A Simulation Approach to Modelling Quality and Reliability Features of Plant Processes

by

Theofanis I. Karagiannis

School of Computer Applications,
Dublin City University,
Dublin 9.

Supervisor: Dr. Heather Ruskin

A dissertation submitted for the degree of
Master of Science

July 1999

Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Master of Science in Computer Applications, is entirely my own work and has not been taken from the work of others save and to the extend that such a work has been cited and acknowledged within the text of my work.

Signed:____________________ **Date:** 8/10/1999

Theofanis I. Karagiannis

Acknowledgements

I would to thank my supervisor Dr Ruskin for all of her quidance, assistance and help throughout this project

Special thanks are also due to many people in Intel, for helping me to understand the way they work – to Sean Lenehan, in particular, for providing me with the project, ant to both Andrew McCarren and Andrew McFadyen for helping me to collect data

My gratitude also to Dr Papadopoulos for his initial motivation for this MSc

I would like to thank many of the Postgraduate Students in C A for their help and friendship, in particular Criostai for helping me to correct my English

Table of Contents

Table of Contents

Appendices

A Simulation Approach to Modelling Quality and Reliability features of plant processes

Abstract

The relationship between component and system reliability is a key factor in the improvement of plant processes and a wide variety of models have been studied, under the general headings of "Probabilistic Methods", "Graph Theoretical Methods" and "Simulation" An outline review of these reliability models is given as a background to the work of the thesis and the ideas were used to steer the design of the software tool, which we have developed The tool is generic in the sense that it can be used for any production system consisting of any number of parallel production lines, although we have considered its application in detail for one system only In particular, we describe an application of reliability theory in the modelling of a plant process, which incorporates examples of Load-Sharing, parallel and series stages and we demonstrate how the production planning control is related to reliability considerations

The tool has been tested in reference to a real production system, for which Quality and Reliability features have been analysed though data collection and simulation The production system is located in Intel's ESSM (European Site for System Manufacturing) plant in Ireland The plant's products are the basic components of a Pentium II processor, based on a new technology, (known as MMX or Secc), which enables enhancements for multimedia and communication applications We have also applied our software tool to the old production line (pre-dating Secc Technology), both for calibration purposes and to compare the two lines Software features include the ability to, investigate line reaction to changes in quality and reliability, to pinpoint problem areas, to cost failures in reliability, to explore degraded operation, stages with poor quality/reliability can be identified and Estimate the real UPH (Units Per Hour) We present an analysis of system performance and provide recommendations for possible improvements to the system

List of Figures

List of Tables

Glossary

PSVI 1, PSVI 2	Two inspections in Intel's production line, which ensure that all the components, are in the correct location and have the right orientation
Bare Fab	A panel consisting of six boards
Panel Mark stage	In this stage the panel takes an identification number
Paste stage	Its function is to apply the solder paste on the bare fab
Chip Shoot stage	Its intended function is to place all the surface mounted components on the board
Pick and Place stage	Its intended function is to place all the surface mounted components on the board
Reflow stage	It leaves the components firmly attached to the board
Visual Inspection	Inspects the panel and ensures that all the components are in the correct location and have the right orientation

Depanel stage	Separates the panel into individual boards, which are required for further processing
ICT inspection	It performs the first automatic test procedures
Cover Mark stage	Gives the board its final look, putting identification laser Marks on all units
OQA stage	A stage that its function is to complete a sampled inspection of the boards coming from end of line
Secc or MMX Tecnology	A high technology designed to improve the performance of complex applications and applications where large amounts of data and processed
Frame	A *frame* is a single image extracted from a sequence of movie images
Pixel	A *pixel* is an amplitude value of an element that represents an image
Machine Utilisation	Is the utilisation of a component/stage of a production line
Equipment Availability	Is the Total number of Equipment (*Total Equip*) minus any equipment held us reserved (*Equip Res*)
Coherent	Detailed definition in Appendix E
Assists	Defined as any unplanned interaction

Unscheduled Downtime	Unscheduled downtime may be due to repair of a component, *assists* and blackouts
Failure	Occurs if any interruption or variability from the specifications of equipment operation requires the replacement of a component
People Capability	Capability of people working for the production line
Nominal Weeks	Period for which we want to do the investigation
Yield	Quality of the product
UPH	The number of units that a component/stage of a production line can produce per hour
Pure UPH	This is the theoretical UPH and it is different for each product It can be estimated as (3600 seconds)/ (*Cycle* per unit)
RunRate	Run Rate = UPH * Util * Yield (thousand units per week)
Desired Gap	This gap is a safety margin, so that the production can cover unscheduled downtimes and accidents
Machine Availability	Machine Availability = Machine Utilisation + Desired Gap
Bottleneck	The *slowest stage* of the system
Production Time	Time is the period for which the equipment is performing its intended function

Standby time	Is the period of time that the equipment is in a condition to function, facilities are available but it is not operating
Engineering time	Engineering time is the period where the equipment is in a condition to perform its intended function but is operational for the purpose of conducting engineering experiments
Equipment Uptime	Equipment Uptime is the sum of three periods of time *Production time*, *Standby time* and *Engineering time*
Scheduled downtime	Occurs when the equipment is not available to perform its intended function due to planned downtime events
Unscheduled downtime	Occurs when the equipment is not in a condition to perform its intended function due to unplanned downtime events
Equipment Downtime	This period of time includes *Scheduled* and *Unscheduled* Downtime
Operation time	Operation time is the sum of two periods Equipment Uptime and Equipment Downtime
Non-Scheduled time	*Non-Scheduled* occurs when the machine is not scheduled to function at periods such as holidays, weekends and non-working shifts
Total time	Total time available is divided into two periods *Operation* and *Non-Scheduled* time

Chapter 1

Introduction to Reliability and Quality

Reliability and Quality are concerned with improvement, analysis, assessment and prediction of system performance The aim of Reliability and/or Quality studies is the achievement of best performance within the resources available Achievement of this aim may be expected to increase system safety, customer satisfaction and, of course, reduce total costs Evans (1997) defines reliability, as "the probability that a system performs its intended function for a stated period of time under specified operating conditions"

During every working day, a plant has the opportunity to collect records for everything occurring in the production line relating to Reliability and Quality In this thesis we present the necessity of collecting this detailed data (history of the plant) All the collected data, relative to Quality and Reliability, are fitted distributions and with the help of three different simulation models (one for Quality Section 3 2 1, one for Component Reliability Section 3 2 2 and one for system Reliability Section 3 4) we generate a simulated sample of data (Quality and Reliability data) for any duration of time for a given production system The production system might be exactly the same as the real one or with some changes By this way we investigate how a production system works and how it reacts to changes of the parameters governing the process (Sensitivity Analysis, section 1 6)

Reliability models are divided into two main categories Models that can investigate *nonrepairable system* and models that can investigate *repairable* systems A nonrepairable system is a system which, once failed, remains in that state Thompson (1988) noted that much of reliability theory investigates nonrepairable systems, which in fact is the study of lifetime distributions In this thesis we present models for repairable systems, and investigate their performance through simulation We discuss appropriate techniques for modelling the production system in the ESSM plant in Ireland (details in section 1 6) Although this thesis is focusing on repairable systems, we also give a brief overview of the models and techniques for nonrepairable systems of which repairable systems form a specified subset

Due to the nature of this project, this thesis involves a large amount of technical terms such as the stages in Intel's production line and the parameters of both Reliability and Quality For this reason a glossary (Page IX) gives brief definitions and explanations of all these terms Detailed definitions of the terms are presented at the place where a term is first met

1 1 Reliability Models on Nonrepairable Systems

A number of authors, including e g Kalbfleisch and Prentice (1980) and, Barlow and Proshman (1996), give a mathematical approach to the definition of reliability of nonrepairable systems Suppose we have a system whose state at time t is described by X(t), a one-dimensional variable Ordinarily the period of time intended for the system to operate is [0,t] Let X(u) = 1 if the device is performing adequately at time u, and X(u) = 0 otherwise, (we assume that adequate performance at time t implies adequate performance during [0,t]) X(t), being a random variable, will be governed by a distribution function F(x, t) , where F(x, t) = the probability that $X(t) \leq x$

Corresponding to any state x, there is a gain, g(x) In terms of our assumptions, the gain from being in the functioning state x = 1 is defined to be one unit of value, so g(1) = 1, and the gain from being in the failed state x = 0 is defined to be 0 so, g(0) = 0 The expected gain G(t) at time t will be

$$G(t) = E[g(X(t))] = \int g(x)dF(x,t) \qquad (1\ 1)$$

So G(t) = P[X(t) = 1] = probability that the device performs adequately over [0, t] Thus G(t) is the reliability of the device In general we shall assume that, unless repair or replacement occurs, adequate performance at time t implies performance during [0, t]

The above definitions comprise the basis for modelling a nonrepairable system To study this type of system, it is necessary that the structure of the system must first be defined This can be done with the help of *Structure Functions* A structure function is a probability expression for a system's reliability

<u>1 1 1 Structure Functions</u>

Suppose that we have a system, consisting of *n* components, and let x_i denote the state of i^{th} component Where

$$x_i = \begin{cases} 1, \mathit{if} \quad \mathit{the} \quad \mathit{component} \quad \mathit{is} \quad \mathit{operating} \\ 0, \mathit{if} \quad \mathit{the} \quad \mathit{component} \quad \mathit{was} \quad \mathit{failed} \end{cases} \qquad (1\ 2)$$

The state of the system can be defined for the vector **X** = $(x_1, x_2, \quad ,x_n)$ by the structure function Φ(**X**) which will take the value 0 or 1 respectively when the system has failed or is operating A vector **X** for which Φ(**X**)=1 is called a *path* and a vector for which Φ(**X**)=0 is called a *cut* So, all the vectors are either paths or cuts and the total number of these vectors is 2^n The *Size* S(**X**), of **X** , is defined as the number of components which are operating when the state of the system is determine by **X**, so that

$$S(X) = \sum_{i=1}^{n} x_i \qquad (1\ 3)$$

A path is a *minimal path* if Φ(X)=1 but for every $Y<X$, Φ(Y)=0 (the comparison "<" respects the size of the vectors) So minimal paths give the minimum number of components required to operate for the system to operate For example suppose that we have a *series system* A series system is a system in which all components must operate for the system to operate (Fig 1 1) So the structure function is

$$\Phi(X) = \prod_{i=1}^{n} x_i \qquad (1\ 4)$$

and there is only one path with size *n*, and this is the minimal path of the system

Figure 1 1 Two component series system

A parallel system is a system in which only one component needs to operate (Fig 1 2) So, the structure function is

$$\Phi(X)=1-\prod_{i=1}^{n}(1-x_i) \tag{1 5}$$

There are $2^n - 1$ paths, as every state of size greater or equal to 1 will be a path and the one cut, is the zero vector, $\mathbf{X} = \mathbf{0}$ Minimal paths are all the *n* paths, size 1

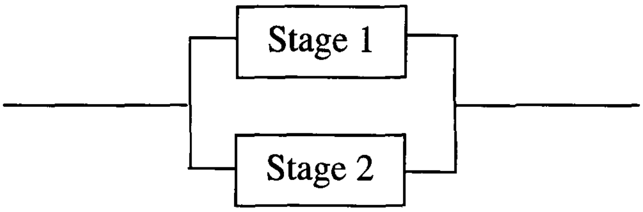


Figure 1 2 Two component parallel system

1 1 2 K-out-of-n Models

A *k-out-of-n* model is concerned with systems in which at least k components must operate for the system to operate That means, that at least k of the x_i must be equal to 1 in order to have $\Phi(\mathbf{X})=1$, with

$$\Phi(X)=\begin{cases}1, if & \sum x_i \geq k \\ 0, if & \sum x_i < k\end{cases} \tag{1 6}$$

Of course that means that all the vectors *Y* with *S(Y)≥k* will be paths and there are $\binom{n}{k}$ minimal paths with size k For example, a series system is an *n-out-of-n* system, and a parallel system is a *1-out-of-n* system, where *n* is the number of components *K-out-of-n* techniques are well described in a number of studies, such as Malinowski and Preuss (1996), and Bruning (1996) Most reliability models refer to *coherent* systems and, in this section, we will give a brief overview for these systems Examples of *noncoherent* systems are less common than those of coherent type Both coherent and noncoherent systems are defined in Appendix E and well discussed by Ansell and Phillips (1994)

Estimation of reliability on some special types of systems, such as systems with identical components, which are placed in series, parallel or a combination of both, is well described by Ansell and Phillips (1994). They also gave a detailed description of the estimation of the reliability for *k-out-of-n* systems with identical components. These types of models can represent production systems very well but they are not very flexible with regard to changing the investigation from the whole production system to subsystems thereof, something that is really useful for sensitivity analysis which is the basic feature of this thesis.

1.1.3 Fault Tree Analysis

Estimation of the structure function of a system usually follows two steps. The first step is the analysis of all possible failures and their results and the second is the creation of the mathematical model. For example, faults trees have been used in order to model two oil/gas production platforms (*Alpha* and *Bravo*) operated by *Marathon Petroleum Ireland Limited*, (Walsh, 1994).

There are two procedures (Ansell and Phillips, 1994) for constructing a fault tree. The main approach is the "Top-Down" procedure, in which the analyst explores how the top event may occur, breaking it down to into contributing factors. This continues until the factors are the basic events of the systems. The other procedure is the FMEA (Fault Modes and Effect Analysis) which is a "Bottom-Up" procedure. An example of "Top-Down" procedure is the following: Suppose that we have the stage of *"Screen Printing"* from Intel's production line. Its function is to apply the solder paste to the pads on the bare fabric (details in section 2.4). Taking the example of *"Screen Printing is Down"* as the top event this can be broken into the contributing factors of *"Unscheduled Downtime"*, *"Scheduled Downtime"*, *"Engineering State"* and *"Standby State"*. The event *"Unscheduled Downtime"* can be broken into *"Repair"*, *"Assists"* and *"Facilities Black Out"*. The last three events can be taken as the *basic events* (detailed definitions of these events are presented both in Section 2.3 and in Glossary). Figure 1.3 presents the fault tree of the above example. We assume that all the links between the objects are type *OR*. Other possible types of links are *AND*, *EXCLUSIVE OR*, and *NOT*. Because in practise, companies do not keep detailed records of all the possible causes, it's difficult to create a detailed fault tree

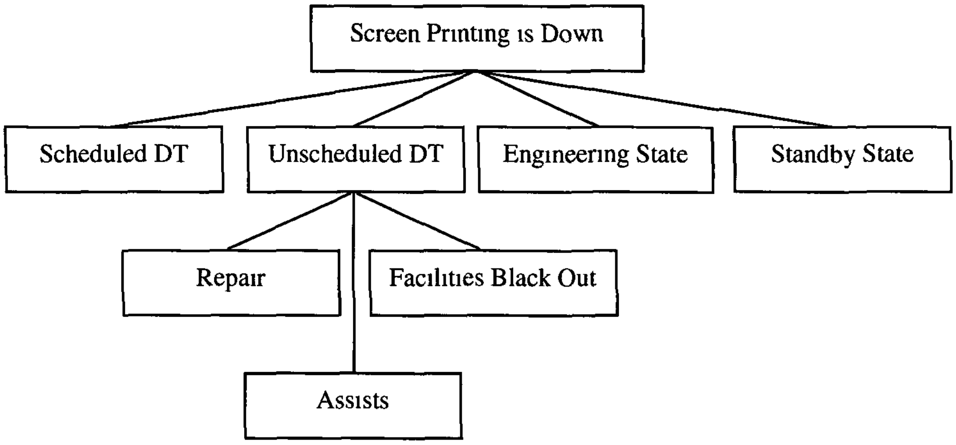


Figure 1 3 The basic events of the factor "Unscheduled Downtime" which can cause the failure of "Screen Printing" stage

Fault trees have long been used for reliability analysis because of their concise representation of system failure combinations, but they can not adequately capture the dynamic system behaviour associated with fault and error recovery Doyle et al (1995) believe that for this reason, many modellers have turned to Markov chains for reliability assessment However, Markov chains have a major disadvantage in that it is difficult to determine the correct Markov model for a given system, since the modeller must specify each operational configuration explicitly and determine the rate at which the system changes from one state to another

The relative advantages of fault trees and Markov models have been exploited by two techniques Behavioural decomposition and Automatic conversion of the fault tree model to an equivalent Markov model

These methods are used in HARP (Hybrid Automated Reliability Predictor), a software package for reliability prediction developed under the sponsorship of NASA (1994) The HARP tool is an integrated reliability tool for reliability/availability prediction

1 1 4 Human –Machines Systems

Suppose we have a system that consists of several machines and a human operator Each machine contains several hardware and/or software components Such systems are called Human - Machine systems The system is on when all its components function and otherwise is down The purpose of the system is to perform missions successfully A mission is defined as what a human requires a "machine" to do Lin and Kuo (1994), analysed a multiple Human - Machine system and simulated the system to explore transient performance Prior to this work, studies concentrated on the simple problem of one machine and one human operator but Lin and Kuo considered a system with several human-machines Each human-machine was assumed to have several hardware and/or software components and one human operator Every mission contains several randomly arriving tasks and the system has two mutually exclusive states for each machine and each machine component namely *on* and *off* The problem was modelled as a series system where all components and operators must be ready and reliable for every task in the mission Human-Machine systems have been widely used by the US Army, especially for estimation of the quality of the performance of air defence operations (Orvis, 1991) Stages belonging to this category can be easily found in plants For example, in Intel, the application discussed here, is found at the stage of *"Off Line Rework Area"*, where boards with minor or major failures are been repaired and then placed again to the line

1 2 Methodology for Nonrepairable Systems

In this section we summarise the most important approaches to estimating reliability of Nonrepairable Systems The techniques are again based on Fault Tree models

Fault Tree Techniques

Dugan (1989) presented the DFTS algorithm, which determines system reliability by enumeration of the operational states that correspond to the fault tree In this technique there is no need to keep the entire state space of the system or for a Markov chain solution A simple alternative solution (DDP) was also presented by Doyle et al (1995), and used existing cutset solution methods Instead of requiring a conversion of the fault tree to a Markov chain, the DDP algorithm combines aspects of behavioural decomposition, sum-of-disjoint products and multistage solution methods This approach is used for reliability estimation of systems that can be represented as a fault tree, with component failures, which are statistically independent Also, discovery of component failures causes immediate system failure, even if adequate redundancy remains The fault occurrence probabilities and the probability that the system can recover when a fault occurs are constant or given in terms of a lifetime distribution

In addition, Heger et al (1995) presented a method for calculating top-event exact probability Specialised techniques for exact top-event probability quantification previously existed, but were limited to small problems that did not reflect realistic situations The method of Heger et al (1995) is called ΣΠ-Patrec and computes the exact probability of top-event of a system fault-tree model as defined by its cut sets It can be used for any system that can be represented as a fault tree

Influence Diagrams

The use of Influence Diagrams is an approach similar to that for fault trees The advantages over other modelling approaches are the smaller number of nodes that are used and the explicit description of dependency within the system Influence diagrams have also been used for decision analysis For example, *TreeAg*e Software (available from http //www treeage com) uses influence diagrams in order to create decision analysis software for manufacturing systems

1 3 Reliability Models on Repairable Systems

In this section we study systems with components that may be repaired The parameter of repair brings new types of models and problems The simplest case occurring is that of instantaneous repair That means that the system will work continuously, despite failures Of interest for these models is the frequency of failures More realistically, however, repairs take a finite period of time and may consist of events such as identifying the failure, sending the repair team, repair time and reinstallation The system after repair is taken to be working as well as it was before failure This is known as a *renewal* process The main statistical measure for these models is the MTTR (Mean Time To Repair), MTTF (Mean Time To Failure) and MTBF (Mean Time Between Failures) In studies of systems with multiple components, there is also a need to decide whether primary interest is in the components or the overall system In the software tool we created, we keep Scheduled and Unscheduled Downtime separate Hence, we estimate the mean time between Scheduled and/or Unscheduled failures

1 3 1 Components of Interest

The investigation we are doing is interested in system's or subsystem's reliability, and for this reason in this section we present a brief overview of the two major processes interested in components reliability There are two models for focusing on components of interest in a system consisting of n components the Branching Process and the SRP (Superimposition of Renewal Process)

Branching Process

A branching process assumes that there is a set of initiating events, which follow either a HPP (Homogeneous Poisson Process), or NHPP (Non-Homogeneous Poisson Process) These events give rise to subsidiary events For any initiating event there will be a random number, s, of possible subsidiary events The s events then form a renewal process with an assumed known distribution Note that HPP occurs when the distribution of time between failure follows an exponential distribution and each component operates independently, (Ansell and Phillips, 1994) NHPP is an extension of HPP where the rate of failures is assumed to vary with time

Superimposition of Renewal Processes

Assume that we have a system with n components where repair is instantaneous and n independent renewal processes are being observed If time to next failure or the number of failures is of interest then the "sum" of these n sequences of the renewal processes is required (Ansell and Phillips, 1994)

1 3 2 System Performance

Where interest focuses on overall system performance, we must assume that repair time is different from zero Assuming that system performance is based on component performance, which is defined by a structure function (section 1 2 1), then the system is either working or has failed We can define a set of states for the component, which ensure system function and a set, which ensures system failure At the system level the *System Probability* is of interest, which is the probability of the system being in a given state at time *t* The usual approaches for modelling these systems include differential equations and simulation We concentrate our investigation on system performance and the effort of slow stages (bottleneck) on the overall system or a subsystem thereof For example in the ESSM plant the bottleneck of the system is the stage of *Primary-Side Pick and Place* (section 2 4)

Differential Equations – Markovian Model

The mam disadvantage of these models is their complexity, which arises mainly from the size of the problem being considered It is assumed that in a small period of time, of length *dt*, the chance of more than one event is negligible if the components function independently So, it is only necessary to assume either a repair or a failure in *dt* After *dt* a component may fail, may be repaired or nothing may happen In the Markovian Model, it is assumed that the probabilities of a working component failing, (or a failed component working), in time *dt* are dependent only on the state of the system at *dt* and the size of this period (See e g Barlow and Proschman (1996) for a detailed study of Markov and Semi-Markov models) An alternative approach to analytical solution of differential equations is to use Simulation

Simulation

Simulation is the technique of imitating the behaviour of a system by means of an analogous situation to gain information more conveniently Types of Simulation approaches fall broadly into the categories illustrated below (Fig 1 4)

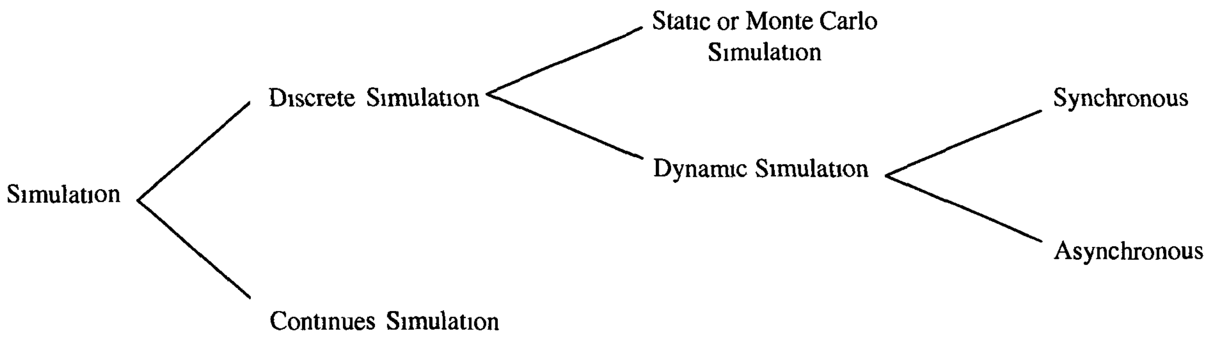


Figure 1.5 Examples of simulation methods

<u>1.4 Methodology for Repairable Systems</u>

Monte Carlo Simulation

In Monte Carlo simulation, the system state and demand are random variables and simulation consists of generating random numbers representing the values of the problem. The state (success or failure) of sources and links is simulated by the random selection of numbers uniformly distributed between 0 and 1. If the random number is in [0, P] (P: Probability that a source or a link functions), the corresponding branch is valid, otherwise it is failed.

Some years ago, Rice and Moore, (1983) examined a series-system with components that experience binomial failures and derived a simple method based on Monte Carlo, for estimating confidence limits for system reliability. The proposed method draws upon the asymptotic normality of the binomial distribution and Monte Carlo simulation. Subsequently, Moore et al., (1985), presented a Monte Carlo method to obtain approximate confidence bounds for system reliability and availability of maintained systems. The technique uses simulated component failure and repair times to estimate the parameters of the failure and repair distributions. Simulated values of parameters are obtained by generating sample failure and repair times of equal size to the original sample, using as parameters the estimates from the real data. The parameters are again estimated using generated data from the same estimator to obtain simulated values. Inserting the estimated values in the equations for reliability and availability, we obtain estimates for these quantities. The process is repeated for a large number of Monte Carlo repetitions These points are used to obtain a cumulative distribution function of system reliability and availability estimates by plotting the order statistics at their median ranks This is the basic idea of the model we are using to estimate the reliability of each stage and the quality of the overall system We give a detailed explanation of this in Chapter 3

Fishman, (1986), described and compared the performance of four alternative Monte Carlo sampling plans for estimating the probability that two particular nodes in the associated node set are connected Models of this type are commonly used when computing the reliability of a system with *Randomly Failing* components The four sampling methods are Dagger Sampling (Kumamoto et al , 1980), Sequential Destruction/Construction (Easton and Wong, 1980), Estimation Based on Failure Sets (Karp and Luby, 1983), and Estimation on Bounds (Fishman, 1986) A brief presentation of the comparison of the results achieved on applying these four techniques to the example in Figure (1 5) is presented below Due to complexity of the four methods presented above, we explain only the last one (Chapter 3), which is the one we use We use one of these four techniques (for the reason presented in the next paragraph) to estimate the reliability of the whole production system by representing each stage of the production line as a node (Chapter 3)

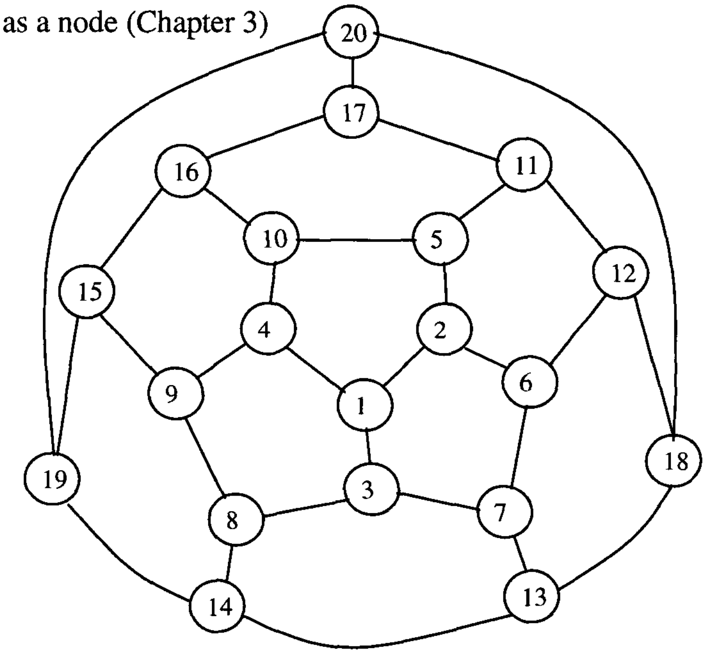


Figure 1 6 A network with 20 nodes (circles) and 30 arcs (lines) that Fishman (1986) used for the comparison of the four Monte Carlo methods

A comparison of these Monte Carlo sampling methods is given in (Fishman 1986) where a network with 20 nodes and 30 arcs is solved (Fig 1 5) The results show that for small *p* (probability that an arc exists), Dagger sampling performs best for *p* around 0 5 The failure sets method performs better than the others for *p* around 0 95 However for big networks, this method requires a lot of memory so that there are serious practical limitations By contrast, the bounds method has more limited demands on space and is a useful alternative method when memory is at a premium

Su et al, (1986), developed a Monte Carlo method for reliability assessment, network flow estimation, and capacity planning It can be used for multisource, multisink, and steady state systems where each component is either good or failed and the states of components are mutually statistically independent Subsequently, Kumamoto, et al, (1987), developed a new Monte Carlo method, under a rare event assumption, for evaluating the top-event probability of a coherent fault tree where the basic events are strictly positive The problem is that since practical complex systems usually have high reliability and are modelled by the rare-event problem, a direct Monte Carlo method requires a large number of trials to provide a good estimate Consequently Kumamoto et al, investigated variance reduction techniques with a view to obtaining smaller variances of estimators compared to direct Monte Carlo with the same number of trials Techniques like Kumamoto et al, (1987) are very useful for evaluating the reliability and quality of systems like Intel's production system, due to the high performance of the system But as we explain (Chapter 3), the exact estimation of the reliability of a system is not always what is required

1 5 Quality

We can define quality, in a broad way, as an attribute of a product that can be improved But as Goetsch and Davis (1994) mentioned, quality does not refer to products only but also to processes, including environmental and human One way to control all these parameters of quality is to follow some international standards such as ISO 9000, which is well described by Johnson (1993) In this thesis, we will refer only to one aspect of quality, namely that of the product There are four major steps that an investigator must follow in order to achieve products with high quality As shown in Figure (1 5), any results that are taken from experiments must passed through analysis until the objective is met

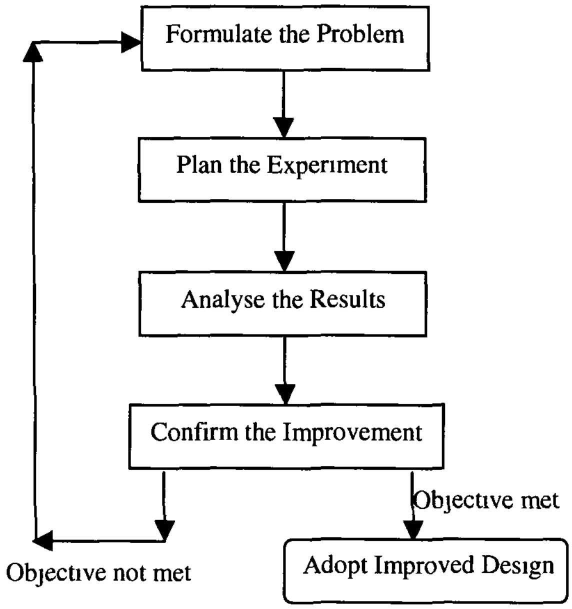


Figure 1 8 The four major steps in robust design methodology (Shoemaker and Holmdel, 1988)

In this section, we discuss three principal methods for the inspection and testing of products to control the quality of output produced These are *Screening*, *Lot-By-Lot Inspection* and *Process Inspection* (Enrick, 1985)

Screening

It is well known that for 100-percent detection of defectives, *Screening or 100-percent inspection* is required However in some types of mass production, screening can be used sparingly only, since costs are high and the time required is long Furthermore, if "Destructive"-testing methods are necessary, the cost is further increased Intel uses screening methods in two major inspections of the production line These are designated PSVI 1 and PSVI 2 (details in section 2 4) and help to ensure that all the components are in the correct location and have the right orientation And also to ensure that all the component placements and solder joints conform to *iWS* (Intel Workmanship Standards)

Lot-by-Lot Inspection

Lot-by-Lot Inspection overcomes some of the high cost of screening Methods are well described by Enrick (1985) but the general principle is to inspect a relatively small number of sample pieces, which are randomly selected, and to judge the acceptability of the whole lot on the basis of their quality The disadvantage of this inspection method is that a sample does not always give a true picture of the entire lot from which it has been selected A wide range of sampling plans has been discussed, with the aim of achieving minimum amounts of inspections with maximum protection against sampling errors Examples include the *Dodge-Romig System, ABC Standards etc* (Grant and Leavenworth, 1980)

The Dodge-Romig System consists of tables of acceptance sampling plans for inspections These plans may be *Sequential Sampling*, *Single Sampling* (Fig 1 6), *Double Sampling*, etc and are well discussed by Grant and Leavenworth (1980), and others The Dodge-Romig tables originally prepared for use within the Bell Telephone System in order to minimise the total amount of inspection ABC Standards is a development of the AQL (Acceptance Quality Level) system that was first devised for the Ordnance Department of the US Army in 1942

Taguchi (1986) introduced robust methods, for experimental design to help identify improved factor levels controlling quality processes Given good results from this technique, many statisticians are improving upon Taguchi's approach with the use of augmented several methodologies For example, Kacker and Tsui (1987) improved Taguchi's method by using interaction graphs, a simple and easy tool for planning experiments, particularly at the production level

Intel's production line has a stage called OQA (Outgoing Quality Assurance), and its function is to complete a sampled inspection of the boards coming from End Of Line, (details about OQA follow in section 2 4) Unfortunately, in practice this sample inspection does not follow statistical samplings method because of the time it takes to inspect a board From each product a sample of 6,000 pieces must be passed through

OQA inspection. Thus for short builds (say 10,000 units for example), the supervisors are responsible for 6,000 of these units being put aside for testing. Since test time is quite long another lot is pulled from the line and tested on the completion of testing on the former lot.

Process Inspection

In this type of inspection, an inspector patrols an assigned area, checking up on equipment, methods of operation and occasional pieces of product from raw material to finished article. The purpose of process inspection is to discover defective products, where and when they occur, so that corrective action may take place. A limitation of this inspection is that inspectors cannot be stationed at all machines at all times. As a result, a defective product can pass away between inspectors' visits. This type of inspection is not applied any more to high technology systems, such as Intel's ESSM plant. Electronic equipment alerts the inspectors to failures occurring at a particular stage or in a particular product.

1.6 Thesis Scope

The impact of reliability and quality features in product processing is specifically addressed for an application relating to the board manufacturing process located in Intel's *ESSM* (European Site for System Manufacturing) plant in Ireland. We seek to provide an accurate model of this process, which incorporates key historical data on quality and reliability aspects of a production system. Processing and analysing data for stages of the line or subset thereof, enables us to detect stages producing the largest number of faulty boards. Sensitivity analyses, applied to the system model, pose a series of *"What if..."* questions for the parameters governing the process. This analysis enables us to explore the effect on the overall system of changes in the parameter estimates. A further feature of the project is the fact that ESSM recently transferred from its previous board building process to a higher-level technology known as Secc or MMX (Section 2.1), which involves parallelism of some process operations. Basic stages of production were otherwise unaffected. Figure 1.7, gives a schematic of how data gathering and feedback on the model of the system might be expected to lead to overall improvements. System performance is measured with the help of the *Output Capacity Model*, which is currently being used by Intel (section 2 2)

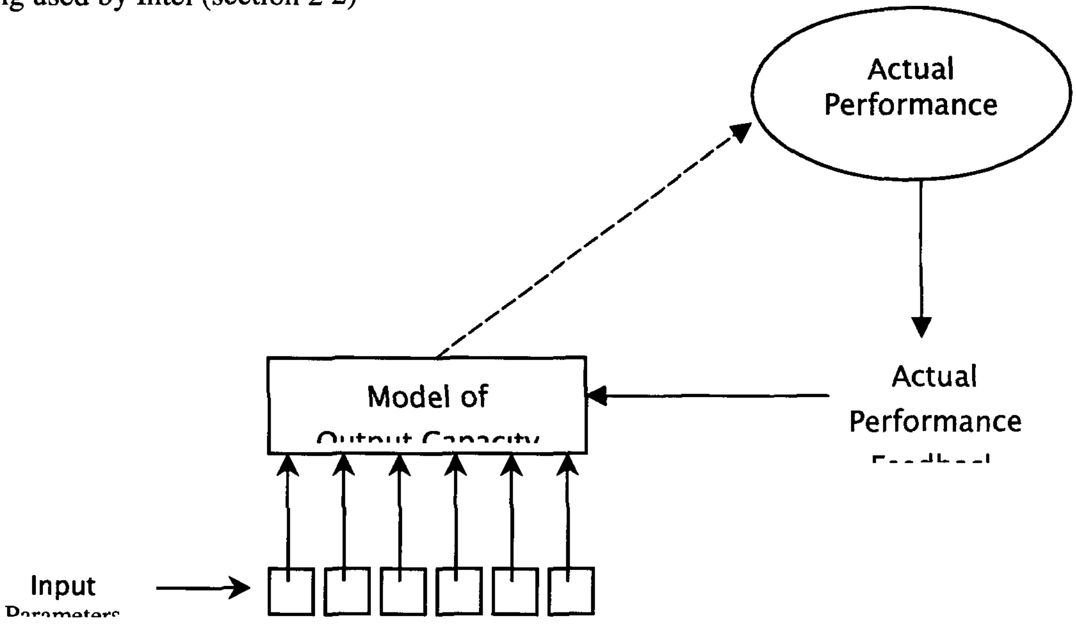


Figure 1 7 A plan for system improvement

In Chapter 2, we explain features of the new technology (MMX) recently introduced to the ESSM plant, contrasting this with the previous system We also present the production Control Process of the ESSM plant, for the current and previous production lines, (the test-bed for our software tool) Parameters, which determine the reliability and quality of the manufacturing system, are also discussed in detail and the methodology described

Details for both production lines are also given in Chapter 2 The flow processes are illustrated, and we give information about the collection of data on Quality and Reliability and the feedback for the production systems In subsequent chapters, Chapters 3 & 4, we describe the methods we are using, the design of the software tool, defining the inputs and outputs

Tool performance is discussed in Chapter 5, with a detailed data analysis, given for performance features of the real system. A comprehensive sensitivity analysis investigates the cost effectiveness and effects of varying the parameters governing the processes Conclusions and recommendations are presented in Chapter 6, including a synthesis of the analysis in order to make recommendations for improving system's performance

Empirical raw data and key software are given in Appendix A, B & C respectively Appendix D illustrates the capabilities of the software tool and is written in the form of a user-manual The full code is given in disk format

Chapter 2

MMX Technology and Intel's Manufacturing System

In Chapter 1 we gave an outline of the major models and techniques for investigating reliability and/or quality of a system The software tool, we created, was developed and tested for Intel's ESSM plant in Ireland, which produces processors based on the new technology known as *MMX* or *Secc (Single Edge Contact Cartridge)* This chapter gives an outline of MMX technology and its applicability We explain it's function by a simple example and compare the old technology with the new one In Section 2 2 there is a description of Reliability and Quality measures and a list of the parameters, used to estimate features of particular interest in Intel production Section 2 3 concentrates on the two production lines, to which we have applied our software tool and we give details of the contrasting layout in each case

2 1Introduction in MMX Technology

Today personal computers are increasing exponentially the volume and complexity of data processed As a result, incredible demands are being placed on microprocessor performance, and it is these demands that drove Intel to define MMX technology (Bistry, 1998) At present, the creation of complex applications, such as the Internet, communications, games, 3D graphics, animation and virtual reality etc demands high technology MMX was designed to improve the performance of complex applications and applications where large amounts of data and processed The basic aim is to improve the performance for multimedia and communication applications

2 1 1 Data Parallelism

Data parallelism is the execution of the same set of operations on a large number of data elements For example, when processing video frames, the same operation is performed between the *pixels* of the *frame* Two sequential frames usual has about 85% of their pixels exactly the same So, MMX improves the performance by executing two, four or eight of these operations at a time A *frame* is a single image extracted from a sequence of movie images, and a *pixel* is an amplitude value of an element that represents an image

Another good example is video streams Generally a video contains a lot of redundant information and that increases the amount of storage A scene is a logical group of shots, where shots, may be defined as a sequence of frames captured in a single continuous action in time and space In a given scene, the frames that it consists of have a lot of similarities and few pixels change from frame to frame So, a good representation of a scene would be to define the first frame in its entirety and then to define the changes from frame to frame This is called MMX technology

2 1 2 An example on Exploiting Data Parallelism

The figure below (Bistry, 1998) shows the representation of the differences between two frames

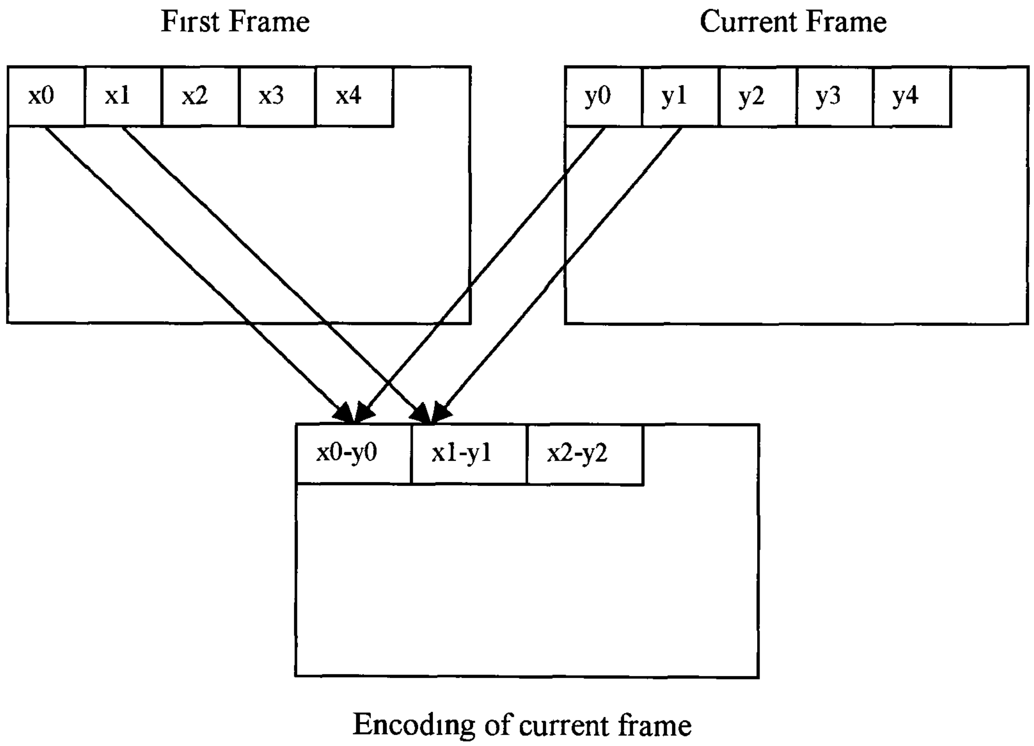
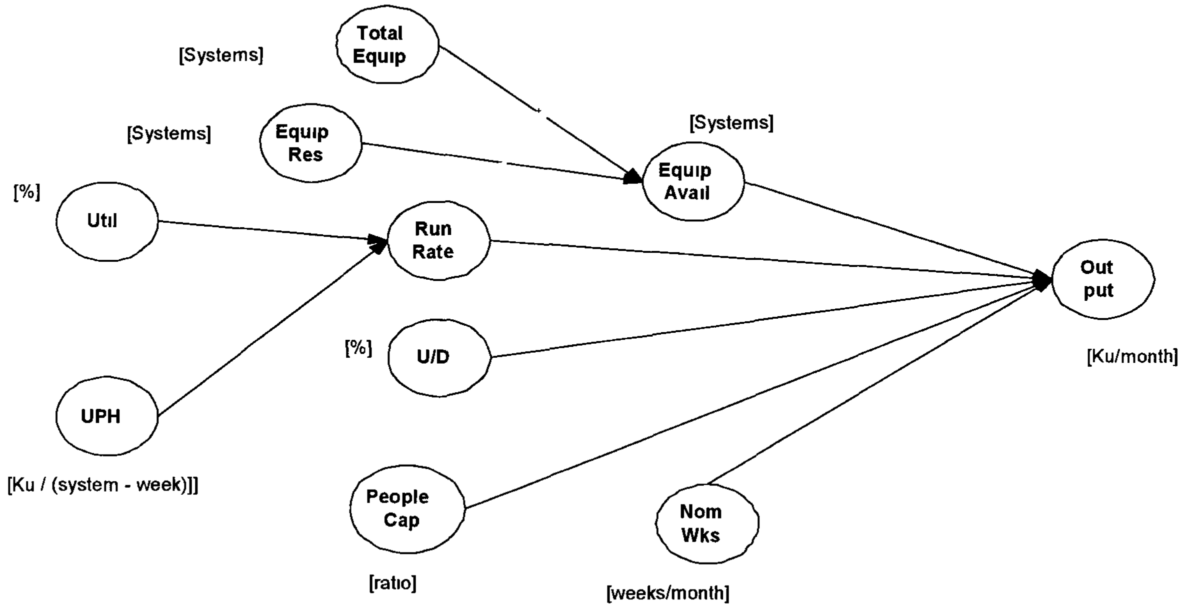


Figure 2 1 Simple video compression Encodes the differences between current and first frames only

Some video compressions use this operation The differences are computed for all the pixels in a frame A simple processor computes these differences one at a time MMX technology allows a parallel estimation of pixel differences and, therefore, improving the speed of the application

2 2 Reliability and Quality terms - Definitions

Every plant has checking procedures to determine whether or not standards are being met These standards are based on both product quality and process reliability In this thesis, we assume that quality is related to the number of faulty items that a process produces On the other hand reliability relates to the production line and depends on three parameters UPH, Equipment Availability and Machine Utilisation Both Quality and Reliability define the "Output" of the production line The figure below (Fig 2 2), illustrates all the parameters that can affect the output of a production line, as given in by the EVF Team in Intel (1999)



UPH x Util x (Total Equip - Equip Reserved) x U/D x Nominal Weeks x People Capability = Output [ku/mo]

Figure 2 2 Parameters governing the output of a process of a production line
In this thesis we will not deal with "People Cap"

Below we give the definitions of all the parameters measuring Reliability (including those presented in Fig 2 2)

Util (Utilisation) Is the utilisation of a component/stage of a production line This utilisation may include scheduled downtime to allow for the setup of a machine, machine cleaning, conversion of the machine etc

Equip Avail (Equipment Availability) Total Equipment (*Total Equip*) minus any equipment held us reserved (*Equip Res*)

U/D (Unscheduled Downtime) Unscheduled downtime may be due to repair of a component, *assists* and blackouts Assists may be defined as any unplanned interaction, which requires human intervention of less than six minutes to correct After six minutes it becomes a failure

Failure Occurs if any interruption or variability from the specifications of equipment operation requires the replacement of a component

People Cap (People Capability) Refers to the capability of people working for the production line

Nom Weeks (Nominal Weeks) Refers to the period for which we want to do the investigation

Yield Quality of the product Counts the number (percentage) of non-defective items

UPH The number of units that a component/stage of a production line can produce per hour UPH should be fairly constant, unless the system is improved or large amount of unscheduled downtime occurs

*Run Rate = UPH * Util * Yield*

Pure UPH This is the theoretical UPH and it is different for each product It can be estimated as (3600 seconds)/ (*Cycle* per unit)

Desired Gap Each company has a production policy, within which desirable gaps of time are allowed for This gap is a safety margin, so that the production can cover unscheduled downtimes and accidents Machine Availability is estimated based on this parameter as the sum

$$\textit{Machine Availability} = \textit{Machine Utilisation} + \textit{Desired Gap}$$

The UPH of the whole production line is the UPH of the *slowest stage* of the system This stage is called the "*Bottleneck*" of the process For example, suppose that we have a production line, which consists of 5 process steps The UPH of each step is given in Figure 2 3 We can see that the capacity (UPH) of the whole production line is based on the slowest process, Step 3

Process	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**
Per Machine Output:	1000	85	120	505	67
# Machines per Step:	1	10	3	1	15
Capacity / process step:	1000	850	**360**	505	1005
Line Capacity:			**360**		

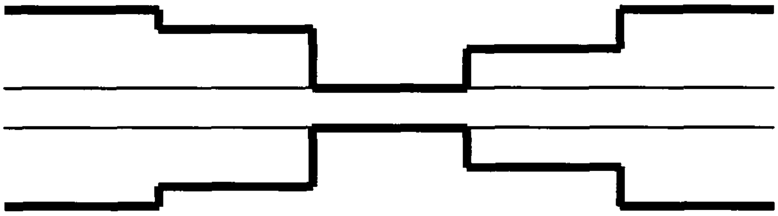


Figure 2 3 A graphical representation of a manufacturing pipeline capacity, (not to scale)

2 3 Production Control Process

Investigating reliability features of plant processes requires good knowledge of the system (the structure, the components, products etc) and of the possible states, (with the time spent in each one) This section presents all the possible states as *SEMI Publications* (a group of people working for Intel and analysing the production processes) presented them

Total time available is divided into two periods *Operation* and *Non-Scheduled* time *Non-Scheduled* occurs when the machine is not scheduled to function at periods such as holidays, weekends and non-working shifts Furthermore, when equipment is out of the line because of installation, rebuild or upgrade, its state is labelled as non-scheduled also

Operation time is further sub-divided into two periods Equipment Uptime and Equipment Downtime

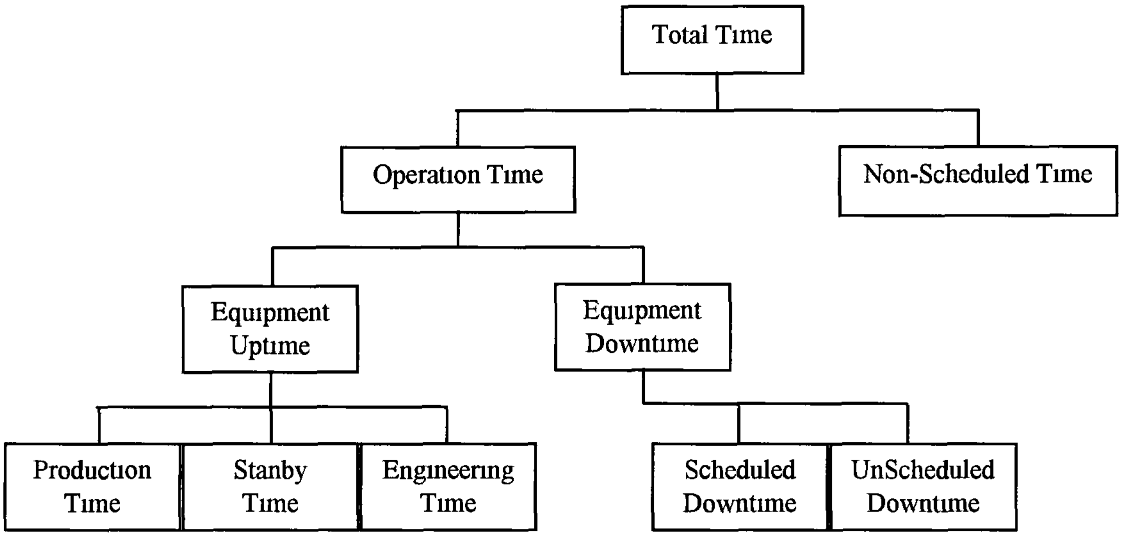


Figure 2 4 The total time divides by equipment status

Equipment Uptime

Equipment Uptime is the sum of three periods of time *Production time*, *Standby time* and *Engineering time* Production time is the period for which the equipment is performing its intended function This includes regular production (including loading and unloading of product), rework, production tests for preventing failures and repair procedures Standby time is the period of time that the equipment is in a condition to function, facilities are available but it is not operating This includes operator unavailability (i e breaks, meetings etc), product unavailability (i e empty buffer) and waiting for the results of a production test Engineering time is the period where the equipment is in a condition to perform its intended function but is operational for the purpose of conducting engineering experiments

Equipment Downtime

This period of time includes *Scheduled* and *Unscheduled* Downtime Scheduled downtime occurs when the equipment is not available to perform its intended function due to planned downtime events This includes preventive actions designed to reduce the likelihood of equipment failure, setup time, which is the required time to complete alteration to accommodate a change, and facilities-related downtime (environmental, power and communications hook-ups) Unscheduled downtime occurs when the equipment is not in a condition to perform its intended function due to unplanned downtime events. This includes repair (the sum of all the repair steps: diagnosis, correcting actions, equipment tests and process test), problems created out of the specification of faulty inputs and facilities-related downtime (unplanned blackouts, environmental etc.).

2.4 Production Control Process – ESSM Plant

In section 1.6, we mentioned that Intel transferred the production control process from the "old" technology to MMX technology. The new, higher technology, refers only to the technology of the product and not to the production line as such. Of course, the production lines changed to produce the new product. The old stages were mainly replaced by new stages with similar function, but with the principal differences of relating to the size of both the components and the machines. In this section we present the control process for both production systems and we give the inputs and outputs of each stage. Another major difference between these two systems relates to the inspection stages.

2.4.1 Old Production Line

The board building production line consists of fourteen steps. Almost half of them involve inspection of the board's quality. The first step is the preparation of the bare fabric (fab) for the production line, which consists of the attachment of appropriate labels onto the board. The next step, *Screen Printing*, involves application of the solder paste to the pads on the bare fab. The paste ultimately is the mechanical and electrical bond between the components and the board. The first test is performed at this stage. If the paste levels are too high then pressure is increased to reduce height, and vice versa if the paste levels are too low. The third step, *SMT Placement*, consists of three machines which accurately position components on the board. The first two are identical and deal with positioning of all the smaller components. The third machine is used for the placement of the larger and heavier components. All three machines have an automatic system for checking the tolerances on the parts as they go through vision processing. As a result, if the part is too big, too small, damaged or missing from the pick up nozzle it will be rejected *Reflow* is the next step and its function is to heat the solder paste above its reflow temperature for a specified period of time so that it melts and adheres to the components leaving them firmly attached to the board

The *Post Reflow Test* ensures that all the correct components are in the right location and in the right orientation It also ensures that all the component placements and solder joins conform to *iWS* (Intel Workmanship Standards) The operator places the overlay over the board and inspects the whole board in a methodical manner Typical failures include missing components, skewed components and damaged components All failures are fed back to the relevant source (step) at which they occur, i e a board with a failure type "Open Joint" is fed back to the stage of "Screen Printing" or with a failure of type "Missing Passive" is fed back to the stage of "SMT Placement" *Manual Assembly* is the sixth stage Its function is to insert the *MTH* (Manual Throughhole Mount) Connectors into the board The board passes between four to five operators (depending on the number of parts per board) who insert a variety of leaded components and connectors of various sizes into plated through holes Each operator has an MAI (Manufacturing Assembly Instruction) to tell him or her where each part goes, the orientation and any other information that may be relevant to the correct insertion of the part As each operator finishes inserting their own components they pass the board to the next operator and the last operator does a general check to ensure all components are accounted for and pushed in fully

Wave Soldering involves soldering the leads to MTH components, hence providing the mechanical and electrical bond, and also attaching the components to the board The wave profile is similar to the reflow oven profile and the process is carried out in much the same way After that, the board passes through another test, the *Post Wave Inspection* This is a visual inspection of the board to ensure that the solder joints and MTH components conform to iWS All failures are fed back to the relevant source (step) as they occur, i e a board with a failure type "Open Joint" is fed back to the stage of "Wave" or with a failure of type "Missing Connector" is fed back to the stage of

“Relevant Manual Operator” *Final Assembly* is the next step and its function is to complete any additional processes that are required to produce the finished product

The next four steps involve testing the quality of the board *ICT* (In Circuit Test) is the first of the automatic test processes Each board is tested for continuity and sort circuits in the various circuits Continuity and sort circuits are created when the manufacturing constraints are not conforming to iWS The tolerances of the various devices are also tested After the board is tested it is either passed or failed on iFICS (Intel Factory Information Control System) A failed board is sent to "debug" to determine the cause of the failure The second quality test is the *Functional Test* Its aim is to do a complete power up of the board and to run a number of tests that verify the functionality of the board This involves similar procedures to ICT Any failed boards are again sent to functional debug At the *EOL* (End of Line) test there is one last check on all boards to ensure none have been physically damaged during test procedures and all parts are in place and conforming to iWS Last, but not least, is the *Outgoing Quality Assurance* (OQA) Its function is to complete a sampled inspection of the boards coming from EOL If any board fails at that stage of the process the entire line is stopped and screened The board is taken back to the relevant area and the root cause and corrective determined A number of boards that follow all go through OQA and depending on the nature of the failure, boards may be pulled back from the pack for re-inspection Board Pack is the last step Each board is placed in an antistatic bag and then is placed in a sectioned cardboard box

For every test, each failure causing a defective board is noted in a logbook and the relevant source is informed if a trend develops The route that the board must follow to correct the failure is also noted Figure 2 5 illustrates the flow of the process described above Before transferring to the new system, Intel used two identical lines of this type, placed in parallel

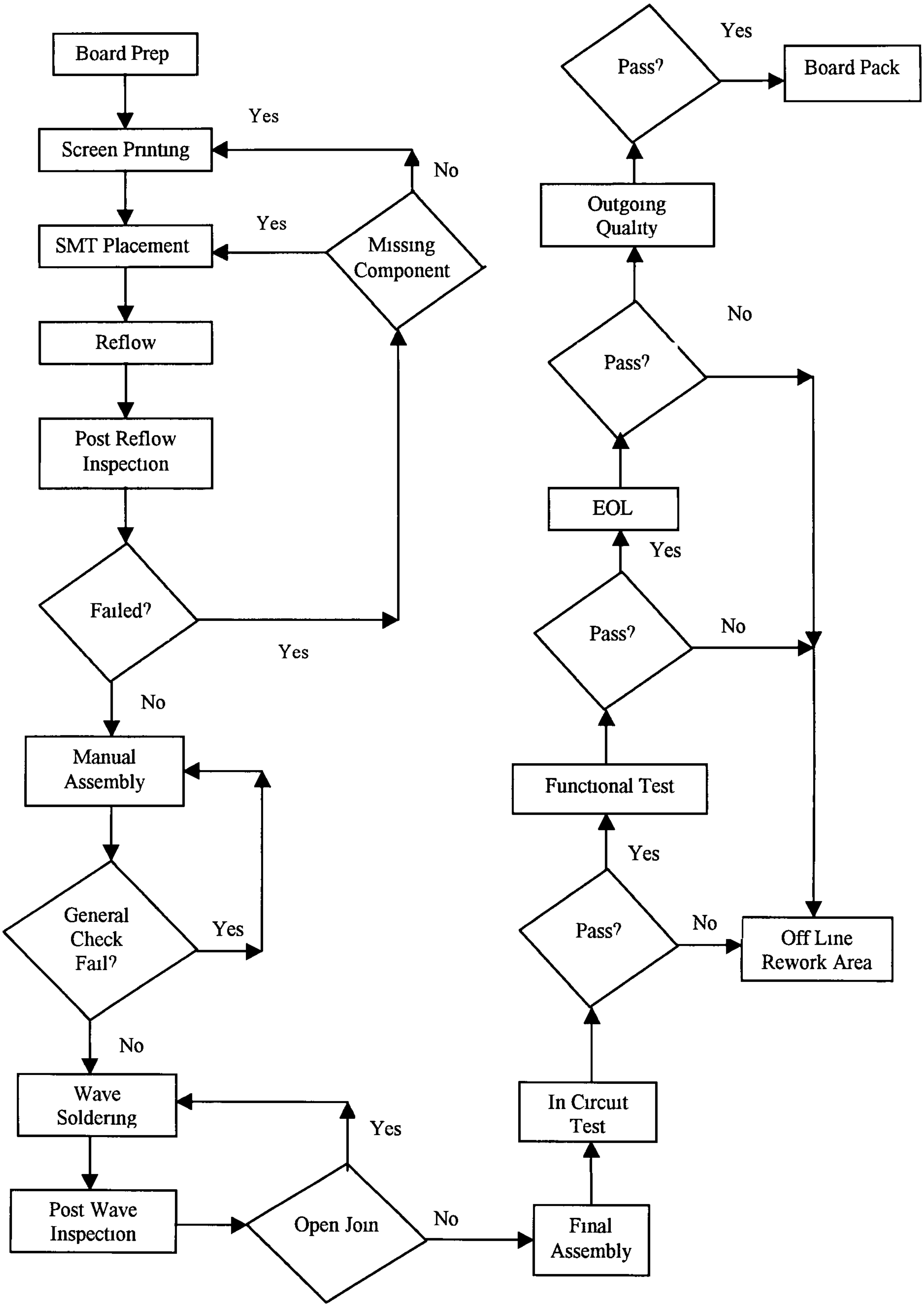


Figure 2 5 Flow chart of the Schematic of Process of the old production line

2 4 2 *MMX Production Line*

In this section we describe the new production system which Intel adopted in last year (1998) At the beginning of the line, the inserted bare fab is a panel consisting of 6 boards (2 * 3) and the separation of those 6 boards takes place after the *ICT* test The flow of this line is divided into three subsystems After the *Panel Mark* stage, in which the panel takes an identification number, it is ready for the first subsystem The stages in this subsystem involve working on the secondary side of the panel The first stage is the *Secondary-Side Paste* and its function is to apply the solder paste on the bare fab The height of the paste is measured on particular locations at specific intervals to ensure that it remains within the control limits If the paste heights are too high the squeegee pressure is increased to lower them and vice versa The next two stages are *Secondary-Side Chip Shoot* and *Secondary-Side Pick and Place* Their intended function is to place all the surface mounted components on the board The first stage places the smaller components (resistors, capacitors, etc) The larger components are placed into the second stage where the speeds of the table (table is the bare fab with the components attached on) are slower, reducing the possibility off the parts falling of the board under their own inertia The machines have an automatic system for checking the tolerances on the parts as they go through vision processing As a result, if the part is too big, too small, damaged, or missing from the pick-up tape they will be rejected The number of retries the machine is allowed to make is one for the first stage and zero for the second Next stage is *Reflow* It functions in exactly the same way as the Reflow stage in the old system It leaves the components firmly attached to the board The last stage of this subsystem is the *Secondary-Side Visual Inspection,* which inspects the panel and ensures that all the components are in the correct location and have the right orientation, it also checks that all component placements and solder joints conform to iWS

The second subsystem functions in exactly the same way and consists of exactly the same stages and machines The only difference is that it works on the primary side of the panel and the components that are placed in this subsystem are more important (e g Pentium chips)

The third subsystem consists of stages that give the product the final look and ensure its quality By this stage, six boards are sharing the same panel Firstly, *Depanel* separates the panel into individual boards, which are required for further processing *ICT* inspection is the next stage and functions in the same way as for the old system It performs the first automatic test procedures The final three stages give the final look to the product Covers, skirts and thermal plates are attached to each unit This is followed by a very important inspection, the *SYS Test*, which involves a complete power up of the board and verifies the functionality This is a similar procedure to ICT The Cover Mark stage gives the board its final look, putting identification laser marks on all units The last stage is the Final Visual inspection and Fit test At this stage an inspector ensures that the final product is ready to be packed

OQA inspection (Outgoing Quality Assurance) is again present in the new production system but is off-line Here, a sampled inspection of the boards coming from the Board Pack stage is completed The process is split between a visual inspection and a functional test If any board fails at this stage of the process the entire line is stopped and screened, 100% inspection A specified number of boards, following a failed board all go through O Q A and depending on the nature of the failure, boards may be pulled back from pack-off for re-inspection

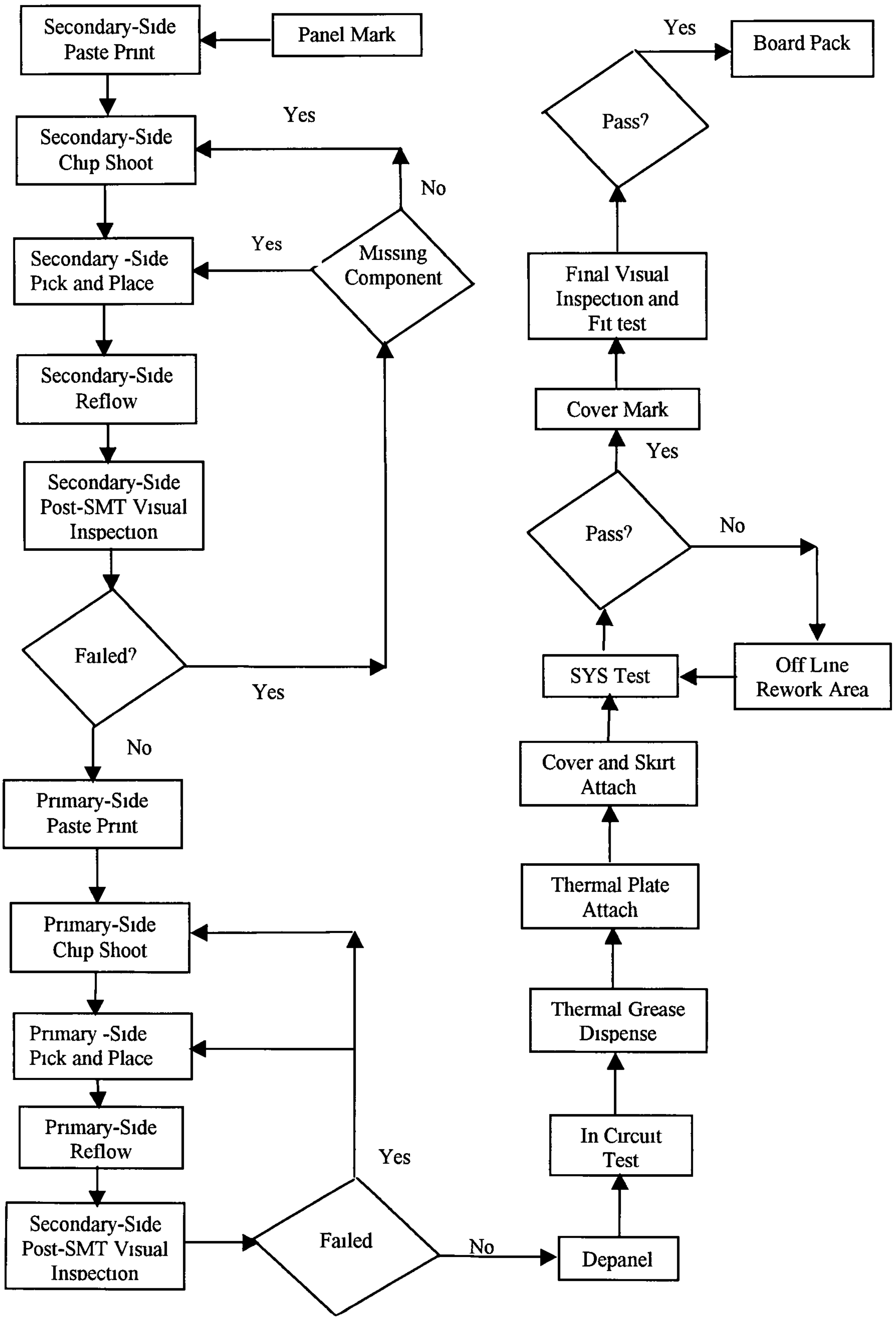


Figure 2 6 Flow chart of the process of MMX production line

2 4 3 Comparison of the two lines

In section 2 4 1 and 2 4 2 we referred to the two production systems which Intel have used to produce Pentium processors Although the two systems perform similar tasks there are some differences between the stages For example, the new system does not have a “Manual Assembly” stage All stages are automated and robots are used in the placement and testing of the components (refer to “Manual Assembly” and “Wave Soldering” in section 2 4 1) There is now no need for either this sequence or for post-wave inspection in the new production system The “Functional Test” has also been replaced by the “SYS test”, a more automated process The end of line inspection for the old system, called “EOL”, has now been replaced by “FVI Pack” (Final Visual Inspection) the test at the very last stage of “Board Pack”

Last but not least is the change of the inspection “OQA” (Outgoing Quality Assurance) This test used to be a part of the production line but in the MMX line is an off-line inspection The process of testing boards is the same as for the previous line, but is now separate from the production system

2 5 In Summary

Chapter 2 presented the basic system to be investigated The next chapter, Chapter 3, gives the model and flow processes for these two lines The mathematical model overviewing the system is presented and how simulation, in particular the Monte Carlo technique, is applied to this system We provide further discussions on the Monte Carlo simulation techniques and we describe the algorithms governing the simulation process Chapter 3 also gives details of the data and feedback gathered from the Intel ESSM plant in Ireland

Chapter 3

Modelling the Production System

3 1 Monte Carlo

The name Monte Carlo was inspired by the similarity to statistical simulation of games of chance, but although the basic procedure of the Monte Carlo method is the manipulation of random numbers, these should not be employed extravagantly Of course a large sample of random numbers will give more accurate results for any model of interest, but when systems are large and complex, each Monte Carlo repetition needs a lot of time, making the software tool very slow

Two subdivisions of Monte Carlo simulation include Direct and Indirect We use the Direct Monte Carlo method to solve probabilistic problems where random numbers directly simulate the physical processes of the original problem and the desired solution is inferred from the behaviour of these random numbers Another way of solving a complicated problem is to use Monte Carlo simulation to solve a similar or related problem with, usually, simplified features This method is called Sophisticated or Indirect Monte Carlo To model the Intel system, we used direct Monte Carlo simulation, generating a random number for each parameter of the problem (Hammersley and Handscom, 1979) For example one parameter *"Scheduled Downtime"* depends on the probability that a failure occurs and empirical frequency distributions can be determined for number of failures in a given period Clearly as more real data (on both Quality and Reliability) become available, so the distributions and simulations based on them can be refined For each experiment, quality and reliability measures are obtained

In the introduction (Chapter 1) we mentioned that we are using three different Monte Carlo models in the Software Tool we created In order to estimate the Quality of a given size of boards we are using a model where each Monte Carlo repetition represents the testing of a single board, passing through the whole production line For example if the user wants to test 60,000 units (boards) for any possible failure, the Monte Carlo model (presented in Section 3 3) should do 60,000 loops On the other hand, estimation of Reliability of a each stage of the line requires a model (fig 4 8 and 4 9) where each loop represents a working day for each stage The procedure for estimating the reliability of the overall system is applied if only the reliabilities for the stages are already estimated (by the model in section 3 3) The idea behind the estimation of the Reliability of the overall system, is for each Monte Carlo loop to generate a state of the system (able or not to finish its intended job) with the help of procedure “Q” and we fully describe this in Section 3 3 Each Monte Carlo loop of this model represents a working day

3 2 Generation of random numbers

3 2 1 Simulation of Quality

As we mentioned above, in simulating Quality, one Monte Carlo repetition is equivalent to the passing of one board through the whole production system Each inspection of the system can detect a specific number of failures For each failure a random number is generated from the Uniform distribution (with maximum value 1 and minimum 0), and is compared with actual percentage of failure for this inspection This actual percentage has been obtained from the relevant inputs at each inspection every day The reason we are using an actual percentage in simulating quality is because the number of faulty boards that occurred every day is very small and almost constant Intel is handling Quality the same way with do (as actual percentage) In the Table 3 1 we can see that the percentages are really small as taken from the PSVI 1 inspection over a period of four weeks time Demonstration of this can easily be found by the fact that stages, (for example the stages of Chip-Shooters, section 2 4 2) do not allow for replacement of a faulty component more than once for the first machine and never for the second

	6/27/98 - 7/04/98	**7/11/98 - 7/18/98**	**8/8/98 - 8/15/98**	**8/15/98 - 8/22/98**
Percent of having a failure	0 067	0 081	0 09	0 091

Table 3 1 Percent of having a board with a failure (15 possible failures) as detected in the PSVI 1 inspection for the duration of 4 weeks

Another fact is that each time a new tape of components is loaded onto the machines, there is a possibility that an error can be made and as a result several boards can be built with a wrong part To prevent this, there is an operator that verifies each stage and also a second “buddy” operator re-verifies them For these reasons we describe the probability of failure of a board by Uniform distribution in the same way with Intel We present in detail the procedure of Quality simulation in Section 4 6 (Figures (4 6) and (4 7))

3 2 2 Simulation of Component Reliability

However, simulation of Reliability works in a different way since reliability of the system depends not only on Scheduled Downtime (section 2 2), which is reasonably constant every day, but also on Unscheduled Downtime (section 2 2) which occurs randomly Consequently, different statistical distributions must be fitted to Scheduled and Unscheduled Downtime for each stage in order to describe and predict a downtime The tool permits the user, after recording observed Scheduled and Unscheduled Downtime data, to do a *Visual Statistical Analysis* with the help of a window especially created (Manual, Appendix) This Visual Analysis is exploratory and includes provisional fits of distributions for Scheduled and Unscheduled Downtime at each stage of the system for the reason described above (Fig 3 1) Each Monte Carlo repetition represents one working day For every loop, two random numbers are generated for each stage, one for Scheduled and one for Unscheduled Downtime from the distributions fitted on historical data at the stage of Visual Statistical Analysis After generating the downtime (both Scheduled and Unscheduled) for each stage is very easy to estimate its reliability Furthermore, since real data available to us were limited, the software tool that we have built can also generate random numbers from various standard distributions for down times e g Exponential and Weibull This generation is supported by the Random Number Generator (*Rnd* function) in Visual Basic, which generates numbers between 0 and 1, U(0,1) At the end of this section we present how we generate random numbers following the Normal Distribution

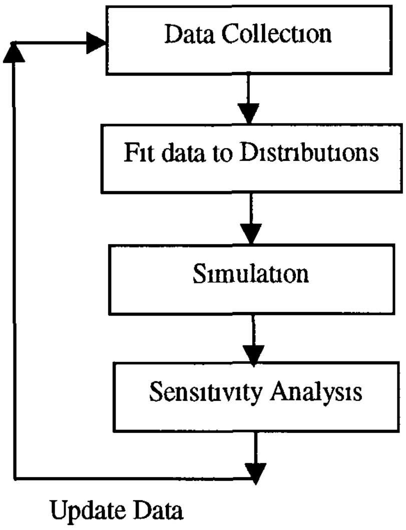


Figure 3 1 Data processing for system improvement

The software tool uses four standard distributions (Exponential, Weibull with one parameter, Uniform and Normal) to which downtime data can be fitted Of course there are a lot of other life time distributions, (well-described by Kalbfleisch and Prentice, 1980), such as Log-Normal, Gamma, Weibull with more than one parameter, etc , which may represent downtime equally well if not better for some applications The reasons we chose those four distributions are both because downtime data collected by Intel usually follows one of these four, but also because Intel is using those four into some other models (such as Output Capacity Model, Intel EVF Team, 1999) and this will allow comparisons between them and our tool Of course the code of the software tool is flexible enough to add more types of distributions Below we present an example, on how we generate random numbers following the Normal distribution

Random numbers from Normal Distribution

Knowing the Mean and the Standard Deviation of the sample we can generate values following the normal distribution as follows We use the Rnd function to generate Uniform Random Numbers U(0, 1) The Rnd values presented in the formula below represents, of course, different numbers

$$\textit{Normal Random Number} = \textit{Mean} + \textit{SD}^{*} \sqrt{- 2 * \log(\textit{Rnd}) / \textit{Rnd}}$$

Where *SD* is the standard deviation of the sample Statistical software package JMP (SAS, 1995) is using this formula to generate random numbers from Normal Distributions

3 3 Monte Carlo Method

In section 3 2 we referred briefly to the rational of how to use simulation for Quality and Reliability Giving more details, Rice and Moore (1983), presented an outline of the Monte Carlo simulation procedure (section 1 4) in order to investigate a series system (Fig 1 1) This procedure consists of

1 For each inspection in turn, assign the number of failures, F_i

2 Calculation of the first estimate $p_i = F_i/n_i$, where p_i is the probability of having a failure of type *i*, and n_i is the number of trials

3 Draw a random sample from U(0,1) for each unit passing the inspection and compare it with the probability p_i

4 Calculation of component reliabilities and/or quality

5 Repetition of steps 4 through 5 a total of n times

Applying this process directly enables us to estimate Quality at inspection Repetition of the procedure as many times as the numbers of units that we want to inspect (usually large for good results) gives us the quality of each inspection in the production line For example, estimation of the Quality of subsystem consisting of two inspections I_1 and I_2 can achieved as follows

1 Collection of the Quality data of the plant will initially give us the total number the number of units passed through these inspections (n_1, n_2), and the number of units detected with a failure (F_1, F_2) for each inspection

2 The probability having a failure at each inspection is $p_i = F_i / n_i$

3 For as many Monte Carlo repetitions as the number of units the user wants to inspect do step 4

4 If Rnd > p_i then the board to has a failure

In order to estimate the reliability of each stage in the production system, it is not necessary to know if the system consists of parallel production lines or parallel stages For this reason we also use the above technique, Rice and Moore (1983), in order to estimate the reliability of each stage Flow charts of this technique applied to both Quality and Reliability are presented in Section 4 6

Estimation of the Reliability of the overall production system

The above technique can be used only in series systems, hence, estimation of the Reliability of the overall system cannot be done using this technique because it is not common to have simple series systems without parallel stages or without having two or more repeated lines For this reason, and because the system we are investigating has both parallel stages and parallel production lines, we use a Monte Carlo procedure (Procedure Q), suggested by Fishman (1986)), a technique known as Monte Carlo simulation Based on Bounds (Section 1 4) This technique was initially used to estimate the probability that two particular nodes are connected in a given network (Fig 1 6) Fishman (1986) used Procedure Q to estimate the reliability of a network, and by incorporating lower and upper bounds, increased the accuracy of Monte Carlo sampling In this section, we demonstrate this technique by estimating the reliability of a small subsystem from Intel's new production system In section 2 4 2 we give information for each stage mentioned in this example

Suppose that we have two identical subsystems of the new production line (Fig 3 2) Both subsystems are producing the same product and when one is down the product is sent to the other subsystem In this example, we suppose that the reliability of each stage (SMT I and SMT II) is equal to 0 89 We chose this probability (0 89) because it is closer to both SMT I and SMT II reliability If any of the stages in subsystems SMT I and SMT II is down the whole subsystem is down

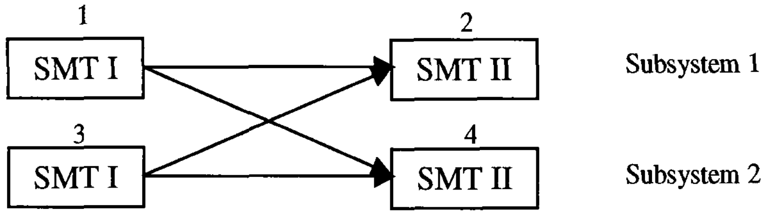


Figure 3 2 Two subsystems from the MMX production line in parallel

Where SMT I consists of *Secondary-Side Paste Print* stage, *Secondary-Side Chip Shoot* stage, *Secondary–Side Pick and Place* stage, *Secondary-Side Reflow* stage, and *Secondary-Side Post-SMT* Visual Inspection

SMT II consists of *Primary-Side Paste Print* stage, *Primary-Side Chip Shoot* stage, *Primary–Side Pick and Place* stage, *Primary-Side Reflow* stage, and *Primary-Side Post-SMT* Visual Inspection (Section 2 4 2 discusses details of the functions of these)

The probability that we took as constant (0 89, a hypothetical value close to reality) for each subsystem (SMT I & II) in the above example, has to be evaluated for each stage of every subsystem to estimate the system Reliability (Fig 3 3) This evaluation is made using the procedure outlined by Rice and Moore, (1983), Section 3 3 Since Procedure Q was initially used to estimate the reliability of a production system and not a network, some changes are necessary The basic difference is that we do not investigate if any two particular nodes are connected (Fig 1 6), but do check to see if the first subsystem of any production line is connected with the last subsystem in another (or the same) line The detailed procedure, as applied to estimation of the reliability of a production system, is given below

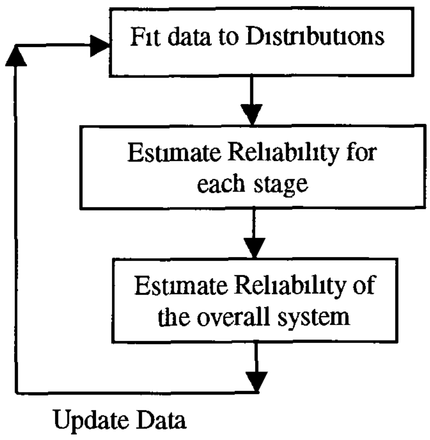


Figure 3 3 Estimation of the Reliability of the overall system

3 4 Procedure Q

1 Estimation of the total number of stages (subsystems) of the production system which is under investigation (Number of stages at each line * Number of lines)

2 Creation of a vector with as many elements as the total number of stages

3 For each element, sample U from U(0,1) If U > p (Where *p* the reliability of the stage that the element corresponds to) then this element will take value equal to 0, otherwise 1

4 For each production line, sum the elements that correspond to identical stages If the sum is equal to 0, then the system is down Otherwise, continue with the next stage

5 If the system is working then *Success = Success + 1*

6 Repeat steps 2 to 5 for very many Monte Carlo repetitions

7 The reliability of the system is equal to *Success / Monte Carlo repetitions*

Applying the above procedure to our example (Fig 3 2), the parameters are as follows
Total number of stages 4
Creation of a vector (X_1, X_2, X_3, X_4), where X_1, X_3 represents the state of SMT I, and X_2, X_4 the state of SMT II for each line X_i can be either 1, if stage is working, or 0 if stage is down Comparing the probability that a stage works (0 89 in our example, Fig 3 2) with the sample U from U(0,1) we generate the vectors The possible values of this vector are as shown in Table 3 2 For example, if the processes generate the factor

$$(X_1, X_2, X_3, X_4) = (1, 0, 1, 0)$$

That means that SMT I subsystems are working in both production lines, but not the whole system, because the units cannot move on to the next stage (SMT II).

X_1	X_2	X_3	X_4	$X_1 + X_3$	$X_2 + X_4$	**System's State**
1	1	1	1	2	2	Working
1	1	1	0	2	1	Working
1	1	0	1	1	2	Working
1	0	1	1	2	1	Working
0	1	1	1	1	2	Working
1	1	0	0	1	1	Working
0	1	1	0	1	1	Working
1	0	0	1	1	1	Working
0	0	1	1	1	1	Working
1	0	1	0	1	0	Failed
0	1	0	1	0	1	Failed
1	0	0	0	1	0	Failed
0	1	0	0	0	1	Failed
0	0	1	0	1	0	Failed
0	0	0	1	0	1	Failed
0	0	0	0	0	0	Failed

Table 3.2 The possible states of a production system consisting of four stages

For 500 Monte Carlo loops this procedure give the system's reliability to be 97.7%. In order to check the accuracy of this result, we compare it with the mathematical model. Before moving to the mathematical model we must explain why we estimate system's reliability by 500 Monte Carlo repetitions (Table 5.4 presents results from different number of repetitions). It is clear that the more Monte Carlo repetitions these are, the more accurate the estimated reliability will be. 500 repetitions are sufficient to ensure good results. According to Fishman (1986), with his method reduced the number of repetitions by using Bounds. In this software tool we do not require a reduction of repetitions. We want to investigate the extreme values of possible downtime, use sensitivity analysis to explore the implications of changing features for production which influence downtime and ultimately to make it more predictable For that reason it is not necessary to use bounds in our software model, since the user can choose the number of repetitions that correspond to the number of working days in this model

Fishman's Bounds

Fishman (1986) took as Upper and Lower bounds A, B, respectively the following

$$A \equiv \sum_{x \in X} \Phi_2(x) P(x) \qquad (3\ 1)$$

$$B \equiv \sum_{x \in X} \Phi_1(x) P(x) \qquad (3\ 2)$$

where Φ_1, Φ_2 are structure functions (Section 1 1)

$$\Phi_1(x) = 1 - \prod_{j=1}^{l} (1 - \prod_{i \in P_j} x_i) \qquad (3\ 3)$$

$$\Phi_2(x) = \prod_{j=1}^{l} [1 - \prod_{i \in C_j} (1 - x_i)] \qquad (3\ 4)$$

and

$$P(x) = \prod [1 - p_i + (2p_i - 1)x_i], x \in X \qquad (3\ 5)$$

Where X the set of all system vectors, P_i, C_i (appeared in formulas (3 3) and (3 4)) the minimal paths and cutsets

3 5 Mathematical Model

With the help of the Equations (1 4) and (1 5) we can estimate the reliability of a system with two parallel production lines In general if we have a system with m **identical** parallel production lines (exactly as found for Intel's ESSM plant) and each production line consists of n series subsystems (Fig 3 4), then a unit which exits from a subsystem can go into any of the available subsystems in the next stage Each subsystem consists of S_i stages, where i, is the number of subsystem (Fig 3 5) and when a stage in a subsystem is down the whole subsystem is down. The whole production system is down when all the subsystems are.

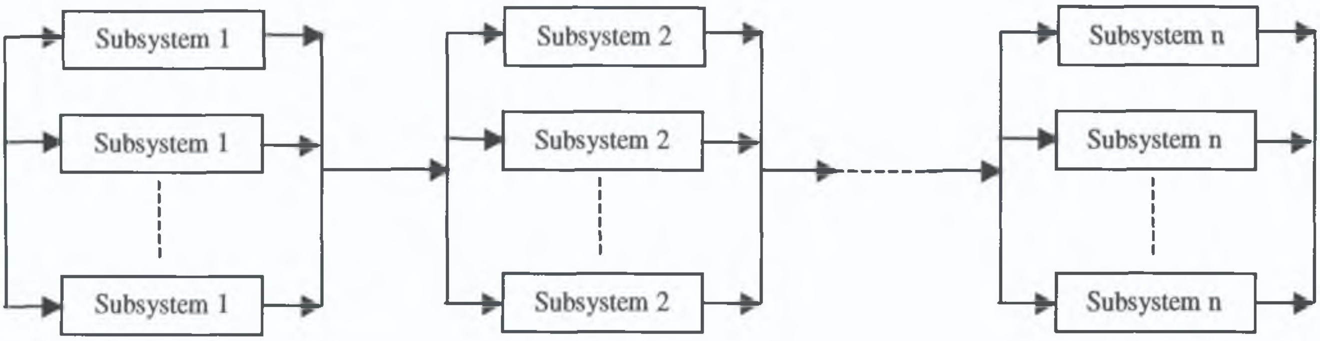


Figure 3.4: A system of m identical production lines

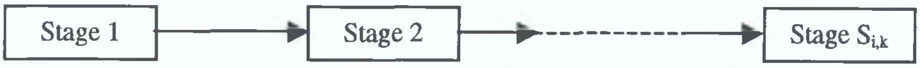


Figure 3.5: The Subsystem i, with k stages.

So, the probability of *n* independent events can be computed as follows:

$$R=R_1R_2\ldots R_n \qquad (3.6)$$

where R_i the reliability of the *m* parallel system, consists of *m* identical subsystems *i.* So:

$$R_i = 1 - (1 - P_i)^m \qquad (3.7)$$

So the reliability of system in Figure 3.4 can be estimated as:

$$\boxed{R = [1 - (1 - P_1)^m]\,[1 - (1 - P_2)^m] \ldots [1 - (1 - P_n)^m] \qquad (3.8)}$$

where P_i, is the reliability of subsystem *i,* given by:

$$P_i = p_{i,1}\, p_{i,2} \ldots p_{i,s} \qquad (3.9)$$

with $p_{i,j}$ the probability that stage *j* in subsystem *i* is down and s the total number of stages in this subsystem.

In our example (Fig. 3.2), we assumed $R_i = 0.89$ (to simplify the example) for every *i*, So the reliability of the system in Figure 3.3 is equal to:

$$R = [1-(1-0.89)(1-0.89)] * [1-(1-0.89)(1-0.89)] = 0.976$$

We can see that the results on systems' reliability from the Monte Carlo procedure are very close (1% absolute difference) to the theoretical results on the same system's reliability. In order to test the validity of the Monte Carlo approach further comparisons with the theoretical model were carried out at all stages. Additional results are presented in Chapter 5.

3.6 Data Gathered

The basis for the experimental simulation work was the historical data collected on both Quality and Reliability data from Intel's ESSM plant. For Quality this included all possible failures that an inspection could detect and the number of boards found with a failure every day. For Reliability, data included downtime, gathered from Intel's *"Green Book"*, (which contains a daily event record). Unfortunately, collection of data on a systematic basis is difficult and time consuming in a plant of the ESSM size, where huge amounts of information are generated daily. Consequently data were available for eight weeks only and empirical distributions are necessarily crude because of this. It is also for this reason that further options on standard statistical probability distributions were incorporated. It is also sometimes difficult to define the exact cause of failure, which leads at times to some ambiguity in the collected data. Nevertheless, the tool developed allows for updating and refining, as further data become available, and consequently performance should improve with time.

In order to estimate parameters such as Utilisation or Run Rate, the pure UPH is required. We have consequently collected the pure UPH for each stage, for two different products. All tables of raw data gathered for both quality and reliability are presented in the appendices.

3 7 In Summary

In this chapter, we presented the Monte Carlo methods that we used and applied it to a small subsystem from the Intel ESSM plant The results from this example compared well with the mathematical model Data gathered were summarised in outline with details reserved for the appendices In the next chapter, Chapter 4, we discuss in detail the design of the software tool

Chapter 4

Design of the Software Tool

This chapter presents the design of the Software tool. It gives information about the aims of the tool and it's structure. It also refers to the inputs/outputs and finally gives an overview of the prototype. Aims and objectives have a large part to play in software design, in relation to outputs and inputs respectively. Both aims and objectives help guide in building the interface of the Tool. The next chapter, Chapter 5, gives detailed information on the testing of the software tool, using both historical and simulated data.

4.1 Requirements Analysis

Intel's requirements on this project were to create a software tool that can measure reliability of a production system. They asked for a tool able to simulate the implications of unreliable stages and estimation of expected cost. Sensitivity analysis, which is a basic feature of simulation models, was required as an option for this software. Sensitivity analysis offers a basis for answering a number of conditional questions about the parameters governing a process, in order to make possible recommendations and improvements in performance.

By the collection of data we realised that the simulation model also includes Quality information since this has implications for smooth–running of the system and therefore links to reliability measures. In particular Run Rate (Section 2.2) depends on the Quality of the product achieved. Hence, a Quality model is included, which of course runs separately from the Reliability model, so that the users can have results on Reliability, Quality or both (for this reason we have three different Monte Carlo models – two on Reliability and one on Quality).

For the creation of an accurate model of the production system, many inputs are required. By talking with people from different working areas, we found that most people were familiar only with a subset of the inputs that the software requires and consequently not all the users wanted to have the same results. For these reasons, we separated the users into three broad categories depending on their primary functions (Manual, Appendix D). Later on in this chapter, we provide information about these three groups. Clearly because of the difference in outlook, a simply accessible interface was necessary which could incorporate choices for less technically focused users, whilst offering the full range of reports/analysis necessary.

Raw data provided by Intel (downtime only data for the reasons presented in section 3.2), should be passed through statistical analysis in order to be used by simulation models. Thus, the addition of a statistical analysis component in the software tool was considered indispensable. Section 4.2 gives detailed information in the Statistical Analysis window. Due to limited routine data collection by stage, the statistical analysis is not as accurate as it could be. Hence, the importance of data daily collection is clearly demonstrated by this tool.

Results on Reliability and Quality are presented in different windows and if the users specify they can have a combination of those two. The reason we kept these results in different windows is because a user does not always want both and also because running both Quality and Reliability models at the same time will increases the simulation time. Equally, users may be interested in the estimation of the reliability parameters of one or more stages or a subsystem only, rather than the reliability of the overall system. Thus, the models run separately in usual mode, to improve simulation efficiency, and only concurrently if specifically requested by the user.

Sensitivity Analysis

Two different windows help the users to investigate line reaction to parameter changes governing both the Quality and Reliability processes. Due to the large number of outputs and of possible scenarios we decided to create a window which can compare all the range of parameters involved. After each simulation run, the user can, if required, save results and compare them with these for other set-ups. After each simulation run, (either on

Quality or Reliability), a window-report is available to summarise the simulation results This report can also estimate the time that the system given by the current model needs to produce a number of one or more desired products Collection of data relating to the cost of Quality failures was very difficult to achieve Due to the complexity of failures, it was very difficult to identify the exact cost The tool has the option to estimate Quality cost results and also to look at a range of hypothetical costs for demonstrating purposes

4 2 The design for each user group

The three groups of users (section 4 1) are *Engineers*, *Statisticians* and *Managers* Engineers are clearly very familiar with the operation of the production system They provided us with the data on how each stage works, the layout of the production line, the failures that a stage can cause, how failures are prevented and what action is taken when one occurs Hence, we decided that they must be responsible for the design of production line, its representation as a software model and the insertion of relevant inputs This includes the number of production lines, Real UPH and the products that the whole system produces Due to the complexity of the line, we thought that a pop-up menu for its creation was appropriate In Figure 4 1, we illustrate the model of the ESSM plant, as an engineer can create it, where these basic processes are denoted by the objects listed over the page (Fig 4 2)

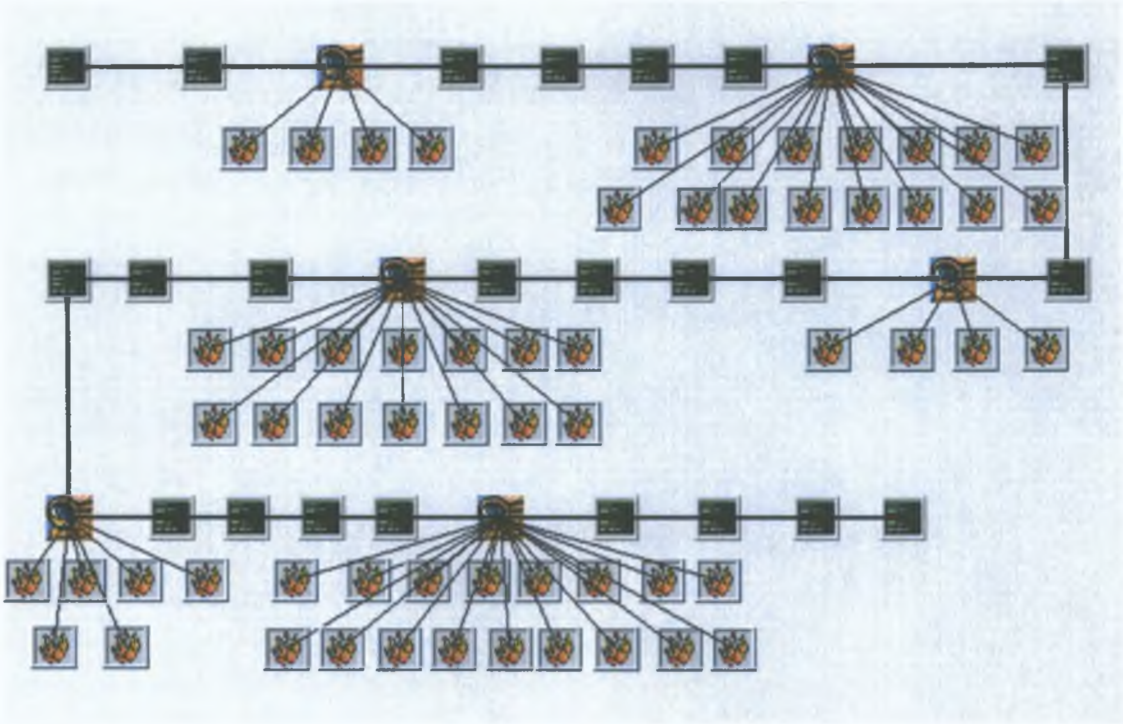


Figure 4.1: The model of ESSM plant as the software tool can represent it

The production system, as shown in Figure 4.1, consists of combinations of these objects and the lines connecting them represent the way a unit passes through each stage. Details on the actual creation process for the model and how to view each object are presented in the Manual for this tool (Appendix D).

Figure 4.2: The three objects with which we represent the production system: Stage, Inspection, Failure respectively

The Statisticians group is responsible for insertion of Reliability and Quality data. Each day, machines and operators collect data from the production system. For that reason we created an input window that will allow users to insert data for each working day (Manual, Appendix D). Each time the user inserts new data, the database is accessed and the chart shows them the current status. Due to the complexity of the system and the potential volume involved, all data are not always simultaneously recorded. For this reason, a window allowing the user to insert data (both Quality and Reliability data) for more than one day was created The difficulty faced for this group of users was in the statistical analysis of this data Hence, the software needed to tackle this difficulty The raw data (Quality and Reliability data recorded) inputted on a daily basis by the statisticians should be changed to frequency data (frequency of having a downtime between e g 30 and 40 minutes) This is achieved by taking the minimum and maximum values (downtime) of the sample and dividing the space between the two values into twenty sections (of equal length, Fig 4 3) Downtime values are mapped to their appropriate sections in order to calculate the number of values that fall within each of the twenty sections The relevant frequency graph can now be traced (Fig 4 4) Incidentally, the space is divided into twenty sections as it was found that this division provided the smoothest graph We are applying this procedure for both Scheduled and Unscheduled Downtime

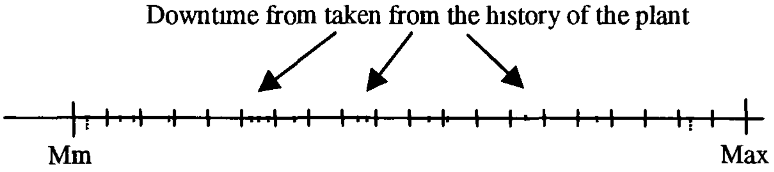


Figure 4 3 Grouping of the inserted data

Since frequency data are available a Statistical Analysis can take place The user chooses the distribution, using parameters (such as mean value and standard deviation) given by the software tool, and a visual comparison (an example is illustrated in Fig 4 4) of the distribution and the data will take place The reason we chose a Visual Statistical Analysis instead of the mathematical is because of the complexity of the last method, making the tool slower Also companies like Intel are already using tools (such as JUMP or Excel) for the statistical analysis, and the purpose of this tool is not simply to do statistical analysis For the last reason, we allow users to insert the estimated distributions in the tool when these are available from other software tools, even if historical data are not inserted

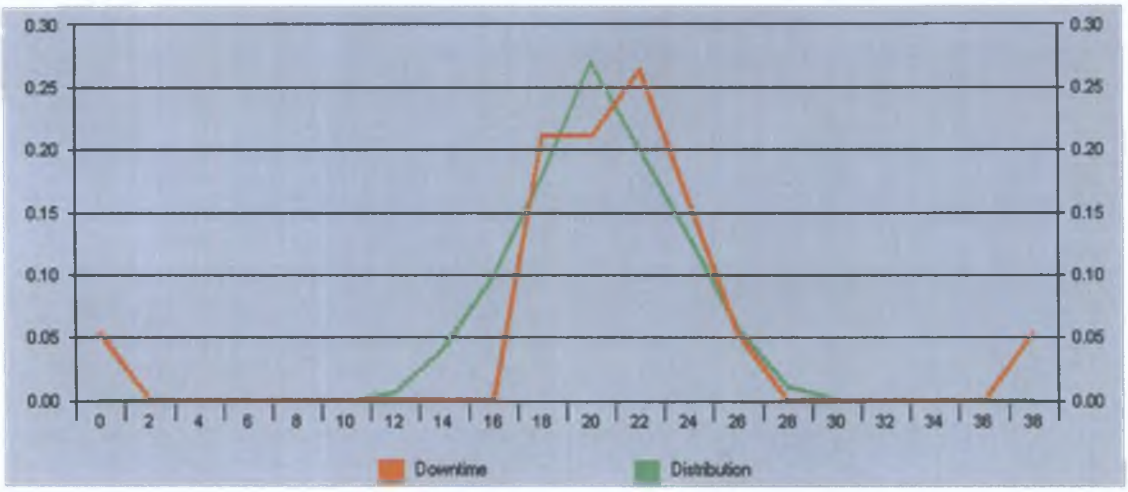


Figure 4.4: Fitting of the downtime data (red line) by a Normal distribution (green line)

Simulation models will use the distribution fitted to the downtime data (as shown above) in order to give results to the *"Managers"* group. The interest of this group of users is on taking results on reliability and/or quality, comparing them, and the sensitivity analyses for the production line in order to produce reports and provide input to the discussion making process. For this reason, we decrease the number of inputs that this group must give to minimum. If Quality results are desired, the hypothetical number of units that a manager wants to "inspect" by the inspections should be inserted. For Reliability results, the number of weeks must be inserted. Due to the separation of the Quality and Reliability results, two different windows are used to present information. The results (both on Quality and Reliability) are presented in a graphical way but numerical results are also available. What is really required is not only a tool providing current system results, but also a tool which can provide the basis for system improvement. Creation of a window, which allows conditional scenarios for the system to be compared, was the next step. For example, the comparison of three different scenarios of "Unscheduled Downtime" for the production line presented in Figure 4.1, is presented below (Fig. 4.5). Were, "Scenario 1" represents the Unscheduled Downtime (in minutes) for a duration of 100 weeks (700 working days, 24 working hours per day), "Scenario 2" is same with "Scenario 1" with only difference the downtime rate in the first stage "Panel Mark" and "Scenario 3" is the same with "Scenario 2" except that represents downtime for a duration of 150 weeks (1050 working days).

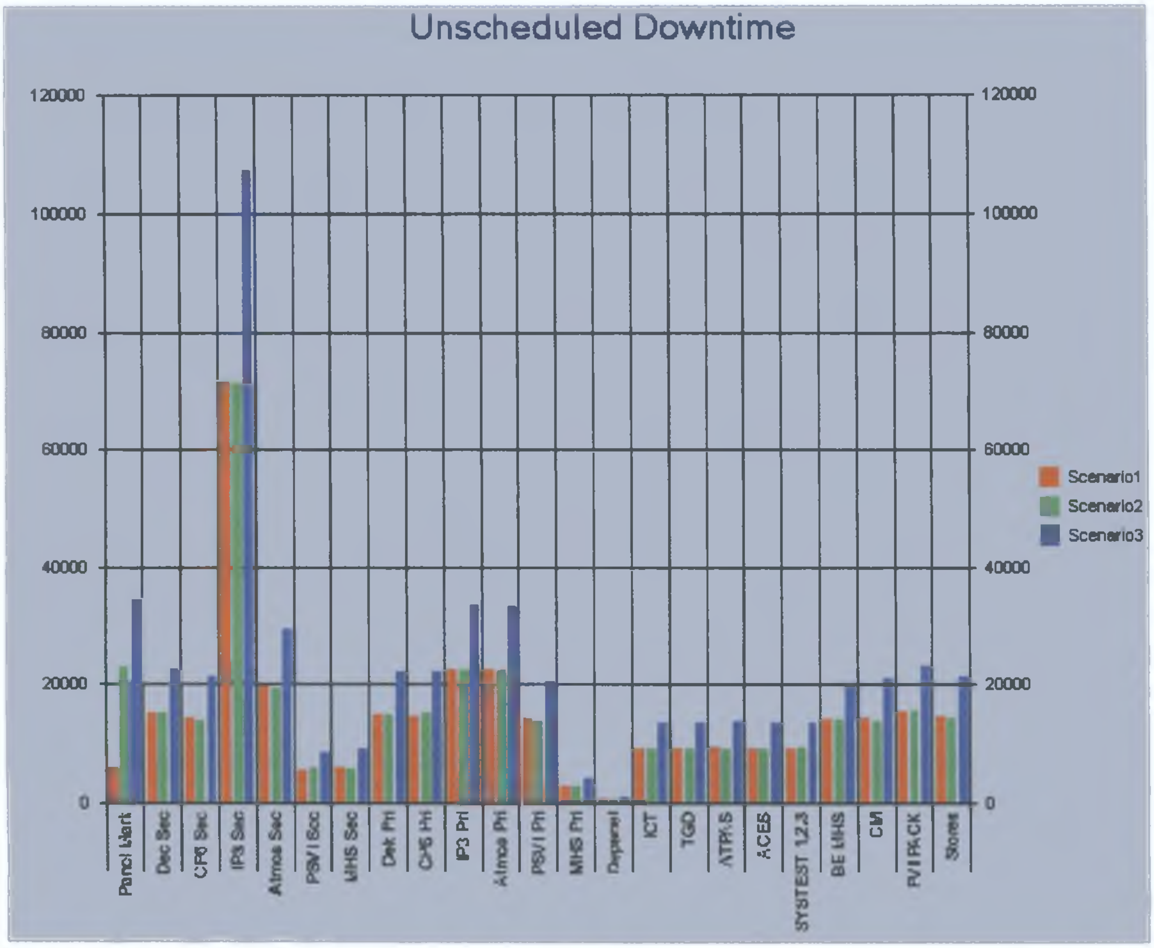


Figure 4.5: Comparison of "Unscheduled Downtime" of three different scenarios

4.3. Nature of Tool

Structure

The software tool is based on an object-oriented language, Visual Basic, and the estimation of outputs achieved through simulation methods, (Chapter 3). We use two types of simulation techniques: Simple Monte Carlo is used to investigate Quality features and Reliability of a given stage, and Procedure Q (a variant of Monte Carlo, Section 3.2), to estimate the reliability of the whole production system. The tool is compatible with Microsoft Excel and it can load data from an Excel file or save data in Excel format. The compatibility with Excel is needed, both because a large number of databases are built as Excel files, but also because it is easier for the user to handle a large amount of data, such as downtime history of a plant, through grid control (data inserted in cells the same way with Excel). Although it is compatible with Excel as regards data insertion, we did not manage to succeed in the online transfer of the outputs from Excel's fittings methods to our software tool Hence, the statistical analysis window was required

The basic problem we had to face when called to save and retrieve data from grid tables was the size of the tables We did not put a specific size of grid table because this would reduce the flexibility and limit the data On the other hand, it is very difficult to retrieve data from a file where the number of columns and rows is unknown because, if the size of the grid table is smaller than the size of the table in the window, data will be lost If the size of the table is larger than the saved size, then the tool will have to spent more time retrieving empty grids This led us to insert the exact size of the grid table as an input to the file Every time the user is saving a file, the tool writes the size (No of columns, No of rows, separated by the symbol “|” e g “32|12”) in the first grid box (0,0), where no data is being kept Loading a file should follow the process

1 Load the first grid box (0,0) only and read the number indicating table size as above
2 Separate the number of columns from the number of rows
3 Close the file and create the grid table by using the size as indicated in the previous step
4 Load the whole file

The layout of the data in the grid table depends on the type of data For each type of data (such as Downtime, Quality, Distributions etc) there is a different way of presentation Details for each layout are presented in Appendix D

4 4 Required information

The tool automatically asks for data and leads the user in insertion of all Quality and Reliability information in order to produce the most-up-to-date results Formats for data, together with typical screen images that are generated, are summarised in Appendix D (Software Manual) For a comprehensive use of this software tool the following information is required

1. Detailed plan of the process with inputs and outputs to each stage, together with information on fault-sourcing and track-back, online repair options and cost related to those repairs For example, the stage of Post Reflow Inspection feeds back boards to Screen-Printing or to SMT Placement All possible reasons for feedback must be known e g open joint leading to screen-printing
2. Down time of each stage and likely causes Each stage consists of several machines and each machine consists of several components Down time for each component of each machine and details of the causes are required For example, the stage of SMT placement consists of three machines Data involving the down time of each component must be related to each machme for accurate assessment of distribution of downtime involved
3. Quality information, relating to number of faulty boards at each stage and the exact cause of failure For example, the stage of SMT placement is responsible for boards with missing components, skewed components, and damaged components It is also necessary to specify which of the three machines from this stage produced the faulty board
4. Cost of repairing a board corresponding to a given fault For example, a board with a damaged component will pass to the off-line rework area Pure UPH of each stage for each product must be available
5. We also wished to have suggestions from Intel's team on possible changes in the parameters of the production line such as increasing the specific component reliability and processing of possible scenarios, for example, adding redundancy in a specific stage of the line

4 5 Assumptions for Dynamic Simulation

Currently, there are five identical production lines in the Intel ESSM plant Each line consists of subsystems and each subsystem, of stages When a stage is down, the subsystem, to which it belongs, is down Hence, the assumptions made are

A. A subsystem behaves like a stage By making this assumption, we decrease the degree of complexity in the mathematical and simulation model

B. When a stage (subsystem) is down, units are sent to the nearest working stage Thus, we assume that the buffer of a stage is infinite and that there is always more than one item in the queue This means that a stage/subsystem that is not down is always busy In practice, there is a safety buffer of three slots that can keep a stage working for three hours, even if the previous buffer is down

C. The data that we have are from two production lines (#1, #2) and we make the further assumption that all production lines are working at the same rate This means that they all have the same probability of producing a faulty board and the same probability that a stage is down This assumption is not big at all if we think that the stages are identical and the products have minor differences

D. A stage of a production line services more than one product, (this is simply achieved by changing the set-up of the machine) One product might result in faster machine throughput than another product, and this may increase the probability of unscheduled downtime when servicing this product The difference between the two probabilities is very small, so we make the further simplifying assumption that the unscheduled down time rate of a stage is the same for all product types

4 6 Design of Quality and Reliability Procedures

The software tool is based on two main procedures (Chapter 3) The first is the "Main Procedure of Quality Inspection" (Fig 4 6) and "Reliability Inspection" (Fig 4 8) Each inspection of a production line examines a specified number of boards for various different failures For each inspection and for each board of the chosen inspection, the "Inspection Procedure" (Fig 4 7) is called, which examines the board for all the possible failures that the current inspection can detect If a failure occurs, it increases the number of boards with this failure by one and adds the cost of this failure to the total cost

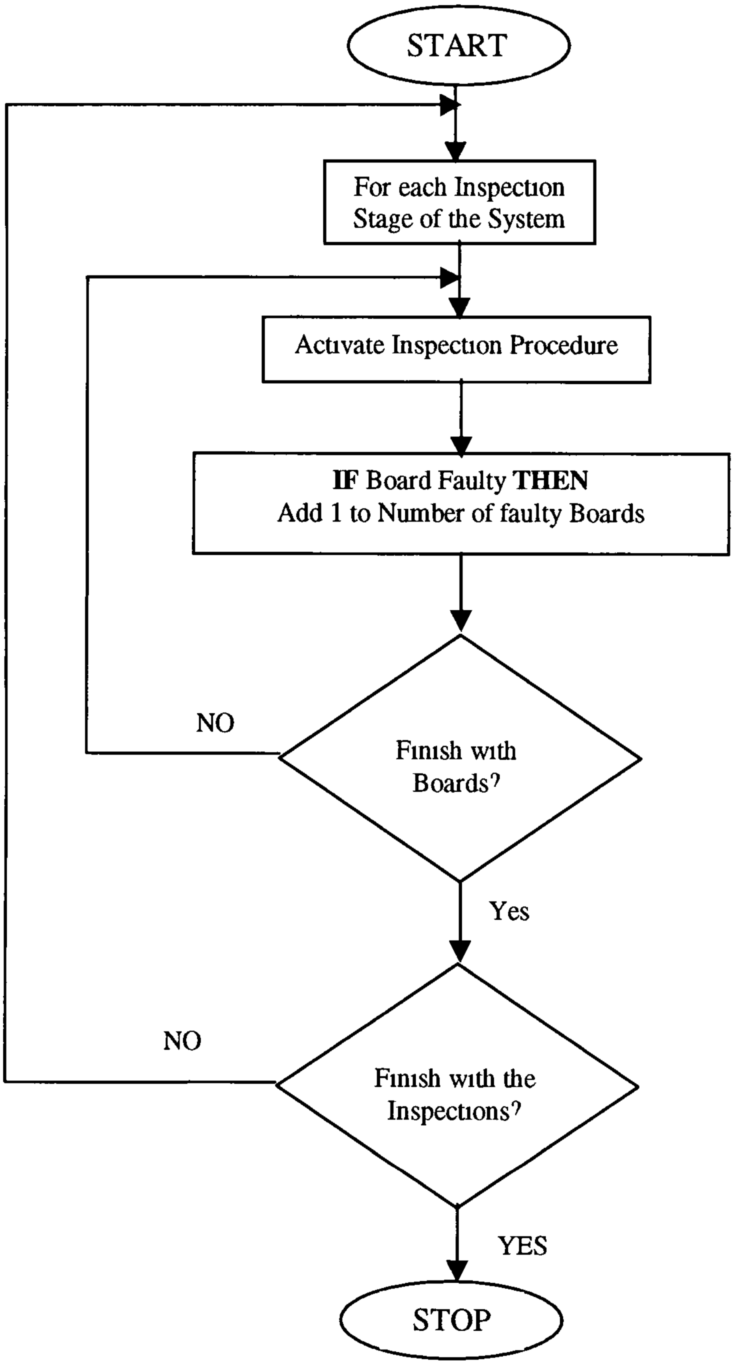


Figure 4 6 Quality Inspection Procedure

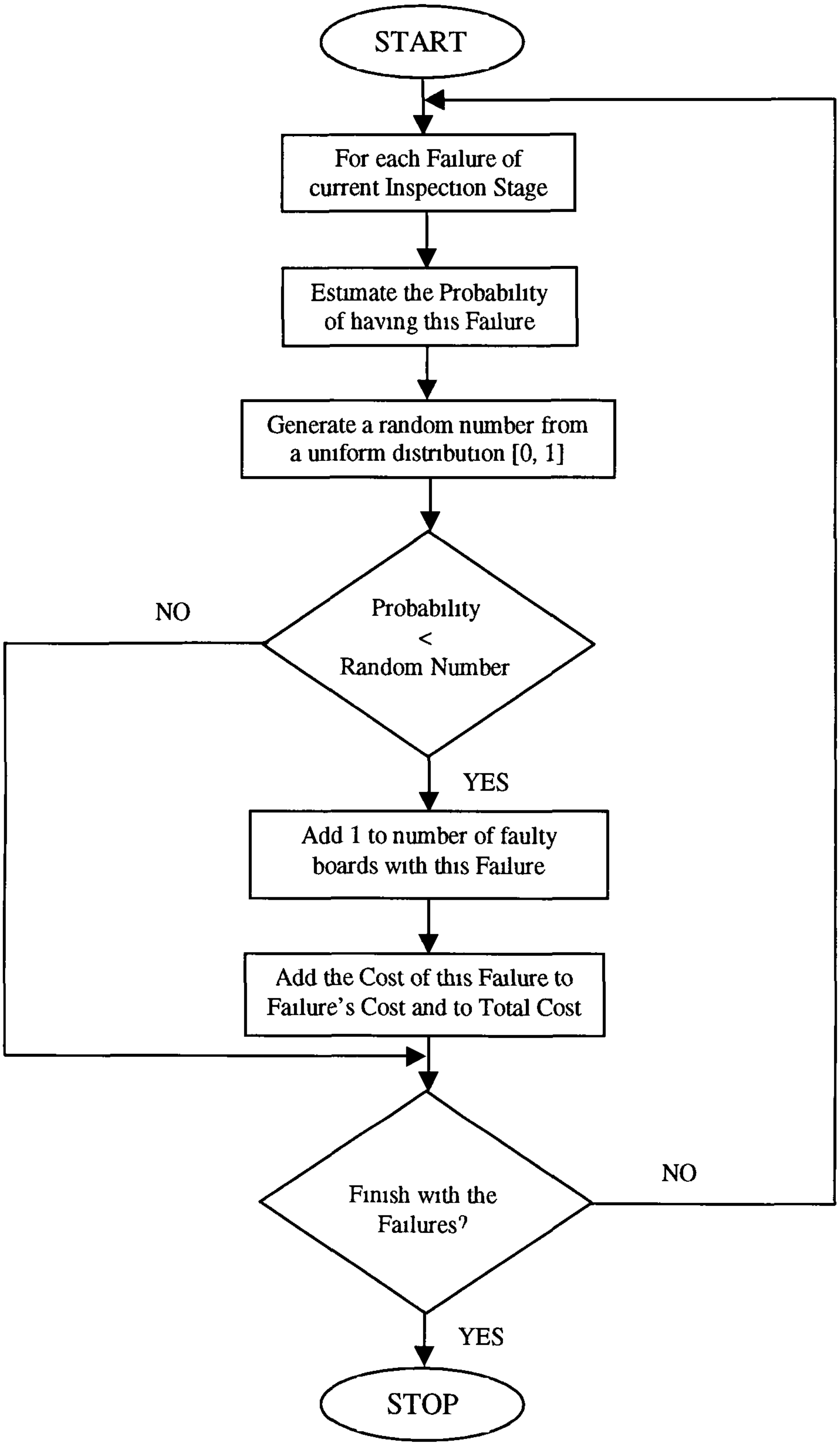


Figure 4 7 Illustrates the procedure called by Quality Inspection procedure (Fig 4 6)

Figure 4 8 illustrates the “Main Procedure for Reliability Features” This investigates the three basic parameters Real UPH, Down Time and Availability for each day of the simulation time and for each subsystem of the system (these three parameters have been defined in Chapter 2) supporting this investigation by the “Reliability Procedure” (Fig 4 9) Knowledge of both scheduled and unscheduled downtime can be estimated (Fig 4 9) the real UPH (equation 4 1) of the system and it’s Availability (equation 4 2)

$$\text{REAL UPH} = \text{UPH} * (\text{DOWNTIME} - \text{AVAILABILITY}) \qquad (4\ 1)$$

$$\text{AVAILABILITY} = \text{DOWNTIME} - \text{Unscheduled DOWNTIME} \qquad (4\ 2)$$

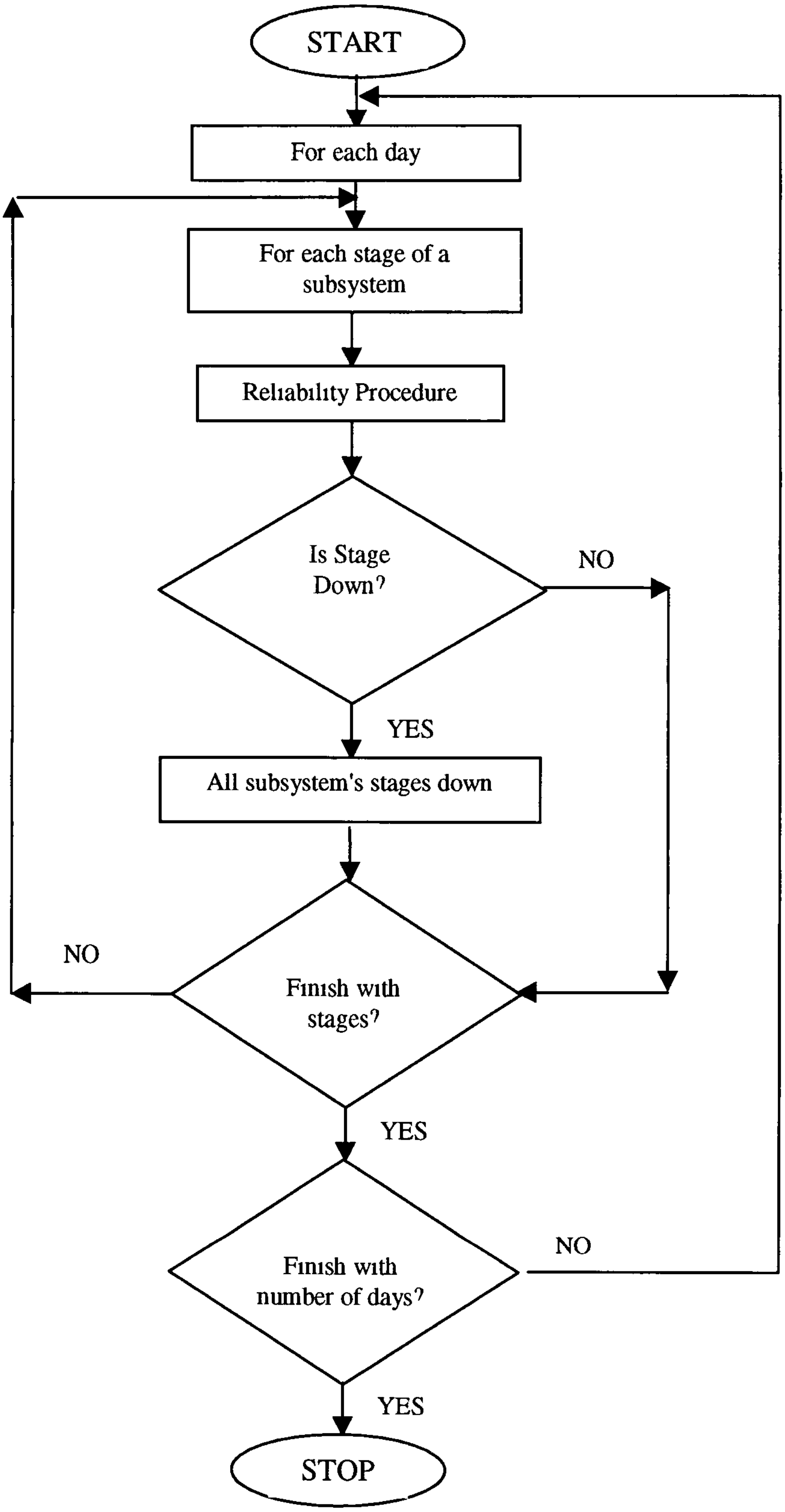


Figure 4 8 Procedure for Reliability Features

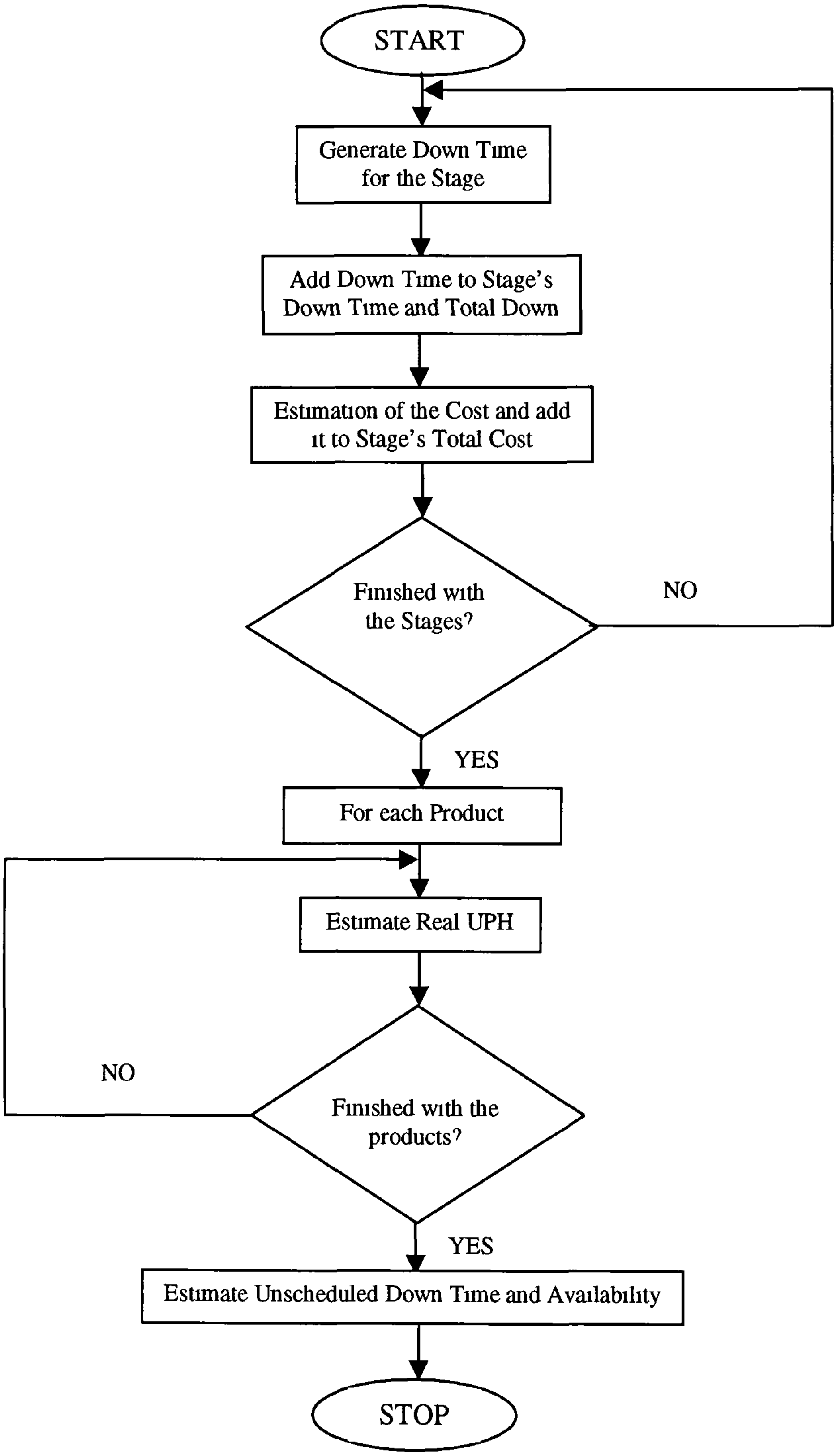


Figure4 9· Illustrates the basic body of Reliability procedure

4 7 In Summary

In this chapter (Chapter 4) we presented the design of the Software Tool and the reasons leading us to create the interface of the tool in the way we did Some windows were presented along with the logic on which they were based Appendix D presents the Software Tool and gives detailed information on how to use the windows described in this chapter with the help of a Manual Chapter 5 gives the results of the testing of the Software Tool

Chapter 5

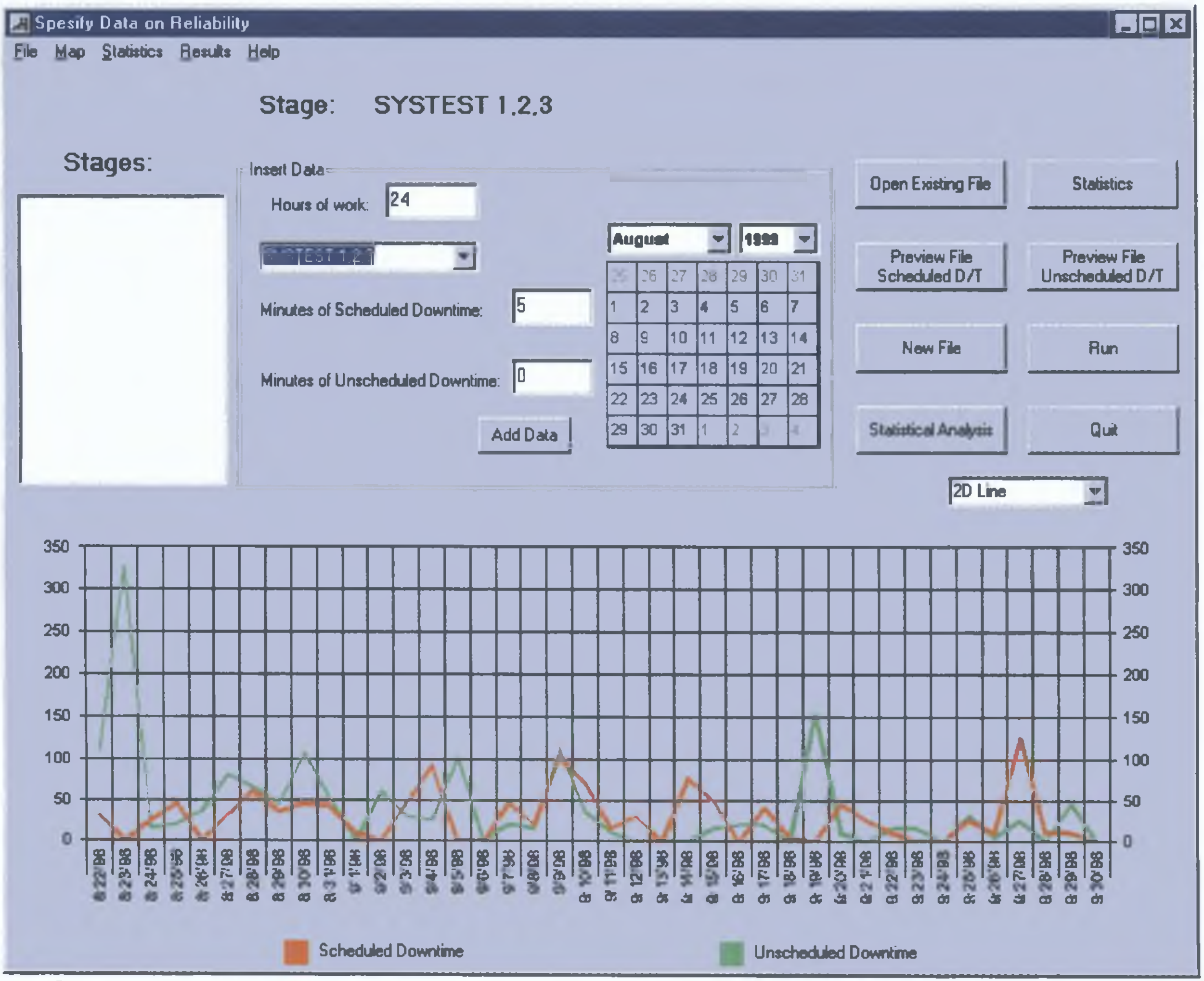
Production Line and Tool Performance

In this chapter we present the results of the Software Tool applied in the ESSM plant. Due to the size and capabilities of the Software Tool (22 different windows) there is a manual in Appendix D and it is recommended that the reader reads this first. The Software Tool is a large part of this thesis and the Manual is important. All the windows presented in this chapter are explained in Appendix D in detail. Of course, using a real production system (ESSM plant) for the test of the Software Tool increases the densityof the technical terms in this chapter. However, a good validation of the models is obtained by comparing the Software Tool with the real system and with the data provided from Intel. All specialist terms are summarised in the Glossary and clarified here for ease of reading.

5.1 Data Manipulation

We referred in previous chapters (Chapter 3 & 4) to the importance of data collection in a production plant. Historical data (Section 3.6), subjected to statistical analysis, provides useful insight into both the day-to-day operation of the system and into the realism of the model. For example, at the stage of "Systest"; Figure (5.1) illustrates *Systest* downtime for the "Specify Data on Reliability" window, (Appendix D, section D.4.1). Scheduled Downtime may give extreme values due, for example, to the cleaning of a stage or a reload of components. In the data, available to us, a Downtime of 327 minutes in one day is recorded with the second longest downtime being 155 minutes. The reason for the former event was the damage to two vital components of the robot, which carries out the inspection. It took 280 minutes (almost 5 hours) to replace them. A statistician, reviewing this sample data, would normally note this as an outlying event, but it is nevertheless information, which should be supplied both to engineering and accounting. We present results showing the effect of inclusion and exclusion of the outlying values in the downtime distributions. It seems clear that serious machine damage will always constitute an extreme or outlying value but other repair work will represent a routine contribution to downtime data.

Figure (5.2) presents the fit for Unscheduled Downtime, using an Exponential distribution, including the extreme value of 355 minutes. Figure (5.3) presents a similar fit for the data, excluding the extreme value and with a difference in the mean time of 10 minutes. The first Exponential distribution has a mean downtime of 40.3 minutes whereas the second has a mean of 30 minutes.



Stage: SYSTEST 1.2.3

Hours of work: 24

SYSTEST 1.2.3

Minutes of Scheduled Downtime: 5

Minutes of Unscheduled Downtime: 0

August 1998

2D Line

Figure 5.1: Scheduled and Unscheduled Downtime for "Systest" (minutes per day)

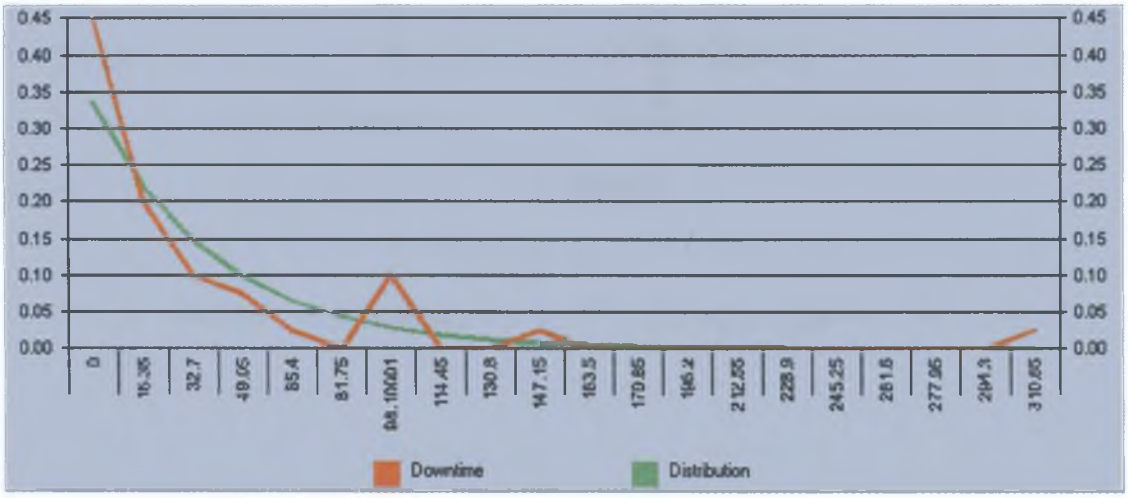


Figure 5.2: Fitting Unscheduled Downtime (including all the values).
X axis represents frequency of the events

[refer to plant process in last chapter...]

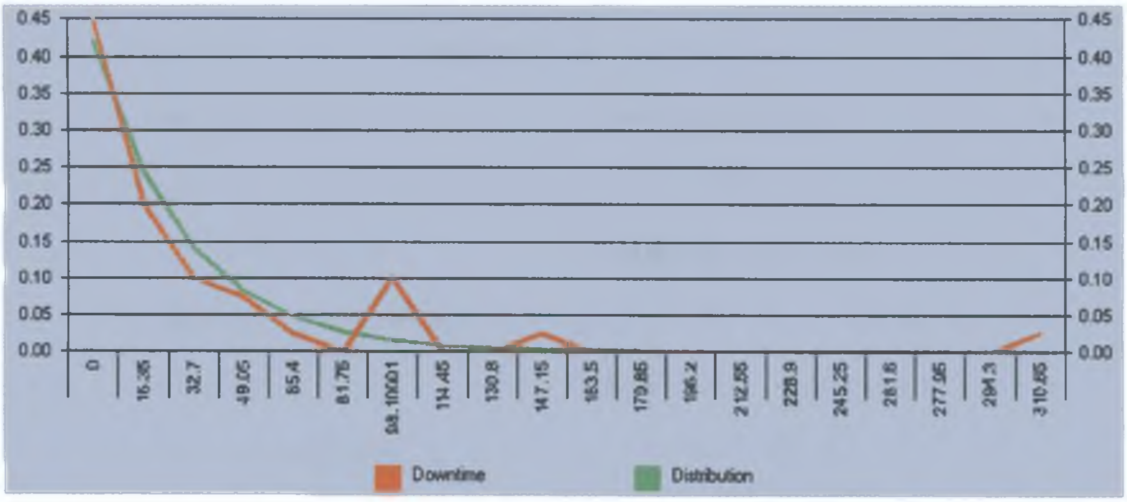


Figure 5.3: Fitting Unscheduled Downtime (excluding extreme values).
Y axis represents the frequency of Downtime.

In Figures (5.2) and (5.3), the red line gives the actual data value and green line the theoretical fit. The empirical distribution chosen by the tool for each stage (excluding extreme values) was tested with the help of χ^2 -test. For example at the stage of "Systest" the χ^2 test for fitting an Exponential Distribution with mean value 30 minutes (green line in Fig. 5.3), to the Unscheduled Downtime is presented in Table (5.1). χ^2 value = 12.99 on 6 degrees of freedom with n-tail the value 12.59 at 5%. Of course χ^2 -test is very crude on 6 degrees of freedom with n-tail the value 12.59 at 5%. Of course χ^2 -test is very crude for such small samples and low expected frequencies but the reason we present this is because the user will use this test in the future when the sample is expected to be much larger. However, it should be noted that for the specific test data presented here, a Fisher Exact test or Kolmogorov-Smirnov would be more appropriate. We should also not that this is a rather ad hoc method of dealing with outliers. One possibility for more sophisticated fitting might be the use of a conditional distribution in situations where frequencies are very low (large proportions of zeroes), using a further distribution to model actual downtime. For such a small data set, this might be rather elaborate but would, in general, reflect the influence for major events. This would require some changes of the tool such as the addition of the formula of the distribution and the inverted function as well. Of course, the addition of the distribution should take place in the key code of the tool and it will inform all the others windows dynamically about this change.

X^2-test	Frequency(f) of historical data	Probability	Frequency of E(30)	$(f-f_e)^2/f_e$
1	17	0.47	15.04	0.255426
2	5	0.24	7.68	0.935
3	3	0.13	4.16	0.323462
4	2	0.07	2.24	0.025714
5	1	0.04	1.28	0.06125
6	1	0.03	0.96	1.126667
7	2	0.01	0.32	8.82
8	1	0.01	0.32	1.445
Total	32	1	32	12.9925

Table 5.1: A X^2-test for the fitting of the Exp(30) to Unscheduled Downtime of "Systest"

The next section (Section 5.2) presents results on Quality and Reliability for the new production line (ESSM plant) as it currently works. Section (5.3) presents the sensitivity analysis of the production line, investigating various scenarios, and Section (5.4) presents the same results as Section (5.2), but this time for the old production system. A comparison of the two production lines is presented as well in the same section Chapter 6 presents conclusions and recommendations made after the estimation of both Quality and Reliability from various possible scenarios Most of the graphs presented below are exactly as presented by the software Tool itself

5 2 Results on Quality and Reliability for Intel's ESSM plant

Simulation Results on Quality

The simulation results on Quality are from the inspection of 10,000 units Inputs, inserted by statisticians (historical data) over a period of 4 weeks, relate to 112,495 units inspected of product "DSP1 C", and 37,938 units from product "P3XP 512k" The products DSP1 C and P3XP 512k are two different types of processors

For the first product, "DSP1 C", simulation results (based on the historical data discussed before) are presented in Figure (5 4) It is clear, from the simulation results that the inspection of "Systest 1, 2, 3" detects the larger number of faulty boards with 98 04% success (of failures = 196 units) From the same simulation results (Fig 5 4), the inspection of "PSVI Pri" (which inspects if the components are well placed in the primary side of a board) records few faulty boards, with the percentage of good boards being 99 66% That means that "PSVI Pri" detects 162 faulty boards less than "Systest 1, 2, 3" That number is statistically quite significant when we know that the number of faulty boards detected by "DEK Pri" was 37 in a sample of 10,000 boards, meaning 81% fewer faulty boards than "Systest"

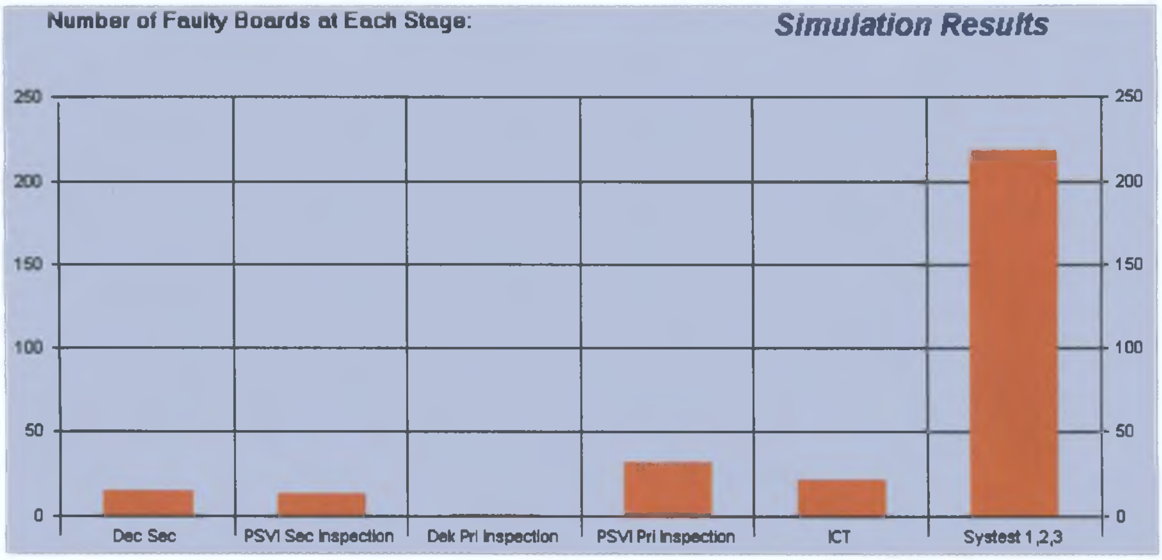


Figure 5.4: Simulation results on Quality, where 10,000 items inspected (number of faulty boards at each stage)

The large number of faulty boards detected by the "Systest" inspection can be explained by the fact that is comprehensive inspection, checking all parts of a board (hardware and software). Hence, the number of failures that this inspection detects is unsurprisingly larger than the number detected by less comprehensive inspections. The four major failures as shown in Figure (5.5), (codes: 8127, IB77, 8129 and IB81), are failures relating both to hardware (8129) and software (8127, IB77, IB81). While failures of the first two relate to the inability to install DOS, failure 8129 relates to the unsuccessful power-up of the board and failure IB81 occurs when the board fails to boot. A detailed list of possible failures is provided in the appendices.

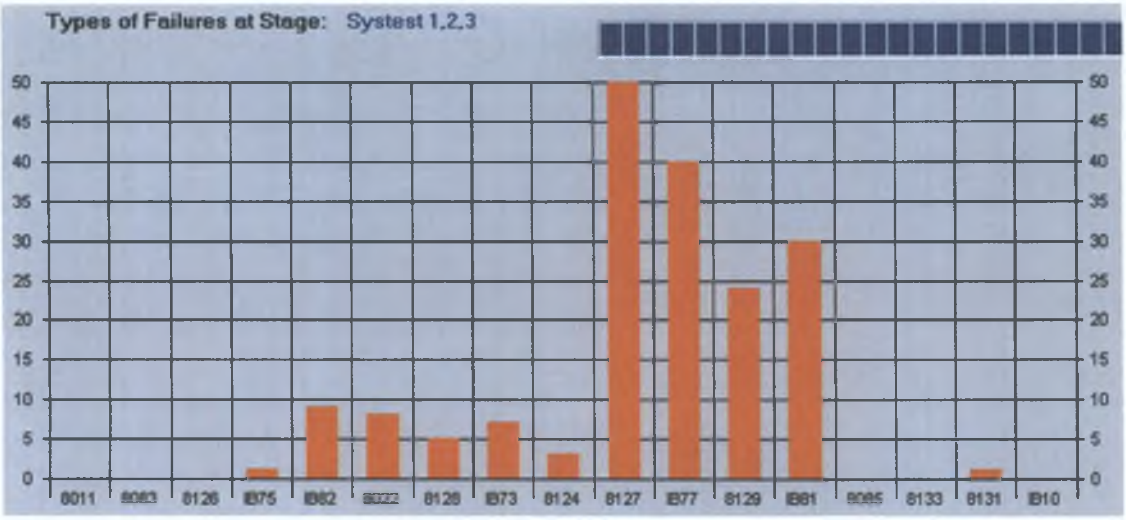


Figure 5.5: Number of boards with each failure

Simulation results on Reliability

Reliability results were estimated with the help of the simulation model for a period of 100 weeks. Figures for simulated Scheduled and Unscheduled results may be requested every day, but the tool automatically presents weekly figures by default. From this we can see the extreme values of simulated downtime, and how often they have occurred. Figure (5.6) illustrates the scheduled downtime for each stage as estimated by simulation for the period of 100 weeks. The Simulated Scheduled downtime in subsystem SMT II, as shown in Figure (5.6), is much bigger than the Scheduled downtime in subsystem SMT I. This generally occurs due to the different types of components in each subsystem. SMT II is responsible for placement of major components (Section 2.4.2), which are more expensive than those in SMT I. It is for this reason that more checks (to ensure the quality of the boards), take place in these stages, increasing the Scheduled downtime. Where SMT I, consists of stages “Dek Sec”, “CP6 Sec”, “IP3 Sec”, “Atmos Sec”, “PSVI Sec” and “MHS Sec”. SMT II consists of “Dek Pri”, “CP6 Pri”, “IP3 Pri”, “Atmos Pri”, “PSVI Pri” and “MHS Pri”. All the stages referred above are presented in Chapter 2 in detail. In the glossary there is also a summarised description of the stages.

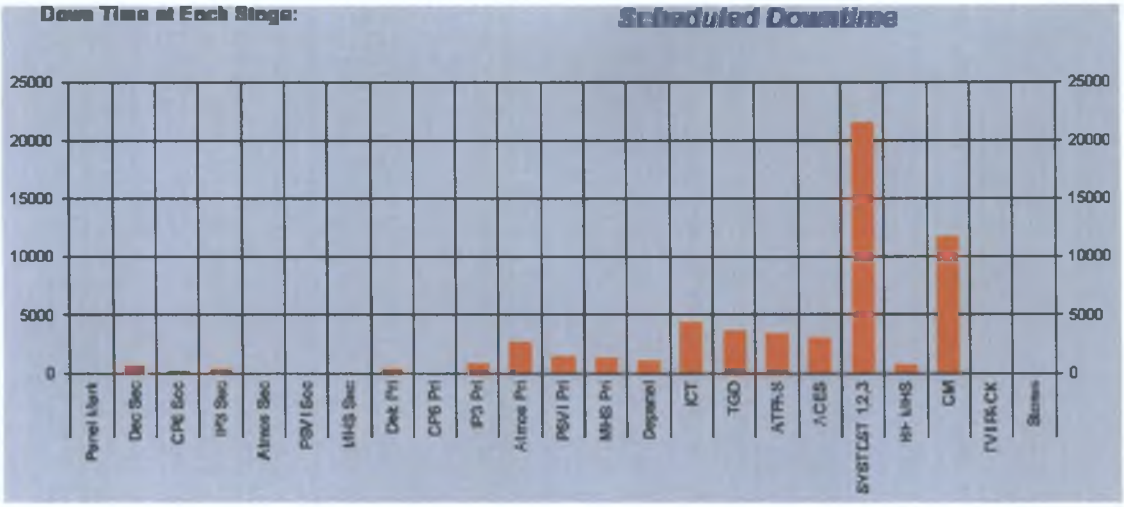


Figure 5.6: Simulated Scheduled Downtime (in minutes) for the duration of 100 weeks

The inspection stages of "Systest" and "ICT" have the longest Scheduled downtime, a consequence of the complexity of these stages, and a reflection of the importance of high reliability. The "CM" stage, (which deals with covering the board and giving it the final look, fig. 2.6) although it has the second longest Scheduled downtime is less important. The downtime at this stage, as estimated by the simulation model, is high due to the loading of the components which are used to cover the boards. The downtime in this stage is not as vital as in "Systest" because of the large values for pure UPH that "CM" has, making it a very fast stage. Detailed presentation of the Simulated Scheduled downtime, as given by the software tool, is presented in Figure (5.7). We also notice a big difference between the simulated downtime each week. There are weeks with less than thirty minutes downtime and weeks with more than seventy minutes. This might happen because our historical data includes the general cleaning of a given stage, together with set-up for a different product. Such factors destroy the true failure data in the statistical sense, since the information does not relate directly to reliability but rather to the availability of the system. Hence the data, though valuable for costing, is not a measure of system performance. For this reason *identifiable* extremes of this type would normally be omitted from distributions which were designed to reflect the operation of the system under normal conditions. Again this raises questions of good statistical practise which might be more rigorously addressed as noted earlier.

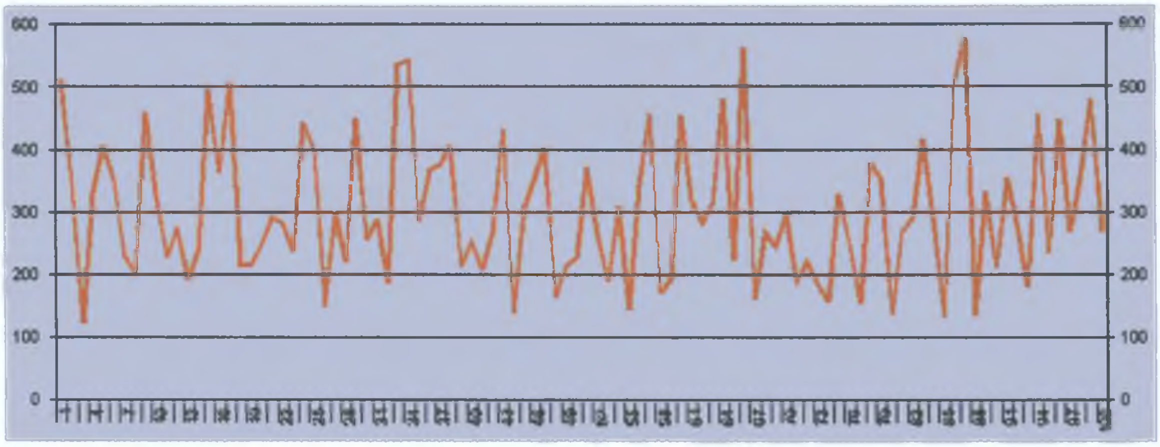


Figure 5.7: Simulated Scheduled downtime (minutes) at the stage of *"Systest 1,2,3" for each week*

On the other hand, Unscheduled Downtime is clearly more unpredictable and the identification of *major events* is far more difficult to achieve, and relies on detailed records being available. Figure (5.8) presents Simulated Unscheduled Downtime as given by the tool. Inspection stages (such as "Systest") again have more downtime compared to other stages. As expected, SMT I (which consists of all the Secondary stages as described above), causes more downtime than SMT II (which consists of all Primary stages), due to the relative importance of the primary stages.

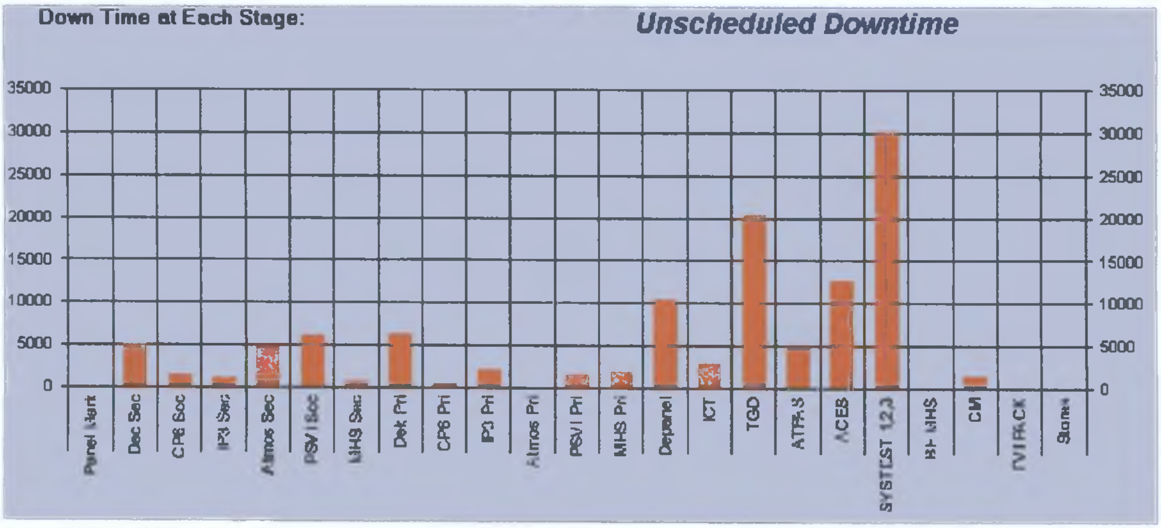


Figure 5.8: Unscheduled Downtime for the duration of 100 weeks

Some stages such as "Panel Mark", have both Scheduled and Unscheduled Downtime which equal zero. The reason for this is that for the period of time for which historical data were supplied, no downtime occurred or was recorded (due to the low importance of these stages). Despite this, we include them in the model, because we want to present the whole production system and the facility exists for assigning distributional values to these quantities. The choice of distribution is simple, and further sophistication would be expected in further development.

Due to the complexity of the robot in the inspection stage "Systest", Unscheduled Downtime is very unstable in that stage (Fig. 5.9). The minimum downtime recorded is 110 minutes and reaches a maximum of almost 600 minutes. The robot consists of a big "arm" which takes all the boards from the buffer to the inspection place and then on to the next stage. On occasion, the "arm" can jam, causing Unscheduled Downtime. The reason for the presence of three identical robots in each line is due to their slow speed (Pure UPH = 150, for each robot).

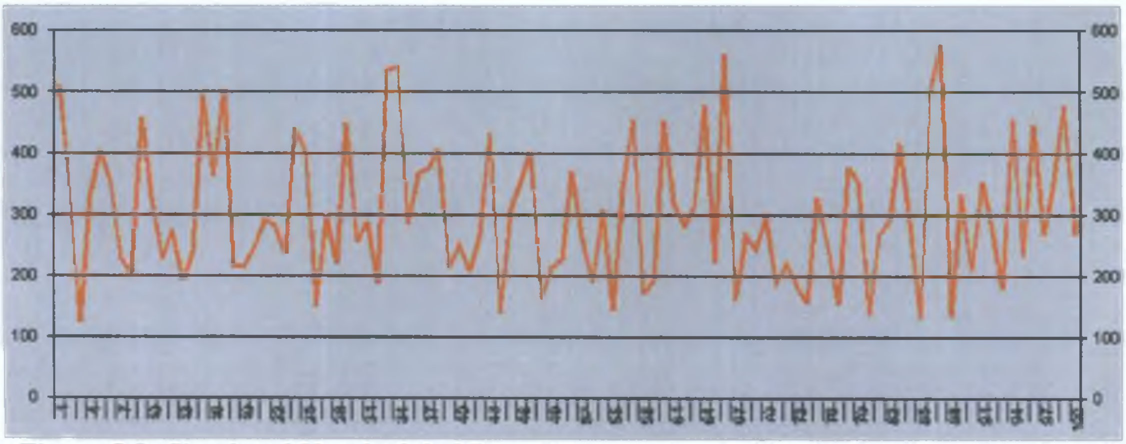
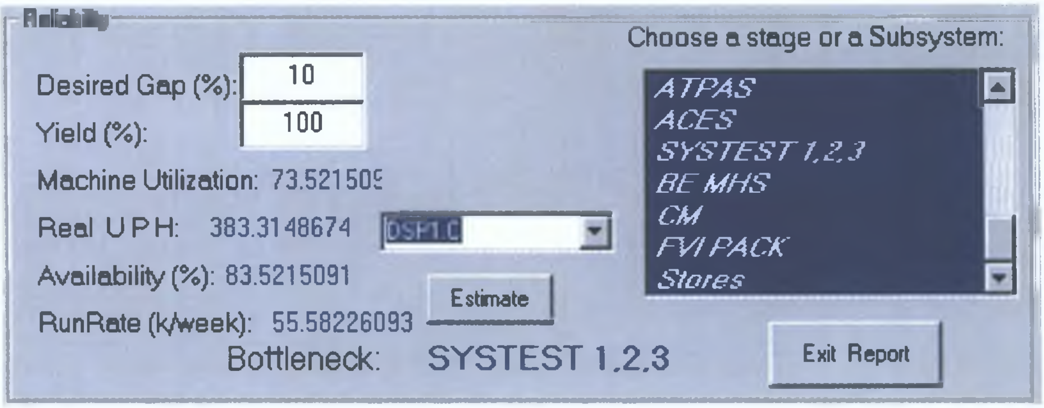


Figure 5.9: Simulated Unscheduled Downtime as estimated by the tool for a duration of 100 weeks for "Systest" stage

The software tool, in addition to the description of downtime, can estimate a number of parameters as given as in Figure (5.10) for the whole production line and for the visualisation example, we choose product DSP1.C: (one type of the boards produced in ESSM plant).



Desired Gap (%): 10
Yield (%): 100
Machine Utilization: 73.52150
Real UPH: 383.3148674
DSP1.C
Availability (%): 83.5215091
RunRate (k/week): 55.58226093
Bottleneck: SYSTEST 1,2,3

Figure 5.10: Estimation of the parameters for the whole production system

We assume that the Yield required is 100% and the Desired Gap (Section 2.2) is 10%. The reason we choose a Desired Gap of 10% is because that is Intel's policy. For the whole system, the bottleneck is the "Systest" with Real UPH of 383.3. The pure UPH of that stage is 450 and due to Downtime (both Scheduled and Unscheduled) it drops by 70 units (more than 14.8%). Machine Utilization is 73.5% and RunRate is 55,580 units per week. The table below presents a comparison of the basic parameters for the two main subsystems (SMT I and SMT II), for the whole system.

PRODUCT: ***DSP1.C***	**Machine Utilization(%)**	**Real UPH**	**RunRate (k/week)**	**Bottleneck**
Production Line	73.52	383.31	55.58	SYSTEST 1,2,3
SMT I	86.58	458.31	79.544	PSVI Sec
SMT II	86.69	449.36	76.032	PSVI Pri

Table 5.2: Comparison of the basic parameters for "DSP1.C" units (Yield=100%, and desired Gap = 10%)

As expected, the two Subsystems, SMT I and SMT II, have almost the same Real UPH. The most important thing is that after subsystem SMT II (75,756 units weekly), the RunRate drops to 62,003 units (a decrease of 18%) due to downtime in subsequent stages. For the second product, "P3XP 512k", the parameters which change are Pure

UPH and, consequently, RunRate The comparison is illustrated in Table 5 3, where we see again a loss of boards (17%) due to the downtime of the other stages

PRODUCT: *P3XP 512k*	**Machine Utilization(%)**	**Real UPH**	**RunRate (k/week)**	**Bottleneck**
Production Line	73 52	159 14	21 98	PSVI Sec
SMT I	86 69	177 24	26 65	PSVI Sec
SMT II	87 28	159 34	26 83	PSVI Pri

Table 5 3 Comparison of the basic parameters for "P3XP 512k" units (Yield=100%, and desired Gap = 10%)

Due to the link between Quality and Reliability it is also of interest to look at the same parameters for a Yield not equal to 100% Table (5 4) presents these for the first type of products (DSP1 C), where we can clearly see the difference in RunRate

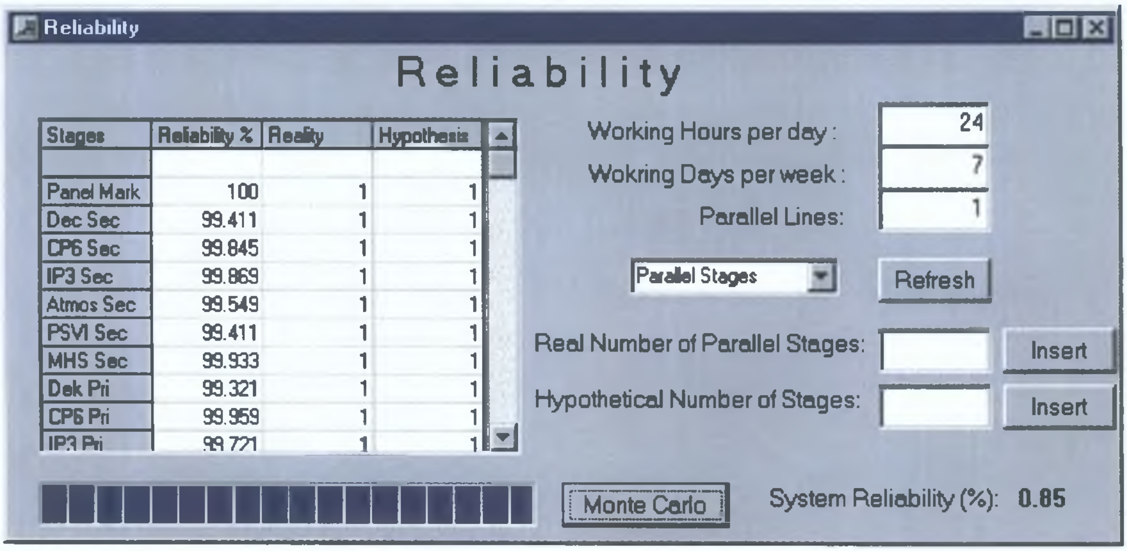
PRODUCT: *DSP1.C*	**Yield (%)**	**RunRate (Yield=100%)**	**RunRate (k/week)**	**Yield estimated by inspection:**
Production Line	97 83	62 003	60 657	SYSTEST 1,2,3
SMT I	99 89	77 150	76 655	PSVI Sec
SMT II	99 68	75 756	76 523	PSVI Pri

Table 5 4 Comparison of the basic parameters for "DSP1 C" units

The Runrate of the whole system falls by 2%, which means a decrease in production rate of 1,500 units per week The reliability of the whole production line as estimated by the Monte Carlo model (Section 3 4) is illustrated in the figure (Fig 5 11) below The function of this window is outlined, (Appendix D, Section D 5 4), and in Section (3 4) we presented the procedure followed for the estimation

Estimation of the Total Reliability

We evaluate system reliability by doing 500 Monte Carlo repetitions. Performance measurements on various experiments sizes using the Monte Carlo method, are given in Figure (5.12). Here the estimated reliability refers to the reliability of the whole production line. As shown in Figure (5.12), the number of 500 Monte Carlo repetitions is a number giving good results within a minimum time (around one minute for 500 repetitions and around 2 minutes and 15 seconds for 1000 repetitions).



Stages	Reliability %	Reality	Hypothesis
Panel Mark	100	1	1
Dec Sec	99.411	1	1
CP6 Sec	99.845	1	1
IP3 Sec	99.869	1	1
Atmos Sec	99.549	1	1
PSVI Sec	99.411	1	1
MHS Sec	99.933	1	1
Dek Pri	99.321	1	1
CP6 Pri	99.959	1	1
IP3 Pri	99.721	1	1

Working Hours per day : 24
Wokring Days per week : 7
Parallel Lines: 1
Real Number of Parallel Stages:
Hypothetical Number of Stages:
System Reliability (%): 0.85

Figure 5.11: Estimation of the reliability of the whole production line

As was expected a number of 1000 repetitions give a good estimation but it needs more time to give a result that is very close to the result given by 500 repetitions. The range of the results on reliability for 100 repetitions is almost 5%, which is not very acceptable. Note that the mathematical model (Section 3.5) gives Reliability 84.41%. That means that the Maximum Absolute Error in 1000 repetitions is 2.7%, 3.3% in 500 repetitions and 7.6% in 100 repetitions. These results come from 30 trials in each repetition. The frequency of the results are shown in Figure (5.12), where we can see that 500 repetitions gives accurate results in good time.

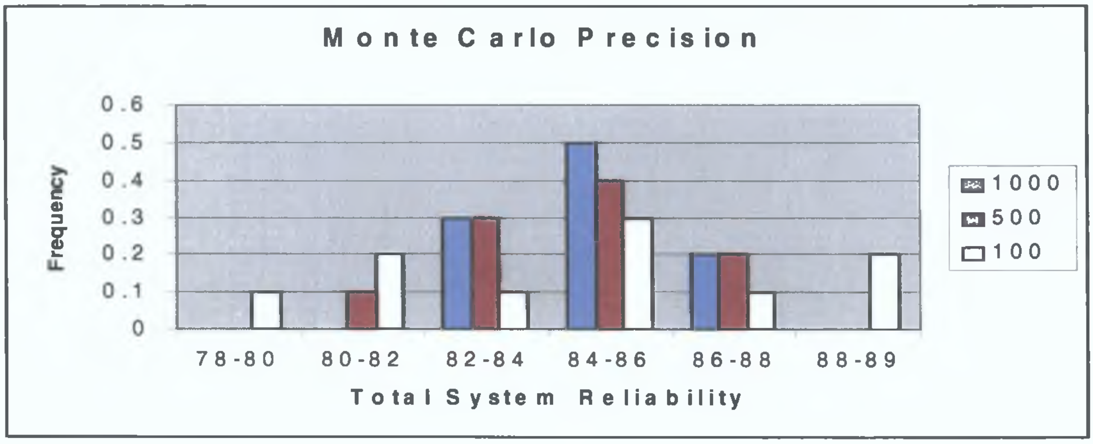


Figure 5.12: Monte Carlo results on system Reliability

<u>*5.3 Impact of Sensitivity Analysis on the ESSM plant*</u>

Quality Sensitivity Analysis

Sensitivity Analysis for Quality will be performed here for the stage principally responsible for faulty boards, namely "Systest" (see Fig. 5.4). From the data gathered, we see an increase (Fig. 5.13) of failures detected in the week defined by dates 8/15/98 – 8/22/98. We have no information on the exact reason(s) for this problem; possibly there was a failure in the set-up of a machine resulting in the production of a large number of faulty items. We will simulate data this last week (8/15/98 – 8/22/98) with a reduced failure rate on the major faults (8127, IB77, 8129 and IB81). In this way, we are trying to overcome the problem which occurred that week (8/15/98 – 8/22/98).

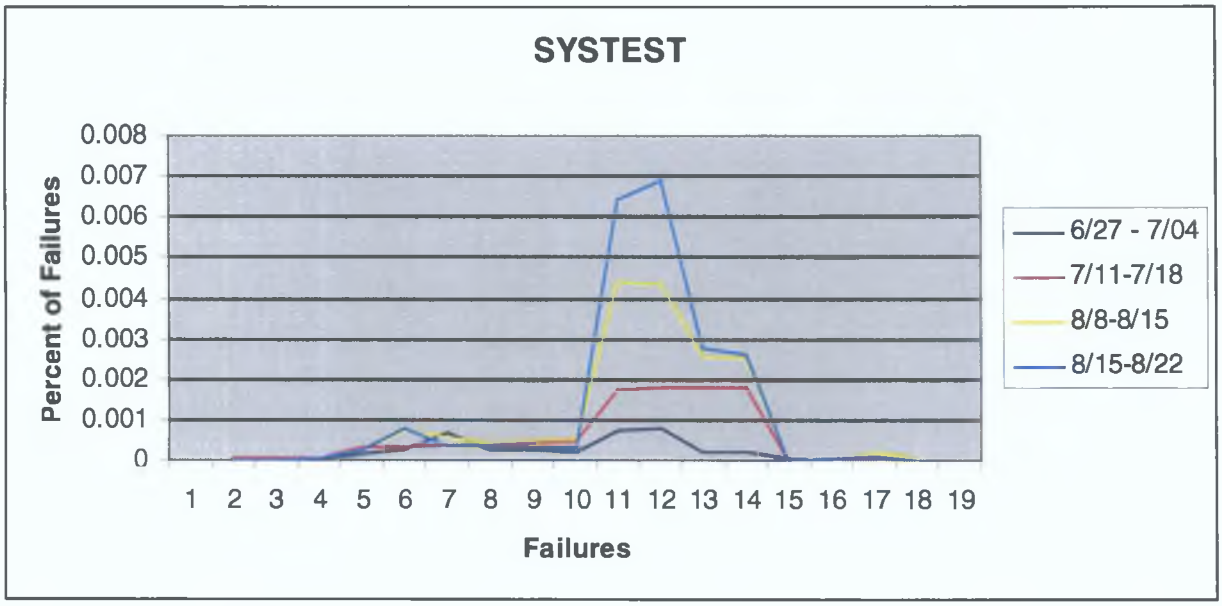


Figure 5.13: Failures detected per week (from real data)

Decrease of the failure for real data by 40% rate for the four specified failures in the last week, gives a failure rate of the week (8/15/98 – 8/22/98) equal to the failure rate of the previous week (8/8/98 – 8/15/98). This change of the percentage for the four failures (8127, IB77, 8129, IB81), increases the "Systest's" Yield from 97.83% to 98.86%, giving simulated results as shown in Figure (5.13). Comparing these simulated results (Fig 5.13) with the results of Quality (obtained from the simulation of the real situation) from Figure (5.5) we can see the difference in failure rates. Hence, the problem is immediately visible and may be affected, e.g. wrong set-up of a machine, which can increase the number of faulty boards by 30% in even one inspection only. Here, 210 faulty boards were detected from simulated historical data, 134 faulty boards from the sensitivity analysis scenario as given above – Sample size: 10,000 units). Clearly the cost of an action to prevent a similar problem is less than the repair cost of the boards. Prevention of a similar problem can be achieved by tracing back the failures and then pointing the exact source of the problem and even providing historical reasons for its occurence.

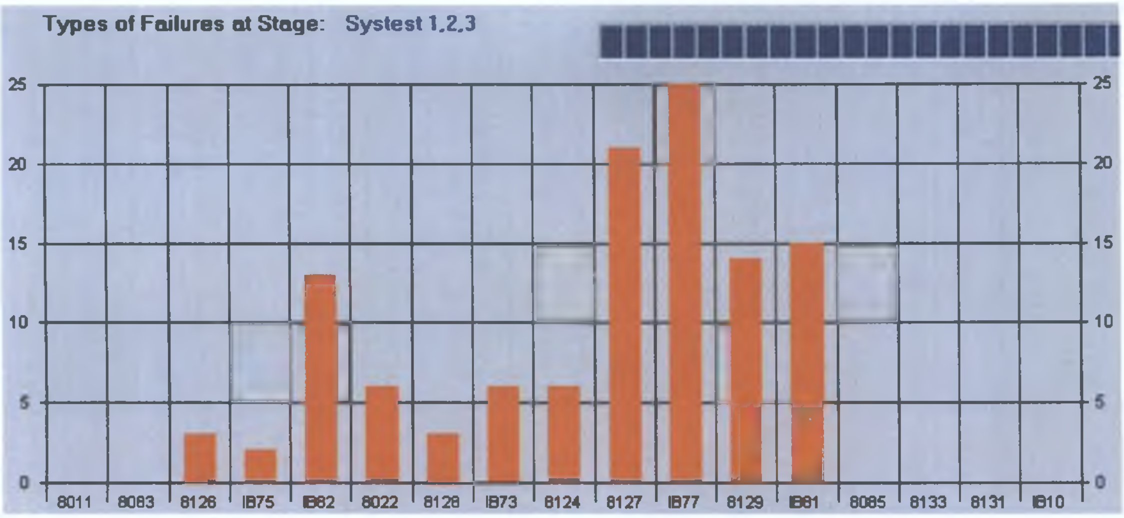


Figure 5.14: Simulation Quality results for 10,000 units with different failure rates.

Reliability Sensitivity Analysis

As for Reliability, we investigate the sensitivity of system performance to the values of Reliability parameters using single distributions of assumttions, for the stages causing the most downtime ? (“Systetest”, “CM”). Again, the case for omitting the extreme values is pragmatic but simplistic in sophisticated terms as discussed earlier. From the real data, “Systest” has a mean Scheduled Downtime of 29.15 minutes. Without the two extreme values (100, 125 minutes respectively) the mean Scheduled Downtime drops to 24 minutes. “CM”, in duration of 40 days, had Scheduled Downtime in only 5 days as given: {10, 90, 180, 40, 360} with a mean Scheduled Downtime equal to 17. You cannot just go around replacing values. If extreme values are considered to 180 and 360 (say) then replacement of these terms by "an average" value of, say, 90 leads to a considerable drop in scheduled downtime of around 8 minutes per day. However, the sample size is small and this can be regarded as a crude sensitivity analysis only. There are only five non-zero values in 40 days and the use of more sophisticated conditional forms for such a high proportion of zeroes is clearly indicated. Downtime fits are clearly dependent on events occurring at all, which would suggest that the use of a conditional distribution and modelling the process in tow stages would be more appropriate. These limitations mean that the analysis can be considered only a first approximation and again suggest that adaptation of the tool to reflect these more finely-grained features of the data might be neceessary. The sensitivity may also be expected to improve as more real data becomes available.

Reducing the mean Scheduled Downtime in "Systest" from 29 to 24 minutes is the first scenario: Scenario 1. Changing "CM" mean Scheduled Downtime from 17 to 8 minutes is Scenario 2, and Scenario 3 is a combination of both scenarios 1 & 2. The table below presents the simulated results on the Scheduled Downtime of these three scenarios compared with the simulated results of the current system. The comparisons focus on the RunRate and the *Range* of the Scheduled downtime, with:

Range = Maximum Downtime - Minimum Downtime

PRODUCT: DSP1.C	RunRate (k/week)	Range of Downtime
Current system	55.50	"Systest": 325 "CM": 192
Scenario 1	55.57	"Systest": 295
Scenario 2	55.82	"CM": 121
Scenario 3	56.17	"Systest": 295 "CM": 121

Table 5.5: Simulated results on Runrate and Scheduled Downtime range

Clearly Scenario 3 increases Runrate by 1.2% (Table 5.5), and it makes the Scheduled Downtime at "CM" stage more stable (i.e. the downtime range is smaller by 37%). Scenario 2 although it increases the RunRate by only 0.6%, it makes the "CM" stage more predictable, which is of considerable importance in practical terms. Scenario 1 shows that we cannot really change Scheduled Downtime in "Systest" because the range of downtime dropped only by 9% which means that few extreme Scheduled Downtime values are found at this stage. This would indicate that tighter control operates to keep this stage running. For this reason we think that Scenario 2, is easier to achieve in terms of reducing Scheduled Downtime in "CM" (Fig. 5.15).

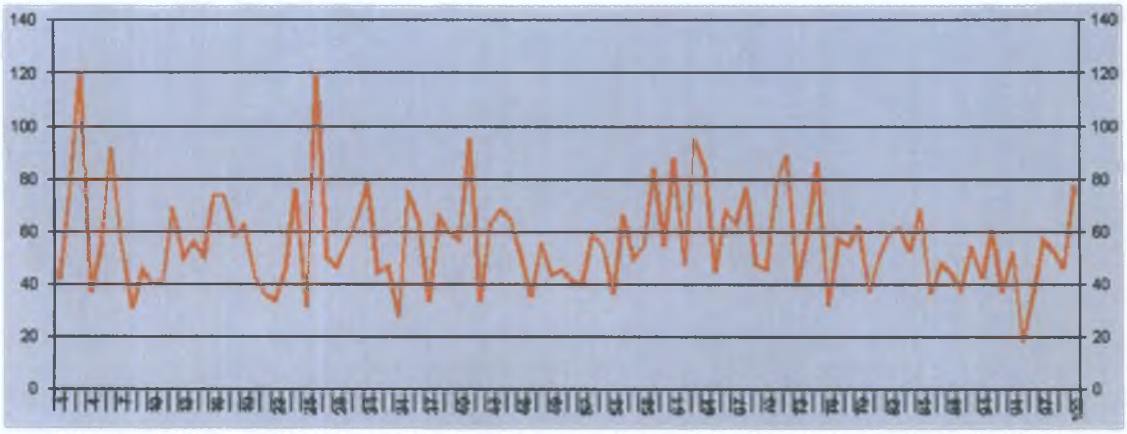


Figure 5.15: Simulated results, for Scenario 2, on Scheduled Downtime of "CM"

As regards Unscheduled Downtime, it is clear that "TGD" and "Systest" are responsible for most of it.

In Scenario 4 we try to investigate the line's reaction if prevention of at least one large Unscheduled Downtime at the stage of "Systest" can be achieved. In any one day, "Systest" has a total of 327 minutes of downtime. If two extreme Unscheduled breakdowns (327, 155 minutes each) can be excluded, the mean downtime (unscheduled) drops by 10 minutes per day (30.25) at "Systest". This will be Scenario 4. In the same way Scenario 5 looks at the effect of changing of "TGD" mean Unscheduled Downtime, from 28.7 to 19.7 minutes per day. Scenario 6 considers a combination of Scenario 4 & 5.

PRODUCT: DSP1.C	RunRate (k/week)	Range of Downtime
Current system	55.50	“Systest”: 570 “TGD”: 330
Scenario 4	56.11	“Systest”: 340
Scenario 5	55.86	“TGD”: 280
Scenario 6	56.45	“Systest”: 340 “TGD”: 280

Table 5.6: Simulated results on Runrate and Unscheduled Downtime range

Table (5.6) shows the importance of preventing Unscheduled Downtime in thousands of units. Scenario 4 is shown to be the best because, by preventing only two unscheduled problems in duration of 40 days (as shown from the real data), we can increase RunRate by 1.1% and at the same time ensuring that “Systest” has a more stable Unscheduled Downtime (40% reduction of the range of the Unscheduled Downtime).

Clearly a combination of Scenario 2 & 4 gives even better results on Runrate. RunRate increases by 1.5% and a combination of all the scenarios together, gives a RunRate of 57.23 (an increase of 3.11%). Thus, preventing one serious unscheduled machine breakdown (in the stages “TGD” and “Systest”) and reducing Scheduled downtime by 7-10 minutes per day in the stages “Systest” and “CM”, the production line outputs 1,730 more products per week. Again these are crude "extreme cases" of sensitivity analyses but, in real terms, even minor improvements will reflect considerable savings in cost.

Sensitivity Analysis on both Reliability and Quality

Putting together the results given by Sensitivity Analysis on the Reliability and Quality, we can see that the system, subjected to analysis of key problem areas and the effect of adjusting performance in these, produces 590 more boards than the current production line at "normal" operation levels.

PRODUCT: ***DSP1.C***	**Yield (%)**		**RunRate based on Yield (k/week)**	**Yield estimated by inspection:**
Current System	97.83		55.89	SYSTEST 1,2,3
Sensitivity Analysis	98.86		56.48	SYSTEST 1,2,3

Table 5.7 Comparison of the RunRate for one production line before and after Sensitivity Analysis

The software tool also provides the required time for producing a number of products. In the current system, as given by Simulated Real data, the time needed to produce 150,000 units of "DSP1.C" and 80,000 units of "P3XP 512k" (these are the maximum numbers of the production control planning at each product) is 889.5 working hours compared to the 894.5 that it was before.

5.4 The old production line

Historical data collected on the old production line were available for just twelve days on both Quality and Reliability. For unknown reasons the production line was also down in one whole day giving a period of 720 minutes downtime so that effectively the analysis is based on eleven days only. Although the data collected are therefore far from ideal, either for individual line assessment on production lines or for comparison with the new system, we attempt a crude performance assessment for the old and new production system. Another problem is that *detailed* data on the old line were not available, due to the change over to the new line. Unfortunately, therefore, we do not have pure UPH of each stage, and the exact downtime for an individual stage, but rather for a group of stages, in this case for "SMT" which consists of all the chip-shooter stages for both secondary and primary side.

The simulation model of Quality based on the historical data for the given days gave us the following results on the number of detected failures at each inspection (Fig. 5.16). The horizontal axis represents the number of faulty boards detected at each inspection. Simulations were generated for the same parameter settings (and 10,000 units)

Comparing with results from the new production line (Fig. 5.4), we can see that the difference in the number of faulty boards from the old production line is almost double.

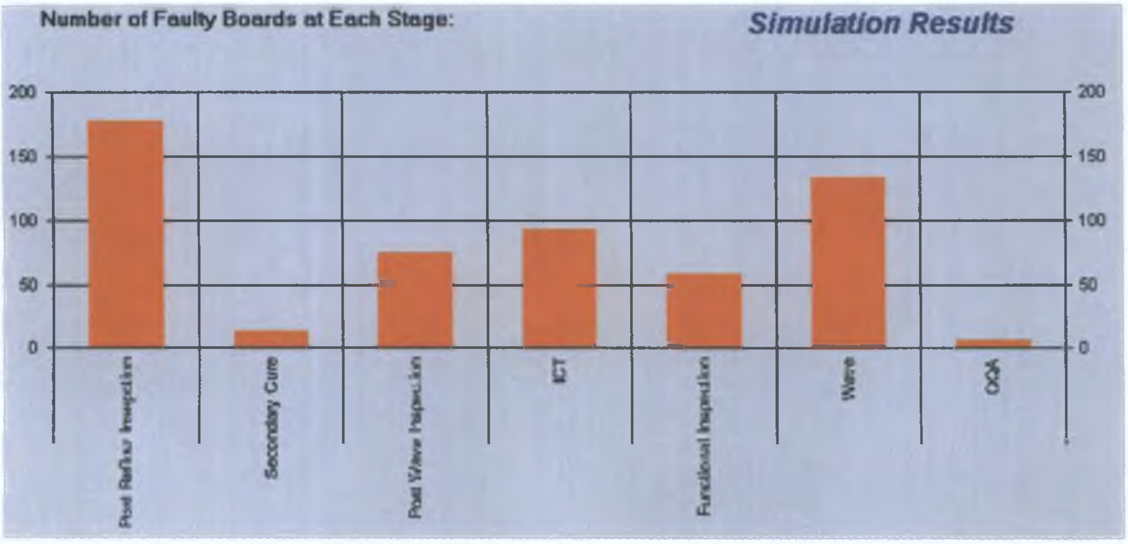


Figure 5.16: Quality results on the old production line, after the inspection of 10,000 units

Although "Post Wave Inspection" detects more faulty boards we present a detailed view of the failures at the "Wave" inspection, due to the importance of this stage. A detailed look at the "Wave" inspection (Fig. 5.17) gives us the number of failures for each failure and clearly "Scndary Passive" failure (which occurs when there is a hardware problem in the secondary side of the board) exists in more than 40 units. As shown, in Figure (5.18), "Post Reflow Inspection" detects the larger number of faulty boards and, as expected, "OQA" the smallest. "OQA" inspection was used to check for all types of failures (hardware and software) and thus, took more time to inspect a board. This inspection assures the quality of the final product, and for that reason the probability of a failure being detected at this, the final stage, was very small.

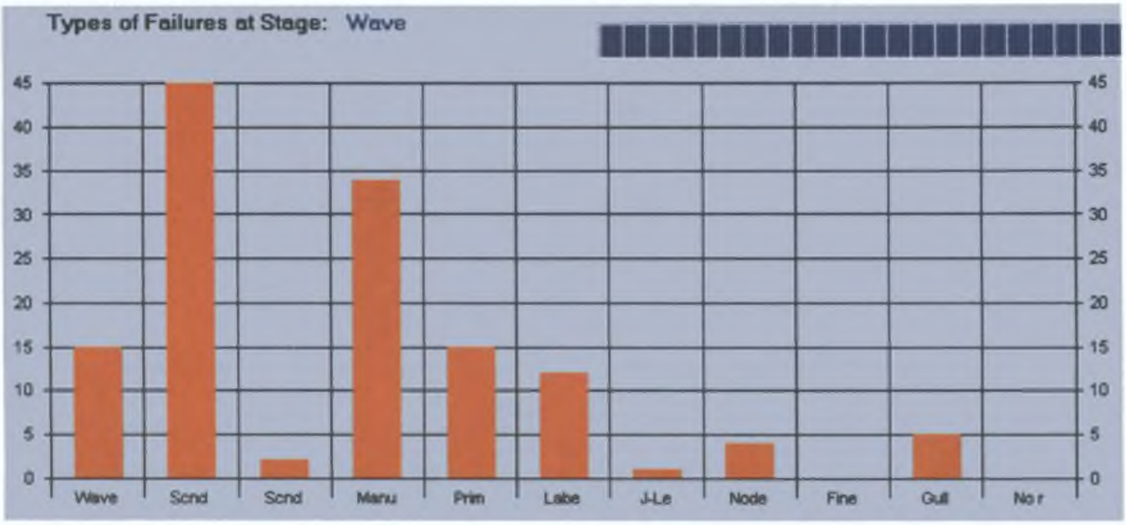
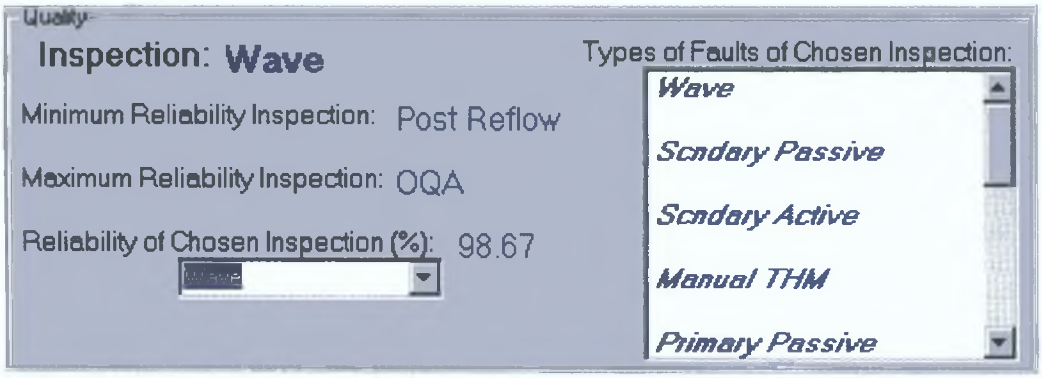


Figure 5.17: Detailed results on Quality for the inspection stage "Wave"



Inspection: **Wave**

Minimum Reliability Inspection: Post Reflow

Maximum Reliability Inspection: OQA

Reliability of Chosen Inspection (%): 98.67

Types of Faults of Chosen Inspection:

- *Wave*
- *Scndary Passive*
- *Scndary Active*
- *Manual THM*
- *Primary Passive*

Figure 5.18: Yield at each inspection

Reliability Simulations for Scheduled Downtime, give us the total downtime as presented in Figure (5.19). Due to the difficulty in comparing the downtime at each stage between the two production systems, we illustrate only the total reliability of the old system. The Monte Carlo method gives a total Reliability of 65.6% (result based on 15 runs only with minimum value 64.4% and maximum 66.3%). The Reliability of the old system as examined by these experiments is almost 20% less than that of the new system, but should be viewed with extreme caution because of the fact that data are crude for the old line and no rigorous attempt at quantification of performance at the various stages had been made. From the Simulated historical data we can obtain "SMT" reliability which is estimated at 94.15%. If we assume that this stage consist of "SMT I" and "SMT II" as given in the new MMX line then we can do a crude comparison with the current set up.

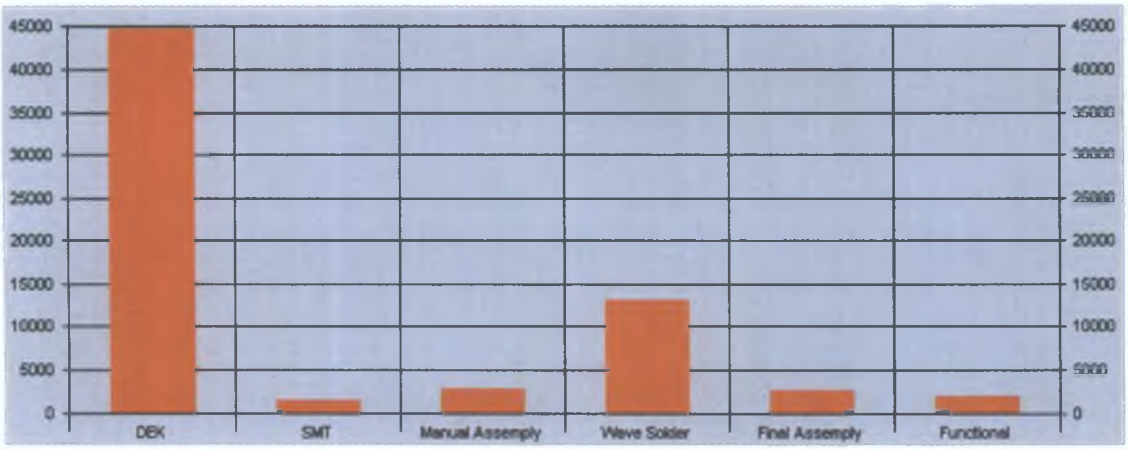


Figure 5.19: Simulated Scheduled Downtime of the whole system (old line) in minutes

"SMT I" has a reliability of 98.02% and "SMT II" 98.11% as taken from the simulated real data for a period of 1000 weeks for more accurate results. Multiplying, we see the reliability of the stage, lets say, "SMT I & II", 98.18%. The Reliability of the old system is lower by 4% in the stage "SMT" which as illustrated in Figure (5.19) does not contribute much to the total downtime.

Overall we suggest that the change from the old production line to a more automated system, reduced the total Downtime, and increased the total quality of the boards.

The Software tool performed very well when it was tested in the real Production System. The flexibility of the tool to investigate different types of models helped us to test it under a lot of conditions. In general we can conclude that the speed of the results depended on the number of boards that the user wanted to inspect and/or the number of days that the user wanted to estimate the reliability. This Software Tool combines two different subjects, Quality and Reliability and provides results for both type of parameters.

As presented in Chapter 5, the Unscheduled is more unpredictable. However the main point we wish to emphasise is that just the two stages (Systest and TGD) are responsible for the 80% of the problem This suggests that an approach that concentrates on these two stages will reduce the total downtime by a respectable percent of change

The new production line is presented more flexible to changes and of course more reliable Due to the small amount of data for the old production line a good comparison is quite difficult and any comparisons fall into the realms of speculation Despite this, by chapter 5 should at least suggest that the present boards are of a higher quality with a decreasing the percent of failures

Chapter 6

Conclusions

This thesis has focused on the estimation of the Reliability and Quality aspects of production lines in Intel ESSM plant, with some attempt to build in more generic features applicable to other similar systems. Both Reliability and Quality are estimated with the help of Simulation models. We have presented a number of methods enabling us to investigate Reliability and Quality (starting with generic models and finishing with the model we use), and have given details on the production system for which our software tool was designed and on which it has been tested. The model of the production system that we used has been presented and a manual of the software tool provided together with the necessary information on how to use the Tool.

The software tool, relies on detailed results on downtime from the models for each stage of the system that is under investigation. This thesis also shows the importance of detailed data collection in a plant, since this acts as primary inputs for any Simulation model and its quality may be expected to determine more accurately both Quality and Reliability aspects as well as providing the basis for better Sensitivity Analysis. Sensitivity Analysis provides us with the opportunity to make possible suggestions on system improvement and clearly many more examples could have been included here. The reason we chose them as demonstration of the Software Tool was the high increase of the performance of the ESSM production line. This Tool proves the increase on both Reliability and Quality aspects by changing from the old production line into a higher lever technology, and the sufficiency that an automated system gives.

This Software Tool provides some very important points on system improvement to each group of users. Managers, with the help of detailed cost data (not available to us) can make changes and compare them not only with regard to Reliability and Quality aspects but also with regard to cost as well. Problem areas can be pinpointed. For example, in

ESSM there are two stages, "Systest" and "TGD", responsible for almost the 80% of Unscheduled downtime On Quality we focused our interest on the "Systest" inspection and we spotted four failures causing a big Quality problem Bottlenecks can also be located by this Tool with information on Real UPH, and RunRate not only for the overall system but for subsystems as well Information like this can be used for production control planning since, the total time needed to produce a number of units from one or more products is available from this software

Statisticians have enough data to test the whole production line with changes focused on the problem areas The Tool encourages them to insert more and more data, giving them more accurate results all the time Detailed data collection is very rare, and through this software we want to show its necessity From a statistical analysis point of view, the Tool provides a visual fitting of the data into distributions allowing the users to watch the extreme values and the importance of including/excluding them from the model The most importance feature is the testing facility i e the consequences of using new materials or of outputting new products, which can be estimated without using the real line, but a model of the system

From an engineering point of view, the Tool provides enough information on changing the production line's layout by either adding/removing redundancy or changing the total number of the lines Engineers can do experiments on the real production and then, when they have collected enough data, continue their experiments in the model provided by this tool The failures responsible for the larger numbers can be traced back allowing engineers to improve the quality of the products Of course, a continuous communication between these three groups (Managers, Engineers and Statisticians) and the feedback of their ideas into the Software Tool, will increase systems performance in all three area

Further Research

A possible suggestion on further research of this thesis would be the expansion of the Software Tool to investigate two or more different production systems at the same time The Tool provided here can investigate one or more identical lines Investigating more than one type would be useful to smaller factories where they work with more than one type of production line This could help the user to test different layouts of the systems and the flexibility of two different systems working together

Another improvement of the tool could take place in the statistical analysis section The availability of some fitting tests from the tool itself, would be very useful for statisticians who would not then have to use other software packages Clearly the most difficult part is the daily collection and insertion of detailed data Thus, an on-line feed of data from the production system to this Tool would be a very good improvement

The language we used (Visual Basic 5) is extremely good at creating high user friendly interfaces and we are satisfied by its performance Some people working in Intel used the Software Tool and it was demonstrated to others All of them are really satisfied with the interface and the results provided from the tool However some improvement in the speed of estimating results (both Reliability and Quality) could be achieved by using another programming language

APPENDIX A

Quality and Reliability

Empirical Raw Data for both Production System

shiftdate	shift	lineid	description	minutes_lost
23/02/98	A	2	DEK MACHINE	30
23/02/98	A	2	SMT EQUIPMENT	30
23/02/98	A	2	IFT MACHINE	20
23/02/98	A	2	MEETINGS	10
23/02/98	A	2	NPI/ECO	119
23/02/98	A	2	UNDERLOADED	45
23/02/98	A	2	RELOADS	50
23/02/98	A	2	MATERIAL AVAILABILITY	145
23/02/98	A	2	IFICS DOWNTIME	60
23/02/98	A	2	CLEANUP	10
24/02/98	A	2	QUALITY	20
24/02/98	A	2	IP MACHINE	30
24/02/98	A	2	START UP	12
24/02/98	A	2	MISSING TARGETS	22
24/02/98	A	2	NPI/ECO	30
24/02/98	A	2	CLEANUP	10
24/02/98	A	2	MEETINGS	15
24/02/98	A	2	SMT EQUIPMENT	40
24/02/98	A	2	DEK MACHINE	10
24/02/98	A	2	RELOADS	80
25/02/98	A	2	QUALITY	15
25/02/98	A	2	MEETINGS	12
25/02/98	A	2	ATE DOWN	15
25/02/98	A	2	RELOADS	32
25/02/98	A	2	START UP	10
25/02/98	A	2	CLEANUP	8
25/02/98	A	2	UNDERLOADED	120
26/02/98	B	2	ATE DOWN	90
26/02/98	B	2	START UP	60
26/02/98	B	2	MATERIAL AVAILABILITY	85
26/02/98	B	2	NPI/ECO	150
26/02/98	B	2	IP MACHINE	10
26/02/98	B	2	MISSING TARGETS	43
26/02/98	B	2	IFT MACHINE	15
26/02/98	B	2	RELOADS	40
26/02/98	B	2	SMT EQUIPMENT	10
27/02/98	B	2	CHANGE OVER	30
27/02/98	B	2	QUALITY	60
27/02/98	B	2	RELOADS	40
27/02/98	B	2	ATE DOWN	200
27/02/98	B	2	MISSING TARGETS	85
27/02/98	B	2	IFT MACHINE	15
28/02/98	B	2	START UP	15
28/02/98	B	2	QUALITY	40

28/02/98	B	2	RELOADS	48
28/02/98	B	2	ATE DOWN	15
28/02/98	B	2	IFT MACHINE	60
28/02/98	B	2	CHANGE OVER	80
28/02/98	B	2	MISSING TARGETS	93
02/03/98	B	2	ATE DOWN	15
02/03/98	B	2	WAVE	60
02/03/98	B	2	QUALITY	60
02/03/98	B	2	RELOADS	38
02/03/98	B	2	MISSING TARGETS	173
02/03/98	B	2	IFT MACHINE	50
03/03/98	B	2	UNDERLOADED	720
04/03/98	B	2	MISSING TARGETS	87
04/03/98	B	2	CLEANUP	180
04/03/98	B	2	MATERIAL AVAILABILITY	60
04/03/98	B	2	MEETINGS	90
04/03/98	B	2	QUALITY	120
05/03/98	A	2	MISSING TARGETS	10
05/03/98	A	2	IP MACHINE	15
05/03/98	A	2	MEETINGS	15
05/03/98	A	2	QUALITY	60
05/03/98	A	2	START UP	10
05/03/98	A	2	SMT EQUIPMENT	25
05/03/98	A	2	CLEANUP	10
05/03/98	A	2	DEK MACHINE	10
05/03/98	A	2	RELOADS	65
06/03/98	A	2	MEETINGS	12
06/03/98	A	2	RELOADS	70
06/03/98	A	2	START UP	10
06/03/98	A	2	DEK MACHINE	10
06/03/98	A	2	MISSING TARGETS	54
06/03/98	A	2	IP MACHINE	15
06/03/98	A	2	SMT EQUIPMENT	25
06/03/98	A	2	CLEANUP	10
06/03/98	A	2	UNDERLOADED	20
07/03/98	A	2	START UP	40
07/03/98	A	2	DEK MACHINE	5
07/03/98	A	2	SMT EQUIPMENT	5
07/03/98	A	2	RELOADS	70
07/03/98	A	2	MEETINGS	135
07/03/98	A	2	MISSING TARGETS	38
07/03/98	A	2	CLEANUP	12

Post Reflow Inspection

Defect Item	Defect	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3	Quality Per Defect	Quality Per Defect Item
Fine Pitch	Bidge	9	16	54	10	8	2	5		2	6	4	1	92 57%	88 85%
	Shift/Skew	4	10	2		1		1		3		6		98 29%	
	Missing Part	1												99 94%	
	Open Joint		1		2	6		4		6	3	11	2	97 78%	
	Damaged												1	99 94%	
Primary Passive	Shift/Skew	1	3					1			3		3	99 30%	97 98%
	Misoriented		1											99 94%	
	Missing Part				3	1		10				1	2	98 92%	
	Open Joint							2						99 87%	
	Bridge												1	99 94%	
J-Lead	Missing Part		1											99 94%	99 94%
Gullwing	Bidge			1										99 94%	99 05%
	Shift/Skew			6			1			2	2	1	1	99 17%	
	Missing Part							1						99 94%	
No Defect Found	No Defect Found			2										99 87%	99 87%

	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3
Observed	101	215	218	125	142	123	108		61	169	173	140
Failed	14	29	52	18	16	3	10		12	12	16	7
FPA	86 14%	86 51%	76 15%	85 60%	88 73%	97 56%	90 74%		80 33%	92 90%	90 75%	95 00%

Quality of the Stage 86 06%

Q1 Sum of Failed? mean quality 80 87%
Q2 two days of 27/2
Q3 The route of the test

Secondary Cure

Defect Item	Defect	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3	Quality Per Defect	Quality Per Defect Item
Scndary Passive	Shift/Skew	3	12	4			6	2			8		1	97 69%	93 95%
	Missing Part	14	3	7	1	1					5	13	9	96 60%	
	Adhesive Defect						1							99 94%	
	Extra Part							2						99 87%	
	Contaminated						3							99 81%	
	Wrong										1			99 94%	
Scndary Active	Shift/Skew				7	22	1			3				97 88%	97 70%
	Missing Part				1									99 94%	
	Wrong						2							99 87%	
BGA	Shift/Skew				1									99 94%	99 94%
No Defect Found	No Defect Found		2	1			1	1				2		99 55%	99 55%
Primary Passive	Missing Part					1								99 94%	99 94%
Fine Pitch	Damaged								2					99 87%	99 87%
	Observed	83	213	238	92	148	140	115	1	32	186	175	137		
	Failed	7	13	10	5	12	8	4	0	1	5	9	10		
	FPA	91 57%	93 90%	95 80%	94 57%	91 89%	94 29%	96 52%	100 00%	96 88%	97 31%	94 86%	92 70%		

Quality of the Stage 91 14%

Q1 2 Damaged when 1 have been observed?

Q2 Sum of Failed? mean quality 95 02%

Post Wave Inspection

Defect Item	Defect	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3	Quality Per Defect	Quality Per Defect Item
Manual THM	Tilted	8	5	9	1	4	2	2	1		3	7	1	97.22%	92.27%
	Missing Part		2			1	1	2	1		7	8	1	98.51%	
	Lead not Thru			2	2	3	5	2			6	5	3	98.19%	
	Misoriented				18	8		1						98.25%	
	Damaged											1		99.94%	
	Misinserted					1								99.94%	
Scndary Passive	Shift/Skew		1	4	1		10	5					1	98.58%	61.31%
	Missing Part			8	4	11	536	4		4		3	3	62.89%	
	Adhesive Defect				1			4						99.68%	
	Contaminated					2			1	1				99.74%	
	Extra Part						1	1		1				99.81%	
	Open Joint								1	4				99.68%	
Primary Passive	Open Joint							2						99.87%	99.74%
	Shift/Skew							1						99.94%	
	Damaged							1						99.94%	
	Bridge													100.00%	
Scndary Active	Missing Part						1							99.94%	99.29%
	Shift/Skew							10						99.35%	
No Defect Found	No Defect Found				2				1	1	2			99.61%	99.61%
Wave	Excess Solder				1									99.94%	99.68%
	Open Joint						4							99.74%	
	Bridge													100.00%	
Fine Pitch	Open Joint						1							99.94%	99.81%
	Damaged								2					99.87%	
	Bridge													100.00%	
PCB (Bare Fab)	Damaged						1	1						99.87%	99.87%
Label	Damaged								1					99.94%	99.94%
	Observed :	65	216	250	78	154	109	153	3	31	170	188	127		
	Failed :	6	5	11	8	17	20	18	2	7	14	17	6		

Quality of the Stage: 55.41%

In Circuit Test

Defect Item	Defect	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3	Quality Per Defect	Quality Per Defect Item
Manual THM	Missing Part											1		99 94%	99 64%
	Lead not Thru	1					1		1				1	99 82%	
	Damaged	5			2	1				1				99 88%	
Passive	Defective	2	19	9	1		2				2	1		99 70%	99 70%
Primary Passive	Open Joint						1		1	2				99 76%	98 37%
	Shift/Skew		1	1		3					1	1		99 70%	
	Extra Part		1											100 00%	
	Wrong		1	1										100 00%	
	Misoriented		1											100 00%	
	Missing Part			1	2	5				1	1	1		99 51%	
	Insufficient		1											100 00%	
	Damaged	2	30	1						2	4	4		99 39%	
	Bridge		1											100 00%	
Fine Pitch	Open Joint	1				2	2				1	3	1	99 45%	98 01%
	Wrong								8					99 51%	
	Misoriented												1	99 94%	
	Shift/Skew	1		1		1								99 94%	
	Bad Rework								1					99 94%	
	Damaged								2					99 88%	
	Bridge	1	2	6	1	1	5			1	4			99 33%	
J-lead	Open Joint	1	2	1							1			99 94%	98 36%
	Misoriented			1							1			99 94%	
	Damaged					1								99 94%	
	Bridge								22	1				98 60%	
	Shift/Skew									1				99 94%	
BGA	Open Joint	3	3	2							1	6		99 57%	96 55%
	Damaged			1										100 00%	
	Bridge								4	44	1	1		96 96%	
IC	Defective	3	6	7		9			9	8	2	1		98 24%	98 24%
PCB (Bare Fab)	Open Circuit	3	2	2							1			99 94%	99 88%
	Damaged									1				99 94%	
Scndary Passive	Wrong	1									1			99 94%	99 94%
Wave	Open Joint	1												100 00%	99 94%
	Bridge						1							99 94%	
Gullwing	Open Joint			1	1									99 94%	99 82%
	Shift/Skew					1								99 94%	
	Bridge										1			99 94%	

THM Comp	Defective			1										100 00%	100 00%
Solder Ball	Secondary Side									2				99 88%	99 88%
SHMOO Failure	Defective									1				99 94%	99 94%
Comp in Socket	Misoriented										1	1		99 88%	99 88%
No Defect Found	No defect Found											1		99 94%	99 94%
	Observed	95	233	220	89	154	110	0	170	83	175	187	131		
	Failed	18	56	24	6	21	8	0	38	55	17	13	3		
	FPA	81 05%	75 97%	89 09%	93 26%	86 36%	92 73%	0 00%	77 65%	33 73%	90 29%	93 05%	97 71%		

Quality of the Stage	88 66%

50 60%

Q1 What about 2/3?
Q2 #Failed > Observed?

Functional Test

Defect Item	Defect	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3	Quality Per Defect	Quality Per Defect Item
IC	Defective	4	1	2	1	4	9	12	7	2	5	10	6	96 64%	0 9664
No Defect Found	No Defect Found	3	1		2								1	99 63%	99 63%
Scndary Passive	Shift/Skew	2												99 89%	99 89%
Manual THM	Lead Not Thru	1				1	1							99 84%	99 47%
	Defective					1	2	1		2				99 68%	
	Shift/Skew	1												99 95%	
Primary Passive	Wrong	1												99 95%	99 95%
Fine Pitch	Bridge		1	1							1			99 84%	99 41%
	Shift/Skew					1								99 95%	
	Open Joint		1					1		1		1	2	99 68%	
	Misoriented						1							99 95%	
PCB (Bare Fab)	Short			1										99 95%	99 89%
	Open Circuit						1							99 95%	
BGA	Open Joint					1				1				99 89%	99 68%
	Bridge							1	2		1			99 79%	
J-Lead	Bridge							1						99 95%	99 89%
	Contaminated							1						99 95%	
Wave	Open Joint										1			99 95%	99 95%

Observed	106	230	222	74	143	106	170	285	44	171	187	137
Failed	8	2	3	2	4	10	11	8	13	5	10	6
FPA	92 45%	99 13%	98 65%	97 30%	97 20%	90 57%	93 53%	97 19%	70 45%	97 08%	94 65%	95 62%

Quality of the Stage 94 50%

56 19%

End Of Line

Defect Item	Defect	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3	Quality Per Defect	Quality Per Defect Item
Wave	Open Joint	16			1	4	8							98 31%	
	Excess Solder						2							99 88%	98 08%
	Bridge								1					99 94%	
	Insufficient								1					99 94%	
Scndary Passive	Contaminated	8			3	4	5	4	2					98 48%	
	Insufficient				1	1								99 88%	
	Missing Part	4	1		3		3	5	5				1	98 71%	
	Open Joint					3		3	1	1				99 53%	95 75%
	Damaged		1		1	1	2	1						99 65%	
	Shift/Skew	3	1		2		2	2						99 42%	
Scndary Active	Damaged	2												99 88%	
	Shift/Skew									1				99 94%	99 77%
	Wrong									1				99 94%	
Manual THM	Lead Not Thru	6			1	3	1	5				1		99 01%	
	Tilted	1	2	5	1			3		4				99 07%	97 11%
	Damaged		4	1	3	1	3	2		1	1			99 07%	
	Misinserted												1	99 94%	
Primary Passive	Shift/Skew	1				3	1							99 71%	
	Damaged				1	1								99 88%	
	Contaminated					1								99 94%	
	Insufficient					1	1							99 88%	98 95%
	Extra Part						1	1						99 88%	
	Missing Part							1	1	1			1	99 77%	
	Open Joint								2					99 88%	
Label	Illegible		9	3							1	2		99 12%	98 89%
	Damaged				1				1	2				99 77%	
J-Lead	Damaged		1											99 94%	99 88%
	Shift/Skew			1										99 94%	
No Defect Found	No Defect Found		1							1				99 88%	99 88%
Fine Pitch	Open Joint				1	2			1					99 77%	99 71%
	Shift/Skew								1					99 94%	
Gullwing	Damaged					1	2		4	1				99 53%	99 53%
No Repair Hist	Process Violat								1	4				99 71%	99 71%
	Observed	94	219	230	78	139	104	165	145	45	173	179	141		
	Failed	20	13	7	15	21	20	16	15	6	0	2	3		
	FPA	78 72%	94 06%	96 96%	80 77%	84 89%	80 77%	90 30%	89 66%	86 67%	100 00%	98 88%	97 87%		

Quality of the Stage	87 89%

56 82%

Outgoing Quality Assurance

Defect Item	Defect	Qty - 23/2	Qty - 24/2	Qty - 25/2	Qty - 26/2	Qty - 27/2	Qty - 28/2	Qty - 2/3	Qty - 3/3	Qty - 4/3	Qty - 5/3	Qty - 6/3	Qty - 7/3	Quality Per Defect	Quality Per Defect Item
BGA	Open Joint					1								99 94%	99 94%
Fine Pitch	Open Joint					1								99 94%	99 94%
Manual THM	Defective					1			2					99 82%	99 76%
	Damaged							1						99 94%	
No Defect Found	No Defect Found					1		1						99 88%	99 88%
Primary Passive	Extra Part					1		1						99 88%	99 70%
	Open Joint								1					99 94%	
	Missing Part									2				99 88%	
Scndary Passive	Missing Part						1		1					99 88%	99 88%
No Repair Hist	Process Violat								1					99 94%	99 94%
Wave	Open Joint									1				99 94%	99 94%
Scndary Active	Wrong									1				99 94%	99 94%
	Observed	103	217	233	63	139	41	148	169	50	167	172	150	**Quality of the Stage**	98 98%
	Failed	0	0	0	0	4	1	3	5	3	0	0	0		
	FPA	100 00%	100 00%	100 00%	100 00%	97 12%	97 56%	97 97%	97 04%	94 00%	100 00%	100 00%	100 00%		

73 98%

Line 1

Date_ID	31/8		30/8		29/8		28/8		27/8		26/8		25/8		24/8		23/8		22/8	
Tool_ID	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns
Panel Mark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Sec	5	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0
CP6 Sec	5	0	0	0	0	0	0	30	0	6	0	0	0	40	0	0	0	0	0	0
IP3 Sec	0	25	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0
Atmos Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	150	0	0	0	0
PSVI Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHS Sec	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
DEK Prt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CP6 Prt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Prt	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0
Atmos Prt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSVI Prt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHS Prt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depanel	0	0	0	0	0	0	0	0	0	55	0	0	0	0	0	0	0	0	0	0
ICT	10	0	0	0	0	0	25	0	0	5	0	0	0	0	10	0	0	5	0	0
TGD	9	0	0	70	0	0	0	15	0	15	0	7	0	0	0	0	0	12	0	48
ATPAS	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	6	0
ACES	0	60	10	0	0	0	0	0	10	0	0	5	0	17	25	0	0	80	8	0
Systest	41	50	45	105	35	45	60	65	30	79	0	35	45	20	20	15	0	327	30	110
BE MHS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CM	0	0	0	0	0	0	10	0	0	0	0	55	0	20	0	0	0	0	0	0
FVI Pack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stores	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Line 2

Date ID	31/8		30/8		29/8		28/8		27/8		26/8		25/8		24/8		23/8		22/8	
Tool ID	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns
Panel Mark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Sec	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0
CP6 Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atmos Sec	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	30	0	135	0	0
PSVI Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHS Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Pri	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CP6 Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Pri	15	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atmos Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSVI Pri	0	0	15	0	20	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0
MHS Pri	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0
Depanel	0	0	10	0	0	180	0	40	0	10	0	0	0	0	0	0	0	0	0	0
ICT	30	0	0	0	80	0	30	0	0	0	0	15	0	0	0	0	0	5	10	0
TGD	0	170	0	0	0	45	0	50	0	25	0	0	0	0	8	0	20	13	0	23
ATPAS	5	0	40	0	16	0	10	0	0	0	0	0	0	23	11	0	35	20	0	0
ACES	5	0	10	0	0	28	0	0	0	17	0	20	0	15	0	0	5	15	0	0
Systest	10	0	0	60	45	30	90	25	0	100	0	0	45	20	20	15	100	110	70	35
BE MHS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CM	0	0	0	0	0	0	90	0	180	0	0	0	40	0	0	0	0	0	0	0
FVI Pack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stores	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Line 3

Date_ID	31/8		30/8		29/8		28/8		27/8		26/8		25/8		24/8		23/8		22/8	
Tool_ID	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns
Panel Mark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Sec	0	0	10	0	10	0	0	0	15	30	0	0	0	0	0	150	0	0	0	0
CP6 Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Sec	0	8	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atmos Sec	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0
PSVI Sec	0	0	0	0	0	0	0	115	0	0	0	0	0	45	0	0	0	0	0	0
MHS Sec	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0
DEK Pri	0	0	0	0	0	0	0	150	0	0	0	0	0	85	0	30	0	70	0	0
CP6 Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Pri	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0
Atmos Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSVI Pri	0	0	0	0	0	20	0	0	0	0	0	0	50	0	0	0	0	0	0	0
MHS Pri	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0
Depanel	0	0	0	32	0	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ICT	20	0	15	0	0	0	10	0	0	0	0	0	0	0	5	0	0	60	0	0
TGD	0	15	15	30	0	32	0	25	0	85	0	5	22	0	20	0	0	82	70	160
ATPAS	0	5	0	0	18	0	12	0	9	0	0	0	0	0	16	0	0	10	0	0
ACES	10	0	0	24	0	12	0	43	8	12	0	15	0	6	0	0	0	10	0	12
Systest	15	11	30	0	0	0	75	0	50	15	0	20	40	20	5	0	0	155	45	10
BE MHS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CM	0	0	0	0	0	0	360	0	0	0	0	0	0	0	0	0	0	0	0	0
FVI Pack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stores	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Line 4

Date_ID	31/8		30/8		29/8		28/8		27/8		26/8		25/8		24/8		23/8		22/8	
Tool_ID	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns
Panel Mark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0
CP6 Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Sec	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	15	0	0	0	0
Atmos Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70
PSVI Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
MHS Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
CP6 Pri	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
IP3 Pri	10	0	0	0	0	0	0	0	0	10	0	0	0	20	0	0	0	0	0	0
Atmos Pri	0	0	30	0	0	0	85	0	0	0	0	0	0	0	0	0	0	0	0	0
PSVI Pri	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHS Pri	0	0	0	0	0	0	0	0	0	10	0	0	0	20	0	0	75	0	0	0
Depanel	0	0	0	0	0	0	30	40	0	0	0	0	0	0	0	0	0	0	0	15
ICT	0	0	0	0	0	0	0	0	0	5	0	0	0	0	5	0	5	0	0	0
TGD	3	0	4	50	0	25	0	45	0	123	0	80	0	0	0	0	36	15	0	15
ATPAS	0	75	5	0	0	70	15	0	0	0	0	0	0	15	0	0	0	25	0	0
ACES	0	50	5	50	0	25	25	10	0	10	0	16	0	25	0	0	47	130	0	20
Systest	25	0	10	15	0	15	0	0	25	30	10	5	125	25	10	0	10	45	0	0
BE MHS	0	0	0	0	0	0	10	0	0	0	0	0	30	0	0	0	0	0	0	0
CM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FVI Pack	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stores	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Line 5

Date ID	31/8		30/8		29/8		28/8		27/8		26/8		25/8		24/8		23/8		22/8	
Tool ID	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns	Sch	Uns
Panel Mark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Sec	0	0	0	0	0	15	0	0	0	0	0	0	30	0	0	0	0	0	0	0
CP6 Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Atmos Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSVI Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHS Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEK Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0
CP6 Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IP3 Pri	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
Atmos Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSVI Pri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MHS Pri	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0
Depanel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
ICT	0	49	25	0	0	0	10	0	10	120	0	35	0	0	0	0	0	55	0	10
TGD	0	54	0	0	0	0	0	23	0	15	5	0	5	0	15	0	0	0	0	10
ATPAS	0	38	0	0	0	0	25	78	10	0	0	2	0	25	0	0	0	47	8	0
ACES	0	20	0	20	0	0	0	0	40	28	0	7	0	8	0	0	0	22	0	10
Systest	0	30	0	30	0	0	0	600	0	730	0	50	130	80	90	0	25	10	30	30
BF MHS	0	0	0	0	0	0	360	0	0	0	0	0	0	20	0	0	0	0	0	0
CM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FVI Pack	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stores	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Inspection **DEK (Secondary)** Product **DSP1 A**

Volume					37335		64722	
Failure \ Date(m/d)	6/27 - 7/04		7/11-7/18		8/8-8/15		8/15-8/22	
	No Defects		No Data					
8238-FIDUCIAL NOT FOUND					0 04550%	17	0 00927%	6
8133-DROPPED BY OTHER EQUIP							0 00927%	6
8131-DROPPED BY DYNAPACE					0 11200%	42		
AS10-ASSEMPLY MISSING					0 11200%	42		

Inspection **ICT** Product **DS1P A**

Volume	22303		33787		66958		37610	
Failure \ Date(m/d)	6/27 - 7/04		7/11-7/18		8/8-8/15		8/15-8/22	
8020-DROPPED BOARD	0 013%	3						
AS10-ASSEMPLY MISSING	0 021%	5	0 059%	20	0 02840%	19		
8131-DROPPED BY DYNAPACE	0 017%	4	0 036%	12	0 01940%	13	0 00266%	6
5001-ELECT FAIL	0 051%	12	0 059%	20	0 08810%	59	0 07440%	28
8022-REMOVED FOR ENGINEERING					0 00149%	1	0 00266%	1
8240-FAILED ICT/FA LOOP 3X			0 003%	1	0 00149%	1		

	Inspection		PSVI1		Product		DS1P A	
Volume					37234		64710	
Failure \ Date(m/d)	6/27 - 7/04		7/11-7/18		8/8-8/15		8/15-8/22	
8041-DAMAGED COMPONENT			0 0028%	1			0 00309%	2
8049-COMPONENT SKID			0 0028%	1	0 01880%	7	0 00618%	4
8092-SURFACE FM			0 0028%	1	0 00269%	1		
8043-MISALIGNED			0 0055%	2	0 00269%	1	0 00309%	2
8090-LEAD DAMAGE	0 015%	3	0 0140%	5	0 01070%	4	0 00155%	1
8044-MISSING COMPONENT			0 0170%	6			0 00155%	1
8051-SOLDER ON FINGERS	0 052%	10	0 0360%	13	0 02150%	8	0 06030%	39
8032-EMBEDDED FM							0 00155%	1
8034-BOARD SCRATCHES							0 00155%	1
8057-FM ON FINGERS							0 00155%	1
8045-SURFACE DAMAGE TO FINGERS							0 00309%	2
8100-LIFTED LEAD							0 00309%	2
8094-INSUFICIENT SOLDER					0 01610%	6	0 00464%	3
8093-COMPONENT FM					0 00537%	2		
8011-CARD MISSING					0 01610%	6		

Inspection **PSVI2** Product **DS1P A**

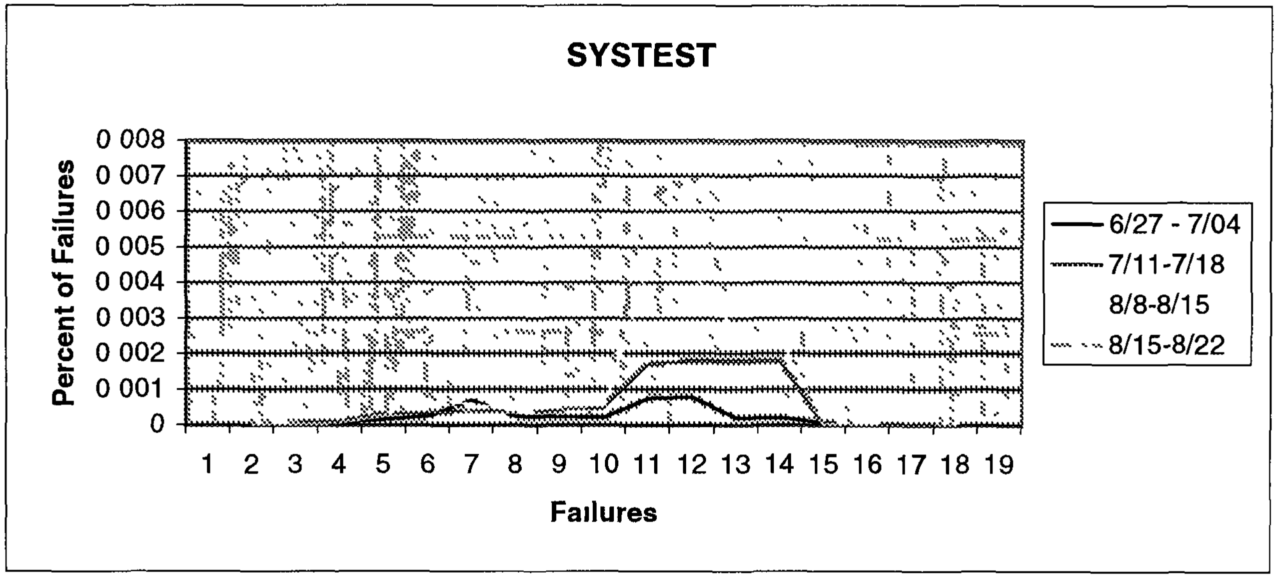
Volume				37234		64710	
Failure \ Date(m/d)	6/27 - 7/04		7/11-7/18	8/8-8/15		8/15-8/22	
			No Data				
8012-REJECT UNDEFINED						0 00152%	1
8057-FM ON FINGERS						0 00152%	1
8049-COMPONENT SKID						0 00305%	2
8045-SURFACE DAMAGE TO FINGERS						0 00457%	3
8043-MISALIGNED				0 01880%	7	0 00762%	5
8051-SOLDER ON FINGERS	0 1500%	33		0 02960%	11	0 00914%	6
8094-INSUFICIENT SOLDER	0 0610%	13				0 01370%	9
8044-MISSING COMPONENT	0 0470%	10		0 00269%	1	0 01980%	13
8031-BREA AWAY						0 02290%	15
8050-WARPED/TWISTED CARD				0 04840%	18	0 02740%	18
8046-CRACK/BROKEN CARD						0 03960%	26
8041-DAMAGED COMPONENT				0 07530%	28	0 06250%	41
8034-BOARD SCRATCHES	0 0047%	1					
8100-LIFTED LEAD	0 0140%	3					

Inspection **SYSTEST** Product **DS1P A**

Volume					34862		63452	
Failure \ Date(m/d)	6/27 - 7/04		7/11-7/18		8/8-8/15		8/15-8/22	
8011-CARD MISSING	0 0000%	0	0 0033%	1	0 0000%	0	0 0000%	0
8083-LOOSE/MISSING ASSEMPLY	0 0000%	0	0 0033%	1	0 00000%	0	0 00000%	0
8126-FAIL UNIX	0 0048%	1	0 0066%	2	0 00574%	2	0 00473%	3
IB75-Fail_WindowsNT_4	0 0150%	3	0 0330%	10	0 02580%	9	0 02360%	15
IB82-Fail_Hardware_Ch	0 0240%	5	0 0330%	10	0 07170%	25	0 07880%	50
8022-REMOVED FOR ENGINEERING	0 0680%	14	0 0390%	12	0 05740%	20	0 03470%	39
8128-FAIL WINDOWS 95	0 0240%	5	0 0390%	12	0 04020%	14	0 03470%	22
IB73-Fail_Windows_95	0 0240%	5	0 0430%	13	0 04880%	17	0 03150%	20
8124-FAIL WINDOWS NT	0 0190%	4	0 0490%	15	0 05160%	18	0 03150%	20
8127-FAIL DOS	0 0730%	15	0 1700%	53	0 43900%	153	0 64100%	407
IB77-Fail_dos	0 0780%	16	0 1800%	56	0 43600%	152	0 69000%	438
8129-FAIL POWER UP	0 0190%	40	0 1800%	56	0 25800%	90	0 27600%	175
IB81-Fail_OS_Boot	0 0190%	40	0 1800%	56	0 25000%	87	0 26300%	167
8085-THERMAL PLATE/COVER/SKIRT DAMAGED	0 0048%	1	0 0000%	0	0 00000%	0	0 00158%	1
8133-DROPPED BY OTHER EQUIPMENT	0 0000%	0	0 0000%	0	0 00000%	0	0 00630%	4
8131-DROPPED BY DYNAPACE	0 0000%	0	0 0000%	0	0 02290%	8	0 01260%	8
IB10-Fail_Shorts_Test	0 0000%	0	0 0000%	0	0 00287%	1	0 0000%	0

Inspection **DEK(primary)** Product **DS1P A**

Volume					34862		63452	
Failure \ Date(m/d)	6/27 - 7/04		7/11-7/18		8/8-8/15		8/15-8/22	
							No Data	
AS10-ASSEMPLY MISSING	0 0047%	1			0 0122%	8		
8021-XED OUT BOARD	0 0093%	2						
8238-FIDUCIAL NOT FOUND			0 0140%	5				
8131-DROPPED BY DYNAPACE			0 0310%	11				


SYSTEST
Percent of Failures
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Failures
6/27 - 7/04
7/11-7/18
8/8-8/15
8/15-8/22

APPENDIX B

Possible Failures

Detected From Inspections

(MMX Line)

Loss Code Decoder Ring

ODE	DESCRIPTION	CODE	DESCRIPTION
001	MISSING	8128	FAIL WINDOWS 95
001	ELECT FAIL	8129	FAIL POWER UP
010	MIXED PRODUCT	8130	FIT GAGE
011	CARD MISSING	8131	DROPPED BY DYNAPACE
012	REJECT UNDEFINED	8132	DROPPED BY OPERATOR
020	DROPPED BOARD	8133	DROPPED BY OTHER EQUIP
021	XED OUT BOARD	8134	FA NOT DONE
022	REMOVED FOR ENGINEERING	8135	ASSEMBLY DAMAGED
023	DROPPED	8136	EQUIPMENT RELATED LOSS
024	SCRAPPED	8137	SUPPLIER RELATED LOSS
025	WARPED COVER	8138	OPERATOR RELATED LOSS
026	OPEN COVER	8139	MISROUTED YTOT
027	BURRS	8140	CLIP POP-OFF
028	HP/HS FINISH	8141	BENT BRIDGE ON LABELED COVER
029	HP/HS ORIENTATION	8142	BENT CLIPS ON LABELED COVER
030	HP/HS DAMAGE	8143	OTHER DAMAGE ON LABELED COVER
031	BREAK AWAY	8144	DROPPED LABEL
032	EMBEDDED FM	8145	LABEL ID MATRIX UNREADABLE
033	HEAT SLUG VOID	8146	LABEL ORIENTATION
034	BOARD SCRATCHES	8147	FM ON LABELED COVER
035	MISSING FINGER	8148	MARK LABEL BUBBLE
036	FINGER NODULE	8149	FAILED ACUITY
037	FINGER VOID	8150	FAILED PPL
038	MISSING LEAD	8151	MARKED OFF INK PAD
039	PEELED/CRACKED TERMINATION	8152	MARKED OFF LABEL
040	COMP. BODY PIT/VOID/INDENT	8153	MARKED OFF COVER
041	DAMAGED COMPONENT	8154	MISPROCESSED
042	MISORIENTED COMPONENT	8155	PASTE SAT TOO LONG
043	MISALIGNED	8156	PANEL HOLE SIZE
044	MISSING COMPONENT	8157	MISPLACED PANEL COMPONENT
045	SURFACE DAMAGE TO FINGERS	8158	MISROUTED XTOT
046	CRACK/BROKEN CARD	8159	MISROUTED Y1
047	SCORCHING	8160	COVER DROPPED/DAMAGED
048	BOARD MISREGISTRATION	8161	COVER INCOMING DAMAGE
049	COMPONENT SKID	8163	SOLDER ON BLADE
050	WARPED/TWISTED CARD	8164	CONNECTOR BODY CHIPPED/CRACKED/BROKEN
051	SOLDER ON FINGERS	8165	CONNECTOR BLADE NOT PLATED/FM/DISCOLORED
052	EXCESS REWORK	8166	CONNECTOR BODY FM/STAIN/DISCOLORED
053	LIFTED LANDS	8167	SUBASSEMBLY MISALIGNED
055	EXCESS THERMAL GREASE	8168	ENCLOSURE BURRS
056	THERMAL PLATE EXPOSED BASE METAL	8170	ENCLOSURE FM/STAIN/DISCOLORATION
057	FM ON FINGER	8171	ENCLOSURE SCRATCHES
058	FM ON HEAT SINK	8172	NON-UNIFORM EDGE RADIUS
059	FM ON SPRING CLIP	8173	DENTS
060	HEAT SINK PEELING/FLAKING	8174	MARK LABEL FM/STAIN/DISCOLORATION
061	HEAT SINK METAL BURRS	8175	MARK LABEL MISALIGNMENT/TILT
062	HEAT SINK BENT FINS	8176	MARK LABEL PEEL/LIFT
063	INSULATOR PAD MISSING	8177	MARK LABEL DAMAGE
064	INSULATOR PAD MISPLACED	8178	FLIPPED COMPONENT
065	INSULATOR PAD SEPARATION	8179	DAMAGED PIECE PART
066	SPRING CLIP METAL BURRS	8180	DOUBLE-LABELED COVER
067	SPRING CLIP MISSING	8221	MARK INCOMPLETE
068	SPRING CLIP ON LATCHED	8222	LASER MARK CONTENT
069	SPRING CLIP LOOSE OR DAMAGED	8223	LASER MARK MISPLACEMENT/MISORIENTATION
070	LABEL DAMAGED	8224	MARK PLACEMENT
071	DISCOLORATION/STAIN	8226	MARK CONTRAST

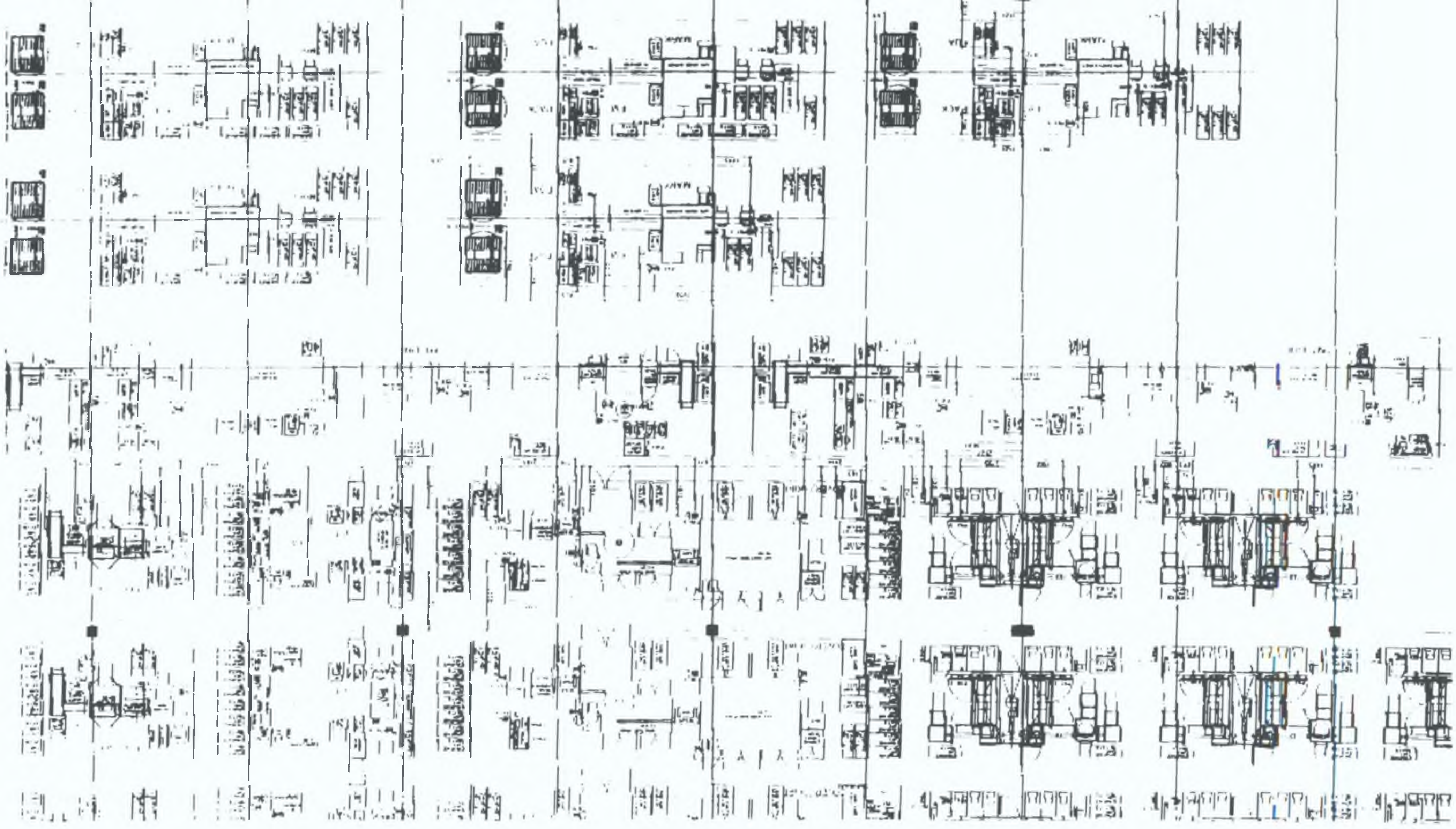
Loss Code Decoder Ring

072	LABEL MULTIPLE	8227	DOUBLE MARK
073	COVER/SKIRT/LATCH ARM BURR/FLASH	8230	MARK OTHERS
074	FM ON SKIRT	8231	MARK BLISTERS
075	FM ON COVER	8232	LASER MARK MISSING
076	FM ON THERMAL PLATE	8233	LASER MARK ILLEGIBLE
077	MOLD INCOMPLETE	8234	MARK SERIALIZATION INCORRECT
078	TURN OFF	8235	MARK 2D MATRIX UNREADABLE
079	KNIT LINE	8236	MARK HANDLING DAMAGE
080	LABEL BUBBLES OR PROTRUSION	8237	MARK DELAMINATION
081	LABEL ALIGNMENT	8238	FIDUCIAL NOT FOUND
082	LABEL VOID	8239	FAILED ICT RETEST
083	LOOSE/MISSING ASSEMBLY	8240	FAILED ICT/FA LOOP 3X
084	LABEL PEEL/LIFT	8241	FINGER EXPOSED BASE METAL
085	DAMAGED PEICE PART	8242	CRACKS
086	VOIDS, BLISTERS, OR POROSITY	8243	COVER/SKIRT/LATCH ARM SCRATCHES
087	COMPONENT STAIN	8244	COVER/SKIRT/LATCH ARM CHIPS/ROLLED EDGES
088	TOMBSTONE	8245	EXCESS INK
089	WRONG COMPONENT	8246	PAD PRINT PEELING/FLAKING
090	LEAD DAMAGE	8247	PAD PRINTING ILLEGIBLE
091	BENT LEAD	8248	LABEL TILT
092	SURFACE FM	8249	LABEL ROTATION
093	COMPONENT FM	8251	LABEL POSITION X/Y
094	INSUFFICIANT SOLDER	8253	LABEL INCOMING DAMAGE
095	SOLDER BALLS	8254	FAILED EEPROM PROGRAMMING
096	EXCESS SOLDER	8260	COMPANION CARD DEFECT
097	COLD SOLDER	8414	FOREIGN MATERIAL/DISCOLORATION
098	SOLDER PROJECTION	8440	LEADS OTHER
099	TOUCH UP FAIL	8520	CHIP/CRACK
100	LIFTED LEAD	8530	MISALIGNED LID/CAP/COVER
101	SOLDER BRIDGING	8540	THERMAL PLATE SCRATCHES
102	GREASE ON BOARD	8580	FOREIGN MATERIAL ON SURFACE
103	ATTACH FAILURE	8590	PACKAGE - OTHER
105	SOLDER IN TOOLING HOLES	8600	OTHERS
106	DEWETTING	9000	ASSEMBLY REWORK
107	DAMAGED COMPONENT (OLGA)	9002	TEST REWORK
108	CRACKED/CHIPPED/BROKEN DIE	AS10	ASSEMBLY MISSING
109	CONNECTOR BLADE BENT/MISALIGNED	DP10	MIS ROUTED
110	CONNECTOR BODY DAMAGED	HS20	MECHANICAL
111	CONNECTOR MISALIGNED/MISORIENTED	RW10	TOUCH UP SUCCESSFUL
124	FAIL WINDOWS NT	RW11	REWORK IDENTIFIED
25	FAIL O/S 2		
26	FAIL UNIX		
27	FAIL DOS		

APPENDIX C

Blue Print

MMX Production Line



Appendix D

MANUAL

"QUALITY & RELIABILITY"

Software Tool

Version 1.0

By

Theofanis Karagiannis

Contents

D.1 Introduction

This manual is geared towards the users of "Quality & Reliability" and contains all the required information for using this software tool. With the help of this tool the user can represent a production system and simulate the quality of the products and the reliability aspects of a system. It allows the user to gauge the reaction of this production system to changes relating to the parameters governing the process. This reaction can be assessed through the graphical and numerical representation of results. The results on quality include the number and type of products with failure and the cost of this failure as default in a given duration of time (defined by the user). Results can also be changed dynamically for other parameter values that the user is interested in. The results on reliability include Scheduled and/or Unscheduled downtime, and important parameters such as Availability, Real UPH (Units Per Hour), Utilisation etc. Sensitivity analysis is also built in as a basic feature of this software. To illustrate this aspect, some graphical comparisons of the different scenarios that the user investigated are also given. Estimation of reliability of the manufacturing system is another capability of this tool, which has more generic approach. The reliability of a production system consisting of one or two or more parallel lines and multiple (parallel) stages can be estimated.

The "Quality & Reliability Tool" is designed for use by three types of users (Section 4.2): The first category, "Engineers", is of people who know the production line and all the types of failures that a product can have. The second group of users, "Statisticians", would be concerned with the inputs of the tool and its assessment, collection of data and its analysis and so on. Both these groups require knowledge in detail of the data, although from rather different viewpoints. The third group, "Managers", involves those users who are interested in an overview of the results and the effects of sensitivity analyses on outputs and efficiency of the production line.

D.1.1 A note for the users

This manual is divided into three main Sections. Each Section contains data for a particular group of users. The first section "Creation of the Production Line" is written for the users of the first group: "Engineers". The second section "Production Line

Analysis" can be used by analysts and "Statisticians" and the third section "Cost and Production Implications" is for the last group of users.

D.2 Choosing a user

When the software tool is started, it asks for the type of user as is shown in Figure D.1. Depending on what group the user belongs, the tool allows him to do different things. For example, what an engineer can do is completely different from what a statistician or a manager can do.

Figure D.1: The tool asks for the group that the user belong

The "Engineers" group is responsible for the accurate representation of the production line. This is created with the help of a pop up menu. Of course, the facilities available to other types of users depend on what the Engineers provide, so that a clear representation of the system is very important. The engineers must also provide some information about the production process, such as the number of lines, the types of products that the system produces and the pure UPH for each product for each production stage.

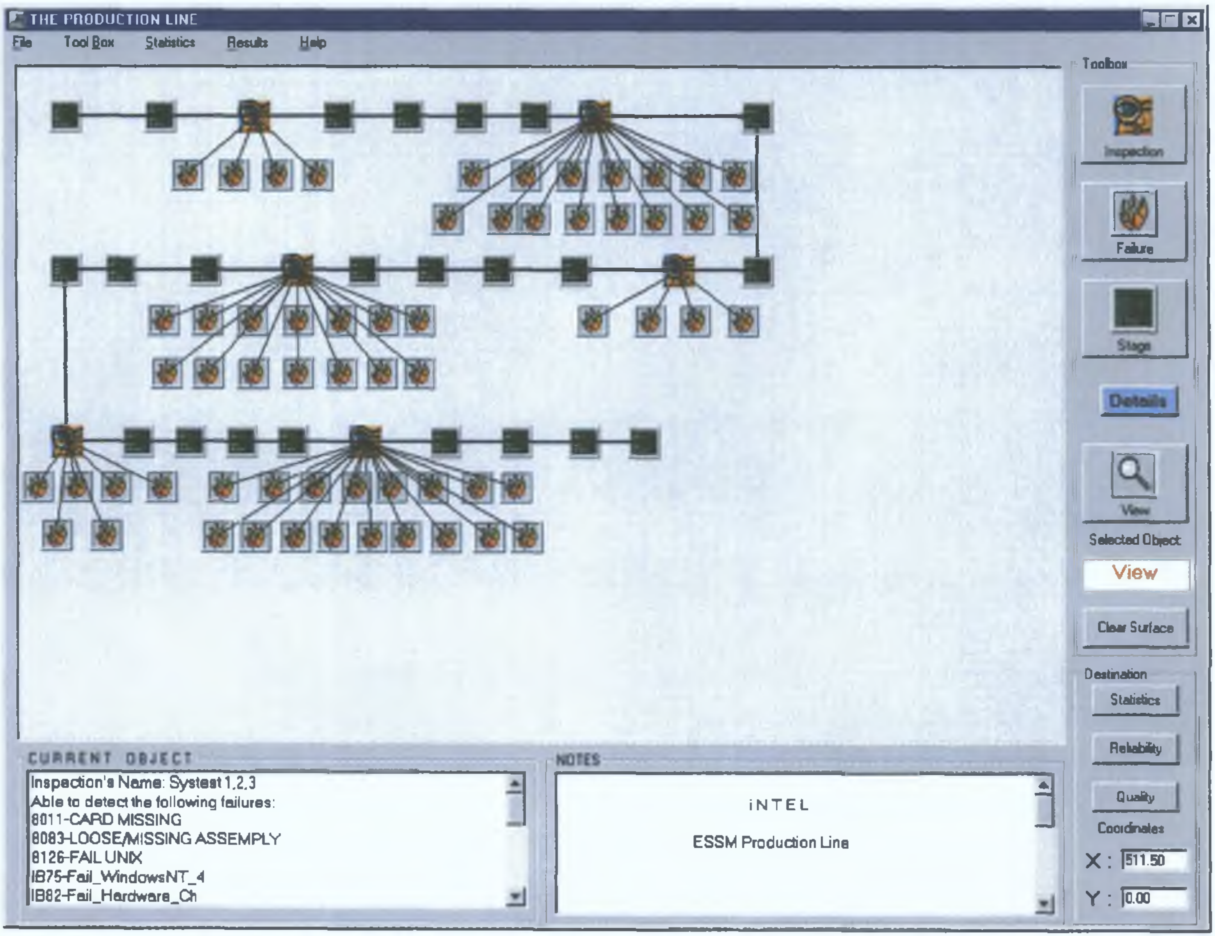
The "Statisticians" group has the responsibility for designating the inputs and outputs for suitable analysis. The inputs involve information about the number of faulty items that have been detected with a particular type of failure and information about the downtime

(Scheduled and Unscheduled) This software tool helps the statistician to do a *visual* statistical analysis of the data

The "Managers" group is interested in the synthesis of the results and production of reports and summaries A manager can both view the analyses and make minor changes to the data in order to see the reaction of the line to changes, i e "What if" exploration A number of different scenarios can be compared with each other, providing the base for system evaluation Estimation of the total reliability of the system is also available from this software tool, i e what is the reliability of a production system consisting of several parallel lines and several parallel stages

D.3 Creation of the Production Line

The "Production Line" window is illustrated in Figure (D.2). The production line presented on this window is one of the five identical lines located in Intel's ESSM plant. This line is the same as the one illustrated in Figure (4.1). The engineers must represent the system or a subsystem thereof by giving the production stages and the inspection stages of the system with all possible failures that each inspection can detect. The extra information that an engineer gives includes the names of inspections, stages, and failure types, the number of production lines and the pure UPH.



Inspection's Name: Systest 1.2.3
Able to detect the following failures:
8011-CARD MISSING
8083-LOOSE/MISSING ASSEMPLY
8126-FAIL UNIX
IB75-Fail_WindowsNT_4
IB82-Fail_Hardware_Ch

iNTEL
ESSM Production Line

Selected Object: View
X : 511.50
Y : 0.00

Figure D.2: The stage of the system's creation

D.3.1 How to represent a system

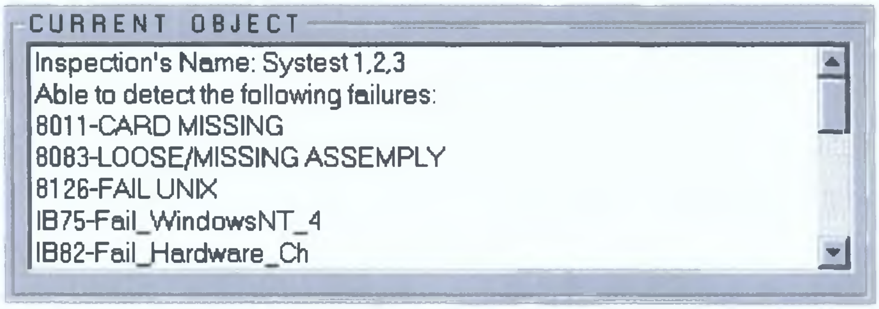
At the top right of the screen there is a "Toolbox" area (Fig. D.3). These tools help the user to represent the system. The system always starts with either a stage or an inspection. By clicking the "Inspection" button the user selects an inspection object, as shown at bottom of the "Toolbox" area (Fig. D.4) and puts it into the large area of the screen. After each inspection, the user (engineer) must give types of failures that the previous inspection can detect. The objects (Inspections, Failures, Stages) inserted in this window are automatically available for all the users. So, after the "Inspection" object, the user must insert the failures in the same way. Every time the user puts an object into the screen, an input dialog box asks for the name of that object.

Figure D.3: The toolbox area

Figure D.4: An Inspection has been selected

By clicking the "Inspection" button the user selects an inspection object. He/she can place this object in the screen, thus creating a representation of the line. When the

"View" button is pressed, the user, by clicking on any object in the screen, can view the data already given on this object. For example, by clicking on the "Systest" inspection the detectable failures are shown in the "Current Object" box as illustrated in Figure (D.5).



Inspection's Name: Systest 1,2,3
Able to detect the following failures:
8011-CARD MISSING
8083-LOOSE/MISSING ASSEMPLY
8126-FAIL UNIX
IB75-Fail_WindowsNT_4
IB82-Fail_Hardware_Ch

Figure D.5: The box where the given data of an object displayed when the "View" button is selected.

The "Notes" box (Fig. D.6) aims to help the user by keeping any additional information for the system, such as the names of the products, the date of creation of his system etc, which will help him/her to overview the system.

iNTEL

ESSM Production Line

Figure D.6: The "Notes" box can save any information about the system.

The "Destination" area at the bottom right of the screen (Fig. D.7) helps the user to watch the co-ordinates of the mouse in the pop up area in order to better position the selected object. It can also give the user the opportunity of visiting the "Statistics", "Reliability" or "Quality" windows (details are given below).

X : 658.50

Y : 358.50

Figure D.7: The "Destination" area

D.3.2 The menu bar

At the top of the "Production Line" window there are five menu lists. These lists allow the user to manipulate the data file, to move between the windows or to find some help topics. We give detailed information only for the menu lists of this window. The menu lists in the other windows contain much the same functions.

The "File" menu list

This menu is a common file menu (Fig. D.8). It gives options to create a **New** file, or to **Open** an existing one. The user can **Save** an update of a file or **Exit** the program.

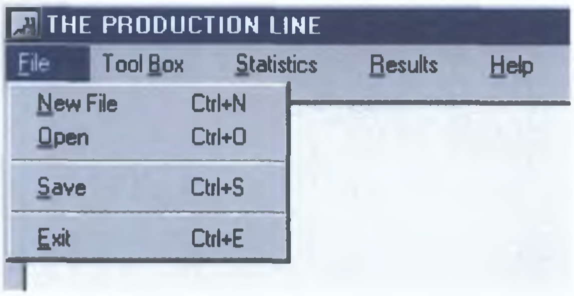


Figure D.8: The "File" menu list

The "Toolbox" menu list

From this menu (Fig. D.9) the user can choose an object (just like from Toolbox area) at the right of the screen (Fig. D.3). From the **Nodes** menu list, corresponding objects are available such as **Inspection**, **Failure** and **Stage**.

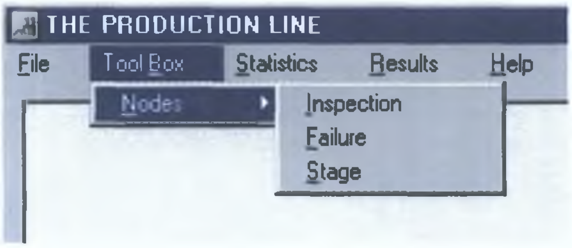


Figure D.9: The "Toolbox" menu list

The "Statistics" and "Results" menu lists

These two menu lists give to the user the option of moving between the windows. From the first one (Fig. D.10) the user can visit the **Historical Data**, **Specify Data** or **Insert Data** windows for both Quality and Reliability aspects. These three windows are the interfaces for the "Statisticians" or analysts. From the second list (Fig. D.11) the user can go to the results windows. Dynamically the user can change to several types of results. Details on the above windows are given in the next two sections.

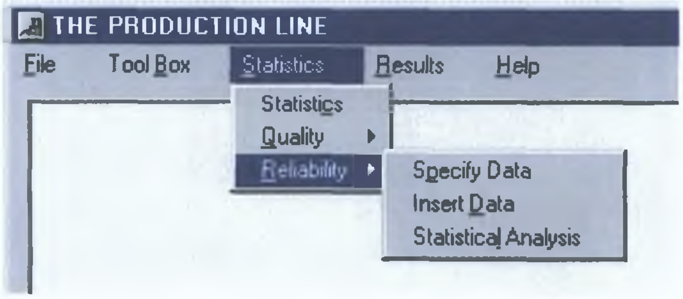


Figure D.10: The "Statistics" menu list

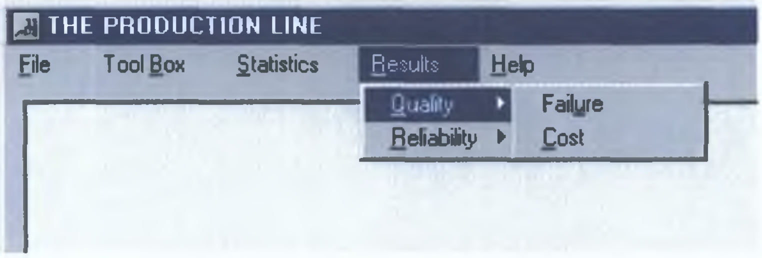


Figure D.11: The "Results" menu list

The "Help" menu list

The software tool also provides a **Help Topics** and an **About** window (Fig. D.12) which aid the user to provide appropriate results.

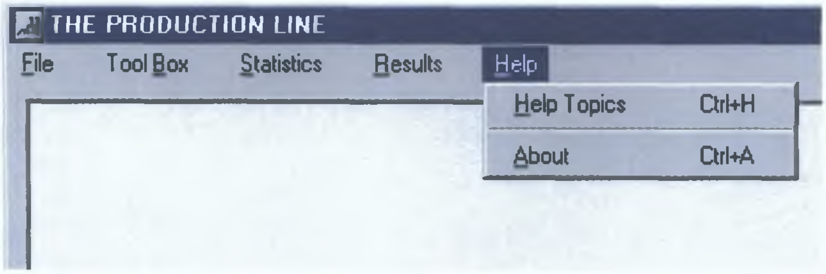
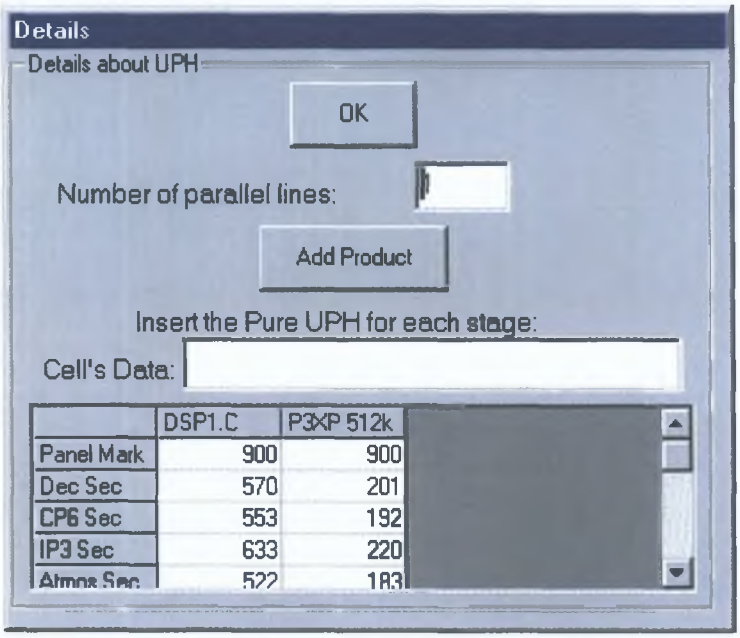


Figure D.12: The "Help" menu list

D.3.3 "Details" window

On clicking the *Details* button (Fig. D.3) the engineer gives details on the layout of the lines and information about them. The "Details" window (Fig. D.13) is shown and UPH data and the number of production lines must be inserted. Each product has a different UPH, depending on the complexity of the product, (number of components that should be attached). Hence, a pure UPH must be given for each stage and for every product. Figure (D.13) presents the pure UPH for two products (*DSP1.C* and *P3XP 512k*) as inserted in the software tool.



Number of parallel lines:

Insert the Pure UPH for each stage:

Cell's Data:

	DSP1.C	P3XP 512k
Panel Mark	900	900
Dec Sec	570	201
CP6 Sec	553	192
IP3 Sec	633	220
Atmos Sec	522	183

Figure D.13: The window in which UPH and layout data inserted

D.3.4 In Summary

The “Production Line” window helps the engineer to set up the system. The system consists of the Stages and the Inspections of the production line, and of the types of failures that can be detected. There are also details on the number of parallel lines and the UPH of each stage. The following two sections give details on what the other two groups of users (i.e. Managers and Statisticians) can do.

D.4 Production Line Analysis

The window "Statistics" (Fig. D.14) will be displayed in two different ways: From the starting window (Fig. D.1) by selecting "Statisticians" user or by following the link "Statistics" (Fig. D.7) from the "Production Line" window.

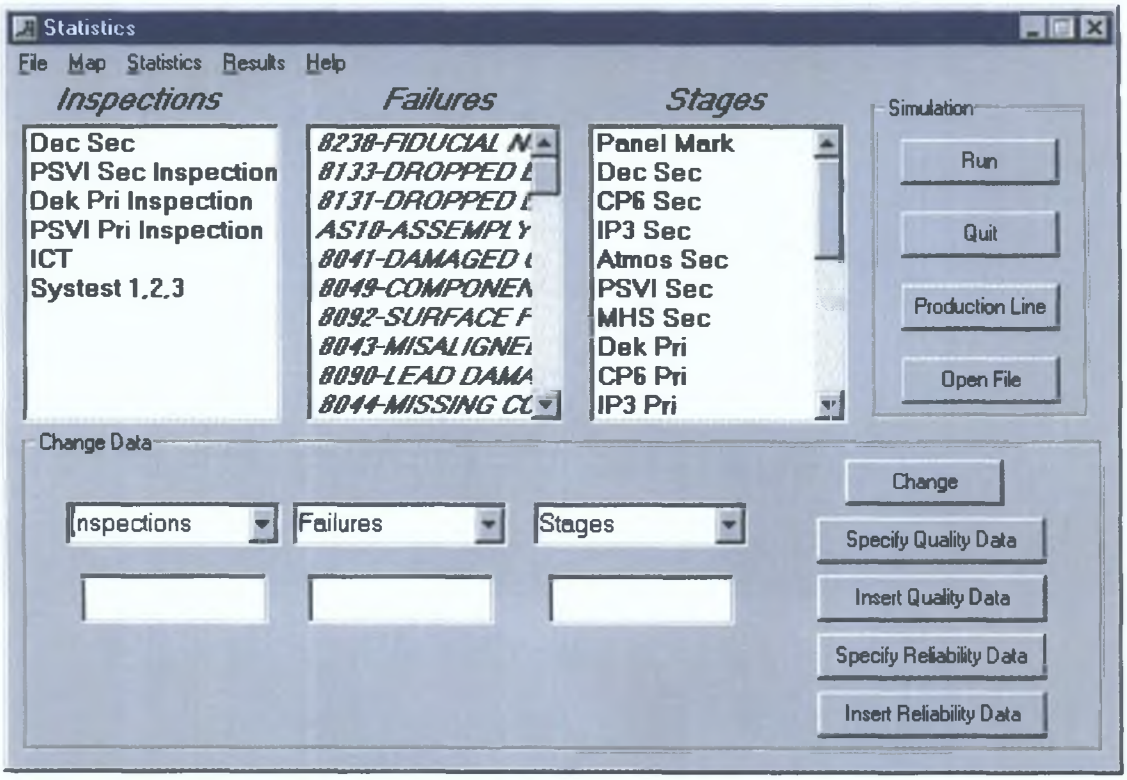


Figure D.14: The window "Statistics"

This window is divided into three areas: "Simulation", "Change Data" and information about the Inspections, Stages and Failures (Fig. D.14). A statistician would typically insert data involving downtime and number of failures at each stage. The three lists (Inspection, Failures, and Stages) give information on the corresponding objects and the user can also change the name of each object. From this window the name of an object can easily be changed by choosing the name from the drop down lists, correcting them and pressing the button "Change".

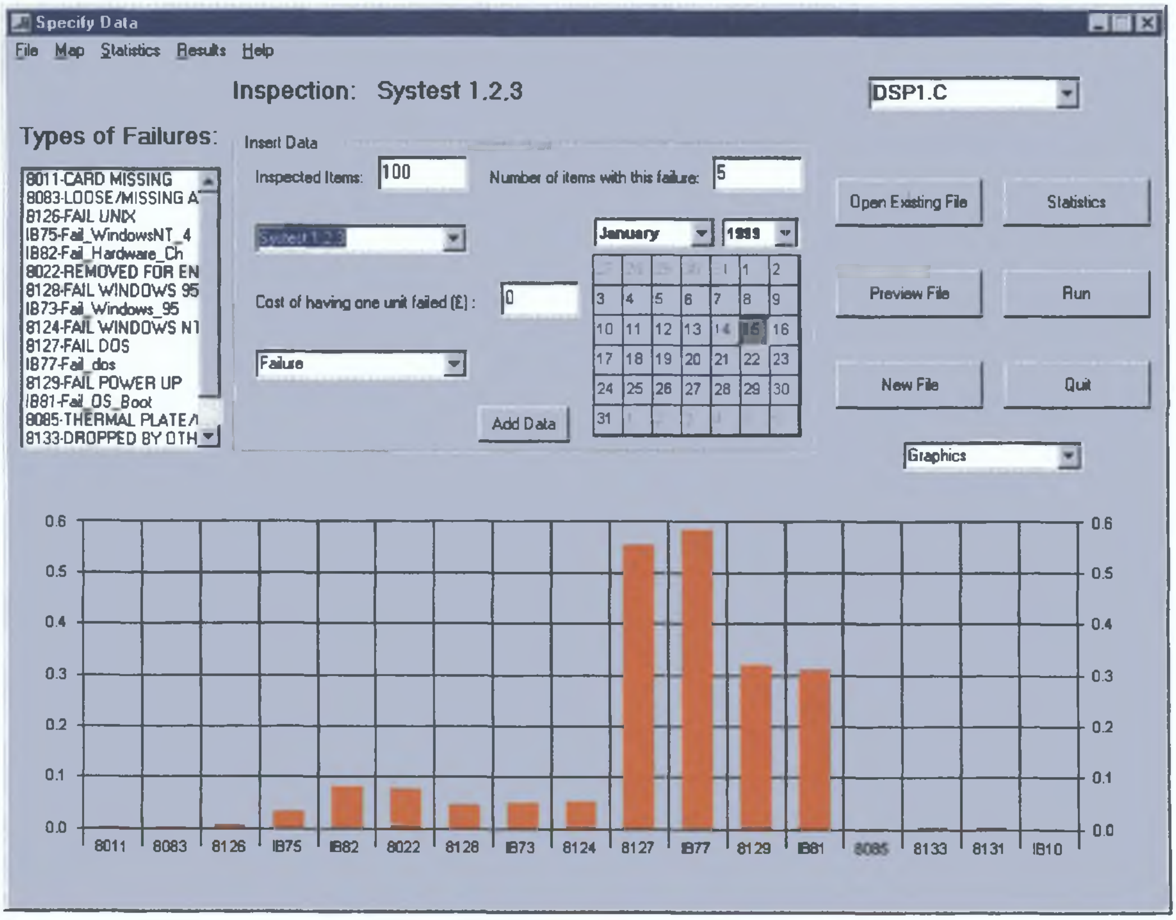
The "Simulation" area consists of four buttons: The "Run" and "Production Line" buttons can send the user to the "Results" and to the "Production Line" windows respectively.

The “Quit” button exits the “Quality and Reliability Tool” and the “Open File” opens an existing file.

The “Change Data” area has four important buttons: The “Specify Quality Data” button, the “Insert Quality Data” button, the “Specify Reliability Data” button, and the “Insert Reliability Data” button. These buttons are illustrated in the following windows:

D.4.1 The “Specify Quality Data” window

The “Specify Quality Data” window (Fig. D.15) helps the user to add the information associated with the current day. Every day, each inspection of the production line finds a number of items with a specific type of failure. So, if the user wants to insert this kind of information, he/she must first choose an inspection from the drop down list “Change Inspection”.



Inspection: Systest 1.2.3

Inspected Items: 100

Number of items with this failure: 5

Systest 1.2.3

Cost of having one unit failed (£) : 0

Failure

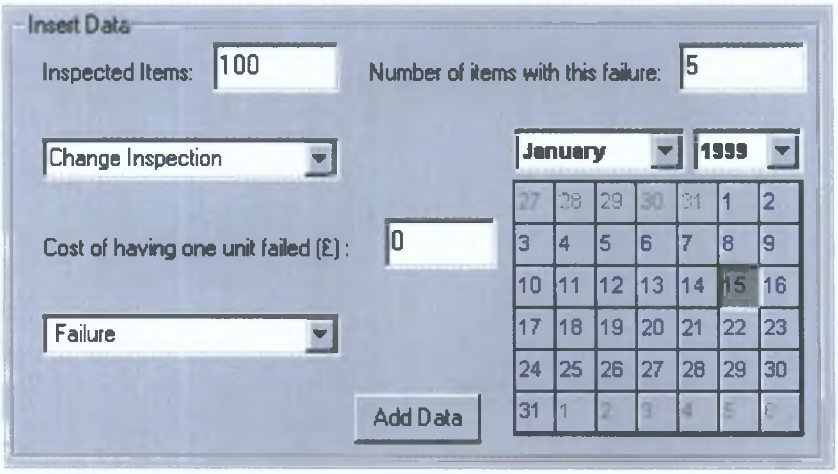
January 1999

DSP1.C

Graphics

Figure D.15: The "Specify Data" window

After that, he/she inserts the data at the "Insert Data" area (Fig. D.16), indicates the failure that has been detected and enters the number of items with this type of failure. This is repeated until all information on failed items has been inserted. Every time the user adds a new number of items with a given failure, the "Add Data" button (Fig. D.16) must be clicked. No failure is indicated by inserting "0" in the appropriate record.



Inspected Items: 100

Number of items with this failure: 5

Change Inspection

Cost of having one unit failed (£): 0

Failure

January 1999

27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31	1	2	3	4	5	6

Figure D.16: The "Insert Data" area adds the data of the day

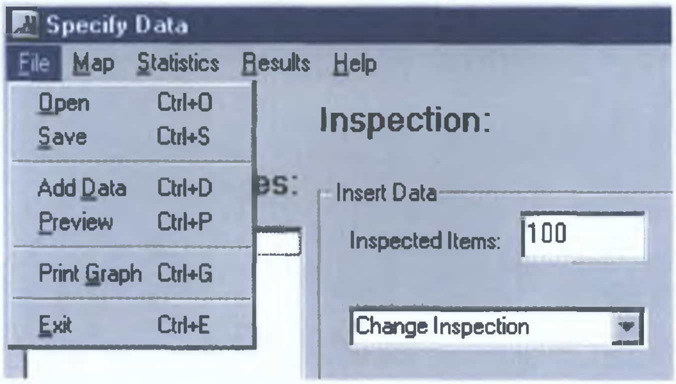
At the bottom of this window (Fig. D.15) there is a graphical representation of the data for the current inspection. It shows the percentage of failures at this inspection. At the top left of the screen the user can see all the possible failures that this inspection can detect. From the drop-list "Graphics" the user can choose the representation of the data as 2-Dimensional or 3-Dimensional. By pressing the "Ctrl" button the user can rotate the 3-Dimensional graphics.

At any time, the user can change the input file and add data into another file by clicking the "Open Existing" file. He/she can also create a new file or preview the open file. The preview of a file shows the user all the data that has been inserted through the "Insert Data" window (details in next paragraph).

The user can again move from window to window easily either with the help of menu lists (Fig. D.17) or by the buttons at the right side. By clicking the "Run" button, the "Results" window is shown. The "Statistics" button brings him/her to the previous window, “Statistics”. There are also buttons to quit the software, to open a file or to preview an open file.

Figure D.17: Window’s menu list

The “Map”, “Statistics” and “Results” menu lists helps the user to perform specific analyses as similarly described in Section (D.3.2). The “Specify Quality Data” window also has a “File” menu list (Fig. D.18). From this list, the option of printing the graph is available. The **Add Data** and **Preview** options do the same as the “Add Data” and “Preview” buttons.



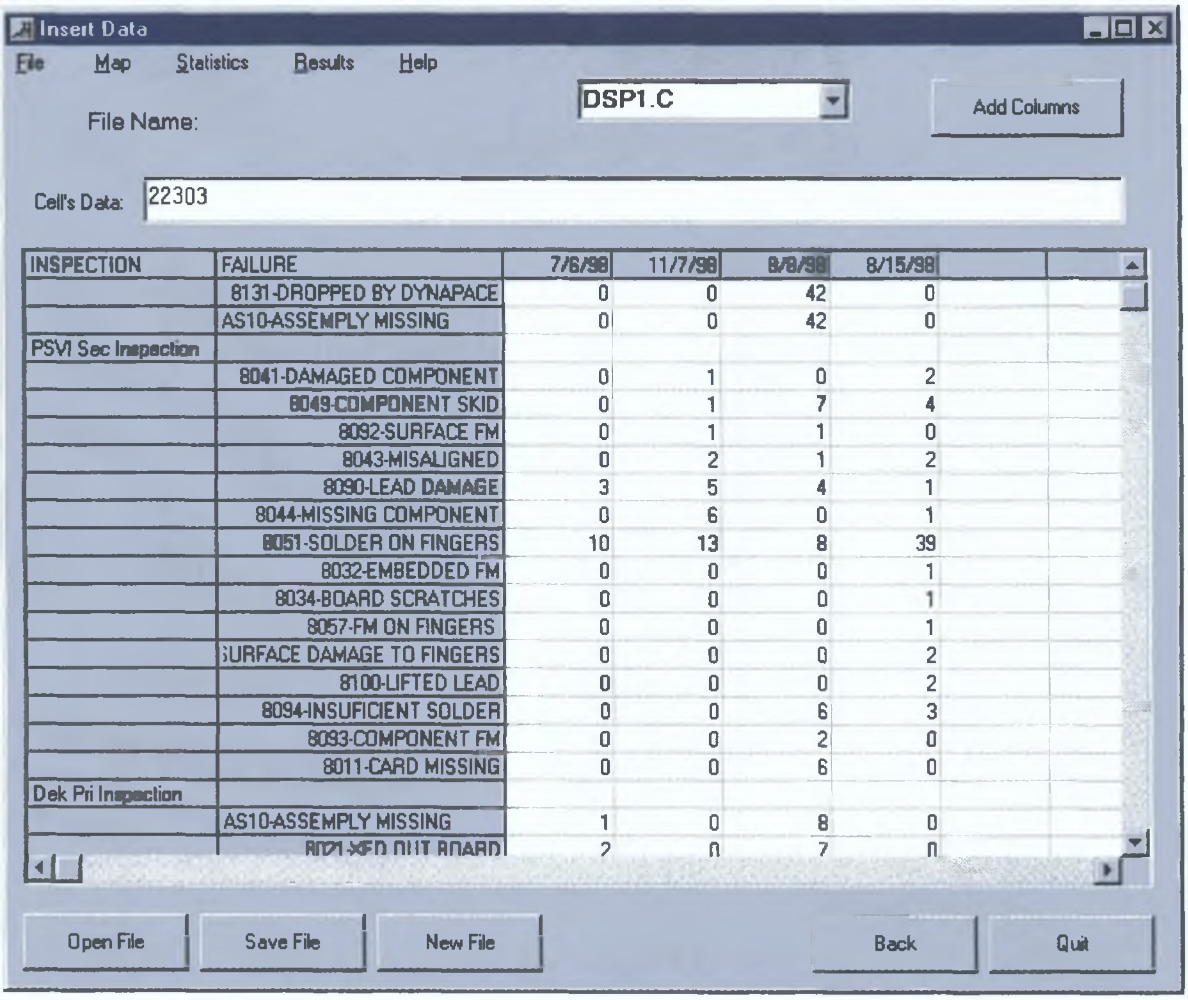
Inspected Items: 100

Change Inspection

Figure D.18: "File" menu list from "Specify Data" window

D.4.2 The "Insert Data" window

This window (Fig. D.19) enables addition of data. The user goes into this window when he/she wants to create a new input file, to preview an existing file or to add data for one or more days.



File Name: DSP1.C

Cell's Data: 22303

INSPECTION	FAILURE	7/6/98	11/7/98	8/8/98	8/15/98
	8131-DROPPED BY DYNAPACE	0	0	42	0
	AS10-ASSEMPLY MISSING	0	0	42	0
PSVI Sec Inspection					
	8041-DAMAGED COMPONENT	0	1	0	2
	8049-COMPONENT SKID	0	1	7	4
	8092-SURFACE FM	0	1	1	0
	8043-MISALIGNED	0	2	1	2
	8090-LEAD DAMAGE	3	5	4	1
	8044-MISSING COMPONENT	0	6	0	1
	8051-SOLDER ON FINGERS	10	13	8	39
	8032-EMBEDDED FM	0	0	0	1
	8034-BOARD SCRATCHES	0	0	0	1
	8057-FM ON FINGERS	0	0	0	1
	;URFACE DAMAGE TO FINGERS	0	0	0	2
	8100-LIFTED LEAD	0	0	0	2
	8094-INSUFICIENT SOLDER	0	0	6	3
	8093-COMPONENT FM	0	0	2	0
	8011-CARD MISSING	0	0	6	0
Dek Pri Inspection					
	AS10-ASSEMPLY MISSING	1	0	8	0
	8021-XFD OUT BOARD	2	0	7	0

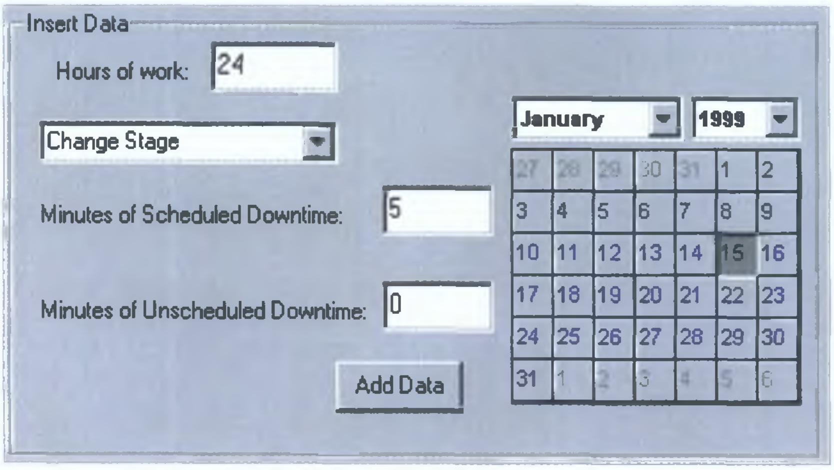
Figure D.19: The "Insert Data" window and the grid area

The grid box at the middle of the screen presents the failures and inspections as the mechanic has defined them. The user can add the number of defective items for one or more days into a new or existing file for a particular type of product. If the user wants results about the cost of failures, he/she must add the relative information (relevant cost per item) to the grid box. Again, this window allows the user to visit all the windows through the menu lists (Fig. D.20) in the same way as discussed in the previous section.

Figure D.20: The menu lists of "Specify Data" window

D.4.3 The "Specify Reliability Data" window

This window helps the user to add the information associated with the current day's downtime. Every day, each stage of the production line may fail short of the desired productivity (Fig. D.21). This may be due to various factors, and this tool divides them into two categories: Scheduled and Unscheduled reasons. Thus, if the user wants to insert this kind of information, he/she must first choose a stage from the drop down list "Change Stage" and insert the minutes of downtime (both Scheduled and Unscheduled Downtime). The differences between this window and the "Specify Quality Data" window are the "Insert Data" area and the presentation of both the scheduled and the unscheduled downtime, rather than quality data.


Insert Data

Hours of work: 24

Change Stage

Minutes of Scheduled Downtime: 5

Minutes of Unscheduled Downtime: 0

Add Data

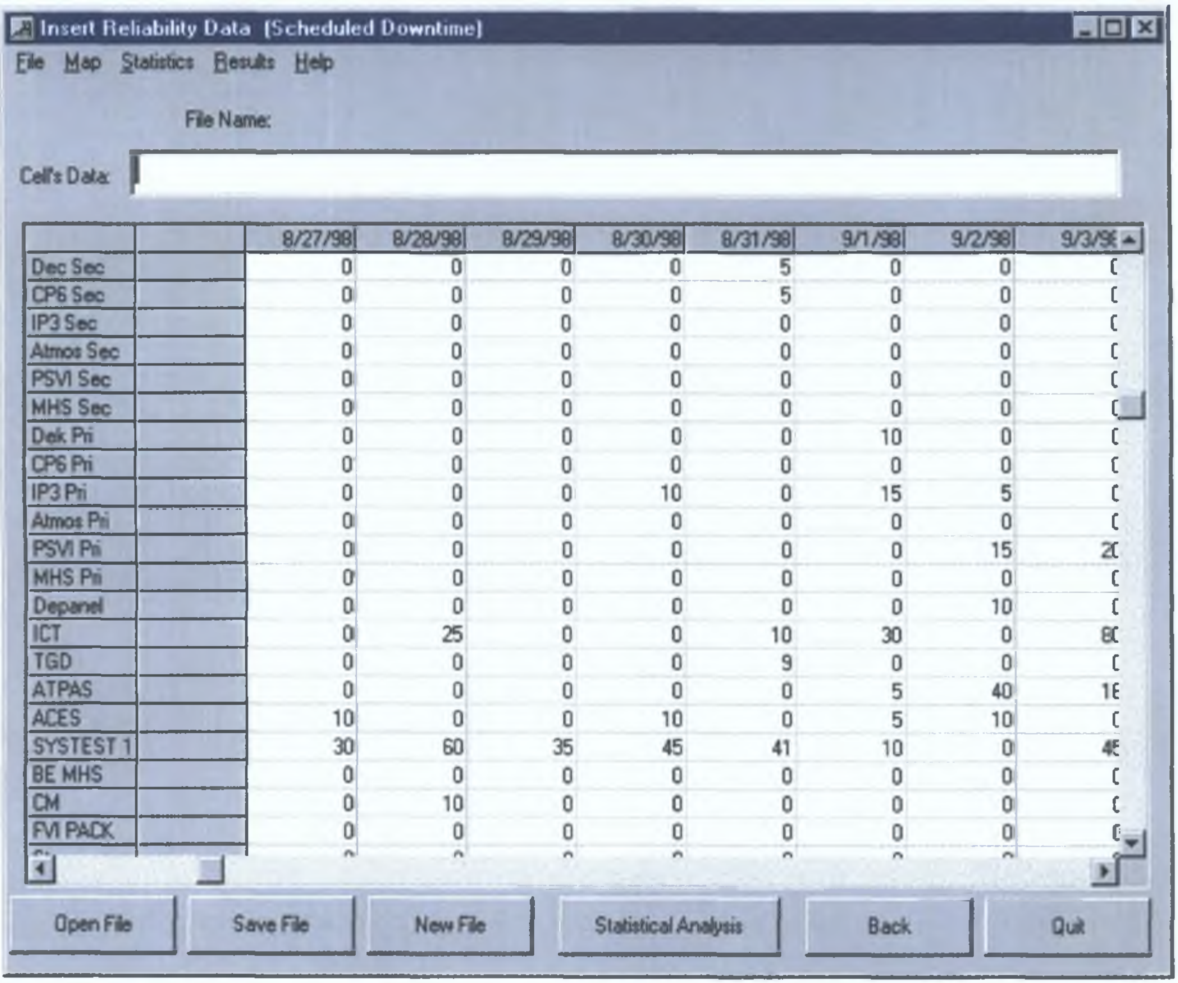
January 1999

27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31	1	2	3	4	5	6

Figure D.21: The insertion of reliability data for every day

D.4.4 The "Insert Reliability Data" window

We mentioned (Section D.4.2) that the user has the option to insert quality data with the help of the "Insert Quality Data" window. Two windows like this exist for importing reliability data. The first refers to Scheduled Downtime (Fig. D.22) and the other to Unscheduled Downtime.



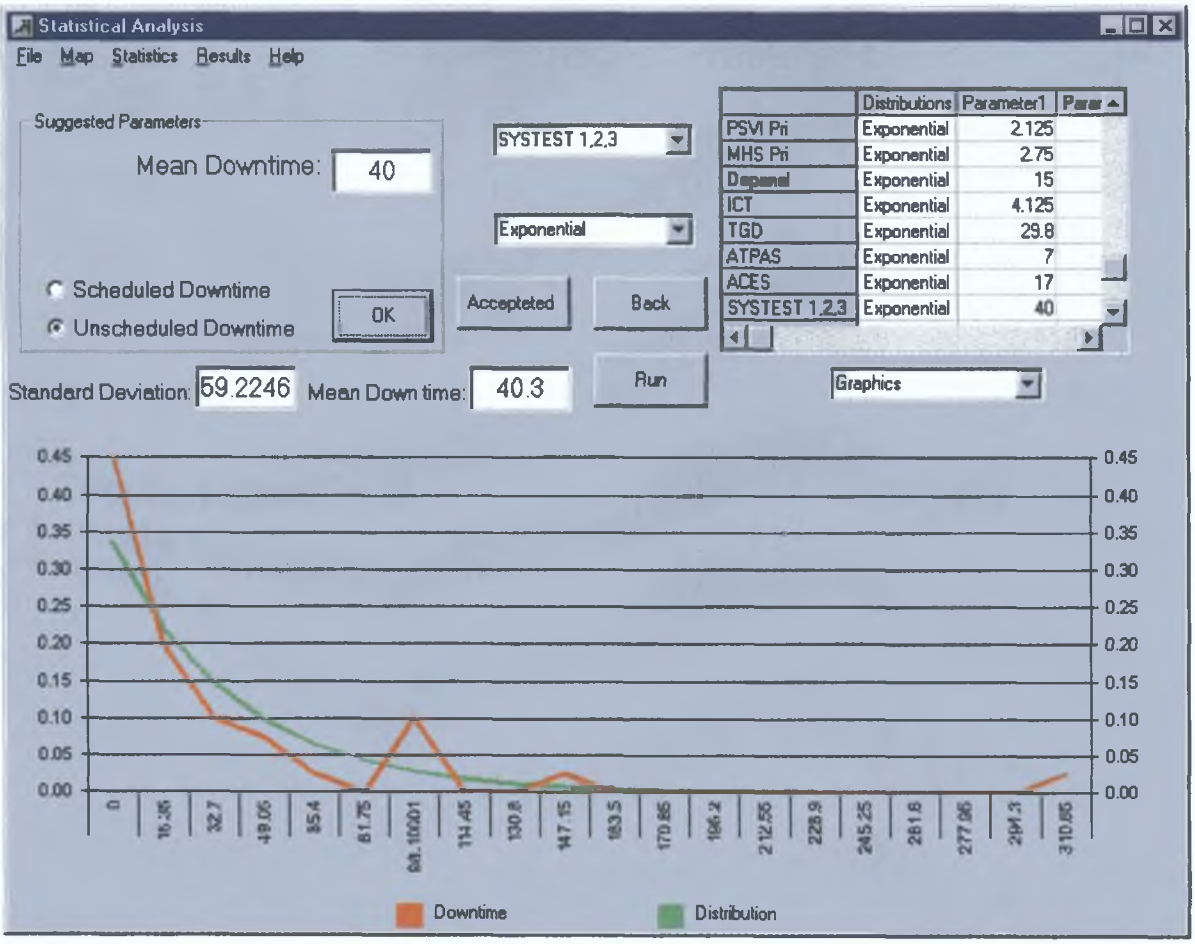
		8/27/98	8/28/98	8/29/98	8/30/98	8/31/98	9/1/98	9/2/98	9/3/9
Dec Sec		0	0	0	0	5	0	0	0
CP6 Sec		0	0	0	0	5	0	0	0
IP3 Sec		0	0	0	0	0	0	0	0
Atmos Sec		0	0	0	0	0	0	0	0
PSVI Sec		0	0	0	0	0	0	0	0
MHS Sec		0	0	0	0	0	0	0	0
Dek Pri		0	0	0	0	0	10	0	0
CP6 Pri		0	0	0	0	0	0	0	0
IP3 Pri		0	0	0	10	0	15	5	0
Atmos Pri		0	0	0	0	0	0	0	0
PSVI Pri		0	0	0	0	0	0	15	2
MHS Pri		0	0	0	0	0	0	0	0
Depanel		0	0	0	0	0	0	10	0
ICT		0	25	0	0	10	30	0	8
TGD		0	0	0	0	9	0	0	0
ATPAS		0	0	0	0	0	5	40	1
ACES		10	0	0	10	0	5	10	0
SYSTEST 1		30	60	35	45	41	10	0	4
BE MHS		0	0	0	0	0	0	0	0
CM		0	10	0	0	0	0	0	0
FVI PACK		0	0	0	0	0	0	0	0

Figure D.22: The "Insert Reliability Data" window for Scheduled Downtime data

In these two windows there is a button called *"Statistical Analysis"*. This button takes the user to the "Statistical Analysis" window in which a visual statistical analysis of the data can be done. Quality data are treated like probabilities so, a statistical analysis to fit them to distributions is not necessary for the reasons discussed in Section (3.2). Reliability data are treated as downtime distributions, so a statistical analysis in order to fit them to distributions is necessary. We present this window in next section (Section 4.5). The simulation model uses all the data that has been inserted into the above windows in order to generate random numbers of downtime and failures reflecting reality.

D.4.5 Visual Statistical Analysis of Reliability Data

Statistical distributions (such as Exponential, Weibull etc.) must be fitted to downtime data (both Scheduled and Unscheduled). The user selects a stage from the "Stages" combo box (Fig. D.23) and looks at the frequency of downtime (depending on their choice) illustrated (in red) at the bottom of this window.



Suggested Parameters
Mean Downtime: 40

○ Scheduled Downtime
● Unscheduled Downtime

SYSTEST 1,2,3

Exponential

Standard Deviation: 59.2246 Mean Down time: 40.3

Graphics

	Distributions	Parameter1	Parar
PSVI Pri	Exponential	2.125	
MHS Pri	Exponential	2.75	
Depanel	Exponential	15	
ICT	Exponential	4.125	
TGD	Exponential	29.8	
ATPAS	Exponential	7	
ACES	Exponential	17	
SYSTEST 1,2,3	Exponential	40	

Figure D.23: Visual Statistical Analysis of Reliability Data

The user may then attempt to fit the data to a standard distribution. The user must decide if extreme values (such as 310 minutes in our example) are to be included. If not the mean time must be reduced. From the combo box "Distributions", some common distributions can be selected Before pressing the "OK" button the user must insert the parameter(s) of the chosen distribution The software provides some suggestions about the values of the parameters by giving the "Standard Deviation" and the "Mean Downtime" By pressing "OK" the distribution is illustrated (in green) and if the selection is the appropriate one, the "Accepted" button must be clicked This should be continued for all the stages and for both Scheduled and Unscheduled Downtime

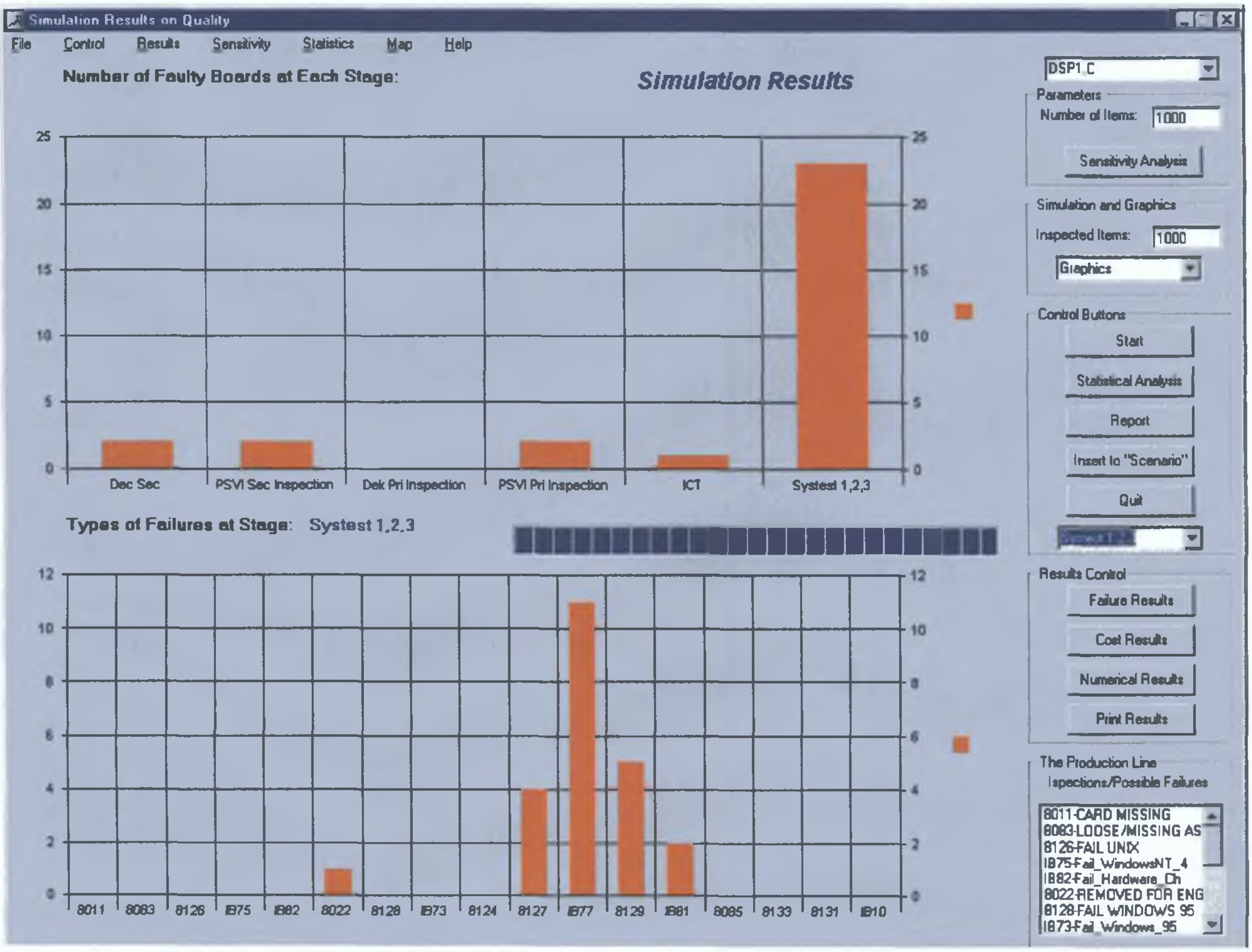
If a statistical analysis of the data is already done by other software packages (such as *JUMP, Microsoft Excel* etc) the user needs just to select the stage, the distribution and inserts the parameters In this way historical data on reliability is not required to be inserted in this window and the step of statistical analysis is not necessary

D 4 6 Footnote

The "Statisticians" group has the responsibility for inserting the data associated with the production line This is crucial since that data are used to simulate further scenarios If downtime distributions are already known, the user can avoid reliance on historical downtime data, which may be limited (Section 3 6) This implies knowledge of what constitutes a realistic distributional form for the failure times At this stage, no data have been generated by the tool through the simulation models Data available to the tool will allow doing this as described in the next section

D.5 Cost and Production Implications

"Managers" tend to be interested only in the results of the simulation model and comparisons between some possible scenarios, together with information on associated costs. Sensitivity Analysis is available for both this group and the "Statisticians" group, in order to test the reaction of the line to changes on the parameters governing the process. After each simulation run, the user gets an analytical report and there is also the option of keeping the results for further comparisons with other results and scenarios.



DSP1.C

Number of Items: 1000

Inspected Items: 1000

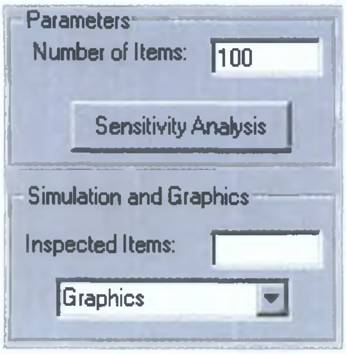
Graphics

8011-CARD MISSING
8083-LOOSE/MISSING AS
8126-FAIL UNIX
I875-Fail_WindowsNT_4
I882-Fail_Hardware_Ch
8022-REMOVED FOR ENG
8128-FAIL WINDOWS 95
I873-Fail_Windows_95

Figure D.24: The presentation of the Quality results

The user has separate results on Quality and on Reliability. For this reason there are two different windows for presenting the results. In Figure (D.24) the window for Quality is illustrated. The only difference between these two windows is the combo box of the top right of the window. For Quality this combo box is necessary in order to choose the product that the user wants the results on. On Reliability results this is not necessary because downtime doesn't depend on the type of product.

The window "Simulation Results on Quality" (Fig. D.24) has input the number of items that we want to inspect. At the top right of the screen there is an area "Parameters" (Fig. D.25). In the blank box in this area the user inputs the number of items for inspection. The "Control Buttons" (Fig. D.26) area consists of five buttons. The first controls the Simulation process. With the help of the other three the user can visit the "Statistical Analysis" window, visit the "Report" window (details in section D.25) or can insert the results into the "Scenarios" window (details in section D.26) in order to compare them. The button "Quit" exits the tool.



Number of Items: 100

Figure D.25: The "Parameters" and area
"Simulation and Graphics" area

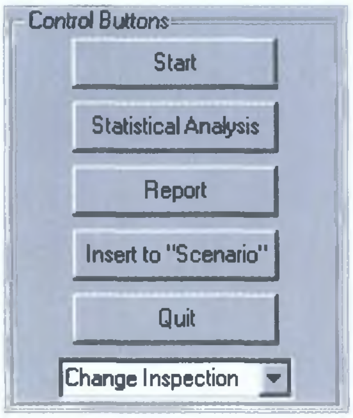


Figure D.26: The "Control Buttons"

There are two graphical representations of the results. The one at the top presents the number of faulty items that have been detected at each inspection. Below that there is a representation of the number of items with a specific failure at a given inspection. The inspection can change from the "Change Inspection" combo box into the "Control Buttons" area. The user can also change the results from the number of faulty items to the cost of having those failures, and vice versa, by clicking on "Cost Results" and "Failure Results" respectively (Fig. D.27).

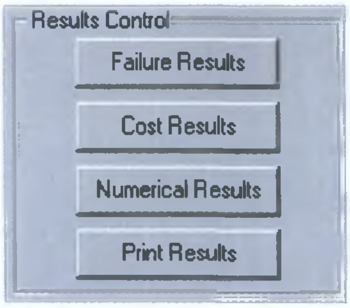


Figure D.27: Presentation of results relating with cost.

By pressing the "Cost Results" button the charts of the cost of having faulty items is shown. This window also allows movement between the windows with the menu lists "Results", "Statistics" and "Map" (Fig. D.28). The menu list "Control" controls the simulation just like the "Control Buttons" area does. The user can simulate any saved production line or **Save** and **Print** the results from the "File" menu list. There is a menu list "Sensitivity" with the option **Sensitivity Analysis**. This option works in the same way as the "Sensitivity Analysis" button in "Parameters" area (Fig. D.25).

Number of Faulty Boards at Each Stage:

Figure D.28: The menu lists

Reliability results are presented in a window similar to this one (Fig. D.24). The user can change from Scheduled to Unscheduled downtime with the help of the "Results Control" area the only difference being that there is no option for cost results (Fig. D.29) in this area, since cost for downtime is very difficult to estimate.

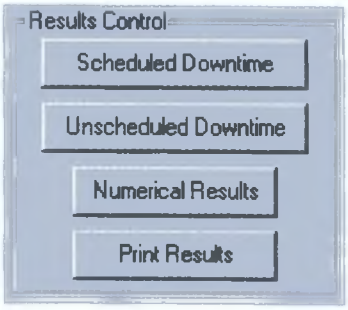
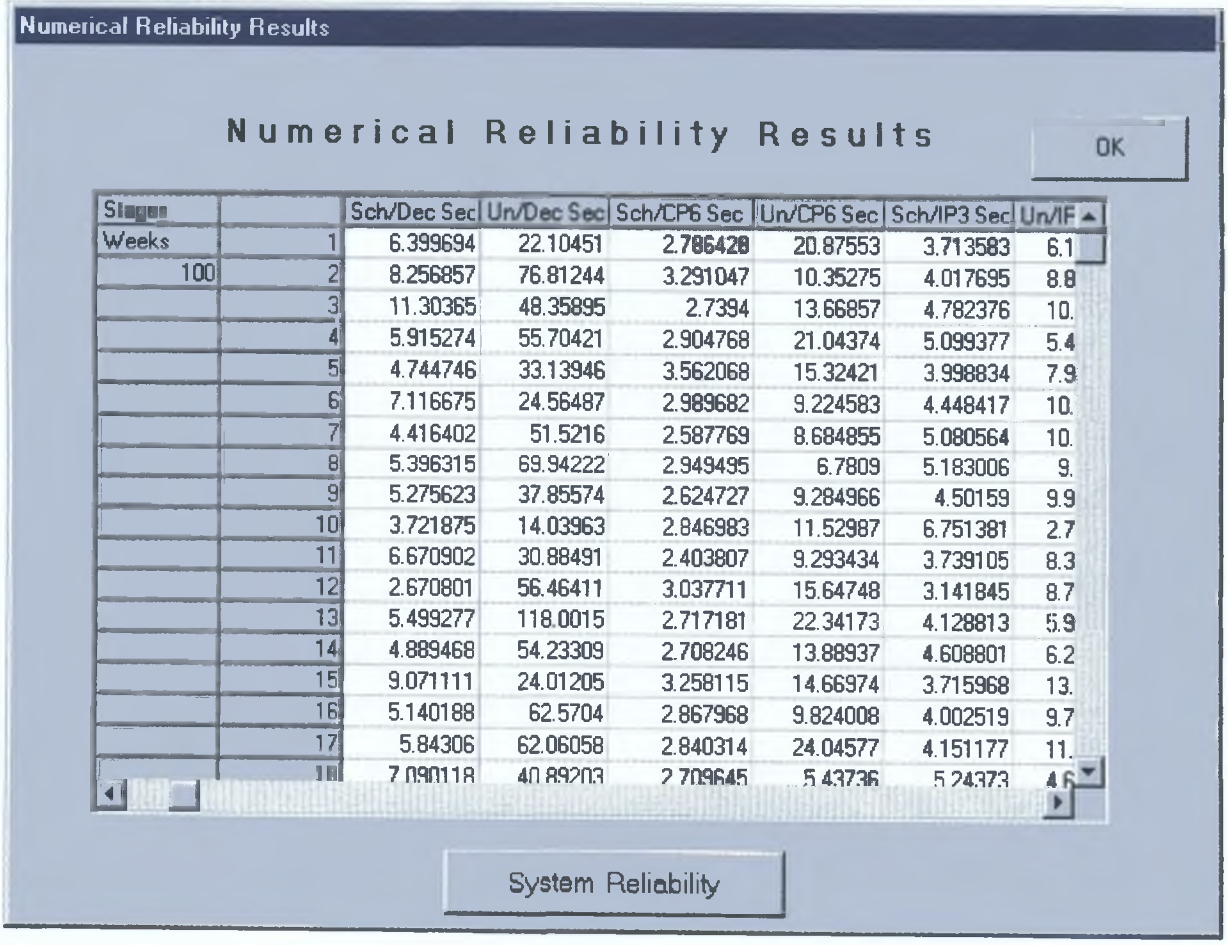


Figure D.29: The Results Control area for the Reliability Results

When the "Numerical Results" button is clicked the Reliability or Quality results are presented in grid form. Figure (D.30) presents the window displayed when "Numerical Results" button is clicked from the "Simulation Results on Reliability" window. The "System Reliability" button helps the user to estimate the system's reliability with the help of simulation. More details on this follow in Section D.4.


Numerical Reliability Results

Numerical Reliability Results

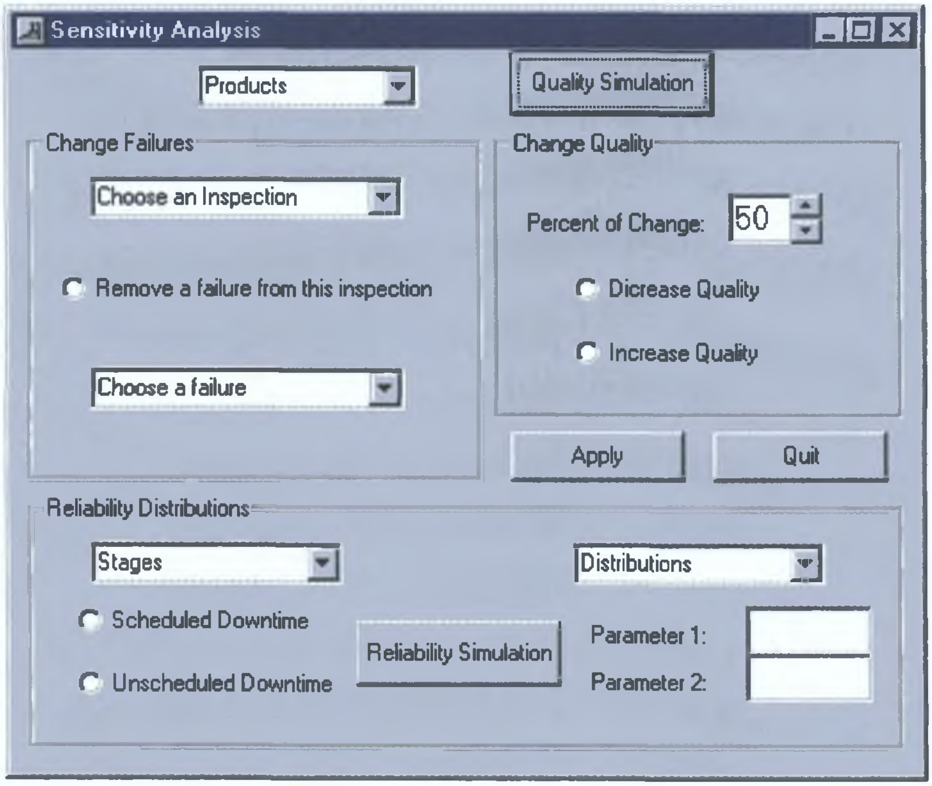
Stages		Sch/Dec Sec	Un/Dec Sec	Sch/CP6 Sec	Un/CP6 Sec	Sch/IP3 Sec	Un/IF
Weeks	1	6.399694	22.10451	2.786428	20.87553	3.713583	6.1
100	2	8.256857	76.81244	3.291047	10.35275	4.017695	8.8
	3	11.30365	48.35895	2.7394	13.66857	4.782376	10.
	4	5.915274	55.70421	2.904768	21.04374	5.099377	5.4
	5	4.744746	33.13946	3.562068	15.32421	3.998834	7.9
	6	7.116675	24.56487	2.989682	9.224583	4.448417	10.
	7	4.416402	51.5216	2.587769	8.684855	5.080564	10.
	8	5.396315	69.94222	2.949495	6.7809	5.183006	9.
	9	5.275623	37.85574	2.624727	9.284966	4.50159	9.9
	10	3.721875	14.03963	2.846983	11.52987	6.751381	2.7
	11	6.670902	30.88491	2.403807	9.293434	3.739105	8.3
	12	2.670801	56.46411	3.037711	15.64748	3.141845	8.7
	13	5.499277	118.0015	2.717181	22.34173	4.128813	5.9
	14	4.889468	54.23309	2.708246	13.88937	4.608801	6.2
	15	9.071111	24.01205	3.258115	14.66974	3.715968	13.
	16	5.140188	62.5704	2.867968	9.824008	4.002519	9.7
	17	5.84306	62.06058	2.840314	24.04577	4.151177	11.
	18	7.090118	40.89203	2.709645	5.43736	5.24373	4.6

Figure D.30: Numerical presentation of reliability results
(both Scheduled and Unscheduled)

D.5.1 Sensitivity Analysis

The option **Sensitivity Analysis** from the "Sensitivity" menu list (or from the corresponding button, Fig. D.25) helps the user to investigate this reaction through the window shown (Fig. D.31). This tool can answer the following types of questions:

- What if no failures are record?
- What is the impact of one or more failures?
- What if a failure has a larger or a smaller probability of occurring?
- What is the cost reduction when the chance of a failure changes?
- What is the impact on real UPH's when downtime rate is changing?



Percent of Change: 50

Figure D.31 The "Sensitivity Analysis" Window

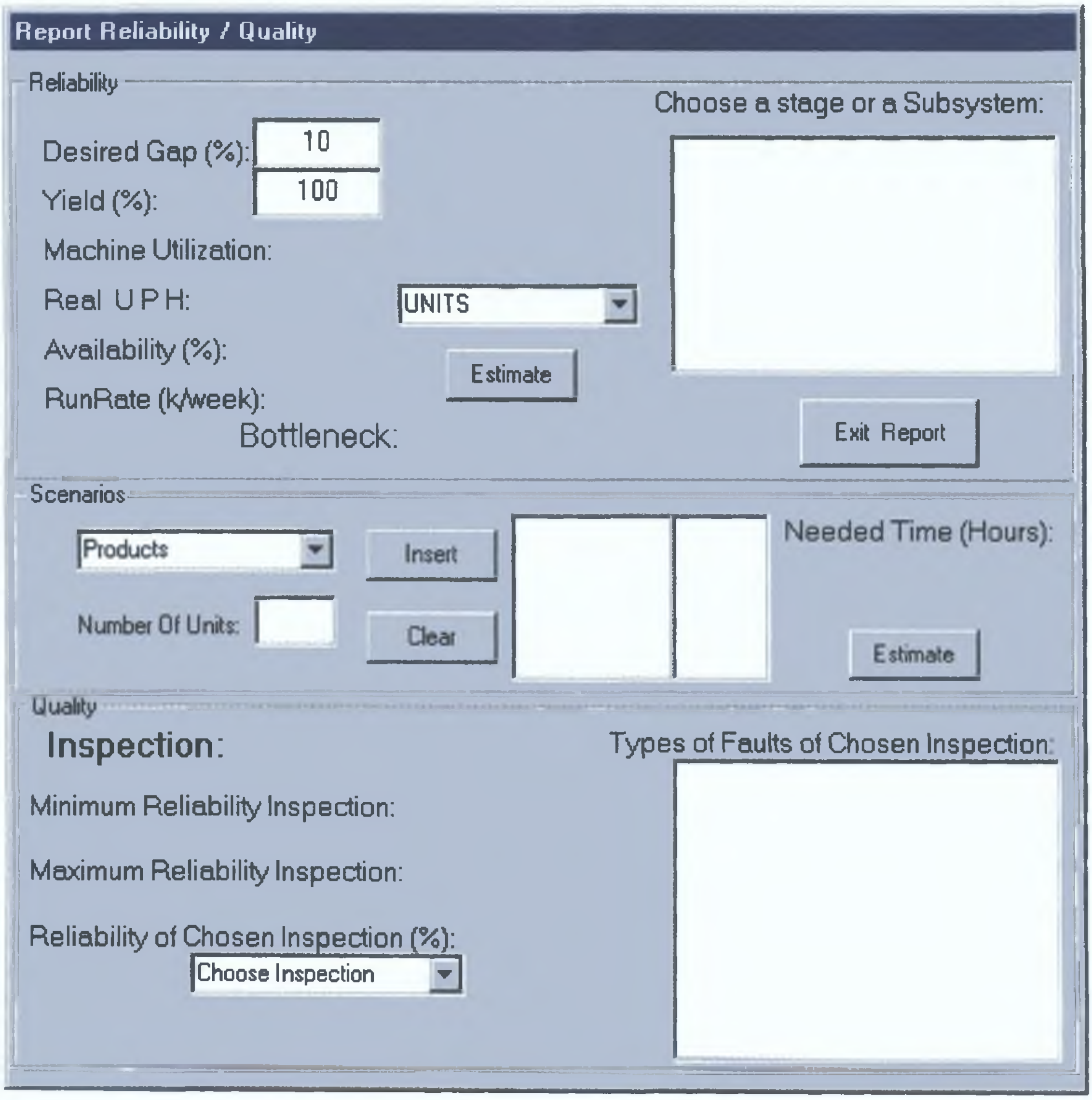
The "Change Failures" area (Fig. D.31) helps the user to answer the first two types of questions. If he/she wants to remove a failure, he/she chooses the option "Remove a failure from this inspection", and he/she also chooses the removing failure and the inspection where this failure occurs from the combo box Clicking on the "Quality Simulation" button the simulation runs again for the chosen product ("Products" combo box)

Other questions can be handled by the "Change Quality" area (Fig D 31) The user chooses the inspection and the failure from "Change Failures" area as before, and declares whether he/she wants to increase or decrease quality and then sets chance of a failure with the help of "Percent of Change" (Fig D 31) When the scenario is ready the user clicks the "Quality Simulation" button If the user wants to make more than one change, he/she must click on the "Apply" button every time a change is ready The "Quality Simulation" button will give the user the results of the new system

In the same way the user can change the downtime rate (Scheduled or/and Unscheduled) from the "Reliability Distributions" area The user can change the downtime rate by changing the distribution or by changing the mean downtime of a stage By these changes, the user can watch the reaction of some parameters such as Real UPH, RunRate, Utilisation, etc

D.5.2 Report Reliability / Quality

From the “Control” menu the user can choose the **Reliability** option. On choosing this, the "Report Reliability / Quality" window is shown (Fig. D.32). This window collects information from both the Reliability and the Quality results. Results for the main Reliability parameters: Machine Utilization, Real UPH, Availability and RunRate are displayed here (terms explained in Chapter 2 (Section 2.2) in detail).



Desired Gap (%): 10
Yield (%): 100

Figure D 32 The "Report Reliability/Quality" window analyses the percentage that a stage in the system is reliable

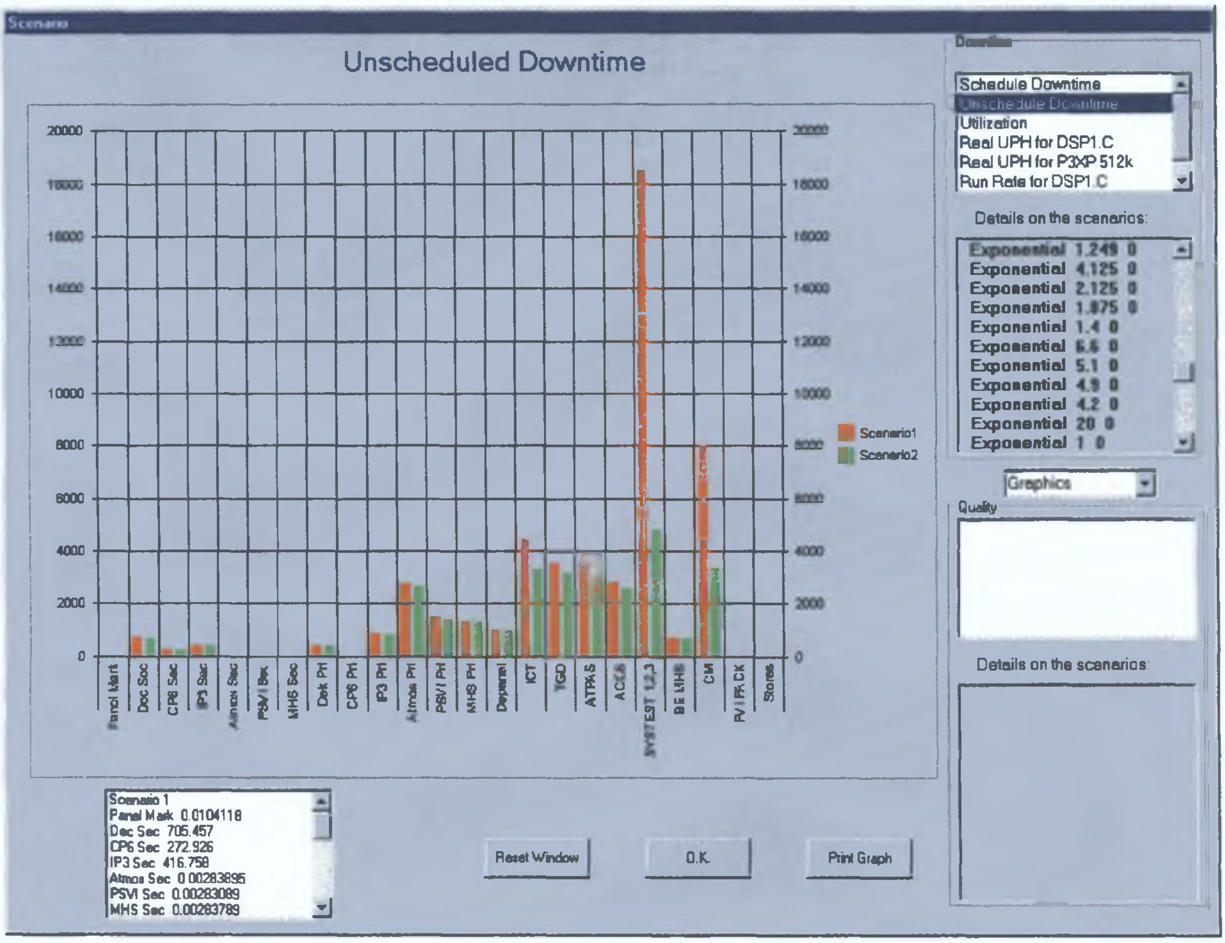
At the top of the window, in the "Reliability" area there is list box from which the user holding down the "Ctrl" key can chose one or more stages Then by choosing a product from the "Units" combo box or by clicking on the button estimate, the user can obtain information a chosen system or subsystem and details on any bottleneck The user can also change "Yield" and "Desired Gap" (Section 2 2) The first depends on the Quality information of the policy that the company follows In Intel they have a desired gap of 10%

If Quality results are estimated (that means that results have been generated by simulation), the user can view the inspection which produces the largest number of faulty items or the inspection with the least faults (area at the bottom of this window, "Quality") By choosing an inspection from the combo box, the user can see the probability of having a failure from this inspection as estimated from the simulation Percentage of failure is used as Yield input at the top of the window

In this window the user can also answer the question "How much time will it take to produce N_1 items of A, N_2 items of B, where A and B are different products After selecting the product A in the area at the middle of this window and inputting the number N1 at the "Number of Units" box, the user clicks the "Insert" button Similarly for B The Estimate" button gives the approximate time required

5 5 3 Scenarios

The user can keep a set of results from different runs of the simulation model (both Reliability and Quality) by clicking the button "Insert to Scenarios" (Fig D 26) Those results can be compared and the user can identify areas that cause problems, stages with low reliability and quality Suggestions for changes can be achieved with the help of this window (Fig D 33) In Figure (D 33), the two scenarios are the same except for the fact that the second has a shorter average downtime - 10 and 5 minutes less at the stages of *"Systest 1,2,3"* and *"CM"* respectively



Schedule Downtime
Unschedule Downtime
Utilization
Real UPH for DSP1.C
Real UPH for P3XP 512k
Run Rate for DSP1.C

Details on the scenarios:

Exponential 1.249 0
Exponential 4.125 0
Exponential 2.125 0
Exponential 1.875 0
Exponential 1.4 0
Exponential 6.6 0
Exponential 5.1 0
Exponential 4.9 0
Exponential 4.2 0
Exponential 20 0
Exponential 1 0

Details on the scenarios:

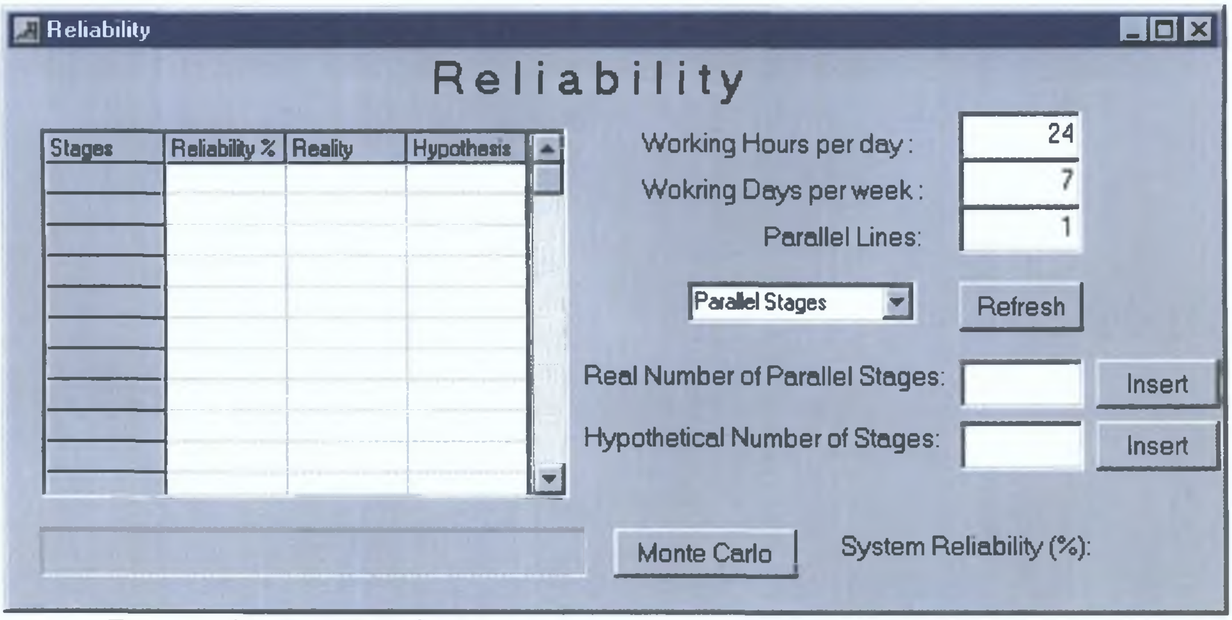
Scenario 1
Panel Mark 0.0104118
Dec Sec 705.457
CP6 Sec 272.926
IP3 Sec 416.758
Atmos Sec 0.00283895
PSVI Sec 0.00283089
MHS Sec 0.00283789

Figure D.33: The "Scenarios" window, for comparing the simulation results

At the right side of this window, there are two areas: "Downtime" and "Quality". From the "Downtime" area, the user can compare Reliability results with comparisons focusing on the Downtime (both Scheduled and Unscheduled), Utilization and Real UPH for each product. In the same area, the user can read information about the scenarios he/she compares and can watch each scenario presented as a chart at the middle of the window. The charts can be 2-Dimensional or 3-Dimensional, bars or lines, depending on what the user choose from the combo box "Graphics". Holding down the "Ctrl" button and moving the mouse at the same time can rotate the 3-D graphics. At the bottom of this window there are three buttons from where the user can "Reset Window" (deletes all the scenarios), can hide the window, "OK" button, and "Print Graph". From the "Quality" area the options are almost the same; the only difference the being comparison of the Yield between the scenarios for each product.

5.5.4 Reliability

In Figure (D.30) the window displays numerical results for Reliability. At the bottom of this window there is a button called "System Reliability" which helps the user to test the reliability of the whole system. The user can estimate the reliability of the real system or of a hypothesised system. Adding a stage in a system can increase reliability, but sometimes adding redundancy is not always the best way to achieve this. The cost might be too large and the results might not be worth such a cost. The "Reliability" window is shown (Fig. D.34).



Working Hours per day : 24

Wokring Days per week : 7

Parallel Lines: 1

Parallel Stages

Figure D.34: The "Reliability" window and the reliability estimation with the help of Monte Carlo Simulation.

In the grid box in this window, the user can see the number of parallel stages in the line. If the number is different to the one entered in the "Production Line" window he/she can change it with the help of the boxes at the right of the window and by choosing the stage from the combo box and then clicking the "Insert" button. The "Reality" column must always show the real number of parallel stages. In the "Hypothesis" column the user must insert the number of stages that he/she wants to investigate. By clicking the "Monte

Carlo" button, the reliability will be presented at the right bottom corner of this window The number of the production lines can be changed as well as the number of the working days that the factory is working and the shifts The estimated reliability is based on the results generated by the simulation model in the "Reliability Results" window

D 5 5 In summary

In this chapter we gave information on how the user can attain Reliability and Quality results The results are being generated from the simulation models, which are based on the historical data given by the "Statisticians" We also presented the option of investigating the reaction of the production line to changes in the parameters defining it The user chooses the scenarios for the sensitivity analysis from the "Sensitivity Analysis" window

D 6 Error Codes - Possible Causes and Solutions

Error codes for tool functions as follows

"ERROR 1 You must choose an object"

This error occurs only when the user clicks in the pop up menu (fig 3 1), "Production Line" window, without choosing any object Insertion of an object requires first it's selection from the toolbar (fig 3 2), and then it's placing in the main area

"ERROR 2 You cannot start with a failure"

This error occurs only in the "Production Line" window A failure follows on from an inspection After placing an "Inspection" a failure must be indicated If the user insert a failure as a starting object, this error will occur

"ERROR 3 Failures expected for the previous INSPECTION"

This error occurs only in the "Production Line" window After inserting an "Inspection" object, the tool is waiting for the failures that this inspection can detect If no failures are placing, this error will be flagged

"ERROR 4 A Stage does not have failures"

This error occurs only in the "Production Line" window An inspection can detect failures and not a stage Trying to place a failure after a stage will show error number 4, because is like saying that a stage can inspect items

"ERROR 5 System Without Inspections"

This error occurs only in the "Simulation results on Quality" Window It is not necessary to use this software tool for both Quality and Reliability results Hense, the user can have a production line without inspections, and this model can be used for Reliability only results If the user tried to obtain Quality results from a model without inspections, this error will occur

"ERROR 6 Select an Object First"

This error can happen in both "Specify Data" and "Specify Reliability Data" windows When the user is about to insert data (Reliability and/or Quality) an object (stage and/or inspection respectively) must be chosen from the corresponding combo boxes If the "Insert Data" (Fig 4 3 and Fig 4 9) button is clicked without choosing an object this error occurs

"ERROR 7 Simulation Error - Invalid distribution"

This error occurs in "Simulation Results on Reliability" window During the statistical analysis of the reliability data, the user might insert distribution or parameters for distributions that are not valid At this stage a simulation error occurs

"ERROR 8 Select a product first"

Error 8 can happen in the following three windows "Specify Data", "Simulation Results on Quality" and "Sensitivity Analysis" windows Every time a user inserts quality data or wants some Quality results from the simulation model, a product must be specified

"ERROR 9 Details are Expected"

Both simulation models are using data from the "Details" window If the user forgets to insert data in this window (Fig 3 12), this error is displayed

"ERROR 10 You should first have simulation results"

If the user is trying to change from Cost results to Failure results in "Simulation Results on Quality" without having any simulation results, this error occurs Further, when the user wants to know the Quality percentage of an inspection, from the "Report Reliability/Quality" window without having data to work form, this failure will also occur

"ERROR 11 'Comments' FILE NOT FOUND Please verify the correct name is given"

This error occurs when the user is trying to open an invalid file name Either the file name is wrong or the file does not exist

References

[AP94] Ansell J I and Phillips M J, "Practical Methods for Reliability Data Analysis", Oxford 1994

[B96] Bruning K , "Determine the discrete-Time Reliability of a Repairable 2-out-of-(N+1) F System", IEEE Trans Reliability vol 45, No 1 1996 March

[BP96] Richard E Barlow and Frank Proschan, "Mathematical Theory of Reliability", SIAM, 1996

[CS82] D R Cox and E J Snell, "Applied Statistics, Principles and Examples", CHAPMAN AND HALL, 1982

[D89] Dugan "Fault trees and imperfect coverage", IEEE Trans Reliability, vol 38, 1989 Jun, pp 177- 185

[DDP95] Stacy A Doyle, Joanne B Dugan and F Ann Patterson-Hine, "A Combinatorial Approach to Modelling Imperfect Coverage" IEEE Trans Reliability, vol 44, 1995 March pp 87-94

[DR89] M T Drum, et al "Analysis of core damage frequency Grand Gulf, Unit 1 interval events", NUREG?CR-4550, 1989, US Nuclear Regulatory Comm

[EW80] Easton M C and Wong C K , "Sequential destruction method for Monte Carlo evaluation of system Reliability", IEEE Trans Reliability, Vol R-29, 1980, April, pp 27-32

[E85] Enrick N "Quality, Reliability, and Process Improvement", New York, 1985

[E97] James R Evans, "Production/Operations Management - Quality, Performance and Value", WEST 1997

[F86] George S Fishman, "A Comparison of Four Monte Carlo Methods for Estimating the Probability of s-t Connectedness", IEEE Trans Reliability, vol R-35, No 2, 1986 June, pp 145-155

[GL80] Grant E , Leavenworth R , "Statistical Quality Control", McGraw-Hill, 1980

[GD94] Goetsch L D and Davis S , "Introduction to Total Qaulity", Prentice Hall, 1994

[HBST95] A Sharif Heger, Jayaram K Bhat, Desmond, W Stack and Dale V Talbott, "Calculating Exact Top-Event Probabilities Using ΣΠ-Patrec", IEEE Trans Reliability, vol 44, No 4, 1995 December, pp 640-644

[J93] Johnson L Perry, "ISO 9000 Meeting the new International Standards", McGraw-Hill, 1993

[KL83] R M Karp, M G Luby, "A new Monte Carlo method for estimating the failure probability of the n-component system", Computer Science Division, University of California, Berkeley, USA, 1983

[KT87] Kacker R and Tsui K , "Interaction graphs graphical aids for planning experiments", Quality and Reliability Engineering International

[KP80] John D Kalbleisch and Ross L Prentice, "The Statistical Analysis of Failure Time Data", JOHN WILEY & SONS, 1980

[K80] Kumamoto, "Dagger Sampling Monte Carlo for system unavailability evaluation", IEEE Trans Reliability, vol-R-26,1977 Dec,p 311-315

[KTI87] Kumamoto, Tanaka, Inoue, "A New Monte Carlo Method for Evaluating System-Failure Probability", IEEE Trans Reliability, vol R-36,No1 1987 April,p 63-69

[LK94] Fen-Hui Lin and Way Kuo, "Simulating Transient-State System Effectiveness for Human-Machine Systems", IEEE Trans Reliability, vol 43, No 4,1994 December, pp 569-574

[LUG96] Dennis K J Lin, John S Usher, Frank M Guess, "Bayes Estimation of Component Reliability-Prediction in the Presence of Masked Data", IEEE Trans Reliability, vol 45, No 2, 1996 June, pp 233-237

[MP96] Malinowski J and Preuss W , "Lower & Upper Bounds for the Reliability of Connected-(r,s)-out-of-(m,n) F Lattice Systems", IEEE Trans Reliability, vol 45, No1, 1996 March

[MHH85] Albert H Moore, John R Hobbs, Mohamed S B Hasaballa, "A Monte Carlo Metho for Determining Confidence Bounds on Reliability and Availability of Maintained Systems", IEEE Trans Reliability, vol R-34, No 5, 1995 December, pp 497-498

[P88] C J Patenaude, "SIGPI A users manual for fast computation of the probabilistic performance of complex systems", NUREG/-4800, 1988, US Nuclear Regulatory Comm

[PP91] L B Page, J E Perry, “Direct evaluation algorithms for fault tree probabilities”, Computers in Chemicals Engineering, vol 15, 1991, pp 157-169

[RFC96] Benjamin Reiser, Betty J Flehinger, Anderw R Conn, “Estimating Component-Defect Probability from Masked System Success/Failure Data”, IEEE Trans Reliability, vol 45, No 2, 1996 June, pp 238-243

[RM83] Roy E Rice, Albert H Moore, “A Monte Carlo Technique for estimating Lower Confidence Limits on System Reliability Using Pass-Fail Data”, IEEE Trans Reliability, vol R-32, No 4, October 1983, pp 366-369

[SK88], Shoemaker A and Kacker R , “A Methodology for Planning Experiments in Robust Product and Process Design”, Quality and Reliability Engineering International, vol 4, p 95-103, 1988

[SWLH86] Ching-Tzong Su, Tien-Shou Wu, Ting-Hsiang Lee and Ching-Lien Huang, “Capacity Planning with Flow and Reliability Evaluation using Monte Carlo Simulation”, IEEE Trans Reliability, vol R-35, No 5, 1986 December, pp 518-522

[T86] Takugi G , “System of experimental Design” Vols 1 and 2, American Supplier Institute, IncDearborn USA 1986

[TC95] Tang L and Chang S , “Reliability Prediction Using Nondestructive Accelerated-Degradation Data Case Study on Power Supplies”, IEEE Trans Reliability, vol 40, No 4, pp 562-566, 1995 December

[T88] Thompson W A , “Point Process Models with Applications to Safety and Reliability”, Chapman and Hall, 1988

[U96] John S Usher, “Weibull Component Reliability-Prediction in the Presence of Masked Data”, IEEE Trans Reliability, vol 45, No 2, 1996 June, pp 229-232