Fisher's pairwise comparisons

Family error rate = 0.672
Individual error rate = 0.0500

Critical value = 1.967

Intervals for (column level mean) - (row level mean)

	Exp1	Original	Exp6	Exp2	Exp4	Exp8
Original	-2685 1213					
Exp6	-3149 749	-2413 1485				
Exp2	-3230 669	-2494 1405	-2030 1869			
Exp4	-3624 274	-2888 1010	-2424 1474	-2344 1555		
Exp8	-3693 205	-2957 941	-2493 1405	-2413 1486	-2018 1880	
Exp5	-4797 -899	-4061 -163	-3597 301	-3517 382	-3122 776	-3053 845

Table D9. Output of ANOVA test

One-Way Analysis of Variance

Analysis of Variance for C2

Source	DF	SS	MS	F	P
C1	10	1.650E+09	164990280	11.20	0.000
Error	319	4.700E+09	14731993		
Total	329	6.349E+09			

Individual 95% CIs For Mean

Based on Pooled StDev

Level	N	Mean	StDev	
Exp1	30	98144	4636	(---*---)
Original	30	98880	3819	(---*---)
Exp6	30	99344	4174	(---*---)
Exp2	30	99424	4770	(---*---)
Exp4	30	99819	3468	(---*---)
Exp8	30	99888	4982	(---*---)
Exp5	30	100992	3841	(---*---)
Exp3	30	101296	2834	(---*---)
Exp7	30	101888	2937	(---*---)
Exp9	30	104800	3732	(---*---)

Pooled StDev = 3838

99000 102000 105000

Fisher's pairwise comparisons

Family error rate = 0.672
Individual error rate = 0.0500

Critical value = 1.967

Intervals for (column level mean) - (row level mean)

	Exp1	Original	Exp6	Exp2	Exp4	Exp8
Original	-2685 1213					
Exp6	-3149 749	-2413 1485				
Exp2	-3230 669	-2494 1405	-2030 1869			
Exp4	-3624 274	-2888 1010	-2424 1474	-2344 1555		
Exp8	-3693 205	-2957 941	-2493 1405	-2413 1486	-2018 1880	
Exp5	-4797 -899	-4061 -163	-3597 301	-3517 382	-3122 776	-3053 845

(Continued)

Exp3	-5101 -1203	-4365 -467	-3901 -3	-3821 78	-3426 472	-3357 541
Exp7	-5693 -1795	-4957 -1059	-4493 -595	-4413 -514	-4018 -120	-949 -51
Exp9	-8605 -4707	-7869 -3971	-7405 -3507	-7325 -3426	-6930 -3032	-6861 -2963

	Exp5	Exp3	Exp7
Exp3	-2253 1645		
Exp7	-2845 1053	-2541 1357	
Exp9	-5757 -1859	-5453 -1555	-4861 -963

Note:

1. Exp1: Changing the speed of conveyor 1
2. Exp2: Changing the speed of conveyor 2
3. Exp3: Adding accumulators
4. Exp4: Changing the speed of casers and stackers
5. Exp5: Adding the accumulators and changing the speed of casers and stackers
6. Exp6: Increasing the efficiency of filling machines
7. Exp7: Increasing the efficiency of casers
8. Exp8: Increasing the efficiency of stackers
9. Exp9: Increasing the efficiency of blowmolding machines

Table D10. Output of ANOVA test

One-Way Analysis of Variance

Analysis of Variance for C2

Source	DF	SS	MS	F	P
C1	10	1.650E+09	164990280	11.20	0.000
Error	319	4.700E+09	14731993		
Total	329	6.349E+09			

Individual 95% CIs For Mean
Based on Pooled StDev

Level	N	Mean	StDev	
Exp1	30	98144	4636	(---*---)
Original	30	98880	3819	(---*---)
Exp6	30	99344	4174	(---*---)
Exp2	30	99424	4770	(---*---)
Exp4	30	99819	3468	(---*---)
Exp8	30	99888	4982	(---*---)
Exp5	30	100992	3841	(---*---)
Exp3	30	101296	2834	(---*---)
Exp7	30	101888	2937	(---*---)
Exp9	30	104800	3732	(---*---)
Exp10	30	105392	1898	(---*---)

Pooled StDev = 3838

99000 102000 105000

Fisher's pairwise comparisons

Family error rate = 0.672
Individual error rate = 0.0500

Critical value = 1.967

Intervals for (column level mean) - (row level mean)

	Exp1	Original	Exp6	Exp2	Exp4	Exp8
Original	-2685 1213					
Exp6	-3149 749	-2413 1485				
Exp2	-3230 669	-2494 1405	-2030 1869			
Exp4	-3624 274	-2888 1010	-2424 1474	-2344 1555		
Exp8	-3693 205	-2957 941	-2493 1405	-2413 1486	-2018 1880	
Exp5	-4797 -899	-4061 -163	-3597 301	-3517 382	-3122 776	-3053 845

(Continued)

Exp3	-5101 -1203	-4365 -467	-3901 -3	-3821 78	-3426 472	-3357 541
Exp7	-5693 -1795	-4957 -1059	-4493 -595	-4413 -514	-4018 -120	-949 -51
Exp9	-8605 -4707	-7869 -3971	-7405 -3507	-7325 -3426	-6930 -3032	-6861 -2963

	Exp5	Exp3	Exp7	Exp9
Exp3	-2253 1645			
Exp7	-2845 1053	-2541 1357		
Exp9	-5757 -1859	-5453 -1555	-4861 -963	
Exp10	-6349 -2451	-6045 -2147	-5453 -1555	-2541 1357

Note:

1. **Exp1:** Changing the speed of conveyor 1
2. **Exp2:** Changing the speed of conveyor 2
3. **Exp3:** Adding accumulators
4. **Exp4:** Changing the speed of casers and stackers
5. **Exp5:** Adding the accumulators and changing the speed of casers and stackers
6. **Exp6:** Increasing the efficiency of filling machines
7. **Exp7:** Increasing the efficiency of casers
8. **Exp8:** Increasing the efficiency of stackers
9. **Exp9:** Increasing the efficiency of blowmolding machines
10. **Exp10:** Increasing the efficiency of blowmolding machines and casers

BIBLIOGRAPHY

BIBLIOGRAPHY

Shannon, R.E. 1975. *Systems Simulation: The art and the Science*, New Jersey: Prentice-Hall, Inc

Shannon, R.E., S. S. Long, and B. P. Buckles, "Operation Research Methodologies in Industrial Engineering: A Survey," *AIIE Transactions*, Vol. 12, No. 4, 1980

Ledbetter, W. N., and J. F. Fox, "Are OR Techniques Being Used?," *Industrial Engineering*, February, 1977, pp. 19 et. seq.

Cook, T. M., and R. A. Russell, "A Survey of Industrial OR/MS Activities in the 70's," *Proceedings of the 8th Conference of the American Institute for Decision Making*, 1976

F&H Simulations B.V., 1995, *Simulation in manufacturing and logistics*. Tilburg: F&H

Pidd, M., 1984, *Computer simulation in Management Science*. New York: John Wiley & Sons

Mott, Jack 1996, *Educating your team*, TaylorII 1996 User conference
Law, A. M. and W.D. Kelton. 1982, *Simulation Modeling and Analysis*. McGraw-Hill, Inc.

Law, Averill 1986, Introduction to simulation: A powerful tool for analyzing complex manufacturing systems, *Industrial Engineering* May 86, 46 – 63

Filmer, J. Jorge A. Marcondes and Robert E. Johnston. 1994, Simulation of High-speed Packaging Lines. *Packaging Technology and Science* Vol. 7 123-130

Musselman, K. J., "Computer Simulation: A design tool for FMS," *Manufacturing Engineering*, September, 1984, 117 – 120

Bob Swientek, Prepared Foods, April 1993, p 68 ~ 71

Carson, J. S., "Convincing Users of Model's Validity is Challenging Aspect of Modeler's Job," *Industrial Engineering*, June, 1986, pp. 74 et. Seq.

F&H Simulations B.V., 1997, *Taylor II User's Manual*. Tilburg: F&H

Joseph F. Hanlon. 1992, *Handbook of packaging engineering*. Technomic publishing CO., Inc. 8-56

C. Glen Davis. 1994, *Introduction to packaging machinery*. Packaging Machinery Manufactures Institute. 12-32

Welch, P. D., 1983, The Statistical Analysis of Simulation Results,” in *The computer Performance Modeling Handbook*, S.S. Lanvenberg (ed.), 368 – 328, Academic Press, New York

Ken J, Musselman and Steve D. Duket. 1984, Simulation in computer integrated Manufacturing, In *proceedings of the 1984 Fall Industrial Engineering Conference*, 251 – 257

Carson, J. S. 1989, Verification and validation: A consultant’s perspective, In *proceedings of the 1989 Winter Simulation Conference*, 552 – 558

Centeno A. Martha 1996, An introduction to simulation modeling, In *proceedings of the 1996 Winter Simulation Conference*, 15 – 22

Kelton, W. D., 1996, Statistical issues in Simulation, In *proceedings of the 1996 Winter Simulation Conference*, 47 – 54

Zeph, P.J., How to Analyze Packaging Line Performance, Institute of Packaging Professionals, Herndon, VA, 1993. (111 pages)

Law, A. M., 1997, How to conduct a successful simulation study, 1997 TaylorII User Conference

Banks, Jerry 1996, Software for Simulation, In *proceedings of the 1996 Winter Simulation Conference*, 31 – 38

Hoover, V. Stewart and Perry, F. Roland 1989, *Simulation: a problem-solving approach*, Addison Wesley.

Urban, G., “Building models for decision makers,” *Interfaces*, Vol. 4, No. 3, 1974

Kelton, W. D., “Statistical Analysis Methods Enhance Usefulness, Reliability of Simulation Models,” *Industrial Engineering*, September, 1986, pp. 74 et. Seq.

Sargent, R. G 1996, Verifying and Validating Simulation Models. In *proceedings of the 1996 Winter Simulation Conference*, 55 – 64

Sargent, R. G 1994, Verifying and Validating Simulation Models. In *proceedings of the 1996 Winter Simulation Conference*, 77 – 87

Sadowski, R. P. 1989, The simulation Process: Avoiding the problems and pitfalls, In *proceedings of the 1989 Winter Simulation Conference*, 72 – 79

Sadowski, R. P. 1993, Selling Simulation and Simulation Results, In *proceedings of the 1993 Winter Simulation Conference*, 72 – 79

Balci, O. and Sargent, R. G. 1982, Validation of Multivariate Response Simulation Models by Using Hotelling's two-sample T^2 test, *Simulation*, Vol. 39, No. 6, pp. 620–629

Schruben, L. W., Establishing the Credibility of Simulations, *Simulation*, Vol. 34, No. 3, pp. 101-105

Perry, R., Hoover, S., & Zelasky, B., "Implementation of simulation results: An Assessment," paper presented at TIMS XXVII International meeting, Gold Coast City, Australia, July, 1986.

Lucas, H., *Toward Creative Systems Design*, New York: Columbia University Press, 1974

Stockdale, Terry, Determining Warm-Up Periods for Simulations, 1997 Witness User Conference

Fox, B. L. 1981, "Fitting Standard Distributions to Data is Necessarily Good: Dogma or Myth," In *proceedings of the 1981 Winter Simulation Conference*

Schriber, T. J., "Basic Concepts in Queuing Systems Modeling," *Simulation Using GPSS*, 1st Edition, John Wiley & Sons, Inc., New York, 1974

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