MONITORING AND CONTROL OF TAPE PRODUCTION PROCESS

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ABSTRACT

This thesis describes a project to collect and process manufacturing data produced by automated testing equipment used in the production of open reel magnetic tape for the computer industry.

The thesis discusses the most appropriate method, in the context of the project, for collecting and processing relatively large volumes of data. The project identified process variables which could most readily be used to represent the overall performance of the combined tape slitting and testing equipment.

An operator-machine interface was designed and implemented. This attempted to improve the representation of the process to the machine operators. This interface implemented principles of human computer interaction, particularly for computer naive users. The interface was hierarchical in structure using a rigidly structured method of interaction based on menu selection.

Elements from statistical process control theory as defined by W. Edwards Deming were used in the design of the interface. These were used to assist in the identification of when and where the process was moving away from expected performance levels.

The thesis also discusses areas where the work performed for this project could be developed further, and suggests that the data that this project has made available could be subjected to statistical analysis to adjust auditing and testing criteria to enhance yields and/or target specific markets.

GLOSSARY.

ANSI	American National Standards Institute
Atlas	The Atlas slitter-tester.
BOT	Beginning of Tape Reflective Sensor Marker.
BPI	Bits Per Inch recording density on tape.
BPS	Bits Per Second - the number of binary digits transmitted or received per second
CPU	Central Processor Unit
DEC	Digital Equipment Corporation
DOS	Disk Operating System
EOT	End of Tape Reflective Sensor Marker
EIA	Electronics Industries Association
EPROM	Erasable Programmable Read Only Memory
GCR	Group Coded Recording format
hyp	Hypercritical error at the 1600 Bits Per Inch recording density
IBM	International Business Machines
jumbo	the in house term for reel (see reel)
PC	Personal Computer
PDP	Personal Data Processor
PE	Phase Encoded tape recording format
RAM	Random Access Memory microprocessor chip
reel	a 26 inch wide polyester reel coated with magnetic oxide
SPC	Statistical Process Control
QA	Quality Assurance
web	used synonymously with reel (see reel)
w/s	Write/Skip error at the 1600 Bits Per Inch recording density

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CHAPTER 1. INTRODUCTION.

This thesis describes a project to collect manufacturing data produced by automated test equipment in the production of open reel magnetic tape by Xidex (U.K.) Limited, in Brynmawr.

The work was completed under the Polytechnic of Wales and Xidex (U.K.) Limited Teaching Company Programme, which was supported by the Science and Engineering Research Council (S.E.R.C.) and the Department of Trade and Industry (D.T.I.).

The project was one of six independent projects being performed at Xidex under this Teaching Company Scheme.

The thesis is organised into chapters which discuss the main subject areas of the project.

This first chapter introduces the background to and the aims of the project.

Chapters two to six inclusive discuss the stages of the study of the manufacturing process. This was a feasibility study performed to identify methods of achieving the aims of the project and to define a specification for the implementation of the project.

Chapters seven to eleven inclusive discuss the implementation of the project.

Chapter twelve discusses statistical monitoring of the production process.

Chapters thirteen and fourteen evaluate the achievements of the project and present a conclusion.

1.1. Background Information on Xidex (U.K.) Limited. The Industrial Partner.

Xidex (U.K.) Limited, formerly Control Data, are a multinational corporation, producing microfilm, microfiche products and magnetic media products, 1/2 inch open reel tapes, 5 1/4 inch flexible disks, rigid disks and 1/4 inch cartridge tape, these last four items for the computer industry.

At the Brynmawr site the emphasis during the period of the project was changing from manufacturing mainly rigid disk and open reel tape to manufacturing cartridge tape and open reel tape. This reflected the changes in technology of storage media and hardware technology which were occurring at the time.
Xidex, initially a microfiche film manufacturer and supplier, had taken over the factory at Brynmawr from Control Data, a large scale manufacturer of computer peripherals, disks, etc in 1986. Xidex were continuing to manufacture the same products, but were withdrawing from the manufacture of floppy and rigid disks at Brynmawr. Xidex is a multinational corporation with sites in North America, Britain and Continental Europe. Control Data were large scale manufacturers of 1/2 inch open reel computer tape, and Xidex continued this business.
Open reel tape was generally manufactured, wound onto reels and then tested. The stages involved are slitting the tape from a 26 inch wide web into 1/2 inch sections, winding the tape on to in-house open reels, testing the tape for recording characteristics, and rewinding the tape onto open reels that could be despatched to the customer.
Control Data had, in conjunction with a small engineering and electronics firm, Double R Controls of Rochdale, set out to manufacture a machine which could combine these three elements of manufacture into one process, thus reducing time wasted through rewinding, time wasted through handling, and also accidental handling damage. Following slitting and testing the tape would be wound directly onto open reels that could be despatched immediately to the customer. A

prototype machine had been manufactured and installed. The machine was a considerable success, testing every tape produced, 50 at each cycle or run of the machine, and reducing manual handling of tapes. A further two machines were purchased, each one offering slight improvements in the efficiency of the test and the volume and presentation of information generated by each test.
The information was captured and displayed on a computer, one of which was attached to each slitter-tester. Reports were generated from data produced by the slitter-testers by manually recording important items of data and re-entering the data onto another computer, away from the shop floor. This data was then processed into reports. The reason for the manual transcription was that the computers attached to the slitter-tester could not produce management style summary reports.

1.2. Project Aims.

The project aims and objectives were initially to provide a more complete, accurate and timely method of analysing and reporting on the data that was produced at the slitting and testing stage of the process of 1/2 inch tape manufacture. The analysis of the data was intended to allow the identification of the process variables that were actually affecting end product quality.

The reporting system had to be capable of providing regular, comprehensive reports for production and maintenance purposes and also be capable of addressing ad hoc queries. The system also had to be flexible enough to allow future data or information requirements to be addressed without major modifications.

It was realised that, once implemented, the system would be providing data that could be analysed in an attempt to reduce production waste by identifying areas of faulty production. There was also an implication for the marketing function, in that it would be possible to estimate the commercial effects of adjusting the test specifications in an attempt to increase the yield of tapes, that is the number of tapes which were of commercial value without reducing quality.

The project was defined in response to a recognition that the system that was currently in situ was using a limited subset of the information that was potentially available and that that information was being produced after a delay of up to 24 hours. A full explanation of the method for collecting and reporting of data is detailed in chapter 2.

CHAPTER 2. PROCESS DESCRIPTION.

The Open Reel Tape Manufacturing Process.

The project was assigned to one area of the manufacture of 1/2 inch open reel computer tape. An understanding of the complete process will assist in defining the scope of the project. Throughout this thesis the terms computer tape or tape will be used when referring to 1/2 inch open reel computer tape.
This chapter describes the process of manufacturing computer tape as it was performed at Xidex. There are nine distinct stages in the manufacture of computer tape. These are as outlined below :

i) **Formulation** : - the dispersion of a magnetisable gamma ferric oxide in a solvent to form a suspension;

ii) **Coating** : - the deposition of the oxide in suspension onto a 26 inch wide clear polyester backing or substrate, which is wound onto a core of approximately 10 inches after coating to form a reel or web;

iii) **Curing** : - the air or oven hardening of the oxide coated reel;

iv) **Slitting** : - the slitting of the 26 inch wide reel into 1/2 inch wide tapes;

v) **Testing** : - otherwise known as certification, which is the electronic testing of each tape, performed by writing a signal onto the tape and reading it back, the level of the recovered signal indicating whether an error is present or not;

vi) **Visual inspection** : - to identify cosmetic faults e.g. a tape that has wound onto the customer reel unevenly;

vii) **Retesting** : - the retesting or re-certification of any tapes which have failed the test criteria specification;

viii) **Quality assurance testing** : - the retesting of randomly selected tapes on separate reel to reel test equipment to verify the correct functioning of the slitter-tester test equipment;

ix) **Finishing** : - the labelling and packing of certified tapes in readiness for despatch.

The finished tapes must meet the standard as prescribed in the ANSI standard number X3.40-1983 (ANSI (1)). This specification defines the electrical and physical characteristics that are required to be able to classify a computer tape. In the context of this project the most important criteria for tape production are those governing the ability to write a signal onto the tape and to read it back again. The presence or absence of a signal of sufficient level is used to indicate a digital 1 or a digital 0. An explanation of the principles of magnetic recording and the criteria for error detection is given in section 2.3.

2.1. Magnetic Tape Products Manufactured by Xidex.

Magnetic tape is divided into a number of different tape lengths, or products. The various products are differentiated by their length and the quality of the magnetic oxide (which is related to the formulation used).

The different lengths produced are :

i) 3600 feet overall length;

ii) 2400 feet between sensor markers;

iii) 2400 feet overall length;

iv) 1200 feet overall length;

v) 600 feet overall length.

These are nominal lengths and do not accurately reflect the total length of the tape. The most commonly produced tape is 2400 feet between markers, this being considered the standard length product. The only significant difference in the manufacture of the different lengths is that to enable the fully wound tape to fit onto the plastic customer reel the 3600 foot tape had a thinner polyester substrate than the other products.

A 2400 foot tape would typically consist of the following sections:

i) 0 to 13 feet - lead tape to enable loading onto tape machines;

ii) 13 feet - BOT sensor marker;

iii) 13 to 2382 feet - the area for recording data;

iv) 2382 feet - EOT sensor marker;

v) 2382 to 2398 feet - tape which stayed on the reel.

A fully coated unslit polyester reel (jumbo) would produce the following numbers of tapes for each product:

i) 3600 foot tape - 250 tapes (5 * 50 tape lengths);

ii) 2400 foot tape - 300 tapes (6 * 50 tape lengths);

iii) 1200 foot tape - 550 tapes (11 * 50 tape lengths);

iv) 600 foot tape - 1100 tapes (22 * 50 tape lengths).

It should be noted that 3600 foot tapes were produced from longer and thinner reels of polyester than the other products. The polyester for this product has to be thinner to allow the wound tape to fit on the customer reel. At the start of the project products were also differentiated by the formulation of the oxide coating used, either standard for Phase Encoding format or GCR for Group Coded Recording format. The formulation was later standardised to the more expensive GCR format for stability and reliability as this gave a better recording and read back performance. Products are also differentiated by customer. Products for certain customers are coated using the same formulation but tested to more stringent criteria.

2.2. The Principle of Magnetic Data recording.

A basic explanation of the process of recording data on to magnetisable media is useful in describing the method that is used by Xidex when testing magnetic tape. Applying a magnetic flux to the tape by passing a current through the write head winding causes the magnetisable particles contained within the tape to be polarised. This polarisation remains permanent until disturbed by erasure

(Degaussing) or rewriting. This polarisation may be detected by a read head working in the reverse manner to that of the write head. The polarisation of the particles which is detected by the read head causes that section of tape to be regarded as a binary 1 or a binary 0. The pattern of binary ones and zeros on a tape constitute the information held on the tape. Figure 2.1. illustrates how this polarisation is achieved using a write head.

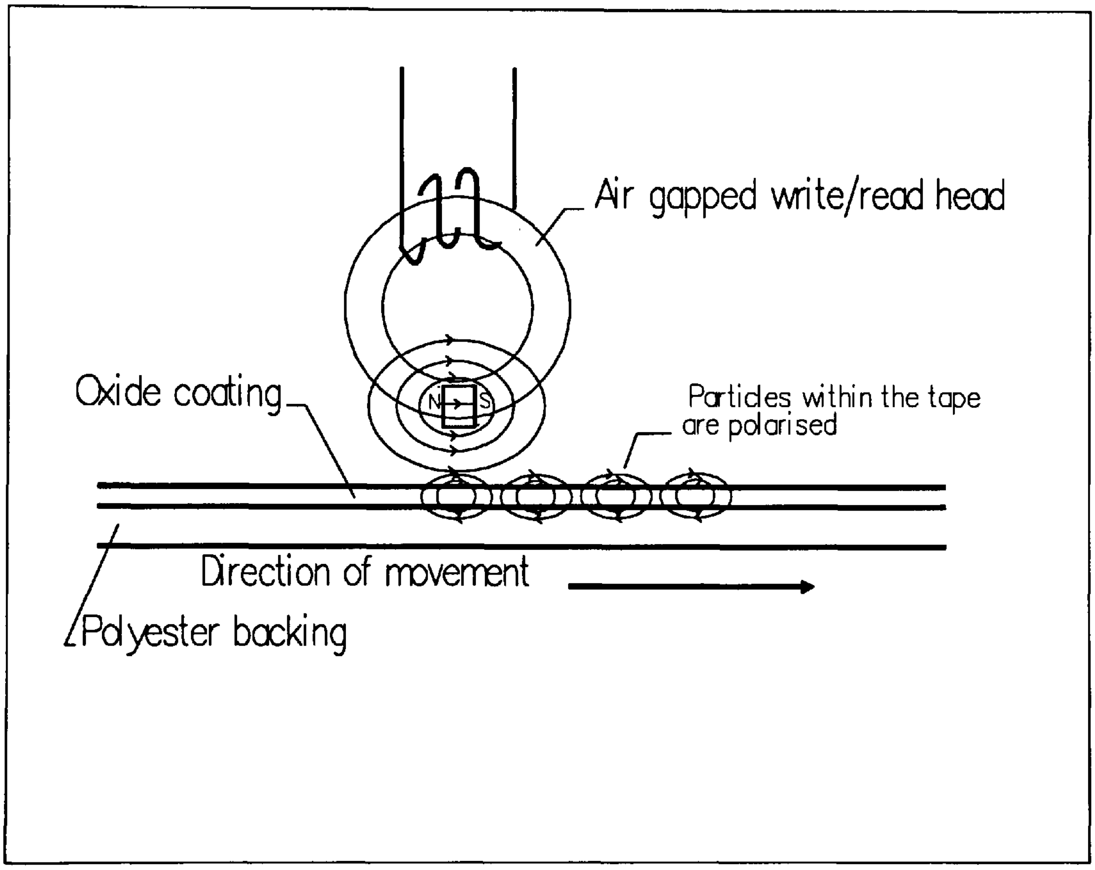


Figure 2.1. The Basic Principle of Magnetic Data Recording.

The signal to be stored is applied as a time varying current to the coil of a gapped write head. The time varying magnetic field polarises magnetic particles on the tape as they move past the head. Each particle of gamma ferric oxide forms an elemental magnet. When the tape is passed over the write head the vectors of the magnetic domains in the coating are re-oriented to align with the magnetic flux induced by the current in the head.

On replay the time-varying flux (caused by the spatially varying magnetisation on the moving tape) induces a voltage in the output coil of the read head.

The material used for magnetic storage must have a high remanent magnetisation and coercivity. The magnetic particles must be small enough and independent enough to allow short wave length recording and give a high Signal to Noise Ratio. This allows the adjoining areas of tape to contain clearly defined fields which can be read as a string of binary digits when passing under or over the read head. Erasure of the tape or Degaussing is achieved by passing the tape over an erase head which applies a high frequency alternating current. As the tape is moved away from the erase head, a slowly diminishing cyclic field is presented to the tape leaving the magnetic vectors in a completely random state. The tape is then demagnetised.

2.3. The Manufacturing Process.

2.3.1. The Formulation Process.

The acicular particles of the Gamma Ferric Oxide are supplied as a powder. These are milled to break down agglomerations of particles in the powder and mixed with plastic binders (to actually bind the oxide particles together) before being applied to the substrate polyester. The formulation had been varied to match product requirements, either phase encoded or group coded recording format but during the period of the project all formulations were altered to meet the stringent requirements of the Group Coded Recording format (G.C.R.). This was done to reduce stoppage time caused by the need to clean equipment between runs and also milling could be reduced for G.C.R. format. Appendix 1 details the different recording formats, Phase Encoding and Group Coded Recording.

2.3.2. The Coating Process.

A catalyst is added to the gamma ferric powder and plastic binders mixture to aid hardening. This mixture is then applied to one side of the polyester substrate by means of carefully controlled rolling and metering operation called coating. The polyester substrate or web is 14000 feet long and 26 inches wide. This metered thickness of the oxide coating is then passed through an oven and then callendered between metal and paper-covered rollers, to compress the surface and give a high gloss finish, reducing abrasiveness of the surface of the tape. A diagram of the coating process is shown in Figure 2.2. The web at this point is then reeled up onto a core and either air or oven cured depending upon the particular product.

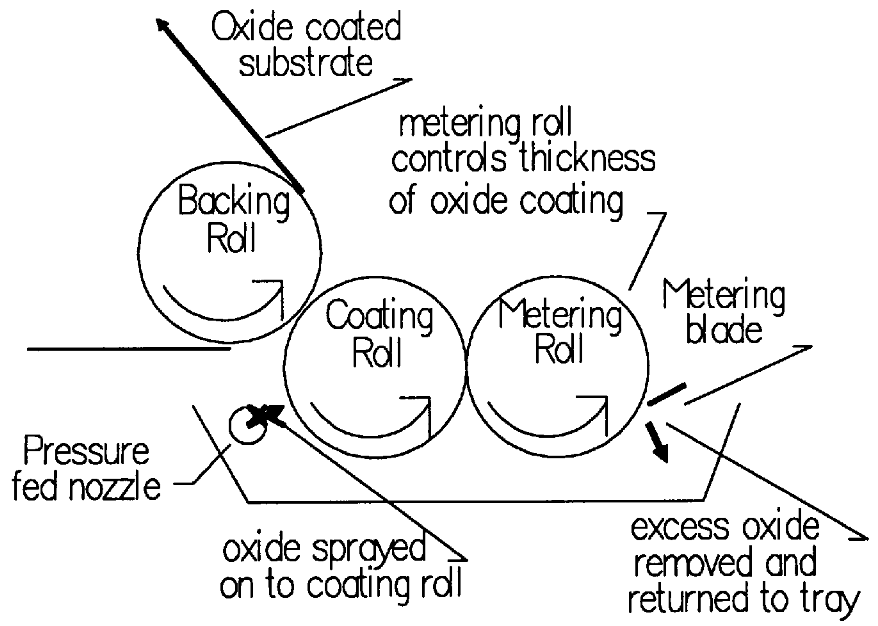


Figure 2.2. The Coating Process.

At regular intervals a coating audit would be performed where one set of tapes would be produced from a freshly-coated web, to enable an audit grade to be assigned to that web and those following it, and retrospectively those preceding it.

2.3.2.1. The Audit Grading Procedure.

At Xidex the coating audit is performed at least every sixth web produced from each coating line. There are three audit grades into which a web can be categorised, these being green, blue and red.

The coating audit is performed by slitting and testing one cut from a freshly coated web i.e. one that is not cured. The total number of 6250 BPI single track errors and 1600 BPI hypercritical errors detected during testing are used to define which category the web is graded into, using pre-determined criteria. Section 2.4. details the testing method and criteria. The lowest number of errors produces a green audit grading, the highest number of errors a red audit grading, with blue being in between.

The application of the audit grade system affects the criteria used for the electronic testing of the tape. The lower the audit grade, the more stringent the testing criteria. This system of grading acts as a quality control measure. The application of more rigorous criteria to those tapes which are produced from a web which has been shown to have more defects from the coating process ensures that the tapes are correctly graded.

The method of grading webs is illustrated in the example below.

If a coating line produces twenty-five fully coated webs, and every sixth web is tested, starting at number one, then webs one, seven, thirteen, nineteen and twenty-five will be tested. If webs one and seven are graded green , then webs two to six inclusive will be graded green. If web thirteen is graded green then webs eight to twelve inclusive will be graded green.

If web nineteen is graded red then all webs produced since the last audit will be graded red retrospectively, as it is not possible to ascertain exactly where the audit grade should change from green to blue to red. Webs fourteen to eighteen will be graded red. All subsequent webs will be graded red until the next audit graded web is not red. If web twenty-five is green then webs twenty to twenty-four inclusive are graded red. This method ensures that tapes are tested to the most rigorous specification that is appropriate.

2.3.3. The Curing Process.

All coated webs are air or oven dried or cured to stabilise the oxide coated mixture. Curing is performed and reels stored using an automated storage racking system. This approach to warehousing employed a first-in-first-out principle, which did not allow flexibility in the order of selecting coated reels for slitting and testing. This effect reduced the ability to perform meaningful slitting and testing tests on consecutively coated reels, which would have enhanced the detection of coating trends at slitting time. Chapter 12 discusses the importance of detection of coating trends.

2.3.4. The Slitting Process.

The slitting process produced 52 half inch tapes from the 26 inch wide web by using two driven sets of circular rotating knives which slit the web longitudinally.

The coated web is loaded onto a driven "unwind unit" and the web threaded through the knife-box and from there onto the test and rewind stations. A diagram of the set up of the slitter is shown in Figure 2.3.

In Xidex the slitting and testing process are combined by the siting of banks of test stations at the discharge of the slitting process. Each bank consisted of nine units, each with three rewind and test stations mounted vertically above one another. This was a new concept at the time of design, tapes previously being slit and the loaded manually onto reel to reel test units. The slitter is manufactured by Atlas Converting Equipment Limited and the whole machine became known as the Atlas slitter-tester, usually referred to as "the Atlas", but referred to in this thesis as the slitter-tester(s) or "Atlas". The complete machine is as shown in the plan diagram shown in Figure 2.3.

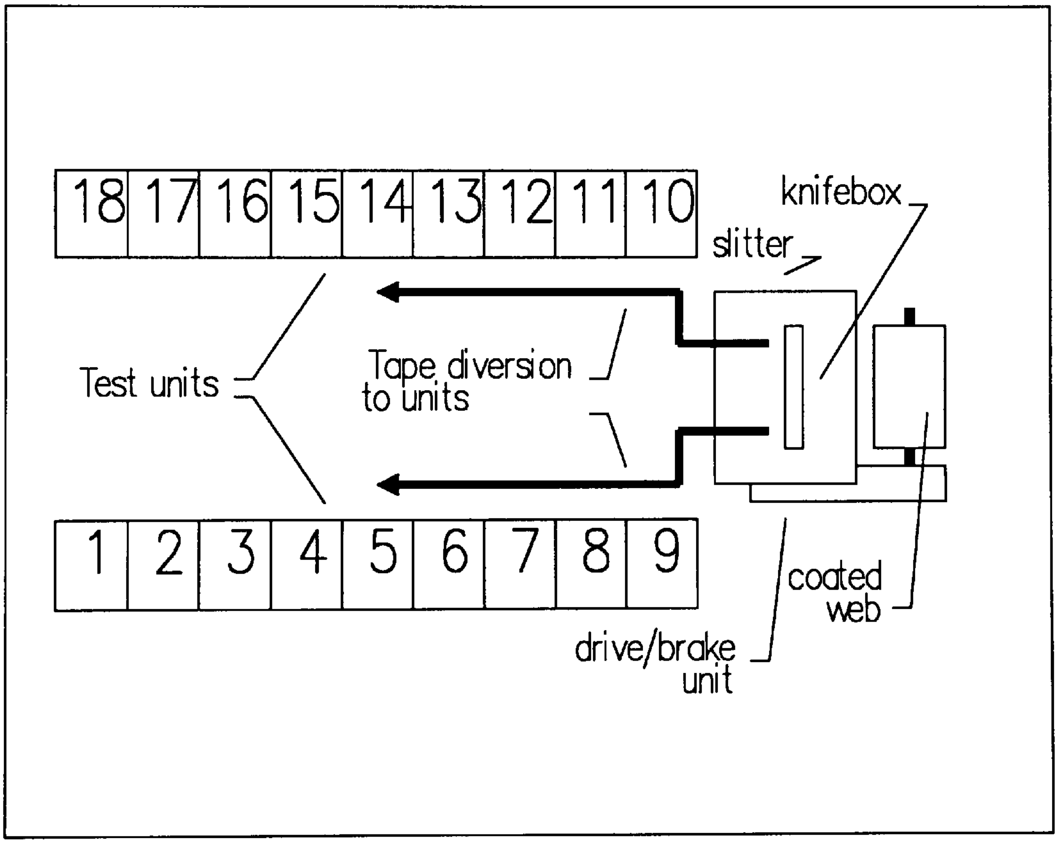


Figure 2.3. Plan of the slitter and tester set-up.

Each bank of units has a maximum capacity of twenty-seven stations. Tapes are diverted equally from the discharge of the slitter, twenty-five to each bank of units.

The slitter itself consists of six main elements.

i) Unwind mechanism.

The core of the coated web is loaded onto two hubs, one of which is driven. The speed of rotation varied to maintain a constant feed rate of one thousand feet per minute of tape during the evaluation stage. The hub is able to accelerate rapidly and had a braking mechanism to enable accurate speed control and rapid slow down after the completion of the evaluation or test cycle.

ii) The Knife-Box.

The web is slit into half inch sections by the knife-box which consisted of fifty pairs of blades. The top and bottom sets of blades rotate in opposite directions so that at the point of slitting the tape is slit by blades rotating in the same direction as the web is passing through the knife-box.

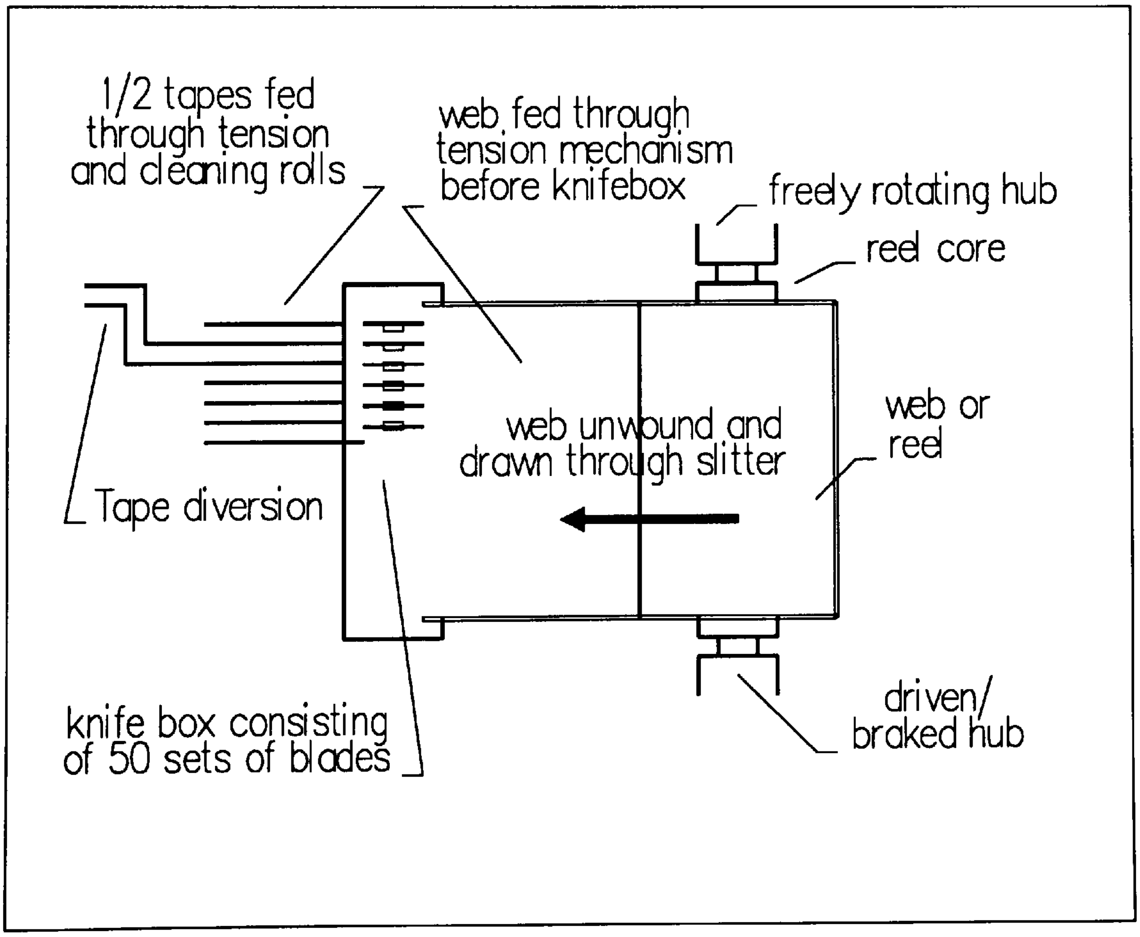


Figure 2.4. The Slitter and Knife-Box Set Up.

The two tapes at the extreme edges of the web are discarded as the consistency of coating thickness is not controlled accurately at the edges of the web. The half inch waste at either edge of the web also allows for a slight weaving of the web from side to side. Figure 2.5 shows a section of the knife-box with the tape being drawn through it.

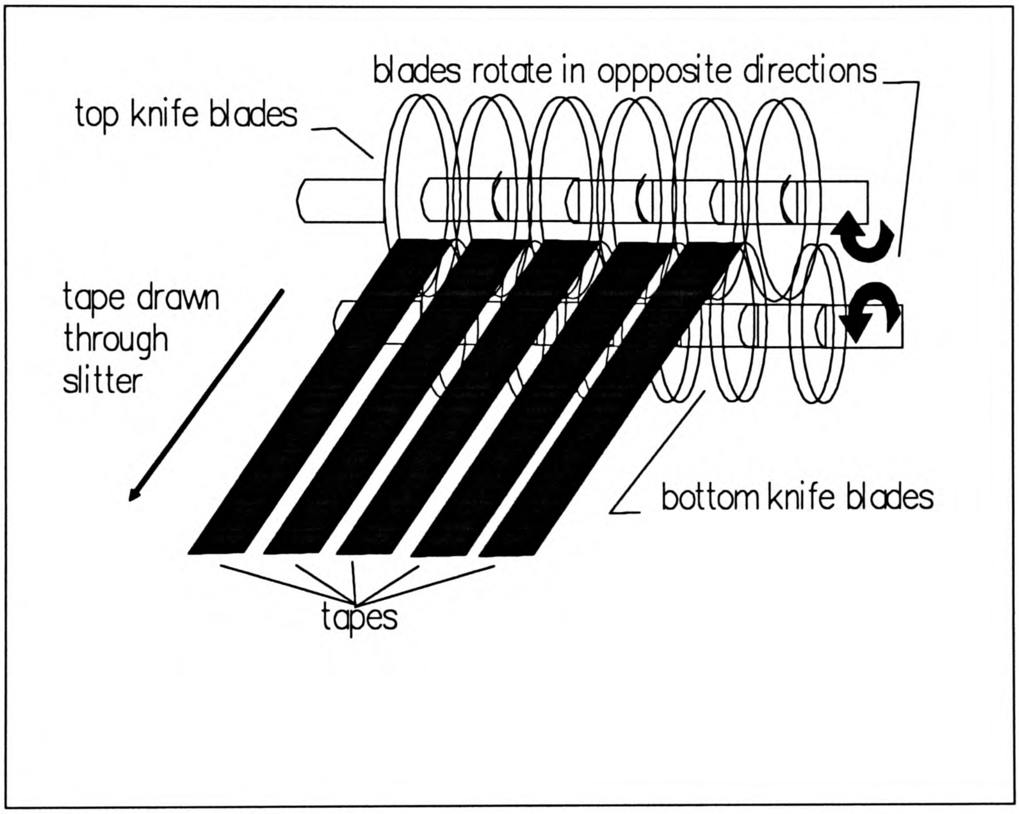


Figure 2.5. A diagram of the slitter knife-box.

The top and bottom knife blades are assembled with a side pressure between them to give a close fit between the blades, thus ensuring a clean cut.

iii) The Tape Guide Mechanism.

The tapes are then separated, alternating up and down from whence they are guided by means of rollers and air-cushioned guides to the correct locations for feeding onto the test and rewind units. The tapes are numbered from 1 to 50 according to their position across the web and are always diverted to the same test and rewind station. The vertical diversion is necessitated by the construction of the rewind stations into vertical banks of three. Following vertical diversion the tapes are further diverted by the air lubricated guides which serve to direct the tapes to the appropriate rewind stations.

A diagram of a section of the guide mechanism is shown in Figure 2.6.

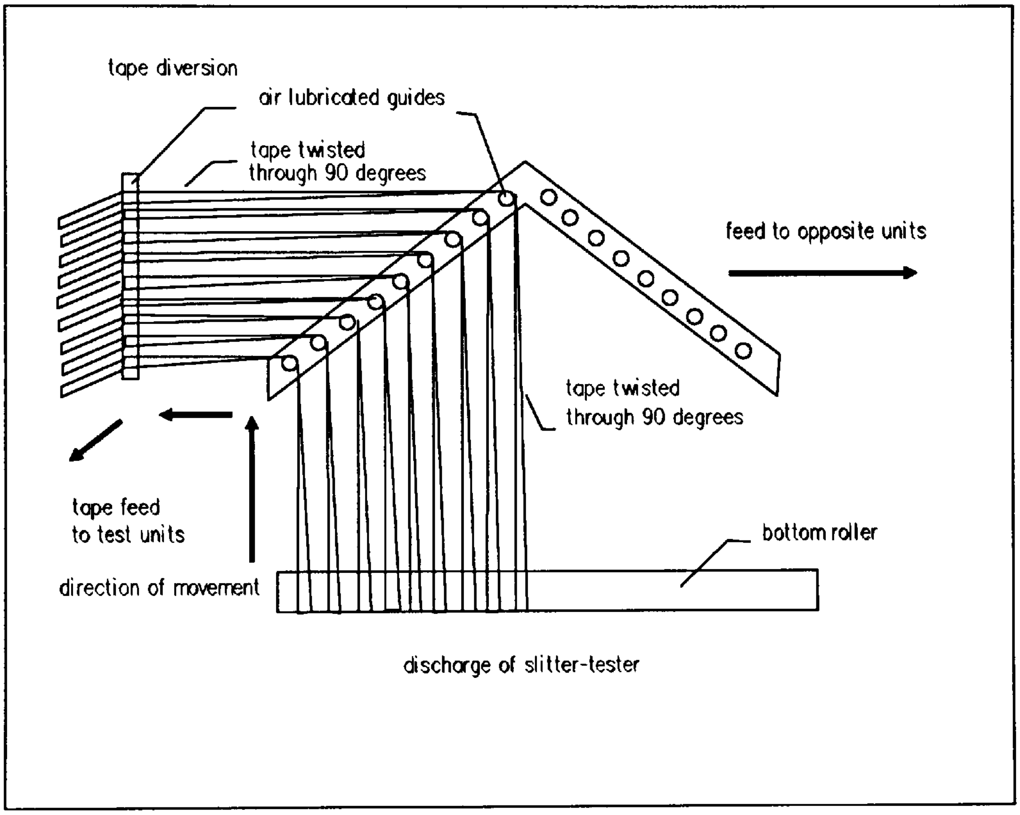


Figure 2.6. Rewind Unit Guide Mechanism.

iv) The Tension Mechanism.

A constant tension is maintained throughout the slitting process by feeding the tape between the chrome guide rolls and rubber "nip" rolls, and by the adjustment of the unwind drive speed and braking force. Slackness in the tape would reduce the accuracy of the slitting process at the edges of the tapes, while over tensioning could cause the snapping of tapes, which necessitates the stopping of the machine and the lengthy process of re-threading the tapes through the machine. All tapes produced on a run during which the machine was stopped have to be re-certified as the evaluation cycle cannot be completed if the machine is stopped.

Tension also has to be maintained throughout the rewinding process to prevent a loss of reading ability due to the tape bouncing away from the write/read head assembly.

v) The Cleaning Process.

The slitting process produces minute debris which affected the accuracy of the testing procedure. This debris is reduced by feeding the tapes over a scraper bar and then bringing the tapes into contact with continuously fed abrasive paper which further reduces debris.

vi) Sensor Marker Application.

Magnetic computer tapes use reflective markers, known as sensor markers, to indicate the area of tape that data can be recorded upon. One marker is applied at the beginning of the tape and is known as the Beginning Of Tape (BOT) marker and the other at the end of the tape and is known as the End Of Tape (EOT) marker. Data is stored and is written or read sequentially between these two markers. These two markers are automatically sensed by tape writing and reading units and necessarily by the test units of the slitter-tester.

2.3.5. The Rewind And Test Procedure.

The full evaluation procedure is performed in the following chronological order.

i) The manual loading of empty customer reels onto the rewind and test stations, including the feeding of the free end of the tape onto the reel.

ii) The running of the machine, during which time the evaluation procedure is performed. To be performed correctly the tape had to be moving at one thousand feet per minute over the write/read heads. To ensure that testing occurs while running at the correct speed, testing is performed between two defined areas while the slitter-tester is running at full speed.

iii) The transmission of test results to the computer attached to the slitter-tester units. Test results are indicated locally on the rewind and test stations enabling the labelling of tapes with their categorised test results.

iv) The removal of the full reels and sorting on to a rack or "dolly" for random sampling by Quality Assurance.

Operations iii) and iv) are performed simultaneously, and the cycle is then repeated.

The rewinding and the testing of the tape is performed simultaneously. The tape is rewound on to customer reels as part of the process. The rewind and test units are in two banks as shown in the diagram shown as Figure 2.3. The tapes are diverted equally after slitting so that each bank receives twenty-five tapes. Each bank consists of nine units, each holding three rewind and test stations, mounted vertically above each other.
Each rewind station is as shown in Figure 2.7.

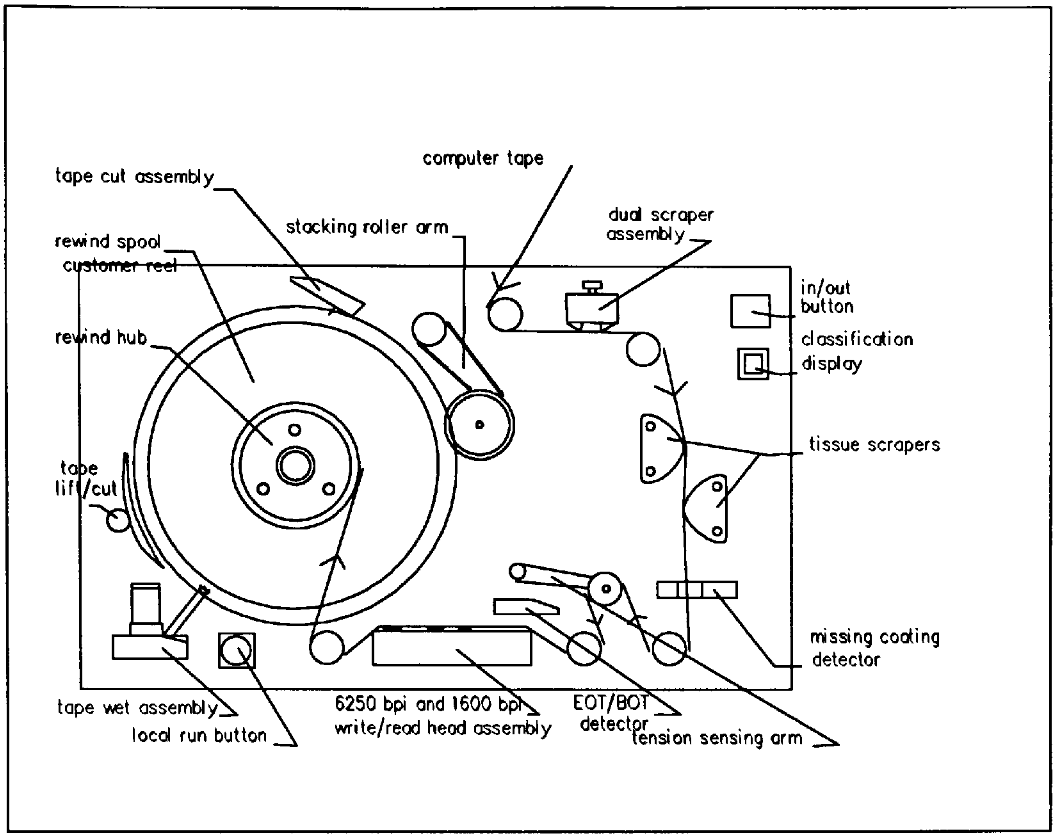


Figure 2.7. Rewind and Test Station Diagram.

Each unit consists of three rewind stations mounted vertically as shown in Figure 2.8. Each station is controlled by separate electronic circuitry, and logs errors in this circuitry, with the unit having microprocessor based circuitry which collects errors from the three stations.

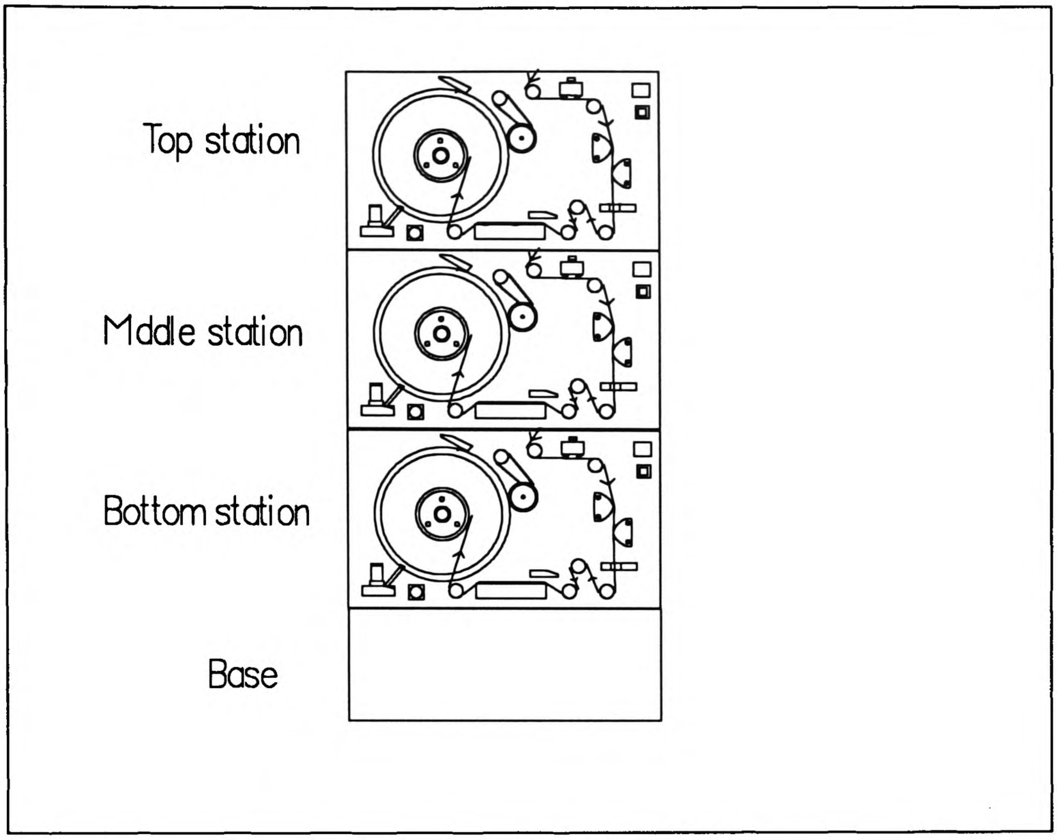


Figure 2.8. Rewind and Test Unit.

The two banks of nine units each containing three rewind stations give a total capacity of fifty-four units, of which fifty are in use at any one time. The remaining four are used as spare stations.

The rewind stations consist of five main sections. (Refer to the diagram Figure 2.7. for the relative positioning of the sections).

i) Tape Scraping and Cleaning.

The scraper assembly is positioned at the feed to the rewind unit. This assembly removes slitting debris from the coated side of the tape. The scraper has two blades and is reversible, with the leading blade being sharpened by the abrasivity of the tape while the other performs cleaning by scraping debris from the coated surface of the tape. A vacuum of 1 to 4 inches water gauge is applied between the blades to prevent the build up of debris on the scraping blade.

To further clean the tape there are two non-fibrous, driven, tissue wipe units which make contact with both sides of the tape as it is drawn through the wipe units. These remove any dust after the scraping operation and are indexed each time the evaluation process is performed.

ii) The Missing Coating Detector.

The missing coating detector detects the absence of magnetic oxide coating from the tape. A light source is directed at the tape and if there is an absence of oxide coating over an area of two square millimetres or more then the receiver detects light and registers the fact that missing coating has occurred.

iii) Tensioning Equipment.

Tape tension is maintained by means of a compensating roller whose vertical movement is controlled by a linear voltage differential transducer which is linked to the rewind hub drive motor. The voltage being generated by the transducer governs the speed of the rewind hub drive motor, this being adjusted to maintain a constant tension.

iv) The Write/Read Head Assembly.

Tape produced at Xidex is tested at two recording densities, 1600 bits per inch (BPI) and 6250 BPI. The Write/Read assembly tests all nine tracks of the tape at the two densities and also detects the presence or absence and correct positioning of the sensor markers. The correct positioning of these two markers is detected by two reflective detectors. The tape is then fed over the 6250 BPI write head, the test signal is recorded onto the tape and is then read back by the 6250 BPI read head. The tape is then fed on to the 1600 BPI write head which overwrites the bit pattern produced by the 6250 write head. The bit pattern recorded at 1600 BPI is then read by the 1600

BPI read head. The pattern is then erased by the erase head. A more complete discussion of the two recording densities is included in section 2.4.

v) The Rewind Section.

The rewind section is divided into three subsections.

a) The Rewind Hub.

The rewind hub is driven by a low inertia servo motor, the speed of which is controlled by the voltage from the linear voltage differential transducer described in 2.3.5.iii).

The hub holds the plastic customer reel in position, and is fitted with a quick release mechanism to facilitate loading and unloading.

b) The Lay On Arm.

A spring loaded neoprene roller maintains pressure on the tape as it is rewound, removing air from between the tape layers and assisting uniform stacking of the tape layers through the reel.

c) The Tape Lift and Cut Assembly.

This assembly allows the cutting of the tape end after the reel has been fully rewound. This is a manual process performed by the operators. The assembly also causes the tape being fed on to the new reel to be wetted by the brush, this giving a good adherence to the hub.

2.4. Tape Testing Methodology.

The method of testing tapes at Xidex is to write a signal of constant level onto the tape and read that signal back, the level of the read back signal indicating if that area of tape is faulty, and if it is faulty, to categorise the error according to the criteria detailed below.

As explained above tapes manufactured at Xidex are tested at two different recording densities, 6250 BPI and 1600 BPI. The definition of errors being different for each density, as explained below.

2.4.1. Tape Testing Criteria at 6250 BPI.

At 6250 BPI three types of error are defined:

i) **Single Track Errors;**

ii) **Two Track Errors;**

iii) **Multi-Track Errors.**

When an error is detected on any of the nine recording tracks a time frame is opened, consisting of 800 timing clock pulses (actually representing 0.177 of an inch longitudinally). All errors on all tracks within this "window" or frame are logged or "latched", causing the microprocessor within the unit to read all the data from both the 6250 BPI and 1600 BPI cards for all three rewind and test stations within that unit.

The diagram shown in Figure 2.9. illustrates the criteria used for 6250 BPI error definition.

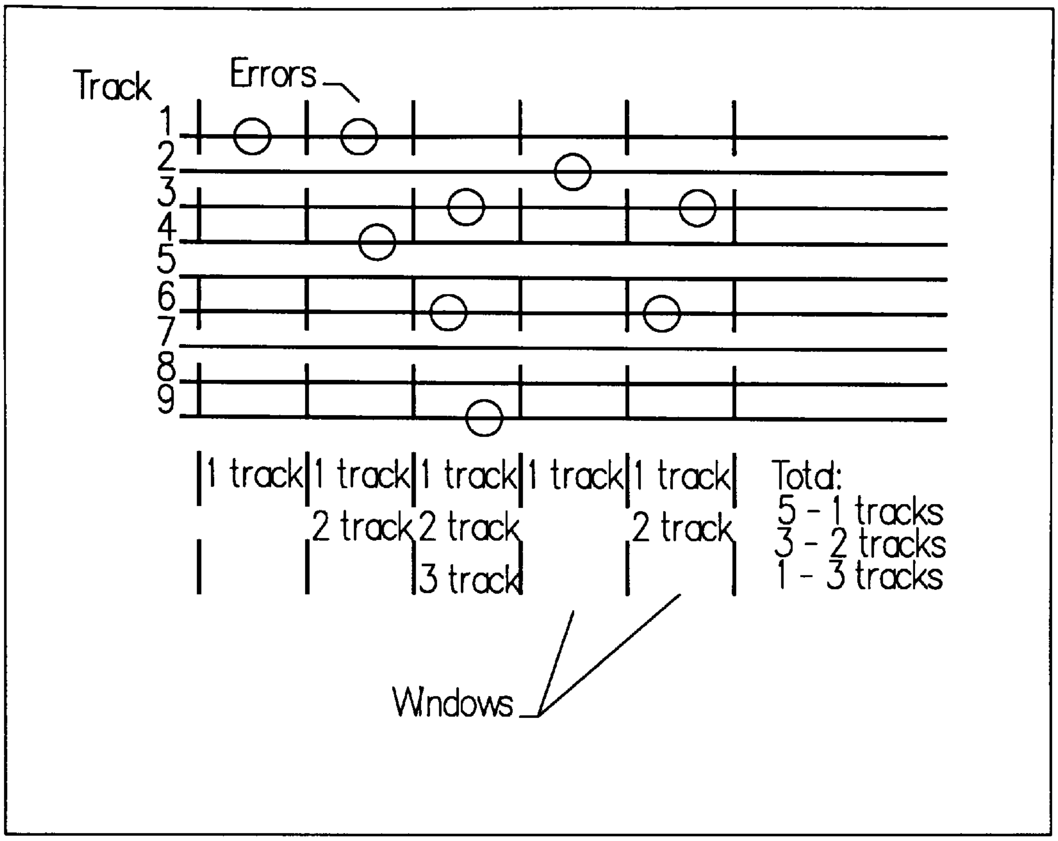


Figure 2.9. 6250 BPI Error Definition.

i) Single or One Track Error.

This error occurred if one track within the time frame contained an error.

ii) Two Track Error.

This error occurred if two tracks within the time frame contained an error.

iii) Multi-Track Error.

This error occurred if errors occurred on more than two tracks within the time frame.

When a two track error occurred obviously two single track errors must have occurred. However, the criterion for calculating the number of errors defined a two track error as one two track and one single track error.

2.4.2. Tape testing Criteria at 1600 BPI.

At 1600 BPI three types of error are defined. These are also defined as being within a time frame, but differentiated between the level of the signal read back and the length of time that the more serious error persisted. The errors are as outlined below:

i) **Hypercritical Error.**

ii) **Write/Skip Error.**

iii) **Gross Error.**

Two levels of threshold are set for error determination at 1600 BPI. The diagram shown in Figure 2.10 illustrates the principle.

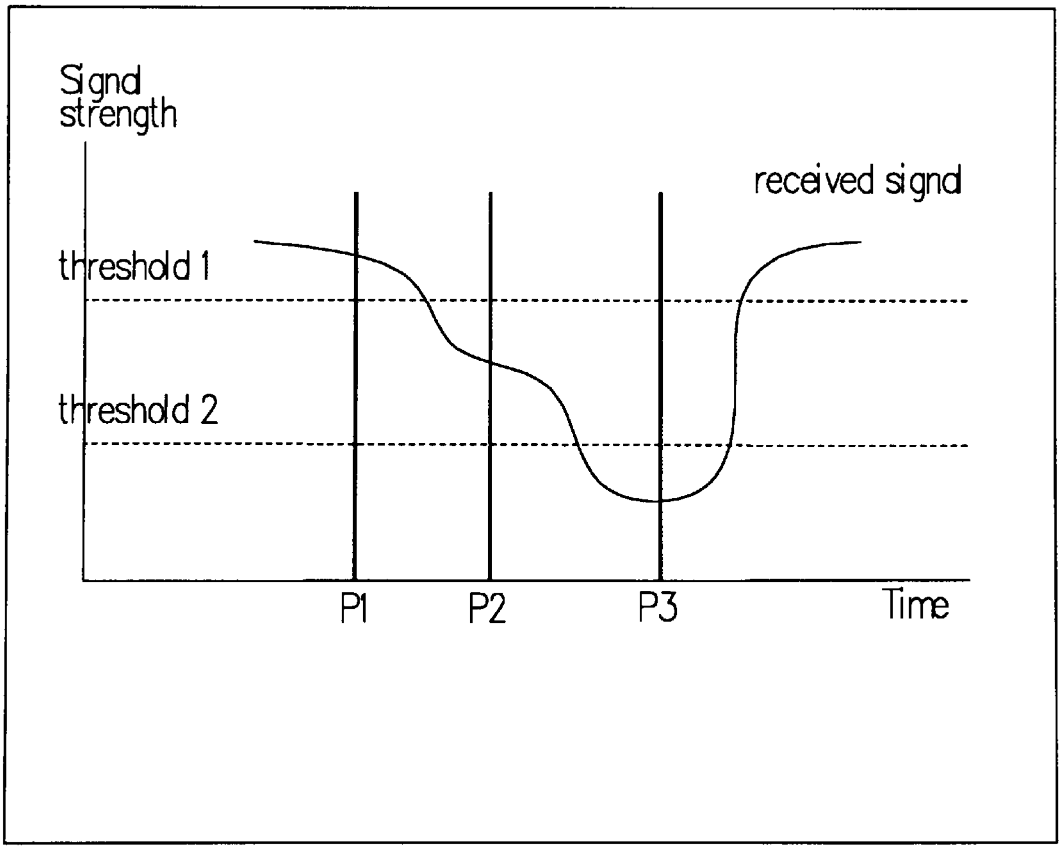


Figure 2.10. Threshold Levels for 1600 BPI Error Determination.

If the strength of the signal is sufficient, that is there is not an error condition, the received signal strength will be above the first (higher) threshold as shown at point P1 in Figure 2.10

i) Hypercritical Error.

This error occurred at point P2 when the read back signal level fell below the upper 1600 BPI error threshold.

ii) Write/Skip Error.

This error occurred at point P3 when the read back signal level fell below the lower 1600 BPI error threshold. When a write/skip error occurred then a hypercritical error is also said to have occurred as the signal level must have dropped below the higher threshold as well.

iii) Gross error.

This error occurred if a write/skip error persisted over the boundary of the time frame into the next time frame.

When an error is detected an interrupt is sent to the Central Processing Unit (CPU) of the units. The interrupt is serviced and all 6250 and 1600 BPI cards are read. The time taken to service the interrupt, a timer count of 4800 units, represents approximately three inches of tape. Thus it is possible that each consecutive time frame or fraction of an inch of the tape would not be tested. This is in line with the ANSI Standard number X3.40-1983 (ANSI (1)) for magnetic tapes.

There is a limit to the number of errors that can be recorded for any one track by any one station for each evaluation cycle, this number being nine hundred and ninety nine.

There is also a limited number of errors that can be recorded in succession. If more than two hundred errors occur consecutively then the interrupt servicing routine cannot guarantee the correct reporting of all faults detected from that station or that unit (as the one CPU has to service all three stations in that unit). This fact is notified to the operator by means of a unit fault code being indicated on the operator's computer.

2.4.3. Tape Classification Criteria.

Each tape is classified, or graded, according to the total number of each type of error which had occurred on that tape. An example matrix is shown in Table 1 showing the number of errors specified for tape grading for a two thousand four hundred foot Group Coded Recording format tape (2400' GCR).

CLASSIFICATION CRITERIA 2400' GCR				
ERROR	1	2	3	4
1 TRK	50	100	400	999
2 TRK	0	2	6	999
3 TRK	0	0	4	999
HYPER	0	16	24	24
WR/SK	0	8	12	12
GROSS	0	0	0	0

Table 1. Classification Criteria Matrix for 2400' GCR.

This matrix is transmitted by the operator from the host computer to the slitter-tester units where it is stored as long as the unit is switched on. The matrix is used to determine tape grades. The matrix is to be read vertically, showing the maximum number of each type of error allowed for a tape to be graded according to the column heading. To use the example above a grade 1 GCR tape had to have less than or equal to the number of errors of each of the following:

50 single track errors;

0 two track errors;

0 three or multi-track errors;

0 hypercritical errors;

0 write/skip errors;

0 gross errors.

It is by definition impossible to have a 1600 BPI hypercritical error without having a 6250 BPI single track error, or a Write/Skip error without a Hypercritical error and so on.
Grade 1 tapes have the lowest number of errors. The lower the number of the tape classification the fewer errors the tape would contain, and consequently the higher the commercial value.

The possible grades are as follows:

i) **Grade 1.** The tape contained either no errors or less errors than specified;

ii) **Grade 2.** The tape contained too many errors to be Grade 1 but too few to be Grade 3.

iii) **Grade 3.** The tape contained too many errors to be Grade 2 but too few to be Grade 4.

iv) **Grade 4.** The tape contained too many errors to be Grade 3 but too few to be failed. Grade 4 is the lowest grade with any commercial value.

v) **Failed.** The tape contained more errors than that defined for a grade 4 tape. All failed tapes are retested on reel to reel testers to ensure that they are correctly classified.

vi) **Non-Certified.** A machine fault, usually temporary, had caused that tape not to be certified, or evaluated correctly. All non-certified tapes are retested on reel to reel testers.

There is a strict order of magnitude of errors in the matrix. If Table 1 is referred to it can be seen that a grade 2 tape had to have at least as many of each type of error as a grade 1 tape, that is it could not have less of any type of error than a grade 1 tape. The other grades use the same criteria.

The reasons for non-certification could vary, from a test station to a unit fault, but the most common cause is the stopping of the machine in the middle of the evaluation cycle due to physical machine problems, such as a tape snapping under tension, necessitating immediate stopping of the machine.

2.5. On-Line Error Reporting Methodology.

The results of the evaluation or test are notified to the operator at the end of each evaluation run or cycle of the machine. The data is transmitted from the CPU in each unit which holds the results from the most recent run to the host computer. The host computers are Digital Equipment Corporation (DEC) PDP11 computers.

The prototype machine, Atlas 1, uses a PDP11/03 minicomputer while the more modern machines, Atlases 2 and 3, use PDP11/23 microcomputers. The minicomputer uses eight inch floppy disks to hold the system software while the microcomputers use the more modern five and a quarter inch floppy disks.
All three slitter-tester units are connected to their computers by an RS-422 communications link. The units are linked together in a daisy chain, each having a unique address. The general plan of the slitter-tester units and their communication links is shown in Figure 2.11. which represents the communications links of Atlas 3.

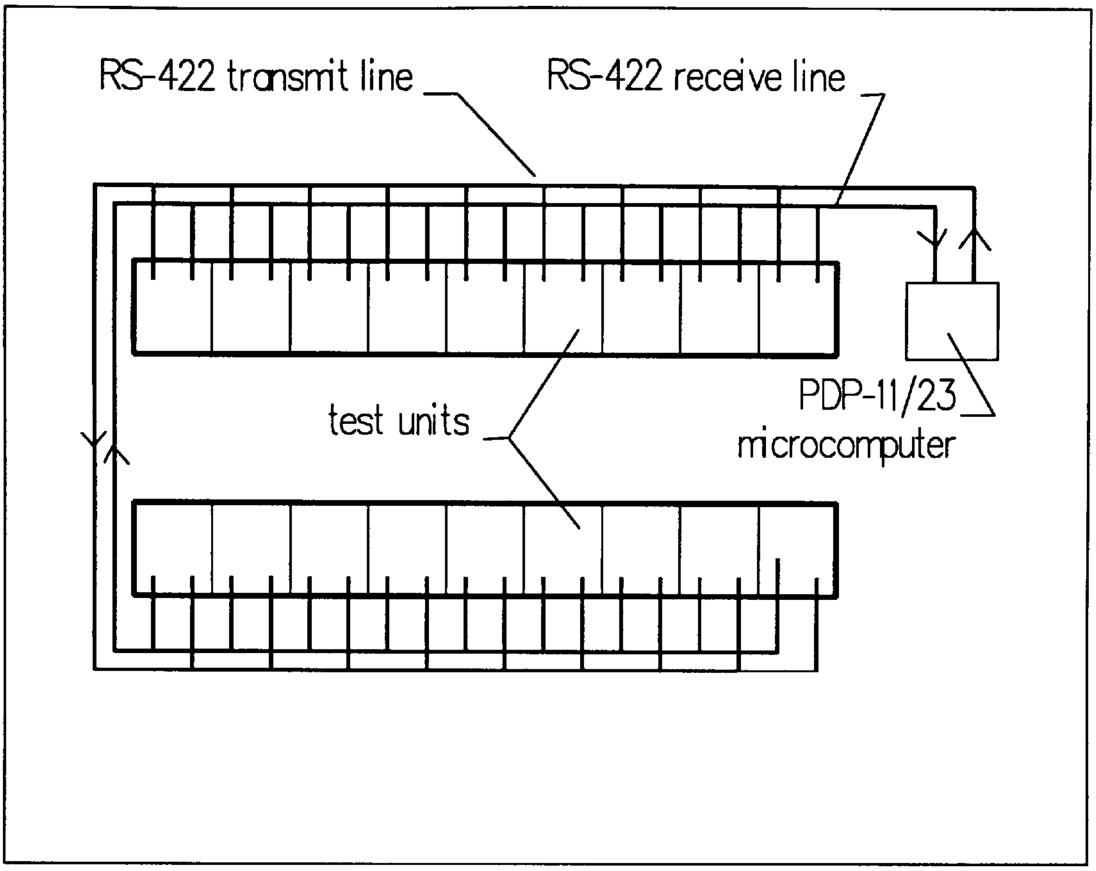


Figure 2.11. Atlas 3. Slitter-Tester to Computer Communication Linkage.

The detection of errors is also indicated by Light Emitting Diodes (L.E.D.s) on a panel in the back of each unit. These are energised when a 6250 BPI single track or 1600 BPI hypercritical error is detected and serve to give a visual confirmation that the unit is functioning.

A more detailed indication of errors is available by attaching a DEC VT100 type terminal to an RS-232 diagnostics port located in the back of each unit. This gives detailed information about each of the stations as the machine is running. This is in contrast to the information presented to the operator, which is only available after the run has ended and the data has been transmitted by the units and received by the PDP11 computer.

2.6. The DEC PDP11s - The Host Computers.

The test results from each unit are transmitted to the host computers at the end of each run. These are transmitted in unit sequence, from one to eighteen, under the control of the host computer. Any faults in the communication of test results from a unit are recognised by the receiving host and a re-transmission requested. The DEC PDP11s are in constant communication with units one and two of the slitter-tester, monitoring their status. This is of particular significance at the end of the evaluation cycle when both units would indicate that they are waiting, thus causing the host to prompt for the transmission of the test results. The host computer is the interface between the operator and the slitter-tester. Using this computer the operator can issue commands which determined the testing criteria and also initialise the test units.

The operator is able to change the slitting criteria as shown in the classification criteria matrix shown in Table 1 and/or alter the threshold criteria used for 6250 BPI and 1600 BPI testing. These criteria are transmitted to each test unit after being entered by the operator. The operator can also initialise units selectively whereby the parameters used by the unit to test the tape would be sent to it in readiness for testing. The operator may also validate each or all units. This causes the unit(s) selected to enter a self-test routine and transmit a message to the host computer verifying correct validation, or otherwise. On start-up of the whole slitter-tester or restarting of the software on the host computer the units would be initialised and threshold levels and classification criteria transmitted automatically to the units.

The host computer provides the operator with information about the most recent evaluation run. The data that is available is detailed in the sub section 2.6.1.

2.6.1. The Data Produced By the Slitter-Testers.

The slitter-tester produces large volumes of data, some 1962 individual items per test cycle. The host computer receives the data from the units and presents the data from the most recent test run. This data is stored in the computer memory until overwritten by the data from the next test run. The data is also stored on a floppy disk until the disk becomes full, at which point the data is no longer stored on the disk. Xidex did not have the equipment necessary to read the disks as they were recorded in a format peculiar to DEC equipment, namely single-sided quadruple density. In addition, the disks from Atlas 1 are 8 inch type and the disks from Atlases 2 and 3 are five and a quarter inch. As the data is not available from the disks, the disks are not changed and so the ability to process the historical data is foregone. The data can be retrieved by the rather cumbersome method of re-initialising the computer, thus stopping the slitter-tester production cycle, and then by printing the data out on a printer before re-initialising the slitter-tester. The operators are able to view all the data from the most recent test run by paging through the hierarchically organised screens on the host computer. The operators manually record a small sub set of the data which is re-entered into an IBM compatible computer for analysis. The data produced by each unit during the test cycle and transmitted the host computers is as shown in Table 2.

1. Unit Status. An integer indicating the status of each station in the unit.
2. Unit Error Code. An integer indicating whether the unit had detected an error during the run.
3. Slitter-Tester Number.
4. Station Data. Data for each station within the unit in the order top, middle and bottom stations.
   - 4.1. 6250 BPI 1 track error total.
   - 4.2. 6250 BPI 2 track error total.
   - 4.3. 6250 BPI 3 track error total.
   - 4.4. 1600 BPI hypercritical error total.
   - 4.5. 1600 BPI write/skip error total.
   - 4.6. 1600 BPI gross error total.
   - 4.7. The classification of the tape.
   - 4.8. The EOT/BOT/Coating status. The bit pattern of this data indicated an EOT or BOT fault or whether missing coating had occurred.
   - 4.9. 6250 BPI 1 track errors - track 1.
   - 4.10. 6250 BPI 1 track errors - track 2.
   - 4.11. 6250 BPI 1 track errors - track 3.
   - 4.12. 6250 BPI 1 track errors - track 4.
   - 4.13. 6250 BPI 1 track errors - track 5.
   - 4.14. 6250 BPI 1 track errors - track 6.
   - 4.15. 6250 BPI 1 track errors - track 7.
   - 4.16. 6250 BPI 1 track errors - track 8.
   - 4.17. 6250 BPI 1 track errors - track 9.
   - 4.18. 1600 BPI hyp track errors - track 1.
   - 4.19. 1600 BPI hyp track errors - track 2.
   - 4.20. 1600 BPI hyp track errors - track 3.
   - 4.21. 1600 BPI hyp track errors - track 4.
   - 4.22. 1600 BPI hyp track errors - track 5.
   - 4.23. 1600 BPI hyp track errors - track 6.
   - 4.24. 1600 BPI hyp track errors - track 7.
   - 4.25. 1600 BPI hyp track errors - track 8.
   - 4.26. 1600 BPI hyp track errors - track 9.
   - 4.27. 1600 BPI w/s track errors - track 1.
   - 4.28. 1600 BPI w/s track errors - track 2.
   - 4.29. 1600 BPI w/s track errors - track 3.
   - 4.30. 1600 BPI w/s track errors - track 4.
   - 4.31. 1600 BPI w/s track errors - track 5.
   - 4.32. 1600 BPI w/s track errors - track 6.
   - 4.33. 1600 BPI w/s track errors - track 7.
   - 4.34. 1600 BPI w/s track errors - track 8.
   - 4.35. 1600 BPI w/s track errors - track 9.
5. Track error data for the middle station, as 4.1. to 4.35.
6. Track error data for the bottom station, as 4.1. to 4.35.

Table 2. Data Produced by the Slitter-Testers.

The data stored on the floppy disk also contained information relating to that evaluation run as a whole as opposed to each particular unit.
This data is as shown below.

1. Slitter-Tester number.
2. Slitter-Tester software version number.
3. Unslit Reel (jumbo) reference. A ten character code identifying the product and the process used to manufacture that reel. An example is shown in Table 3, which uses the reel reference X2L6A1236H.

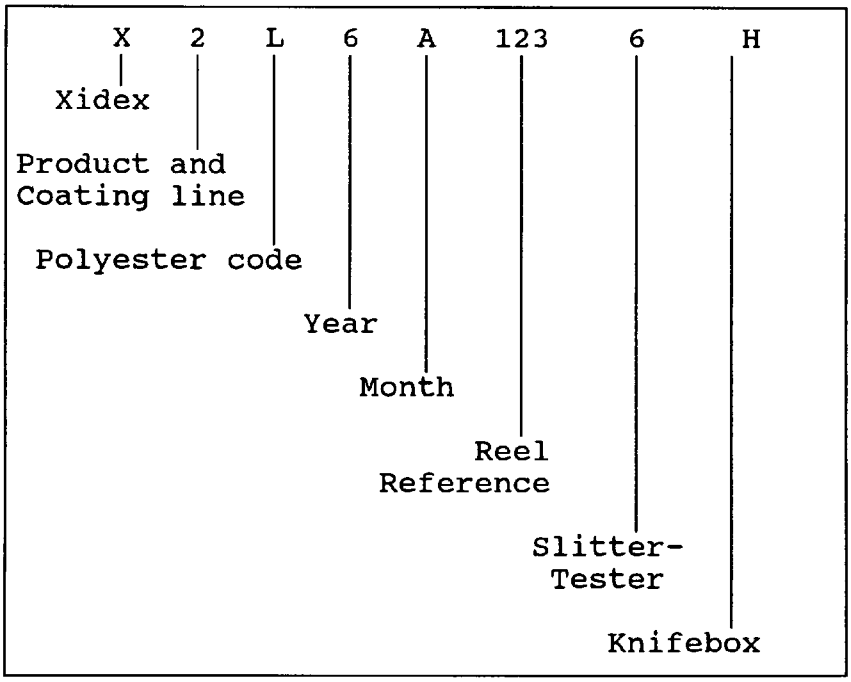


Table 3. Reel Reference Coding.

4. Date.
5. Time (except on Atlas 1, the prototype).
6. Operator name.
7. Threshold levels used.
8. Classification criteria used.

It is useful to clarify here the meaning of some of the items of data returned by the slitter-tester, namely the items numbered 1, 2 and 4.8. from the Table 2 above.

Item 1, the unit status, indicated the status of each station within that unit for the previous run. Each station had a number associated with it to indicate that the station had been calibrated and initialised correctly.

The top station is represented by the number 16.

The middle station is represented by the number 32.

The bottom station is represented by the number 64.

At the end of a run where the three stations are operating correctly the number 112 would be transmitted as the unit status, which is the sum of the three numbers. A station functioning incorrectly would produce a number indicating which station is at fault.

Item 2, the unit error code, indicated the status of the unit throughout the run. The following codes could be transmitted.

Code 0 represented correct functioning.

Code 1 indicated a fault in receiving commands from the host computer.

Code 3 indicated that the unit had received a command (other than calibrate) while the machine is running.

Code 4 indicated a CPU buffer overload caused by the detection of consecutive errors by one station, this code notifying the operator that all errors might not be reported.

Code 5 indicated that the run finished before the calibration sequence had been completed.

Code 6 indicated a time out error during data transfer to the host computer.

Code 7 indicated that the Erasable Programmable Read Only Memory (EPROM) chip containing the software to perform the test contained an error.

Code 8 indicated an unspecified fault on the unit.

Code 9 indicated that the unit had not been fully initialised.

Item 4.8. the EOT/BOT/Coating status indicated whether or not the EOT and BOT sensor markers had been correctly placed and also whether missing coating had been detected on that station. Atlas 1, the prototype machine, did not include data for the coating status, although this is indicated locally on the rewind panel.

The sum of each type of error detected at both recording densities is calculated and transmitted as a total. A direct relationship between the number of errors seen at 6250 BPI and the total is only possible if no three or multi-track errors had occurred. However a direct relationship did exist between 1600 BPI track errors and the total. A detailed track by track analysis is transmitted for 6250 BPI 1 track and 1600 BPI hypercritical and write/skip errors.

CHAPTER 3. FEASIBILITY STUDY.

The project aims are stated in Chapter 1 section 1.2. Basically these were to provide a more complete, accurate and timely analysis of data produced by the slitter-testers. The analysis was to be produced as reports for production and maintenance purposes.

To assess the various possible methods of collecting the data it was necessary to perform a feasibility study. Large volumes of data were being produced by the slitter-testers but this data could not be completely analysed. This was due to incompatibility of the installed recording media (floppy disks) and any existing equipment.

A feasibility study was carried out to accurately assess the volume and nature of the data being produced by the slitter-testers, and to investigate potential methods of collecting this data and reporting or presenting it.

The ideas arising are detailed in this chapter. The initial feasibility study involved examining all three slitter-testers and the data that was produced during the test cycle. This data is described in Chapter 2. Section 2.6.1.

Before the options are discussed in detail it is useful to discuss general background information regarding the slitter-testers.

3.1. Slitter-Testers General Information.

During the feasibility study differences between the slitter-testers became apparent. Atlas 1, the oldest machine, (being the prototype) is controlled by a DEC PDP11/03 minicomputer using 8" flexible disks as system and data disks. The system disk contains the software (computer programs) used by the PDP11 to set criteria, thresholds and head gains which the slitter-tester uses as test parameters, while the data disk holds test data results. Test results are held in files, each file

representing one evaluation cycle (also termed run, or cut). These data files are held in 10 blocks of 512 bytes, each file being 5120 bytes.
Atlas 2 and 3 are controlled by DEC PDP11/23 microcomputers using 5 1/4" flexible discs as system and data disks. The data is stored on the flexible disks in 10 blocks of 512 bytes for Atlas 2 and more efficiently in 9 blocks of 512 bytes for Atlas 3. During the feasibility study a fact that had to be considered was that any system developed was required to produce information in a format that could readily be used for further analysis on IBM personal computers or compatibles which were already in use within the company. During the period covered by the project the shift patterns and production volumes changed according to production requirements. The calculations used were based on maximum output on a 3 shift working pattern.

Each shift on each machine was required to produce 32 cuts during normal production. If each file on Atlas 1 and 2 were 5,120 bytes and each file on Atlas 3 were 4,608 bytes, then each shift could produce a calculated maximum of :

	64	*	5,120 bytes	=	327,680
+	32	*	4,608 bytes	=	147,456
					475,136 bytes

3.2. Options Considered During the Feasibility Study.

The options considered can be summarised as follows:

i) Standardising the slitter-tester host computers. The slitter-testers differed in two main aspects: firstly, the host, or controlling computers were different, and secondly, the size of the recording media (floppy disks). It was proposed to purchase two additional PDP11/23 microcomputers to allow standardisation, one replacing the PDP11/03 minicomputer used on slitter-tester 1 and the other being a spare to allow the in-house development of a control and reporting system.

ii) To retransmit test data from the controlling PDP11 computers to a central point for data processing. Each host computer could retransmit results to a central microcomputer for processing of results.

iii) To use any equipment already installed in the company to process the data.

iv) a) To use the RS232 port contained within each unit to transmit test data as it was collected. These ports were intended as diagnostic ports, to which could be attached VT100 terminals to display test information as it occurred. The purpose could be modified by attaching to each port a purpose-built circuit which would retain all information for one evaluation cycle and then transmit this to a microcomputer which would be attached to each slitter-tester.

b) To reprogram the central processor contained within each unit to log test data against time, and to then retransmit at the end of the evaluation cycle to a microcomputer attached to each unit.

v) To capture the data in parallel with the host computer, by connecting to the data transmission line from the units to the host computer. This data would be processed by a microcomputer attached to each slitter-tester.

The options are discussed in more detail below.

3.2.1. Option 1. Standardisation of Slitter-Testers including purchase of extra PDP11/23.

As described above, slitter-tester 1 differed from slitter-testers 2 and 3 in that it was controlled by a minicomputer, a PDP11/03, as opposed to a microcomputer PDP11/23.
This option proposed the purchase of two microcomputers, namely PDP11/23s, to match those installed on slitter-testers 2 and 3.
The microcomputer not required to control a slitter-tester would then be available for use for two purposes:

i) to allow analysis of test data results by either linking these directly to the microcomputers attached to the slitter-tester or by analysing data stored on the floppy disks on a batch basis;

ii) to allow development of software to improve the interaction of the operator and the slitter-tester.

This would also reduce dependence upon the original supplier for future modifications. Due to licensing and contractual difficulties, Xidex were not able to amend the software which was used to control the slitter-tester. Any modifications required from the original supplier were expensive and it was difficult to obtain fixed dates for the completion of proposed modifications.
The standardisation upon micro PDP11/23 computers would also have required a standardisation of the CPU boards and re-programming of the Erasable Programmable Read Only Memory (EPROM) chips contained within those boards of Atlas 1. Some hardware modifications - specifically the minimum speed relays, would be required. It would also have been possible to purchase an "IBM Option Card" for the DEC microcomputers thus facilitating the conversion of data to IBM format, and enabling a micro PDP11/23 to run IBM personal computer software packages.

The costs for this option were as follows at 1986 prices:

i)	the purchase of two micro PDP11/23 computers (refurbished) at £4,040.05 each	=	£8,080
ii)	the purchase of the RSX operating system and related software	=	£1,352
iii)	purchase of IBM option card	=	£2,500
Total cost		=	12,932

There would have been a trade in cost reduction of £2,352.00 by returning the PDP11/03 installed on Atlas 1 to the supplier of the new PDP11/23s, thus reducing the financial outlay to £10,580.10. The time needed to implement this option was estimated to be two weeks to modify the CPU boards in the slitter-testers, minimum speed relays and re-programming of the EPROMs. This would have taken place while there were no production requirements. One day would have been required to install hardware (computers), and two to three months to develop test and install software to analyse the data - if the data were not to be transferred to IBM PC's for analysis, which was estimated to require a further three months.

The justification for and the benefits arising from this option were only viable if two PDP11/23 microcomputers were purchased to standardise slitter-tester 1 and to provide the spare machine needed for development. Having the spare machine and developing a new system would have allowed Xidex to reduce its dependency on the original supplier for future modifications. If the IBM option were to be purchased, spreadsheet and database packages for data analysis were already available within the company.

3.2.2. Option 2. To Transmit the Data from the DEC PDP11s to an IBM PC.

This option proposed to link an IBM PC directly to the PDP11 computers present on all 3 slitter-testers. These would have transmitted test data results to the IBM, as and when they occurred, allowing an on-line collection and analysis of results. The communications cards on the two PDP11/23 microcomputers on slitter-testers 2 and 3 both had a spare port which could be configured for serial data transmission using EIA RS232-C protocol (EIA (1)). The slitter-tester which did not have the spare capacity, slitter-tester 1, could have been modified, either by replacing the printer port by a serial data port, or by installing a second communications card to provide the extra capacity.

This option required the commissioning of a software modification by the original supplier. This modification would have transmitted the test data results using serial data transmission to the IBM PC at 9600 bits per second.
A further software modification would have been required to allow the operator to input information about reasons for tapes not being certified. This would then have been transmitted to the IBM PC. As the IBM PC can only receive data on 2 ports (due to limitations within the operating system) it would have been necessary to buffer the transmissions from the PDP11 using a buffer (similar to a printer buffer) on more than 1 port and hold, or buffer, files or data re-transmitting it in a manner such that the ultimate receiver could identify the original source of the transmission and reconstruct the transmission correctly. This is shown in Figure 3.1.

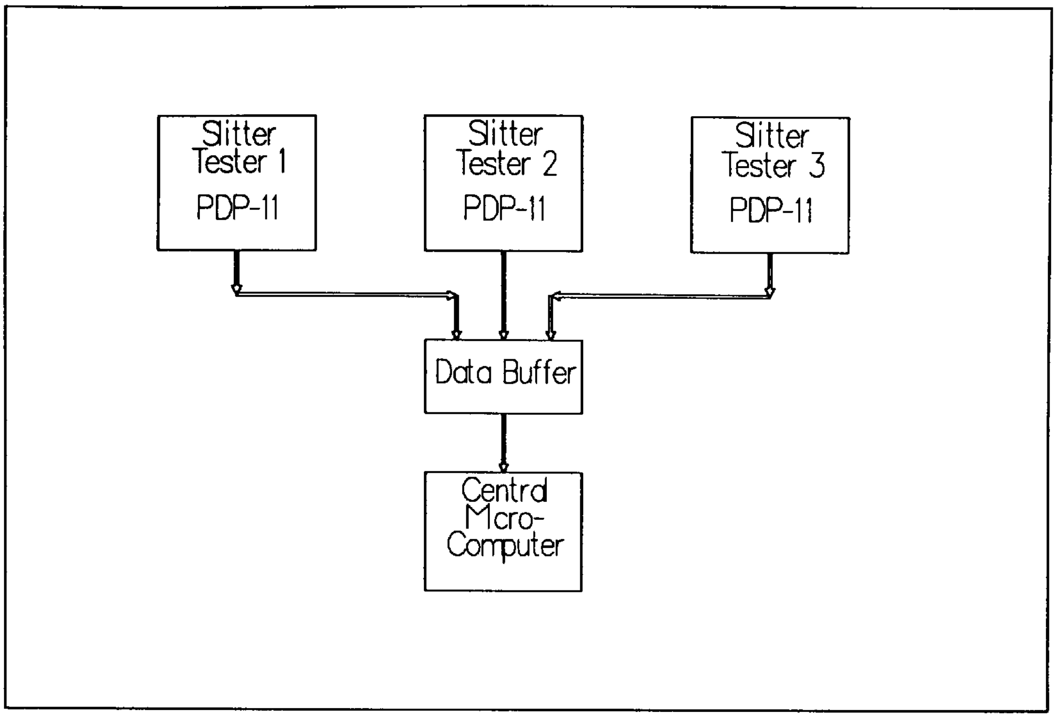


Figure 3.1. Block Diagram of Buffered Link from 3 Slitter-Testers to 1 IBM PC.

To allow the concurrent receiving and analysis of data it would also have been necessary to purchase a concurrent operating system, allowing the IBM PC computer to perform two tasks or processes simultaneously, firstly the receiving of data at irregular times, and secondly the analysis of that data received.
The amount of data to be analysed would have required a large rapid access storage facility on the IBM PC. A 20 megabyte hard disk would have held software packages and up to 12 days test results data at the production rates identified in Section 3.1. (Slitter-Testers General Information.)

It was proposed that a PC based relational database package such as Dbase III+ (which was available within Xidex) would be the medium for analysing test data, as well as allowing data users to address their own queries to the data. Due to the large quantity of test data produced daily a large volume storage device would be required to archive data. An additional requirement would be that this data was readily identifiable and retrievable. These requirements suggested the use of a tape streamer which provided a compact, efficient and cost effective method of meeting those requirements. To enable the more efficient handling of data within the IBM PC, it was proposed to install a 1 megabyte memory expansion card. This was available packaged with the concurrent operating system which was concurrent PC-DOS produced by Digital Research.

The time that this option would have taken was estimated as follows :

i) Three months for the software modifications by the original supplier to transmit data to the buffer;

ii) One month to write an applications program to receive the data on the IBM PC;

iii) Three to four months to program the database package to provide an automated reporting package.

The costs for option 2 were as follows:

i)software modification by the original supplier to transmit data to the buffer			=	£2,300
ii)IBM PC XTS FD			=	£2,327
a) Concurrent DOS XM packaged with InterQuadramQuad EMS and 1 megabyte card	=	£585		
b) IBM Proprinter	=	£417		
Subtotal cost for IBM PC computer			=	£3,330
iii)4 channel 512 kb shared printer spool buffer			=	£750

iv)4 male/female D type 25 way connectors + 100

metres screened cable = £105

Total costs for option 3.2.2 = £6,584

The justification and benefits arising from this option were that it would have taken little time to interpret the data as the data would have been transmitted from the PDP11s in ASCII text format in a pre-decided order. The development time would have been concentrated upon establishing correct communications and setting up the database package to produce reports and address queries. The financial cost was relatively low at £6,500. The crucial drawback to this option was the necessity of involving the original supplier, and his inability to confirm a suitable date for the delivery of the required software modification. A further, more minor, drawback was that the operator would not be able to enter information regarding reasons for the machine having stopped. This could not have been gathered automatically.

3.2.3. Option 3. To use any Existing Equipment to Read and Analyse Data.

Any equipment already installed in Xidex was considered for use as a method of analysing data.

3.2.3.1. The main computing facility within Xidex was provided by DEC PDP11/44 minicomputers and various methods of utilising these were considered, but rejected for the following reasons:

i) the continued use of the DEC PDP11/44s was under review, with no assurance of the continued use of Digital Equipment Corporation (DEC) equipment in the future;

ii) there was little or no spare capacity between the hours of 07.00 and 19.00. Degradation of the service to other users would have ensued as the slitter-testers would have required priority to avoid delay in production.

3.2.3.2. The possibility of using IBM PC or compatible computers was investigated. The data disks used by slitter-testers were physically similar to the 5 1/4" flexible disks used by the IBM PC or compatibles already installed. The proposition was to use these computers to perform an analysis on a regular, or batch basis, at the end of every shift by removing and replacing the data disks from the slitter-testers, and transferring the data held on these disks to the IBM PC for analysis. The disk formats were found to be incompatible and the slitter-tester data disks could not be read by the IBM PC. Also slitter-tester 1 used 8" data disks, which would have required both hardware and software modifications to change these to 5 1/4" disk drives.

It was decided that this option was not feasible due to the above problems.

3.2.4. The Collection of Errors in Real Time.

The test data collected and processed by the PDP11 computers (as shown in Table 2 in Chapter 2 Section 2.6.1.) attached to the slitter-testers was collected at the end of the evaluation cycle. If it were possible to collect the errors in real time, or as they occurred, noting the time that they occurred, then a calculation based on the time that had elapsed since the start of the evaluation cycle would give an approximate location along the length of the tape. This was seen to be a potentially valuable item of information, allowing the more precise analysis of causes of error. Two methods of implementing this option were identified, and are discussed below.

3.2.4.1. Option 4. Using the RS232 Diagnostics Port on Each Unit.

Each unit had a port to which a DEC VT100 terminal could be attached to provide diagnostics for interpretation by the engineering and technical staff. This port used EIA RS232C protocol. A pre formatted screen of information was transmitted to the VT100 terminal. The screen was updated or refreshed whenever errors occurred or whenever significant events occurred, such as the Beginning at Tape sensor marker being located. The information on this screen was as shown in Table 4.

```
          RS232 DIAGNOSTIC PORT INFORMATION

1.   Unit Status
2.   EPROM Checksum
3.   Unit Error Code
4.   Thresholds to assess errors or dropouts
5.   Classification criteria
6.   Summaries of track errors by station
     (top, middle and bottom)
7.   End of tape sensor marker status
8.   Beginning of tape sensor marker status
9.   Coating status (whether missing coating has
     been  detected)
10.   6250 bpi single track errors from tracks 1 to
      9 for top middle and bottom stations
11.   1600 bpi hypercritical errors from tracks 1 to
      9 for top middle and bottom stations
12.   1600 bpi write/skip errors from tracks 1 to 9
      for top middle and bottom stations
```

Table 4. Information Available from the RS232 Diagnostics Port.

This indicated that the information collected by the PDP11 computers (as shown in Table 2 in Chapter 2 Section 2.6.1.) attached to the slitter-testers was available through the RS232 diagnostics port.

To capture this data it would have been necessary to construct a circuit for each unit containing the necessary hardware to hold the data until the end of the run when it would have been collected by a microcomputer. Each slitter-tester would have required a microcomputer in addition to the PDP11 computers already installed. These would have functioned as data collecting devices and provided new interfaces between the slitter-testers and the operators. One of these microcomputers would have acted as a central data collection point, in addition to a data collection point for that slitter-tester.

A diagram of this option is shown in Figure 3.2. Two of the microcomputers would have needed only limited processing power while the third, acting as the central data processor would have required a hard disk and larger memory.

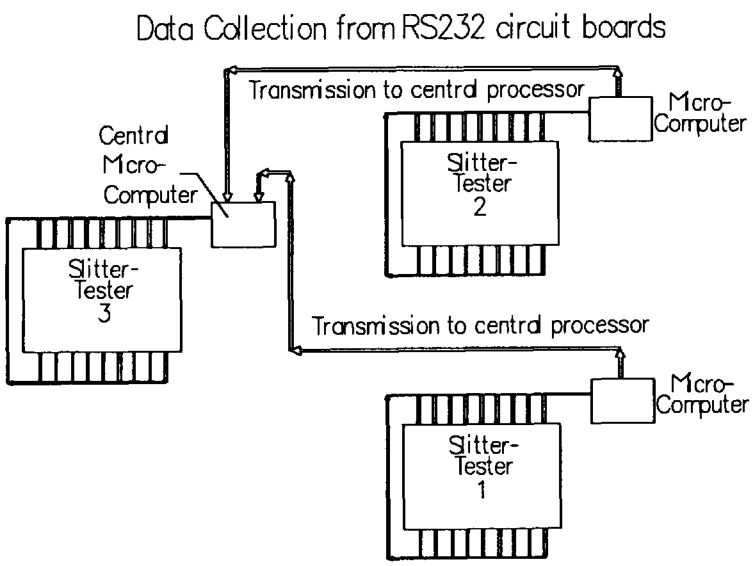


Figure 3.2. Diagram Showing Proposed Microcomputer Set-Up for Data Capture from the RS232 Diagnostics Port.

The costs for option 3 were as follows at 1986 prices:

i)		additional circuitry estimate at £35 per board with 54 boards required	=	£1,890
ii)		2 cheap IBM PC compatibles at £549 each	=	£1,098
iii)		100 metres of communications cable	=	£ 67
iv)	a)	PC compatible with 20 Mbyte hard disk	=	£ 949
or				
	b)	IBM PC XT 20 Mbyte with hard disk	=	£2,327

Total for option a)	with PC compatible =	£4,004
Total with option b)	with IBM PC =	£5,382

The time required to implement option 3 was estimated as follows:

i)Delivery of microcomputers	2-3 weeks
ii)Specification and construction of boards	3-4 weeks
iii)Programming additional boards	3-4 weeks
iv)Programming PC based systems	3-4 weeks
v)Installation of additional boards	3-4 weeks

The justifications and the benefits arising from this option were similar to those expressed in option 1, and are as listed:

i) Xidex would have been able to reduce their dependence upon the original supplier for future modification;

ii) All currently collected data would have been collected automatically with the addition of useful data.

3.2.4.2. To re-program the operation of the central processor in each unit.

Each unit of the slitter-tester contains a Central Processing Unit Board which had capacity for 1 more Erasable Programmable Read Only Memory (EPROM) chip and 1 more Random Access Memory (RAM) chip. By re-programming the operation of this board it might have been possible to achieve the same objective as that discussed in Option 4.1..

The costs for this option were as follows at 1986 prices.

i)1 EPROM + 1 Ram chip at £6 per unit *18			=	£324
ii)2 IBM compatible at £549 each			=	£1098
iii)Cable at £60 per 100 meters			=	£ 60
iv)	a)	PC compatible with 20 Mbyte hard disk	=	£949
or				
	b)	IBM PC XT with 20 Mbyte hard disk	=	£2327
Total for option a)		with PC compatible	=	£2438
or				
Total for option b)		with IBM XT	=	£3816

The justifications and benefits for this option are as for option 3.2.4.1. These options would have required a substantial investment in time as the program that controlled the operation of the CPU board would have either had to have been disassembled, or the original program purchased from the original supplier, and then re-programmed. An estimate of the total time required to implement this option was 18 months. These options, while providing useful additional information, involved an altering of the fundamental operation of the slitter-tester, which was not seen to be desirable.

3.2.5. Option 5. "Tapping the RS422 Communications Line from the Units to the Slitter-Testers.

Communication between the slitter-tester units and the PDP11/03, and PDP11/23 computers was achieved by means of an EIA RS422 twin differential balanced link (EIA (2)). If a connection were to be made to this link and communications received in parallel, then all test data results would have been available for collection and analysis. It was proposed that the communications from the additional line would be received on an IBM PC or compatible. While this would not have given the full set of data which was available from the PDP11 data disks, the missing information could have been added by the slitter-tester operator.

The twin differential link is achieved by having two pairs of twisted wires contained within an earthed and screened cable. The twisting of each pair of wires is intended to reduce the effects of inducted noise on the signal that that pair of wires is carrying. This option required a connection to one pair of the wires contained within this cable. The connection would have been to the pair of wires which were used to receive transmissions from the units to the PDP11s.

This option would have enabled the development of an alternate, improved operator interface and reduced the dependence upon the original supplier for future modifications with regard to the manipulation and display of data.
The data would have been presented on-line to the operator i.e. as it happens at the end of each evaluation run, and stored on that computer. The large volume

of data anticipated necessitated the use of IBM personal computers or compatibles with fixed disks to enable the storage of the data.
The additional information to be added by the operator would have had to include an identification of the source of the tape, that is a full reel reference code, the operators name and shift rota.

As the PDP11/03 and PDP11/23 computers were required to set criteria for the classification of the tapes, thresholds to determine error levels, and to ensure that the slitter-tester units were functioning correctly, the additional microcomputers would not be replacements for, but in addition to, these computers. This required the connection to be made only to the RS422 line which the slitter-tester units use to transmit test data results to the host PDP11 computers, not to the RS422 line used to transmit from the PDP11 computers to the slitter-tester units. The communication lines between the slitter-testers and the host computers are shown in Figure 3.3. below.

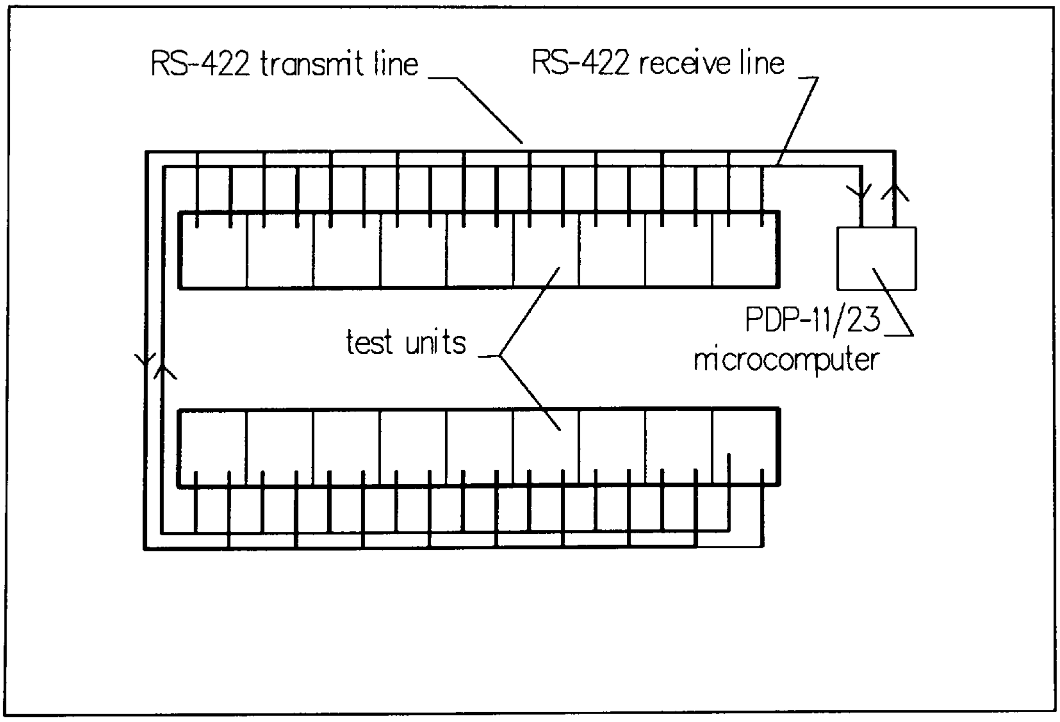


Figure 3.3. Slitter-Tester to Host Computer Communications.

The information collected on these microcomputers could then have been transmitted on to a fourth microcomputer via a data buffer as described in section 3.2.2. This fourth microcomputer was intended to be used as a central data collection point, holding and processing all data files produced by the three slitter-testers, producing the required daily reports.

The time estimated to implement this option is as shown:

i) Two to three months for connecting and decoding transmissions on the RS422 receive line;

ii) Three months for programming the microcomputers attached to the RS422 communications cables to collect, interpret and transmit the data files to the fourth microcomputer;

iii) Three months to program the database package on the fourth microcomputer.

The costs for this option were at 1986 prices:

i)	4 IBM PC compatible microcomputers at £800	=	£3,200
ii)	100 metres screened cable + connectors	=	£105
iii)	data buffer	=	£1,000
	Total cost for this option	=	£4,305

The justifications and benefits arising from this option were that this option was felt to be achievable within the time scale of the project, and to provide enhancements in two areas:

i) firstly, that of operator understanding and interpretation of test results through the new operator interface, and

ii) secondly, there would be a reduced dependence upon the original software supplier, with future changing requirements being able to be met by in house modifications.

3.3. General Points Arising From the Feasibility Study.

It became obvious that whatever the option selected there was a desire on the part of Xidex to have more control over the new data collection system than they had over the old one implemented by the original supplier. This necessitated the development of a system which would incorporate flexibility and be able to be modified by Xidex personnel to cope with changing data requirements. Several of the options identified were intended to reduce the dependence of Xidex upon the slitter-tester manufacturer for data processing and analysis requirements.

Several of the options involved the use of microcomputers, namely IBM Personal Computers or compatibles (able to use the same software). This was intended to allow the development of a more efficient operator and slitter-tester interface, whereby the operator would be notified of error conditions instead of actively having to search these out.

The above were the options presented to the company. Before a selection could be made it was essential to ensure that all the data that had been proposed for collection was actually necessary and also to ensure that this data would be sufficient. A further feasibility study was therefore required to assess information needs, both current and potential. To this end, the study discussed in this chapter was presented at a meeting of relevant management and engineering personnel. The response from this meeting and the investigation it prompted are discussed in Chapter 4.

Table 5., presented below, displays the options with costs and time in a tabular form.

	TITLE	ADDITIONAL EQUIPMENT	DEPENDENCE	COST £	TIME months	BENEFITS
1	Standardisation of PDP-11 computers	2 DEC PDP-11s	In-House	10,600	7	New data analysis system, compatible control system
2	Retransmit results to IBM PC	1 IBM PC +	In-House + DRC s/ware	6,600 + DRC	8	Automatic report generation, all data captured.
3	To use any existing equipment	------------	---------	-----	-----	---------------
4	i) Use RS232 diagnostic port	Circuitry + 3 IBM PC's	In-House	5,400	19	Real time data collection
	ii) Reprogram CPU in each unit	Circuitry	In-House	3,800	18	Real time data collection
5	Capture data from RS422 line	4 IBM PC's	In-House	4,300	9	Operator interface + all data collected

Table 5. Options Presented by the Feasibility Study

CHAPTER 4. PRESENTATION OF THE FEASIBILITY STUDY AND THE INVESTIGATION OF ADDITIONAL DATA.

The options arising from the feasibility study were presented at a meeting of management, engineering and technical staff who were involved in the slitting and testing production process. From this meeting it was agreed that the most appropriate course was to investigate exact information requirements and to assess the costs and benefits of obtaining more information than that currently available. This investigation was to include all measurements and data which could practicably be collected and communicated to the selected data collection equipment.

4.1. Information not Automatically Available from the Slitter-Testers.

The data sheets which the operators completed for their particular shift included categories of information or data which were not available automatically from the slitter-tester. A copy of this operator log sheet is included in Appendix 2. This manually entered information was subdivided into three broad categories:

4.1.1. Tapes not Certified or Graded Correctly by the Slitter-Tester.

This category contained sub-categories which were caused by a fault on the slitter-tester requiring the machine to be stopped. These can be listed as:

i) sensor marker wrap-around - where the sensor markers had wrapped around the roll upon which they were applied;

ii) tape wrap-around - where one or more tapes had broken and been wrapped around one or more of the guide or nip rollers on the slitter-tester;

iii) salvage wrap-around - where the 1/2" edge of the web which was discarded had broken and wrapped around one of the guide or nip rollers.

iv) machine stop - where the operator had stopped the slitter-tester for any reason whilst the machine was in the evaluation cycle.

The above 5 sub-categories were all instances where all 50 tapes would be regarded as being non-certified, as the slitter-tester would have to be stopped immediately.

vi) beginning of tape (BOT) or end of tape (EOT) marker fault caused a tape to be regarded as not certified regardless of the exact number or type of errors on the tape;

vii) unit error indicating that one or more of the evaluator or rewind units had caused all three tapes being certified on that unit not to have been tested;

viii) computer error where the host PDP-11 computer would malfunction, causing one or more tapes not to be certified;

ix) "others" sub-categories to allow for causes not already defined to be accounted for.

The categories vi to viii would generally be appropriate if between 1 and 50 tapes were not certified correctly.

4.1.2. Rewinding Problems.

This category comprised two sub categories both of which represent cosmetic defects which while not affecting the certification of the tape rendered it unacceptable and necessitating a further rewinding (on a separate reel-to-reel rewinding unit).

These could be categorised as follows:

i) bad wind where the successive layers of tape are not stacked perfectly on a reel producing a ridged side view of the reel of tape;
ii) stack arm fault where a lack or surfeit of pressure is responsible for a cosmetically poor rewinding.

4.1.3. Problems Necessitating Cutting Down of Tape to Produce Shorter Length Tapes.

This category comprised sub-categories where web defects caused the tape not to fulfil the specified requirements for its full length. Sections from these tapes may meet requirements for shorter length tapes:

i) short web where the length of web was insufficient to allow the correct number of tapes to be slit from a full web e.g. a full length standard coated web should allow 300 tapes to be produced in 6 runs or cycles of 50 tapes. The last cut from a short length web would not be of the required length;
ii) uncallendered web where the callendering of the coating process was not applied for the length of the coated web;
iii) creasing of the web where the web showed stress creases producing poor slitting and test results.

The above 3 categories applied to all 50 tapes being tested, while the following 3 occur on individual tapes being evaluated.

iv) missing coating where sections of oxidecoating are incomplete;

v) lipping where the profile assumes a convex appearance laterally, that is if the tape is viewed as a cross section;

vi)cupping where the tape profile assumes a concave appearance laterally.

From the matrix and graph above it could be seen that these items of data were required for any data collection and analysis system to be devised.

4.2. Additional Information Identified as Potentially Useful.

4.2.1. The Amplitude of the Signal Read Back from Tape.

The amplitude of the signal read back from the tape during the test procedure was used to compare with three digital thresholds, one for 6250 BPI error detection, one for 1600 BPI hypercritical error detection, and one for 1600 write/skip error detection. The analogue signal read back was a proportion of the signal written on to the tape by the respective write head. This was converted to a digital signal and compared with the threshold level. This information could be obtained on a continuous scale by reading the signal directly and not restricting analysis to the thresholds stated above.
This information would be useful for identifying and analysing coating problems and slitting and testing problems.

4.2.2. Error Position with Reference to Longitudinal Tape Position.

The longitudinal position of errors along the tape could be obtained by measuring when the errors occurred with reference to the particular time of the evaluation cycle. By measuring when the errors occurred this could be converted to a measurement in feet. This information would be particularly useful in analysing coating faults and problems with the slitting and testing process itself.

4.2.3. The Tension of The Rewinding Mechanism During the Evaluation Cycle.

The accuracy of the evaluation or test cycle could be affected by the tension of the tape during the rewinding process. If a rewinding hub were to rotate erratically then the tape would "bounce" over the write and read heads, causing the processor to record that those areas which had not been in firm contact with the write/read heads were indicating errors. As there is a large degree of latitude in the required tension for rewinding a simple measurement of: below; in; or above, the specification would have sufficed to assist in analysis of machine problems. A measurement was available from the Linear Voltage Differential Transducer (LVDT) situated on each rewind unit. The LVDT served to control the speed of the rewind hub.

4.2.4. The Width of the Tape.

The width of the tape could be measured by the incorporation of an optical width detector consisting of one or two light sources and two detectors. Tapes which were too narrow would allow a lateral movement over the read and write heads, thus causing possible misalignment of the tracks in relation to the head, while tapes which were too wide would experience similar problems and also produce a cosmetically unsatisfactory appearance on the reel. A differentiation of tapes into three categories as whether the tape was too narrow, was the correct width, or was too wide would have been sufficient for assessing the width of tapes.

4.2.5. The Measurement of the Vacuum at Tape Cleaning Apparatus.

Each rewind unit had a scraper and cleaner assembly prior to further cleaning and testing. Figure 4.1. shows the assembly, which was reversible. While the trailing blade cleaned slitting debris from the coating surface of the tape the leading (reversed) blade was sharpened by the abrasiveness of the tape.

A vacuum was created in the area between the blades to draw debris removed by the cleaning blade. The level of suction affected the efficiency of this process. A measurement of vacuum level would have been useful to indicate that slitting debris might not be removed by this process, thereby possibly increasing transient errors due to debris. A transient error is one which was detected at the time of testing but has now disappeared, as in the case of debris from the slitting process, which could be removed by the cleaning process on re-testing.

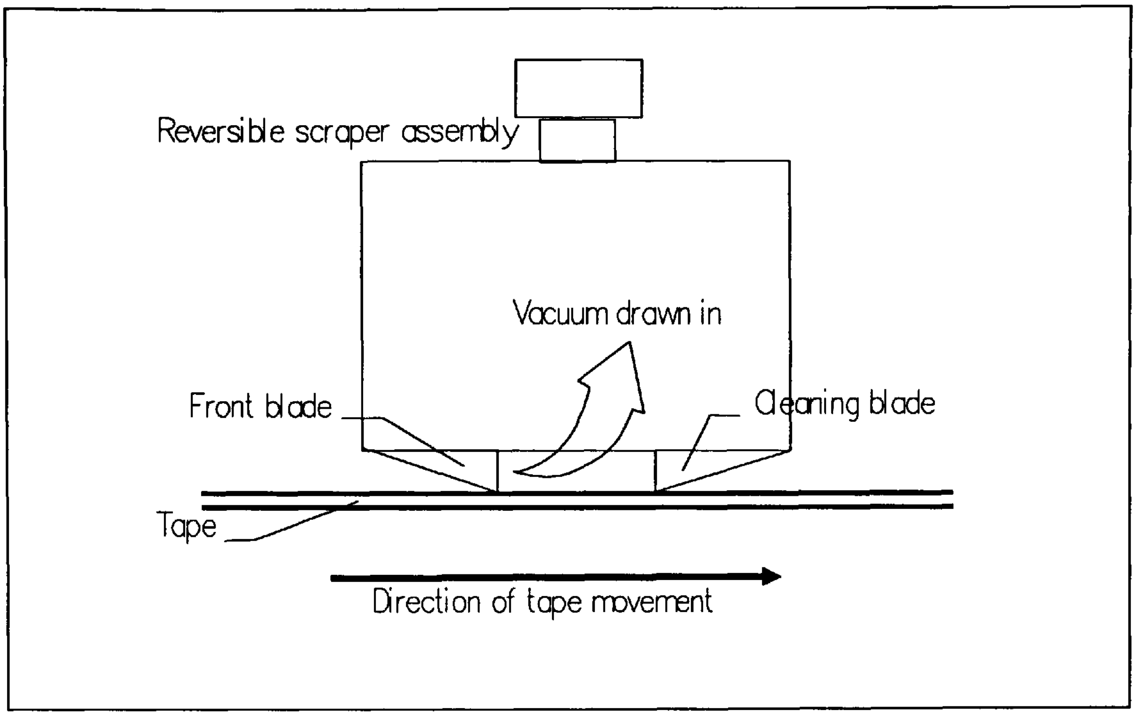


Figure 4.1. The Tape Scraping and Cleaning Assembly.

4.3. The Perceived Importance of Data Items.

To assist in the process of assessing the importance of all items of data which could feasibly be obtained from the slitter-testers, individual interviews were conducted with the relevant technicians, engineers and management personnel. A matrix was constructed to prioritise data and information requirements. This matrix is shown in Table 6 consisting of all relevant parties who required information from the slitter- testers. The items which were essential are marked by a 2, those regarded as useful but not absolutely essential by a 1. Blank entries indicate that data was not important or was not required by that person or by that function.

DATA MATRIX FOR ASSESSMENT OF ADDITIONAL PRODUCTION DATA														
DATA ITEM	FUNCTIONARY													
	1	2	3	4	5	6	7	8	9	10	11	12	13	T
1 Track error		2	2	2	2	2	2	2	2	2	2		2	22
2 Track error		2	2	2	2	2	2	2	2	2	2		2	22
Multi track error	2	2	2	2	2	2	2	2	2	2	2		2	24
Hypercritical		2	2	2	2	2	2	2	2	2	2		2	22
Write/Skip		2	2	2	2	2	2	2	2	2	2		2	22
Gross	2	2	2	2	2	2	2	2	2	2	2		2	24
EOT fault		2	2	2	2	2	2	2	2	2	2			20
BOT fault		2	2	2	2	2	2	2	2	2	2			20
Coating status	2	2	2	2	2	2	2	2	2	2	2			22
Classification		2	2	2	2	2	2	2	2	2	2	2		22
Station status		2	2	2	2				2	2	2	2		16
6250 track errs	2	2	2	2	2	2	2	2	2	2	2	2		24
1600 hyp trk errs	2	2	2	2	2	2	2	2	2	2	2	2		24
1600 w/s trk errs	2	2	2	2	2	2	2	2	2	2	2	2		24
Slitter number		2	2	2		2	2	2				2		14
Reel reference		2	2	2		2	2	2				2		14
Date		2	2	2		2	2	2						12
Time		2	2	2		2	2	2				2		14
Operator Name		2	2	2				2						8
Thresholds		2	2	2		2	2	2						12
Short reel ref		2	2	2				2						8
Class criteria			2			2	2	2						8
Unit status		2	2	2				2						8
Sensor wrap		2	2	2				2				2		10
Tape wrap		2	2	2				2				2		10
Salvage wrap		2	2	2				2				2		10
BOT wrap		2	2	2	2			2				2		12
EOT wrap		2	2	2	2			2				2		12
Machine stop		2	2	2	2			2				2		12
Blade fail		2	2	2				2				2		10
Unit error		2	2	2	2			2				2		12
Computer error		2	2	2	2			2				2		12
Others		2	2	2				2				2		10
Bad wind		2	2	2				2				2		10
Stack arm		2	2	2				2				2		10
Missing coating	2	2	2	2	2	2	2	2				2	2	20
Short Web	1	2	2	2		2	2	2				2		15
Uncallendered web	2	2	2	2		2	2	2				2		16
Creasing	2	2	2	2		2	2	2				2		16
Lipping		2	2	2				2				2		10
Cupping	2	2	2	2		2	2	2				2		16
Comments														
Seq yield analysis	2				2	2	2	2	2	2	2	2	2	20
Tape/web length	2	2	1	2		2	2	2			2	2		17
Dble application		2	2	2				2	2	2	2	2	2	18
Knife box		2	2	1				1				2	2	10
S/M application									2	2	2	2	2	10
Leader length													2	2
1. Amplitude	1	1	1	1	2	2	2	2	2	2	2	2	2	22
2. Error footage	2	1	1	1	1	1	1	1	2	2		2	1	16
3. Rewind tension		1	1	1	1	2	2	2	2	2		2		16
4. Tape width		2	2	2	2			2	2	2	2	2	2	20
5. Cleaning vacuum					1	2	2	1	2	2				8

Table 6. The perceived importance of additional items of data.

The information obtained from this matrix was presented graphically to illustrate the perceived importance of the various items of data.

This graph is shown in Figure 4.2.

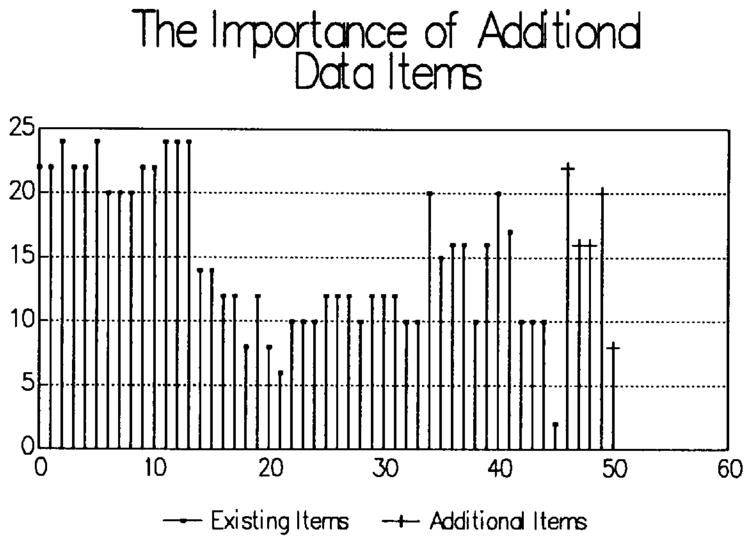


Figure 4.2. Graph of perceived importance of data items.

From the matrix shown in Table 6, and the graph shown in figure 4.2. it could clearly be seen that the additional items of data listed in 4.1.1, 4.1.2, 4.1.3, 4.1.4 and 4.1.5 could be regarded as highly significant for the analysis of production data. The study indicated that the area of additional data was worth pursuing. Outline proposals with costs, timings and benefits were drawn up. If the project had included these items of data then much longer time scales would have been involved, estimated to be up to 18 months, or three quarters of the way through the project, before any results could be obtained. The long timescales were considered unacceptable by Xidex management, and so any proposal to collect these items of data was considered to be unfeasible within the time scale allowed by the project, although they were recognised as potentially important pieces of information.

4.4. Time-Based Categorisation of Information.

The items of data used in the matrix shown in Table 6 were categorised with regard to the time that they were to be reported. Some items of data would best assist the slitter-tester operator by being reported on-line i.e. as they became available on a cut by cut basis, while other items would convey more information by being grouped and reported on a batch basis in reports produced on a per shift, machine, day, week, month basis.

The items identified as requiring reporting to the operator in an on-line mode were as follows:

i) classification or grade of tape with totals;
ii) whether or not a unit or station is not functioning correctly;
iii) indications of definite and potential faults or trends.
iv) whether or not tape(s) have missing coating;
v) whether or not tape(s) have EOT or BOT sensor marker faults;
vi) 6250 BPI single track totals.

Generally those items considered to be important were those which would assist the operator in monitoring and rectifying any short term faults or problems occurring before starting the next run.

Longer term analysis was required to give a more stable view of machine, or coating trends. This involved all categories of information. An analysis of results from one or two cuts was naturally too variable to be used as a reliable indication of trends. For example, a high number of one track errors on several stations over a period of several cuts might due to one or more transient causes, which can be divided broadly into slitter- tester related problems, or web related problems.

The items identified as producing meaningful data generally when grouped together and analysed over a period of time were as follows:

i) 6250 single, two, and multi-track errors;
ii) 1600 BPI hypercritical, write-skip and gross errors;
iii) classifications, plotted across the width of the web to enable comparisons with adjacent tapes, as adjacent tapes should have similar recording characteristics;
iv) coating status to enable trends to be spotted i.e. if a certain station is regularly experiencing missing coating then this might indicate a coating fault, or a slitter-tester malfunction;
v) EOT, BOT sensor marker faults;
vi) comparison between shifts and between operators in an attempt to improve production.

The totals produced from the longer time based data would serve as data for daily, weekly and monthly reports.

A fuller discussion of the analysis of reporting requirements and the methods used to address these requirements is given in Chapter 6. Reporting Requirements. The long time-scales that would have resulted if the project had set out to collect the information that was not readily available ruled out any option which would collect the additional data. The decision was made to base the data collection on the data that was currently collected and readily available. This data has been identified in Chapter 2 in Table 2. Data Produced by the Slitter-Testers.

Another factor that was taken into consideration was that the operators entered additional information on to the log sheet, which the machine could not determine automatically. An example of this is that if the machine was stopped by the operator in the middle of the evaluation cycle the machine would indicate that it had stopped, but not why it had stopped and the operator had to enter the reason on the manual log sheet. It was important that this information could be captured electronically by being entered into a computer by the operator.

CHAPTER 5. SUMMARY OF OPTIONS FROM THE FEASIBILITY STUDY.

This chapter compares the benefits, costs and drawbacks of each option, and outlines the reasons for selecting the preferred option.

Before discussing each option it is useful to outline the considerations which affected the eventual decision.
The cost of all the options were relatively low, the highest estimate being £10,500 (or approximately the annual cost of one junior engineer at the time of the project), and the lowest estimate being about £4,000. There were widely differing time estimates from 7 months for option 1 to 18 months for options 4i) and 4ii).
A crucial factor in the selection of which option to implement was the probability of success of the option. On this criterion option 4i) and 4ii) had a lower likelihood of completion within the project timescales. This was taken into consideration.

5.1. Summary of Options.

Option 1. To Standardise the Slitter-Testers.

This proposal was supported by the electronic engineering and maintenance staff as it would standardise the host computers and the slitter-tester units, allowing interchangeability of components, and also providing a spare computer. While problems due to computer faults were few, the provision of a new computer would have allowed in-house development of a new system, and reduced dependence upon the original supplier for future amendments. The total cost of this option was relatively high (in comparison with the alternative options) at £10,500.

The total cost for Option 1

£10,580

Total estimated implementation time 6-7 months

Option 2. To Transmit Data from the Slitter-Testers via a Data Buffer to a Personal Computer.

This option presented few technical problems as the original machine and software supplier would be modifying the existing software to re-transmit the test result data. The data would have been received via a sequencing buffer into an IBM PC or compatible. This reduced software development time, allowing concentration on the setting up of the communications hardware, and the processing of the data into reports. However the original software supplier could not commit to a firm date for the completion of the software modification.

One slitter-tester would have required a minor hardware modification in addition to the generally applicable software modification. A flexible reporting system would have been implemented on the IBM PC using a commercially available database package such as DbaseIV. Some information identified in the feasibility study as important, namely the operator entered data, would not be collected by this system. This option avoided most of the problems presented by the fact that the slitter-testers were not standard.

The total cost for Option 2
£6,580

Total estimated implementation time (including manufacturer's software modification)	7-8 months

Option 3. To use any Existing Equipment.

This option proposed to use any existing equipment to analyse the data produced by the slitter-testers. It was not feasible for two main reasons :

firstly, that there was no spare capacity available on the main computing facility at Xidex;

and secondly, that the floppy disks that the data was be recorded on could not be read by any equipment already installed within Xidex.

Option 4. To Use the RS232 Diagnostics Port/To Reprogram the Operation of the CPU within the Unit.

Option 4i). To Use the RS232 Diagnostics Port.

This option would have provided valuable additional information as the errors that occurred on the tape could have been logged against time and thus mapped to an approximate longitudinal location on the tape. This could have proved a useful facility in assessing production problems. However, it would have required a heavy investment in time as an electronic circuit would have had to be designed, constructed and tested, to receive data during the evaluation cycle and then transmit that data to a personal computer on the operator's desk at the end of the test run. The personal computer however, would be programmed to present the data to the operator in an improved manner, that is in a way which reduced time spent looking for real and potential faults. The data would then be transmitted to a central data processing computer, which would be a personal computer with a more powerful processor and more storage capacity than those on the operator's desk. This central facility would store and process the data. All currently collected data would be available with the addition of the data logged against time, and the data that needed to be entered by the operator.

The total cost for Option 5.4.1.	£6,000
Total estimated implementation time	18 months

Option 4ii). To Reprogram the Unit Central Processor.

This option provided the same benefits as 5.4.1. but instead of development time to design and construct add-on boards as in 5.4.1., a considerable investment in time was needed to reprogram the central processing unit within each slitter-tester unit. The total estimated time for this 18 months, which was unacceptable within the 2 year time scale of the project, given that 6 months of the project had already elapsed. Little or no margin would have been left to deal with potential problems or delays.

The total cost for Option 5.4.2.		£3,800
Total estimated implementation time	18 months	

Option 5. Connecting to the RS422 Communications Line.

This option involved little interference with the slitter-testers, with the only physical connection being into a terminal block. The interpretation or decoding of the transmitted data was not seen to be problematical, and the total cost was comparatively low. The option allowed the development of an improved operator interface to the slitter-tester, also allowing the operator to enter useful information into the computer and providing the installation of a separate central data processing computer for report generation.

Total cost for Option 5.5.

£4300

Total estimated implementation time

9 months

5.2. Discussion of the Selection of Option 5.

Following on from the feasibility study described in Chapter 3, and the investigation of actual data and information requirements described in Chapter 4, it was obvious that the most important data requirements were for those items of data that could currently be collected. The additional items were assigned a high priority in the investigation performed in Chapter 4, but due to the long timescales necessary to implement these options these items were considered to be potentially useful rather than absolutely necessary. Given this, the options which involved collecting data which was not currently available were not progressed as they involved extensive interference with the operation of the slitter-tester, or extensive time-scales. A period estimated to be 18 months (without problems) would be required for development before any data could be produced by options 4i) and 4ii). A more suitable option was available and so these options were discarded. The options discarded at this stage were :

i) option 4i) to use the RS232 diagnostics port;

ii) option 4ii) to reprogram the CPU in the unit;

iii) any requirement to collect the additional data items discussed in Chapter 4 Section 3, namely the amplitude of the signal read back from tape, longitudinal error mapping, rewind tension, tape width and tape cleaning vacuum level.

It was seen to be important to collect, by computer, information that the operator would know which would have to be entered manually. These are detailed in Chapter 4 section 4.2. "Information not Automatically Available from the Slitter-Testers." These were tapes not certified correctly, or rewinding problems, or web length problems.

These criteria reduced the number of acceptable options to 2, these being option 1, to standardise the slitter-testers and option 5, to connect to the RS422 communication line. Option 2, to re-transmit the results from the PDP-11 computers to a personal computer did not allow the manual entry of data, and so was rejected.

Option 1 involved a large investment in money (£10,500) and re-programming the operation of the host computers. This represented an unacceptable level of interference with a valuable, operational machine, and so was rejected.

Option 5, to connect to the RS422 communications line linking the slitter-tester units to the host computers could meet all the more important information requirements and offered a definite enhancement of the operator interface. This was estimated as a relatively low cost option which could be implemented successfully within the time-scale allowed by the project. It also represented a low risk option with little disruption to the production process.

CHAPTER 6. REPORTING REQUIREMENTS AND SYSTEM SPECIFICATION

The investigation performed for the feasibility study and the investigation to assess which additional data could practicably be captured were used to draw up a specification for the new data collection and reporting system.

The first stage of defining a specification for the hardware and software had been completed in outline for the feasibility study, in order to estimate the cost of and development time required for each option. The items of data available had been identified. These now had to be re-defined into categories: those items needing to be reported on-line to the operator, in order to enhance the operator's ability to identify machine faults, and those needing to be reported on a longer time-scale for production management or maintenance purposes.

In addition it was desirable that ad-hoc queries could be addressed to the data collected for the current reporting period and also for historical data. The most suitable medium for achieving this was investigated.

This section defines reporting requirements, on-line and regular, and briefly discusses the commercially available personal computer based packages available which could provide a regular reporting and query addressing facility.

6.1. Reporting Requirements.

The data collection system had to be designed to meet three categories of reporting requirements: on-line; regular; and irregular reports.

The difference between the on-line and regular categories lay in the time base, the machine operator needing to know of any faults or potential faults as they occurred, while the longer time based regular reports were required to condense large volumes of data. This would enable them to be subjected to statistical analysis looking for longer trends. Irregular requests would constitute queries seeking to address particular problems with these requests having to be formulated to address that specific requirement.

6.1.1. On-Line Reporting Requirements.

The slitter-tester operator would have to refer to the microcomputer which provided the new data collection and analysis system after every evaluation run of the machine. The new system had to provide information which could be readily assimilated and understood, providing the operator with a summary of information about the most recent evaluation run.

The computer system already present on the DEC PDP—11 computer provided all the information available from the previous run, but in a manner that was unhelpful in several respects, not least the fact that much important information had to be searched for. The method of searching was by calling different pages, or screens, on the computer system. As the new data collection system was not to replace this existing system it was felt unnecessary to duplicate the old system in many ways, or to present a plethora of information which would not be readily assimilated.

A requirement was identified to provide an analysis for the purpose of coating audits. At regular intervals, a newly coated web was slit on a slitter-tester, and the results used to assess the grade of that web. The web was then categorised as either green, blue or red. A fuller explanation of the coating audit system of grading can be read in Chapter 2 Section 2.3.2.1.

The coating audit was performed by printing out detailed results from the particular evaluation run in question. The results were then plotted manually to show a graphical plot of 6250 BPI single track and 1600 BPI hypercritical errors across the web. This delayed the running of the slitter-tester as the printing operation took precedence on the computer over the evaluation procedure, thereby delaying the production process. It was anticipated that this requirement could be fulfilled by the central data processing microcomputer, in the new system, although this was not a requirement specified by Xidex.

The items of data which were considered to be important for on-line reporting are detailed in this section:

i) units not functioning correctly due to either electronic faults or faults in communication of data;

ii) units experiencing an overflow of errors where the central processor for that unit was unable to register all errors occurring on that run;

iii) stations experiencing missing coating between the two sensor markers;

iv) a calculated figure known as "Drop-outs Per Hundred" (DPH). This was calculated by totalling all errors of a certain type e. g. all 6250 BPI single track errors were grouped together to give a total. This figure was then multiplied by two to give the number of errors or drop outs that would have occurred if one hundred tapes had been produced instead of fifty;

v) totals of each grade or classification of tape, these being grade 1, 2, 3, 4, failed and, non certified tapes;

vi) stations experiencing EOT and BOT sensor marker faults. If a station could be identified as having only a BOT fault then the sensor marker could be applied by hand and the tape then retested. The normal procedure would be to disposition all failed tapes for re-certification on separate reel to reel testers. A tape with a sensor marker fault would therefore be re-tested twice, once to establish that the sensor marker was missing and once after the marker had been applied by hand;

vii) an overview of the grade or classification of each tape assigned by station. This would serve to assist the operator in detecting trends or potential faults;

viii) a graphic plot of 6250 BPI single track and 1600 BPI hypercritical errors across the web ie. from 1 to 50. A normal trend would follow the flattened U shape shown in Figure 6.1., shown below. Any deviation from this could indicate potential faults;

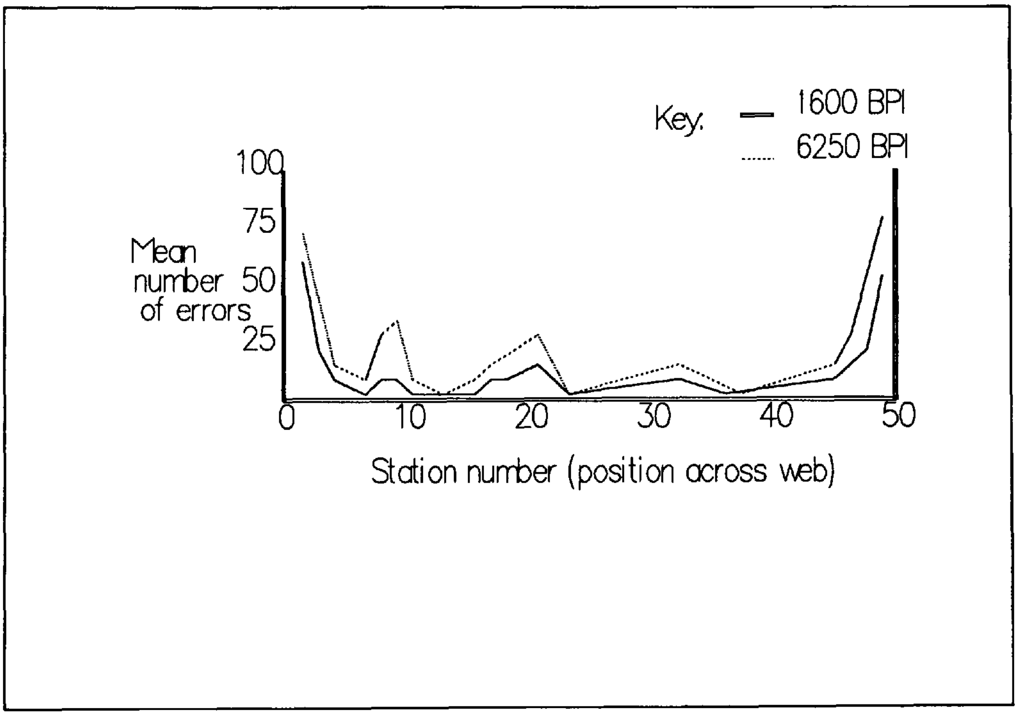


Figure 6.1. 6250 BPI and 1600 BPI Errors Plotted Across the Web.

ix) a graphic plot of grades of tapes across the web highlighting failed and not certified stations;

x) a summary of grades and product types produced as totals for that shift. This was intended to assist the operator in summing up for end of shift totals.

It was also considered important to automate the process of identifying the reason for non certification of tapes. The collection and storage of this information was seen to be a definite advantage over the PDP-11 system which simply did not cater for this aspect. Using the original system this data was manually recorded and then entered into a computer, but without identification of the units or stations which were causing faults.

The new computer system had to collect this data by allowing the machine operator to enter it as it occurred. The data that would require entering in this manner is detailed in Chapter 4 Section 4.1. "Information not Automatically Available from the Slitter-Testers".

6.1.2. Regular Reporting Requirements.

The regular reports required were basically summations of the data available. Information was required to be presented to allow totals for, and comparisons between, each shift and machine. Also daily reports presenting a summation of shift reports and weekly reports presenting a summation of daily reports. Reports also needed to distinguish between each type of product and which coating line the reel or web was coated on. This information was intended to highlight areas where improvements could be made in both machine and human performance. It was felt by the operational and technical staff that there were significant differences between the three slitter-testers in both testing, and ease of manual operations between evaluation runs. The new system had to allow the easy comparison of production figures from each of the three slitter-testers.

The information identified as requiring reporting on a shift basis for production purposes was as follows:

i) the total number of cuts performed. A standard requirement was stipulated;

ii) the type of product being slit and tested;

iii) the totals of each grade of tape for each product;

iv) the operator responsible for running the machine;

v) the number of times that the evaluation cycle was not completed and the reason for the non completion of the evaluation cycle e.g. the 1/2" edge of the web (known as "salvage") often snapped, causing a wrap around which necessitated the immediate stopping of the slitter-tester;

vi) the number of times that a web was not long enough to produce the required number of runs e.g. a full 14,200 foot reel should have produced six (6) full length runs of 2,400 tape;

vii) the number of cuts that the knifebox had performed. This could have a significant effect on the number of errors that appear at each edge of the slit tape. As the knife-box blades wear the accuracy of the edge cutting diminished, potentially causing errors;

viii) the reason for the failure of particular tapes;

ix) the percentage of time that the slitter-tester was not operational. This could be have been obtained from automatically logging the time that each evaluation run was recorded by the computer system;

x) these figures also needed to be presented using the line on which the reel was coated as a basis;

xi) the yield i.e. number of each grade of tape mapped against its position within the reel. Cut number 1 was always on the outside diameter of the reel and cut number 6 was always on the inside diameter of the reel, nearest the core. If a creasing problem occurred as the web was wound onto its reel then those tapes produced from cut number 6 would show a significant increase in creasing in comparison with cut numbers 1 to 5.

A requirement of the system was that it had to be able to produce reports regarding the performance of a reel in relation to its coating audit grade specification. Chapter 2 Section 2.3.2.1 gives a detailed explanation of coating audit methodology and logic.

There was a duplication of some items of information required for process purposes. Process monitoring was more interested in machine performance and the reasons for malfunction than yields or human performance.
The following items of information were regarded as important for process oriented shift reports:

i) recurring faults on a station or unit. These could indicate either web related faults which could be traced back to coating faults or slitting or testing faults. For example, if a unit were to register a high incidence of an error overflow condition this could represent a potential fault. For example, a slackness in the rewind tension mechanism would allow the tape to "bounce" away from the write-read head - thus appearing as 1600 BPI gross errors and possibly causing an error overflow condition. Chapter 4 Section 4.1.3. explains the effects of tape "bounce" more fully. Similarly if a station were not to detect any errors at 6250 BPI for several cuts then this could indicate a fault;

ii) a comparison of yields on a station by station basis across the web. A typical yield could be expected to produce the plot shown in Figure 6.2., shown below. Stations producing high or low average yields could represent potential problems;

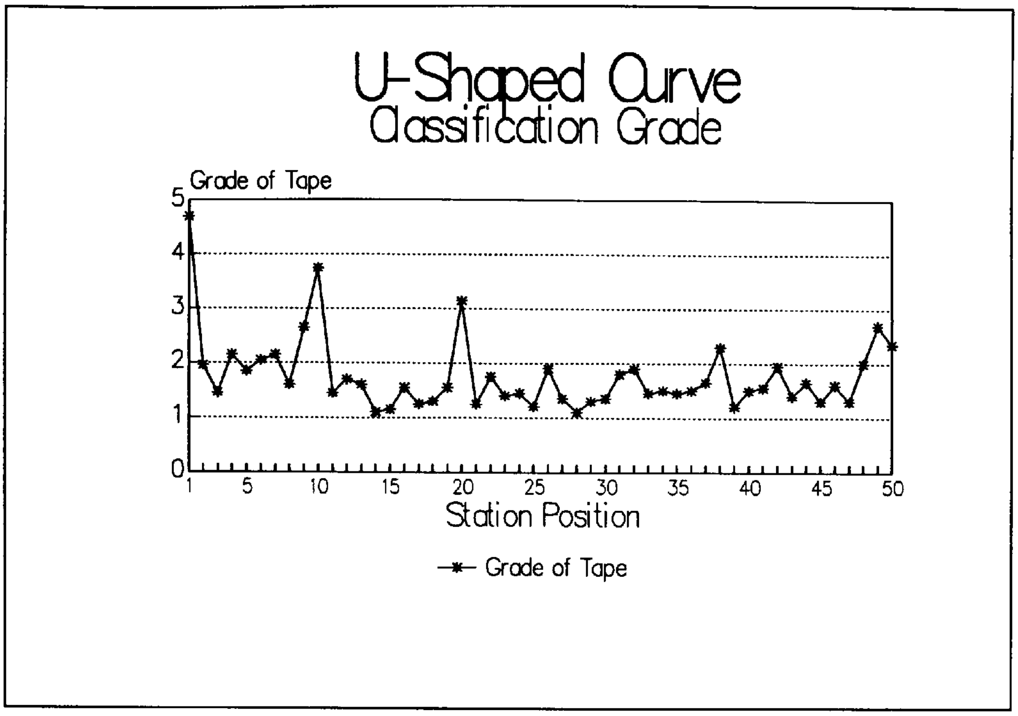


Figure 6.2. Plot of Grades Across the Web.

iii) recurrences of missing coating on a particular station could indicate web related problems, or slitter-tester problems;

iv) the accuracy of sensor marker application, both BOT and EOT;

v) the yield of the different cut positions within the web as explained in xi) in the previous section;

vi) a lateral track by track analysis. Data for each of the nine recording tracks was collected for 6250 BPI single track, 1600 BPI hypercritical and 1600 BPI write-skip errors. If the majority of errors were occurring on a disproportionately small number of tracks then this could indicate web or machine related problems;

vii) the reasons for the non-certification of tapes, or stopping of the evaluation run were important.

Quality assurance demanded reports which in general sought to use grouped or accumulated data. The following items of data were thought to be important:

i) the number of tapes with 1 error;

ii) the actual recording track(s) on which the errors were occurring;

iii) which particular faults were causing the tape to be downgraded.

iv) the range of errors on tapes;

v) averaged error figures;

vi) the ability to link coating audit results to final slitting and testing results. Coating audit results produced from a freshly coated web could be compared to the final slitting-testing results, which would take place days later, to see if the intervening period had affected web quality in any way;

vii) the ability to correlate slitting and testing results with those obtained on the machines used for quality assurance purposes. A quality assurance audit was carried out on a random batch sample of tapes. Results from the Q.A. process were difficult to relate to slitter-tester results due to increased debris removal;

viii) a sequential analysis of web yields. Webs were not slit in the sequence that they were coated. A sequential analysis would allow a more accurate assessment of coating trends to be made. It would also enable an assessment of the validity of the audit grading methodology to be made.

While many of these reporting areas overlap there were significant differences between the regular reports. The fact that they all use the same basic information helped to determine the reporting methodology. Rather than use individually written computer programs, the nature of reports indicated the use of a report generating package. As the quality assurance development was responsible for determining the classification criteria, an understanding of the disposition and types of errors would allow an assessment of the potential for altering criteria. Altering the classification criteria could have significant commercial benefits, for example, if it were found that a significant proportion of tapes classified as grade 1 actually contained only 50% of the maximum errors allowed then it might be possible to introduce a new, higher graded, classification which could be marketed at a premium (provided that sufficient demand existed for such a product.

6.2. Investigation into Packages Suitable for Regular Reporting and Query Addressing.

Individual application programs could have been written for each reporting function. A more efficient and more easily updated method was to load all the data for the stipulated reporting period into a commercially available package and produce all the regular reports from that package. It was also important that the same package should be able to apply queries to the data.

Staff within Xidex were familiar with reports produced on personal computer based spreadsheets, and a database package was also available within the company. The two different types of package were investigated by performing a survey of available personal computer based spreadsheets and databases. Where possible, evaluation copies or the actual packages were tested. The database would handle text reports, with simple calculations, and the spreadsheet would handle more complex manipulations of the data, and produce graphical output. On the basis of this survey a relational database package and a spreadsheet were selected. The packages selected, namely the Paradox relational database management system, and the SuperCalc4 spreadsheet, were the most suitable for use by Xidex personnel.

Paradox is a relational database management system which handles large volumes of data and has an integral report generating package. It also has its own programming application language which allows it to be very flexible. One of the most important factors though is that it uses a very simple, easily learned, method for addressing queries. The method used is Query By Example (QBE), where the user completes a form on the computer screen, entering an example of what he or she wants to be included in the answer. Query By Example (Zloof 1979) is often cited as an interface technique which is easy to learn and use. This enable computer naive users to formulate and address their own queries to the data, without being expert users of the package. This was a significant factor in selecting this package, as it was for use by engineering staff, who were not computing experts. The package was able to process all the files for a stipulated reporting period, storing these on a hard disk, putting all the results into a table or matrix of results. A one line summary of each file (representing each cut) was produced, for loading into the spreadsheet package.

The spreadsheet SuperCalc4 could be used for performing more complex mathematical queries. It was not suitable for processing the large volumes of data produced by the slitter-testers in the manner which was required, but possessed good graphical facilities. It was therefore proposed to use Paradox as the medium for processing the data initially. Further processing and graphical output could be produced by loading the output from Paradox, which was in summarised form, into SuperCalc4. These processes could be largely automated by the setting up of "scripts" in Paradox and "macros" in SuperCalc4. Scripts and macros are simply terms for a sequence of keystrokes or commands as a list, which can be re-run by a short sequence of commands, or by using a name or identifier to initiate the recorded sequence..

6.3. System Specification.

6.3.1. Software Specification.

The microcomputers serving as the operator interface had to :

i) receive all transmissions from the slitter-tester units;

ii) determine when evaluation test data was being transmitted, and capture that data;

iii) process the transmitted data to identify relevant items of data and extract these;

iv) present the data to the operator in a manner which allowed rapid identification of faults, and if possible, potential faults;

v) allow the operator to enter data regarding the run e.g. the reason for the non completion of the evaluation cycle;

vi) to transmit the processed data to central processing machine;

vii) to process the data at that central data processing point into reports and also allow the addressing of queries to the processed data.

The requirements for reporting are as detailed in this chapter, Section 6.1.

6.3.2. Hardware Specification.

To fulfil the software specification the following hardware was required :

i) For Each Unit :

a) 1 RS422 receiver and transmitter to connect to the RS422 communication line from the slitter-tester units to the host PDP11 computer. RS422 was selected to provide a noise resistant signal. The cabling passed through the floor which also contained power cables.

b) 1 IBM personal computer or compatible, to serve as the data collection point, operator interface, and to process the data into a format suitable for transmission to the central data collection computer using the RS232 standard;

c) cabling and connections to link item a) to item b)

ii) <u>For the Central Data Collection Point :</u>

a) 1 microcomputer capable of receiving and storing transmissions from each of the microcomputers attached to the slitter-tester units. It is essential that this computer has a hard disk to allow the storage of the large volumes of data involved;

b) 1 data buffer to store and sequence data transmissions from the slitter-tester microcomputers to the central point. The buffer was required as personal computers cannot receive transmissions on more than two ports. The buffer must be able to store data in the event that the central computer was inoperable, thus preventing the loss of data;

c) 1 tape streamer to provide a large data archive, to prevent the hard disk becoming full;

d) cabling to connect the slitter-tester microcomputers to the central data collection point.

From these rather loose specifications a tighter specification for both hardware and software could only be drawn after the stage of connecting to the RS422 line and deciphering of transmissions on the line had been completed. To perform this, a microcomputer was purchased, and an RS422 receiver and transmitter was constructed.

This chapter marks the dividing point between the investigations performed in order to understand what was required, and the practical aspects of the implementation of the system. The following chapters describe how the work performed up to this point was used in the implementation of the system.

CHAPTER 7. EXECUTION OF PLAN TO COLLECT DATA TRANSMISSIONS.

7.1."Tapping" the RS422 Communications Link.

The option selected was that described in Chapter 3 Section 3.2.5, that of connecting a communication cable to the RS422 communications link used by the slitter-tester to communicate test results to the host computer. This cable contains two pairs of wires each pair using unidirectional transmission, one as a transmission line from the host to the units, one as a receiving line from the units to the host. The diagram shown in Chapter 3 as Figure 3.3., and reproduced below as Figure 7.1., shows how the slitter-tester and host computer communication was accomplished.

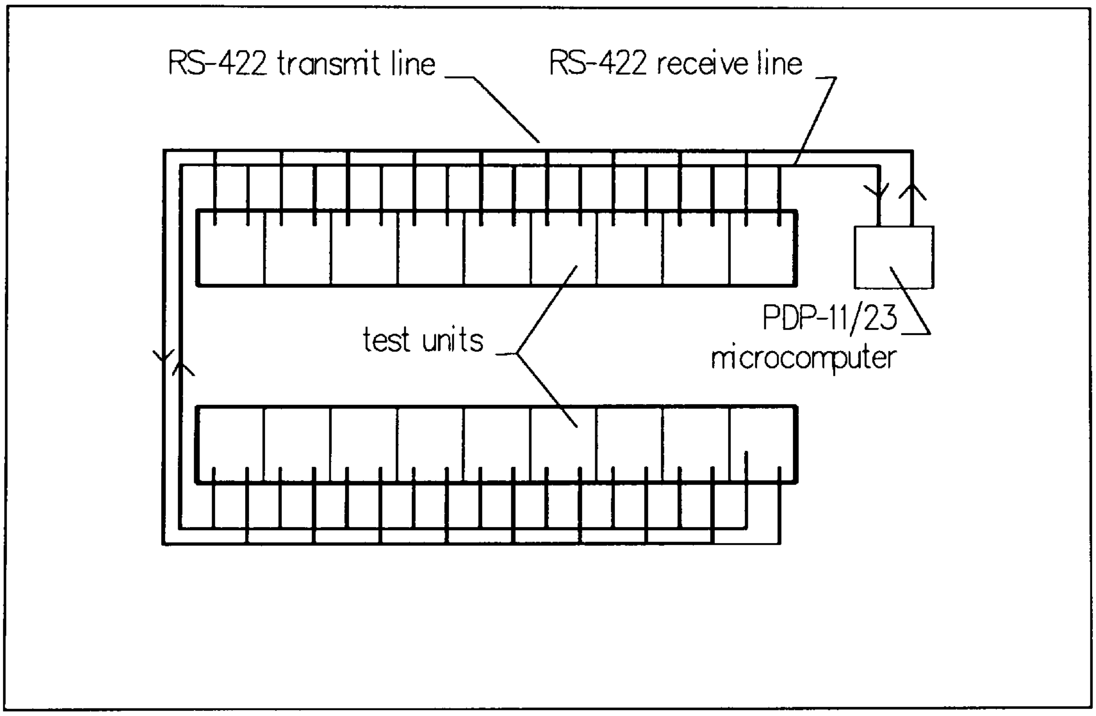


Figure 7.1. Slitter-Tester to PDP11 Communications.

The host computer transmitted along the pair of wires labelled RS-422 transmit line and the units respond by transmitting along the pair of wires labelled RS-422 receive line.

As the project was only concerned with the messages transmitted from the units to the host computer the decision was taken to connect only to the pair of wires carrying messages from the units (the line labelled RS-422 receive line in Figure 7.1.) This would allow the observation, collection and detailed analysis of any transmissions from the units to the host computer. At this stage the format and content of the transmissions were completely unknown. The paired wire connected to the communications link was then to be linked to an IBM Personal Computer with an RS422 receiver card installed in it to allow reception of this signal. A block diagram of the proposed connection is shown in Figure 7.2.

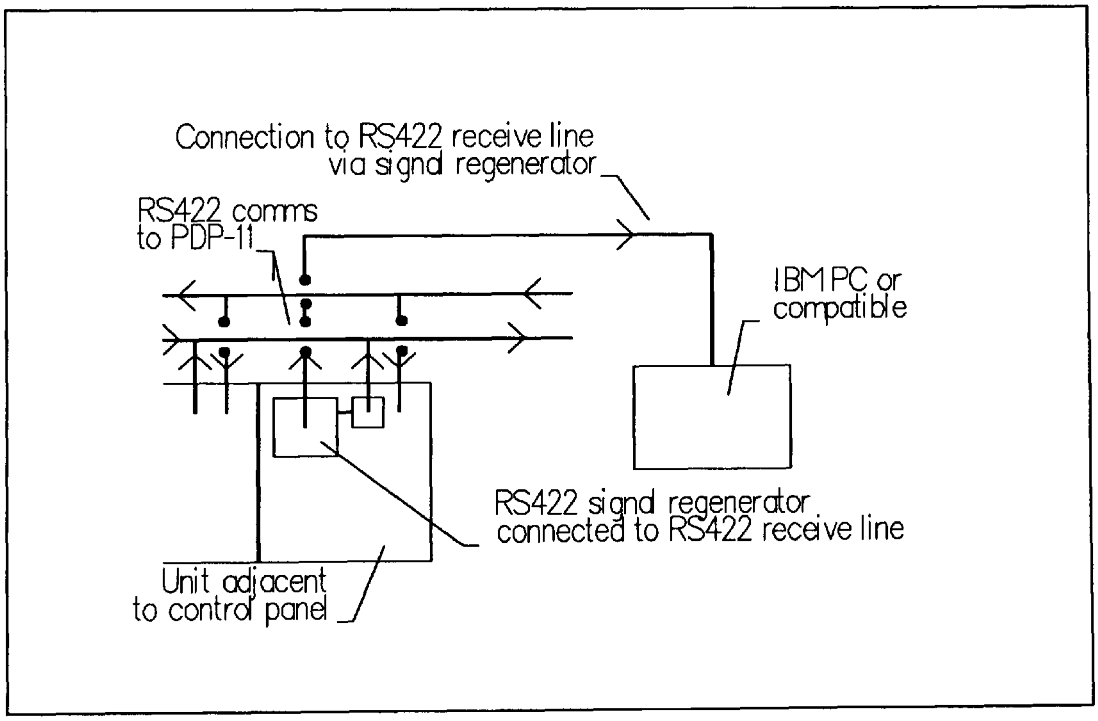


Figure 7.2. Block Diagram of IBM PC to RS422 Communications line connection.

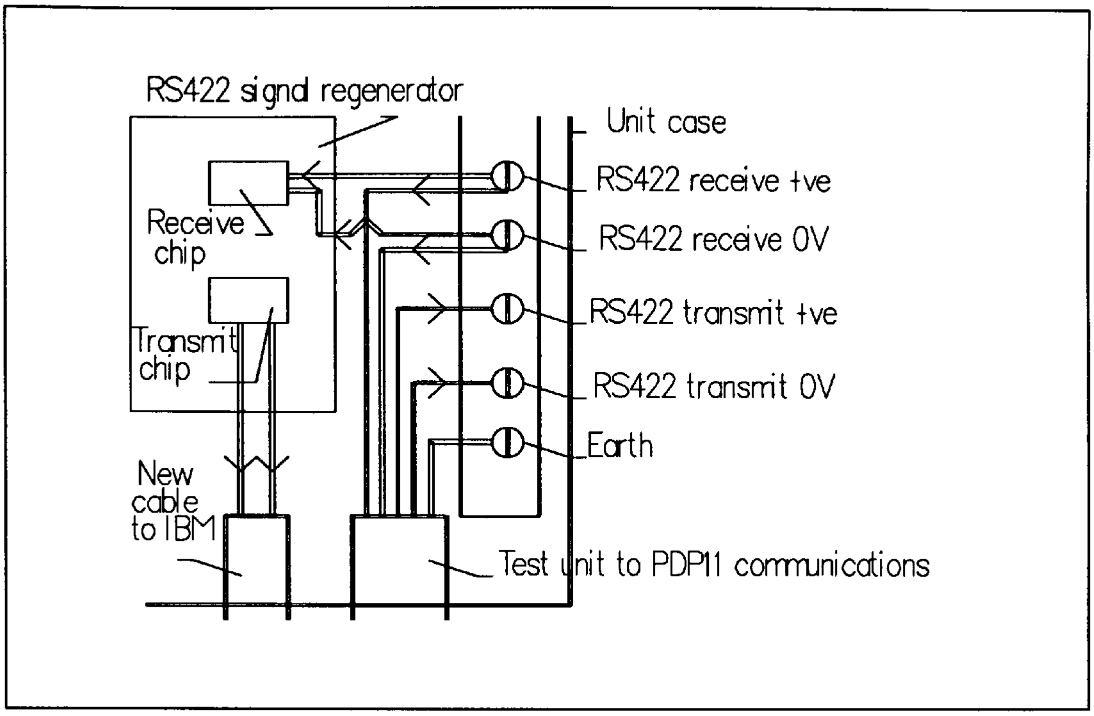


Figure 7.3. Siting and Connection of RS422 Signal Regenerator.

7.2. RS422 Signal Regenerator.

The RS422 communications link between the slitter-tester units and the host computer was prone to electrical problems such as noise and voltage spikes. While these problems had been virtually eliminated by the use of communications cable with better screening properties than that originally used, the connection of a cable in parallel to that installed was perceived by Xidex electronics staff to be a potential source of problems. It was decided to connect to the line by developing a circuit to receive the signal close to its source in the units and to regenerate the signal to be transmitted to the IBM PC. The circuit was designed to be connected in to the existing RS422 communications link at a terminal block in one unit, to have its own external power supply, and to be capable of reliably transmitting through an electrically noisy environment at distances of 60 feet or more. The block diagram of the circuit is shown in Fig. 7.4.

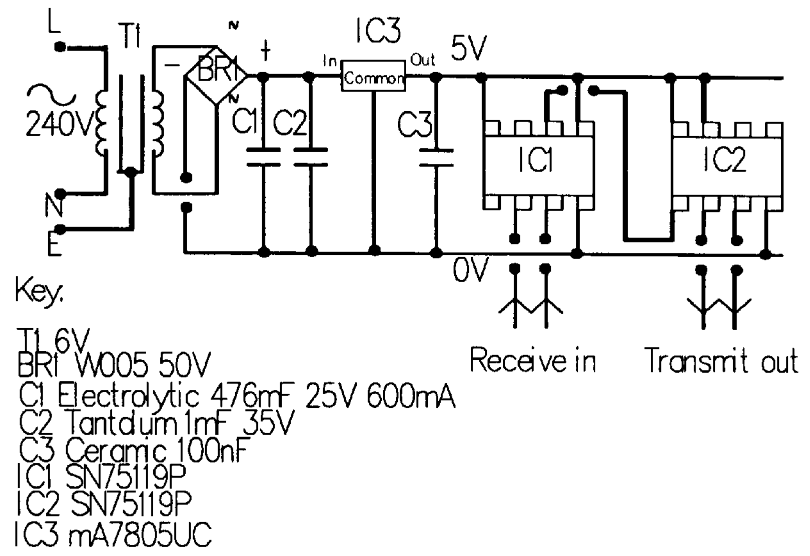


Figure 7.4. RS422 Signal Regenerator Circuit Diagram

The circuit was designed to be as compact as possible, to be contained within a small box in a unit. The design was implemented and 4 boards were assembled to allow one for each slitter-tester and a spare.

7.3. RS422 Communications. Results and Observations.

After a reliable hardware connection to the RS422 communications had been established it was necessary to decipher transmissions on that line. Preliminary observations were made by attaching an IBM PC XT to the RS422 signal regenerating circuit described in 7.2. A communications package with adjustable communications parameters was available and so this was used to receive transmissions.

7.3.1. Initial observations.

With the RS422 generator connected to slitter-tester 3 the received data did not make any sense. On comparing the data with the data sheet for the transmitting chip which dictates the order of transmission it appeared that the differential lines carrying the RS422 signal into the signal generator might be reversed.

Reversing these wires produced sensible data, as described in Chapter 8 - Data Transmission Formats. However, this data seemed incomplete with the 5 byte messages being truncated. The DEC PDP11, however, was receiving data correctly. As the maximum baud rate achievable by an IBM PC XT, which has the Intel 8086 microprocessor as a central processing unit, was 9600 Bits Per Second (BPS) or Baud and the transmission rate from the units to DEC PDP11 was 9600 BPS it was decided to test this as being the possible source of the problem by replacing the IBM PC XT with an IBM PC AT which operates more quickly, using a 16 bit Intel 80286 microprocessor. The flow control parameters of the software package being used to receive data were set so that no hardware handshaking was performed. This produced longer streams of correct, decipherable data, but which were still incomplete with messages being truncated and the software behaving in an unpredictable manner. This was determined to be due to one particular character being interpreted as a control character by the communications package, causing it to cease receiving data. It was decided to write an application program to perform the initial collection and analysis of transmission and hence circumvent the problem.

7.3.2. The Program to collect data.

A program was written in IBM Advanced Basic, an interpreted language. The program opened the communications port into the IBM PC AT, and displayed the received data in hexadecimal format. This was necessary as the transmitted data was in character format and contained indecipherable non-printing characters, including control characters and was impossible to interpret directly. The program written could not receive and process characters as fast as they were being transmitted, thus leading to the rapid filling of the communications buffer, and the loss of incoming characters. To eliminate this problem the program was compiled using a program written by Microsoft. The program QuickBasic 3.0, is a BASIC compiler, which converts BASIC statements into directly executable code, greatly enhancing the speed of operation of the program. This produced data which was largely correct, with one bit out of each 5 byte message being corrupted. An analysis of the problem indicated that the fault lay in the interpretation of the parity bit. The transmission format was known to be 8 data bits and 1 parity bit. Adjusting the line control register of the communications port on the microcomputer by use of a software command produced the correct interpretation of messages. The time taken to write the characters to the screen proved to be detrimental to the reception of the whole data transmission. To ensure that the complete data transmission was captured a communications buffer of 50,000 bytes was set and the transmission received was saved directly to disk for later analysis. Analysis of the whole of the transmission revealed that the transmission of data followed a pattern whereby the PDP11 repeatedly transmits messages to the units. These messages interrogate units 1 and 2 while the slitter-tester is in the evaluation cycle. It did this by asking their status, with the results of the test or evaluation data being transmitted at the end of the run, a "busy" message being sent during a run. The analysis of the transmission established that the part of the transmission that was relevant to this project, that is the part containing the test result data, varied between 40,000 and 60,000 bytes depending on which slitter-tester was being used. Continued observations and analysis enabled the exact format of the transmissions to be described. These are shown in detail in Chapter 8.

"Data Transmission Formats", where the different lengths and content of data transmissions are also discussed.

CHAPTER 8. DATA TRANSMISSION FORMATS.

Once it had been established that correct transmissions were being received those transmissions had to be deciphered. Due to contractual difficulties only limited information was available to assist in this task and so this aspect involved a large degree of investigation and experimentation. Using the RS422 repeater circuit installed into slitter-tester 3, the data patterns were observed and collected using an IBM PC, and then analysed by hand.

As the communications to and from the units are via a MOSTEK SCU20 RS422 receiver, the data sheet for that chip was referred to. Appendix 3 consists of a extract from the data sheet for the chip.

The machine manufacturer co-operated in the analysis of test data by indicating that transmission of test data is in unit sequence. Within that sequence, the data for each unit is transmitted in the following order : summary of all stations; top; middle; then bottom stations. The machine manufacturer also offered the crucial information that each message received from the unit is a 5 byte sequence. The interpretation of transmissions proved to be a painstaking task of analysing whole data files, each containing at least 40,230 bytes from slitter-testers 2 and 3 and 59,670 bytes from slitter-tester 1. The reason for the difference in length of the data files is explained in more detail later in this chapter. The data content of the file was already known from the investigation for the feasibility study, and is described in Chapter 2, Section 2.6.1. and is shown in Table 2.

8.1. Transmission on the Receiving Line.

Each item of data transmitted on the RS422 line from the units to the host was identified as part of a message, the message being constructed of 5 sections, each being represented by one character, or byte.

It was realised that the unit identifier is produced by adding decimal 32 to the actual unit number e.g. unit 1 is represented by 33 etc.

The format for transmission is ASCII character. A typical message would be (in hex):

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5
02	21	04	40	67
Message header	Unit id.	Command	Data	Linear redundancy check

The linear redundancy check (LRC) is produced by exclusive-oring the bit patterns of the first 4 bytes of the message together to use the example given above.

Hex	Binary	Function
02	00000010	Command
21	00100001	Unit identifier
04	00000100	SCU Command
40	01000000	Data byte
67	01100111	Linear redundancy check

8.2. Transmission Sequences.

Over a period of time clear transitions in the messages became apparent and these were matched to the status of the slitter tester.

While the slitter-tester is running the PDP11 interrogated units 1 and 2 of the slitter-tester alternately. These responded usually (apart from the transmission of test results) with the message (in hex) 02 21 04 40 67 for unit 1 and 02 22 04 40 66 for unit 2. The different units are indicated by the number of the second character, 20 (hex) and 21 (hex) representing units 1 and 2. The linear redundancy check adjusted by one bit from 67 (hex) to 66 (hex) in accordance with the bit pattern of the preceding 4 bytes. When the slitter-tester had completed the evaluation and test cycle and is ready to transmit test results the results are transmitted in a serial sequence from unit 1 to unit 18. The start of this transmission of test results in indicated by the message 02 21 01 50 72 (in hex) for unit 1.

8.2.1. Mostek SCU20 Port Set Up.

It was realised that the transmission of data from each unit involved apparently spurious messages, which bore no relation to actual test data transmitted.

A typical transmission for one unit is shown in Appendix 4. The purpose of these extra messages was resolved by consultation of the data sheet for the SCU20 communications chip in each unit. To transmit test data the SCU20 has to load that data from the CPU in the unit, after setting up the CPU to download the test data it is holding. These commands are transmitted from the PDP11 and echoed on the receive line which is the line being monitored. The series of commands is identical for each unit and so allowed the easy separation of each unit's data from the transmitted file.

The normal sequence of commands transmitted to (and echoed from) each unit for the start of test data transmission is as shown:

1. load port 4 with a hex value of 50
2. read port 0 with a hex value of 42
3. load port 0 with a hex value of 74
4. read port 0 with a hex value of 08
5. read port 0 with a hex value of 29
6. read port 0 with a hex value of 21

The sequence shown above precedes the transmission of test data results for the top, middle and bottom stations for that unit.
After the transmission of a summary of results for that unit, the PDP11 has to command the MOSTEK SCU20 chip to transmit a detailed analysis of test data.

This is performed by the sequence

1. read port 0 with a hex value of 40
2. load port 4 with a hex value of 46
3. read port 4 with a hex value of 42
4. load port 0 with a hex value of 4A
5. read port 0 with a hex value of 08
6. read port 0 with a hex value of 29
7. load port 0 with a hex value of 21

This is followed by the transmission of a detailed analysis of which tracks the errors occurred on.

The transmission for each unit is ended by the command read port 0 with a hex value of 40 which indicates that the unit is in the ready state. The transmission for the next unit follows immediately. The total transmission of test result data for each unit consists of the following sections:

i) The setting up of the SCU20 transceiver chip prior to the transmission of a summary of results for all three stations within the unit;

ii) the transmission of the summary of results for that unit;

iii) the setting up of the SCU20 transceiver chip prior to the transmission of detailed track by track results of the data for all three stations within the unit;

iv) the transmission of the detailed track data results;

v) the transmission of the unit waiting character.

The transmission of test data uses the following sequence of commands for slitter-testers 2 and 3. This is echoed down the receive line.

1. load port 0 with a hex value of 24
2. read port 5 with a data byte A
3. read port 0 with a hex value of 20
4. read port 5 with data byte B.

Slitter-tester 1, the prototype machine, uses a less efficient sequence to transmit data, the sequence being as follows:

1. load port 0 with a hex value of 24
2. load port 0 with a data value of 20
3. read port 5 with a data byte A
4. load port 0 with a hex value of 24
5. load port 0 with a hex value of 20
6. read port 5 with data byte B.

8.3. Representation of Numbers Over 255.

As the transmission format is ASCII character, and the maximum number that can be represented by one byte is 255 the method shown above is used, i.e. by having data bytes A and B to represent one number. The actual test results are obtained where appropriate by performing an algorithm on these numbers. Where data byte B is zero then the result is that represented by data byte A. Where data byte B is non-zero then the result is produced by the following algorithm:

data byte A + (256 * data byte B)

For example the decimal number 774 is represented by data byte A being 6 and data byte B being 3

6 + (3 * 256) = 774

8.4. The Complete Transmission of Data for Each Unit.

A clear transmission sequence becomes obvious for each unit if the non-relevant bytes and messages are ignored. This sequence is as shown below:

1. unit status
2. unit error code
3. top station summary of 6250 1 track errors
4. top station summary of 6250 2 track errors
5. top station summary of 6250 multi-track errors
6. top station summary of 1600 BPI hyper-critical track errors.
7. top station summary of 1600 BPI write/skip errors
8. top station summary of 1600 BPI gross errors
9. middle station summary of 6250 1 track errors
10. middle station summary of 6250 2 track errors

11. middle station summary of 6250 multi-track errors
12. middle station summary of 1600 BPI hyper-critical track errors.
13. middle station summary of 1600 BPI write/skip errors
14. middle station summary of 1600 BPI gross errors
15. bottom station summary of 6250 1 track errors
16. bottom station summary of 6250 2 track errors
17. bottom station summary of 6250 multi-track errors
18. bottom station summary of 1600 BPI hyper-critical track errors.
19. bottom station summary of 1600 BPI write/skip errors
20. bottom station summary of 1600 BPI gross errors
21. top station classification of grade
22. EOT/BOT/Coating status
23. middle station classification or grade
24. EOT/BOT Coating status
25. bottom station classification or grade
26. EOT/BOT Coating status
27. slitter-tester identifier

28 to 36. top station 6260 BPI 1 track errors track 1-9

37 to 45. top station 1600 BPI hypercritical errors track 1-9

46 to 54. top station 1600 BPI write/skip errors track 1-9

55 to 63 middle station 6250 BPI 1 track errors track 1-9

63 to 72 middle station 1600 BPI hypercritical errors track 1-9

73 to 81 middle station 1600 BPI write/skip errors 1-9

82 to 90 bottom station 6250 BPI 1 track errors track 1-9

91 to 99 bottom station 1600 BPI hypercritical errors track 1-9

100-109 bottom station 1600 BPI write/skip errors track 1-9.

This data matches the table of information shown in Table 2 which lists all the information produced and collected by the slitter-testers.

A typical transmission from slitter-testers 2 and 3 was found to be 40,230 bytes, or 2,235 bytes transmitted to convey 109 pieces of information for each unit. A typical transmission from Atlas 1 was found to be 59,670 bytes or 3,310 bytes transmitted to convey 1 units information. The difference between the slitter-testers is accounted for by the different pattern of commands required to set-up the MOSTEK SCU20 chip to transmit the test results as shown above in section 8.2.1. The prototype machine, slitter-tester 1, used a less efficient sequence of commands to transmit the data as is shown in the example below.

Atlas 1 transmission sequence for one complete item of data (shown in hex):

0222002404 0222002000 0222063412

data byte 1

0222002404 0222002000 0222060224

data byte 2

Atlas 2 and 3 transmission sequence for one complete item of data (shown in hex):

0222002404 0222063412

data byte 1

0222002404 0222060224

data byte 2

8.5. Transmission of Non-Test Data.

Observation and analysis of transmissions on the receive line from the units was performed during full normal production running of the slitter-tester. This enabled the observation of some transmissions which were not test data transmissions, these arising as a result of miscellaneous operator commands which concern the correct operation and performance of the slitter-tester units. The operator determines the criteria used to classify the tapes (as described in Chapter

2, Section 2.4.3.), and to determine the level of signal read from the tape to be used as a threshold for determining whether or not a drop out or error has occurred. As a result the units addressed respond with additional transmissions not containing tape test data. These are described and summarised below. It should be noted that all the operator initiated actions cause the transmission of commands to the unit(s) addressed, and the echoing of these commands on the receive line, and in the case of calibration and validation, any results to be returned.

8.5.1. Calibration.

The command to calibrate is normally used by a technician or engineer to set the head gains for accurate testing of tape. Calibration results are transmitted to the host computer and stored on the systems disk to be reloaded when required into the unit. This sequence of commands is echoed down the receive line, commencing with the sequence in hex 0221014361 and continuing with the test results from all stations and the calibration results from the unit addressed.

8.5.2. Classification.

The operator enters the classification criteria to be used to determine grades or classification of tapes according to operating instructions. This is explained in more detail in Chapter 2, Section 2.4.3. This sequence of commands is echoed down the receive line, commencing with the sequence in hex 022101496B and continuing with the classification criteria entered.

8.5.3. Initialisation.

Initialisation is performed either automatically during powering up of the system or on request. The initialisation procedure transmits head gains, threshold and classification criteria to the unit, using default values contained on the PDP11's system disk. Initialisation may be used to individual units or all units. This sequence of commands is echoed down the receive line, commencing with the sequence in hex F9AA and continuing with the response from each unit in turn.

8.5.4. Threshold transmission.

The operator enters the threshold criteria to be used to determine at what level a drop-out or fault is deemed to have occurred. This is explained in more detail in Chapter 2, Section 2.4.2. This sequence of commands is echoed down the receive line, commencing with the sequence in hex 0221015476 and continuing with the threshold levels entered.

8.5.5. Validation procedure.

The validation procedure causes all units to perform a self-test of hardware and software contained within each unit. This sequence of commands is echoed down the receive line, commencing with the sequence in hex 0221015371 and continuing with the response from each unit in turn.

8.6. Non-Standard Transmissions.

Variations were observed in the transmissions monitored on the receive data line. These could be subdivided into two categories, these being faults in test data transmission and valid non test data transmissions.

8.6.1. Anomalies in Test Data Transmission.

Variations were observed in the transmission of test data results. This could be attributed to two distinct causes, timing delay within a unit, or faulty communications.

8.6.1.1. Timing Delay.

Within the setting up of the SCU20 transceiver communications chip in each unit prior to the transmission of the test data results, a time delay usually occurs before a response is generated to one of the commands. The normal result of this is that the PDP11 repeated the command, by which time the CPU within the unit is able to respond correctly. This time delay was seen to be reduced at irregular, but frequent intervals. This is detected by the transmission of the particular message once and not twice. Double R Controls explained this delay as depending upon critical timing within the CPU board within the unit, but that this did not represent a machine fault. This had to be accounted for in the design of the new data collection and processing system.

8.6.1.2. Faulty Communications.

Errors in communications between the units and the host computer are dealt with by the re-transmission of all test data for the unit. A fault in communications can be attributed to one of several causes:

a) an incomplete message resulting in an incorrect linear redundancy check byte;

b) electrical noise in the transmission cable resulting in an incorrect or incomplete message;

c) failure of the unit to transmit.

If data from a unit is not received correctly then two re-transmissions are attempted before continuing the transmission sequence by requesting transmission from the next unit.

A request for re-transmission is indicated by the appearance of the bytes (in hex) 02F1. This is then followed by the sequence, using unit 1 as an example.

message 1 0221015270

message 2 0220045374

message 3 0221005878

message 4 022104193E

message 5 022104193E

message 6 022104290E

message 7 0221002102

This is followed by a correct complete data transmission for that unit.

8.6.2. Valid Non-Standard Transmissions.

Transmissions were observed which did not match the standard pattern but were valid. These fall basically into one of two types, either having additional information transmitted or incomplete information.

8.6.2.1. Additional Information Transmitted.

If the calibration of a unit is requested then the results for that test are transmitted for each unit but with the head gains for the calibrated unit being transmitted immediately after the test data had been transmitted. This effectively increases the length of the transmission.

8.6.2.2. Communications Hardware Faulty or Absent.

As stated earlier, the communication between the units and the host computer are via an RS422 transmit/receive chip. If this chip is not functioning or absent then results will not be communicated, although the unit functions correctly otherwise.

8.6.2.3. Unit not Initialised.

Each unit needs to be initialised before it can test correctly. The initialisation procedure loads test criteria, thresholds and head gains from the system disk of the host computer to the CPU card of the unit, where these are maintained as long as there is power to the unit. Switching a unit off necessitates initialisation. If the unit has been switched off then a message is transmitted indicating this state. This is as shown in hex using unit 5 as an example.

02 25 FE D9

This is re-transmitted twice before the next unit in sequence is interrogated.

8.7. Summary.

After a lengthy process of analysing test data transmissions from all machines, it was now possible to capture these transmissions accurately, store and process them on a personal computer. Initial data capture was performed by reading all transmissions on the RS422 line, starting just before test data transmission commenced, and saving this to disk. The analysis allowed a modified program to selectively capture test data, with the data being written to a file on the hard disk only when a valid test data transmission was detected. Leading on from this, the relevant data stored in this files could be extracted and processed into the forms identified as being required by the earlier investigation process.

The key facts arising from this analysis were that the transmission from slitter-testers 2 and 3 are highly similar, but differed from slitter-tester 1 in the format and length of the file transmitted. Each file contained data transmitted in order of unit from 1 to 18 and within each units data the order is summary, top, middle and bottom stations. Each file contained 109 items of data for each unit, a total of 1962 items of data for each run of the machine. The data lengths are not exact for the reasons explained in this chapter, and so the data could most efficiently be extracted by selectively extracting the data items in the sequence of transmission, and processing those items only. The usual length of the data file is 40,230 bytes for slitter-testers 2 and 3 and 59,670 bytes for slitter-tester 1.

The exact order of transmission for each unit is shown in Chapter 2 Table 2. or section 3 of this chapter.

CHAPTER 9. THE OPERATOR INTERFACE.

During the feasibility study it was recognised that the information contained within the test data was not being presented to the operators in the optimum manner. An example is that, while the operator would be informed on the first screen to be displayed after a run was completed that a unit had malfunctioned, this figure would be in the form of a total percentage, and would not identify which unit was faulty. The operator would then have to search through the system screen by screen to identify the unit(s) at fault. As each unit occupied one screen then up to 18 screens would have to be searched.

The microcomputers attached the slitter-testers had to capture the test data and transmit it to the central data collection point. The operators had to enter a reel code into the computer, in order to identify the web and the position of the cut within the web. They also had to read the test results from each run of the machine. This provided an opportunity to implement an enhanced interface between the operator and the slitter-tester, which would improve the operator's understanding of how the slitter-tester was performing. The primary aim of the interface was to reduce the time spent searching the computer for important information and to reduce waste by identifying potential problems more rapidly.

An operator interface was implemented on the microcomputers attached to the slitter-testers with a separate system being implemented on the central data collection machine.

This chapter discusses the development of the operator interface and the selection of a suitable programming language. The chapter is divided into sections:

i) the software development cycle - a brief outline of the phases of development;

ii) the operator interface - discusses the general design considerations;

iii) the operator requirements from the system;

iv) the hierarchical design of the new system;

v) the selection of the programming language and the operating system.

In order to meet the requirements of this project the software development cycle had to be planned, and the computer system design carefully tailored, to meet the requirements of the users at machine operator and engineering levels. Emphasis was placed upon enhancing the operators understanding of the slitter-tester as it was clear that improvements in this area would reduce waste by allowing more rapid fault finding.

At this point it was necessary to determine the purpose of the software, the most suitable programming language to implement the system in, and to ensure that the system would be flexible enough to meet future information requirements.

Included in the development of the system was an element of operator training, necessary to familiarise the operators with the design and use of the software. This was partially achieved by involving the operators in the design of the system, and partially by instruction and guidance while using the system.

9.1. Software Development Cycle.

The software element of this project constituted a relatively small scale development, being developed and implemented over a period of 1 year.

There were four phases to the project; conceptual, implementation, evaluation and operational phases.

9.1.1. The conceptual phase used the requirements for the system to produce a specification and plan for the project.

9.1.2. The implementation phase involved the specification and writing of the programs which constituted the operator interface to the slitter-tester.

9.1.3. The evaluation phase consisted of the presentation of a prototype system to the operators and the modification of that system based upon the feedback from the operators.

9.1.4. The operational phase involved the running and monitoring of the system's usage.

9.2. The Operator Interface.

The slitter-tester operators were required to use the new computer system, both to use the data and information it could provide and to enter data into the computer for further analysis. The interaction between the operators and the computer had to be simple but effective for two main reasons: firstly to allow the relatively computer-naive operators to use the system easily and secondly to be effective in the sense that it could be seen to be assisting them in running the slitter-tester. Cuff (1980), quoted in Nickerson (1986a) lists several characteristics of casual users which the slitter-tester operators could legimately be considered to be. These characteristics are:

i) poor retention of detail;

ii) a propensity for error;

iii) limited typing ability;

iv) a reluctance to use documentation.

These characteristics were allowed for in the design by :

i) presenting one idea per screen;

ii) allowing the operators to back out of any screen they had entered;

iii) presenting only a limited number of options;

iv) and no requirement for documentation.

Eason (1976) asserts that the naive user tends to regard the system as a tool and assesses it in terms of its ability to serve his/her task needs, and generally draws the conclusion that attitude towards the computer system and its perceived usefulness determines the success or lack of success of the system. The operators needed assistance to rationalise a large volume of data to provide useful information for problem-solving. The computer system had to organise and reduce information. Nickerson (1986b) notes that the general goal in using displays is to provide the users with just enough information to support their decision-making activities but not to inundate them with more than they can use effectively.

The design of the operator interface was seen to be crucial to the acceptance of the system. It was perceived that the most effective way of ensuring that the design was successful was to involve the operators in the design of the interface. Fischhof, Macgregor and Blackshaw (1987) claim that with the active involvement of the users, and if the users can state how they want the raw material organised, and articulate their requirements, then the system should be able to match their (mental) representation of the system. Gould and Lewis (1983) quoted in Nickerson (1986a) put forward four principles for developing a system, these being :

i) that the designer must understand who the users will be;

ii) that a panel of expected users should be closely involved in the formulation stages;

iii) that prototyping should be used;

iv) that to resolve problems the design process must be iterative.

This participation encompassed the determination of screen content, positioning of screen elements, and the method of interaction. The information conveyed had to offer advantages over the contemporary PDP-11 based system which had been designed with little operator participation, this system being perceived by the operators to be unhelpful in some aspects of presentation of machine faults.

9.2.1. General Design Considerations.

As stated above the directing philosophy behind the design and implementation of the operator interface was that the information currently available should be presented in a manner which could more readily be assimilated, and to enhance understanding of the slitting and testing process.

The large volume of data generated by each evaluation cycle of the machine (see Chapter 2, Section 2.6.1 for a detailed description of data produced) presented the operator with more data than could readily be assimilated, with little information being conveyed apart from a general summary of tape grades and a summary of faults. The slitter-tester operator could only gain an overall impression of how the machine was performing.

It was felt that the operator would be assisted in the process of decision making by presenting the data in several ways, including a graphical overview of the most recent run and also an historical view of several runs. This would then allow the pin-pointing of actual and potential faults. The potential faults did not present themselves in a binary manner, either not faulty or faulty, but as trends. For example, one particular potential fault can be indicated by the consistent grading of a tape as a low or failed grade. While there may not be a detectable fault occurring, the tape or the testing station might not be functioning correctly. This could not be easily detected on a run by run basis, as the operator has to consider 50 individual testing stations, but the building up of patterns would assist in the detection of these potential faults. This was perceived to be an important element in assisting the operator to build up a picture of the process from information that on a run by run basis was imprecise or incomplete.

The relative computer naivety of the operators governed the style of interaction, or dialogue, to a degree. The operators were familiar with selecting options from a menu from their use of the existing computer system installed on the PDP-11s. Discussion with the operators established that menu selection was the preferred method of interaction with a computer, this serving to limit errors in the interaction and reducing the incidence of typographical errors, which were further reduced by de-activating any non-relevant keys. Kirakowski (1988a) states that the menu system is the easiest method of interaction for a novice computer user. In this project "novice" is compatible with "naive". Recent papers (Macgregor and Lee (1987) suggest that menu search is random and not systematic and that a naive user may select the same items repeatedly resulting in repeated or redundant searches. However, Pulat and Nwankwo (1987) have noted significant effects of familiarity and experience in the use of alphanumeric displays, and the interface was designed to allow users to exit or "back-out" from screens erroneously entered.

The method of interaction was consistent throughout the system, and designed to occupy as little of the operator's time as possible. Gaines and Shaw (1983) state that consistent and informative dialogue allows the users to feel that they are in control and that consistency reduces short-term memory load. The use of the computer constituted a small element of the operator's time in running the machine generally 5% to 10% of a typical evaluation cycle. The new system was designed to reduce to a minimum the amount of time the operator had to spend scanning the system, by presenting at a keypress a more complete summary of important information than that previously available.

9.2.2. Human Computer Design Considerations.

Research into the literature regarding human-computer interaction produced guide-lines which were followed as closely as possible during the design and implementation of the system. The references quoted provide illustrations of some of these principles, while the bibliography list selected books and papers which were helpful in studying the area of man-machine interaction. While this research indicated that the use of colour would be highly desirable in a system such as the one being developed, budgetary constraints and compatibility considerations dictated that monochrome monitors were necessary in order to ensure compatibility and ease of replacement with those already installed in the company. The use of colour would have been particularly useful for the clear indication of actual and potential faults. Galitz (1981a) states that the colour is useful for acting as a visual code, that is categorising the data. Murch states that the use of unique colour within a background is easily and rapidly detected, while colour generally allows more distinctions than black and white. Brou, Sciascia, Linden and Lettvin (1984) state that "color vision supports many more distinctions than monochromatic black and white. The facilities that were available without recourse to colour, such as differentiated luminance levels, inverse video, allowed enough variation, with careful screen format design, to highlight those areas requiring attention Treisman (1988) writes that objects in a display, or "targets" stand out if their discriminability is large. The implication of this is that if an object is given some unique property then it can be detected in the midst of other distracting items and that the visual system responds positively to more stimulus. The design of the interface sought to utilise this theory by using additional characters in the display to draw attention to objects, notably the overall system view (Level 2 Screen 2 detailed in Chapter 10). Galitz (1981b) enumerates the various attention getting devices available within black and white, which include blinking, inverse video, underlining. He cautions against the overuse of these facilities as this would actually reduce the legibility and the ability to draw attention to these areas.

Design considerations were constrained by the hardware configuration of the computer and as discussed above by the limitations of the monochrome monitors. Consistency of design was important to reduce learning time, also to give the related screens a system identity. Galitz (1981c) states that users wish to see the system as a single entity with an overall look, or feel, and that excess learning requirements become a burden to their (the users) achieving and maintaining high performance and can ultimately influence their acceptance of the system. To assist in the operation of the system it was important to understand exactly where they (the operators) were within the system, and so the system was organised into a rigid hierarchy with limited access paths up and down. The user was made aware of the location of the particular screen they were viewing by the use of clear, unambiguous headings at the top of each screen and a hierarchy level number followed by a screen number - e.g. when the screen on display is the graphical view of the last evaluation run of the slitter tester, this is at level 3 and is screen 1. Consistency of design was applied to all aspects, with all the screens having a frame and a heading with a menu selection at the bottom of the screen, beneath the frame. Fields where data had to be entered were indicated by an expanded flashing cursor, one field at a time with the fields to be completed being to the right of the prompt commands. Status messages and input fields were positioned consistently.

As mistakes were bound to occur when entering text the operator was asked for confirmation of the whole screen when completed. Screens incorrectly completed could be re-typed. The area where mistakes were most likely to occur, that of entering the 10 digit reel reference number, was validated by checking whether digits and alphanumeric characters were correctly placed. If these were incorrectly positioned this was highlighted to the operator by the use of a blinking expanded cursor, and the use of the computer's beeping sound.

Errors detectable by validation, such as the typing of numeric characters where alphabetic characters only were allowed, were indicated immediately following the entering of the data and the operator was prompted to re-enter the information.

A symmetrical balance about a vertical axis was maintained on all screens to give a balanced appearance to the screens. Human information processing systems attempt to impose structure on to data to give the data some form or meaning which improves the understanding of that data (Nickerson (1986a)) Information on each screen was kept to a minimum, with the whole screen having a recognisable identity e.g. on starting up the system the operator was prompted for information pertaining to themselves, their shift and no more. On completion of this screen the screen was cleared and the operator prompted for information relating to the web which was being processed. Each screen was a complete and separate entity.

Information was presented in a directly usable form. The slitter-tester transmits information in unit order, which is not directly usable. The new computer system translated this into a station order allowing action to be directed to the exact position requiring attention.

Whilst it was essential that the operator be guided to important pieces of information, particularly those which required rectification before the next evaluation run of the machine, the use of attention directing devices had to be carefully controlled, otherwise their ability to attract attention would be diminished (Galitz (1981d)). The over-use of these techniques would cause them to be ignored or distracting. As the display units were monochrome the range of attention directing devices was limited to shades of white and occasional use of the computer's bleep. A blinking cursor reduces legibility but does provide a good contrast to direct the operator's attention. Alternative techniques had to be used to indicate certain non-critical occurrences. For example transient faults which might have indicated problems requiring the attention of technicians were shown on the graphical display of the most recent evaluation run. These included non certification, indicated by an X, and the incidence of a higher number of 1600 BPI hypercritical errors than 6250 BPI single track errors, indicated by an H. It was not possible to use line graphs in the text display mode that had to be used given the constraints imposed by the hardware.

The terminology used in the dialogue between the computer and the operator was based on the terms used by the operators in their normal work and would not necessarily make complete sense to someone who was not familiar with the slitter-tester, for example, the prompt for entering the web identifier referred to the web as a "jumbo" which was the term used by the operators.

At one stage the operation of the system necessarily involved a time delay between the pressing of a button and the desired screen appearing. This delay was due to the need to extract the relevant data from the transmission file (an explanation of the transmission format is contained within Chapter 8). During the period of this delay the operator was informed when each unit (from 1 to 18) had been processed. This maintained the understanding that the system was working correctly, while giving a clear guide-line as to how quickly the desired screen would be available. Nickerson (1979), and Carbonell, Elkind and Nickerson (1968) indicate that uncertainty regarding response times can be more aggravating than a delay, and that an indication of the period of delay alleviates this aggravation.

The design of the system sought to reduce operator uncertainty to a minimum, by providing status messages if an immediate response was not possible. This can be illustrated by the displaying of a message to indicate that data was being written to disk, which would be preventing the operator from obtaining a response.

9.3. Operator Requirements.

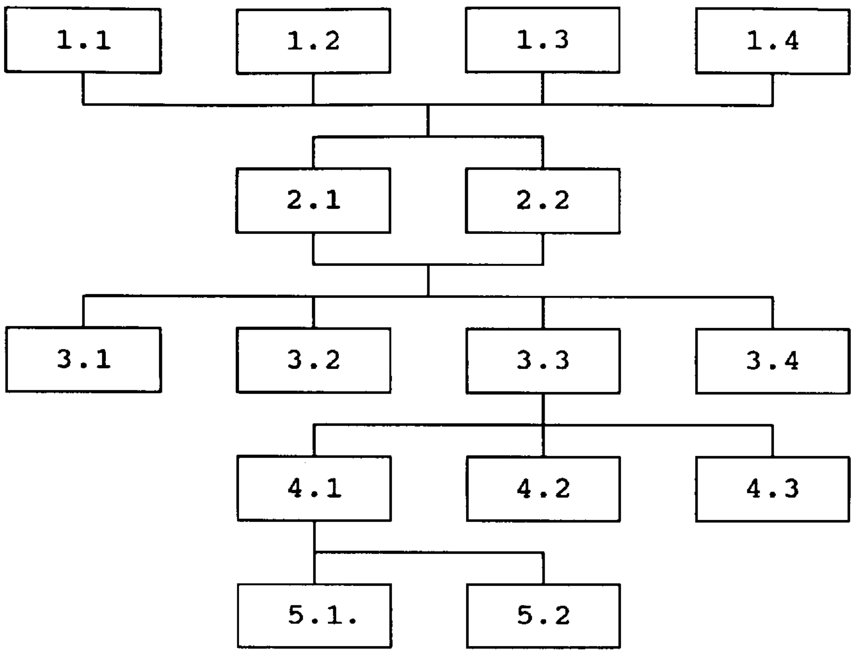
It was important to involve the operators in the design of the interface. This process of involvement was conducted on an informal and a formal basis.

On an informal basis the operators requirements and views were discussed at their place of work. These discussion began to lead to a definition of what would constitute a better design of interface. The current system was criticised by the operators for not providing enough information in a manner which could readily be assimilated. As stated, the use of the computer constituted a small percentage of the operators task, which was mainly concerned with the physical running of the slitter-tester, the unloading of full, tested reels and the loading of empty reels. As faults with the web, or slitter-tester increased the proportion of time spent in trying to identifying machine faults and the proportion of time spent in searching for evidence of the faults on the computer increased. The operators stressed the need for the computer to offer information in order to assist in deciding where and whether or not a fault existed.

The method and style of interaction was observed, with the number of key-presses required to reach a desired state or screen noted. While the existing system used a

QWERTY style keyboard only limited use was made of the keys, with the space-bar being used for menu selection. The keystroke model suggested by Card, Moran and Newell (Card, Moran and Newell 1980) was used to produce theoretical timings for the use of the new interface as compared with the existing PDP11 interface. The number of keystrokes were reduced by producing summary or overview screens which presented overall views of the most recent run of the slitter-tester. These summary screens were essentially the Top level Summary and Overview screens (screens 1.1 and 2.3 in the new system's hierarchy shown in Figure 9.2. The new system did not always offer a reduction in response time, but did reduce the time that the operator actively searched the computer system for information. For a detailed description of calculated timings using the keystroke level model see Appendix 5. It was also observed that potentially useful information was not being used on the original system as it was inaccessible, or not brought to the operators attention, and the operators were not fully aware of the potential of the system for faults diagnosis. These points were taken into consideration when designing the new system.

An initial design was proposed for the operator interface. This is shown in Figure 9.1. The design was a hierarchy with a menu being used to navigate around the system. The process of monitoring the RS422 communications line (see Chapter 7 for hardware configuration and details) was to be performed by an applications program running as a background or invisible process, using a multi-tasking operating system. The initial design was presented to all the operators at meetings. The feedback from the meetings was used to modify the design to that shown in Figure 9.2 The hierarchy of the original PDP-11 system is shown in Figure 9.3.

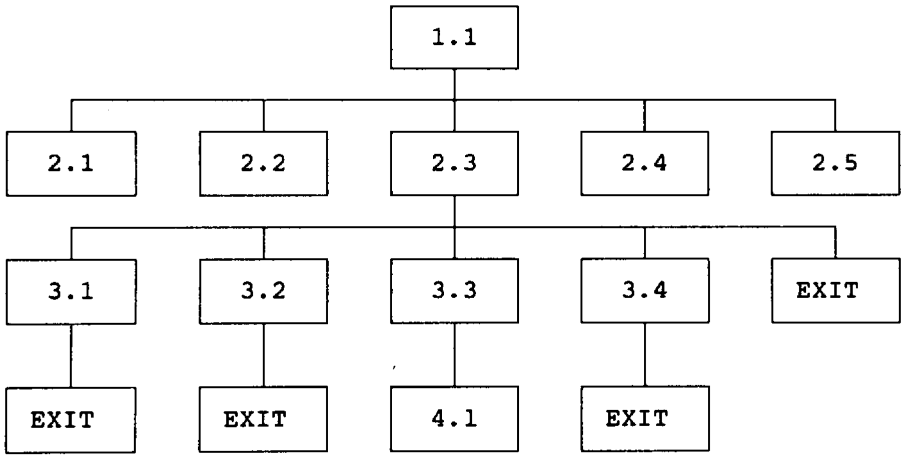


1.1. Enquiry interface to the last three cuts.
1.2. Line monitor.
1.3. Retrospective data entry for cuts omitted.
1.4. Shift summary.
2.1. Top level summary.
2.2. Non certified tape data entry.
3.1. Alter station position table.
3.2. Current thresholds, classifications, tape length.
3.3. Unit overview.
3.4. Graphical plot across the web.
4.1. Unit 1 tape and track overview.
4.2. Unit 2 tape and track overview.
4.3. Unit n tape and track overview.
5.1. Unit 1 tape errors compared with average.
5.2. Unit n tape errors compared with average.

Figure 9.1 Original Operator Interface Design Hierarchy.

The initial design was felt by the operators to offer facilities which were more complex than they would require. The proposed 4th and 5th level of the interface would not be used, as the operator could obtain enough information to assist them in running the machine from the higher level screens in the hierarchy. The low level detail was also present to a large extent on the existing computer system. While the presentation of each station's or units data compared with an average was felt to be potentially useful, the majority of operators did not feel that they would use this data, as to use it would increase the proportion of time spent using the computer and not running the machine.

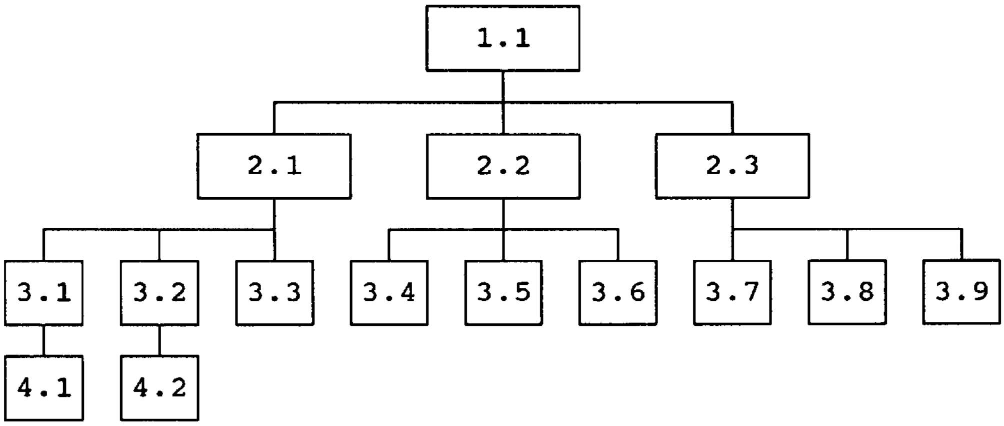
The proposed level 3 screen 1 would have allowed the operator to reassign the stations to their units. The operators felt that they did not wish to be responsible for the assignment of stations. The need to reassign stations would be better performed by the electronics engineering staff actually amending the software. As this was not a common event the screen was not included in the modified design. Similarly the option to enter data retrospectively about previous evaluation runs was not felt to be useful. As the operator was present throughout the running of the slitter-tester, this screen was superfluous to requirements and so was also not included in the modified design, as shown in Figure 9.2.



1.1. Top Level Summary.
2.1. Extract.
2.2. Un-certified Tape Data Entry.
2.3. Overview of all Units.
2.4. Web Related Information.
2.5. Shift Summary.
3.1. Graph Plot across the Web.
3.2. Stations Displayed Relating to Units
3.3. Current Classifications.
3.4. Enquiry.
4.1. Hierarchical System View.
EXIT

Figure 9.2. Revised Operator Interface Design Hierarchy.

The benefits of reducing the number of levels in the hierarchy allowed the revised design to follow the principle of a broad and shallow hierarchy. This follows the work of Kirakowski (1988b) who states that the optimum number of choices for menu selection should be 6 or less. The final interface design offered five or less options. The number of menu options that could be fitted on a screen was limited to five to allow each option to be as fully captioned as possible, this following the guide-lines produced by Galitz (1981e), who suggests that abbreviations are not generally useful.



1.1. Last run analysis.
2.1. Evaluator unit display.
2.2. Classification.
2.3. Engineer's page.
3.1. Tape error display
3.2. Track error display.
3.3. Print all tape errors.
3.4. Change reel data.
3.5. Change classification data.
3.6. Transmit classification data.
3.7. Threshold/initialise.
3.8. Display head gains.
3.9. Calibrate units.
4.1. Tape error display for each unit (incremental).
4.2. Track error display for each unit.

Figure 9.3. The Existing PDP-11 Operator Interface Hierarchy.

9.4. The Selection of the Programming Language and the Operating System.

9.4.1. The Selection of the Operating System.

While analysing data transmissions on the RS422 communications line it became clear that the operator interface would have to perform two distinct tasks. The first was to monitor the communications line for data transmissions, and when a data transmission was detected, to capture that data and store it as a file. The second was to process that data, present it to the operator and transmit the processed data to the central data collection point. The DEC PDP-11 host computers did not face this problem as they remained in control of the process, and were the initiators of the transmission of data. The test data was processed as it was received and saved to disk. The operator used the keyboard to display the various screens, or to initiate a different process such as changing the thresholds used as testing criteria.

The new microcomputer system had to monitor the communications line constantly as it could not determine when a transmission would occur. To ensure that transmission were not missed the operator interface was divided into the two discrete tasks described above, with one task being dedicated to monitoring transmissions on the RS422 communications line.
This necessitated the use of a multi-tasking operating system.

The multi-tasking operating system available were either DOS (Disk Operating System) based or UNIX based. The UNIX based system was relatively expensive and would not run DOS-based applications such as database packages. A requirement of the new system was that it should interface with those currently in use within Xidex. There was little UNIX experience within Xidex. These factors increased the preference for a DOS based system.

Two DOS based systems were readily available at the time of the project, Concurrent PC-DOS at £500 and DoubleDos at £50.

Concurrent PC-DOS was a large, relatively sophisticated package capable of running up to 4 tasks. DoubleDos was a very simple package capable of running two tasks.

DoubleDos was selected as it provided all the facilities required to implement the operator interface and was easily configured. The package has two partitions, one visible and the other invisible, or foreground and background. On starting up the package, or re-booting, the operating system can automatically start programs running in both partitions.

The package works by time slicing, that is each process or task is allowed to use the computer's central processor for a stipulated time (a fraction of a second) before being switched out and the other process switched in. In DoubleDos, the time allowed for each process was adjustable in the ratios 2:1, 1:1 or 1:2 (visible process:invisible process).

The communication line monitor program was set to operate in the background partition, and the operator interface set to operate in the foreground or visible partition. The ratio was set to be 2:1 in favour of the visible partition, thus reducing visible delay for the operators to the minimum.

9.4.2. The Selection of the Programming Language.

The language chosen had to be able to use the communication ports effectively, format the screens effectively for the presentation of data to operators, and be able to be easily understood and modified. Most important though was the ability to process the data and display screens rapidly to reduce delay to the operators.

The language had to be DOS based for ease of maintenance and interfacing to DOS-based packages.

The languages surveyed were those commercially available for personal computers, these being BASIC, PASCAL and the new language MODULA-2. Of these PASCAL could not handle input and output from and to the communications ports effectively and so was rejected. MODULA-2 was investigated as it could have functioned as both the operating system and programming language. However it is not as widely known as BASIC and did not allow the display screens to be formatted as easily.
Three versions of BASIC were surveyed, BASICA which is IBM's interpreted version of the language, Borland's TURBO BASIC, and MicroSoft's QuickBasic version 3, both of which can be compiled, and therefore run much faster.

BASICA is an interpreted language and could not meet performance requirements.

TURBO BASIC could not handle the particular communications requirements of the project, that is to capture data being transmitted using the following protocol : 9,600 bits per second, no parity, 8 data bits and 1 stop bit. The line control register had to be adjusted to receive data using the above protocol and the software did not provide that facility.

MicroSoft QuickBasic Version 3 proved to meet the criteria specified. It was easy to understand and modify, but more importantly did handle the communications ports accurately, and allowed easy display screen formatting. The ease of modification was important as the system had to be able to be amended by Xidex staff to meet future information requirements.

QuickBasic provided support for structured programming and also for modular programming. This meant that programs could be constructed from a set of modules, each performing a specific task. This allowed the modules to be relatively independent of each other, that is changes to one module do not necessarily require changes to be made of the others.

CHAPTER 10. THE OPERATOR INTERFACE IMPLEMENTATION.

This chapter describes the implementation of operator interface. Operator participation in the design was continued after the implementation of the initial design, with the implemented system being modified in response to operator reviews.

10.1. The Operator Interface Implementation.

In the design the concept of modularity was maintained. Each node or screen of the hierarchy was treated as a module. In this manner, changes made to one screen had little or no effect on remaining modules, minimising re-programming.

Each module was written and tested separately, this often involving the use of stored data files. When the module was completed it was integrated with the main module by linking the modules together at compilation time.

Linking at compilation time was performed by including the modules into a main module. The main module, called "System", defined variable names and arrays as common, or global, to all modules linked in at compilation time. This meant that any module could freely access any variable or array defined as common. This was the technique used to provide basic data for all modules requiring access to that data.

The purpose and screen display of each module is outlined below.

It should be noted that there were two processes running. One as a background task, monitoring all transmissions on the RS422 communications line from the slitter-tester units, the second as the foreground task, extracting transmitted data from the data file transmitted. As described in Chapter 5, less than 20% of the transmitted data file represented pertinent data. The other 80% of the data file was involved in the protocol of controlling the hardware transmission and reception of data. Figure 10.1 illustrates the concept of the two processes and how they interacted.

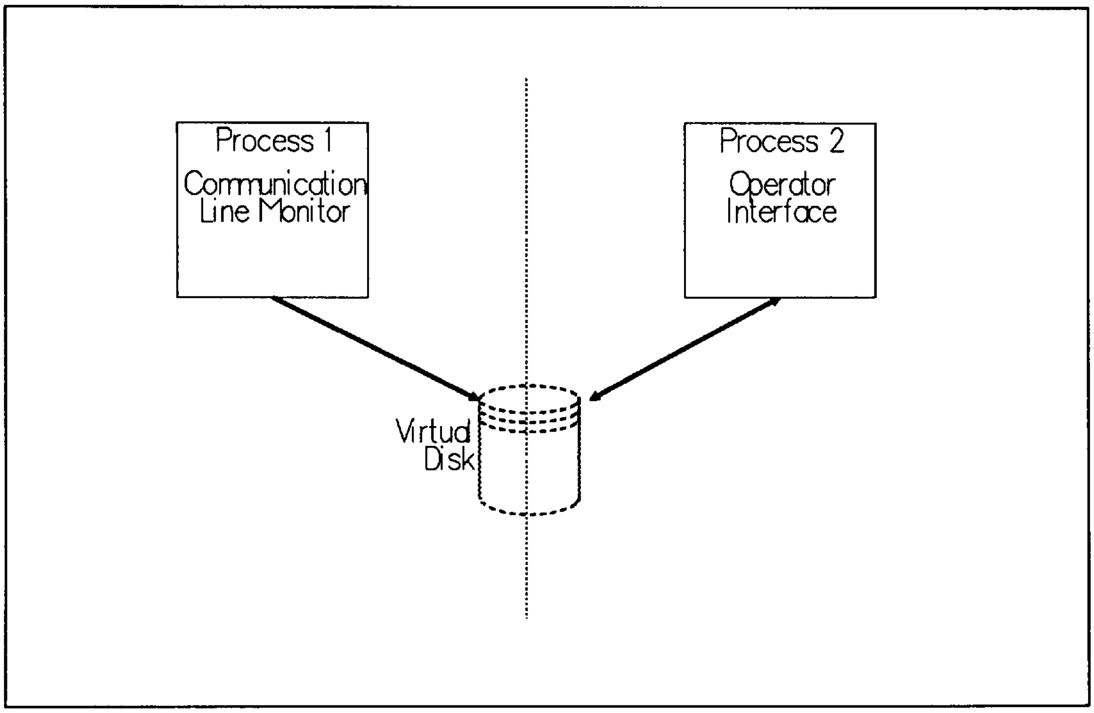


Figure 10.1. Foreground/Background Process Interaction.

10.1.1. Process One. The Communication Line Monitor.

The operator interface described in this chapter was used to display information to the operators and to collect information from the operators. The interface produced data from a file transmitted from the slitter-tester units to the DEC PDP-11 computers, which was also collected on the IBM PC compatible microcomputers. The data was collected by a communication line monitoring program which acted as a distinct process from that displaying information to the operators. This communication line monitoring program was one task, or process, in a multi-tasking environment. The operator interface was run as the second task. The multi-tasking operating system used, Doubledos, provided two tasks, or processes, which could be run concurrently, by switching each process in and out of memory. One task was run as a visible or foreground task, and the other as an invisible or background task. To simplify the use of the operator interface the program monitoring the communication line was run in the invisible partition. This program could be switched to the foreground for the diagnosis of problems. The program's method of operation was to open the communications port number 2 on the IBM PC AT compatibles (actually OPUS PCVs which served as the operator interface microcomputers). Figure 10.2. Shows the screen displayed while the communication line monitor was running (only visible by switching the background process to the foreground).

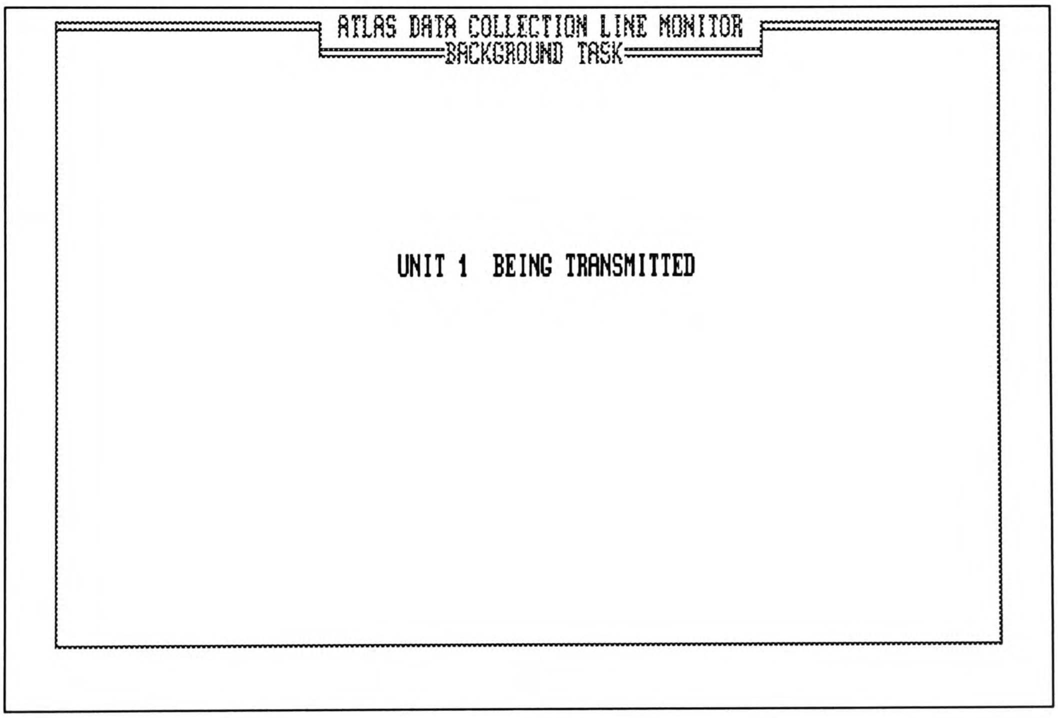


Figure 10.2. Communication Line Monitor.

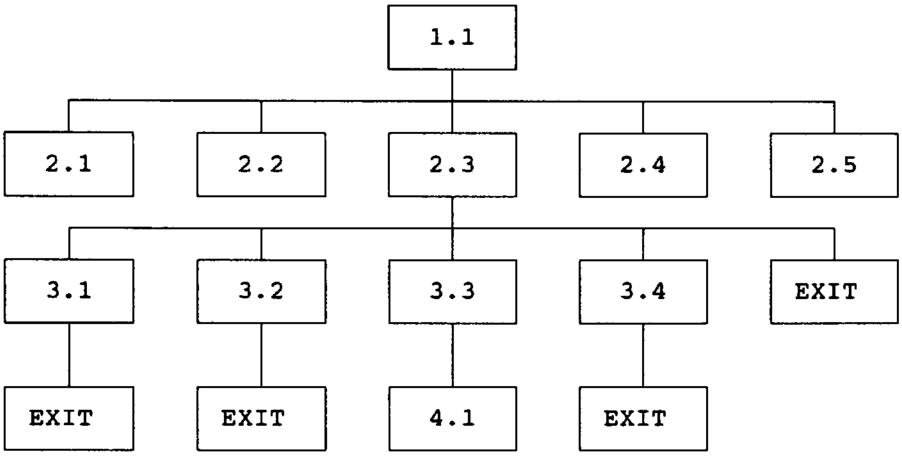
The purpose of this module was to monitor communications on the RS422 data line from the slitter-tester to the PDP-11, and capture valid data transmissions. All test data was transmitted on this line following the completion of the test.

As communication on this line was constant, mainly being a stream of status signals from the units to the PDP-11, the program had to recognise the start and finish of a valid transmission of a file of test data, using the information discussed in Chapter 8 "Data Transmission Formats". When the start of a stream of valid evaluation test results was encountered these were written to a file called OUTPUT.FIL on the virtual disk. A flag or semaphore was set on the virtual disk by using a file called FLAG1 to indicate the status of the data file i.e. whether there was: no data file collected; a valid data file being received; or a valid data file received and ready for processing. This prevented the corruption of the data file by the operator interface (running in the visible partition) accessing the data file before the communication line monitor program had finished writing it. An additional security measure to prevent corruption of the data file was utilised, namely collecting the data as OUTPUT.FIL and renaming the file to be OUTPUT.DTA only after the evaluation test data had been completely collected. The operator interface would only then be able to access the data file OUTPUT.DTA.

The line monitoring program had a robust error correction routine which allowed it to recover from most errors, barring the actual disconnection of the RS422 receiving line. The most common error experienced was that the first character read into the input buffer after the communication line was opened was not completed and therefore could not be correctly interpreted. A status message was displayed on the monitor, and the reading of the communications port resumed. In the event of an unexpected error, the program closed the read channel, displayed an error count and attempted to restart the program. The monitor program could be switched into the visible partition to display error messages if problems were experienced.

10.1.2. Process 2. The Operator Interface.

The overall hierarchical design of the operator interface is shown in Figure 10.3.



1.1. Top Level Summary.
2.1. Extract.
2.2. Un-certified Tape Data Entry.
2.3. Overview of all Units.
2.4. Web Related Information.
2.5. Shift Summary.
3.1. Graph Plot across the Web.
3.2. Current Classifications.
3.3. Stations Displayed Relating to Units
3.4. Enquiry.
4.1. Hierarchical System View.
EXIT

Figure 10.3. Operator Interface Hierarchy Diagram.

This program was written and compiled as a set of modules, linked together at compilation time. Its purpose was to interpret the data which had been captured by Process One, the communications line monitor, and present it to the operator according to the requirements defined earlier in this chapter. The modules are described according to their position in the hierarchy. The main module, from which all the other modules were controlled was called System.

This module did not appear as a screen itself, but initialised the variables and arrays. The modules were linked in by this module and a start-up sequence was initialised by this module.

As an operator started the shift they would restart the program. This would prompt the operator to enter details which were relevant to them which would be held until the start of the next shift. These details were their name, and their shift. They were then prompted to enter details about the web being slit and tested. These details were the 10 digit reel reference (jumbo number), the length of the tape being produced, the position of the particular cut on the reel (from 1 to 6 for standard length web) and the audit grade of the reel. The module System would then prompt the operator to extract the data from the transmitted file. This they would only be able to do after a valid transmission, due to the control imposed by the use of the flag file described above. Following a valid transmission and extraction, the module would control use of and navigation around the system by presenting a screen and displaying a set of menu choices on the bottom line of the screen. The operator was then able to control the interface by selecting from this menu.

10.1.2.1. The System Module.

This constituted the main module of the operator interface. It initialised all variables and arrays used by all the modules, defining these to be of a common nature. Any variable or array defined as common could be accessed by any module simply by referring to it by name. This allowed data to be defined once and used by all modules. It controlled the start-up of the operator interface process, calling modules to prompt the operator for details relevant to that operator, then prompting for details regarding the work in hand, then passing control to the operator through the use of a menu system.

The menu system worked in a simple manner. After a module had been displayed on the screen, the appropriate menu was displayed on the bottom line of the screen. Which menu choices appeared was controlled and presented according to which screen was being displayed. This technique was used to control navigation around the system. For example to get from the Top Level Summary at Level 1 to the Graphical display of the system and its hierarchy "Hierarchical System View" at Level 4 the operator had to select Unit overview from the menu to access Level 2, then Classification from the menu to access Level 3, then System View to access Level 4. Exiting from a level took the operator back up one level. This illustration can be assisted by referring to Figure 10.3. which shows the interface hierarchy.

An error handling routine in this module dealt with processing errors, informing the operator that processing error had been experienced, and returning, to display the Top Level Summary. A file containing a log of the type of error, the time and the data was appended to in the event of a general processing error.

10.1.2.2 Shift Start Up Routine.

On commencing a shift the operator was required to re-boot the system, either by switching the computer off and back on again, or by a soft reset, pressing the Control, Alt, and Delete keys together. This cleared the system program and returned control to the ROM based single user operating system (DOS) that was supplied with the computer. This in turn would load the multi-tasking operating system, Doubledos which then loaded the line monitor program into the background partition and the operator interface system into the visible partition. These would automatically execute. This sequence would take between 30 seconds and 1 minute depending on whether or not the computer was switched off.

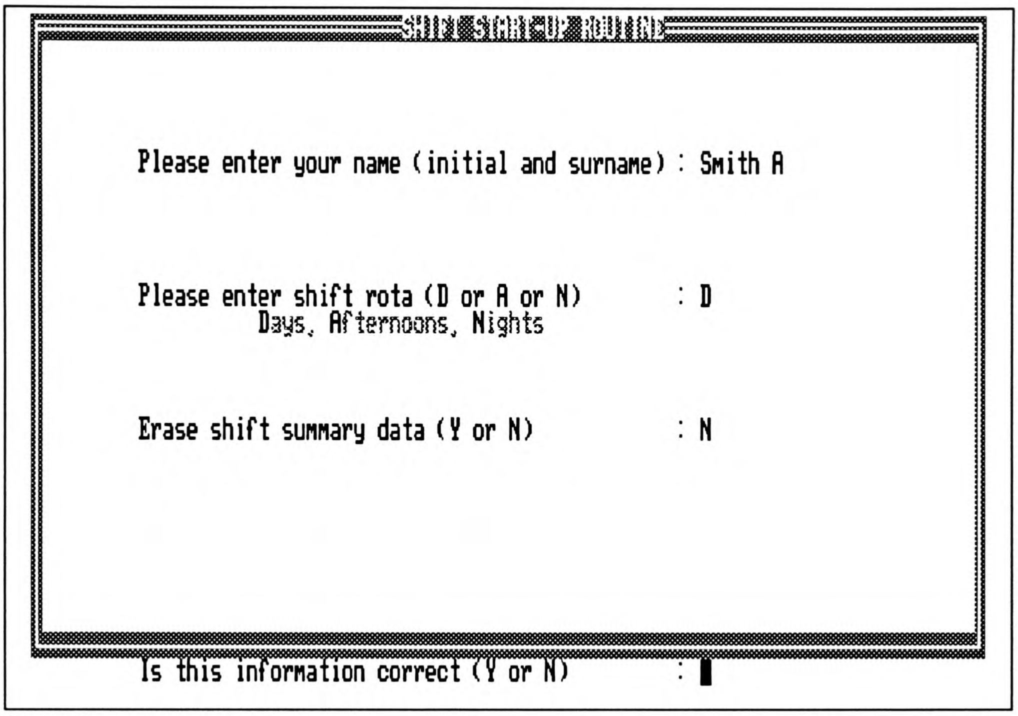


Figure 10.4. Shift Start-Up or Reset Screen

This module or screen was presented automatically whenever the system or computer was restarted. The operator entered details pertinent to themselves and their shift. These details were included in the data collected for each file to ensure accurate identification of process conditions at the time of production. The operator was prompted to enter a text field, detailing initials and surname. This was limited to 15 characters with no validation. The operator was then prompted to enter their shift time, entries being restricted to one character and validated to be D (days 0600-1400 hours), A (afternoons 1400-2200 hours) or N (nights 2200-0600 hours).

Details of the date were obtained from the system date held within the microcomputer. Data identifying which slitter-tester the system was being

used on was assigned automatically by this module. This data was essential for the production of accurate reports. The operator was then prompted whether they wanted to erase the shift summary data file or not. This file was built up throughout the shift, consisting of information regarding the numbers of each grade produced and test identifiers, that is the reel reference and cut number. If the operators were starting their shift then they would erase the file. This ensured that they file would then only consist of data produced on their shift. In the event of having to restart the system in the middle of the shift then they would not erase the file, thus allowing the file to continue being added to throughout their shift. The shift summary file contained data which was presented on display of the Shift Summary screen (see 10.1.2.8 for details), presenting the operator with a summary of figures produced on their shift.
Finally, the operator was presented with a prompt which allowed the operator to correct the details. If the operator wished to correct any of the details they had to re-enter all details on the screen. As the system used default conditions to accept certain answers this was not considered to be arduous. The default values used were Days for the shift pattern, and not to erase the shift summary file.

Errors were minimised due to the method of interaction, using validation and allowing defaults to be used where possible. Typing was minimised at all points, with the valid possible answers being displayed on the screen under the prompt, and most operator responses being limited to two key presses, one for the selected answer and then confirmation by the Enter key.
The shift start up routine returned control to the main program, System. This program then displayed a screen which prompted the operator to enter information relevant to the web which was to be slit and tested.

<u>10.1.2.3. Top Level Summary. Level 1 Screen 1.</u>

This module constituted the top of the hierarchy during the operation of the system. It was automatically displayed after the operator had requested the extraction of data from the valid data transmission file.

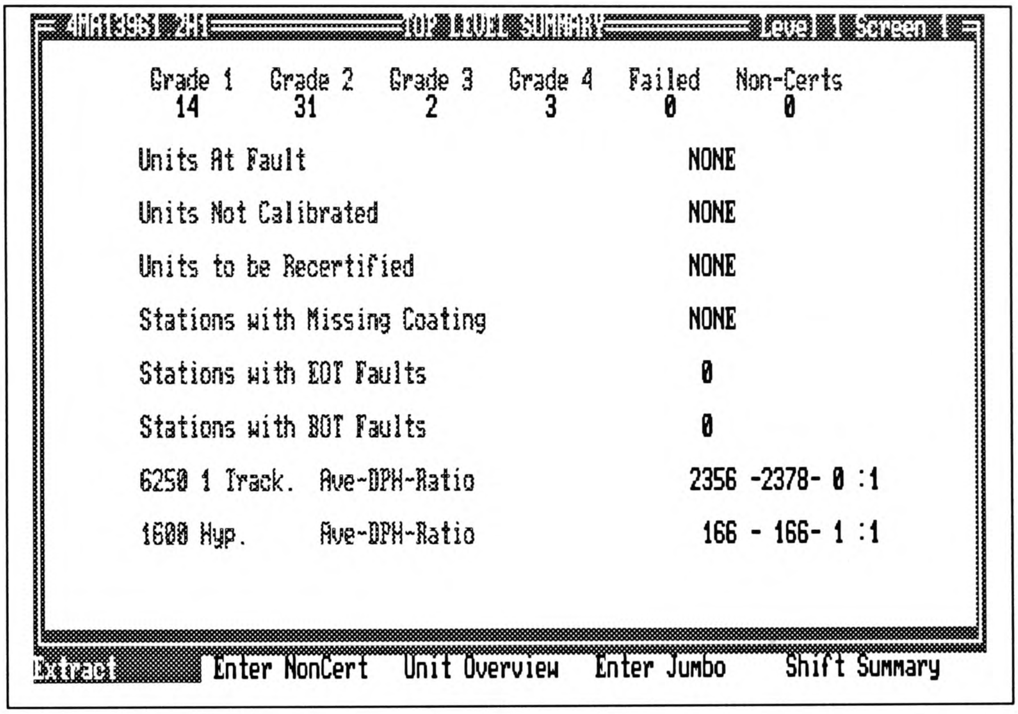


Figure 10.5. Top Level Summary Screen.

This module extracted the data from the transmitted file (i.e. ordered by unit number) and used that data to produce the following information, each item of which is shown in Figure 10.5. :

i) the numbers of each grade of tape grade 1 to 4, failed, and not certified;

ii) the identity of units not functioning correctly;

iii) the identity of units not calibrated correctly;

iv) the identity of units experiencing an overflow of errors, thus necessitating a re-certification of all tapes on that unit;

v) the identity of all stations experiencing missing coating;

vi) the identity of stations experiencing EOT sensor marker faults;

vii) the identity of stations experiencing BOT sensor marker faults;

viii) an average number of errors a drop out per hundred number of errors with a ratio between the two for 6250 BPI test;

ix) as for viii) but for 1600 BPI hypercritical error testing;

The module then reorganised the data to produce the test data assigned to its station across the web, from 1 to 50.
The module also reassigned data from the last 6 cuts to produce a rolling historical record of the grade of tape for each station. A rolling average of the last 6 cuts was also maintained. These historical data sets were used by the enquiry screen detailed in 10.1.2.10.
The module then wrote the data to hard disk in unit format and station format as two files. The files were differentiated by their prefix letter. An X signified unit format, an S signified station format. Example files are shown in Appendix 6. These files were written to hard disk to maintain data in the event of a failure in communication to the central data collection and processing computer. The files could then be copied from the hard disk and processed in the normal way after transfer to the central computer.
A summary file, "SUMMARY.DTA" was appended with a summary of the details of the cut. This file was not used by this module, but by the shift summary module, detailed in 10.1.2.11, which was used by the operators for checking what had been produced on their shift.

The data files were then transmitted to the central data collection and processing computer by using the computer's communications port 1. Both station and unit format files were transmitted. The transmission format was as follows for the unit format.

The file was made up as follows:

HEADER	DATA

The header was made up as follows :

"**FILENAME : "filename "LENGTH " length

where the filename was an 11 digit code produced from the reel number and slitter-tester number (see the module on web related information detailed in 10.1.2.4 for an explanation of filename composition) and the length is the length of the file of data.

10.1.2.4. The Data Extraction Screen. Level 2 Screen 1.

Chapter 8 described the format of the file containing the test data that was transmitted from the units to the PDP-11. This file was stored in memory, on a virtual disk, until the operator requested that the information be presented to them. This was performed by requesting the system to extract the data from the file. The term Extract, was used to indicate that the data had to be selectively extracted from a larger file of transmitted data. A time delay (of about 15 seconds from slitter-testers 2 and 3 and about 20 seconds from slitter-tester 1) was unavoidable at this stage as the Extract module processed a file of 40,290 bytes for Atlas 2 and 3 and 59,000 bytes for Atlas 1.

As each transmission to the PDP-11 formed 5 bytes, every 5 bytes were loaded into memory and inspected. To increase the speed of the process, initially only one byte was inspected, the third byte. This contained a character which represented whether or not the byte immediately following it was data. When this character was identified then the 2nd byte of the message was inspected. A typical "message" containing data from the slitter-tester units is shown below (in hex).

Byte 1	Byte 2	Byte 3	Byte 4	Byte 5
02	21	06	01	24
Message header	Unit id.	Character identifying data present	Data	Linear redundancy check

Hex 02 as the byte representing the message header indicated that the message was a transmission from the slitter-tester unit to the host PDP-11. The second byte of the message identified which unit the transmission was from.

After the second byte was inspected and identified, the data held in the 4th byte was converted to an ASCII value and assigned to the appropriate element of the appropriate array.

As described in Chapter 8 the order of transmission formats did not change, i.e. Unit 2 always followed Unit 1 and within data results for Unit 1 the data for the middle station always followed the data for the top station.

This method reduced the inspection of bytes to 4 out of 10 in actual data transmissions, and actually 2 out of 10 in the messages setting up each unit for data transmission.

The module differentiated between extracting the data from the transmission format file and actually processing it. Following the findings of Nickerson (1979) that an unspecified delay in response time by a computer is more aggravating than having an indication of response time, the progress of the extraction process and the processing process were clearly illustrated to the operator, by an indication of which units had been extracted and then processed.

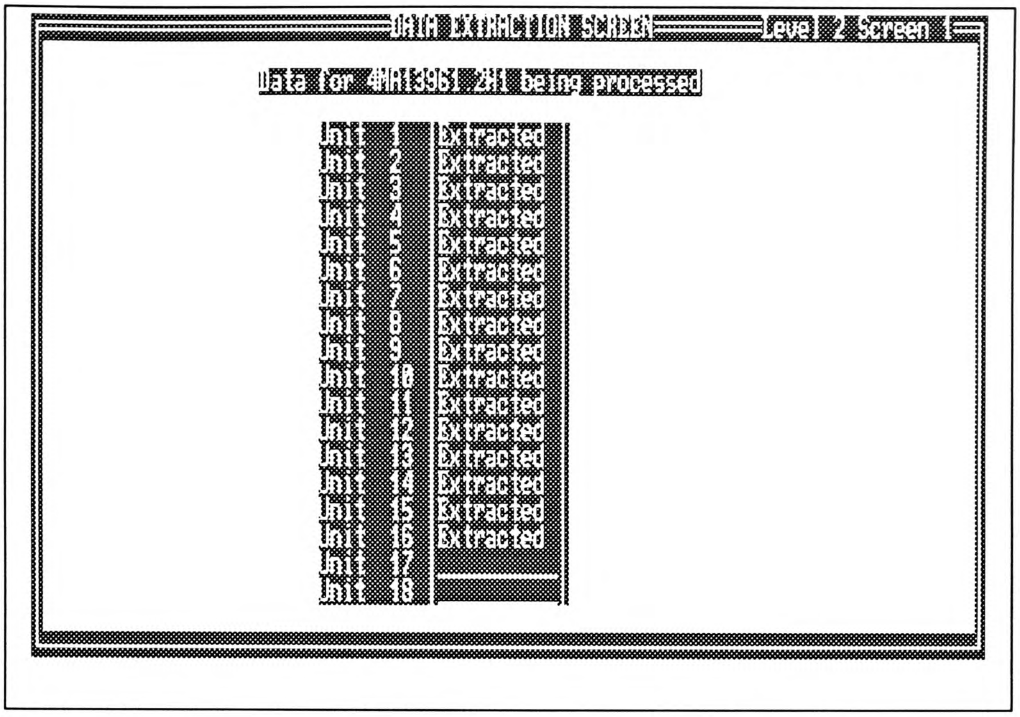


Figure 10.6. Data Extraction Screen.

As the data for each unit was extracted, this was indicated to the operator by the display of the word Extracted, next to the Unit number, and similarly for the processing, except that the processing was accomplished very much more quickly.

This extraction process also involved converting the data into actual integer values which could be directly related to the actual values of the errors. As described in Chapter 8, File Transmission Formats, Section 8.3., values over 255 which could not be represented by one character byte had to be represented by two successive bytes. The actual value is produced by adding the value of the first byte to the value of the second byte multiplied by 256.

This module was used for information purposes only and so was only displayed for the period of processing. The name of the file being processed was displayed to inform the operator which file they were extracting.

When extraction and processing were finished, the module returned control to the System module which automatically displayed the Top Level Summary (which presented the operator with most of the important facts regarding the last evaluation run).

10.1.2.5. Un-certified Tape Data Entry. Level 2 Screen 2.

Potentially useful information about the evaluation run had to be entered by the operator. This module or screen allowed the operator to enter reasons for the non-certification of tapes. The data entered was useful for the longer term reporting system, not for the on-line presentation of information.
To simplify data entry the potential causes of non-certification were categorised and listed in a vertical format as shown in Figure 10.7.

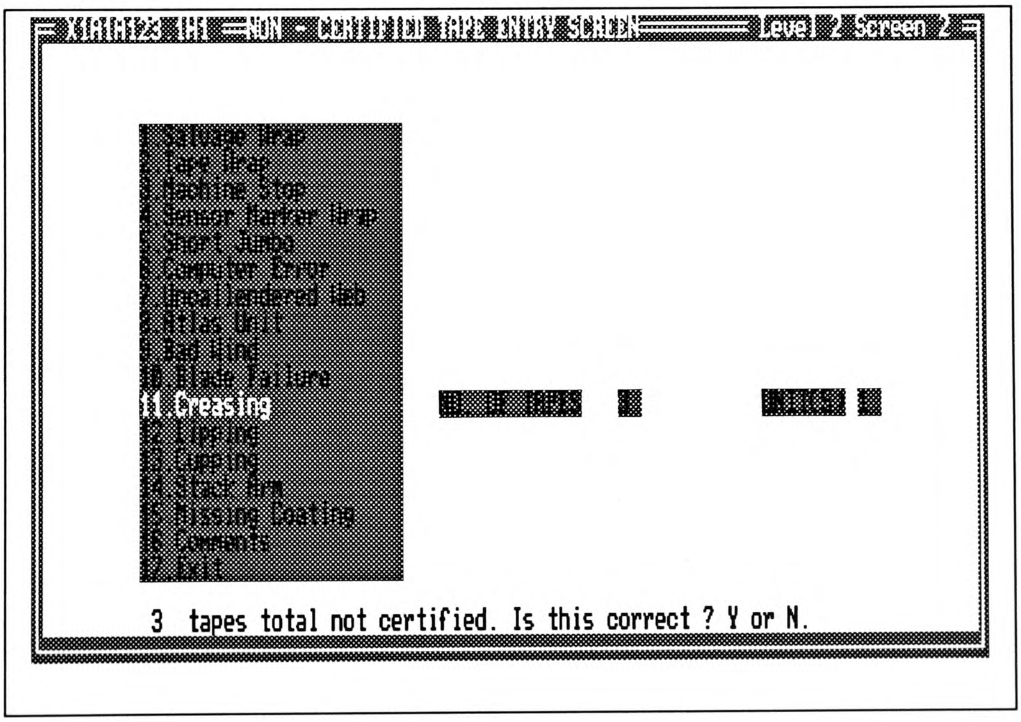


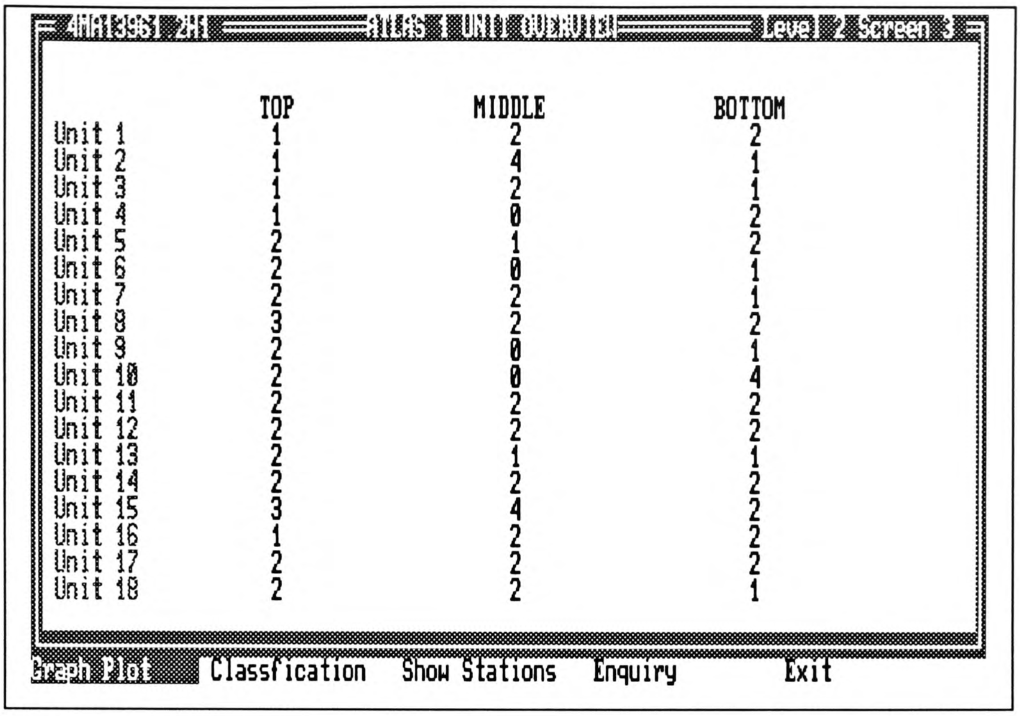
Figure 10.7. Non-Certified Tape Data Entry Screen.

The operator entered data by using the vertical arrow keys, up or down, before selecting by pressing the Enter key. The operator was then prompted to enter the total number of tapes not certified for that category, and confirming that figure by pressing the Enter key. The operator then entered text identifying which unit or units were at fault, separating individual unit numbers with commas. The categories were ordered from top to bottom, with the most frequently used category at the top. The cursor was positioned at this point whenever the screen was requested.

The first 7 categories would all indicate that all 50 tapes were non-certified due to the nature of the fault. These faults would generally occur if the slitter-tester were stopped in the middle of the evaluation run, invalidating all test results. If one of these categories was selected the operator would be directed to the validation routine at the end of the module, confirming the type of fault and the number of tapes not certified for that fault.
If the category selected was not one of the first seven then the operator could make multiple entries, including category 16 which allowed the operator to enter a 40 character text field. After entering a category of non-certified tapes the operator would be asked to confirm the entry and whether they wished to make any more entries. If the response was to not make any more entries then they would be prompted to confirm the total number of tapes not certified. Details were then appended to the unit order file on the hard disk. A mechanism to prevent the re-entering of data on this screen was included, which simply notified the operator that they had entered the data.

10.1.2.6 Overview of All Units. Level 2 Screen 3.

This screen presented the operator with an overview of the results of the last evaluation run, showing the classification or grade of each tape in its station position with regard to its unit as shown in Figure 10.8.



4MA13961 2H1 ATLAS 1 UNIT OVERVIEW Level 2 Screen 3

	TOP	MIDDLE	BOTTOM
Unit 1	1	2	2
Unit 2	1	4	1
Unit 3	1	2	1
Unit 4	1	0	2
Unit 5	2	1	2
Unit 6	2	0	1
Unit 7	2	2	1
Unit 8	3	2	2
Unit 9	2	0	1
Unit 10	2	0	4
Unit 11	2	2	2
Unit 12	2	2	2
Unit 13	2	1	1
Unit 14	2	2	2
Unit 15	3	4	2
Unit 16	1	2	2
Unit 17	2	2	2
Unit 18	2	2	1

Graph Plot Classfication Show Stations Enquiry Exit

Figure 10.8. Overview Of all Units Screen.

The purpose of this screen was to assist the operator in the assessment of potential faults while describing visually the location of faulty stations or units. Failed or non-certified tapes were highlighted by the inverting of the colours for the word Unit and the unit number on the left of the screen and printing the word "STATION" and the station number of the faulty station in its position relative to its unit.

One particular fault explained in Chapter 6 Section 6.1.1.ii) required the re-certification of all 3 tapes from a particular unit. This was highlighted by inverting the colour of the word "UNIT" and the unit number and printing "R" for re-certification adjacent to the actual classification of the tape on each station for that unit.

10.1.2.7. Web Related Information. Level 2 screen 4.

This module was called GetJumbo, jumbo being the term that the operators used to describe a coated web. The module was executed on one of three conditions being met:

i) as part of the shift start up routine;

ii) when the system recognised that a previous web must have been completed;

iii) at the request of the operator, when a new web was loaded onto the machine.

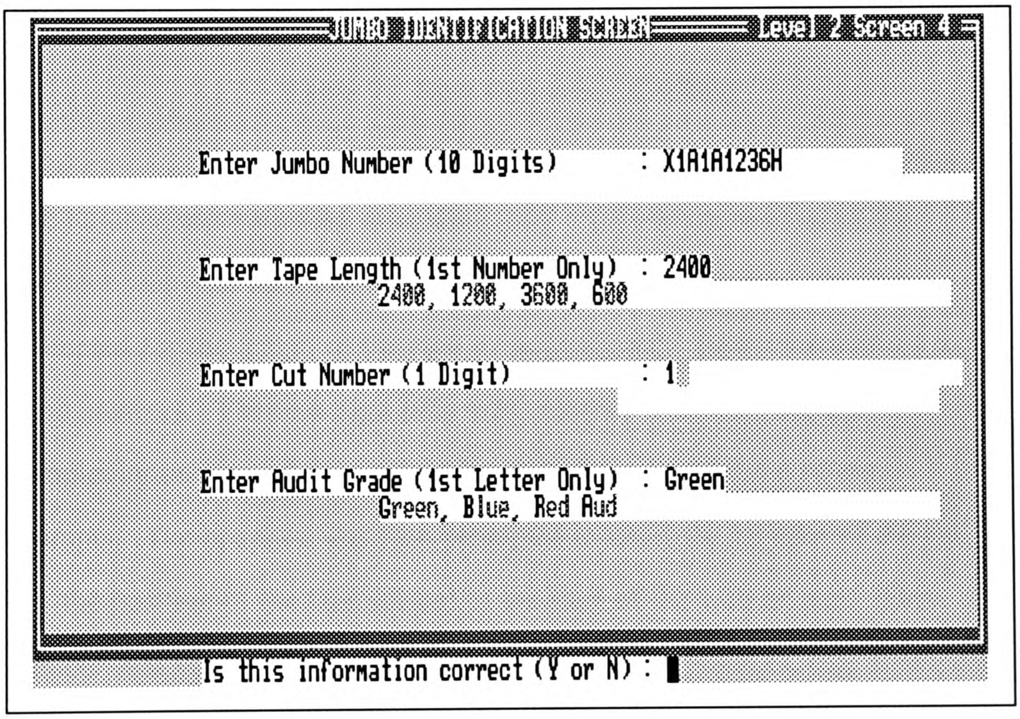


Figure 10.9. Web Related Information Screen.

The operator was prompted to enter a 10 digit reel reference. This number was generated at the coating stage of production and served to identify the exact origin of the web. This number was constructed as shown in Table 7. overleaf, which uses the reel reference X2L6A1236H.

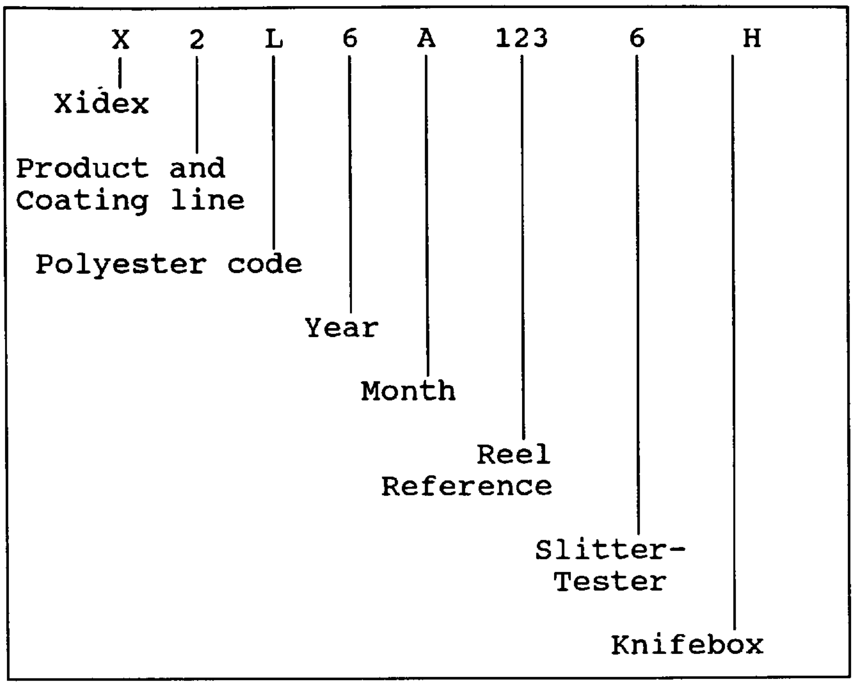


Table 7. Reel Reference Coding.

The number was validated as entered, any errors being notified to the operator who was then prompted for re-entry. The operator was then prompted for the length of the tape to be produced. Entry was limited to valid answers. The first digit only was entered, with the program completing the rest of the product length. Errors generated re-entry prompts. The operator was then prompted to enter the number of the cut, i.e. the position of the tape related to the start of the web or reel. This number was validated using tape length as validating checks, e.g. if standard length tape is being produced the position of the cut had to be between 1 and 6 inclusively. An identifying code was generated from the reel reference, cut length and cut position. This code was used as the basis for the filenames for both unit and station order files. To use the example given above, a reel reference of X2L6D1236H, slit on slitter-tester 3, at standard length for the first cut position on a web would generate a filename of X2L6D123.3H1 where the extension (the 3H1 after the .) would represent slitter-tester 3, knifebox H, and cut position 1. The X prefix signified that the file was in unit order. An S in the same position signified that the file was in station order. The operator was then prompted for the Audit grade of the web. Chapter 2 Section 2.3.2.1 explains the audit grading system in more detail. Again operator key-presses were minimised to two characters, one to identify the audit grade of the tape and the second to confirm the selection by pressing the Enter key.

The system used a method of default entry to further minimise key-presses by the operators. By pressing the Enter key instead of actually entering a value, the operator could select default values. These were set to be the most commonly used values for the particular entries. In the case of this module the default details would be :

i) a cut length of 2400 feet

ii) a cut position or number of 1

iii) and an audit grade of green

These were the most common entries for a web being loaded onto the machine. The operator then had to confirm that the entries on the screen were correct. A negative answer returned the operator to the jumbo (reel reference) prompt at the top of the screen. Again, the likelihood of error was minimised by the validation routines, reducing the frequency of error. This was felt to outweigh the need for a selective error correction as opposed to the operator having to correct the whole screen. The module then returned control to the main program, System. This module was executed once for every reel slit on the machine.

10.1.2.8. Shift Summary. Level 2 Screen 5.

A summary of the data available from the shift was available to the operators. This was an important element in the system being accepted by the operators. Previously, totalling data at the end of a shift was done manually and an automated facility was seen by the operators as a positive benefit in their task.

A file built was up on hard disk throughout the shift. This was then used on request to display the total numbers of each grade, and also to indicate the numbers of evaluation runs for different tape lengths.
Figure 10.10 illustrates this screen.

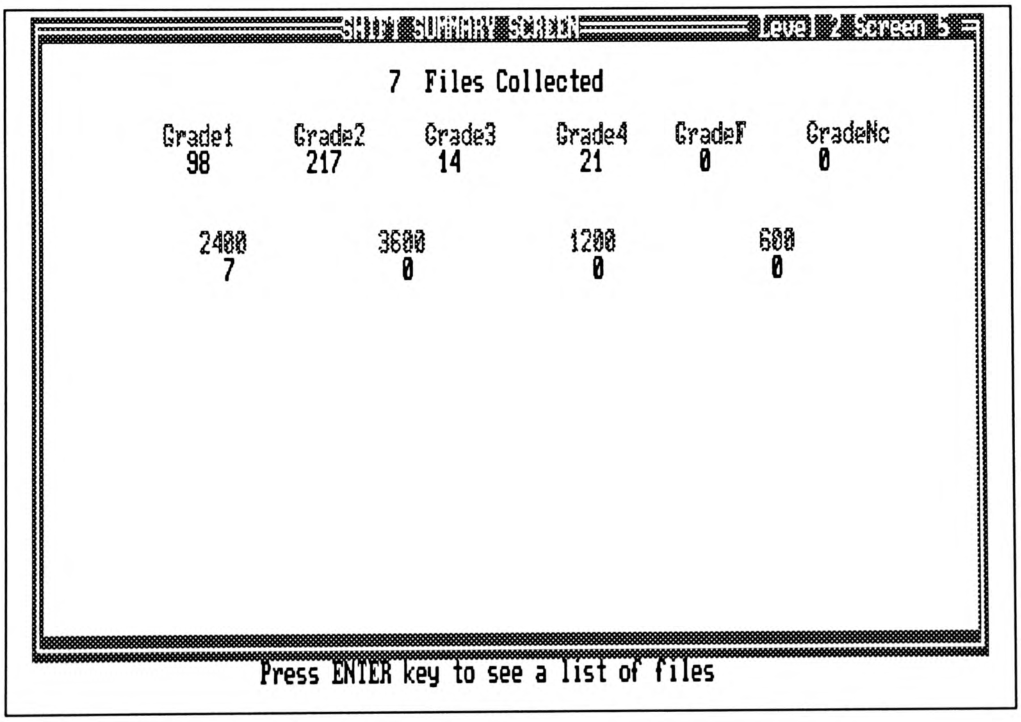


Figure 10.10. Shift Summary Screen. Grade Totals.

The operator was also presented with a list of files that were produced on their shift. Figure 10.11 illustrates this screen.

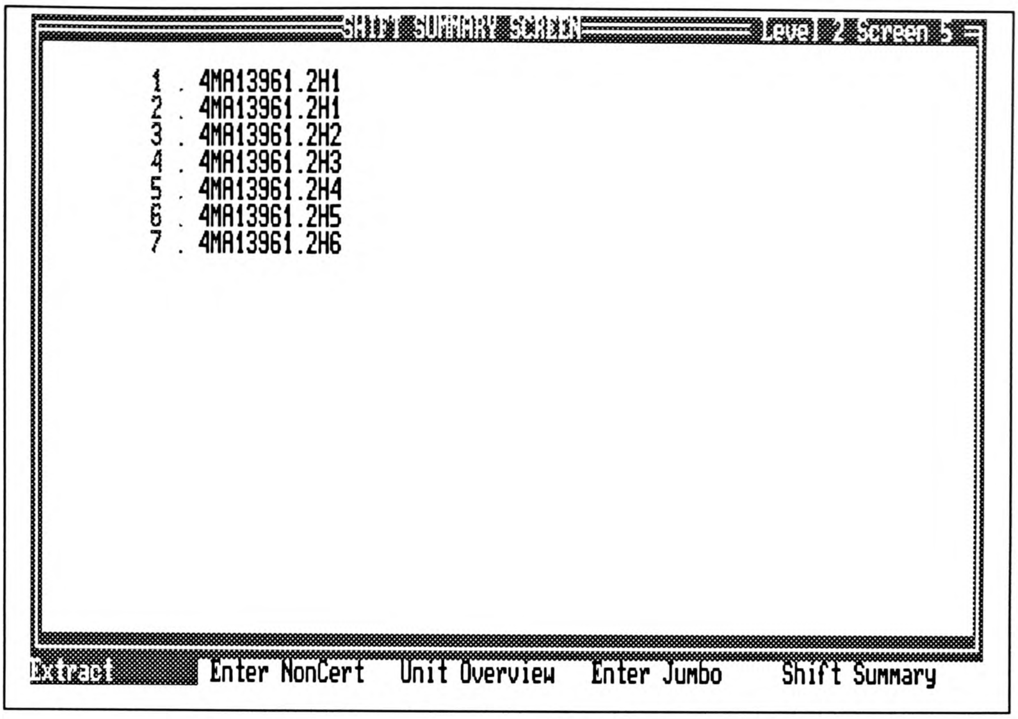


Figure 10.11. Shift Summary Screen. File List.

As the responsibility for ensuring that the file was constructed only from data for their shift was in the hands of the operators, a routine was included to reconstruct the figures from the last 40 files if the summary file contained data from the previous shift.

10.1.2.9. Error and grade display across the web. Level 3 Screen 1.

A useful method of comparing the results of the evaluation run was to plot a graph of 6250 BPI 1 track errors and 1600 BPI hypercritical errors across the web, i.e. from stations 1 to 50 in that order. The purpose was to allow a comparison of adjacent stations.

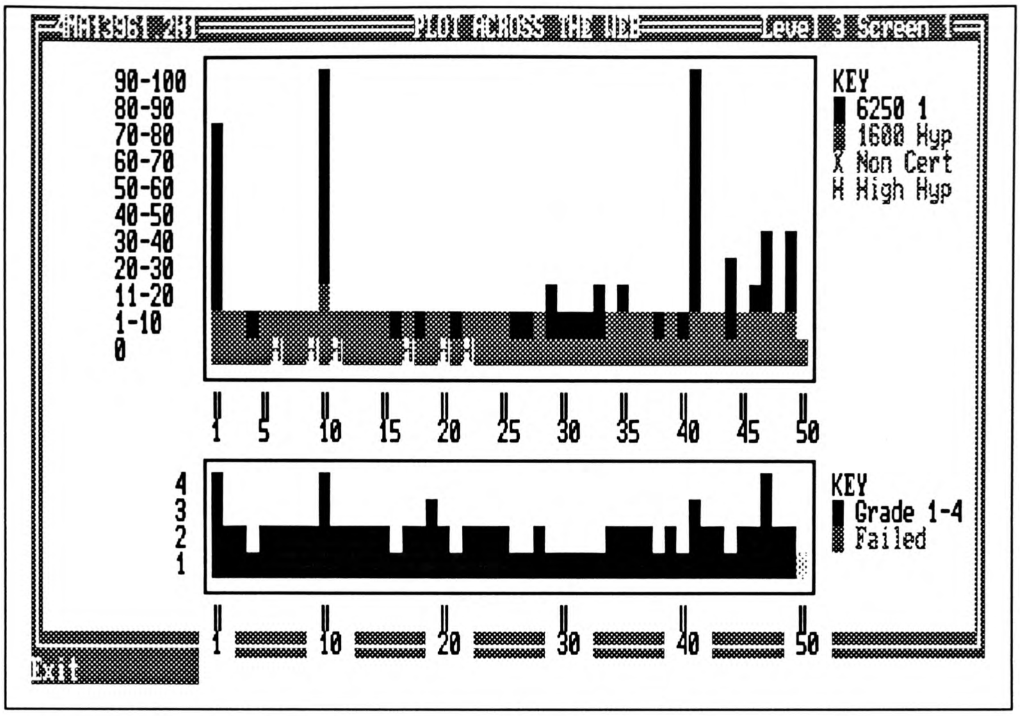


Figure 10.12. Error and Grade Plot Across the Web.

Empirical data (see Appendix 7) had shown that a typical curve should be obtained from an evaluation run. An example is shown in Figure 10.13. The number of 6250 BPI single track errors and 1600 BPI hypercritical errors were used as the Y axis and station positions were used as the X axis. The overall U shaped plot was the result of coating thickness non-uniformity at the extremes of the web.

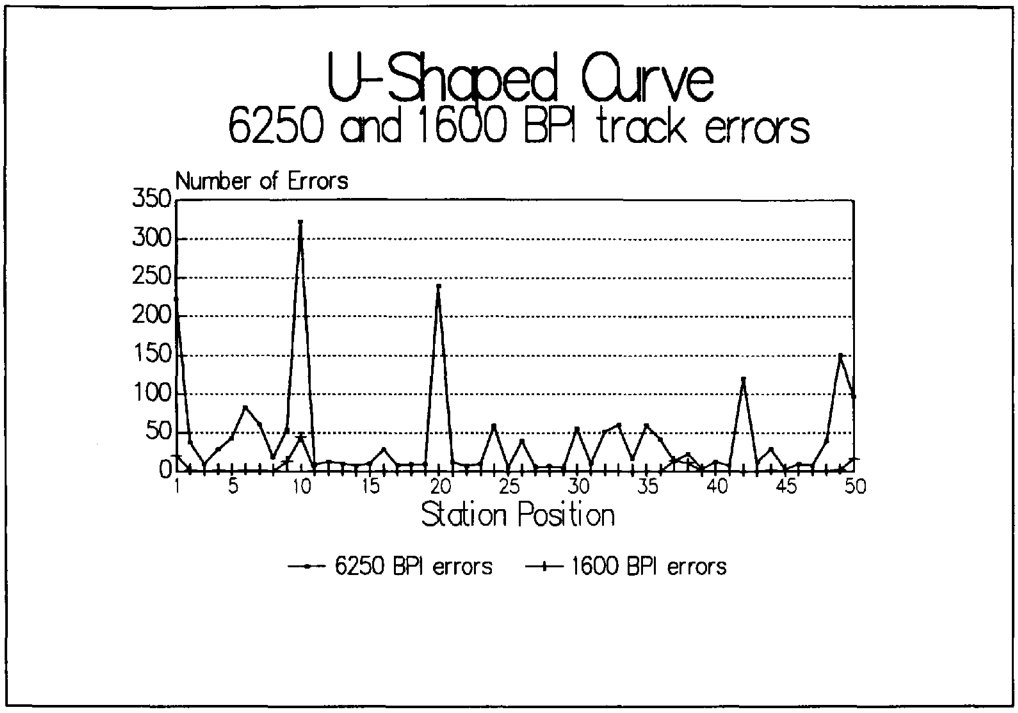


Figure 10.13. Typical error curve from an evaluation run.

A similar plot of the grades of tapes across the web would serve to further illustrate this general trend, as shown in Figure 10.14.

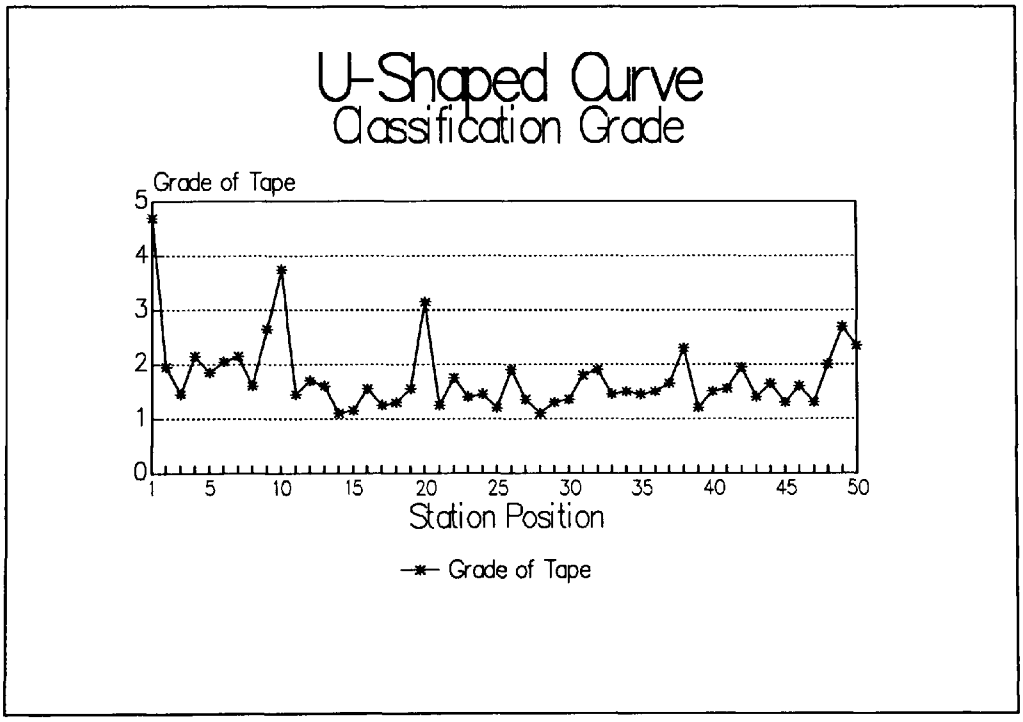


Figure 10.14. Typical plot of grades across a web.

Transient anomalies would not necessitate investigation but if anomalies were occurring over a wide enough range or over several evaluation runs this could serve as an indication of process faults. In the figures 10.13 and 10.14 above it can be seen that stations 10 and 20 are producing noticeably worse results than adjacent stations, but the overall U shape of the curves are clear.

The combination of hardware and software used did not allow a pixel by pixel plotting of errors and so a grouped method of plotting errors was used. In the top half of the screen errors were grouped in 10 ranges with each range being 10, so from 0 to 100 errors were represented. This proved to be the optimum range for plotting errors, if both 6250 BPI and 1600 BPI errors were to be plotted. If the number of errors for 6250 BPI exceeded 100 then that tape would have a higher grade and hence a lower value. A tape with over 100 1600 BPI errors would be graded as failed and re-certified. Stations not-certified were indicated by an "X". If a station experienced more hypercritical than single track errors this was indicated by an "H". This was not a valid test result and could have indicated an electronic fault in the evaluation system within the slitter-tester unit.

In the bottom half of the screen the grades for each station were plotted, the height of the bar representing the grade of the tape for that station, with a grade 1 being shown by a bar height of 1 character and a grade 4 being shown by a bar height of 4 characters. Stations experiencing failed tapes were indicated by a bar height of 1 with a dark grey bar.
Stations experiencing no error were indicated by a grey bar of 1 bar height. The pattern used to define the character used to represent this bar differed from that used for a failed tape, assisting in differentiation.

10.1.2.10. Display of classification criteria. Level 3 Screen 2.

The slitter-tester operators were required to enter classification criteria into the PDP-11, before transmitting this to the slitter-tester units where this data would be used for classifying or grading the tapes.

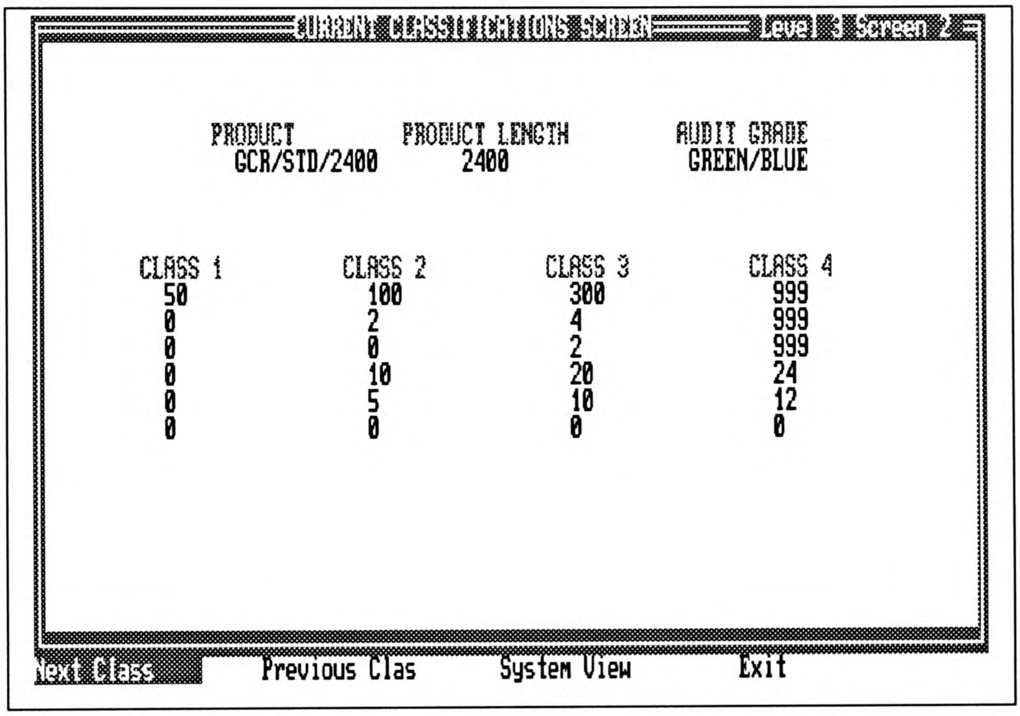


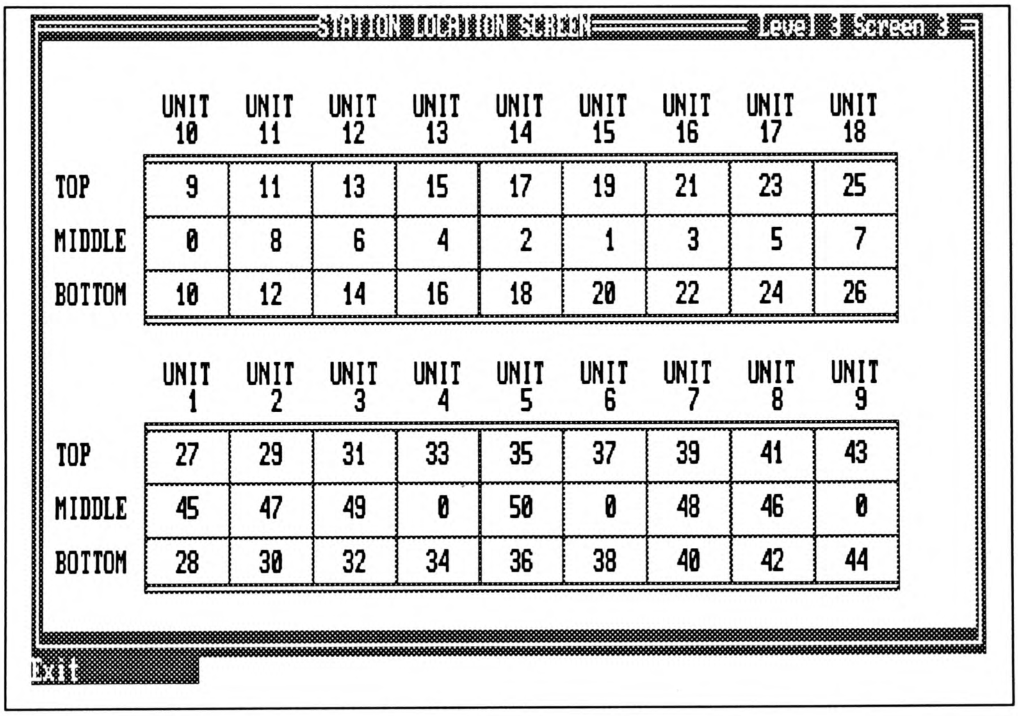
Figure 10.15. Classification Criteria Screen.

Each operator was responsible for ensuring that they were aware of the current classifications. These were generally entered into notebooks or on paper data sheets. This screen acted as a single valid source of information which could only be altered by engineering staff who would then need to re-compile the software. The operator could then refer to this screen, paging through the current products to find a valid current classification which could then be used to enter the criteria into the PDP-11.

Each page contained the classification criteria for one product, a product being defined by the length of tape, customer (sometimes) and the audit grade of the web.

10.1.2.11. Display of stations as they related to the units. Level 3 Screen 3.

A screen showing the position of stations with reference to their units was included as shown in Figure 10.16.



	UNIT 10	UNIT 11	UNIT 12	UNIT 13	UNIT 14	UNIT 15	UNIT 16	UNIT 17	UNIT 18
TOP	9	11	13	15	17	19	21	23	25
MIDDLE	0	8	6	4	2	1	3	5	7
BOTTOM	10	12	14	16	18	20	22	24	26

	UNIT 1	UNIT 2	UNIT 3	UNIT 4	UNIT 5	UNIT 6	UNIT 7	UNIT 8	UNIT 9
TOP	27	29	31	33	35	37	39	41	43
MIDDLE	45	47	49	0	50	0	48	46	0
BOTTOM	28	30	32	34	36	38	40	42	44

Figure 10.16. Station Plan Showing Relationship to Units Screen.

This screen replaced a paper diagram used by the operators to record current positions. While the new system removed the need for this visual cross reference of stations to units, it was included to enhance the acceptance of the system.

10.1.2.12. Display of the most recent 6 runs. Level 3 Screen 4.

An historical plot across the web of the grades of the tapes on the 6 most recent evaluation runs was available to the operators.

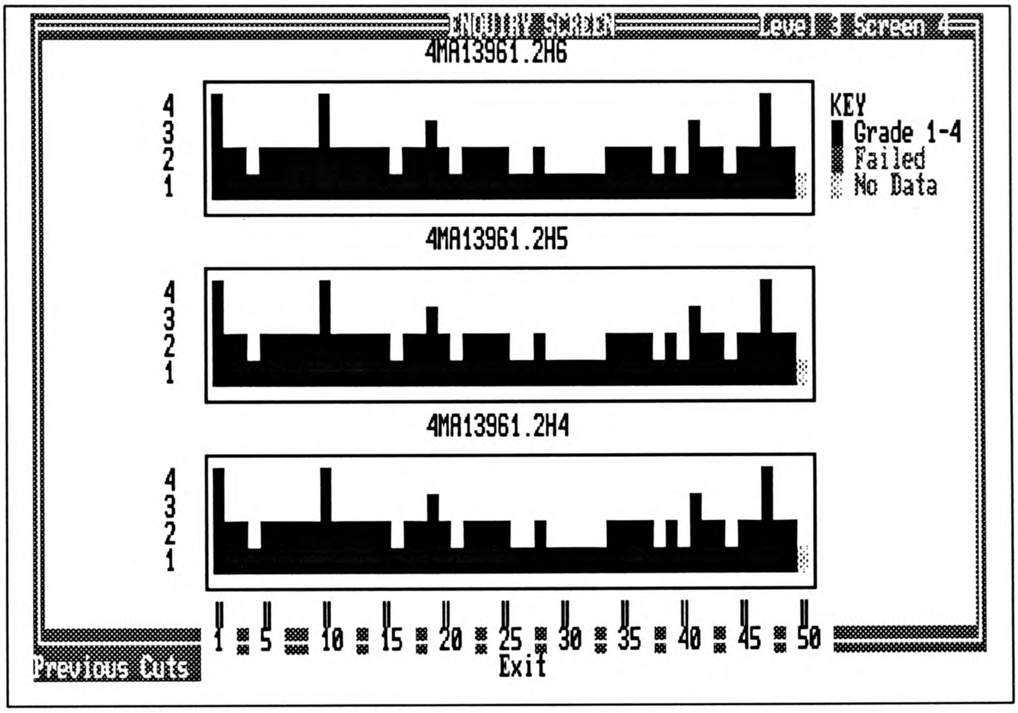


Figure 10.17. Enquiry Screen.

The purpose of this display was to allow the operator to see and understand trends which are not obvious if only the most recent run is viewed. Certain results would make sense when viewed as a trend over 3 or more runs. An example of this would be if a station was continually finding no errors, or continually evaluating tapes to be grade 4. This was a useful tool in identifying potential and actual faults.

The display occupied two screens, over which a complete standard length jumbo could be viewed.

10.1.2.13. Software System Schematic. Level 4 Screen 1.

The system schematic module was designed to improve and reinforce the operators understanding of the hierarchical structure of the system and to illustrate graphically the permissible access paths through the system. Each conceptual level of the hierarchy was shown as a distinct level in the hierarchy, with each node in the hierarchy representing a module which can be selected from the menu. Each node or module appeared to the operators as a discrete screen. The theoretical basis which forms the reasoning behind this module is described at the beginning of this chapter.

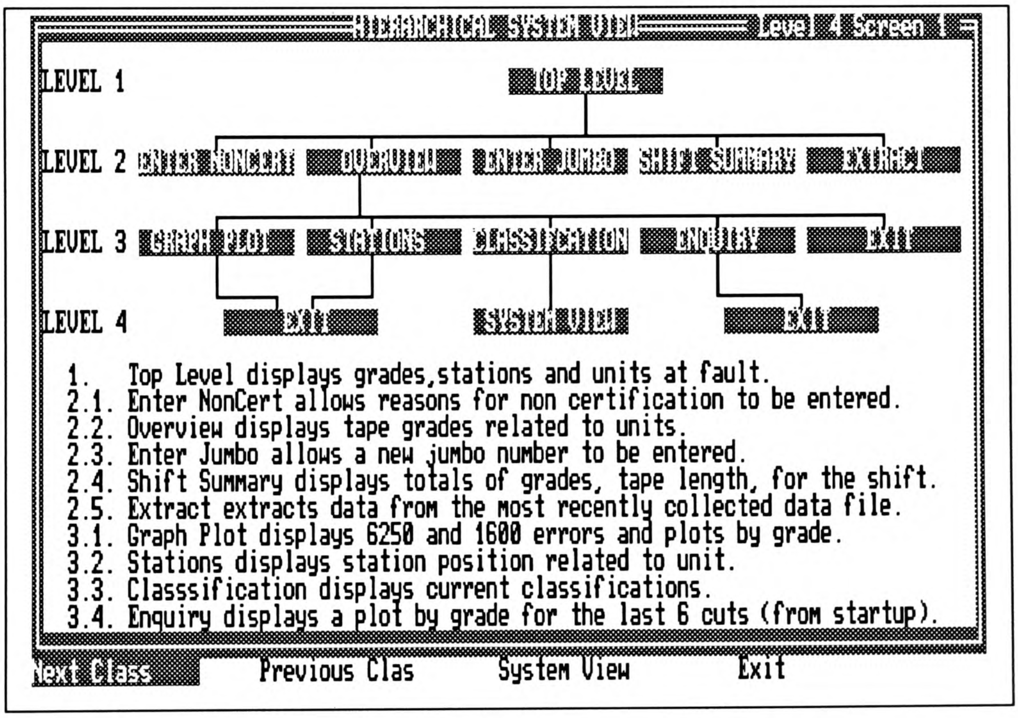


Figure 10.18. Operator Interface Software System Schematic.

The access paths are represented by the vertical and horizontal lines e.g. when the Top Level Summary screen was displayed the menu choices available were:

a) Enter NonCert;

b) Overview;

c) Enter Jumbo;

d) Shift Summary;

e) Extract;

Where a link was shown by a vertical line this indicated that access to the lower level must be via this link e.g. the method of accessing Level 3 in the hierarchy was by selecting Overview from the Top Level Summary, and then by selecting the appropriate option from the menu appearing at the bottom of the Overview Screen. Nodes or modules with no link downwards were not access paths to lower levels.

10.1.2.14. The Menu Display.

The Menu module was the mechanism to enable the operator to navigate around the system. During the operation of the system the operator selected which screen or function to engage by selecting from the menu choices at the bottom of the screen. Which options were displayed and therefore selectable was controlled from the main System module which passed parameters to the Menu module. The parameters were used to define exactly the elements displayed. The elements were arranged in an array. By passing a minimum number and a maximum number to the Menu module as parameters the range of menu options to be displayed was controlled, e.g. when the Top Level Summary was displayed the Menu module was called with the parameters 1 and 5, thus displaying the first 5 elements from the array namely Extract, Enter NonCerts, Unit Overview, Enter Jumbo and Shift Summary. Only one of these options could then be selected. Figure 10.19 shows menu options at the bottom of the Top Level Summary screen.

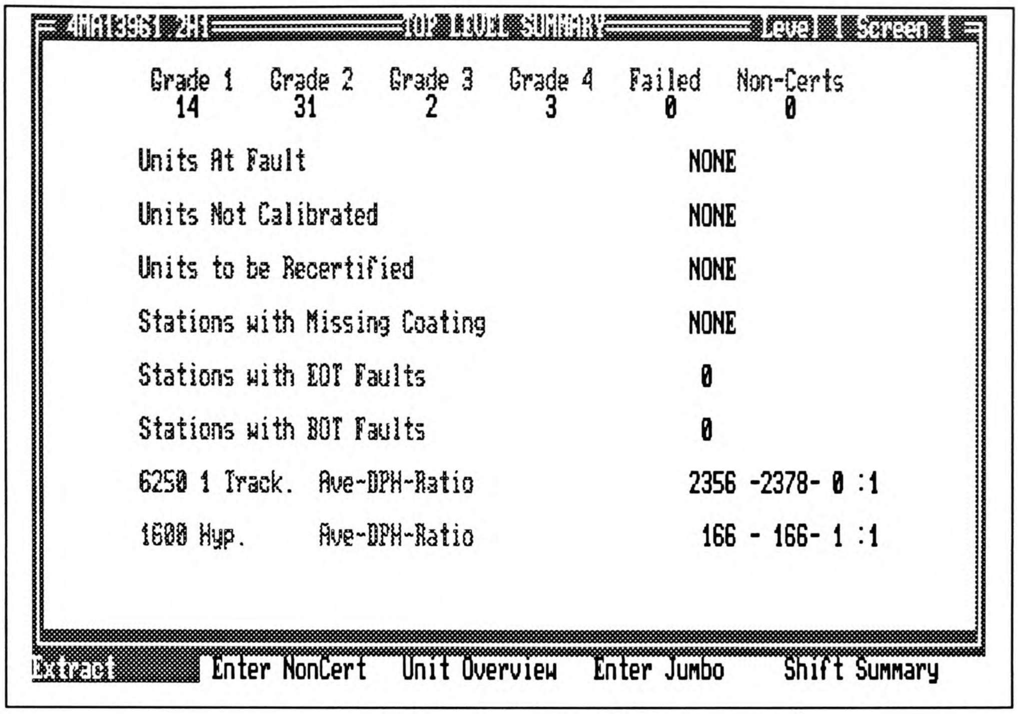


Figure 10.19. Top Level Summary Highlighting Menu Options.

The cursor position was indicated by an inverse video effect. The current option was highlighted by reversing the background and foreground character colours. In the Figure 10.19 the cursor is on the menu option to Extract. The cursor was moved by using the arrow direction keys, either left or right. Moving past the right hand end, returned the cursor to the left hand end and vice versa. The required menu choice was selected by pressing Enter when that option was highlighted. The name of the selected option represented a module, the name being returned to the System module and used to call, or display, that selected module. The cursor always appeared initially at the left most option that was displayed, giving a consistent reference point for the operator. The option to Exit from the currently displayed screen was always displayed at the right of the screen. Exiting from a screen always returned the operator to the hierarchy level above from which it had been called.

10.1.2.15. The Incrementation Module.

As stated previously, the operator was only required to enter reel information data once for each reel to be slit and tested on that machine. The incrementation module simply incremented the cut number (or position of the tape within the web) between evaluation runs. This was performed automatically. Extract was selected from the menu, incrementing the cut number and thus producing a new file name.

This module calculated the normal end of a jumbo or web by using the length of the tape being produced to determine how many cuts or separate evaluation runs could be performed from a full length web. The operator was required to enter the length of the web when completing the reel information screen. If the end of a web were calculated then the reel information module was called to prompt the operator to enter the reel information needed to identify the data file about to be produced.
The operator was not aware of the existence or function of this module, as its operation was transparent, and not significant for the operator.

10.1.2.16. The Box Plotting Module.

All screens were displayed within a box or frame drawn on the screen. This routine simply plotted the box edges and bottom. The area below the defined box was reserved for menu selections, or validation prompts to the operator.

10.2. Potential Developments.

10.2.1. The conceptual design incorporated elements from Statistical process control. Data could be collected from all three slitter-testers and processed to provide initial control parameters. The data could then be used to provide acceptable production parameters for each audit grade of each type of product. During normal production these parameters could be used as control limits to provide a useful indicator of web or machine performance, enhancing the assistance of the operators interface in decision making. As each audit grade had its own criteria for classification, web(s) consistently performing outside the specified control limits for that audit grade could be re-graded accordingly.

10.2.2. All transmissions on the RS422 communication line between the slitter-tester and the PDP-11 could be monitored. The actual criteria used for any particular evaluation run could be collected and stored with the data file. This would involved modifying the line monitor program and to a lesser extent the module in the operator interface which writes the data file to disk (Top Level Summary). This would have ensured that the operating conditions such as thresholds and the classification criteria used for each evaluation run were available for referencing to the test results.

CHAPTER 11. THE DATABASE REPORTING SYSTEM.

The results of the feasibility study determined a need for data and information to be grouped and reported upon over differing timescales. These were typically by periods of a shift, a day or a week. These longer term reports would offer comparisons of performance between different shifts, slitter-testers, coating lines and products. These reporting requirements are presented in detail in Chapter 6.

The method decided upon for fulfilling this function was to provide a fourth microcomputer situated on the shop floor which would receive data files from each microcomputer attached to a slitter-tester. These files were to be transmitted automatically immediately after the data had been extracted from the full transmission file by the operator interface, as described in Chapter 10, Section 10.1.2.3. which discusses the Top Level Summary screen of the operator interface.

An application program was used to receive and organise the data files. These files could then be processed using the fourth microcomputer or removed and processed off-line using the same package.

11.1. Hardware Design.

The microcomputers attached to the slitter-testers were linked to the fourth microcomputer via a self-contained data buffer. The buffer surmounted the hardware limitations imposed by the microcomputer hardware and software which only allowed 2 serial communication ports. The buffer was equipped with 3 serial RS232C receiving ports and 1 serial RS232C transmission port. Figure 11.1. shows a block diagram of this part of the system.

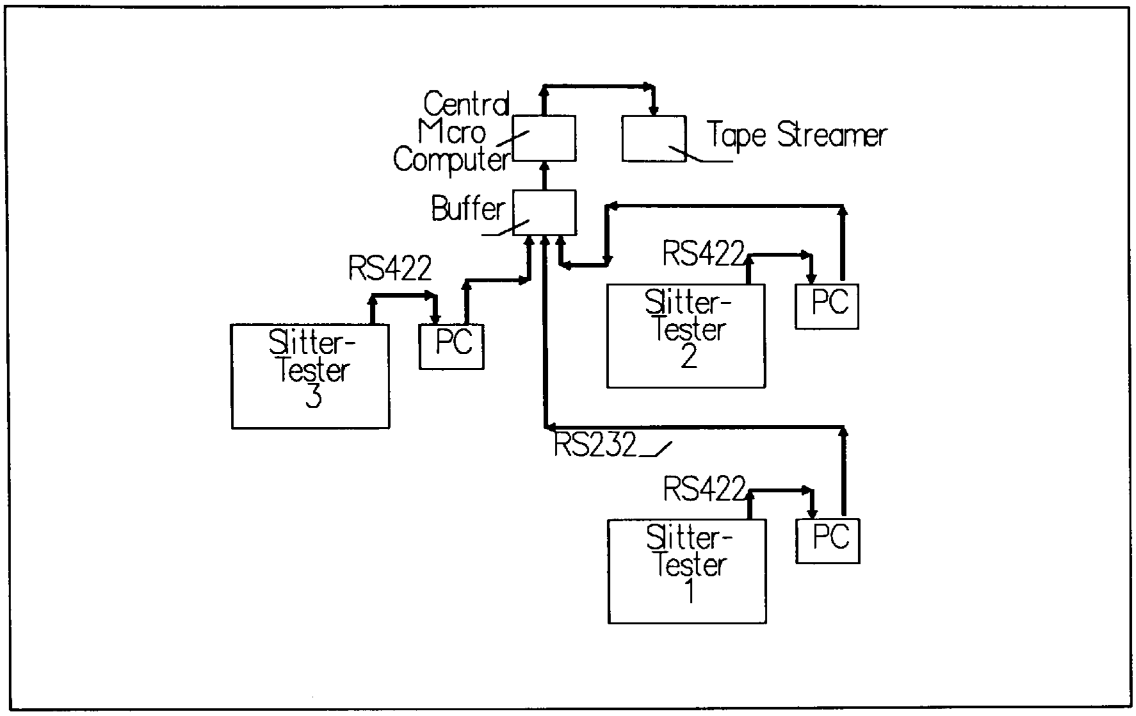


Figure 11.1. Database Reporting System. Hardware Set-Up.

The receiving ports used by the buffer were set at the following baud rates:

a) transmission from slitter-tester 1 = 9600 BPS

b) transmission from slitter-tester 2 = 4800 BPS

c) transmission from slitter-tester 3 = 9600 BPS

Note that slitter-tester 2 could transmit at only 4800 BPS as the buffer had a maximum concurrent rate of reception of 24,000 BPS. The buffer contained one megabyte of memory and the necessary hardware and software to operate as a First In First Out (FIFO) buffer, sequencing the data files transmitted so that the central data collection point would be able to receive one data file at a time at 9600 bits per second. In the event of a simultaneous transmission on two receiving ports, priority was given to the lowest order port (numbered from 1 to 3).

The buffer had the facility to store data without re-transmitting, thus providing two useful features. Firstly, the central data processing microcomputer did not have to be permanently operational as the buffer would retain 1 Megabyte of

information (approximately 8 hours of data at full production rates) and secondly, the buffering allowed the use of both PC-AT compatible and PC-XT compatible microcomputers, allowing the reporting function to be operated using the database package on either microcomputer.
The original concept was to use a PC-AT compatible, which offered a faster operating speed than the PC-XT compatible. For reasons of cost a PC-XT compatible was used. The buffer allowed the receiving computer to control the transmissions from the buffer by using flow control signals.

A 30 Megabyte tape streamer was attached to the PC-XT, by means of a plug-in card. This served as a large scale storage device, with all data files being stored onto magnetic cartridge tape for archiving purposes after the daily reports were generated.
The design catered for the transmission of data to the office floor, which was approximately 40 metres away, proposing the use of RS422C for this purpose. Extensive testing ensured that RS232C was satisfactory for transmissions from the slitter-testers to the buffer and from the buffer to the central data processing computer.

11.2. Software Design.

11.2.1. Operating System.

The multi-tasking operating system used on the operator interface, Doubledos, was used on the report generating PC-XT to allow two processes to be performed concurrently. One process was the receiving of data files in the two formats, unit order and station order as output by the operator interface described in Chapter 11. The second process was to allow the database reporting system to be run while data was being collected. The design also allowed for alternative applications programs to be run as one of the two processes.

11.2.2. Applications Software.

Several applications programs were written using Microsoft Quick BASIC version 3.0, the same version of the BASIC language used for the operator interface. These programs are described below:

a) Data Receiving Program.

This program opened the communications port on the PC compatible computer which was used as a central data processing facility, to receive data files using RS232C protocol at 9600 bps with no parity and 8 data bits. The program set the port up as a receiver which monitored any transmissions on that line. On the reception of a valid recognisable transmissions which started as shown below :

** FILENAME ** filename ** LENGTH ** nnnn

This start of transmission acted as a file header which informed the receiving program of the name of the data file and the length of the data file that the program would receive. The program then reads in the correct number of bytes from the communications lines. The file was then written to a directory, the directory being determined by which slitter-tester the data originated from.

The program would then return to a listening mode, waiting for the next transmission. As stated above, each data file was transmitted in two different formats, unit format , indicated by the first character of the filename being a capital X, and station format, indicated by the first character of the filename being a capital S. The unit order files allowed the faster processing of the data files while the station order files simplified the formulation of queries for use on the database management system.

This program was designated as one process (usually the visible process) and provided basic status messages, informing the user whether a data file was being collected or not, and the last data file collected.

The program could be run continuously to ensure the reception of all data files or could be suspended by disabling the transmission facility of the data buffer (by the use of a button on the front of the buffer). The ability to stop the transmission process and use the central data processing computer to perform a single task increased the speed of processing by the database reporting system. The multi-tasking operating system allowed two processes to be run concurrently, but at a reduced speed, due to the switching in and out of memory of each process;

b) Daily File Processing Program.

A batch file (or program) was written to enable the user to organise, archive and then delete the data files collected daily. The organisation of files put all appropriate data files into one directory for processing from within the database reporting system. The archiving wrote the data files to the tape streamer using the slitter-tester number and the date as a directory reference. When the files had been organised, processed and archived, they were deleted from the hard disk of the computer, requesting confirmation from the user. Individual files or directories of files could be retrieved from the tape streamer on request, allowing ad-hoc requests to historical data to be performed;

11.3. The Database Reporting System.

A database management package was selected as the medium for reporting. The package selected, Paradox 2.0i, produced by Ansa, was a relational type database package, which also contained an applications generating facility and a report generating facility. This package provided a consistent method of obtaining information from the data, whether for regular reporting requirements already identified in Chapter 6, or for irregular ad-hoc queries. The package became the accepted standard database within the engineering section of the company.

Simple queries could be addressed by the use of a query by example (QBE) type interface. More complex queries could be set up by an experienced intermediary. The data files used for standard reports were the same files used for querying the data. By selecting which of the two transmission format files to query all data available from the slitter-testers could be accessed in a straightforward manner. An applications program was set up, using the package's integral Applications Language, to automatically process all data received by the central computer in the system. The modular programs, or scripts as they were termed, acted to load all data files for the current day's production into a single database. Queries performed automatically on that database produced reports, consisting of subsets of that data. These reports and their contents are detailed in Appendix 8. For production data, these reports replicated those already in existence, producing data organised on a per machine, per shift, and per coating line basis. A copy of a typical contemporary report produced from the manually recorded data is contained in Appendix 9.

It should be noted that simply automating the existing report produced two direct benefits. The existing reporting methodology was to retain the sheets produced by the operator during their shift, detailing the most important production data for each evaluation run of the machine. A copy of this log sheet can be seen in Appendix 3. The information recorded represented a small subset of the total information available. The details from the sheet would then be entered into a spreadsheet, Lotus 1-2-3 version 2. This was done on a daily basis, starting at 6 o'clock in the morning, entering the data from the log sheets for the preceding 24 hours i.e. the previous day's morning shift (0600-1400) afternoon shift (1400-2200) and the night shift which had started on the previous day (2200-0600). The report produced from this data would be produced between 3 and 4 hours later. A copy of this report is included in Appendix 9.

There were four problems arising from this:

i) The delay in producing data or information. Some of the data being reported would have actually been produced over 24 hours previously, with the most recent being 3 hours previously. Potential faults, such as recurring conditions on a particular machine, might not have been picked up in the intervening period.

ii) The transcription of data from the computer screen to the log sheet and back again from the log sheet into a computer spreadsheet allowed two opportunities for error (although manual checking of totals should have detected obvious errors).

iii) The manual logging of the data appearing on the computer screen and re-entering the data into a spreadsheet occupied the machine operator's time and between 3 and 4 hours of a clerk's time per day in total for all slitter-testers.

iv) The reports that were produced were of use for production purposes, detailing the numbers and grades of tapes produced by each machine and coating line, but were based on less than 5% of the data available, and did not contain enough information for the electronic department's maintenance needs.

The reporting system that was designed to replace this was able to be run at any time and could therefore could give sensible information after any shift, but was in general expected to be run once per day, after the previous day's night shift had been completed. The new system did not avoid the first problem arising above, that of a delay in producing the reports. However, the improved error and potential error detection of the new operator interface could serve to lessen the effect of this delay. The clerk also had to continue her involvement in producing the reports, but the task was reduced and could be performed in less than half the time originally taken. The new system avoided the possibility of transcription errors, as all communication was automated, and all the data produced by the slitter-tester was recorded.

As Paradox had become the accepted database within the company and familiarity was increasing, it was agreed that the most useful course of action was to hand over the development of the reporting system to Xidex electronic engineering staff. This would ensure that the system could continue to be modified as an increase understanding of the nature and capabilities of a relational database developed.

The reporting format that was in use was a table, produced on a computer spreadsheet, Lotus 1-2-3 Version 2. As most of the engineering staff were familiar with this format it was decided to process the data initially using the database reporting package and transfer the results into a spreadsheet, thus producing the tabular format, and facilitating calculations and the automatic production of graphical output. The database had limited mathematical functions and could not produce graphs, while the spreadsheet had relatively sophisticated mathematical functions and could generate graphs easily.

CHAPTER 12. STATISTICAL TECHNIQUES FOR MONITORING SLITTER TESTER OPERATION.

Throughout manufacturing industry there is an increasing recognition of the need to closely monitor production processes and provide a mechanism for the more rapid rectification of faults. The underlying philosophy of Statistical Process Control (SPC) as defined by W. Edwards Deming and discussed in his book "Out of the Crisis" (1982a) is to put the tools for detecting errors or potential errors into the hands of those best placed to monitor the production process, that is the operator of the equipment. These are also the most appropriate people to initiate correction procedures. The philosophy extends beyond simply improving the product, to increasing the sense of contribution to the end product that the operator experiences. For further reading see the book referenced above.

The main idea embraced in Deming's philosophy could sensibly be applied to the slitter-testers. That is to establish whether the results from the slitter-tester are in statistical or stable control, and that any variation seen is due to common causes, that is those variations of the production system that the machine operator cannot affect. All fleeting or special causes of variation detected have to be removed before a machine is in stable control. (Deming 1982b). Deming (1982c) states that the ratio of the faults that the operator cannot control to those that he/she can control are of the order of 94:6..

Due to the complexity of the process and the frequent changes of product it proved impossible to undertake an accurate machine process capability study during the period of the project. The insurmountable difficulty of organising and altering the slitting sequence of coated webs onto one slitter-tester, to follow the order in which they were coated precluded the establishment of capability limits. The reasons for this are given overleaf.

1. The process of evaluating whether or not each slitter-tester is in stable control is complicated by the web curing and warehousing system which is interposed between the coating and slitting stages. The warehousing operates on an automated first in-first out basis (irrespective of whether air and oven curing is used). It is disruptive to this method of warehousing to reorganise the output so that the slitting and testing of sequentially coated webs takes place on a particular slitter-tester.

2. On the slitter-testers any measurement of stability is also complicated by the use of the audit grading system which categorises the webs at the coating stage. This does not preclude the use of control charts but means that a different control chart would be necessary for each audit grade and possibly each product. The audit grading process, by its nature, produces a more rigorous testing criteria for those webs which perform less well at the coating audit. As discussed in Chapter 2 Section 2.3.2.1. this method of audit grading safeguards quality. If a web does not meet the coating audit criteria, then the slit tapes produced from that web are tested to a more rigorous criteria than that to which they would otherwise have been subjected. The method of audit grading used at Xidex cannot accurately assess the correct grade for each web, as the webs are tested on a sampled basis. The audit is performed usually:

i) every sixth web;

ii) when there is a change in production (formulation, length)

3. A further complicating factor is the decision about which piece or set of data should be used to gauge whether or not a process is in stable control. As has been discussed, the operator should not be presented with a large volume of incomprehensible figures. The object of any exercise employing an element or form of statistical control must be to provide the operator with a single, simple,

easy to understand, measure of performance. The items of data that are best suited for the purpose of accurately representing the process are:

i) the number of grade 1 tapes achieved on a run;

ii) an algorithm which includes all grades of tapes from a run;

iii) the total number of 6250 BPI 1 track errors achieved on a run;

iv) the total number of 1600 BPI hypercritical errors achieved on a run.

The most obvious criteria for representing the performance of a slitter-tester is the number of tapes achieving the highest grade - grade 1. A sequential plot of the number of grade 1 tapes produced by each evaluation cycle could be used in a control chart. Deming (1982d) states that a trend of six or more points below an average could be used as a trigger for initiating investigation of a special cause. A plot of the number of grade 1 tapes for a series of test data in the order of production for one slitter-tester is shown in Figure 12.1.

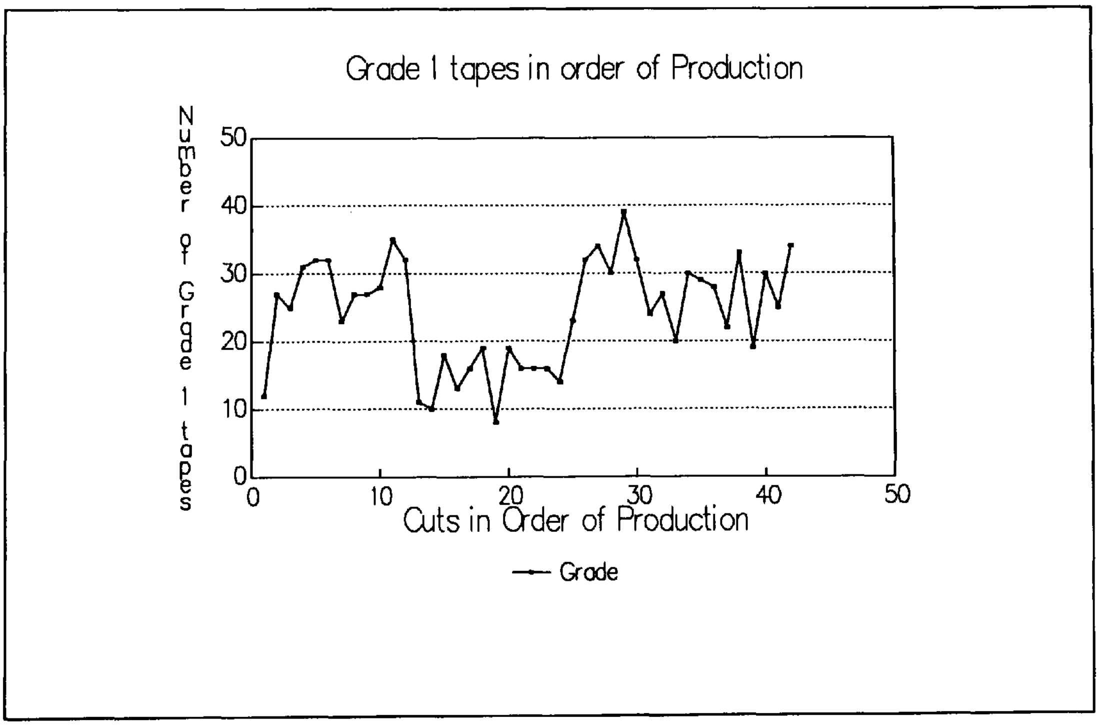


Figure 12.1. Plot of Grade 1 Tapes in Order of Production

The number of grade 1 tapes achieved on a run is affected by the audit grading procedure and so a more accurate measurement of absolute performance would be to use the actual number of errors. A plot of the total of 6250 BPI 1 track errors for the same data set as shown in figure 12.1. is shown in Figure 12.2.

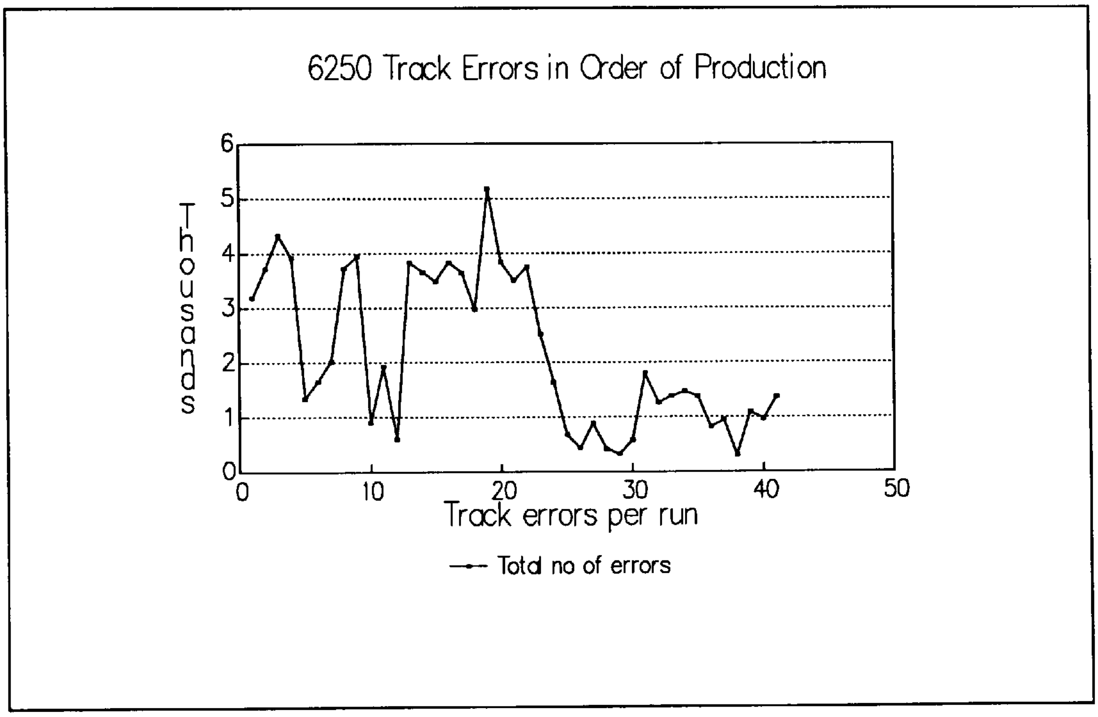


Figure 12.2. Plot of Track Errors in Order of Production

The importance of slitting and testing webs in the order that they were coated needs to be explained. Deming (1982e) states the need for measurement in the order of production. If you are looking for a trend or pattern which would indicate a production problem, particularly coating problems in this case, then it is essential to test the product in the order of production to be able to provide as accurate a picture as possible.

There were thought to be trends underlying the production process which cause a difference in test results. These could be measured if it were possible to sequence coating.

These trends were :

i) formulation differences where a variance in formulation or the polyester substrate reel would affect results;

ii) trends over the whole web from cut 1 to cut 6;

iii) differences between machines.

12.1. Measured Process Variation.

Due to the difficulties of the sequencing work in the order of production, points i) and iii) above could not be achieved but point ii) was measured by collecting and processing data for whole, completed webs (that is webs which produced 6 cuts). A regular process variation became obvious from examination of data already collected. A relatively simple analysis of the number of grade 1 tapes produced for each cut of a web showed a typical graph as shown in figure 12.3 which uses the example of standard length tape.

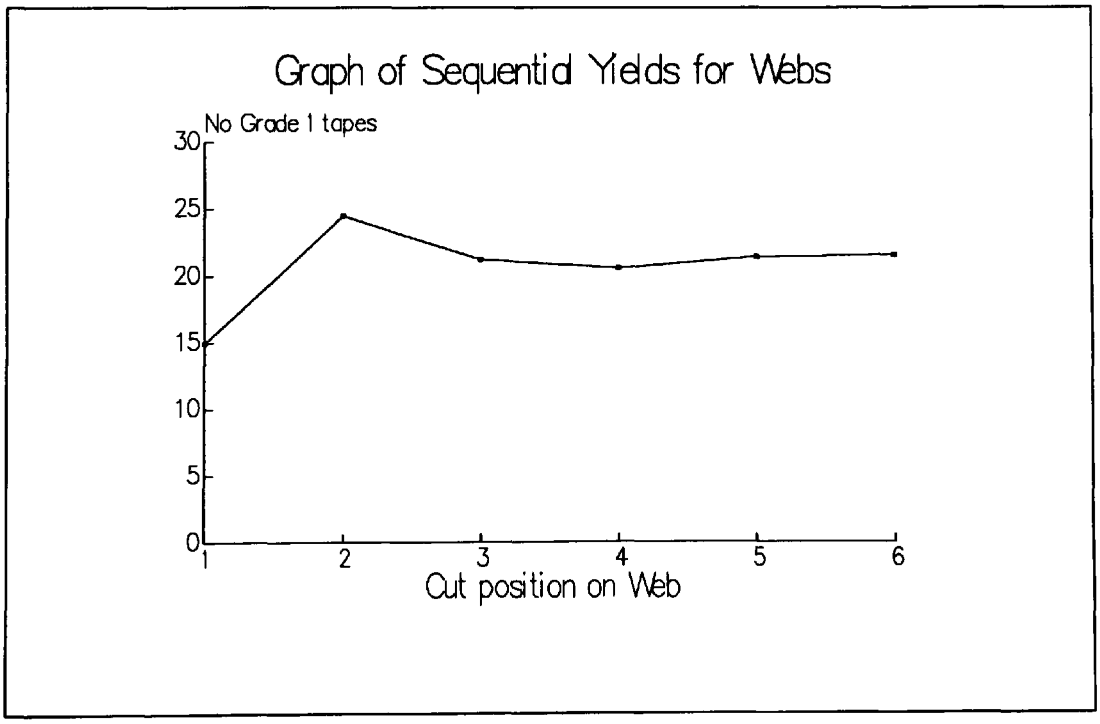


Figure 12.3. Analysis of grade 1 tapes produced from complete standard length webs.

The interpretation which could be made of this was that better coating and winding performance or characteristics were consistently being achieved in the mid section along the length of the web. Coating and winding aberrations e.g.. creasing around the hub or core were more likely to occur at the start or end of the web.

This trend could be built into any analysis of data which was seeking to improve operator control and understanding of the process.

12.2. Establishing a Valid Statistical Comparison Between Slitter-Testers.

In order to reliably and accurately compare slitter-tester performance a method was devised for reducing the effects of long-term trends upon results. This plan was proposed, but the difficulties of sequencing work prevented its use. Webs coated on one line would be ordered, for example, from 1 to 9 in addition to their full identity coding. These would then be assigned to the slitter-tester in the following manner:

Slitter-tester 1: Webs 1, 6 and 8

Slitter-tester 2: Webs 2, 4 and 9

Slitter-tester 3: Webs 3, 5 and 7

If the numbers of the webs are totalled up for each slitter-tester, the sum is 15 in each case. The intention would be to limit the effects of any long term coating trends, which could distort the results if for example, the first three webs were slit and tested on slitter-tester 1 etc.

This technique proved somewhat problematical as selection of webs to be slit and tested was governed by first in first out fully automated mechanical storage system. The method was proposed as a technique for producing as accurate as possible machine comparisons. The process of slitting and testing 3 webs on each machine would take some 6 hours in total.

12.3. Machine Capability Study.

If sequencing of coated webs into the order of coating were possible, then data could be collected from each machine, the purpose being to analyse that data identifying typical patterns or trends and to infer from that population that a typical tape in a particular position in a particular section of the web should produce a grade n tape.

12.3.1. Control Limits.

If it were possible at some future date to sequence the order of slitting then it would be possible to :

i) establish if there were a difference between the slitter-testers;

ii) establish control limits for :

a) sequential production using the number of tapes achieving the highest grade, grade 1, as the measure;

b) plotting across the web.

It was envisaged that control limits would be defined by interpreting historical data and then selecting limits which could give realistic guide lines for a set of control limits within which to constrain the process. Deming (1982f) has stated a method which is based upon measuring production variables and calculating control limits based on three standard deviations from the stable process level. These control limits provide "under a wide range of unknowable circumstances, future and past, a rational and economic guide to minimum economic loss from mistakes" Deming (1982f). With the correct sequencing of slitting and testing of webs it should be possible to calculate control limits which could be applied to each slitter-tester.

However without proper sequencing of webs the points i) and ii)a) above are not possible. However ii)b) was possible in a meaningful way and was implemented in a simple visual manner as shown in the operator interface, level 3 screen 4. This showed a plot of grades across the web for the six most recent cuts, allowing the operator to see which, if any, stations were performing at an unlikely or undesired level, particularly in comparison with adjacent stations. It would be expected that a graphical plot of grades across the web would follow the general U shape shown in figure 12.4. A station which consistently produced a grade 4 or failed tape would clearly show up on the graph. Equally, a station which is not certifying would show up clearly.

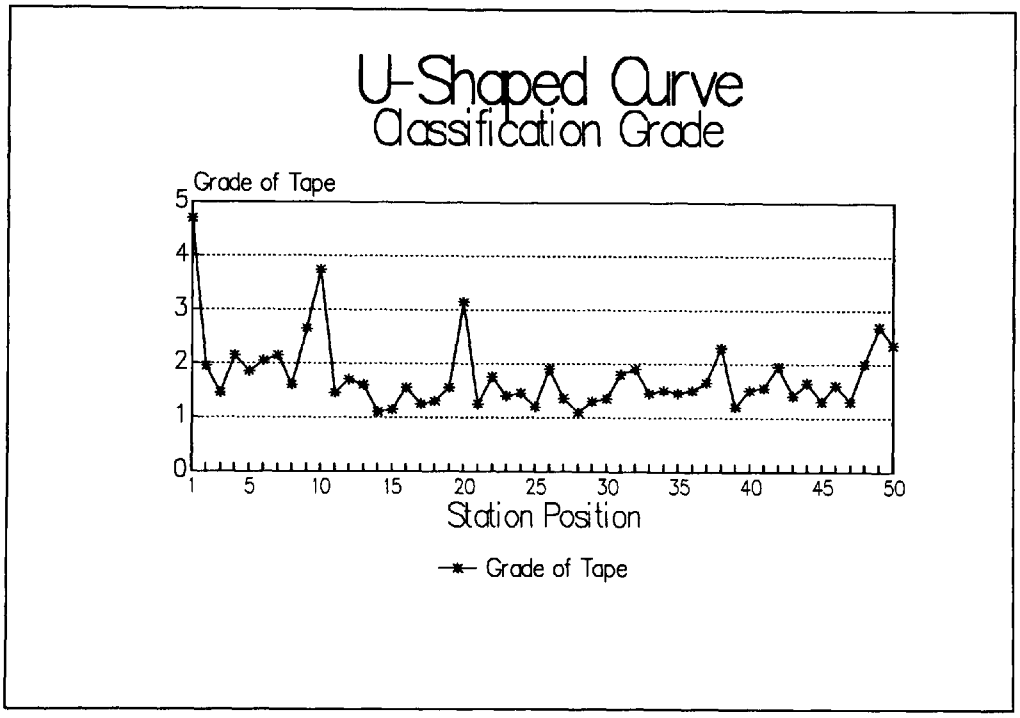


Figure 12.4 Grade plot across the web.

12.3.2. Representation of Process Variation.

As a simple visual tool it would be possible to plot data as a histogram or line chart representing the number of grade 1 tapes, or the track error data, as shown in figures 12.1 and 12.2, for the last 40 cuts. This data was already contained in the file used to inform the operator of the summary of data for that shift. This data would be plotted with the inclusion of control limits. The control limit is produced statistically from previous runs. The suggested control limit is an adaptation of Deming's ideas, using the statistical average as the centre line and one standard deviation above and below the average as control limits. Ideally, each audit grade would have its own control limit.

This would provide a clear representation of the process and allow the rapid identification of trends which could indicate several things, as outlined in this chapter Section 12.1., but including the possible incorrect audit grading of the web. The graph produced in figure 12.1 is used to illustrate this, and is shown as figure 12.5 with the inclusion of suggested control limits. The second, lower control limit is used to compensate for the fact that the first cut from a web consistently produces a lower number of grade 1 tapes (as shown in Figure 12.3). The control limits are at 1 standard deviation above and below the average, this providing a reasonable control limit which would not precipitate corrective action too frequently.

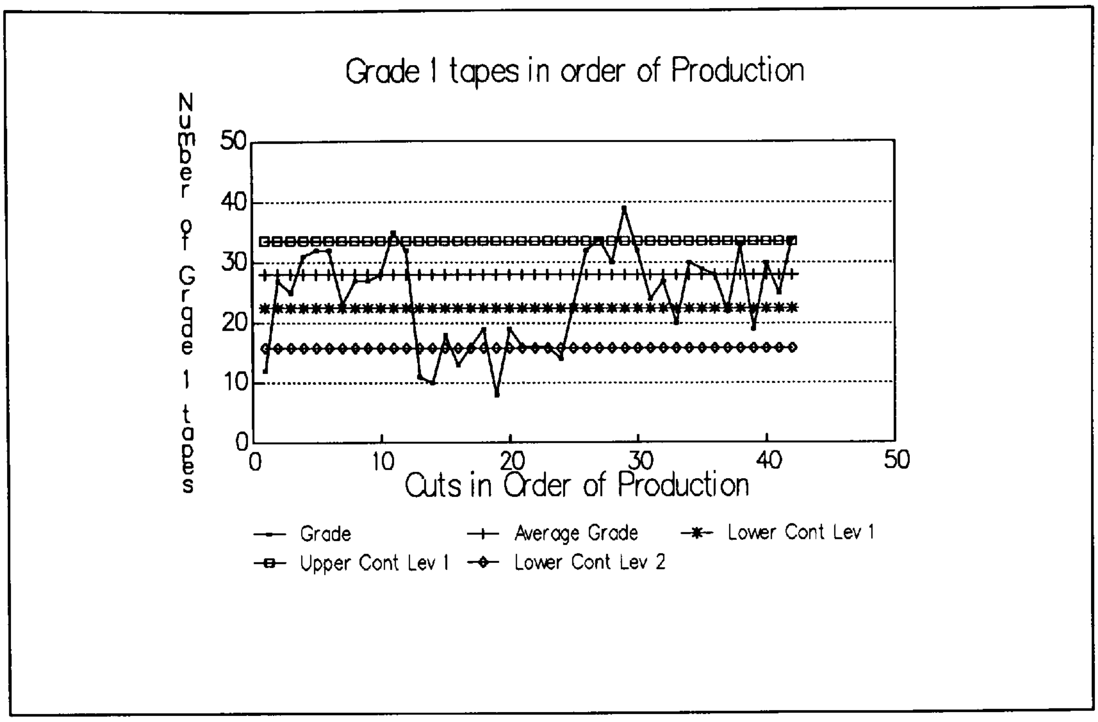


Figure 12.5. The Representation of Process Variation and Control Limits.

12.4. Process Measurements Achieved.

Four potential sources of slitting and testing problems were identified :

i) faulty electronic test equipment at one point, producing erroneous results

ii) temporary web related problem. A temporary problem is defined to persist for the duration of one web;

iii) a permanent web related problem i.e. distributed at the same point over more than one web. This could indicate either slitting or coating faults;

iv) slitting problems- which would produce a continual deterioration in results (although Xidex did employ a preventive maintenance system to reduce or eliminate this).

In order to make sense of the mass of data, historical data was processed. Measurements of mean, maximum, minimum and standard deviation for all 6250

BPI 1 track, 1600 BPI hypercritical and write/skip track errors for all 50 stations across the web. A typical set of data produced for one station is shown in Table 8. These sets of data were produced from test results for standard length tape (2400').

STATION	1			
	MEAN	MAX	MIN	SD
6250 1 trk sum	221.90	999.00	43.00	267.69
6250 2 trk sum	185.90	999.00	2.00	266.29
6250 3 trk sum	138.90	999.00	1.00	230.77
1680 hyp sum	20.50	107.00	3.00	24.44
1680 w/s sum	8.90	34.00	0.00	8.74
1680 grs sum	4.65	21.00	0.00	6.08
6250 trk 1	190.05	999.00	11.00	265.20
6250 trk 2	198.65	999.00	11.00	274.73
6250 trk 3	83.10	427.00	0.00	102.10
6250 trk 4	72.80	272.00	7.00	76.73
6250 trk 5	131.05	999.00	16.00	225.80
6250 trk 6	115.25	999.00	4.00	220.59
6250 trk 7	48.50	179.00	3.00	48.78
6250 trk 8	57.55	211.00	7.00	55.75
6250 trk 9	17.25	98.00	0.00	24.02
1600 hyp trk 1	18.05	93.00	1.00	21.47
1600 hyp trk 2	19.65	106.00	2.00	24.44
1600 hyp trk 3	6.15	24.00	0.00	6.60
1600 hyp trk 4	5.10	20.00	0.00	5.87
1600 hyp trk 5	3.65	17.00	0.00	4.87
1600 hyp trk 6	1.80	9.00	0.00	2.95
1600 hyp trk 7	1.15	8.00	0.00	2.06
1600 hyp trk 8	1.10	6.00	0.00	1.71
1600 hyp trk 9	0.30	2.00	0.00	0.57
1600 w/s trk 1	2.20	8.00	0.00	2.71
1600 w/s trk 2	8.65	33.00	0.00	8.54
1600 w/s trk 3	1.20	5.00	0.00	1.74
1600 w/s trk 4	1.85	9.00	0.00	2.83
1600 w/s trk 5	0.70	3.00	0.00	1.17
1600 w/s trk 6	0.15	1.00	0.00	0.37
1600 w/s trk 7	0.05	1.00	0.00	0.22
1600 w/s trk 8	0.10	1.00	0.00	0.31
1600 w/s trk 9	0.15	1.00	0.00	0.37
Classification	4.70	5.00	3.00	0.57
EOT/BOT status	5.00	5.00	5.00	0.00
Occurrences of Missing Coating		0		

Table 8. Statistical data produced for all stations.

Patterns began to appear in the data both from station position to station position across the web. This can be demonstrated by plotting the mean of 6250 1 track errors across the web. A general u-shaped curve can be seen. Investigation of the reasons for this curve indicated that the accuracy of coating was more difficult to control at the outside edges of the web than in the centre. During the coating process the thickness of oxide coating is controlled by the application of a metering, or doctor, blade. At the edges of the web control is more difficult to achieve and coating is less uniform. This in turn is felt to lead to the registering of more errors at these points. A typical curve of a plot of errors across the web is shown in figure 12.6

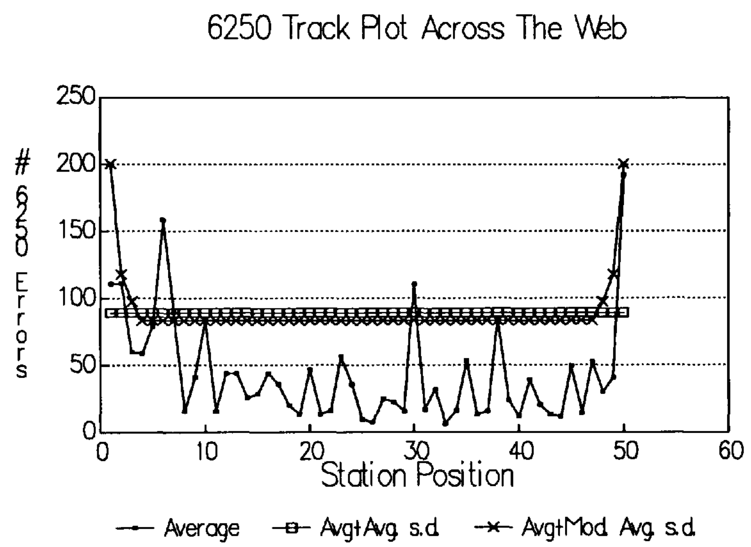


Figure 12.6. Plot of 6250 BPI track 1 errors across the web

This provided a baseline on which to base control limits or control parameters, both above and below this line. A suggested upper control limit is shown in figure 12.6. Two suggested limits are shown. The first, marked Avg.+Avd s.d. is a line representing the average number of errors over the whole 50 stations plus one standard deviation for the whole of the 50 stations. The second, marked

Avg.+Modified Avg is the average number of errors over the whole 50 stations plus a modified standard deviation which takes into account the coating characteristic mentioned above and produces a higher, more realistic control limit for the stations at each edge of the web. A lower control limit could be 0 errors, but it might be appropriate to select a level below which the lack of errors could indicate faulty testing equipment. Investigative or corrective action would not be appropriate over 1 or 2 runs. To reduce the possibility of initiating action too frequently it would be appropriate to produce this graph every sixth cut (or at the end of each jumbo) and then interpret results with regard to the control limit.

It was anticipated that within a tape a similar curve would be seen on a track by track basis. That is those tracks adjacent to the edges, 1 and 9, generally exhibited more errors than the inner tracks. The expected general curve is shown in figure 12.7.

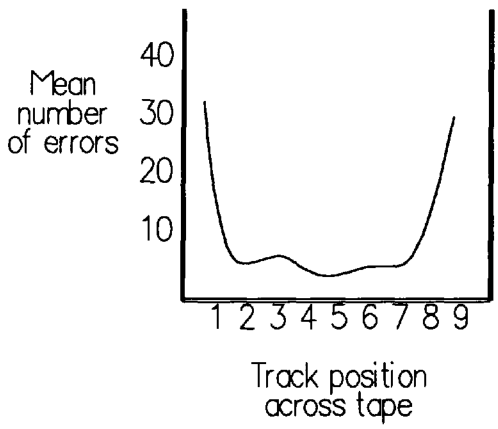


Figure 12.7. Expected error curve across the tracks of one tape.

The reason for this expected characteristic was that the tracks nearest to the slit edge were thought to be more liable to transient errors, caused by debris from the slitting process, or permanent errors, caused by physical damage at the slitting process. Actual results did not confirm this hypothesis, with the error distribution across a tape appearing to be random. An actual typical profile is shown in figure 12.8.

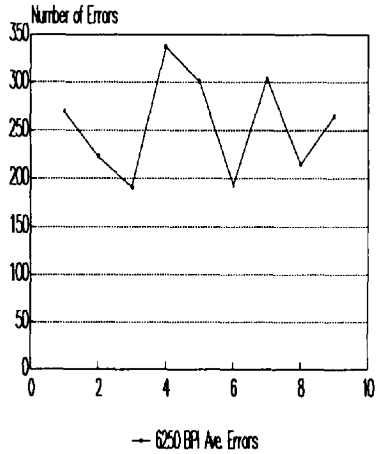


Figure 12.8. Actual error curve across the tracks of one tape.

As errors could be due to transient problems such as slitting debris or temporary web-related faults, no action would be appropriate over one or two evaluations, but these would contribute a tendency to move away from the defined baseline of the curve towards the control limits. The results of this comparison would need careful interpretation by the operator, rather than a reliance on the values presented. While the nature of the test data could only be used to provide information about an event which had already occurred the use of control limits would serve to identify problem areas rapidly, thus facilitating the resolution of that problem, or its tracing back to source.

12.5. The Potential Application of Statistics in Assessing the Accuracy of the Audit Grading System.

An example of the use of statistics with relation to the slitter-testers would be in assessing whether the audit grade assigned to any particular web were correct. The grading of webs by auditing is described in more detail in chapter 2 section 2.3.2.1 but simply, it is a method for determining the criteria to be used for testing webs. Briefly, every sixth web is tested immediately after coating. The number of errors of different grades determined the audit grading. These were generally green for the lowest numbers of errors, blue, a higher number of errors and red for a high number of errors. A red graded web would be slit and tested using more rigorous criteria than green or blue, thus reducing the number of lower classified (higher value) tapes produced.

Webs coated between audited webs would be assumed to be of the lowest audited grade of the audited webs. For example, if a web were to be assigned a green audit grade and the next audited web was assigned a red grade all intermediate webs would be graded as red. This categorisation meant that the testing criteria was harsher than perhaps necessary for a web, but ensured that customers received correctly graded tapes, as a more rigorous criteria is applied if a web is suspected of containing more errors due to coating faults.

However, this did mean that the intermediate webs could be mis-graded as it was not possible to state at which point the webs coated between the two actual audit tests changed from green to red. The application of control limits for each audit grade would enable a more accurate assessment of whether a web being slit using red criteria was actually correctly graded as red. By grading a web as red, there is the likelihood of producing fewer grade 1 tapes than if the web had been graded as green. This has an accompanying loss of revenue as grade 1 tapes can be sold for a higher profit than grade 2 and similarly for all grades. The purpose of implementing statistical controls on the slitter-testers would be to detect faults as soon as possible thereby preventing or reducing any waste.

12.6 An Assessment of the Value of the SPC Approach to Tape Setting And Testing.

It is appropriate to assess the value of these proposals to the tape production process. One of the guiding principles of statistical process control techniques is to provide the production worker with the analytical tools to understand the process better. These are often implemented in simple ways, such as manually plotted process control charts which show actual performance against control limits. This principle of providing the workforce with analytical tools, was used in the new slitter-tester and operator interface, providing simple visual tools or screens to complement the operators impression or "feeling" about what was happening to the process or machine. Adapting Deming's ideas of building the methods for quality control into the process, rather than trying to inspect them in Deming (1982g), it was important to provide the operators with assistance in monitoring the performance of the slitter-tester continually. The graphical display screens were designed with this intention in mind.

A continuation of this would be to provide a simplified control chart, or charts, automatically generated, which would map actual performance against carefully selected control limits. The example given in 12.3.2 would be the most obvious, with different control limits being defined for each particular audit grade for a particular product. This could provide the operators with a valuable tool in assessing and interpreting machine performance, assisting in the more rapid identification of real or potential faults.

CHAPTER 13. EVALUATION OF ACHIEVEMENTS.

This chapter assesses the actual achievements of this project and draws together the areas or subjects discussed in the earlier chapters. It assesses the value of this project to Xidex and puts forward ideas or areas which, with hindsight, the project could have been improved upon.

13.1. Project Achievements.

In this section the various achievements of the project will be discussed.

13.1.1. Installation of a new Operator-Machine Interface.

The main objective of the project was to establish a method or system for improving upon the existing analysis of tape production data relating to the slitter-testers.

Problems lay in three main areas :

a) the majority of the data was inaccessible, being stored on a medium that was incompatible with any installed computer systems,

b) the data was only accessible at the time of production, in a manner that did not assist in the identification of production faults,

c) the data that was available was a small subset of the total volume of data produced, the existing data analysis was prone to transcription errors and reports were up to 24 hours out of date.

In order to address these problems the requirements of all the relevant personnel in the company were established. This was accomplished by work study, and informal and formal interviewing. A feasibility study identified various methods of meeting these requirements. The option selected from the available methods offered compatibility with the company's increasing computerisation within a reasonable cost and within the restricted time scale of the project. The option selected was to use IBM personal computers or compatible microcomputers (thus ensuring compatibility with existing hardware within the company) to record the test data and allow it to be manipulated by software running under the IBM PC-DOS (Personal-Computer Disk Operating System) or Microsoft MS-DOS (Micro Soft Disk Operating System) operating systems. This ensured that the different elements of the system, hardware or software, could easily be replaced or transported.

Microcomputers were attached to data transmission lines which were used to communicate from each slitter-tester to its host computer, either DEC PDP11-03 minicomputer or DEC PDP11-23 microcomputers. Test data transmitted along these communication lines was interpreted and processed into a readily comprehensible form. The data was then transmitted under operator control to a fourth microcomputer via a data buffer. The data buffer served to allow the fourth microcomputer, acting as a central data collection point, to handle simultaneous transmissions from the microcomputers attached to the three slitter-testers.

The microcomputers attached to the slitter-testers were programmed to present a menu-driven system to the machine operators. This system manipulated the data into forms and screens which assisted the operator in decision making relating to fault finding.

The fourth microcomputer, the central data collection point, had the potential to allow the data to be analyzed and viewed without interrupting the operation of the slitter-tester. This represented a definite improvement over the existing system installed on the slitter-testers DEC PDP-11 computers because analysis could be performed automatically, without the need for manual transcription with its inherent problems of errors and time delay. Moreover the whole set of data could be used for analysis, whereas the existing system only allowed 3% of the total data available to be processed for management reports.

The software installed as the operator-machine interface was written in a compiled form of BASIC, this giving the benefits of easy comprehension and modification while operating at a satisfactory speed. The system presented test data to the operators in a manner that was more readily comprehensible than before, with data being presented in order across the web, giving valuable comparisons of data from adjacent positions within the web. The data was presented graphically to enhance the operators understanding of how the slitter-tester and the web were performing and where actual or potential faults could be occurring. The data was presented in a way to minimise the time that the operator spent searching or viewing the computer.

The software installed on the fourth microcomputer, the central data collection point, was in the form of a small applications program to receive the data and a third party relational database package which could be used concurrently with the data receiving program, or as a single task on the computer with data reception suspended, the data buffer retaining the data until requested. An elementary data reporting system was set up using the report generating package within the database package, with Xidex engineering staff tailoring the package to meet their own needs.

Both the operator interface system installed on the microcomputer attached to the slitter-testers and the database reporting system were handed over to Xidex thus ensuring future flexibility and ease of future modification to meet changing information needs.

13.2. The Value of the project to Xidex.

An initial estimate of the value of the project to Xidex was a saving of £25,000 per year. This estimate was based on an estimated figure of a reduction in waste of 1/2% (half a percent). This figure has more recently been amended to £50,000 per year. This value is derived from a direct reduction in waste, due to the more rapid detection of faults. The targeting of maintenance effort has not produced a direct saving in terms of a reduction in manpower, but does allow a more efficient use of that manpower, freeing technicians for other tasks.

13.3. Reporting Benefits.

The objective was to make the data from the slitter-testers available for regular, complete, accurate and timely reporting. This was achieved by the re-transmission of test results to the central data collection point. At this point the test results were received and stored on the microcomputer's hard disk. The data was then available to be processed automatically using a relational database package which was initially set-up to produce a report matching existing reporting requirements, albeit more accurately and more rapidly. This package processed all the data on the hard disk, producing tables of results which could then be further queried to address specific data information requirements. All test result data was archived to a tape streamer, from which the data could later be recalled and re-processed if required.

This system enabled Xidex to process and retain much more data than before. More importantly, the facilities were in place to allow the extraction of meaningful information from that store of data, with the ability to adapt to future requirements.

The operator interface was designed to assist the operators in their understanding of their task of running the slitter-tester. It was designed to aid rapid fault finding, highlighting actual faults, and drawing their attention to areas of potential faults which previously depended on the operator's experience and interpretation of the test results from 50 stations. While the new system also needed interpretation, the graphical displays helped to reinforce operator comprehension.

The system was designed with the co-operation and participation of the operators, this having two aims. Firstly to ensure that the system as designed and implemented was actually useful to them, and secondly to ensure that the system was accepted and used, benefiting production by reducing both waste and time spent searching computer screens. The reduction in waste was achieved by improving the accuracy and content of information available to the operator, thus enabling the more rapid identification of faults.

The involvement of the operators in the design and development of the system allowed them to contribute towards, and to a degree, control some aspect of their work and its environment. The feedback regarding the implemented system indicated that this involvement was beneficial. To re-iterate the philosophy of W. Edwards Deming in describing the benefits of Statistical Process Control the end results of increasing shop floor workers control over their own task actually extend further than improving the product, into increasing their sense of contribution to the end product and the company.

To a large extent the new system addressed the stated aims of the project. The data available for analysis is more complete and available in a more timely manner, while the rectification of faults identified more rapidly by the new system reduces the burden of searching for faults retrospectively through the previous 24 hours data (which in the original system was incomplete).

While it would be possible to use the reporting system at the end of every shift it is more likely that the system is being used to produce reports during the morning shift, using data produced during the previous day's shifts.

The system is qualitatively better than the original in that it actively assists the operators in their task, contains more potentially useful information, and also preserves the data in a form that is easy to interrogate historically, using the database package already in use by the reporting system.

The system has the potential to produce more information than that initially anticipated. Potential developments are discussed in Section 13.4 of this chapter.

13.3.1. Intermediate Data Produced.

During the course of implementing the project data became available from one slitter-tester. This data was processed into several forms, each form serving a different a purpose. These intermediate reports were produced whenever time permitted.

One report was produced daily for the electronic engineering function. All the data from the slitter-tester which was attached to the microcomputer was processed and re-formatted from its unit by unit transmission format into a station by station format. A copy of a printout for one station is shown in Table 9 which is repeated from Table 8 in Chapter 12.

STATION	1			
	MEAN	MAX	MIN	SD
6250 1 trk sum	221.90	999.00	43.00	267.69
6250 2 trk sum	185.90	999.00	2.00	266.29
6250 3 trk sum	138.90	999.00	1.00	230.77
1680 hyp sum	20.50	107.00	3.00	24.44
1680 w/s sum	8.90	34.00	0.00	8.74
1680 grs sum	4.65	21.00	0.00	6.08
6250 trk 1	190.05	999.00	11.00	265.20
6250 trk 2	198.65	999.00	11.00	274.73
6250 trk 3	83.10	427.00	0.00	102.10
6250 trk 4	72.80	272.00	7.00	76.73
6250 trk 5	131.05	999.00	16.00	225.80
6250 trk 6	115.25	999.00	4.00	220.59
6250 trk 7	48.50	179.00	3.00	48.78
6250 trk 8	57.55	211.00	7.00	55.75
6250 trk 9	17.25	98.00	0.00	24.02
1600 hyp trk 1	18.05	93.00	1.00	21.47
1600 hyp trk 2	19.65	106.00	2.00	24.44
1600 hyp trk 3	6.15	24.00	0.00	6.60
1600 hyp trk 4	5.10	20.00	0.00	5.87
1600 hyp trk 5	3.65	17.00	0.00	4.87
1600 hyp trk 6	1.80	9.00	0.00	2.95
1600 hyp trk 7	1.15	8.00	0.00	2.06
1600 hyp trk 8	1.10	6.00	0.00	1.71
1600 hyp trk 9	0.30	2.00	0.00	0.57
1600 w/s trk 1	2.20	8.00	0.00	2.71
1600 w/s trk 2	8.65	33.00	0.00	8.54
1600 w/s trk 3	1.20	5.00	0.00	1.74
1600 w/s trk 4	1.85	9.00	0.00	2.83
1600 w/s trk 5	0.70	3.00	0.00	1.17
1600 w/s trk 6	0.15	1.00	0.00	0.37
1600 w/s trk 7	0.05	1.00	0.00	0.22
1600 w/s trk 8	0.10	1.00	0.00	0.31
1600 w/s trk 9	0.15	1.00	0.00	0.37
Classification	4.70	5.00	3.00	0.57
EOT/BOT status	5.00	5.00	5.00	0.00
Occurrences of Missing Coating		0		

Table 9. Processed data showing mean, maximum, minimum and standard deviation figures for one station.

The data for each measured variable was processed for all files collected in a given period (usually 24 hours) into a table showing the maximum, minimum, mean number of errors and the standard deviation for that variable.
When compared with the data for adjacent stations this gave an indication of potentially faulty stations. For example, if station number 10 showed a mean number of single track errors detected at 6250 BPI to be 60 and stations 9 and 11 showed a mean of around 10 then this could be interpreted and assessed as a possible indication of station 10 being faulty or a slitting problem at that tape position. Whether the fault, if one existed was actually with the tester or the slitter would require investigation.

Reports were also generated to address specific queries. One report was requested to indicate the grouping of errors detected within each grade of tape. The report showed how many errors were in the range 0-10, how many errors were in the range 11-20 etc, for each grade of tape. If applied regularly this analysis could be a useful tool for assessing the value of changing the criteria used to grade or classify the tape. The use of more rigorous criteria would enable Xidex to produce and market tapes produced to a higher specification than the existing ANSI standard which all tape manufacturers use (ANSI (1)). Obviously this would have to be accomplished without significantly reducing the volume of tapes achieving that grade.

Another report produced to address a particular information need is detailed below. One particular station, station 49 on slitter-tester three consistently produced lower graded tapes than other stations, including its adjacent stations. One of the electronics technicians suggested that this particular station was detecting a high number of transient errors due to excessive debris from the slitting process being deposited on the write/read head assembly.

To test this theory a small experiment was set up, increasing the frequency of cleaning of the read/write head assembly. This was performed in three stages. Firstly the assembly was cleaned between every cut, secondly between every web (the standard cleaning frequency) and as a final test not cleaning at all over several webs. Cleaning between each run is impractical on a regular basis due to time constraints and production targets.

The results obtained are shown in Table 10.

	1 TRK	2 TRK	3 TRK	HYP	W/S	GROSS
	101.0	7.0	2.2	0.4	0.0	0.0
# errs	999.0	573.6	140.2	49.6	28.6	5.4
	572.3	291.2	70.7	26.8	15.9	2.7
	468.1	213.7	50.6	20.7	11.9	1.9

Table 10. Atlas 3 Station 49 Cleaning Test Results.

There was a marked improvement when the write/read head assembly was cleaned between every cut. When the cleaning frequency was reduced to the usual frequency, i.e. between each web (usually every 6 cuts) there was a marked increase in the number of errors detected. When the frequency of cleaning was further reduced there was no significant in the number of errors detected. This tended to confirm the original theory, that of slitting debris building up on the write/read head, and also suggesting that the debris was building up rapidly over several cuts to a level where the build up ceased to have any further significant effect.

A practical solution to this problem would have involved modification to the slitter or the tester or both.

Generally, when the electronic or mechanical engineering staff became aware of the potential of the information available from the data being collected, more requests for data were generated. The relational database package implemented was capable of addressing these requests for information in a more efficient manner than writing application programs for each particular information need. However some familiarity with the package was necessary to obtain the best performance from it.

13.4. Potential Improvements to the System.

While the project achieved its main objectives there were areas where, had more time been available, further improvements or additional data processing could have been accomplished. This section outlines some of the areas which were identified for potential improvement.

13.4.1. Correlation of Slitter-Tester Results and Quality Assurance Data.

Tapes produced on the slitter-testers were accumulated on transportable racks called dollies. Typically 100 tapes were stored on 1 dolly. Quality Assurance (Q.A.) staff would then sample tapes at random from this dolly, usually sampling 13% of all tapes produced. These tapes would then be re-tested on separate reel to reel testers. A difference in test results was experienced, in the ratio of two to 1, that is for every two errors experienced on the slitter-tester one error would be found on the Q.A. reel to reel tester. This was attributed to a "clean-up" factor, caused by further cleaning of the tape during the Q.A. test.

The purpose of the Q.A. testing was to ensure that the testers on the slitter-tester were certifying correctly. An exact correlation of results was not experienced, and so the accuracy of the testing operation could not be verified with 100% confidence.

It was proposed to link the Q.A. testers and the slitter-testers to a separate microcomputer, to enable a more accurate correlation of test results from the two sources. A logical choice of computer to perform this function would have been the central data collection microcomputer already attached to the slitter-tester. Software modifications to the Q.A. testing machines would have enabled the sampled test results to be transmitted to this central data collection point, where the results for the same tapes would already be held on the hard disk. A software modification to the data receiving program on this microcomputer would have enabled the Q.A. data to be collected and retained. A program to correlate the results could have been, and could still be written.

This idea was proposed and was seen to be a valuable extension or feature of the project but time constraints did not allow this idea to be implemented.

13.4.2. Coating Audit Information.

Freshly coated webs were slit and tested immediately to enable that web and those coated after it to be assigned an audit grade. The assignment of audit grades was governed by the number and distribution of errors throughout the web. A more complete description of the audit grading system can be found in chapter 2 section 2.3.2.1.

The existing method for audit grading was to slit and test the freshly coated webs on either slitter-tester 2 or slitter-tester 3, as these machines had modified software which enabled the printing of an audit graph and a printout of error details to be obtained. The graphic display of error details was somewhat restricted, consisting of a histogram type chart using asterisks to represent the number of errors. Initiating this process had to be performed before test results were received by the DEC PDP-11 and production was suspended while the computer was occupied printing out the data.

The central data collection computer in the new system held the relevant data. This data could have been processed by an applications program to produce the same audit report but without suspending production. This would have necessitated the purchase of an additional printer. It would have represented an improvement as the data from any of the three slitter-testers could have been processed in the same manner as that on the most sophisticated slitter-tester. Obviously an "in-house" applications program would be able to be modified as required.

13.4.3. Electronic Information.

Fault diagnosis on the slitter-tester often involved technical engineering staff monitoring production data as it was produced, looking for faults or potential faults to help guide maintenance effort. This could involve monitoring the slitter-tester for 2 or 3 runs to establish the nature of the perceived fault. As each run could take 10 minutes this could involve periods of unproductive inactivity from the technical staff.

As with the coating audit information, an applications program written to display historical test data, allowing selection of specific files would reduce time and enhance error detection. This program could be modified and tailored as required.

The above are the major areas where a need or definite benefit was recognised, but could not be addressed within the period of the project. The coating audit information and electronic information discussed above were not central to the project's objectives but would have contributed to the usefulness of the new system, They could be developed "in-house" by Xidex staff. The two programs would reside on the hard disk of the central data collection microcomputer, to be used as required by electronics or coating technicians. These could be run concurrently with the program which already received data from the slitter-tester.

These potential developments could be capitalised upon, with 13.4.2, 13.4.3, and 13.4.4 presenting little more than an analysis of requirements and some relatively simple programming to achieve. In the longer term it should be possible to integrate QA test results into the system and correlate these with slitter-tester results. This would involve analysis of hardware and software requirements and their implementation.

13.5. An Assessment of the Benefits of the Project to Xidex.

The benefits of this project to Xidex have been discussed in this and the preceding chapters, and will be summarised briefly in this section.

One of the main reasons for implementing a new computerised system was to enable the more rapid identification of faults this bringing benefits in several ways. Tapes which were categorised as having failed, by having too many errors, had little or no commercial value. The approximate retail value of a standard length tape is £10, so savings could be considerable. Costs are incurred by the tapes having to be removed from the reels before the reels can be re-used for production. Before tapes are finally scrapped, however, they are re-tested on reel to reel testers. This process involves a high level of manual intervention, in the transport, loading and unloading of reels onto the testers. The process of re-testing involves manpower, power and time. As the major factor affecting the volume of production from the slitter-testers is the time taken to load empty reels and unload full reels, by hand, then the more personnel who are usefully employed in this manner, the faster production can run. It follows that if personnel are released from re-testing then this could have a beneficial effect on production.

During the period of the project it was suggested that there was a potential market for tapes which had no, or very few, errors and could be dispatched to the customer with a printout or certificate stating the number and type of errors on that tape. The suggested market for these tapes was Japan. With minor modifications, the operator interface system could have rapidly identified tapes meeting this rigorous criteria. This would enable these tapes to be segregated and possibly re-tested to ensure quality, and sold at a premium. This could have been a worthwhile exercise, the potential of which could be assessed using an applications program similar to that used to group errors by grade as discussed in this chapter section 13.1.3.

There have been several less tangible, but nevertheless real, benefits which have arisen from the project. One benefit arising from the difficulties which accompanied the project. The slitter-tester manufacturer also supplied the software which ran the DEC PDP-11 computers which in turn ran the whole slitter-tester system. At the time of purchase of the slitter-tester Xidex did not purchase the software which ran on the computers. The difficulties, which were not anticipated, did not arise until the need for software modifications was recognised. Request for software modifications indicated that any changes would be relatively expensive and would take a long time to produce. The source code was offered to Xidex at a relatively high cost which they declined to pay. Through use and increasing experience of the system staff at Xidex, operators, technicians and engineers identified requirements for information which could only realistically be addressed by modifying the software.

Two issues arose from this. Firstly that in the specification for any further equipment which incorporated an element of modifiable software, the contract should be flexible or include purchase rights to the software. This would reduce the probability of the system appearing to become restrictive and inflexible. Secondly the presentation and possible uses of data or information should receive careful consideration and forethought with the participation of all relevant personnel. This second point is obviously easy to make with the benefit of hindsight and it is true to say that at the time of the design and development of the first slitter-tester nobody in the company could have been fully aware of the total information needs for the future.

As has been stated the effects of this inflexibility became obvious during the execution of this project, and it was considered important to involve the slitter-tester operators in the design of the system. The aim of this was two-fold, firstly to increase their perception of having some control over their working environment and secondly to design a system which used the data it contained in an optimum fashion to present the operators with useful information.

13.6. Problem Areas Arising from the project.

The difficulties of integrating research and development with the demands of the production environment became obvious during the execution of the project. The pressure for staff to meet short-term production requirements, including a quota system, ensured that production had precedence over longer-term development work. As a part of this there was a demand for data as soon as it became available to assist in addressing technical production problems, in spite of the fact that this was clearly detrimental to the long-term objectives of the project.

13.7. Complementary Issues.

Issues arose which were outside the scope of slitting and testing where it would have been interesting, if not obviously useful, to investigate further the whole production process and attempt to identify those production variables which actually affected the end product.

During the period of the project two other Teaching Company projects were performed which affected tape production. One was performed on the tape formulation process and the other on controlling the thickness of the ferric oxide coating which gave the magnetic tape its magnetic characteristics.

The project investigating the formulation process measured variables in that process, such as milling time for the ferric oxide and the plasticising agent, and investigating the effects and measurement of agglomerates in the oxide and plasticiser mixture.

The second project implemented a highly accurate system of gauging the thickness of the oxide coating on the polyester substrate of the web. This allowed the company to reduce the thickness of the oxide coating, this reduction in thickness representing a very large monetary saving.

These areas, including the slitter-tester project were performed as projects in isolation. Valuable data could possibly have been gained by correlating results from all three processes. For example it could have been useful to investigate the effects of milling time on recording and error characteristics, or the effect that reducing the coating thickness to the bottom limit of its specification had on recording characteristics. The combination of variables could have been investigated to identify which variables actually affected the quality of the end product.

The investigation of these items within any one of the above-mentioned projects would have necessitated a longer time-scale, but all three projects implemented data collection by computer. The variables discussed above were all available on discrete computers and in different formats, but could be transformed to enable analyses of the various involved.

CHAPTER 14. CONCLUSIONS.

This final chapter presents a summary of the achievements of this project and draws a conclusion to this thesis.

14.1. Installation of a new Data Collection and Reporting System.

14.1.1. Hardware Installed.

Microcomputers which were compatible with the IBM personal computer using the MS-DOS operating system were attached to data transmission lines which were used to communicate from each slitter-tester to its host computer, either DEC PDP11-03 minicomputer or DEC PDP11-23 microcomputers. Test data transmitted along these communication lines was interpreted and processed into a readily comprehensible form. The data was the transmitted under operator control to a fourth microcomputer via a data buffer. The data buffer served to allow the fourth microcomputer, acting as a central data collection point, to control transmissions from the microcomputers attached to the three slitter-testers. This microcomputer had the potential to allow the data to be analyzed and viewed without interrupting the operator. All data produced by the slitter-testers was available on this microcomputer for reporting and analysis.

14.1.2. Installation of a new Operator-Machine Interface.

The microcomputers attached to the slitter-testers were programmed to present a menu-driven system to the machine operators. This system manipulated the data into forms and screens which assisted the operator in decision making relating to fault finding. The system presented test data to the operators in a manner that was more readily comprehensible than before, with data being presented in order across the web, giving valuable comparisons of data from adjacent positions within the web. The data was presented graphically to enhance the operators understanding of how the slitter-tester, or the web, was performing and where actual or potential faults could be occurring. The data was presented in a way to minimise the time that the operator spent searching or viewing the computer.

The software installed on the fourth microcomputer, the central data collection point, was in the form of a small applications program to receive the data and a third party relational database package which could be used concurrently with the data receiving program, or as a single task, on the computer with data reception suspended, the data buffer retaining the data until requested. An elementary data reporting system was set up using the report generating package within the database package, with Xidex engineering staff tailoring the package to meet their own needs.

Both the operator interface system installed on the microcomputer attached to the slitter-testers and the database reporting system were handed over to Xidex thus ensuring future flexibility and ease of future modification to meet changing information needs.

14.2. Benefits Arising from the Implemented System.

The new system represented an improvement over the existing system in several ways:

1. All data produced by the slitter-testers was now accessible for daily reporting and historical analysis;

2. Reports could now be produced with minimal intervention and, if required, could be produced more frequently and with less time delay than the existing system;

3. The implementation of the operator interface assisted in the detection of test equipment and material faults, as they occurred, thus reducing the production of waste and the level of rework and assisting in the targeting of maintenance effort. These factors produced a monetary benefit to Xidex of £50,000 per annum or 1% of total tape production;

4. The project was open ended and could be developed or improved upon to produce increased benefits to the production process, as outline in Chapter 13 Section 4.

14.3. Conclusion.

The project and the new system implemented provided Xidex with an accurate, complete, functioning data collection system which has the potential to be developed, increasing its value to the company. It also provides data which could be linked to two existing microcomputer-based projects in the oxide milling and coating areas of tape production in order to examine the effect of production variables upon the end product.

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APPENDIX 1

A Comparison of Phase Encoded and Group Coded Recording Formats

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A Comparison of Phase Encoded and Group Coded Recording Formats.

Phase encoded tape has each data bit encoded into a cell consisting of two clock times. At the first clock time, a transition may (or may not) be written, in order to establish the correct polarisation on tape. At the second clock time, a positive transition represents a digital one, while a negative transition represents a zero. Phase encoding makes it possible to detect 'dropouts', or defects in the media. A cell time with no transitions indicates a dropout. Once detected, an error can be corrected using the parity track.
The limitation of Phase encoding is that it requires twice as many flux changes compared with Non Return to Zero (NRZI) format for a given amount of data. Thus in order to attain a data density of 1600 BPI, it is necessary to record 3200 flux changes per inch (FCI). This represents 50% efficiency.

Group Coded Recording (GCR) format uses what is basically the NRZI format. A flux change represents a one and the absence of a flux change represents a zero. However a restriction is placed on the data in that there can not be more than two zeros in a row. This guarantees a transition at least once every three bit cells and allows self clocking capabilities similar to the Phase Encoding technique. Obviously the restriction which ensures that no more than two consecutive bits in a row are zero cannot be placed upon the data. GCR formatters translate every four bits of computer data (along each recording track) into a five-bit storage group. There are sixteen combinations of the four bit pattern and the corresponding five bit code translation. The translation ensures that stacking any two of these five bit groups together never gives more than two zeros in a row.
Additional redundant characters are generated, for purposes of error detection and correction. A parity bit is also calculated.

Essentially GCR adds 16 bits to every 56 bits of data, this code overhead enabling two track error correction as opposed the single track error correction of Phase Encoded format This two track error correction is a major advantage of GCR. Any two tracks can drop out or be completely destroyed and the data can still be completely reconstructed.

Once a GCR word is formed, the eight byte data group is then broken down into two four-byte subgroups. These four byte subgroups are operated upon by the four-to-five conversion to form two five-byte subgroups. The two five-byte subgroups then are rejoined into a ten-byte recording group, which is then recorded onto the tape.

In addition to the encoded recording groups, a GCR record contains other groups which are used for data synchronisataion and verification of data integrity GCR block consists of preamble, data, resynchronisation bursts and data interspersed, endmark, cyclic redundancy check, and postamble. The resynchronisation burst allows the tape drive read circuitry to recover synchronization after long drop-outs, unlike Phase Encoding which must 'dead-track' a channel after a dropout until the end of a block.

Thus a GCR drive can recover from multiple two-track dropouts per record (provided that these are separated by resynchronisation bursts, while a Phase Encoding drive can handle only one dropout per record.

The principal advantage of GCR encoding over Phase Encoding and Non Return to Zero format are increased data storage, improved error correction and reduced back-up time.
Within a 2400 foot reel of tape, the maximum capacity for a GCR transport, using a data density of 6250 BPI is 180 Megabytes, four times that of Phase Encoding. The

inter-block gap was cut from 0.6 inch to 0.3 inch on GCR, allowing for more storage.

GCR's higher data density relative to Phase Encoding is achieved by a higher recording density on tape 9042 fci against 3200 fci, and because of the higher efficiency of NRZI run length coding.

Advantages of GCR over Phase Encoding include:
error correction, where there is a 125% improvement in write mode and a 442% improvement in read mode for temporary errors , and a 130% improvement in write mode and 30% improvement in read mode for permanent errors (Britten 1984).

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APPENDIX 2

Operator Log Sheet for Manual Entry of Results

ATLAS SLITTER/TESTER PRODUCTION RECORD

OPERATOR NAME: ____________________ MACHINE 1 ☐ 2 ☐ 3 ☐ PRODUCT __________ KNIFEBOX __________

DATE ____________________ SHIFT 0600-1400 ☐ 1400-2200 ☐ 2200-0600 ☐ CUTS START SHIFT __________

CUTS END SHIFT __________

SHIFT ROTA A ☐ B ☐ C ☐

									NON-CERTS										REWIND		CUT DOWN				
	JUMBO No.	1	2	3	4	SAL	HYP DPH	ITRK DPH	S/M Wrap	Tape Wrap	SAL Wrap	BOT	EOT	M/C Stop	Blade Fail	Unit	Comp Error	Others	Bad Wind	Stack Arm	Miss Coat	Short	Uncal	Cr/sD	COMMENTS
1																									
2																									
3																									
4																									
5																									
6																									
1																									
2																									
3																									
4																									
5																									
6																									
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4																									
5																									
6																									
1																									
2																									
3																									
4																									
5																									
6																									
HALF SHIFT TOTALS																									

									NON-CERTS										REWIND		CUT DOWN				
	JUMBO No.	1	2	3	4	SAL	HYP DPH	ITRK DPH	S/M Wrap	Tape Wrap	SAL Wrap	BOT	EOT	M/C Stop	Blade Fail	Unit	Comp Error	Others	Bad Wind	Stack Arm	Miss Coat	Short	Uncal	Cr/sD	COMMENTS
1																									
2																									
3																									
4																									
5																									
6																									
1																									
2																									
3																									
4																									
5																									
6																									
1																									
2																									
3																									
4																									
5																									
6																									
AUDITS																									
SHIFT TOTALS																									
																					No. of Starts				

	Jumbo No.	Footage	Tape Slit	Comments
1				
2				
3				
4				

	Jumbo No.	Footage	Tape Slit	Comments
5				
6				
7				
8				

APPENDIX 3

Extract from MOSTEK SCU-20 data sheet, showing data transmission format.

MOSTEK®

3870 MICROCOMPUTER COMPONENTS

Serial Control Unit SCU20

FEATURES

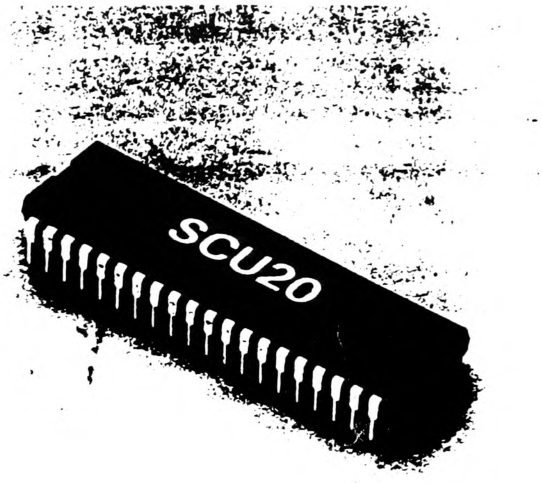
- Provides programmable remote I/O functions, real time operational capabilities, and standardized network communications on a 40 pin chip.
- Performs preprogrammed functions on command, including:
  - Byte input and output
  - Bit input and output
  - Set, clear, and toggle selected pins
  - Data access from real time functions
- Performs real time preprogrammed functions, including:
  - Data log on external interrupt, timer, or host control, up to 63 bytes of data
  - Five Event Counters driven from external interrupt, timer or host control
- Up to 24 programmable I/O pins
- Allows user to network up to 255 SCUs on a single communications channel
- Asynchronous serial data transmission
- Selectable Baud rate (300, 1200, 2400, or 9600 Baud)
- Secure, Error resistant data link protocol
- Requires single +5 volt supply
- Low power (275mW typ)

INTRODUCTION

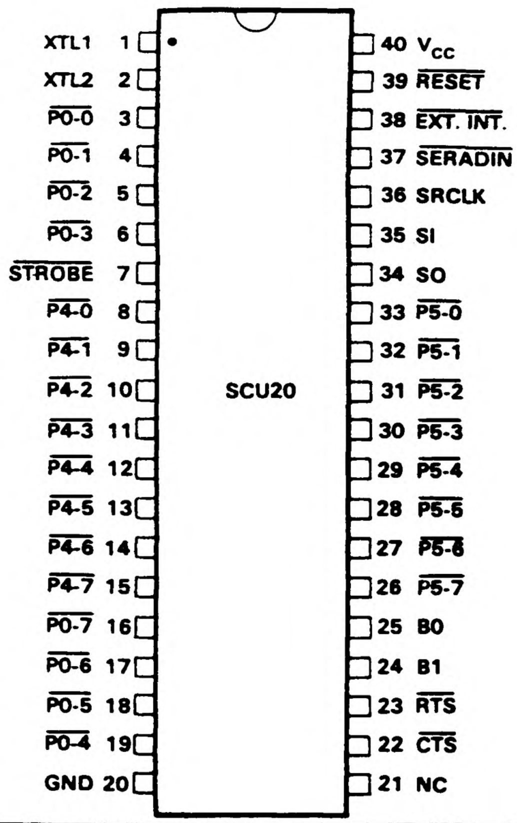
The SCU20 serial control unit is a preprogrammed MK3873 single chip microcomputer. It is a general purpose remote control/data acquisition unit, with 38 preprogrammed functions available to the user.

Communications with the SCU20 take place over an asynchronous half duplex communications channel at 300, 1200, 2400, or 9600 Baud. The communications protocol is efficient and error resistant, and yet easy to implement on the host system.

SCU20
Figure 1



SCU20 PINOUT
Figure 2



ach SCU2x in the network has an individual address to which it will respond. All SCU2x devices in the network are slave processors to the host, and are unable to initiate communications except in response to the host.

When the system is initialized, all SCU2x devices are in the listen mode, and are performing no functions. The host will issue an inquiry command to each device. Once all devices have been queried, the host will issue commands to each device to set up the particular operational parameters required of it. When this has been done, the host may then use the devices to control equipment, measure values, etc., by issuing commands and receiving responses.

Unless issuing a response, the SCU2x is always in the listen mode. If a command has been sent to an SCU2x, a response is expected within a specific time period. If none is forthcoming, it means that the command transmitted was not successfully received by the device. In this case, the host must take steps either to notify the operator or to retransmit the command.

If a system error occurs in the host, it may suspend operation of the entire network by transmitting the network reset command which causes all devices to be reset. This is the only command that does not require a specific SCU2x address as part of the command. It uses the system reset address which is recognized by each device.

SCU20 ADDRESS

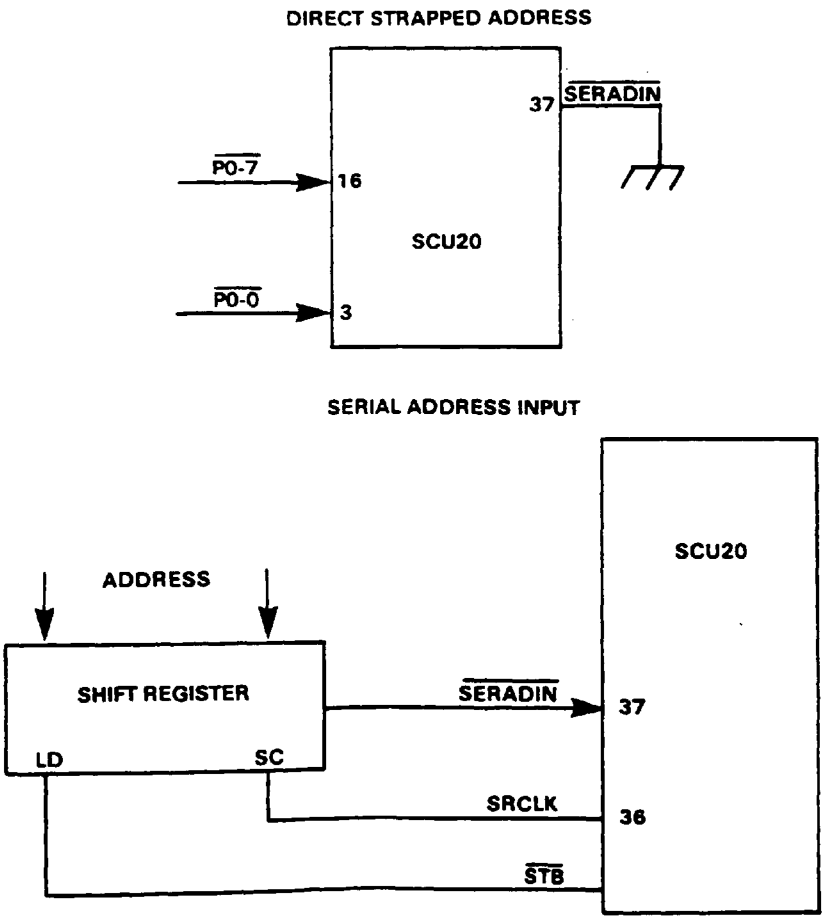
The address to which the SCU20 responds may be established in one of two ways.

The first mode is the Direct Strapped Address mode, and is enabled by tying the $\overline{\text{SERADIN}}$ pin directly to ground. In this mode, the SCU20 address is strapped at port 0. Because of this, port 0 is not available as a general purpose I/O port.

The second mode is the Serial Address Input mode. The $\overline{\text{SERADIN}}$ pin is used to input the address as a serial 8-bit stream from a shift register. SRCLK is used as a shift clock for this operation. The $\overline{\text{STROBE}}$ signal is used at initialization time to cause the address to be loaded into the shift register before shifting begins. In the Serial Address mode, port 0 becomes available for use as a general purpose data I/O port.

Figure 4 illustrates both methods of establishing the SCU20 address.

SCU20 ADDRESS ESTABLISHMENT
Figure 4



:U20 COMMUNICATIONS

he SCU20 communicates with the host computer over a alf duplex asynchronous serial link. The communications rotocol is simple, yet error resistant.

he general form of the communication message is as ollows:

HDR	ADDR	CMD	DATA	DATA	• • • •	LRC

HDR - Message header. Hex '01' indicates a command message from the host; Hex '02' indicates a response from the SCU20.

ADDR - SCU20 Address. Indicates which SCU20 the message is for, or originates from.

CMD - Command. Indicates the function to be performed.

DATA - Any data that may be required by the particular command.

LRC - Linear Redundancy Check.

Msg. "A"	≥14 Bit Times Message Separation	Msg. "B"

Byte m	≤8 Bit Times Byte Separation	Byte m+1

Messages are to be transmitted in block mode, with a message separation of at least 14 bit times. Interbyte separations should be no more than 8 bit times within a message.

A message from the host to the SCU20 will generate a response if there is no transmission error. If any transmission error is detected, no response will be made.

Possible transmission errors are LRC errors, parity errors, interbyte separation errors, or intermessage separation errors.

BAUD RATE SELECTION

The serial Baud rate is selected by a strapped option on the SCU20. Those options are listed below:

BAUD RATE	B0 (Pin 25)	B1 (Pin 24)
300	Low	Low
1200	Low	High
2400	High	Low
9600	High	High

MODEM SIGNALS

$\overline{RTS}$ and $\overline{CTS}$ are provided to facilitate handshaking with modems. Just prior to responding to a valid command, $\overline{RTS}$ will go to logic 1, indicating that the SCU20 is ready to send data back to the host. $\overline{CTS}$ is an input to the SCU20 that is tested after $\overline{RTS}$ goes active to determine if the SCU20 may begin transmitting data.

PARALLEL I/O PORTS

The SCU20 has a minimum of 2 parallel I/O ports and a maximum of 3 available for general use, depending on the address selection mode chosen. For each of these ports, there exist 2 registers that control and modify the I/O to and from the ports. These are the Data Direction Register (DDR) and the Mask Register(MR).

The Data Direction Register defines the usage of each pin in the port. If a bit is set to 0, then the corresponding pin is used as input. If a bit is set to 1, then the corresponding pin is used as an output. When a port is read, all bits are sampled for input whether or not they are marked for input. When a port is written to, however, only those pins declared as output will be modified.

The Mask Register provides a data mask that may be applied to the input data before transmission to the master. The mask is established once and may be used repeatedly before being changed by establishing a new mask value. If a pin is to be available upon read, the corresponding bit in the mask register is set to 1, while a pin that is to be masked out will have its mask bit set to 0.

SCU20 PREPROGRAMMED FUNCTIONS

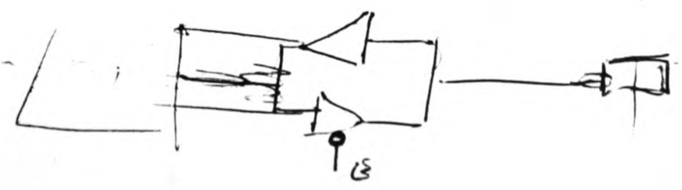
The SCU20 has a variety of preprogrammed functions available to the user. Each of these functions addresses a different general area of application such that the SCU20 is truly a general purpose device.

PORT COMMANDS

There are several commands which allow the host to manipulate the 8-bit general purpose I/O ports. The host may load data into any one or all of the ports, may read any or all of the ports with or without a mask, may read with a new mask, or may read using the last defined mask. When data is loaded, the resulting port state is returned in the response message.

LOGIC COMMANDS

In addition to performing data I/O with the ports, the host may perform logical operations with the ports and data from the host. These commands allow the host to AND, OR, or Exclusive OR (XOR) data with any or all of the ports, and output the result to the ports. The resultant output is returned in the command response message.



OMMANDS

ese commands allow the host to SET, CLEAR, TEST, or TOGGLE bits in the ports by specifying bit number (0 - 24). Any pin that is declared as an input will not be changed.

EVENT COUNTERS

There are 5 Event Counters defined in SCU20. They are 16 bit up counters, and are driven by the timer, the external interrupt, or by host command. They may be used as simple event counters, or may be used in conjunction with the Data Log, and Pulse functions.

DATA LOG

The Data Log function allows the user to command the SCU20 to log data from the ports specified in the command, and store the data in the on-board RAM. Up to 63 bytes of data may be accumulated in the log, and may be captured on external interrupt, timer, or host command through use of an Event Counter.

Data from the Log is transmitted back to the host in a single read command burst.

CONTROL COMMANDS

There are several commands to control the SCU20 as well as the entire SCU2 network. These commands provide the host with the ability to query each individual SCU2x on the network for its type, the last message it sent, and for detailed error codes. In addition, there are commands that allow the host to reset an individual device, or to cause the entire SCU2 network to reset with a single command.

ERROR PROCESSING

The SCU20 does not provide a "negative acknowledge" response to command stream errors. Those errors are parity errors, LRC errors, unidentifiable commands, overrun, or violation of the separation specifications as described earlier.

In some cases, the SCU20 will provide error response to functional errors in commands that have been recognized. This response will be either a "NAK0" or a "NAK3" as specified for the command. "NAK0" is the hex value H'FB', and "NAK3" is the hex value H'FE'.

H'2'	ADDR	H'FB' or H'FE'	LRC

SCU20 COMMANDS

Figure 5 gives a complete list of the commands and functions available to the SCU20. For a full description of these commands and their use, refer to the SCU20 Operations Manual.

SCU20 COMMANDS
Figure 5

FUNCTION	COMMAND CODES	# DATA BYTES (CMD)	# DATA BYTES (RESP)	ERR COD RET
** PORT COMMANDS **				
Load Data Direction Registers	1E	3	0	-
Load Port (0, 4, 5)	00,01,02	1	1	-
Load All Ports	03	3	3	-
Read Port (0, 4, 5)	04,05,06	0	1	-
Read All Ports	07	0	3	-
Read Port Masked, Mask Provided	08,09,0A	1	1	-
Read All Ports, Masks Provided	0B	3	3	-
Read Port using Previous Mask	0C,0D,0E	0	1	-
Read All Ports using Previous Masks	0F	0	3	-

** PORT LOGIC COMMANDS **				
AND Data to Port	10,11,12	1	1	-
AND Data to All Ports	13	3	3	-
OR Data to Port	14,15,16	1	1	-
OR Data to All Ports	17	3	3	-
XOR Data to Port	18,19,1A	1	1	-
XOR Data to All Ports	1B	3	3	-
** BIT COMMANDS **				
Set Bit in Port	1F	1	0	-
Clear Bit in Port	20	1	0	-
Toggle Bit in Port	21	1	1	-
Test Bit in Port	22	1	1	-
** EVENT COUNTERS **				
Start Event Counter	80	1	0	-
Read Event Counter	81	1	2	NAK0
Clear Event Counter	82	1	0	NAK0
Stop Event Counter	83	1	0	NAK0
Step Event Counter	84	1	0	NAK0
** DATA LOG COMMANDS **				
Start Data Log	85	3	0	NAK0
Stop and Read Data Log	86	0	var.	-
Read Data Log Count	87	0	1	-
** SCU CONTROL COMMANDS **				
Enquiry	1C	0	var.	NAK3
Return SCU Type	1D	0	1	-
Read Error Code	F7	0	1	-
Reset SCU20 (data byte must be H'AA')	F9	1	0	-
General Reset (SCU2 Network)	FF	0	-	-

APPENDIX 4.

Hexadecimal Listing of Slitter-Tester to PDP-11 Transmission on RS-422 Communication Line.

The following listing represents the transmission containing the data from unit 1.

```
02 21 01 50 72
02 21 04 42 65
02 21 00 4A 69
02 21 04 08 2F
02 21 04 29 0E
02 21 00 21 02
02 21 06 70 55
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 03 26
02 21 00 24 07
02 21 00 21 02
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
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02 21 00 24 07
02 21 00 20 03
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02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 0A 2F
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
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02 21 00 24 07
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02 21 00 24 07
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02 21 04 40 67
02 21 01 46 64
02 21 04 42 65
02 21 00 4A 69
02 21 04 08 2F
02 21 04 29 0E
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02	21	06	00	25
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02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 01 24
02 21 00 24 07
02 21 00 20 03
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02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 01 24
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 01 24
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 01 24
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 01 24
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 01 24
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
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02 21 00 24 07
02 21 00 21 02
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 06 00 25
02 21 00 24 07
02 21 00 20 03
02 21 04 40 67
```

APPENDIX 5

Timings for the use of existing and new interfaces using the keystroke level method.

APPENDIX 5.

The keystroke level model put forward by Card, Moran and Newell (Card, Moran and Newell 1980) uses a combination of operators to calculate the time that a given text editing task will take. It was appropriate to use this model to produce anticipated timings for the new operator interface and compare these with the existing interface, and establish whether or not the new system produces advantages.

Card, Moran and Newell provide operators which are added together to produce the time that a task should take. These include:

K	the time taken to depress a key
H	the time taken to home in on the required key
M	the time taken to mentally prepare for the task
R	the time taken for the system to respond

To these I have added

A	the time taken for the user to assimilate the information

I have used the following values (in seconds) for these operators :

K	0.20	
H	0.40	
M	1.35	
R	i) existing PDP11 interface	0.40
	ii) new interface	0.80
A	1.0 to 2.0 depending on the complexity of the screen	

Assumptions.

I have made two major assumptions which are I feel valid for the purposes of the calculations :

i) that the user always starts from the left most menu choice of the highest level of the hierarchy in both systems,

ii) that the user is expert, and does not make mistakes

Timings.

1. Direct comparisons.

   1.1. The use of the system to assess faults.

      a) if no faults exist.

         i) PDP11 - one keypress displays overall total.

         $t = 0.20k + 0.40h + 0.40r + 2.0a$

         $t = 3$

         ii) new system - one keypress extracts the data and displays a more useful summary.

         $t = 0.20k + 0.40h + 15.0r + 1.5a$

         $t = 18.1$

         N.B. the operator is only occupied by keying tasks for 2.1 seconds.

      b) if faults exist (not simply failed tapes).

         i) PDP11 one keypress to display overview plus an average search of 9 units (half of the total number of units).

         t for the first screen $= 0.20k + 0.40h + 0.40r + 2.0a$

         $t = 3$

         t for each subsequent screen $= 0.20k + 1.35m + 0.40r + 0a$

         $t = 1.95$

         total $t = 3 + (8 * 1.95)$

         $t = 18.6$

         ii) new system where one keypress will display all information necessary.

         $t = 0.20k + 0.40h + 15.0r + 1.5a$

         $t = 18.1$

         N.B. the operator is only occupied by keying tasks for 2.1 seconds.

APPENDIX 6

Files Output from the Operator Interface Computers.

APPENDIX 6.

6.1. Station Order Format Files Output from the Operator Interface.

1,21,1,0,2,1,0,15,53,3,1,0,4,13,0,0,0,1,0,0,0,1,1,0,0,0,0,0,0,0,1,0,0,0,0,X3J8F
157.2K1,K DAVIES,D,12:32:55,2,G,2,
2,8,0,0,0,0,0,15,37,0,0,1,2,1,1,2,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
3,15,3,0,2,0,0,15,37,1,0,1,10,1,0,0,2,3,0,0,0,1,1,0,1,1,0,0,0,0,0,0,0,0,0,
4,1,0,0,2,2,0,15,37,0,0,0,1,0,0,0,0,1,1,0,1,0,0,1,1,0,0,1,0,1,0,0,1,0,0,
5,3,0,0,0,0,0,15,37,0,0,0,0,0,0,0,3,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
6,8,0,0,1,0,0,15,37,1,0,0,0,0,0,0,7,1,1,1,1,0,0,1,1,1,0,0,0,0,0,0,0,0,0,
7,1,0,0,1,0,0,15,37,0,0,0,1,0,0,0,0,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,
8,4,0,0,0,0,0,1,5,0,0,0,3,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

9,78,78,78,0,0,0,15,37,52,78,78,78,77,76,78,78,78,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,
10,2,0,0,1,1,0,15,37,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,1,0,1,1,1,1,1,1,1,
11,1,0,0,0,0,0,15,37,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
12,0,0,0,1,0,0,15,37,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
13,0,0,0,1,0,0,15,37,0,0,0,0,0,0,0,0,1,0,0,1,0,0,1,0,0,0,0,0,0,0,0,0,0,
14,3,0,0,1,1,0,15,37,0,2,0,0,0,0,0,0,1,1,1,0,1,0,0,0,0,0,1,0,1,0,0,0,0,0,
15,0,0,0,1,1,0,15,37,0,0,0,0,0,0,0,0,1,1,0,1,0,1,1,0,0,1,0,0,1,0,0,1,0,0,

16,0,0,0,890,888,0,15,37,0,0,0,0,0,0,0,0,0,0,890,95,0,0,0,0,1,0,0,888,0,0,0,0,0
,0,
17,5,0,0,0,0,0,15,37,1,1,0,1,0,0,0,0,2,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
18,1,0,0,1,1,0,15,37,0,0,0,0,0,0,1,0,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,
19,2,0,0,3,2,0,15,37,0,0,0,1,0,1,0,0,0,1,1,1,2,1,1,1,1,0,0,1,0,0,0,1,0,0,0,
20,1,0,0,0,0,0,15,37,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
21,0,0,0,0,0,0,15,37,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
22,0,0,0,1,0,0,15,37,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,
23,0,0,0,0,0,0,15,37,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
24,16,0,0,1,1,0,15,37,0,0,1,1,3,0,11,0,0,0,1,0,1,0,0,1,0,0,0,1,0,1,0,0,0,0,0,
25,1,0,0,0,0,0,15,37,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
26,0,0,0,0,0,0,15,37,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
27,1,0,0,1,0,0,15,37,0,0,0,1,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,
28,0,0,0,1,0,0,15,37,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
29,3,0,0,0,0,0,15,37,0,0,2,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
30,5,1,0,3,1,0,15,37,1,1,1,1,0,0,1,1,0,1,0,0,1,0,0,1,1,0,0,0,0,1,0,0,0,0,0,
31,6,0,0,1,0,0,15,37,1,1,0,0,1,1,1,1,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,
32,7,0,0,1,1,0,15,37,0,3,1,0,0,1,1,1,0,1,1,1,1,0,0,1,1,0,1,1,1,1,0,0,1,0,0,
33,1,0,0,0,0,0,15,37,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
34,0,0,0,0,0,0,15,37,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
35,4,0,0,0,0,0,15,37,1,0,1,0,1,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
36,0,0,0,0,0,0,15,37,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

37,208,12,0,1,0,0,15,37,78,0,3,18,0,3,64,47,7,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0
,
38,7,0,0,0,0,0,15,37,0,0,0,2,1,0,2,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
39,5,0,0,1,1,0,15,37,4,0,0,0,0,0,1,0,1,1,1,1,0,1,1,1,1,1,1,0,0,0,0,0,0,1,
40,6,0,0,1,0,0,15,37,1,3,0,1,1,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
41,9,0,0,1,0,0,15,37,3,1,1,1,0,0,1,2,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
42,6,0,0,0,0,0,15,37,1,0,1,0,0,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
43,3,1,0,1,0,0,15,37,0,2,0,0,0,1,1,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,
44,5,1,0,2,1,0,15,37,0,0,2,2,0,0,0,1,1,1,1,1,2,1,1,1,1,0,0,0,0,0,0,0,1,0,0,

45,10,0,0,0,0,0,15,37,0,1,1,2,1,1,2,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
46,13,0,0,1,0,0,15,37,1,0,0,0,2,0,0,1,9,0,0,0,0,1,0,1,0,0,0,0,0,0,0,0,0,
47,0,0,0,0,0,0,15,37,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
48,15,1,0,1,0,0,15,37,1,1,5,2,0,1,2,3,1,1,1,1,0,1,1,0,1,0,0,0,0,0,0,0,0,

49,31,25,24,0,0,0,15,37,21,25,25,24,24,25,26,23,22,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,
50,34,0,0,1,0,0,15,53,3,3,7,2,5,9,2,2,1,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,

6.2. Unit Order Format Files Output from the Operator Interface.

X3J8F157.2K1,K DAVIES,D,12:32:55,2,G,2,

1,1,112,0,1,0,0,1,0,0,10,0,0,0,0,0,0,0,0,1,0,0,15,37,15,37,15,37,3,0,0,0,1,0,0,0,
0,0,1,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,1,1,2,1,1,2,1,1,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

2,2,112,0,3,0,0,0,0,0,0,0,0,0,0,5,1,0,3,1,0,15,37,15,37,15,37,3,0,0,2,0,0,0,1,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,1,1,1,1,0,0,1,1,0,1,0,0,1,0,0,1,1,0,0,0,0,1,0,0,0,0,0,

3,3,112,0,6,0,0,1,0,0,31,25,24,0,0,0,7,0,0,1,1,0,15,37,15,37,15,37,3,1,1,0,0,1,1,
1,1,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,21,25,25,24,24,25,26,23,22,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,3,1,0,0,1,1,1,0,1,1,1,1,0,0,1,1,0,1,1,1,1,0,0,1,0,0,

4,4,112,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,15,37,0,0,15,37,3,0,0,0,0,0,0,1,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

5,5,112,0,4,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,15,37,0,0,15,37,3,1,0,1,0,1,0,0,1,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

6,6,112,0,208,12,0,1,0,0,34,0,0,1,0,0,7,0,0,0,0,0,15,37,15,53,15,37,3,78,0,3,18,
0,3,64,47,7,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,3,3,7,2,5,9,2,2,1,0,0,1,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,2,1,0,2,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

7,7,112,0,5,0,0,1,1,0,15,1,0,1,0,0,6,0,0,1,0,0,15,37,15,37,15,37,3,4,0,0,0,0,0,0,
1,0,1,1,1,1,0,1,1,1,1,1,1,0,0,0,0,0,0,1,1,1,5,2,0,1,2,3,1,1,1,1,1,0,1,1,0,1,0,0,0,0
,0,0,0,0,0,1,3,0,1,1,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

8,8,112,0,9,0,0,1,0,0,13,0,0,1,0,0,6,0,0,0,0,0,15,37,15,37,15,37,3,3,1,1,1,0,0,1,
2,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,2,0,0,1,9,0,0,0,0,1,0,1,0,0,0,0,0,0
,0,0,0,0,0,1,0,1,0,0,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

9,9,112,0,3,1,0,1,0,0,0,0,0,0,0,5,1,0,2,1,0,15,37,0,0,15,37,3,0,2,0,0,0,1,1,0,0,
0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,2,2,0,0,0,1,1,1,1,1,2,1,1,1,1,0,0,0,0,0,0,0,1,0,0,

10,10,112,0,78,78,78,0,0,0,0,0,0,0,0,2,0,0,1,1,0,15,37,0,0,15,37,3,52,78,78,78
,77,76,78,78,78,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,0,1,1,1,1,1,1,1,

11,11,112,0,1,0,0,0,0,0,4,0,0,0,0,0,0,0,0,1,0,0,15,37,1,5,15,37,3,0,0,0,0,0,0,0,1,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,3,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,

12,12,112,0,0,0,0,1,0,0,8,0,0,1,0,0,3,0,0,1,1,0,15,37,15,37,15,37,3,0,0,0,0,0,0,0
,0,0,1,0,0,1,0,0,1,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0,7,1,1,1,1,0,0,1,1,1,0,0,0,
0,0,0,0,0,0,0,2,0,0,0,0,0,0,1,1,1,0,1,0,0,0,0,0,0,1,0,1,0,0,0,0,0,

13,13,112,0,0,0,0,1,1,0,1,0,0,2,2,0,0,0,0,890,888,0,15,37,15,37,15,37,3,0,0,0,0,
0,0,0,0,0,1,1,0,1,0,1,1,0,0,1,0,0,1,0,0,1,0,0,0,0,0,1,0,0,0,0,0,1,1,0,1,0,0,1,1,0,0
,1,0,1,0,0,1,0,0,0,0,0,0,0,0,0,0,0,890,95,0,0,0,0,1,0,0,888,0,0,0,0,0,0,

14,14,112,0,5,0,0,0,0,0,8,0,0,0,0,0,1,0,0,1,1,0,15,37,15,37,15,37,3,1,1,0,1,0,0,0
,0,2,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,2,1,1,2,0,1,0,0,0,0,0,0,0,0,0,0,0,
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15,15,112,0,2,0,0,3,2,0,21,1,0,2,1,0,1,0,0,0,0,0,15,37,15,53,15,37,3,0,0,0,1,0,1,
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APPENDIX 7

Daily Report produced for Maintenance Purposes showing mean, maximum and average data for all measured variables.

APPENDIX 7

Empirical data.

The data in this appendix is reproduced from a daily report which detailed mean, maximum, minimum and standard deviations for the following data items for each of the 50 station positions across the web:

6250 BPI 1 track total errors;
6250 BPI 2 track total errors;
6250 BPI 3 track total errors;
1600 BPI hypercritical track total errors;
1600 BPI write/skip track total errors;
1600 BPI gross track total errors;
6250 track 1 errors
6250 track 2 errors
6250 track 3 errors
6250 track 4 errors
6250 track 5 errors
6250 track 6 errors
6250 track 7 errors
6250 track 8 errors
6250 track 9 errors
1600 hypercritical track 1 errors
1600 hypercritical track 2 errors
1600 hypercritical track 3 errors
1600 hypercritical track 4 errors
1600 hypercritical track 5 errors
1600 hypercritical track 6 errors
1600 hypercritical track 7 errors
1600 hypercritical track 8 errors
1600 hypercritical track 9 errors
1600 write/skip track 1 errors
1600 write/skip track 2 errors
1600 write/skip track 3 errors
1600 write/skip track 4 errors
1600 write/skip track 5 errors
1600 write/skip track 6 errors
1600 write/skip track 7 errors
1600 write/skip track 8 errors
1600 write/skip track 9 errors
Classification
EOT/BOT status
Occurrences of Missing Coating

STATION	6250 BPI MEAN	1600 BPI MEAN	GRADE
1	221.90	20.05	4.70
2	37.65	1.05	1.95
3	09.35	0.50	1.45
4	28.15	1.45	2.15
5	42.60	0.75	1.85
6	82.95	1.30	2.05
7	60.75	1.10	2.15
8	18.85	0.55	1.60
9	54.05	13.15	2.65
10	322.00	45.00	3.75
11	08.60	0.60	1.45
12	13.10	0.60	1.70
13	10.15	0.75	1.60
14	07.55	0.05	1.10
15	10.40	0.05	1.15
16	28.85	0.20	1.55
17	08.35	0.30	1.25
18	09.35	0.35	1.30
19	09.60	0.50	1.55
20	238.70	0.25	3.15
21	11.70	0.05	1.25
22	07.10	0.35	1.75
23	10.05	0.25	1.40
24	59.25	0.20	1.45
25	05.25	0.25	1.20
26	40.00	0.25	1.90
27	05.85	0.55	1.35
28	07.35	0.10	1.10
29	04.70	0.30	1.30
30	55.85	0.25	1.35
31	10.25	0.70	1.80
32	51.90	0.75	1.90
33	60.25	0.35	1.45
34	16.50	0.15	1.50
35	60.25	0.35	1.45
36	41.80	0.35	1.50
37	13.25	13.40	1.65
38	22.60	11.20	2.30
39	04.00	0.15	1.20
40	11.70	0.25	1.50
41	08.10	0.75	1.55
42	121.05	0.50	1.95
43	11.65	0.15	1.40
44	29.05	1.80	1.65
45	03.10	0.15	1.30
46	09.25	0.80	1.60
47	07.55	0.95	1.30
48	39.30	0.95	2.00
49	150.25	2.30	2.70
50	96.60	16.40	2.35

APPENDIX 8

Example Daily Reports from the new Database Reporting System.

Daily summary report showing slitter-tester results by shift

3/23/91 Page 1

Machine	Shift	Sum of Grade1	Sum of Grade2	Sum of Grade3	Sum of Grade4	Sum of Failed	Sum of Noncert	Sum of Misscoat
1	D	1523	1790	422	175	458	32	86
1	A	859	827	181	121	112	0	0
2	D	745	781	203	111	309	1	112
2	A	413	216	41	14	66	0	53
2	N	232	170	19	11	55	13	11
3	D	297	184	28	17	174	0	83
3	A	683	347	17	30	71	2	9
3	N	688	289	34	30	96	13	0

Daily summary report of Slitter-tester results by machine

3/23/91

Machine	Sum of Sum of Grade1	Sum of Sum of Grade2	Sum of Sum of Grade3	Sum of Sum of Grade4	Sum of Sum of Failed	Sum of Sum of Misscoat
1	2382	2617	603	296	570	86
2	1390	1167	263	136	430	176
3	1668	820	79	77	341	92

Daily summary report showing slitter-tester results by shift

3/23/91

Page 1

Machine	Sum of Sum of Grade1	Sum of Sum of Grade2	Sum of Sum of Grade3	Sum of Sum of Grade4	Sum of Sum of Failed	Sum of Sum of Misscoat	Sum of Gr
1	2382	2617	603	296	570	86	2100
1	2382	2617	603	296	570	86	4454
2	1390	1167	263	136	430	176	498
2	1390	1167	263	136	430	176	803
2	1390	1167	263	136	430	176	2261
3	1668	820	79	77	341	92	783
3	1668	820	79	77	341	92	1137
3	1668	820	79	77	341	92	1157

APPENDIX 9

Daily Report from the Existing Manually-Based Reporting System.

DATE 1 NOVEMBER 1988 REPORT ON COATLINE NO. 2

WEEK 44 DAY : 4

ATLAS	SHIFT	1 OMEGA	2	3	4 STD.A	1200's	FAIL	NON.CRT	CUT DN	M/COAT	STARTS
1	3	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0	0
1	2	21	27	1	1	0	0	0	0	3	50
TOTALS		21	27	1	1	0	0	0	0	3	50
2	3	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0
2	2	17	30	1	2	0	0	0	0	0	50
TOTALS		17	30	1	2	0	0	0	0	0	50
3	3	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0
3	2	0	0	0	0	0	0	0	0	0	0
TOTALS		0	0	0	0	0	0	0	0	0	0
GRAND TOTAL		38	57	2	3	0	0	0	0	3	100

% YIELDS

	ELECTRICAL										I/O					
ATLAS	1 OMEGA	2	3	4 STD.A	1200's	OVERALL	NONCRT	CUT DWN	M/COAT	STARTS	1 OMEGA	2	3	4 STD.A	1200's	OVERALL
1	42.0%	54.0%	2.0%	2.0%	0.0%	100.0%	0.0%	0.0%	6.0%	50	42.0%	54.0%	2.0%	2.0%	0.0%	100.0%
2	34.0%	60.0%	2.0%	4.0%	0.0%	100.0%	0.0%	0.0%	0.0%	50	34.0%	60.0%	2.0%	4.0%	0.0%	100.0%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SHIFT																
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	38.0%	57.0%	2.0%	3.0%	0.0%	100.0%	0.0%	0.0%	3.0%	100	38.0%	57.0%	2.0%	3.0%	0.0%	100.0%
COMB	38.0%	57.0%	2.0%	3.0%	0.0%	100.0%	0.0%	0.0%	3.0%	100	38.0%	57.0%	2.0%	3.0%	0.0%	100.0%