

BLL ID No.: DSS109/85

LOUGHBOROUGH
UNIVERSITY OF TECHNOLOGY
LIBRARY

AUTHOR/FILING TITLE

LAURENCE, P D

ACCESSION/COPY NO.

007842/02

VOL. NO.

CLASS MARK

LOAN COPY

000 7842 02





AN ANALYSIS OF STOCKING STRATEGY IN A MULTI-
ECHELON ASSEMBLY SYSTEM BY COMPUTER MODELLING

=====

by

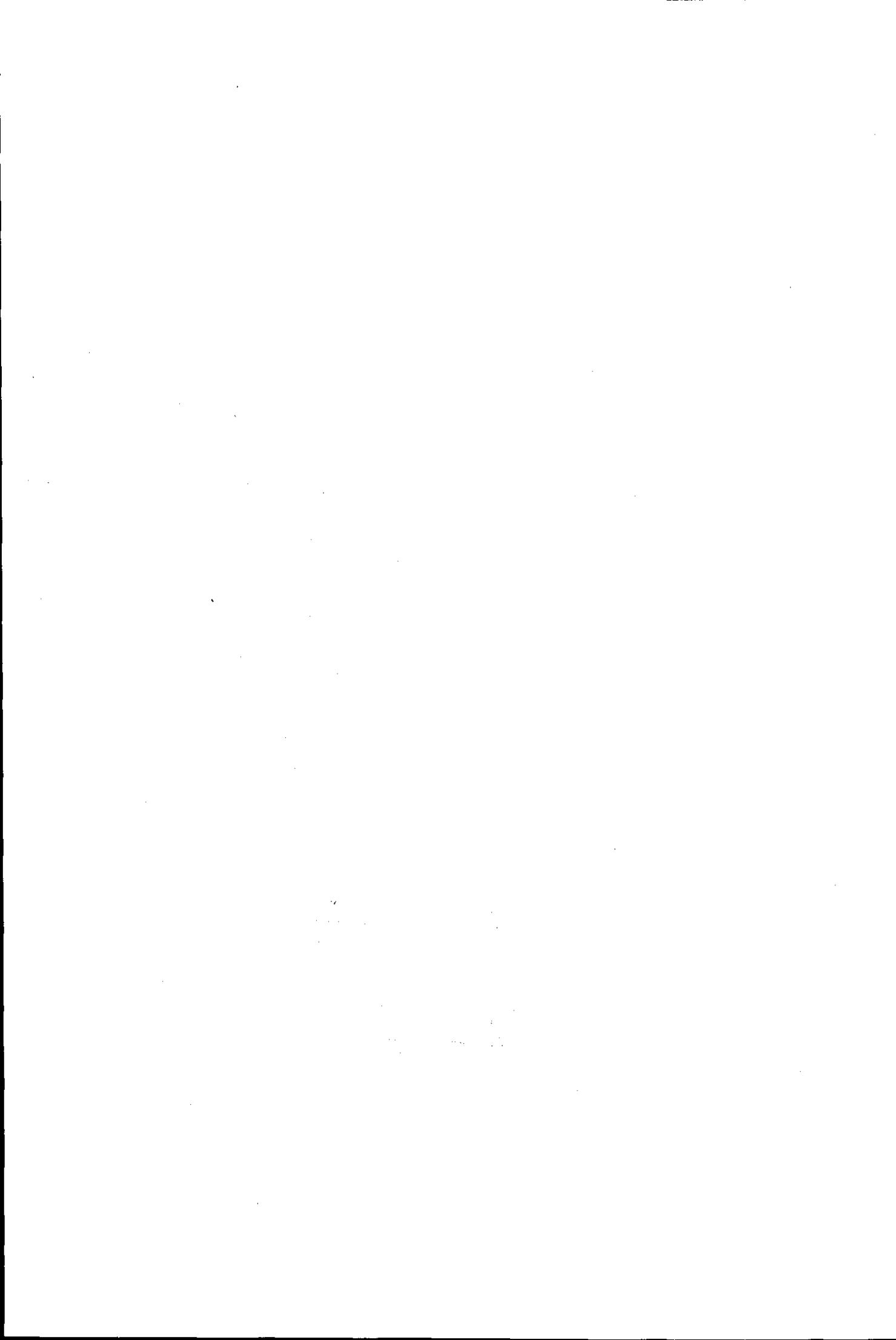
P.D. Laurence

A Doctoral Thesis

Submitted in partial fulfilment of the requirements
for the award of
Doctor of Philosophy of the Loughborough University of Technology

August 1984

Loughborough University	
of	Library
DATE	Feb 84
ISSUE	
Acc. No.	007842/02



ACKNOWLEDGEMENTS

I wish to acknowledge the support and assistance given by staff of Pye Telecommunications Ltd. during the course of the research work. In particular, Mr. M.A. O'Loughlin who was instrumental in the definition of the project, Mr. A.J. Edwards for providing the necessary time and resources to execute the work required, and Mr. P.K. Crowcroft for his contribution to the structure of the manufacturing systems.

Special thanks are due to the staff of the Computer Centre at Loughborough University of Technology for their advice in the use of ICL 1900 Fortran and in the many instances of personal intervention to ensure programs were run.

For their contribution to the structure of the project, advice on the use of computer simulation and assistance in the preparation of the thesis, I offer thanks to Dr. J.W. Rourke and Dr. E. Roberts, both of Loughborough University of Technology, and Dr. P. Nash of the Department of Engineering, Cambridge University.

Finally, I wish to offer my thanks to my secretary, Mrs. J.C. Blake, for her valuable assistance in the testing of the program modules, and my wife, Erika for the many hours of typing and retyping the final thesis.

S Y N O P S I S

The business problem described is typical of the professional electronics industry, where product customisation is achieved by assembly to order, but the relatively short delivery lead times demanded by the market imply a high degree of speculation both in material procurement and manufacturing. The research objectives were to establish a methodology by which the influence of buffer stocks within the above environment could be observed, with particular reference to their contribution to delivery performance.

The business environment is analysed in depth, since the combination of market characteristics, both supply and demand, with the internal processes has resulted in the application of specific policies and procedures.

The wide scope of the business system and the complexity of the processes involved argued against the use of mathematical analysis, favouring a simulation approach.

The simulation model which was evolved is unconventional in many respects, but offers several unique possibilities not available using more established techniques. Fortran was selected as the programming language, in preference to a specialised simulation language, due to its relative flexibility and the need to emulate closely the detailed planning processes. The model is structured to include Material Requirements Planning concepts, adapted to follow the special features of the observed business system. The model is very adaptable in use, permitting experiments to be conducted at summary level, at transaction detail or any intermediate level. Facilities are provided to redefine external parameters, sampling profiles, internal parameters and process definitions with relative ease, providing a broad spectrum of experimental possibilities.

Conclusions have been drawn on the most suitable stock policy for the stated business environment and service level objectives. The modelling technique is shown to offer a number of advantages over the more conventional approaches, whilst permitting statistically rigorous analyses to be conducted.

I N D E X
=====

	<u>PAGE</u>
1. <u>INTRODUCTION</u>	
1.1. PERSPECTIVE	1
1.2. THE COMPANY	2
1.2.1. Historical Note	2
1.2.2. Corporate Structure	4
1.2.3. Products	6
1.2.4. Markets	12
1.2.5. Development of Production Control Systems	14
1.3. PROBLEM DEFINITION	22
1.3.1. Environmental Considerations	22
1.3.2. Hypothesis	27
1.3.3. Scope	27
1.3.4. General Applicability	28
2. <u>LITERATURE SURVEY</u>	
2.1. PRODUCTION CONTROL AND MRP	29
2.1.1. History of Production Control	29
2.1.2. Material Requirements Planning	31
2.1.3. Comparison of SIC and MRP	43
2.1.4. Period Batch Control	44
2.2. DELIVERY PERFORMANCE	45
2.3. SIMULATION	47
2.3.1. Perspective	47
2.3.2. Techniques	48
2.3.3. Comparison of Simulation Languages	49
2.4. CONCLUSIONS	50
3. <u>RESEARCH METHODOLOGY</u>	
3.1. PROBLEM APPROACH	54
3.2. THE PRODUCTION SYSTEM	54
3.3. DATA ACQUISITION	66
3.3.1. Introduction	66
3.3.2. Product Definition	66
3.3.3. Customer Data	68
3.3.4. Supplier	81

	<u>PAGE</u>
3.4. SIMULATION MODEL	88
3.4.1. General Design	88
3.4.2. Computer Facilities	90
3.4.3. Simulation Language	92
3.4.4. Diagnostic Facilities	95
3.4.5. Summarised Program Description	98
3.5. EXPERIMENTAL DESIGN	141
4. <u>RESULTS</u>	
4.1. INTRODUCTION	144
4.2. PRIMARY EXPERIMENTS	146
4.2.1. Effects of Planned Buffer Stock on Delivery Performance	146
4.2.2. Effect of Planned Buffer Stock on Value	162
4.2.3. Relationship between Delivery Performance and Stock Investment	181
4.3. VARIANCE REDUCTION TECHNIQUES	184
4.3.1. Methods	184
4.3.2. Replication	185
4.3.3. Antithetic Pairs	185
4.3.4. Results	186
4.4. SECONDARY EXPERIMENTS	188
4.4.1. Effect of Manufacturing Mode on Delivery Performance	188
4.4.2. Relationship between Component Buffer Stock and Service Level	190
4.4.3. Effect of Priority Rules	191
4.4.4. Relationship between Commercial Stock and Delivery Performance	191
4.4.5. Effect of changing Capacity Utilisation Factor	194
4.4.6. Effect of Orders Received Trend	195
4.4.7. Long Term cyclic Effects	196
4.5. MODEL EFFICIENCY	200
5. <u>CONCLUSIONS</u>	
5.1. INTRODUCTION	203
5.2. BUFFER STOCK DISPOSITION	203
5.2.1. Component Buffer Stock	203
5.2.2. Sub-assembly versus Equipment Stock	204
5.2.3. Cost versus Delivery Performance	207
5.2.4. Impact of Human Intervention	208
5.2.5. Assumption/Validity	209

	<u>PAGE</u>
5.3. SIMULATION MODEL	210
5.3.1. Statistical Significance	210
5.3.2. Scope	211
5.3.3. Efficiency	212
5.3.4. Language	213
5.3.5. General Applicability	214
5.4. GENERAL CONCLUSIONS	214
5.4.1. Cyclic Effects	215
5.4.2. Manufacturing Mode	215
5.4.3. Priority Rules	216
5.4.4. Relationship between Commercial Stock and Delivery Performance	216
5.4.5. Effect of Capacity Utilisation	217
5.4.6. Effect of Orders Received Trend	217
6. <u>RECOMMENDATIONS FOR FURTHER RESEARCH</u>	
6.1. INTRODUCTION	218
6.2. EXPERIMENTAL DESIGN	218
6.2.1. Variance Reduction Techniques	218
6.2.2. Long Term Cyclic Effects	218
6.2.3. External Parameters	219
6.2.4. Internal Parameters	219
6.2.5. Probability Distribution Functions	220
6.2.6. Product Definition	221
6.3. MODEL DESIGN	222
6.3.1. Interactive Analysis of Results	222
6.3.2. Logic Changes	223
6.4. EFFICIENCY	224
6.5. EDUCATION	225
<u>BIBLIOGRAPHY</u>	227
<u>APPENDIX A</u> - EXPERIMENTAL RESULTS	238
<u>APPENDIX B</u> - FULL PROGRAM DESCRIPTION	278
<u>APPENDIX C</u> - FILE DESCRIPTIONS	469
<u>APPENDIX D</u> - DATA DICTIONARY	516

1. INTRODUCTION

1.1. PERSPECTIVE

During the middle 1970's, the management of Pye Telecommunications Ltd. had arrived at an important point in their awareness of sound inventory control techniques as a means of improving business efficiency. The computer was well established as a Materials Management support tool and the formal disciplines required to operate a data based information system were becoming established. The actual production processes had, however, remained unchanged over a number of years, including the policies governing material throughput and logical stocking points.

Neither Materials nor Manufacturing Management were convinced that the existing policies were the optimum, and the techniques required in the resolution of the problem were not clear.

Discussions between the Company and Loughborough University of Technology supported the view that the problem was, indeed, relatively complex and culminated in a proposal to research further the impact of stocking points in a multi-echelon production system with particular emphasis on the relationship between inventory investment and delivery performance.

It was recognised that the scope of the project would have to be constrained if meaningful results were to be obtained within a practical time period and that more than one researcher would almost certainly be required.

The solution was to view the problem from two perspectives. The first would be to treat the Company as a "black box", and analyse in detail the characteristics of the external environment as viewed from the company boundaries. The second was to look more closely at the internal operation of the business in response to the conditions created by the external environment. The two research objectives would be complementary yet sufficiently independent to minimise the potential interaction between the two projects.

Figure 1.1. portrays the research environment in diagrammatic form, indicating the project boundaries.

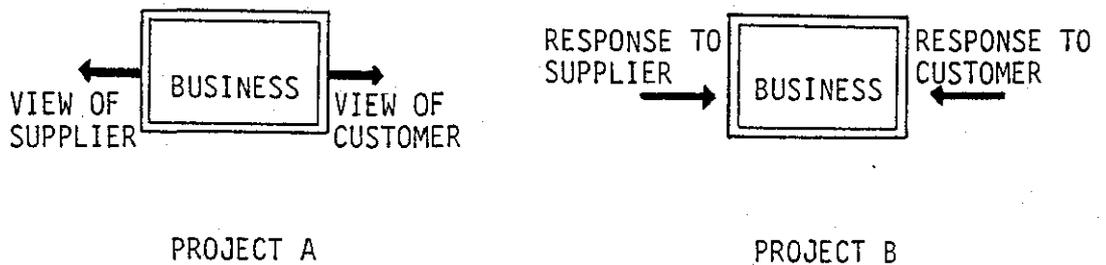


Figure 1.1. RESEARCH ENVIRONMENT

The perspective described as Project A would provide a profile of the supply and demand characteristics that could be used to evaluate the response of the business system in Project B.

The external environment research was established as a Total Technology project conducted within the Engineering Production Department of Loughborough University of Technology by Mr. T. Skelton.

The research defined as Project B is described within this thesis.

1.2. THE COMPANY

1.2.1. Historical Note

Pye Telecommunications Ltd. was formed as a subsidiary of Pye Ltd. in 1946, to offer, commercially, the benefit of two-way radio. The techniques were largely pioneered by the parent company during the Second World War with the famous WS18 set, of which some 400,000 were made.

The first commercial customer was a local taxi company in Cambridge, Camtax, who equipped their fleet with mobile radios based on valve and rotary converter technology. These first products were developed in laboratories at an old mill at Quy in Cambridgeshire and manufactured at the Ditton Works plant in Newmarket Road, Cambridge. This plant was extended in 1954 to include a new laboratory block and support services.

Demand for the commercial application of two way radio was brisk, and in 1957 a new plant in Haverhill, Suffolk, was opened. A substantial part of the product load at the Haverhill plant for a number of years was 24 channel Admiralty synthesised equipment.

During the 1960's, expansion continued and a further subsidiary of the parent company, Cambridge Works Ltd., was asked to act as a subcontractor for certain products, notably the first range of true hand portable equipments. The factory already had experience in producing electronic equipment although largely in the consumer market. Over a period of years, the consumer load was transferred out of Cambridge Works and the plant became a dedicated Pye Telecommunications facility.

From its small beginning, the company grew to an employer of some 2500 staff engaged in the full business spectrum of design, production, sales, service.

A significant factor in the professional electronics industry is the ability to provide a comprehensive after sales service and, over the years, a network of some 20 main service depots across the length and breadth of the United Kingdom was established. It is the total customer support capability which developed such a strong hold on the home market, where a market share of at least 50% is still maintained. This support is augmented by aerial sites in prime locations, administered by the company and available for lease to commercial customers.

The corporate structure of the Group has changed significantly over the past 20 years. In 1963, the existing Pye Ltd. companies were re-organised into the Pye of Cambridge Group. Further rationalisation took place in 1966, when Pye Holdings Ltd. was established. Subsequently in 1967, the Dutch multi-national, Philips Gloeilampenfabrieken N.V., obtained a 60% interest in the Group. The final consolidation took place in 1977, when Philips took up the remaining equity and incorporated the various Pye companies into the "concern".

1.2.2. Corporate Structure

Philips is a matrix organisation structured geographically and by product line. A "national organisation" is established in each major country in the world, with specific responsibility for local sales and manufacturing. "Product divisional" management, situated predominantly in Eindhoven, Netherlands, determines the product development and marketing policy, and allocates the manufacturing resources and volumes.

Product Divisions range from electronic components (Elcoma), through consumer products (white goods, small domestic appliances, audio, video) to professional products (medical systems, telecommunications, defence, scientific and industrial instrumentation). Pye Telecommunications is part of the Telecommunications and Defence Systems product divisions, steered by the Mobile Radio Management Group based in Cambridge, and is also a non-quoted company within Philips Industries Ltd. in the U.K.

The Company differs from the majority of Philips organisations by maintaining a full spectrum of business responsibilities, including design, manufacture, finance, marketing and after-sales service.

A characteristic of the Philips organisation is the segregation of "Technical" (design, manufacture) and "Commercial" (marketing, sales, service) functions, the structure dating back to the birth of the Philips activities when the two founder brothers defined their responsibilities. It is rumoured that the technically minded sibling argued that he could "make more lamps than his brother could possibly sell", whereas the commercial argument was that he could "sell more than could possibly be made". The interface was the "commercial store" containing manufactured lamps.

The technical/commercial structure survived well during the pre- and post-war years, but came under some pressure as the markets migrated from "sellers" to "buyers" during the 1960's and 1970's.

The present internal organisation comprises a number of traditional line functions with some Philips specific activities as shown in Fig. 1.2.

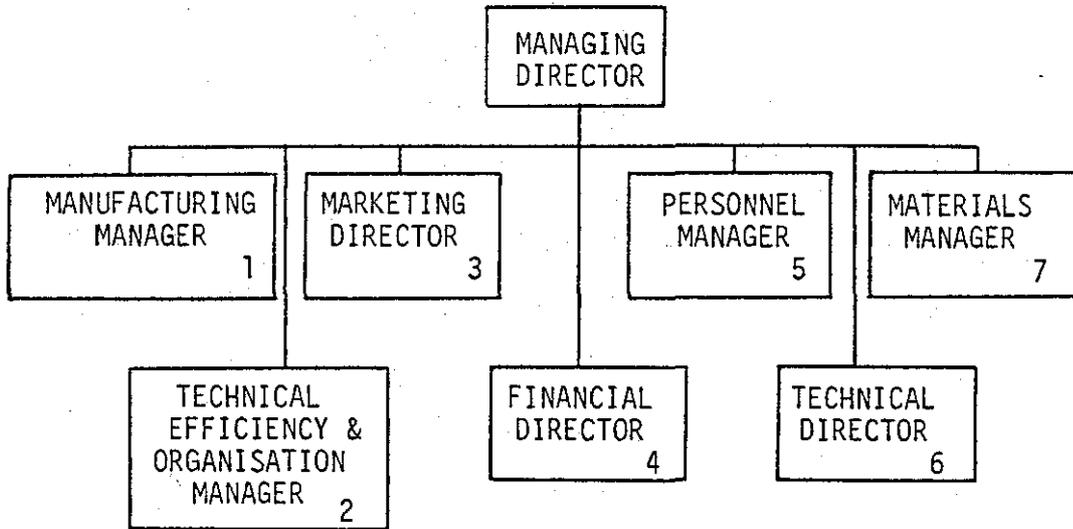


Figure 1.2. ORGANISATION STRUCTURE

NOTES:

1. Manufacturing includes equipment production, quality control, test, industrial engineering.
2. Technical efficiency and organisation includes central production engineering, work study and operations research.
3. Marketing include sales, marketing, product management and after sales service.
5. Personnel includes welfare, training and certain administrative duties.
6. Technical includes product development, documentation support and customer engineering.

7. Materials management includes planning, warehousing, receiving and purchasing.

Due to the constant state of change in the organisation over the duration of the study, the above is shown as representative only.

1.2.3. Products

The product range offered by Pye Telecommunications Ltd. may be described in overview by reference to Figure 1.3.

The range is described through a hierarchy of six levels, defined as

- Level 0 - all products
- Level 1 - Product division
- Level 2 - Product group
- Level 3 - Catalogue level
- Level 4 - Standard variations
- Level 5 - Sales variations

A further level of definition, which is not normally recognised for planning purposes since the value and basic specification is unchanged, includes the absolute definition of customer carrier and selective calling frequencies.

The designation of major product classification is by the product division, of which currently eight exist. (See Table 1.1.)

The majority of products are modular in design, either comprising physical modules (i.e. discrete printed wiring or sub-assemblies) or logical modules (i.e. groups of components logically sorted for planning purposes). In each case, a module will represent a specific single or combination of sales features.

A typical product code sheet is shown in Figures 1.4. and 1.5. The example is for a mobile product code M294 for installation into the dash of a vehicle. The product operates over the VHF frequency spectrum (68-174 MHz) and is frequency modulated (FM). Special versions of the product are required in seven export markets in addition to the standard production model. Most export models are only available in certain authorised variations.

SCOPE OF LAND MOBILE RADIO BUSINESS

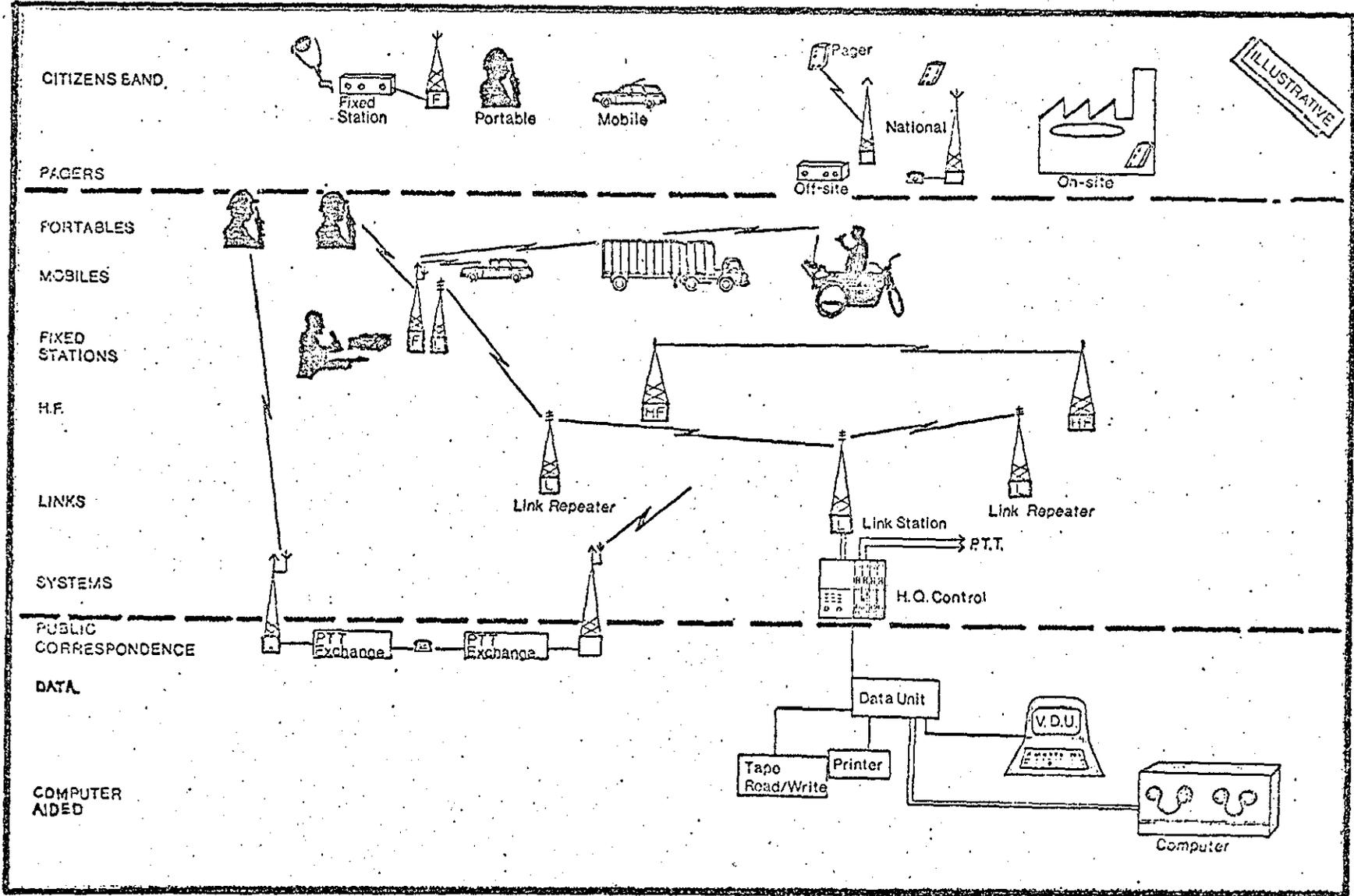


Fig. 1.3. - Scope of Land Mobile Radio Business

TABLE 1.1. DEFINITION OF PRODUCT DIVISIONS

<u>REFERENCE</u>	<u>SHORT DESCRIPTION</u>	<u>DEFINITION</u>
73	Fixed equipment	Transmitting and receiving products usually in a fixed location used as a control centre for the operation of a multiple number of mobile and/or portable products. Fixed equipment includes certain adaptors which convert mobiles into fixed centres.
74	High Frequency equipment	All products, including fixed and mobile, operating in the high frequency spectrum (also referred to as Single Side-Band).
75	Kits	All products which are supplied in part assembled form for final assembly overseas. Kits may be CKD (completely knocked down) which implies component level or PKD (partly knocked down) at sub-assembly level.
76	Link equipment	Transmitting and receiving equipment used for fixed point to point communication either of speech or data.
78	Mobiles	Transceivers designed for installation in vehicles. Mobiles also include adaptors for installing portable transceivers in vehicles.
79	Pagers	Portable receivers which may be activated by radio signals and cause an audible signal.
80	Portables	Transceivers designed to be carried by the user either attached to the clothing or by hand. Portables also includes adaptors for converting mobile products into a transportable form by the provision of a power source and aerial.
83	Sundries	Products designed to complement the above range of products but not falling into a predefined category, including battery chargers, power units, selective call modules, module housings.

FM VHF 'M294' FRONT MOUNT
MOBILE RADIOTELEPHONE

M294

CATALOGUE NUMBER	MKT CODE	SALES VARIATIONS				STANDARD VARIATIONS				OPTIONS	
		INSTALLATION ITEMS	NO. OF CHANNELS	Tx POWER	FUNCTION	CHANNEL SPACING	Tx BAND	Rx BAND	NO. OF CHANNELS	PRIMARY	SECONDARY
M294						S	A0	A0	1		
M294						S	A0	A0	6		
M294						S	B0	B0	1		
M294						S	B0	B0	6		
M294						S	E0	E0	1		
M294						S	E0	E0	6		
M294						S	M1	M2	1		
M294						S	M1	M2	6		
M294						S	P5	P8	6		
M294						R	A0	A0	1		
M294						R	A0	A0	6		
M294						V	A0	A0	1		
M294						V	A0	A0	6		
M294						V	B0	B0	1		
M294						V	B0	B0	6		
M294						V	E0	E0	1		
M294						V	E0	E0	6		
M294						V	P5	P8	6		
M294		OPTION 1	OPTION 2	OPTION 3	NOT USED; INSERT '0'	C	A0	A0	1	OPTION 5	OPTION 6
M294						C	A0	A0	6		
M294						C	B0	B0	1		
M294						C	B0	B0	6		

MARKET CODE	01 = Standard Production 02 = France (SA0 E0 Only) 03 = West Germany (R A0 Only) 07 = Sweden (VA0 Only) 10 = Norway (VA0 Only 15W Nominal) 11 = Switzerland (VA0 Only) 13 = Holland 25 = Austria (VA0 Only)
-------------	--

OPTION 1	0 = Less installation items 1 = Standard mount installation items with loudspeaker 2 = Standard mount installation items less loudspeaker 3 = Facia mount installation items with loudspeaker 4 = Facia mount installation items less loudspeaker
----------	---

OPTION 2	0 = No crystals fitted 1-6 = Number of crystallised channels
----------	---

OPTION 3	1 = 25 Watts (standard test setting for all equipment despatched less crystals) 2 = 15 Watts 3 = 10 Watts 4 = 6 Watts
----------	--

EXAMPLE

CATALOGUE NUMBER	MKT. CODE	SALES VARIATIONS	STANDARD VARIATIONS	OPTIONS	
M294	01	11101	SA0A01	20	42

1.11.81

Fig. 1.4. - Product Code Sheet - Part 1

M294

**FM VHF 'M294' FRONT MOUNT
MOBILE FACING PAGE**

OPTION 4	0	= Less front panel (Tech. Sales and Overseas Operations use only)
	1	= Standard (Front panel with "Pye" label)
	2	= Standard (Front panel less "Pye" label)
	3	= Fitted with TED1
	4	= TED6 fitted
	T	= Transit panel (non-operational)

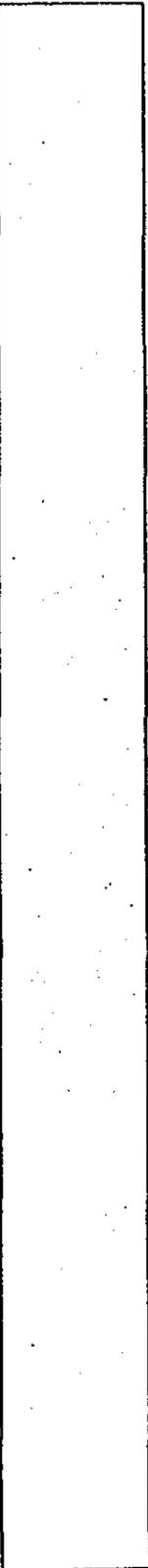
CHANNEL SPACING	S	= 12.5 kHz
	R	= 20 kHz (Market codes 03 & 13 only)
	V	= 25 kHz
	C	= 25 kHz temperature compensated oscillators

FREQUENCY BANDS	A0	= 148-174 MHz
	B0	= 132-156 MHz
	E0	= 68- 88 MHz
	M1	= 105-108 MHz
	M2	= 138-141 MHz
	P5	= 79- 88 MHz
	P8	= 96-106 MHz

NUMBER OF CHANNELS	1	= Single channel
	6	= Up to six channels
	A	= Up to six channels with automatic Selcall Defeat on Channel 1 (Refer all orders to Tech. Sales)

OPTION 5	00	= No Primary option
	20	= Fist microphone Type MPH/F
	30	= Fist microphone Type MPR/1
	90	= Fist microphone with integral timer

OPTION 6	42	= Standard production
	43	= Mobile to be installed within AC200PU (Option 1 code 0 only)
	44	= Mobile to be installed in P200PU



1.11.81

Fig. 1.5. - Product Code Sheet - Part 2

The customer may define the installation items required to operate the product and how many separate frequency channels are required. On occasions the customer may purchase and install his own frequency determining crystals.

The example illustrated has the capability of operating at different output powers but these must be set by the factory.

The type of front panel must also be specified according to the associated ancillary equipment.

The above variations, with the exception of Market Code, are termed Sales variations. Many of these items are at the customer's discretion and generally do not alter the basic product construction.

Standard Variations will normally have a significant impact on the structure of the product, and changes from one version to another are not considered economically viable. The Standard Variations include the channel spacing (how close each frequency channel is spaced from the next), the transmitter and receiver bands (a band is a range of frequency over which the product may be tuned without changing the component content) and the number of frequency channels available (as opposed to actually utilised). Standard Variations are usually outside the control of the customer since the operating characteristics are defined by the local Telephone Authority.

The final group of variations are the Primary and Secondary Options. These are usually items which are easily accommodated after the product has been manufactured and are at the discretion of the customer.

The communication language between the salesman and manufacturing is through the product code, comprising the Catalogue Number, Market Code, Sales Variations, Standard Variations and Options. One further level of detail is required to fully specify the product; the operating frequencies. These include the transmitter and receiver carrier frequencies, determined by a crystal (or more recently a synthesiser programmed via a Programmable Read

Only Memory) and, if applicable, selective call frequencies determined by reeds, "twin T's" or PROMS. Since these frequencies are customer specific, they are undefined in the product code and specified only in the customer order.

The flexibility with which manufacturing can react to the demands of the market consistent with acceptable levels of intermediate stock is related to the depth of the variation in the manufacturing cycle. As a general rule, the degree of flexibility is as illustrated in Figure 1.6. below.

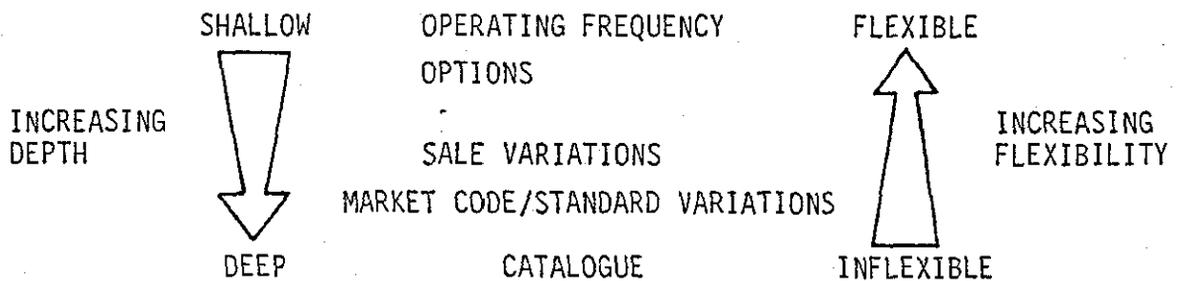


FIGURE 1.6. PRODUCT VARIATION FLEXIBILITY

1.2.4. Markets

The company is currently structured to recognise four different market types, each demanding certain specialist sales and distribution expertise. The four major markets are:

- United Kingdom - commercial
- United Kingdom - Government and forces
- Export via Philips Group subsidiaries
- Direct export

The balance of trade between each market type has varied significantly over the recent years, largely due to the gradual integration into the Philips organisation and the subsequent exploitation of established distribution channels. The United Kingdom commercial market has historically been a successful and reliable segment, due to the high market share enjoyed,

the reputation for comprehensive after-sales service and the nature of the product, which, due to its ability to enhance the client's operating efficiency, has minimised the worst effects of declining economic growth.

Each major market has a number of features which characterise the different sales organisations and procedures.

The United Kingdom commercial market comprises three main customer types. The first is the client operating (or wishing to operate) a small to medium sized communication scheme, typically taxi operators, farmers, construction companies, doctors, service and repair agencies. The business is usually placed in regular small orders, starting with a basic scheme (e.g. one base station with about ten mobile and portable units) and extending as the client becomes more familiar with the medium, or the business grows. The second customer type is the large national organisation, (e.g. AA, Securicor, British Road Services) requiring sophisticated communications schemes, often with customer specific engineering and usually spanning a number of sales territories. The third customer type is the area of public utilities, including water authorities, fuel and power. These customers are similar to the large national client, with the exception that they are more subject to central policies and are highly organised in terms of cash resources and budgets.

The United Kingdom government market differs substantially from the commercial activity. Business is placed in typically larger discrete quantities and may be for systems or "shopping lists" of products to extend schemes or hold in reserve. Opportunities arise through the tendering process and thus the business may be described more as reacting to a defined requirement rather than stimulating a need. The level of business is highly dependent upon the economic climate and the level of government spending, and the product will often be tailored to the specific requirement.

Export through the established Philips Group subsidiaries is a relatively new and expanding activity. Growth is limited by the technical competence of the subsidiary concerned, since many organisations may have to supply a range of services from lighting through white goods to audio/video. Each subsidiary will normally

offer a limited range of products, generally in the most basic form. Only the more established subsidiaries would support a full systems installation and service facility.

Direct export comprises two categories; business conducted in areas where no competent Philips organisation exists, and specialised business in established Philips territories where a close supplier/customer liaison is required. Export orders are typically larger than home market orders and the method of payment is often a key feature of the contract. Selection of the trading territories is a major consideration for Product Management since entry into a new market will often involve significant changes to the product specification to comply with local P.T.T. (post, telephone and telegraph) requirements, each of which may demand extensive type approval acceptance trials.

1.2.5. Development of production control systems

The evolution of Production Planning and Control methodology in the company is described here in three stages. The first is the early computer experience prior to the use of data base facilities. The second phase is the emergence of requirements planning. The final phase includes the current development programme.

The computer was first introduced into the company in the late 1960's, at which time an IBM 360/35 facility was installed on the premises. The bulk of the Production Planning and Control procedures were manual, with stock being replenished according to historic usage based on classic (at that time) re-order point theory.

In the early 1970's, the "product structures" comprised decks of punched cards, organised in groups according to the features or options. Material procurement for the higher usage value items was subject to "material releases", which were bulk manufacturing quantities authorised by the marketing management. The product mix was applied by using judgement and experience and the final plan presented for procurement action. Gross buying lists were prepared by selecting the card decks for the required features and inserting multiplier cards defining the quantity. The cards, or "quick decks", were presented to the computer which aggregated the requirements into a Gross Buying List. The resultant list had to be

manually compared with the on hand stock and orders to determine the net requirement, from which both purchase orders and delivery schedules were established.

The most significant advancement in technique came in 1971 with the development of the Material Support System and the use of the DBOMP data base management system. The system was proposed as part of a comprehensive programme to upgrade the existing business systems and was the first use of requirement planning techniques in Production Planning and Control.

This framework, which has been extended and modified over a period of years, is still the basis of the present operating procedures. To provide some background to the problem area, the procedures are now described in some detail and include the activities with which the production systems relate.

The major relationships between each activity are shown in Figure 1.7., which also indicates which functions are essentially manual and which are computer assisted.

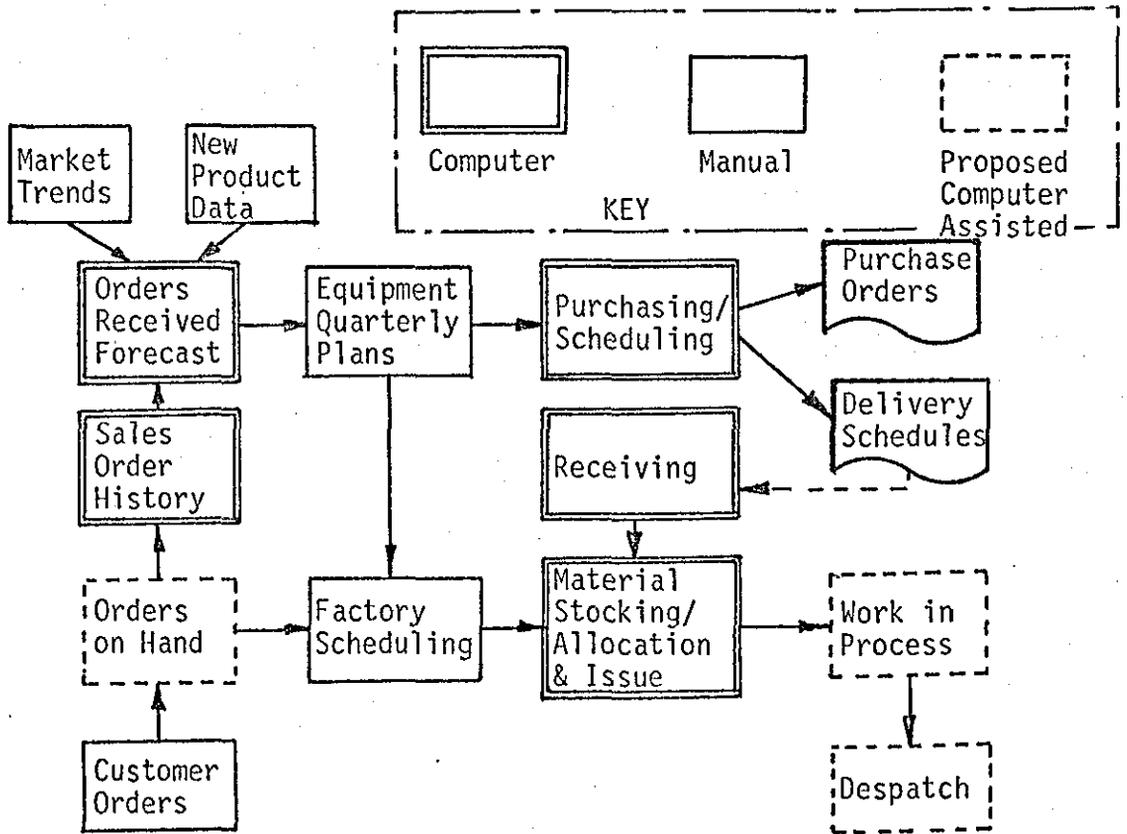


FIGURE 1.7 MAJOR SYSTEM RELATIONSHIPS

1.2.5.1. Orders Received Forecasting

The Company has been using a formal orders received forecast as the prime input to the Production Planning process for about nine years.

The early forecasting procedure was entirely manual, using moving annual total (M.A.T.) data to project forward a period of four quarters. The method was simple and allowed a significant element of judgement to be applied.

In 1975, a computer assisted forecasting mechanism was introduced, in which the past 12 months sales history for "trend" business is projected up to 24 months in the future. Facilities are available to introduce large order prospects into the programme and to summarise the total forecast in a number of ways, e.g. by equipment and value. Projections are based on a regression algorithm, with a facility for single exponential smoothing being available, although currently not used.

Various statistics have been used to measure forecast "accuracy", but this is an area of confusion due to the problems in large order timing, product mix and other considerations.

1.2.5.2. Quarterly Planning

The equipment "hardware" forecast is used each quarter and is the basis for compiling the Equipment Quarterly Plans.

Each equipment plan is set at Level 3 (Catalogue number) and excludes variation codes and options. The plan uses as base data:

- known phased manufacturing order load
- sales orders received forecast
- opening work-in-process (main equipment)
- opening finished equipment stock
- previous plan

and projects the forward delivery, off-line and on-line plans within a number of constraints. The constraints include; reaction time to changes, projected delivery lead times and stock/WIP policies

1.2.5.3. Resource Planning

Each quarter, following the compilation of the Equipment Quarterly Plans, the implication of the total plan is manually evaluated in terms of deliveries against budget; stock; labour requirements and factory order book.

Due to limitations in base data, the evaluation is in gross terms and cannot reflect the activity of each work centre or factory.

1.2.5.4. Bills of Material

The present bills are essentially Engineering Bills of Material. Some attempt is made by Production Engineering to restructure according to the manufacturing requirements, although this is not always possible and is constrained by certain fundamental system limitations.

Options and variations are present within the "top-level" bills of material, although they are not constructed in modular form.

The development of the fully defined Bill of Material includes three phases:

- Advanced Bill of Material (ABOM)
- New Equipment Bill of Material (NEBOM)
- Full checked status structures

The Advanced Bill of Material conforms closely to the development, or Engineering Bill of Material described earlier.

The New Equipment Bill of Material is the transition between the Advanced Bill of Material and "checked" status structure. This reflects the firming up of engineering data and the restructuring by Production Engineering and Production Control to support the manufacturing methods and logistical requirements. At the New Equipment Bill of Material stage, the Chief Engineer has full authority to approve a change to the structure.

When a product has been manufactured for a sufficient period of time that the structures are deemed to be reasonably stable, a sample product is selected for full status checking, following which all prospective changes must be referred to and approved by the "Change Note Committee".

1.2.5.5. Customer Order Receipt

Customer Orders received from Sales Depots, Agents and Customers are accepted into the Sales Administration Department. The orders are checked against the code manual for technical accuracy and compatibility, and are subject to a commercial edit for payment terms, shipping data, etc. The order is passed to Customer Accounts for credit clearance before passing to Central Planning for order loading.

The Order Loading Planner searches for the earliest date that the order can be delivered, taking account of part delivery requirements, the availability of merchandise, crystals, etc. When all information is available, the order is entered into Redifon order processing equipment and a number of copies of the order produced. One copy will be passed to the Salesman/Customer as an order acknowledgement. At the time the order is copied, two cards (equipment and control) are produced for each equipment on the order.

1.2.5.6. Factory Planning

The order received from the Sales Administration Department is copied in the Factory Production Control department onto factory order books by equipment and due dates. Equipment cards are filed and control cards passed to the factory.

Allocation requests are made for material to support the customer order load between 6 and 8 weeks before the due date on a fortnightly basis. Certain equipments are designated "stocking" types and are produced on the assembly line unallocated to customer order. These equipments may be allocated to customer orders from stock.

Printed circuit board requirements are derived from the factory order books and incorporate an element of buffer stocking on the more common variations.

Coil requirements are based on the gross requirements listing derived from the quarterly planning procedures, modified against buffer stock requirements and economic batches.

1.2.5.7. Material Procurement

The foundations of the present Purchasing and Scheduling systems were established in 1972, when the Engineering Department formed a Data Base Control section and created the Part Number Master and Product Structure Files. This was followed closely by the stock records and associated costing information.

The Purchasing and Scheduling sub-systems were introduced some 6 months after the data base was established and operated, essentially, as two independent systems. In 1977 the proposal was put forward to integrate the Purchasing and Scheduling sub-systems into one, which subsequently eradicated the problem of inconsistent procurement data and contributed largely to a substantial reduction in technical inventory whilst improving the service level to manufacturing.

Input to the sub-system is the "on-line" data derived from the Equipment Quarterly Plans. This data, which is applied at catalogue level, is converted by the system into full code/option requirements by applying sales history mix to the phased plan. The resultant detail is inspected and modified, if necessary, to incorporate any abnormal mix elements (eg. large orders, movement in mix trends). The plan is exploded using a procedure which includes lead time off-sets and intermediate netting to arrive at a material requirement plan at component level.

A facility exists to adjust the sub-assembly requirements to reflect the balancing of stock/WIP. The resultant nett material plan is the basis for generating two sets of data for procurement.

The Nett Buying List provides the Buyer with information on the phased requirements and their source. The requirements are adjusted for buffer stock considerations and on-hand balances. Static supplier and component data is also available, with suggested alternatives where applicable.

The buyer makes a decision on the amount of order cover to be placed and, using his knowledge of the supplier's capability, price, etc., makes a choice of supplier. A purchase history card for each part number purchased indicates from whom the part was purchased in the past and the price and quantity.

The purchase history card is accompanied by a punched paper tape which is used to automatically print the fixed fields on the Purchase Order on Farrington automatic typewriters. A byproduct tape is produced for up-dating the outstanding orders file on the central computer.

A copy of the order is passed to Goods Reception for future use.

The computer Buying and Scheduling system produces a call-off schedule for component requirements, usually on a fixed monthly basis. The call-off schedule reflects the same requirements data as the Nett Buying List but in addition recognises the schedule reaction time (for changes), arrears to schedule and outstanding reject notes. The Schedule provides a firm call-off by month for the next six months and indicates a tentative requirement for the following quarter.

The buyers check the schedules and forward them to the vendors for acceptance. Any agreed changes are re-submitted to the computer for schedule corrections. There is no facility to track back any schedule changes to the effect on the higher level demands.

1.2.5.8. Material Allocation

Allocation requests submitted to the computer cause the explosion of component requirements and the identification of shortages.

A copy of the "shortages to allocation" report is available for internal expediting and is summarised for the purpose of external expediting into a "shortage by supplier" tabulation.

A decision may be made to release the allocation for picking, which causes a picking list to be generated and subsequently for the material to be issued to work-in-progress. Shortages remaining at this point are raised to "line-hold" status and advised to Purchasing on a manual list.

A person from Production Control is resident within the Goods Receiving area to intercept incoming goods and define priorities as required.

1.2.5.9. Shop Floor Control.

At equipment level, two monitoring points track the progress of products through the factory.

The off-line point signifies transfer from the main assembly line into test (for customer equipments) or unallocated commercial stock.

The final output point identifies the movement of the equipment from final test to the despatch department.

Information on equipment status is summarised on the Status Report, which is manually compiled each week from the shop monitoring documents.

Printed circuit boards are passed to a computer recorded work-in-process store, thus a byproduct of the stock transaction paperwork is to update Production Control records.

A close communication link exists between the equipment and sub-assembly areas in the form of "hot lists", for the expedition of urgent items.

Work has reached an advanced stage in the definition of a computer system to improve the areas of Customer Order Servicing, including shop floor monitoring - Telecom Order and Production Information and Control System (T.O.P.I.C.) - through the use of on-line order entry terminals and shop floor data collection equipment.

The final phase of development is the Manufacturing Control System. The early stages of investigation were initiated by the author and the Data Processing Manager in 1978 with two prime objectives; to exploit the capability of contemporary computer hardware, in particular the enhanced communication facilities, and to make use of the latest Production Planning and Control facilities with particular emphasis of Manufacturing Resource Planning. This early work led to a fact finding visit to the United States of America, the findings subsequently being published in a report (Crowcroft and Laurence 1978). This was followed by a detailed Feasibility Study published in 1979 (Crowcroft and Laurence 1979) and the selection of IBM COPICS as the software solution. The revised procedures are expected to become effective over the period 1982-1984.

The study area is concerned primarily with the situation obtaining under the Material Support System phase, but where significant differences in the revised procedures exist, they are amplified where applicable.

1.3. PROBLEM DEFINITION

1.3.1. Environmental Considerations

The problem area is defined by further analysis of the manufacturing system, with particular emphasis on the underlying theory, assumptions and constraints rather than the detailed systems methodology.

To provide a perspective and improve the clarity the operating environment has been restated.

A characteristic of the land mobile radio market is that the customer expects to secure delivery of his equipment in a relatively short lead time compared with typical delivery lead times offered by the component suppliers. Typically, the customer will require a delivery within 6-12 weeks of placing an order. Component lead times currently vary between 8 and 52 weeks, since the Company's policy is to purchase directly from the manufacturer wherever possible rather than use stockists and suffer a consequential price disadvantage. The material provisioning is executed by means of a requirements planning system, based on information derived from forecasts of orders to be received and current orders in hand.

A generalised schematic of the goods flow within the standard products sector is shown in Fig. 1.8.

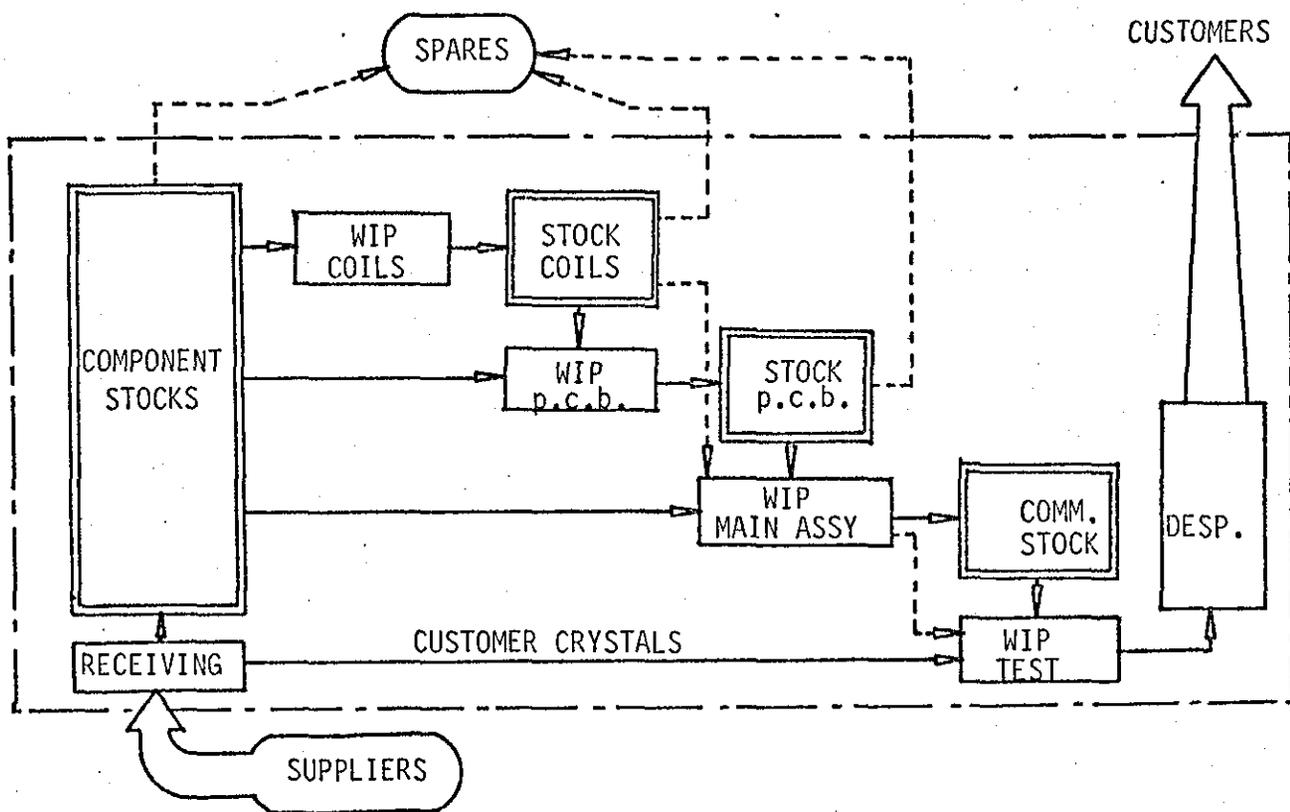


Fig. 1.8. - Goods Flow Schematic

The major flow is indicated by a solid line and secondary flow is shown by a broken line.

To assist in the clarification of the stock-holding areas, formal (i.e. recorded) stock holding areas have been denoted by a double box, and work in progress areas by a single box.

The formal stock holding points serve a dual purpose. Firstly to maintain a substantially constant load on the production resource, and secondly to offer a consistent delivery lead time to the customer which is shorter than the total manufacturing throughput time.

The diagram in Fig. 1.8. may therefore be logically transformed as shown in Fig. 1.9.

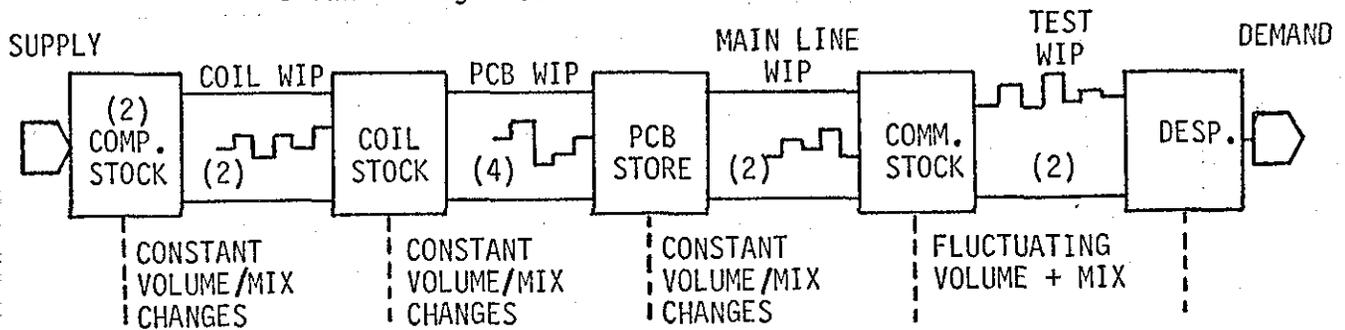


Fig. 1.9. - Logical Stock Points

The figures in parentheses are the typical lead times in weeks through each part of the system. The lead time in stores is the time required to assemble an issue of material from presentation of the picking documentation to availability for production and does not include any element related to buffer stock.

It can thus be seen that the commercial (or finished equipment stock) will tend to buffer the effects of volume changes and provide a constant load for the main assembly W.I.P., within which there will be changes in product mix. Articles held in the commercial store can be delivered to the despatch department within the time taken to acquire the customer's crystals (which determine his operating frequency) and pass through the test department. Allowance must also be made for the internal planning cycle, (i.e. the frequency with which orders are matched against the stock and allocated).

The printed circuit board (p.c.b.) and other customer conscious sub-assemblies are held in a p.c.b. buffer store. A substantially stable programme in terms of both volume and mix can then be applied to the p.c.b. manufacturing facility.

The coil stocks are held mainly to facilitate economic production runs. The unit price tends to be relatively low, and the machinery often involves lengthy set-up times, thus a simple economic batch quantity approach which balances the stock holding costs against the set up costs can be used.

A characteristic of the product design is that the profile of part numbers has the form shown in Fig. 1.10.

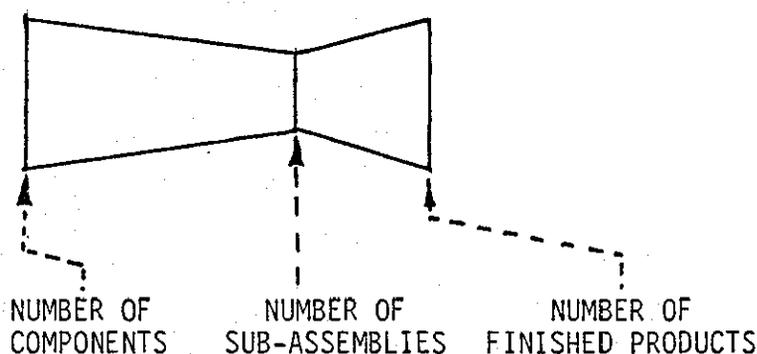


Fig. 1.10. - Part Number Profile

A large number of components (some 20,000) are used to produce a smaller number of sub-assemblies (approx. 10,000). These sub-assemblies are then incorporated into a potentially much larger number of finished equipment varieties ($> 25,000$). The acknowledgement of this relationship is fundamental to the design of the production control procedures.

Combining the consideration of desired delivery lead time, manufacturing process and product design, the strategic and tactical role of the formal buffer stocks may be considered.

Ideally the stock should be held at the point of greatest uncertainty; the commercial stock point. Assuming that this stock is sufficient to absorb all volume and mix fluctuations in the raw customer demand pattern, the rest of the system is completely

deterministic. Thus the only stocks required to be held are work in progress (pipeline) stocks and any "working" stock due to economic batching considerations. No additional stocks need be held to buffer demand uncertainty.

In practice, due to the large number of products and the many possible variations within each product, such a policy would result in a massive commitment in commercial stocks and a high risk of obsolescence.

For example, the present range of products offered for sale is 354, of which 160 are variant conscious. If all variations, including sales, standard and options, were to be offered in every conceivable combination, the number of possibilities could be in excess of 6 million.

This is based on a "typical" product with the following range of variations

<u>CHARACTERISTIC</u>	<u>AVERAGE NUMBER OF VARIANTS</u>
Catalogue number	1
Market code	4
Sales variations	4 each with 3 attributes
Standard variations	15
Primary options	4
Secondary options	2

Thus, the possible combinations are 38,880 for each of 160 products plus 194 non variant conscious products, or 6,220,994.

In practice the number of fully defined codes does not approach this number, but is still in the region of several hundred per product. Therefore, assuming only 100 variations on a typical product and an output rate of 100,000 products, the mean rate for each type would be $\frac{100,000}{(354-160)+160 \times 100}$ or about six units per year. The actual number of variants sold is considerably in excess of 100 per product, thus the forecasting and buffer stocking problem would be formidable at this level of definition.

The other extreme would be to hold all stocks in the component form, which would have the effect of an unacceptable delivery lead time to the customer and a highly variable capacity requirement on the factory. The minimum lead time would be in the region of 12 weeks and allowing for the planning cycle time, would be typically 14 weeks.

1.3.2. Hypothesis

The basis of this work is that a compromise situation exists whereby, if the stocks are distributed throughout the system, a balance may be found between the investment in stocks, the cost of over capacity (or productivity) and the achievement of an acceptable and reliable customer delivery lead time.

The prime objective of the research project is to arrive at an acceptable solution to this problem by means of constructing a computer simulation model of the goods flow system and conducting experiments on the model to test various alternative hypotheses.

The model should also provide the facility to observe the reaction of the system to a wide variety of customer and supplier reactions and quantify the primary and secondary consequences of decisions.

An essential requirement of the model is that it should emulate the actual manufacturing process rather than the ideal world and should be capable of evaluating both the existing procedures and also the revised planning procedures under development based on contemporary requirement planning practice.

1.3.3. Scope

The scope of research may be defined by reference to Fig. 1.11.

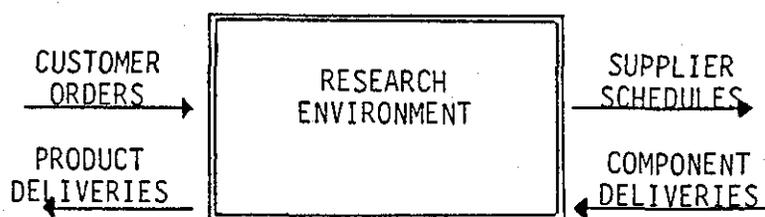


FIG. 1.11. - Scope of Research

The research environment is confined within the Company boundaries. The customer and supplier are both outside the scope of the investigation and may be described by predefined observed characteristics. The objective is to analyse the internal operation of the business structure in response to changes in external environment and to draw conclusions about the rules and policies governing the internal performance, which may subsequently be used to establish formal operational policies and planning procedures.

1.3.4. General Applicability

The design of the simulation model should be such that, whilst addressing the main research objectives, it is able to be applied to more general situations. Thus, the structure should, ideally, accommodate a range of environmental changes. This should include:

- Changes to the external environment through the definition of sampling profiles;
- Changes to internal processing parameters;
- Modification of program logic or replacement of logical segments to reflect more significant differences in internal procedural conditions.

The model should thus be capable of adaptation as the given business environment evolves, and provide a basis for the evaluation of similar problems in other business situations.

2. LITERATURE SURVEY

2.1. PRODUCTION CONTROL AND MRP

2.1.1. History of Production Control

Analytical techniques were first applied to manufacturing problems as early as the beginning of the 20th century by the American pioneers F.W. Taylor - the "father of the time study" and the F.B. and L.M. Gilbreth team, who developed motion study as a technique. Work study, the combination time and motion study, became an accepted part of the manufacturing research and was developed in technique and application by such names as H.L. Gantt, D.B. Porter (New York University), R.M. Barnes (University of Iowa), M.E. Mundel (Purdue University), G. Nadler (Washington University).

A further dimension was added to the application of scientific approach to manufacturing problems by the development of Operational Research. This branch of science was developed in the Services during the Second World War, the first application being the calculation of the number of casualties from a given bombing raid, having estimates of the number of planes, types of bomb, etc. The study was conducted by Blackett, a physicist and Zuckermann Professor of Anatomy at Birmingham University. The techniques were further refined by Sir Charles Goodeve (Director of BISRA) for industrial applications. The recognition of Operational Research was established by the formation of the Operational Research Society in 1948 and the publication of the first Operational Research Journal in 1949.

During the early 1950's, Production Planning and Control was becoming established, developing largely from the Operational Research theories. Production Control was defined (BS1100, 1953) as follows: "Production Control is the means by which a manufacturing plan is determined, information issued for its execution and data collected and recorded which will enable the plan to be controlled through all its stages". A wealth of literature emerged describing the fundamentals of Statistical Inventory Control (SIC),

ranging from Landy (1950) through Brown (1959, 1965), Prichard and Eagle (1965), Magee and Boodman (1967), Greene (1970).

The common thread of all the SIC literature is part-orientation, in that each part is considered independent of all other parts and the requirement for demand forecasting at component level. The first move towards product-orientation and the calculation of component requirements from the schedule of finished products was through the use of rudimentary Bills of Material, described by Vazsonyi (1958), Trux (1968) and New (1973) as the Gozinto (goes into) Chart. New (1973), states that "such a chart is very useful for rapidly exploding or imploding part structures" but that it would "clearly become unwieldy if more than, say, about 100 items were involved".

The real breakthrough into the calculation of requirements for dependent items was the development of electronic computers with direct access storage. During the 1950's some companies were making use of mechanical punch card equipment to analyse Bill of Material card files for use in material gross buying lists and stores pick lists. The introduction of direct access storage computers, such as the IBM 305 RAMAC, enabled far more complex structures to be exploded than could ever be considered manually. During the early 1960's a number of companies were pioneering the use of computers to perform material requirements calculations, including J.I. Case, Black and Decker, Perkin Elmer. The term Material Requirements Planning for the logic of exploding the product demands through the bill of material to generate the component requirements was first used in public in 1970, with the paper presented to the 13th APICS (American Production and Inventory Control Society) International Conference by Orlicky, Plossl and Wight (1970), although mention of the technique had been made earlier by Plossl and Wight (1967), Wight (1968) and Everdell (1968).

The contribution of APICS to the body of knowledge in MRP is, in the words of Wight (1974), "dramatic". He comments that "three major influences have accelerated the development of a body of knowledge in this field:

1. The American Production and Inventory Control Society (APICS).
2. Operations research.
3. The computer.

APICS was formed in 1957. By improving communications among professionals and its support of education, publications and seminars, it has done a great deal to advance the state of the art".

Material Requirements Planning is, today, the recognised technique for the control of dependent demand items. Wight (1970), however, is critical of the emphasis on SIC in the past by observing "that the number of pages written on independent demand-type inventory systems outnumbers the pages written on material requirements planning by over 100 to 1. The number of items of inventory that can best be controlled by material requirements planning outnumbers those that can be controlled effectively by order point in about the same ratio. It is a sign of the adolescence in our field that the literature available is in inverse proportion to the applicability of the techniques".

2.1.2. Material Requirements Planning

2.1.2.1. Overview

The history of MRP is described by Plossl (1980), one of the veterans of MRP. Reference is made to the first published example of the technique in 1744, showing the bills of material and quantities of components required to construct a Franklin Store. He suggests that the first textbook to include any information on MRP is Plossl and Wight (1967), followed by articles by Wight (1968) and Everdell (1968). Reference is also made to the unique contribution to MRP knowledge by the so-called "MRP Crusade", sponsored by the American Production and Inventory Control Society in the early 1970's.

There is little doubt, however, that the single most significant contributor to knowledge on Material Requirements Planning (MRP) is Orlicky. In 1961, at the Tractor Plant in Racine, Wisconsin, a project group was established under the direction of Dr. Orlicky, who was then Director of Production Control, to design an advanced MRP system to replace the existing punch card based facility. The original system was implemented on an IBM 305 RAMAC computer with some 15m characters of disk storage. This system was crude because of the storage limitations, and the movement of another tractor plant to Racine presented data volumes which precluded any attempt at a regenerative MRP system. The system was only capable of providing support to common material and all unique parts were handled manually. The system was subsequently re-implemented on an IBM 1410 computer, which was capable of supporting considerably more disk storage.

The technical application of MRP is well documented by IBM, who produced, in 1972, a series of eight manuals on "Communications Oriented Production Information and Control System" (COPICS) on the concepts of closed loop manufacturing control. It is only recently that IBM have undertaken the development of application software to support the COPICS manuals, but they have, nevertheless, been widely quoted reference material.

The technique of MRP is most completely described by Orlicky (1975), who has a strong bias towards the logic of MRP rather than the application. The emphasis is on the Master Production Schedule and the development of material plans rather than "closing the loop" by effective capacity planning and control. The description of the MRP logic is excellent, as is the treatment of bills of material, in particular as applied to option conscious products.

Plossl (1973) is less rigorous technically, placing more emphasis on the use of MRP as a management tool and its relationship to capacity planning, priority control and capacity control.

This view is further enhanced by Plossl and Welch (1979) in a text aimed specifically at top management.

New (1973) provides a clear, easily digestible text on the principles of MRP, using simple manual examples to back the theory. The text concentrates on the requirements calculation and the application of buffer stocks and lot sizes. A unique feature of the text is a chapter on the relationship between MRP and cellular manufacture. The text does, however, have the disadvantage of understating the key nature of the Master Production Schedule, the link with resource planning and the importance of realistic lead times.

It is interesting to note that, despite the enthusiasm and publicity accorded to MRP in 1971 by the "MRP Crusade" discussed by Plossl (1980), the publication by Starr (1972) has no single mention of the techniques of MRP, notwithstanding the central theme being the synthesis of production systems.

2.1.2.2. Bills of Material

The Bill of Material is the heart of the MRP system, providing the mechanism for requirements calculation and describing the logical assembly of the product. New (1973) notes that "if a company seems to have too many bills-of-material for reasonable implementation it is almost certain that their product structure will enable some degree of 'modularisation' to help".

The first really comprehensive article on "structuring the bill of material for MRP" is by Orlicky, Plossl and Wight (1972). The problems of structuring complex option conscious products are described in detail and an attempt is made to establish a standard set of terminology for the process involved. Bourke (1975) provides a useful set of guidelines for implementation but avoids the theoretical structuring considerations.

The sources of information on structuring the bills of material are limited, most being case studies of specific applications. Garwood (1970) was one of the first papers to introduce the modular product approach. Hoffman (1977) extends the modularisation discussion into the use of a "product model data base" to support order promising, option forecasting and final assembly scheduling. Problems encountered in highly complex products are discussed by Langenwalter (1976), who adopts a decision table approach and Gangopadhyay et al (1978) who favour a modification to the basic bill of material structure to ease the problem.

The subject of engineering change as addressed by MRP is discussed by Andrew (1975), including the various techniques that may be applied.

2.1.2.3. Lot sizing

Lot sizing, or the determination of economic batch sizes and their relationship to MRP is discussed widely in both the standard texts and in specialist articles. Berry (1972) provides an overview of the applicability of lot sizing techniques to MRP and compares the relative performance. Orlicky (1975) lists the most widely recognised approaches to lot sizing as:

- Fixed order quantity
- Economic order quantity (EOQ)
- Lot for lot
- Fixed period requirements
- Period order quantity (POQ)
- Least unit cost (LUC)
- Least total cost (LTC)
- Part period balancing (PPB)
- Wagner - Witin algorithm

He further draws a distinction between "fixed" and "variable" order quantities, and "static" or "dynamic" usages. Examples of each method are discussed, as does New (1973), who also provides a summarised comparison of the performance of each algorithm. Wight (1974) further discusses the application of "discrete lot sizing" in dependent demand systems and provides a management

perspective on the place of economic order sizes in MRP systems stating that "getting the right quantity at the wrong time does not accomplish anything." Welch (1956) argues that, from his observations, most applications of EOQ, were not the "most economical", just "more economical than intuitive methods".

The use of dynamic lot sizing techniques is discussed by Kropp et al (1979) and Chang and Inoue (1977). The problems of lot sizing at several levels in a multi-level MRP system are examined by New (1974). Karine (1980) offers a possible solution with the "Uniform Order Quantity" approach.

2.1.2.4. Safety Stocks

The role of safety stocks in MRP systems is an integral part of the standard texts. New (1973) develops the method of calculating safety stock, but tends to bypass the question of applicability of such stocks. Wight (1974) draws a clear distinction between the requirements of independent demand and dependent demand items, arguing that safety stocks should only be held at the Master Schedule level. Orlicky (1975) further suggests that "safety stock (at item level) is part of the stock replenishment concept and as such has no legitimate place in an MRP system". Plossl (1973) proposes that safety stocks should be carried at only the "high and low levels", implying sound capacity planning and a dynamic priority technique. A balanced overview of the applicability of safety stocks is provided by New (1975), who also explores the effects in a multi-level planning system.

2.1.2.5. Forecasting and the Master Production Schedule

The Master Production Schedule is an essential element in an MRP system, yet its true importance was not apparent in the early texts on MRP technique. Everdell (1972) provides an insight into the true role of the Master Production Schedule (MPS) in MRP systems and New (1973) emphasises the need for realism in that the MPS must reflect "what is actually expected to happen not what the production manager or director would like to see happen". Orlicky (1975) provides a comprehensive view of the development of the MPS from the Production Plan and defines the links with

Resource Requirements Planning and the Final Assembly Schedule. Mather and Plossl (1978) describe the objectives of Master Scheduling;

- To provide top management with a means to authorise manpower levels, inventory investment and cash flow, giving them a real handle on customer service and profitability.
- To provide a mechanism to co-ordinate Marketing, Manufacturing, Engineering and Finance activities so they all work together to achieve a common performance objective.
- To provide a device to reconcile the needs of Marketing with the capabilities of Manufacturing.
- To provide an overall measure of how well each major function in the business is able to make a sound plan and then execute it.
- To provide input data to programs developing detailed material, capacity and financial requirements.
- To provide a means to make a more reliable delivery promise to customers and evaluate the specific effects of changes in delivery schedules.

Wight (1974) provides some examples of Master Scheduling in different types of business and develops further the aspects of "managing the Master Schedule". This is discussed further by Plossl and Welch (1979), who emphasise the need for management to define the Master Schedule policy.

Because of the wide variety of business types, the application of Master Planning theory is equally varied. Berry et al (1979) have produced a series of case studies which attempts to define the characteristics of successful MPS applications across a range of MRP users.

A number of articles on the application of Master Scheduling have been appearing since 1975, many of which have been compiled by APICS (1977) to provide a useful reading base for system designers. Articles may be classified as basic techniques - Ling and Widner (1974), Maranka (1976), Malke (1976) - case studies of specific MPS applications - Ulberg (1975), Visagie

(1975), Spampau (1975), Kohankie (1976) - and the strategic application of Master Scheduling - Conlon (1976), Orlicky (1975), Wilkerson (1976), Bobeck and Hall (1976), Brenizer (1977), Steele (1975).

Forecasting in an MRP environment is viewed in quite a different perspective from that of the statistical inventory control exponents. Orlicky (1975) suggests that, although there have been improvements in forecasting over the past decades as far as sophistication of technique is concerned, improvement in forecasting effectiveness has been "rather modest". Wight (1974) argues that, although most companies have to do some forecasting "there is no such thing as a reliable forecasting technique". Wight also draws a clear distinction between "intrinsic" and "extrinsic" forecasting. Plossl (1973) comments further on this theme and quotes his view of the five basic characteristics of forecasts:

- "1. They are always wrong.
2. They need two numbers (i.e. an estimate of the forecast accuracy).
3. They are more accurate for families of products than individual items.
4. They are less accurate far into the future.
5. They are no substitute for calculated demand."

The technique of forecasting has, therefore, become secondary to the evaluation of the effects of poor forecasts and the provision of facilities to respond more rapidly to new forecasts. Forecasting is seen to be an integral part of the MPS development and maintenance procedures, a view which is confirmed by Gaylord (1977) and Leach (1977). Odnards (1978) further discusses a number of the points raised and deals specifically with the problem of uncertainty at the Master Schedule.

2.1.2.6. Net Change and Regenerative Systems

There are two types of MRP systems found in practice; "regenerative" and "net-change". Regenerative systems are the most universal and work on the principle that the full planning hierarchy is

periodically regenerated from the MPS through all structure levels. Thus, all active inventory records and bills of material are accessed, resulting in a re-statement of each inventory plan. Typically, regeneration is carried out monthly or weekly, usually resulting in a large volume of printed output. Regeneration is, however, argued to be relatively efficient, since certain data-processing optimisation may be performed. It could also be argued that such optimisation may be mandatory, since the regeneration of a full set of inventory plans will often require a dedicated mainframe computer for periods in excess of 15-20 hours per run.

Net change systems are based on exception replanning and are usually transaction oriented, in that each transaction (egs. stock receipt, MPS change, unplanned disbursement, bill of material change) is processed to completion, any secondary transactions being placed in a temporary file for further processing. Net change systems are far more responsive than regenerative since replanning may take place more frequently (typically daily) and are intrinsically exception oriented, thus focussing the planner's attention on the required actions. Net change is said to be more "nervous" than regenerative because of the higher frequency of replanning, but this could be argued to be a system management problem rather than a technical limitation.

Net change systems are acknowledged by the major software vendors to have a distinct edge over regenerative, particularly where large volumes of data are processed. It is ironic that, although both techniques were developed at about the same time, the regenerative mode was exploited more actively. The net-change method was created by the team headed by Dr. Orlicky in J.I. Case as the only possible solution to the problem of handling the volumes of data required to operate the tractor plant. The relatively slow development of net-change is almost certainly due to the significantly greater technical problems involved in maintaining the integrity of the system data files.

The logic of both regenerative and net-change systems is excellently described by Orlicky (1975), who argues strongly in favour of net-change. It could, however, be argued that there is some bias

when considering his early experiences and his acknowledged position as the creator of net change. A more concise view of the net-change/regenerative comparison is given by New (1973) who suggests that "net-change systems have considerable advantages and should be the eventual goal. However, a company contemplating an initial system should start with the regenerative approach". This view is based on the enhanced data integrity and management skill demanded by net-change, whereas regenerative systems are more tolerant and have a degree of "self-purging" capability.

Orlicky (1972) provides an introduction to the concepts of net-change and offers a more rigorous technical description in the seminar material re-produced by IBM (1976).

2.1.2.7. Management Issues

The scope of MRP has expanded steadily over the recent years from the basic Material Requirements Planning, which was essentially a requirements calculation mechanism, to a comprehensive business planning technique. To accommodate these changes, the term MRP has been developed to MRP II, and redefined as Manufacturing Resource Planning. The scope of Manufacturing Resource Planning includes the consideration of capacity in addition to material and embraces planning and control in a closed loop system. The view of MRP has also evolved from a technical facility to a management philosophy. The discussion and treatment of management issues is therefore a key feature in MRP related literature.

Wight (1974) argues that there is a ABC relationship in systems implementation, where the "computer part of the system is the C item". He further defines the system data and its associated integrity as the 'B' item, and the people part of the system as the 'A' item. Both the B and A elements may be classified as management issues.

2.1.2.7.1. Record Accuracy

Record accuracy refers to the integrity of the system data and master files. The two most significant problem areas are acknowledged to be stock record and bill of material accuracy.

A significant volume of literature has been produced on the importance and achievement of stock record accuracy. Both Wight (1974) and Plossl (1973) suggest methods of enhancing stock record accuracy, while sound, practical experience is offered by Brooks (1977) and Anderson (1977).

The technique of cycle counting, which is a pre-requisite of an inventory record accuracy improvement programme, is described by Hablewitz (1977) and Tallman (1976).

Compared to stock record accuracy, bill of material accuracy has received little attention. This fact is quite surprising since, although a stock record error will only affect one item, a bill of material error will often cause erroneous data to appear against at least two records. Bill of material errors are also more difficult to detect and require more interfunctional consensus to correct. Orlicky states that the "bill of material must be accurate and up to date" but offers no practical advice on how to achieve this end. The emphasis in most standard texts is the structuring of bills of material to represent the manufacturing method, and the associated accuracy problem is badly neglected.

2.1.2.7.2. Group Technology

The relationship of production methodology to MRP is attracting some attention, the most significant area being its applicability to Group Technology or cellular production systems. New (1973, 1977) has researched this area and describes the combination "affectionally" as SCRAGOP (Short Cycle Requirements And Group Organised Production), based on a "special form of MRP inlet control and Group organisation of the production facilities". Suresh (1979) further supports the combination for certain

manufacturing processes and demonstrates impressive case results. Further description of the MRP-GT combination is provided by Hsu (1978), Mahany and Tompkins (1977) and Sata et al (1978).

2.1.2.7.3. Financial Planning

The extension of MRP into business planning is evident from the literature now emerging on budgeting and cost control. The Production Plan is the Company operating plan and is the instrument for the acquisition of material, labour and tooling. The Production Plan also provides the best estimate of shipping levels and income. In a mature MRP environment, the Production Plan is the basis for, and merges into, the flexible budget.

Boback and Hall (1976) provide a good introduction into the potential of the Master Schedule as a financial management tool and in particular develop the argument for sophisticated simulation capability to enhance the decision making process. Campbell and Porcano (1979) develop further the theme of the "MRP budget", both in the preparation of the budget and the subsequent performance and variance reports used for analysis and control.

Financial modelling has been used for a number of years as a tool to aid the development and maintenance of financial budgets. The relationship between the MRP system and financial modelling is described by Jagetia and Patel (1979), who discuss the tangible results achieved following the implementation of an "integrated annual planning and budgeting sales, production and inventories procedures."

2.1.2.7.4. Implementation

Wight (1974) describes MRP as a "people" system. This implies the development of an effective and skilled multi-functional team as part of the implementation plan. Nicholas (1980) describes the techniques that may be employed to create an effective systems development team, placing great emphasis on the proven "working" approach. The more critical problems, however, are not in the development phase, but in the post-implementation period. According

to Orlicky (1975) "that most serious obstacles to MRP systems success lie outside the system boundaries. The problems must be solved not in computer hardware and software but in people, their attitudes, habits and knowledge level". Belt (1979) further develops the theme with particular reference to McGregor (1960) and the Theory X/Theory Y concept. The behavioural aspects of implementation are also discussed by White (1977), Blasingame and Weeks (1981), and Wacker and Hills (1977).

Practical guides to implementation problems are given by Jones (1978), Hay (1978) and Rose (1978).

2.1.2.7.5. Performance Measurement

The vast majority of publications on the subject of MRP concentrate, understandably on the design and implementation phases and ignore the problem of maintaining a healthy system. Accountants argue that you can not control without first establishing a measure, and this is as true for MRP performance. Laurence (1981) concludes that "a well designed MRP system can provide substantial benefits. These benefits can only be quantified and realised by effective management of the system, which implies measurement and control of the key performance indices". This is linked back to the original justification process and the degree of success in implementation.

An introduction to performance measurement is given by Grieco (1980), but the content is shallow with limited scope. A more comprehensive guide to system (rather than business) performance is provided by Edson (1978), while some new business performance measures are suggested by Higgins (1980).

2.1.2.8. Distribution Systems

X The technique of requirements planning is not confined to manufacturing systems. New (1973) describes the dependency in distribution networks and introduces the concept of "time-phased forecasts". Orlicky (1975) describes in detail the "time phased order point" technique and argues its superiority over statistical order point theory.

Distribution Requirements Planning (DRP) brings together the Time Phased Order Point theory and the inter-level dependency by replacing the product structure with the distribution network. Martin (1980) describes the mechanics of DRP as applied to a complex pharmaceutical company exemplifying the shared logic between MRP and DRP. Whybark (1975) introduces the concept of DRP as an MRP derivative, with Stenger and Cavinato (1979) further defining DRP and providing some mathematical analysis of performance. Their argument is that "an integration of inbound and outbound physical flow activities is necessary for true logistical efficiency". Historically, companies have attempted to bridge the gaps organisationally (Materials Management - Logistics Management) but these ambitions often failed through lack of proven techniques. The integration of MRP for the supplies/factory interface and DRP for the factory/market interface provides the missing link.

2.1.3. Comparison of SIC and MRP

The movement away from Statistical Inventory Control (SIC) to Material Requirements Planning has been remarkable, due largely to the success of the MRP Crusade and the criticism that SIC received from the early MRP proponents. The basic distinction between the two approaches was formulated by Orlicky in 1965, who proposed the concept of dependent versus independent demand. "Demand is defined as independent when such demand is unrelated to demand for other items Independent demand must be forecast". "Demand is defined as dependent when it is directly related to, or derives from, the demand of another inventory item or product Such demand can, of course, be calculated and should not be forecast".

New (1973), in describing the application of MRP in the field of production and inventory control, states that "a requirements planning system can always be used in place of a re-order point system".

Fortuin (1977) takes a less extreme position and attempts to categorise the situations in which MRP is "impossible".

The analysis is based on the pre-requisites and assumptions stated by Orlicky (1975, p.41) and a number of cases are subsequently cited where certain of the pre-requisites are apparently not met. It would appear from the text that the author draws conclusions from certain assumptions that would not now be considered valid.

- a) It is suggested that, if the data processing costs outweigh the inventory savings by introducing MRP in favour of SIC, MRP would be "impossible", rather than "unwise".
- b) If the demand on the master schedule is irregular and frequently occurring, it is proposed that SIC should be used, presumably in preference to the Time Phased Order Point technique (Orlicky 1975, p.36), which provides additional time phasing and rescheduling capability to the basic SIC facilities.
- c) The use of MRP when the Bill of Material is not known with certainty, wildly varying yields are experienced or items presenting counting problems are also cited. Each of these items is addressed by Bolander and Taylor (1982), who recognise the above symptoms in the process industry and recommend a slightly modified MRP framework.

Fortuin (1978) further compares MRP and SIC by analysing a single echelon model, demonstrating that for the simple case results are similar.

It is acknowledged, however, that "MRP has advantages that cannot be expressed in money" and that, as the number of levels is extended, MRP becomes increasingly superior.

It can be concluded that MRP is substantially superior to SIC and that, with some effort, the basic pre-requisites of MRP may be satisfied thus enabling many of the cited benefits to be obtained.

2.1.4. Period Batch Control

A critique of literature relating to MRP is not complete without reference to Burbidge (1980), who argues that manufacturing

management should examine their MRP System and "make the few simple changes which will convert it to Period Batch Control".

The arguments presented are not fully conclusive, as can be seen from the series of criticisms published in the Production Engineer during the period December 1980 to March 1981.

The author suggests that, due to the very nature of the MRP concept being a "multicycle ordering system", poor system performance will result. This will be evident in high stock and work in progress investment, high material obsolescence, poor response to seasonality, unpredictable swings in stock investment and machine loading, incompatibility with Group Technology concepts and complicated, expensive, uncontrollable systems. Most of the symptoms described have been addressed in recent MRP literature within the broad subject of "managing the MRP system". It has been successfully proven by many Class A MRP users as defined by Wight (1974) that all of the above symptoms will be addressed by a well designed closed loop MRP system with a defined Master Schedule policy, and that MRP can direct management attention towards the optimisation of the production process.

Wight (1974) describes MRP as a "simulation of the real world". It therefore follows that if the MRP system is designed to simulate the actual production system, the results achieved are, ultimately, limited only by the physical constraints of the production system.

2.2. DELIVERY PERFORMANCE

The objective of the study was to observe the internal performance of the manufacturing system, rather than analyse in depth matters relating to the definition and measurement of delivery performance. For completeness, however, some discussion on applicable sources of information relating to delivery performance is included.

Sources of information may be viewed as either qualitative or quantitative, the former addressing the impact of delivery performance on both business and national economic performance, and the latter deriving quantitative conclusions about the measured delivery performance of a given manufacturing system.

The most complete example of qualitative literature is Paulden (1977). A number of actual case studies are used to support the main arguments and much of the advice is simple yet practical. Further advice on the improvement of delivery performance is offered by Atkin (1981) who again cites the results of a specific case study.

Paulden's work seems to have been inspired in part by the survey conducted on behalf of the British Institute of Management by New (1976). The report is confined to the United Kingdom and covers a number of topics in addition to delivery performance. The conclusions of the survey, however, leave no doubt that delivery performance is a major failing across British industry. The report quotes that only one plant in five delivers in excess of 90% of their orders on time, and one plant in four delivers more orders late than on time. The conclusion is that "either work flow in most companies is very badly managed or there is a chronic shortage of effective capacity across the industries represented".

Both Paulden and New have assumed the prime measure of delivery performance as the proportion of orders delivered on or before time. Voss (1980) suggests a number of alternative methods for performance measurement in make to order plants and offers a full explanation on their derivation and applicability. Fogarty and Hoffman (1980) also list a range of performance measures, but include a number of instances relating to the deliver from stock plant. The need for customer service objectives consistent with the market need is emphasised, as is the choice of appropriate measurement techniques.

A quantitative analysis of customer service level is given by Buffa and Bryant (1980) for a deliver from stock plant. A model is described, which predicts the expected logistics costs associated with a given customer service level objective and offers management a tool to assist in the establishment of inventory policy.

2.3. SIMULATION

2.3.1. Perspective

As background to the survey on simulation theory, a perspective on the specific application was derived, addressing two main considerations:

- a) the nature of the project;
- b) the facilities available.

A number of guidelines were then established, aimed at controlling the scope of the project and achieving the stated project objectives.

The study is classified as an Industrial Project, therefore the emphasis is placed on the analysis of the business problem and the application of the simulation technique as an analytical tool, rather than a detailed study of simulation techniques.

A fundamental requirement was that the computer hardware and software facilities available at Loughborough University should be employed unless subsequently proven to be impractical. This requirement was based on the expected cost of external services and the relative convenience of local facilities and experience.

The decision to use local facilities, however, established clear boundaries within which the choice of simulation software could be made. Firstly, the ICL 1904S at Loughborough supports CSL as the only dedicated simulation language. Secondly the computer has limitations in terms of capacity and speed, thus favouring the more efficient languages. Finally, the computer utilises the George Operating System, which has proven high performance in the execution of Fortran programmes.

Recognising these factors, the literature survey relating to simulation techniques and languages was not intended to be exhaustive, but was supportive to the main area of application.

2.3.2. Techniques

The number of papers on specific aspects of computer simulation is vast, probably because certain aspects lend themselves to rigorous mathematical analysis and many of the earlier users of simulation were mathematicians or statisticians. The available literature which gives a complete overview is, however, relatively limited.

Among the first introductory books on simulation was Tocher (1963), who suggests that computer simulation techniques are derived from three sources:

- a) the theory of mathematical statistics;
- b) the demands of applied mathematicians for methods of solving problems involving partial differential equations;
- c) the "new science" of Operational Research.

The text starts with basic sampling theory and random number sources moving into some general simulation models, with particular emphasis on the queue problems. A brief overview on the design of experiments is given but the problems of variance reduction are not adequately covered at this summary level.

One of the most complete texts on simulation is Naylor et al (1966), who offer the following definition:

"Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behaviour of a business or economic system (or some component thereof) over extended periods of real time". Ironically, although the only example in the text on the subject of Inventory Systems is of re-order point, the above definition is as true for MRP as it is for simulation.

Although the book is a general text, a number of subjects are covered in some degree of detail, thus offering a good working knowledge of the technique. Subjects covered outside the scope of standard statistical theory include:

- pseudo-random number generation
- simulation languages
- model verification
- variance reduction
- analysis of results.

A further, in depth, treatise on the theory of random number generation and tests for randomness is given by Jansson (1966). Although some previous knowledge of number theory is implied, the text is invaluable for the designer of pseudo-random generations in particular from the more widely used statistical distributions.

Specific texts on the various simulation languages are too numerous to include in an overview analysis, however, the most popular languages are described by reference to Kiviat et al (1968), Gordon (1961), Buxton and Laski (1962) and Forrester (1961).

Mize and Cox (1968) emphasise the mathematical theory of simulation more than the previously mentioned general texts but also offer good advice on the construction of the simulation models, including the problems of starting conditions and equilibrium. The methodology for the design of simulation experiments is a useful framework, and checklist for the simulation practitioner.

2.3.3. Comparison of Simulation Languages

The choice of simulation language for a specific application is limited, as explained by Teichroew and Lubin (1966) - "Usually the user will be forced to use a simulation package made available by his computing facility... The computer centre management naturally tends to choose a package that is available for the installed computer and its operating system. If there is any choice, it will choose one that is consistent with its operating philosophy and for which the implementation is easy".

Krasnow and Merikallio (1964) describe the services provided by General Simulation Languages, discussing both the "discrete" examples and the "continuous" (DYNAMO) as described by Forrester (1961). Four discrete languages are described in detail;

SIMSCRIPT, Control and Simulation Language (CSL), General Purpose System Simulator (GPSS) and SIMPAC. The authors tend to favour SIMSCRIPT and CSL for flexibility and power for modifying system state, although they argue that, for certain applications, both GPSS and SIMPAC offer some advantage.

Tocher (1965) concentrates on the discrete languages and compares the structure and performance of nine packages, adding SIMULA, ESP, GSP, MONTECODE and SIMON to the languages described by Krasnow and Merikallio. Tocher observed that, with the exception of CSL, all other languages are available on one type of machine only. The analyses and comparisons included are comprehensive but assume a prior knowledge of simulation theory and some degree of practical experience. The choice of language is "most likely to be resolved by what machine is available to him (the experimenter)... For occasional use, a simple language, which is easy to understand and learn, may be more valuable than one of the sophisticated languages which have many facilities, but by the very nature of these extra facilities, becomes more complicated to use and understand".

Krasnow and Merikallio (1964) suggest that future developments will address this problem by the evolution of special General Languages which may be modified by a specialist to provide a unique user oriented simulation language for the specific application, thus maintaining the ease of use whilst dramatically broadening the scope of application.

2.4. CONCLUSIONS

The two prime areas of interest are the application of Manufacturing Resource Planning techniques and the use of simulation as an analytical tool for the evaluation of manufacturing system. The background information on delivery performance is to provide some perspective to the business problem and demonstrate the lack of fundamental research in the area.

The discussion on the Manufacturing Resource Planning technique leads to a number of associated conclusions.

- a) The amount of formal literature on MRP compared with Statistical Inventory Control is as yet limited, but is being added to at a significant rate, due largely to the impetus created by APICS.
- b) The literature tends to be qualitative rather than analytical, due to the rapidly increasing complexity of multi-echelon systems.
- c) Some comparisons of performance between MRP and SIC systems have been conducted, but the examples have, necessarily, been trival and therefore, inconclusive.
- d) The boundaries within which MRP may be appropriate cannot easily be defined, since the technique has been extended into Distribution Resource Planning at the supply interface and process control (computer aided manufacturing) at the production control interface.
- e) Simulation of the Production Plan as an important management tool is a reality, although few actual examples have yet been described.

The conclusions on the simulation techniques and choice of language are more succinct. A compromise should be sought, taking account of a number of factors, the significance of which will depend on the circumstances:

- the computer facilities available (size, speed)
- resident simulation software available
- prior knowledge or experience of the language both by the researcher and the computer support staff.
- applicability of the available languages to the business problem area.

The most significant factor arising from the literature is the link between MRP and simulation. New (1973) suggests that many business problems may be analysed by use of an "MRP-like" model, but "the existing simulation packages available do not allow

overall evaluation of systems where several levels are involved... the only answer to this problem lies in simulating a company's own requirements planning system step-by-step". To perform this task, there appear to be two choices:

- (i) use the same MRP programmes as the "live" system and provide some form of execution software to simulate the periodic activities.
- (ii) write some special programmes which are similar in logic to the "live" systems.

The former option has certain advantages in that the logic is, necessarily, identical, but has a number of disadvantages.

- it may be difficult to run the same programmes with more than one data base;
- the run cost is likely to be high;
- new programmes have to be written for the execution simulator and must be logically compatible;
- modifications to the existing programmes to test various hypotheses would be complex and risky;
- the programmes are probably more comprehensive than required.

The latter option resolves most of the above constraints but introduces some new considerations, including:

- compatibility in processing logic between the "live" system and the model;
- the time and expense involved in writing and validating an independent model;
- the final choice will, again, depend on the present system facilities and other special circumstances relevant to the researcher.

Orlicky (1975) provides a checklist of further research into MRP related topics based on his own experience.

1) Theory

- Manufacturing lead time
- Safety stock for independent demand items
- Links between the MRP system and execution subsystems

- 2) Justification
 - Applicability of material requirements planning
 - Costs of an informal system
- 3) System Design
 - Design criteria for different business environments
 - Bill of Material modularisation
 - Alternatives in the treatment of optional product-feature data
- 4) System Implementation and Use
 - Analysis of implementation problems
 - Master Production Schedule development and management
 - Operational aspects of MRP system use
- 5) Education
 - Curricula design and teaching tools.

It is apparent from a review of the points raised, that many topics could be analysed with the help of a simulation model. A specific company model would, as a minimum, permit conclusions to be drawn relating to the local application; a more general model would provide valuable guidelines to the designers, implementers and users of future MRP based business systems.

The survey relating to delivery performance was included specifically to review measurement techniques. It can be concluded, from the references given, that the most widely used measure, and the one most easily understood, is the proportion of orders delivered on or before time. This should, therefore, be included as a prime method of measurement. However, since the literature is critical of its ability to portray the profile of achieved deliveries, a secondary measure such as average lateness should also be considered.

3. RESEARCH METHODOLOGY

3.1. PROBLEM APPROACH

The Problem Definition states that the production system will be analysed by means of computer simulation techniques to provide information which will assist in arriving at a stock distribution decision.

The research phases were derived directly from this definition according to the following logic:

- Phase 1 Further definition of the Production System to provide a framework for the development of the model.
- Phase 2 Acquisition of data defining the system variables.
- Phase 3 Detailed design of the simulation model, including the choice of simulation language and model validation.
- Phase 4 Design of the simulation experiments and the subsequent execution of each experiment.
- Phase 5 Analysis of experimental results.

Each phase was conducted substantially in the sequence described, except for the data acquisition task which, due to the extended timescales involved, was undertaken in parallel with the model design activity.

3.2. THE PRODUCTION SYSTEM

The Production System is defined here as the integrated planning and execution activities. The planning activities have been described in the development of production control systems (Sect. 1.2.5.), which embrace also some of the execution activities associated with the physical goods flow. A more detailed explanation of the goods flow is described within the problem definition (Sect. 1.3.) indicating both the flow of material between formal stocking points and the strategic role of each stock point.

The two concepts can be combined in a single representative model, which links the planning (information activities) with the execution (goods movement) activities. This general model is shown below in Fig. 3.1.

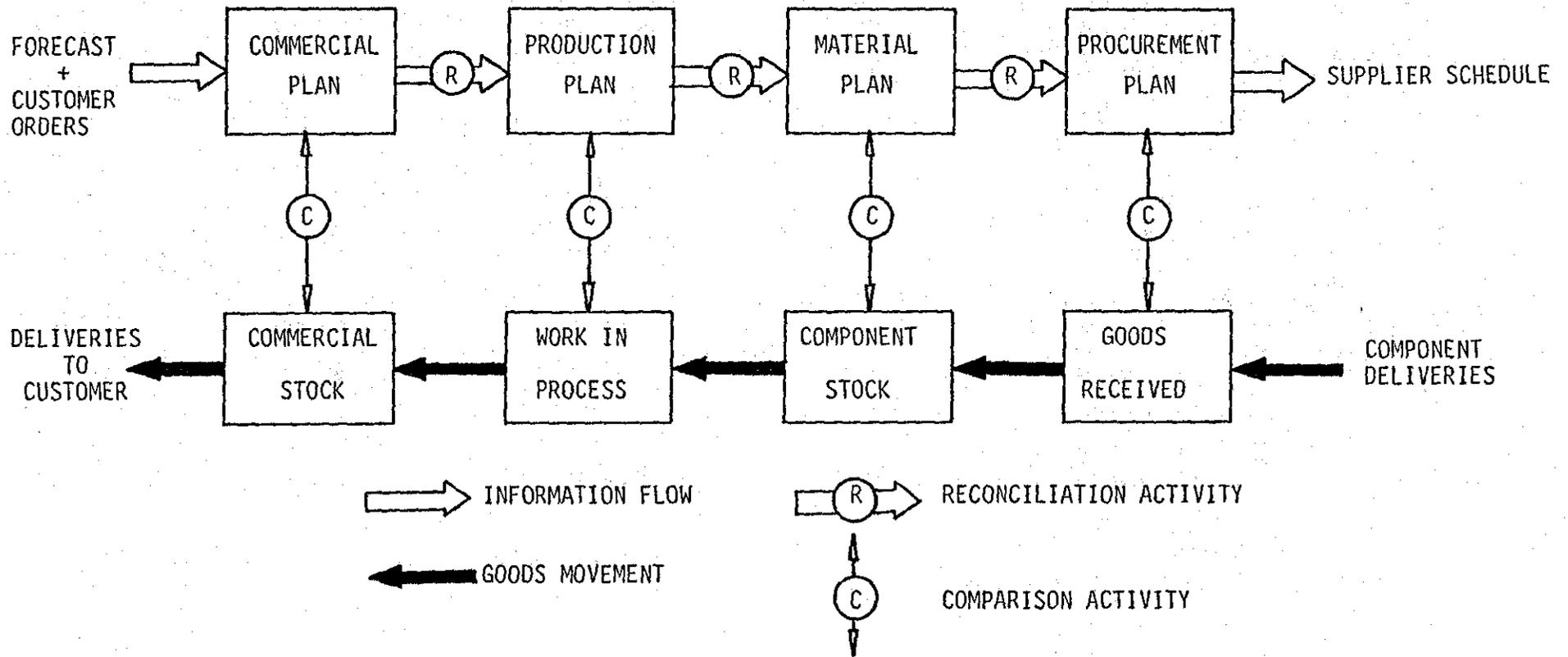


Fig. 3.1. - General Goods Flow Model

The model has been simplified by treating the production process as one level only, thus ignoring at this stage the intermediate work in progress and stock points between the component and commercial stock points. Excluding the intermediate levels does not detract from the logic whilst enhancing the clarity of the model.

The planning activities start with the preparation of the Commercial Plan, which describes the expected deliveries to customers from commercial stock and the resultant stock replenishment plan. The Production Plan describes the planned production rate through work in progress which will service the Commercial Plan and maintain the desired level of commercial stock. The interface between the Commercial and Production Plans is the point of reconciliation between the requirements of the commercial activity and the capability of the production activity. The term reconciliation implies the matching of the two sets of information and any consequential feedback and adjustment of either plan.

The Production Plan defines the resources required to service the required activity level including labour, machines and material. The Material Plan is derived from the Production Plan but requires reconciliation with any expected supply constraints and compensates for any differences between the actual and required levels of component stock. The Procurement Plan is the mechanism for creating the schedules which request material deliveries from the supplier, taking account of items in the receiving department prior to registration into stock.

The supplier schedule is the prime link between the planning and execution activities, since it controls the subsequent delivery of material to the receiving department.

The execution activities which define the goods flow operate in the reverse sequence to the planning activities. Material received from suppliers is registered into the receiving department prior to verification and movement into component stock. Components are subsequently moved into work in progress according to the Production Plan and completed products are registered into commercial stock for sale and despatch to the customer.

The Production System cannot be fully described without defining the timing of activities. The timing applicable to the process described in the present system (Sect. 1.2.5.) is as follows:

Quarterly

- Prepare new Orders Received Forecast
- Prepare Commercial Plan
- Prepare Production Plan
- Generate Material and Procurement Plan

Monthly

- Monitor actual activity against plans
- Monitor stock levels against targets
- Adjust plans as necessary.

Weekly

- Determine customer order requirements
- Determine stock replenishment requirements
- Establish manufacturing orders

Continuous

- Receive customer orders
- Receive material from suppliers
- Release manufacturing orders
- Register goods movements
 - deliveries of products to customers
 - receipts of goods from manufacturing
 - issue of material to manufacturing
 - transfer of material from receiving to stock
 - receipt of material to receiving.

Timing in the context of both the model and the actual production system has two meanings; it determines the frequency with which each activity is executed and it defines the absolute time that information is derived for the purpose of comparison or reconciliation (also known as "cut-off" times at the end of each discrete period).

The core of the planning activity is the "Equipment Quarterly Plan". This process logically embraces both the Commercial and Production Plans, thus ensuring a total reconciliation. The Equipment Quarterly Plan includes four separate time phased plans, each of which is linked through a series of relationships. The plans comprise:

- the orders received forecasts
- the delivery plan (or "production to the allocated" from stock or work in progress)
- the manufacturing plan (or "off-line plan")
- the material plan (or "on-line plan").

The orders received forecast is prepared in quarterly increments by projecting the previous twelve months of actual orders received information. The trend forecast so derived may be modified to reflect changes in market conditions or specific large order opportunities.

Each product plan is manually derived according to the format shown in Fig. 3.2. Plan quantities are aggregated and calculated in quarterly (13 week) values.

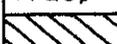
	B/F	Q1	Q2	Q6
Orders carried forward	OCF \emptyset	OCF1	OCF2	OCF6
Current order load	COL \emptyset	COL1	COL2	COL6
Orders received forecast		ORF1	ORF2	ORF6
Production to be allocated		PA1	PA2	PA6
Finished equipment stock	FES \emptyset	FES1	FES2	FES6
Off-line plan		OFF1	OFF2	OFF6
Work in progress	WIP \emptyset	WIP1	WIP2	WIP6
On-line plan		ONP1	ONP2	ONP6

Fig. 3.2. - Equipment Quarterly Plan

The values carried forward are the quantities valid at the time of reconciliation (i.e. the end of the prior quarterly period). The orders carried forward at the cut-off time is the sum of the current order load for all future periods including any outstanding customer orders from the previous period (overdue orders).

The relationships which link each plan, where "q" is the quarter number, are:

- a) $OCF(q) = OCF(q-1) + ORF(q) - PA(q)$
- b) $FES(q) = FES(q-1) + OFP(q) - PA(q)$
- c) $WIP(q) = WIP(q-1) + ONP(q) - OFP(q)$

The final definition of the plan is achieved by the application of rules, which describe constraints within which the plan must be prepared.

- (i) The stock is planned to be at a level of one half of the maximum authorised.
- (ii) The work in progress is planned to be equivalent to two weeks worth of production output.
- (iii) The delivery plan, or production to be allocated, cannot be less than the current order load for the period.
- (iv) The current order load for the opening period cannot fall below six weeks worth of delivery plan.
- (v) Changes to the previous material plan must conform to pre-defined rules.

For example:

If $ONP(3) < 50$ then $ONP(4) \leq ONP(3) \times 5$

If $50 \leq ONP(3) \leq 250$ then $ONP(4) \leq ONP(3) \times 2$

If $ONP(3) > 250$ then $ONP(4) \leq ONP(3) \times 1.5$

- (vi) Changes in the manufacturing plan must comply with the rules governing the ability to increase or decrease the direct labour requirement.

When the Equipment Quarterly Plan is finalised it becomes the basis for two dependent plans; the weekly delivery plan and the weekly off-line plan. Both are extensions of the quarterly values, using simple rules to determine whether the rate is continuous or in discrete multiple batches each period. The weekly delivery plan is subsequently used as the base for order loading, and the weekly off-line plan provides the master plan for the material planning calculation in addition to controlling the release of manufacturing orders.

The requirements calculation follows Material Requirements Planning logic as described in the standard texts, with the exception that the open manufacturing orders are not time phased. Thus, the existing system may only be regarded as a tool for material planning and does not offer any assistance to manufacturing in the task of priority maintenance through the re-scheduling of manufacturing orders.

The plan for sub-assembly manufacture is relatively decoupled from the main requirements planning logic. Nett requirements are derived from the requirements calculation, these subsequently being extended by applying economic batching criteria to arrive at a sub-assembly weekly programme.

The nett requirements at component level are passed to the Purchasing and Scheduling sub-systems, where two activities are undertaken. Proposals are prepared for the placement of purchase orders, by aggregating the gross requirement over the purchase lead time nett of the outstanding order balance. The buyer is then able to review the recommendations and select the appropriate supplier before confirming the purchase order. Supplier schedules, which identify the discrete material call-off within the open purchase order, are prepared from the nett component requirements within the constraints imposed by the schedule response time (i.e. the time required by the supplier to respond to a requested change in schedule).

The activities undertaken each month are limited to monitoring and review of the two prime plans; delivery and off-line. The delivery plan may be modified to accommodate variances of order intake to the original forecast, the result of which is either a change in delivery period or finished equipment stock. Changes in off-line plan may be required to recover a failure to achieve planned output

in a prior period or to limit the investment in assembled inventory.

In addition to the equipment plans, each sub-assembly programme is reviewed each month to correct any unplanned change in sub-assembly stock level.

The only weekly scheduled activity is the preparation of manufacturing orders according to the weekly plans. Sub-assembly orders are prepared and released strictly as defined by the sub-assembly programme.

Equipment orders are prepared according to the weekly equipment programme, however, the detailed content of each order must include a definition of each customer and stock replenishment requirement. The inclusion of customer or stock orders depends upon the mode of manufacture, which may be make to order only, make to stock only, or mixed production. The inclusion of customer orders in mixed production mode is within a pre-defined forward horizon, since customer orders may not be delivered substantially before the promised due date. Under-utilisation of the manufacturing order is made up with a stock order of the most suitable variety.

All other activities may be considered continuous, since they do not conform to any pre-defined timing. Such activities are normally termed transactions, and include:

- a) the receipt of customer orders;
- b) the loading of customer orders against the delivery plan;
- c) the receipt of material into receiving;
- d) transfer of material from receiving to stock;
- e) issue of material to manufacturing;
- f) receipt of sub-assemblies and products to stock;
- g) transfer of products from stock or assembly to test;
- h) transfer of products to despatch function;
- i) despatch of customer orders;

Customers typically order a mix of products for simultaneous delivery as part of a communication "scheme". The orders are received into a processing pipeline where technical and commercial audits are performed prior to assigning the delivery date. In describing the production system, the customer order profile is an essential factor influencing the total system performance. The relationship between the production view of the customer and the customer order may be described as shown in Fig. 3.3.

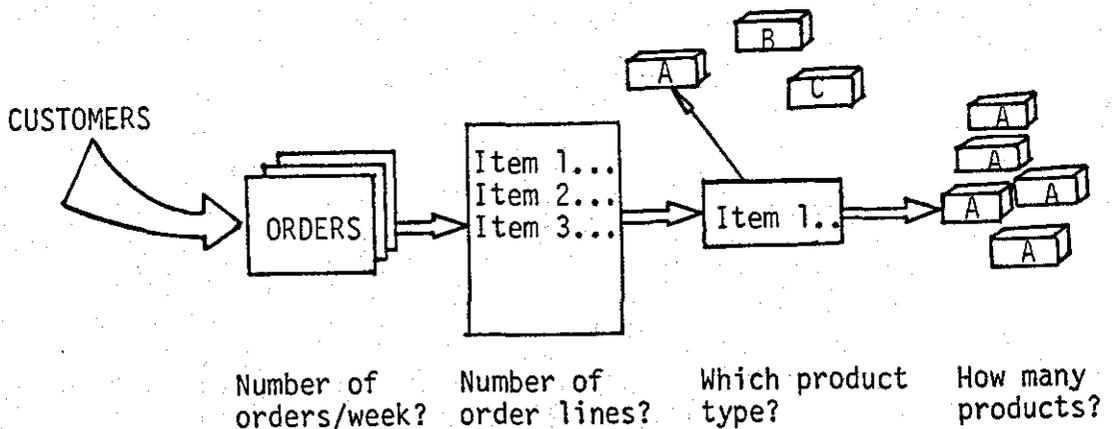


Fig. 3.3. - Customer Order Definition

The establishment of a delivery date, also termed order loading, is performed by matching the product requirement with the capacity available for sale derived from the delivery plan. The order may be classified as a "part shipment permissible" order, or a "no part shipment" order. For the "no part shipment" case, all items have to be delivered together and will thus be assembled in the despatch warehouse prior to delivery. To minimise the investment in inventory, each comprising product should have the same factory due date. Part shipment orders may be delivered in batches, although in many instances certain groupings of products or delivery priorities are requested by the customer to facilitate his installation programme.

Material received from suppliers is controlled primarily by the delivery schedule, which establishes the requested (and usually acknowledged) delivery date. Variations from the schedule date, which is a fixed calendar date in each month, will occur due to:

- the normal time spread considered by the supplier to be acceptable.
- the degree of expediting performed on the component
- the stability of the released schedules
- the internal control procedures exercised by the supplier
- variability in shipping times, especially on imported goods
- other random elements associated with the supplier (e.g. total arrears, strikes)

This process may be demonstrated by reference to Fig. 3.4.

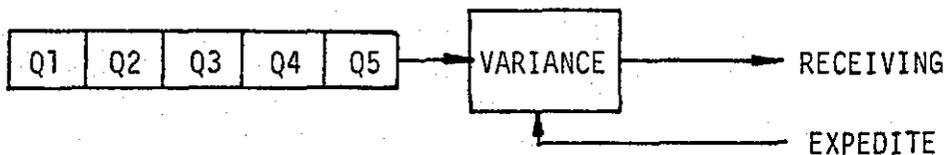


Fig. 3.4. - Receiving Process

Two delivery profiles are apparent; the first representing the unexpedited mode and the second in an expedite mode.

The profile will have the form as shown in Fig. 3.5. where the probability density function is influenced by each of the above mentioned factors.

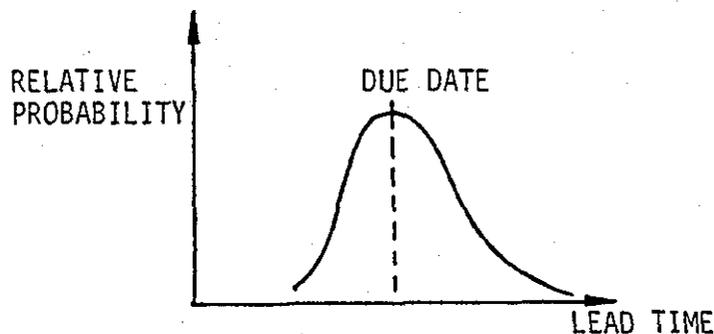


Fig. 3.5. - Representative Receipt Profile

The effect of expediting may change both the mode and the shape of the profile, the probability density function being influenced by factors describing the "success of expedition" in addition to the previously described factors.

Items registered into receiving are checked to ensure that the correct parts have been received, that the receipt conforms to the delivery schedule, the quantity advised is correct and that the quality is acceptable. Quality checks are to pre-defined Acceptable Quality Levels (AQL) using sampling techniques. Normally, unless there is a critical production hold, a reject sample will cause the rejection of the complete batch. Items in receiving are shown in the computer files as "pending inspection".

The probability that an item will pass inspection is dependent upon two factors: the probability that a reject exists, and the proportion found faulty given that a reject has been detected.

Material accepted into stock is located and registered into a pre-assigned stock location, with bulk items being randomly located. The stock receipt updates the physical stock balance on the customer files.

Preparation of a manufacturing order, also called a material issue, will cause the component parts to be allocated in the computer stock files. If the required service level can be achieved, a picking list is prepared identifying the comprising components. When all items have been picked and assembled for production, the picking list is returned to the computer to cancel the allocation and downdate the physical stock balance.

Completed sub-assemblies are returned to stock and the stock files are updated. These items are then available for re-issue.

Products made for stock are only partially completed and tested, to avoid an excess of duplicated tasks. Stock products are subsequently allocated to customer orders and passed to the test department for completion. Products assembled to customer order pass directly from the assembly to the test department.

Each work in progress department may be described as shown in Fig. 3.6.

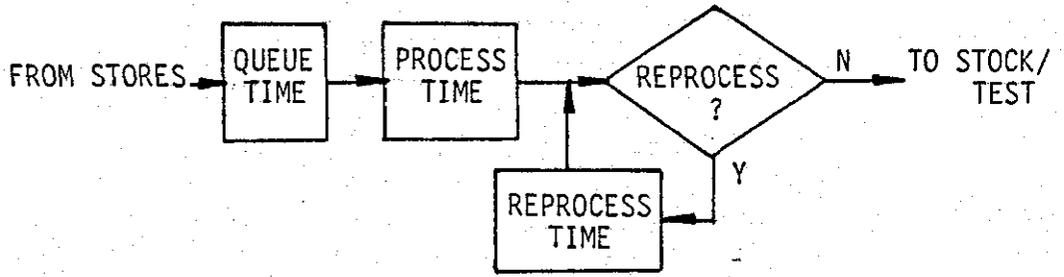


Fig. 3.6. - Manufacturing Process

X

The queue represents the independent manufacturing facility; for sub-assemblies all types may be considered to share the same facilities, but different products do not share common facilities. Sub-assemblies are produced for stock only, whilst products are manufactured either to customer order or stock. The queues will therefore be described differently as shown in Fig. 3.7.

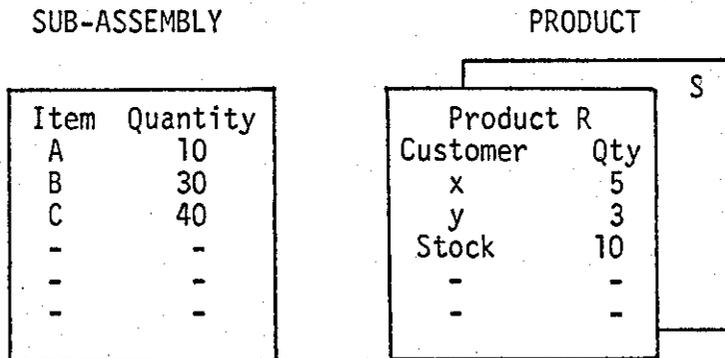


Fig. 3.7. - Manufacturing Queues

The process time is a fixed minimum time required to manufacture each product, including preparation and move times. The reprocess activity represents the quality audit which may result in further time required to correct a detected fault.

The process described is applicable to both assembly and test operations.

Tested products are moved to the despatch department on completion where they are marshalled pending a despatch decision. If the customer order has achieved the part delivery criteria, the order (or part order) is despatched.

3.3. DATA ACQUISITION

3.3.1. Introduction

The model is required to simulate as faithfully as possible the real world, and yet be simple enough to draw both quantitative and qualitative conclusions about the behaviour of the business system. This implies that the data, in particular the characteristics of the probability density functions resident in the model, must be representative of the real world in profile, although not necessary in scale.

The data may be classified as describing the product, the customer (or orders), the supplier or the manufacturing process.

3.3.2. Product Definition

The requirement in terms of product definition is to represent the essential characteristics and yet retain a high degree of control over the operation of the model. Background to the development of the product definition profile was provided by an analysis conducted by the author and the Information Systems Manager in preparation for a survey of Manufacturing Systems in the U.S.A. (Crowcroft and Laurence, 1978).

The results were subsequently published in the Manufacturing Control System Feasibility Study (Crowcroft and Laurence, 1979), the relevant statistics as at September 1979 being as follows:

3.3.2.1. Number of End Products

The company define their products by divisions as follows:

Fixed Equipment (73), High Frequency Equipment (74), Kits (75), Link Equipments (76), Mobiles (78), Pagers (79), Portables (80), Sundries (83).

A large number of variants are possible within each product type, for example: channel spacing, frequency, channel capacity, microphone, handset, front mounting, boot mounting, hand held, body worn, etc. A seventeen digit code defines the specific combination of options for each equipment.

A total of 354 products is available for sale, of which 160 are variant conscious. The remainder are ancillaries (e.g. battery chargers) or standard merchandise.

3.3.2.2. Item Master File Records

The Item Master File contains 35,236 records, classified as follows:

Purchased items	21,341
Purchased items with free issue	1,298
Made-in items	<u>12,597</u>
	<u>35,236</u>

3.3.2.3. Bills of Material

The Product Structure File comprises 175,800 structure records. The structures are essentially engineering bills of material with facilities to determine stores issuing characteristics, examples being: do not allocate, breakdown further, bulk items, advance issue.

The average structure depth is 7, with a maximum capacity in the system of 14.

3.3.2.4. Items per end Product

The number of items in a typical product (M201) is 1846. This number comprises 544 different part numbers, of which 91 are made-in assemblies, 4 are free issue assemblies and 449 are purchased parts.

3.3.2.5. Discussion

The volume of data present in the real world is far too complex for meaningful analyses to be made. The data base used by the model has to be sufficiently manageable to demonstrate control over each item and must be representative of the various conditions encountered. This will include multiple structure levels, a mix of common and unique parts, transient (or non-stocked) assemblies and a range of unit values. The final structure of the model data base, as described in Section 3.4.5.2., was therefore to include four final products, three of which contain a high degree of commonality. Each product or assembly may comprise up to five components. Six sub-assemblies are used, one of which is a transient item. A total of thirteen purchased parts are incorporated into the structure. The format of the data base and the structures selected offer a wide variety of combinations of unique and common items to enable in depth analyses to be conducted. Duplication of item types has been kept to a minimum to avoid redundancy and over-complication.

3.3.3. Customer Data

Information describing the ordering pattern and the structure of the customer order has been drawn from a number of independent sources. Each source is described further with a summary of conclusions.

3.3.3.1. Commercial Order Servicing (COS) System

The company has been active for a number of years in the definition and development of an order processing system. Part of the process of developing a Technical Specification was the establishment of business volumes as a means of defining file sizes and operating costs.

The study, which was conducted over a period of time between late 1979 and early 1980, was in three phases. The first phase comprised the detailed analysis of a full week's worth of customer orders in the Order Processing Department for a number of independent weeks, selected to represent a variety of business activity levels. The results of each survey were then consolidated and further verified in the second phase by the systems analysts by means of random samples.

The final phase was to verify the results and add new parameters, again from observation of representative periods of activity. The final results are published in the Customer Order Servicing System Technical Specification, dated November 1980, the relevant extracts being:

- Total number of orders per annum	7500 - 8500
- Average lines per order	3.75
- Total orders on file at any time	5000 - 8000

3.3.3.2. Manufacturing Control System (MCS)

The Feasibility Study for the Manufacturing Control System contains a Company Profile, based on observations taken by systems development staff over the period August/September 1979. Statistics relating to customer order profiles have been extracted as follows:

- Total number of orders per annum	7200
- Ratio of home/export orders	4 : 1
- Number of item lines per order	
1 item	50%
1 - 3 items	80%
1 - 6 items	92%
- Proportion of part-shipment orders	25%
- Number of Radio Systems orders (in addition to Standard Products above)	590
- Order amendments	
- total (of standard products orders)	41%
- affecting manufacturing	28%
- affecting delivery (total)	4%
- affecting delivery (in manufacturing)	2%
- radio systems	88%

3.3.3.3. Research Results

A research project was conducted by Skelton (1977) with the objectives:

- a) To record and analyse the orders received by the Company, as far as sales history allows.

- b) To identify the salient features of orders received with a view to creating a general image of the customer.
- c) To identify patterns and distributions of demand for the Company's products, which may be used to model demand in a digital computer simulation.

The results of the investigation are the most comprehensive statistics available and are sufficiently rigorous in their analysis to provide a suitable base for quantified Customer Data. The relevant factors have been extracted for further comment.

3.3.3.3.1. Weekly Order Intake

The weekly order intake rate for the years 1973 to 1977 is shown in Table 3.1., with an extrapolation of the annual rate.

<u>YEAR</u>	<u>WEEKLY MEAN INPUT RATE</u>	<u>ANNUALISED RATE</u>
1973	181	9412
1974	124	6448
1975	126	6552
1976	192	9984
1977	209	<u>10868</u>
		<u>43264</u>

Table 3.1. - Weekly Order Input Rate

The mean annualised rate over five years is 8652 orders per annum.

3.3.3.3.2. Number of Amendments

The ratio of amendments to orders was observed for the period January 1976 to May 1977, indicating that 34% of orders are subject to amendment.

3.3.3.3.3. Order Intake Distribution

The distribution of orders per week was recorded as shown in Table 3.2.

YEAR	QUANTITY OF ORDERS	INTERVAL VALUE (y)	FREQUENCY OF OCCURANCE (f)	f.y	(y-y)	f(y-y) ²
1973	70 - 89	80	1	80	-100.4	10080.2
	90 - 109	100	1	100	- 80.4	6464.2
	110 - 129	120	3	360	- 60.4	10944.5
	130 - 149	140	5	700	- 40.4	8160.8
	150 - 169	160	8	1280	- 20.4	3329.3
	170 - 189	180	9	1620	- 0.4	1.4
	190 - 209	200	15	3000	19.6	5762.4
	210 - 229	220	6	1320	39.6	9409.0
	230 - 249	240	2	480	59.6	7104.3
	250 - 269	260	1	260	79.6	6336.2
				<u>9200</u>		<u>67592.3</u>
Summary for year:		$\mu = 180.4$	$\sigma = 36.4$	$\frac{\sigma}{\mu} = 0.20$		
1974*	70 - 89	80	1	80	- 46.4	2153.0
	90 - 109	100	3	300	- 26.4	2090.9
	110 - 129	120	11	1320	- 6.4	450.6
	130 - 149	140	7	980	13.6	1294.7
	150 - 169	160	3	480	33.6	3386.9
				<u>3160</u>		<u>9376.1</u>
Summary for year:		$\mu = 126.4$	$\sigma = 19.4$	$\frac{\sigma}{\mu} = 0.15$		
1975	70 - 89	80	2	160	- 48.4	4685.1
	90 - 109	100	9	900	- 28.4	7259.0
	110 - 129	120	17	2040	- 8.4	1199.5
	130 - 149	140	13	1820	11.6	1749.3
	150 - 169	160	7	1120	31.6	6989.9
	170 - 189	180	1	180	51.6	2662.6
	190 - 209	200	1	200	71.6	5126.6
				<u>6420</u>		<u>29672.0</u>
Summary for year:		$\mu = 128.4$	$\sigma = 24.4$	$\frac{\sigma}{\mu} = 0.19$		
1976	70 - 89	80	1	80	-104.6	10941.2
	90 - 109	100	0	0	- 84.6	0.0
	110 - 129	120	1	120	- 64.6	4173.2
	130 - 149	140	4	560	- 44.6	7956.6
	150 - 169	160	6	960	- 24.6	3631.0
	170 - 189	180	19	3420	- 4.6	402.0
	190 - 209	200	10	2000	15.4	2371.6
	210 - 229	220	9	1980	35.4	11278.4
	230 - 249	240	2	480	55.4	6138.3
				<u>9600</u>		<u>46892.3</u>
Summary for year:		$\mu = 184.6$	$\sigma = 30.0$	$\frac{\sigma}{\mu} = 0.16$		

*Only 6 months data available for 1974

Table 3.2. - Distribution of Number of Orders Received/Week

3.3.3.3.4. Items per Order

The number of item lines per order was recorded by month for the period September 1973 to March 1977. This was summarised in the frequency histogram shown in Fig. 3.8.

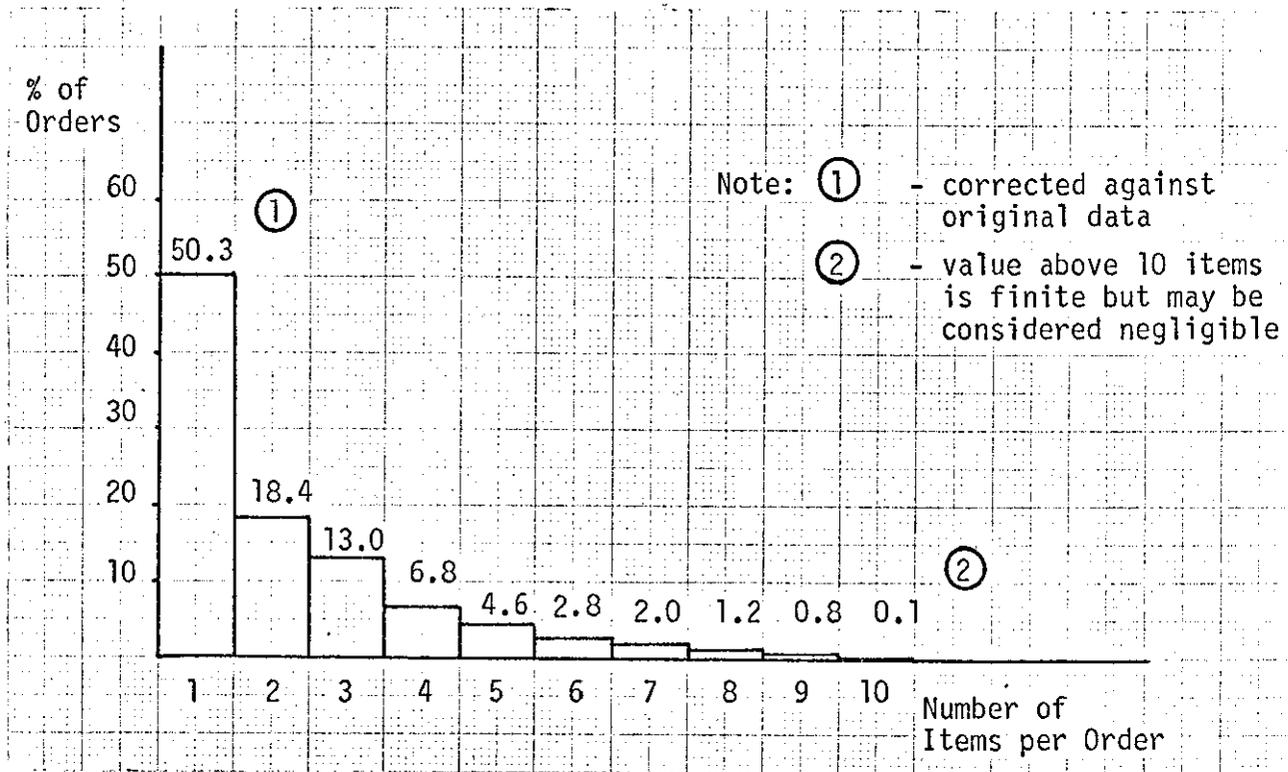


Fig. 3.8. - Number of Items per Order

3.3.3.3.5. Order Quantity Distribution

Distributions of item order quantities were recorded for a variety of product types. Six products have been selected, based on a mix of home market (MF6AM, M201, W15AMDS) and export based (MF25FM, MF5FMDS, W15FMDS) products. These are shown in Table 3.3. which also indicates the total number of occurrences of each item quantity for the six products and the relative frequency of each quantity.

The profile has been simplified for subsequent analysis by the selection of nominal values to represent a range of order quantities. For example the order quantity range 4 to 7 has a weighted value of $(4 \times 6.57 + 5 \times 4.77 + 6 \times 5.30 + 7 \times 1.97) / 18.61$ or 5.1. The nominal value has thus been selected as 5.

A histogram based on the nominal values is shown in Fig. 3.9.

ORDER QTY.	PRODUCT/FREQUENCY						TOTAL	RELATIVE FREQ. %	NOM. VALUE	PROP ^N . %
	MF25FM	MF5FMDS	MF6AM	M201	W15FMDS	W15AMDS				
1	117	175	303	268	260	1161	2284	31.92	1	31.92
2	86	51	167	141	118	530	1093	15.27	2	23.58
3	33	66	112	62	42	280	595	8.31	↓	
4	31	34	74	57	45	229	470	6.57	↑	
5	27	37	49	52	29	147	341	4.77	5	18.61
6	32	29	67	60	36	155	379	5.30	↓	
7	8	16	27	18	17	55	141	1.97	↓	
8	13	15	21	17	19	50	135	1.89	↑	
9	5	7	12	11	11	31	77	1.08	↓	
10	35	24	34	31	57	103	284	3.97	10	12.59
11- 15	35	35	63	46	63	152	404	5.65	↓	
16- 20	29	20	26	40	40	57	252	3.52	↑	
21- 25	24	22	19	24	16	48	153	2.14	↑	
26- 30	16	14	9	13	15	28	95	1.33	25	8.61
31- 35	7	10	9	10	3	9	48	0.67	↓	
36- 40	7	19	3	10	6	23	68	0.95	↓	
41- 45	4	10	2	8	3	8	35	0.49	↑	
46- 50	28	13	6	10	14	16	87	1.22	↓	
51- 60	7	3	2	9	2	14	37	0.52	50	2.86
61- 70	4	2	0	4	0	6	16	0.22	↓	
71- 80	5	5	2	6	5	6	29	0.41	↓	
81- 90	1	1	0	12	2	0	16	0.22	↑	
91- 100	14	14	0	17	8	3	56	0.78	100	1.85
101- 200	4	8	3	11	9	4	39	0.54	↓	
201- 300	2	4	0	1	1	1	9	0.13	↓	
301- 400	2	1	0	0	0	1	4	0.06	↓	
401- 500	0	0	0	0	0	0	0	-	↓	
501- 600	2	1	0	0	1	0	4	0.06	↓	
601- 700	0	0	0	1	1	0	2	0.03	↓	
701- 800	1	0	0	0	0	0	1	0.01	↓	
801- 900	0	0	0	0	0	0	0	-	↓	
901-1000	1	0	0	0	0	0	1	0.01	↓	
1001 +	0	1	0	0	0	0	1	0.01	↓	

Σ=7156

Weighted Quantity = 8.418

=====

Table 3.3. - Order Quantity Distribution

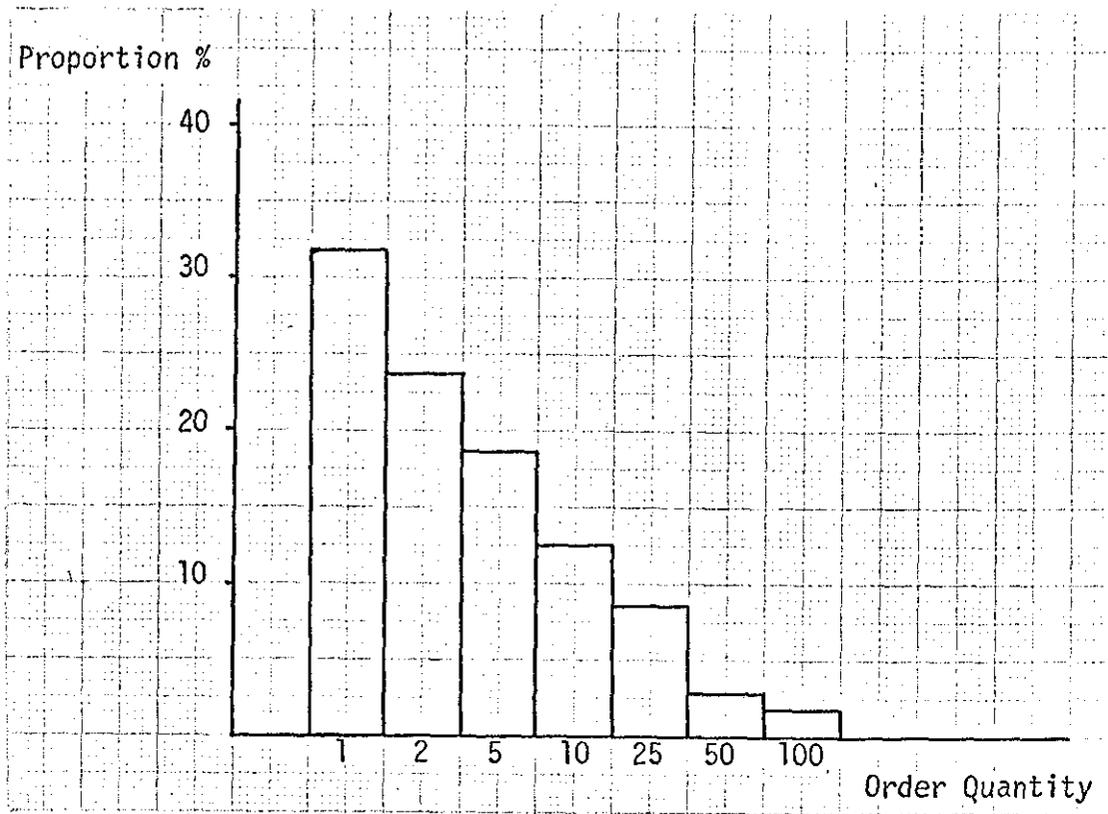


Fig. 3.9. - Order Quantity Distribution

3.3.3.4. Other Sources

3.3.3.4.1. Product Popularity

The relative volume of orders received for each product is published internally by the Marketing Services Department in the form of a "Top 30" profile. The statistics relating to the years 1973, 1974 and 1978 have been reproduced in Table 3.4. for comparison.

Statistics are also maintained for the volume of main unit sales, the appropriate values being:

1973	66264
1974	62967
1978	53688

It should be noted that the "Top 30" products include certain items that would not be classified as "main units".

RANK	1973			1974			1978			TOTAL		
	PRODUCT	QTY	% OF EST.TOT.	PRODUCT	QTY	% OF EST.TOT.	PRODUCT	QTY	% OF EST.TOT.	QTY	% OF EST.TOT.	% CUM
1	W15AMDS	9753	11.5	W15AMDS	8131	10.8	MF6AM	10106	15.5	27990	12.4	12.4
2	MFSFMD	8117	9.5	MF5FM	5228	7.0	M201	5738	8.8	19083	8.5	20.9
3	MF25FM	7940	9.3	W15FMD	4840	6.5	MF25FM	4528	7.0	17308	7.7	28.6
4	W15FMD	5359	6.3	MF25FM	3176	4.2	MF5FM	3273	5.0	11808	5.2	33.8
5	W30AM	3277	3.8	M201	2738	3.7	A200	2017	3.1	8032	3.6	37.4
6	PG1AM	3002	3.5	PF2UB	2673	3.6	VR200	1632	2.5	7307	3.2	40.6
7	PF2AMB	2663	3.1	PG1AM	2581	3.4	MH1	1533	2.4	6777	3.0	43.6
8	MF5AM	2359	2.8	W30AM	2367	3.2	M202	1332	2.0	6058	2.7	46.3
9	MF5U	2107	2.5	MF5U	2347	3.1	M206	1283	2.0	5737	2.5	48.8
10	PF2/3FMB	2012	2.4	PC1	2081	2.8	PF2AMB	1265	1.9	5358	2.4	51.2
11	PF5UH	1966	2.3	MF5AM	2077	2.8	PC1	1251	1.9	5294	2.4	53.6
12	W15AMB	1922	2.3	PF2AMB	1702	2.3	PF2UB	1226	1.9	4850	2.2	55.8
13	PF2UB	1626	1.9	PF2FMB	1681	2.2	PG1AM	1043	1.6	4350	1.9	57.7
14	PF2/3FMH	1406	1.7	M201	1554	2.1	BC10A	1024	1.6	3984	1.8	59.5
15	T30AM	1375	1.6	PG1FM	1480	2.0	P5002	1009	1.6	3864	1.7	61.2
16	R17AM	1331	1.6	PF5UH	1420	1.9	PF9T	972	1.5	3723	1.7	62.9
17	SSB130M	1101	1.3	W15AMB	1409	1.9	FSC5	946	1.5	3456	1.5	64.4
18	PF2UB2e	1086	1.3	SSB130M	1348	1.8	PF9R	943	1.4	3377	1.5	65.9
19	PF1R	1021	1.2	T30AM	1265	1.7	SSB130M	931	1.4	3217	1.4	67.3
20	PF1T	1004	1.2	W25FM	1001	1.3	AT00457	900	1.4	2905	1.3	68.6
21	T30FM	973	1.1	PF1R	997	1.3	W1SUBL	899	1.4	2869	1.3	69.9
22	W15FMB	937	1.1	PF1T	976	1.3	MF5U	892	1.4	2805	1.2	71.1
23	W25FMB	934	1.1	PF2UB2e	968	1.3	PF8	885	1.4	2785	1.2	72.3
24	PF5UH2e	784	0.9	R17FM	960	1.3	AT00245	860	1.3	2604	1.2	73.5
25	R7AM	771	0.9	T30FM	922	1.2	AT00249	860	1.3	2553	1.1	74.6
26	R18FM	744	0.9	PF2FMH	881	1.2						
27	W15/20U	711	0.8	R18FM	834	1.1						
28	PF2UH	631	0.7	R412	831	1.1						
29	R6AM	625	0.7	T412	821	1.1						
30	PF6UH	610	0.7	PF2FMBAA	800	1.1						
	Sub-total	68147	80.0		60089	80.3		47348	72.9	168094	74.6	74.6
	Assumed Proportion	80%			80%			75%				
	Approx. Total	85000			75000			65000				

Table 3.4. - Product Popularity

3.3.3.5. Discussion

The various surveys conducted have taken place at different points of time and with significantly different depths of analysis. The research conducted by Skelton is the most formal and detailed, and has therefore been taken as a prime source. The remaining studies have been used to corroborate findings rather than establish the base statistics.

3.3.3.5.1. Number of Orders

The total order input rate is shown by Skelton to vary from 6448 per annum to 10868 per annum over the period 1973 - 1977, with a mean of 8650 orders per annum. This compares with the Commercial Order Servicing survey in 1979 of 7500 - 8500 per annum, and the Manufacturing Control System Survey, also in 1979, of 7790 (including Radio Systems). The latter two results are compatible and compare favourably with the research results, taking consideration of the different points in time and the observed business cycles. The value is well within the limits observed over the period 1973-1977. It seems reasonable to assume that, with a constant business volume and no change in the customer buying habit, a rate of around 8500 orders per annum is typical.

3.3.3.5.2. Order Intake Distribution

The profile of order intake per week is shown in Table 3.2. This has been further analysed to derive the variability of the number of orders around the expected value.

For the four years shown, the following parameters have been derived.

<u>YEAR</u>	<u>MEAN RATE/ WEEK (μ_i)</u>	<u>STANDARD DEVIATION (σ_i)</u>	<u>VARIANCE (σ_i^2)</u>	<u>CO-EFFICIENT OF VARIATION(σ)</u>
1973	180.4	36.4	1325.3	0.20
1974	126.4	19.4	375.0	0.15
1975	128.4	24.4	593.4	0.19
1976	<u>184.6</u>	<u>30.0</u>	<u>901.8</u>	<u>0.16</u>
Total Period	155.0	28.3	3195.5	0.18

Thus, the co-efficient of variation of the order input rate approximates to 0.18 for the total period observed.

3.3.3.5.3. Number of Item Lines per Order

The number of item lines per order shows some inconsistency between surveys. The average number of lines suggested by the Commercial Order Servicing Survey is 3.75. The Manufacturing Control System Survey does not quote an average, but this may be derived approximately from the statistics quoted. Extending the given data:

Proportion of orders with	
1 item	50%
2 - 3 items	30%
4 - 6 items	12%
> 6 items	8%

Taking the minimum point, where greater than 6 is defined as equal to 7, and assuming that the weighting is even for each interval, the number of items, N is at least

$$N = (1 \times 0.5) + (2.5 \times 0.3) + (5 \times 0.12) + (7 \times 0.08) \\ = 2.41$$

The data obtained by Skelton summarises all orders received for the period 1973 - 1977 and provides a full profile by absolute number of items. The mean number of items is given by

$$N = (1 \times .503) + (2 \times .184) + (3 \times .13) + 4 \times .068) + (5 \times .046) \\ + (6 \times .028) + (7 \times .02) + (8 \times .012) + (9 \times .008) + (10 \times .001) \\ = 2.249 \\ =====$$

The profile may be compared to the Manufacturing Control System Survey by changing the values to the Manufacturing Control System base as follows:

<u>NO OF ITEMS</u>	<u>MCS SURVEY</u>	<u>SKELTON ANALYSIS</u>
1	0.50	0.503
2 - 3	0.30	0.314
4 - 6	0.12	0.142
> 6	<u>0.08</u>	<u>0.041</u>
	1.00	1.000

The last two results are sufficiently close to consider the Skelton analysis, which provides more detail, to be a reasonable profile for further consideration.

3.3.3.5.4. Order Quantity

For the six products selected, a similar pattern of quantity is observed, with some minor differences based mainly on market type. The amplitude modulated products (AM) are predominantly sold in the home market, where there is a tendency towards the support of small customers requiring individual equipments. This is due to two factors; the facility to lease products through an affiliated finance company, and the market penetration provided by the regional sales offices.

Frequency modulated products (FM), which have a lower share of the home market, are predominantly an export product and portray a number of different market related characteristics. Firstly, the export market is supported through agents and distributors rather than direct sales, thus the ordering pattern as seen by the parent company comprises a proportion of stock orders, often in "rounded" quantities of 10, 50 or 1000. Secondly, the small customer is unlikely to buy directly from the U.K., so many of the small orders will go to the agent or distributor.

A further characteristic which may be observed is that, although there is no distributor network in the home market, certain major customers will tend to place regular orders for either new or replacement schemes in large quantities, again often rounded to convenient quantities. The actual occurrence of discrete quantities of 50, 100, 200, etc. is almost certainly higher than indicated, since many orders for large schemes with special customer engineering content have a small number of products split from the main item quantity for evaluation in the complete system test, thus showing an apparent "non-preferred" quantity for the main item.

Thus, a number of conclusions about the order quantity distribution may be drawn.

- a) The distribution is not continuous, portraying a number of "preferred" quantities.
- b) The distribution for each product type shows a high degree of consistency, although there is some distinction between home market and export products.
- c) The bias is towards small order quantities, with more than half of the order items requiring a quantity of three or less products.

3.3.3.5.5. Product Popularity

The raw data contained in Table 3.4. has been further analysed to derive a representative profile for each product type.

The proportion of total unit orders is difficult to define, since

- the definition of a product is not precise (e.g. ancillaries, merchandise, sundries)
- some items in the catalogue are rarely ordered
- orders are received for special adaptations of products (e.g. PF2FMBAA - 1974)

The only statistics available for the number of units in total is for main units only, (i.e. transceivers, excluding ancillaries and merchandise). The values for the above periods are:

1973	66264
1974	62967
1978	53688

A further volume of approximately 25% is the assumed value for the balance of unit volume. Thus, the total volume has been estimated as:

1973	85000
1974	75000
1978	65000

Using the above assumptions the proportion of each product has been estimated, and a sum for all three years has been derived. The cumulative proportion of each rank position has also been derived and displayed in Fig. 3.10.

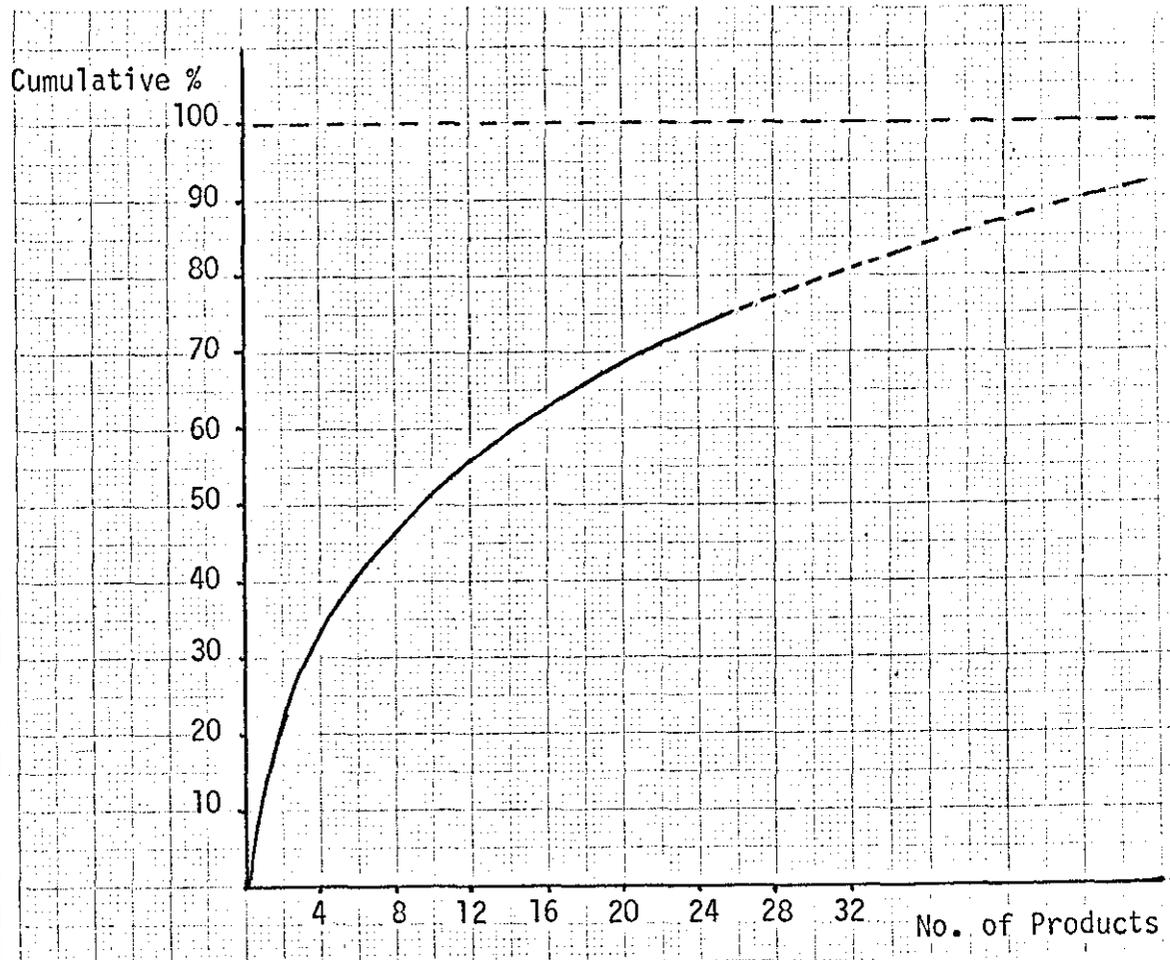


Fig. 3.10. - Product Popularity Profile

It should be noted that the reasonableness of the volume assumption has minimal effect on the result since

- a) a 100% error in the volume balance will have only a 20% effect on each proportion.
- b) the shape of the profile will not be changed.

An important distinction at this stage is that product popularity has been defined as total volume sales per product, rather than the probability of an item being ordered regardless of quantity.

3.3.4. Supplier

The supplier characteristics relate to the performance to specified due dates, and their response to items returned for re-work. The statistics relating to supplier performance have been extracted from studies conducted by Skelton (see Section 1.1.) as part of a parallel research project.

3.3.4.1. Delivery Timeliness Profile

Observation of a sample of delivery batches suggested that some 60% of deliveries of scheduled items could be identified against a specific schedule batch and that a further 20% were part deliveries against a specific batch. A further 14% of deliveries could be identified as eroding outstanding backlogs, or arrears, to schedule. The full analysis is shown in Fig. 3.12.

Delivery timeliness statistics have been recorded for those items identifiable against schedule batches, amounting to 80% of all scheduled items in the sample. The results are summarised in the histogram shown in Fig. 3.11.

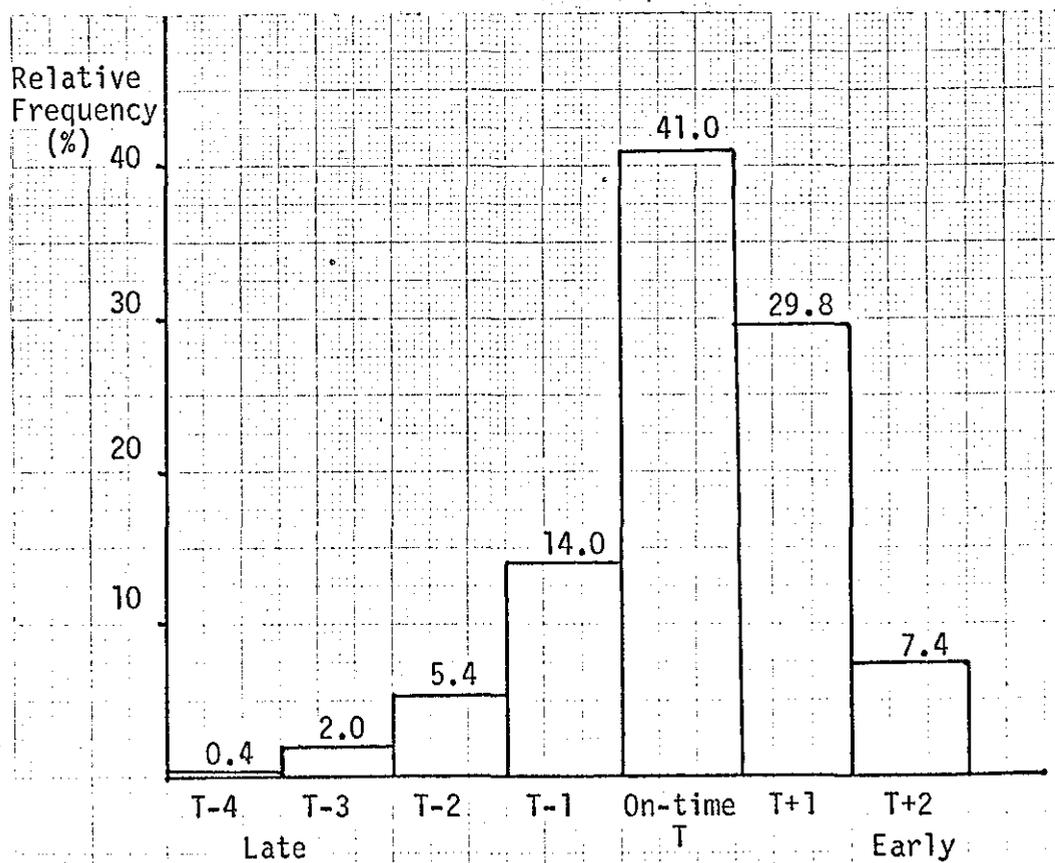


Fig. 3.11. - Delivery Timeliness Profile

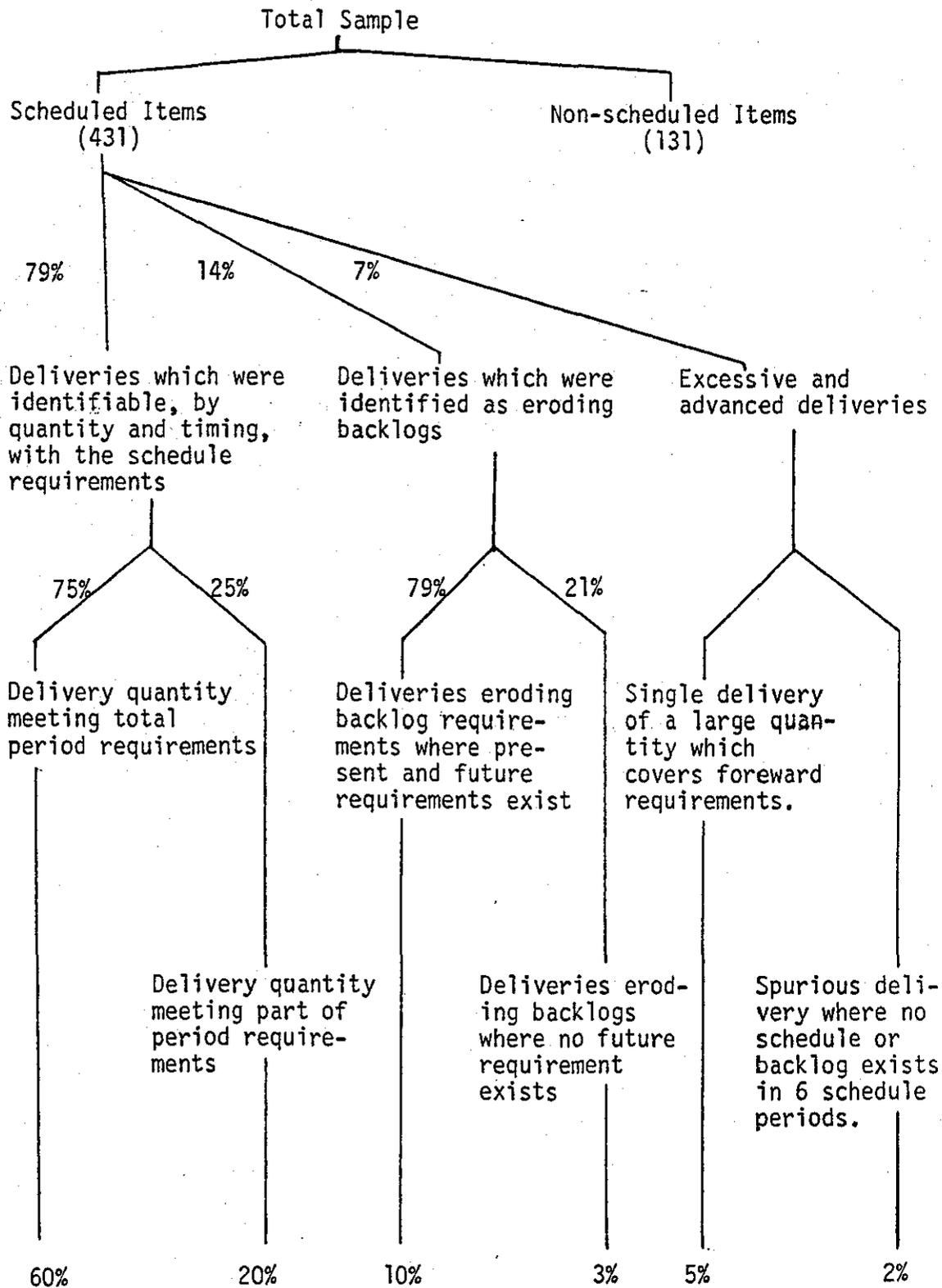


Fig. 3.12. - Breakdown of Observed Deliveries from Suppliers

3.3.4.2. Shortage Duration

The duration of shortage batches was recorded as shown in Table 3.5. and has subsequently been displayed in histogram form in Fig. 3.13. and 3.14.

The results indicate that, for the sample observed, 84% of shortage items were cleared within eight weeks of detection.

<u>NUMBER OF WEEKS DURATION (n)</u>	<u>RELATIVE FREQUENCY</u>	<u>PROBABILITY OF SHORTAGE DURATION EXCEEDING n WEEKS</u>
1	22%	78%
2	15%	63%
3	17%	46%
4	12%	34%
5	9%	25%
6	3%	22%
7	3%	19%
8	3%	16%

Table 3.5. - Shortage Duration Data

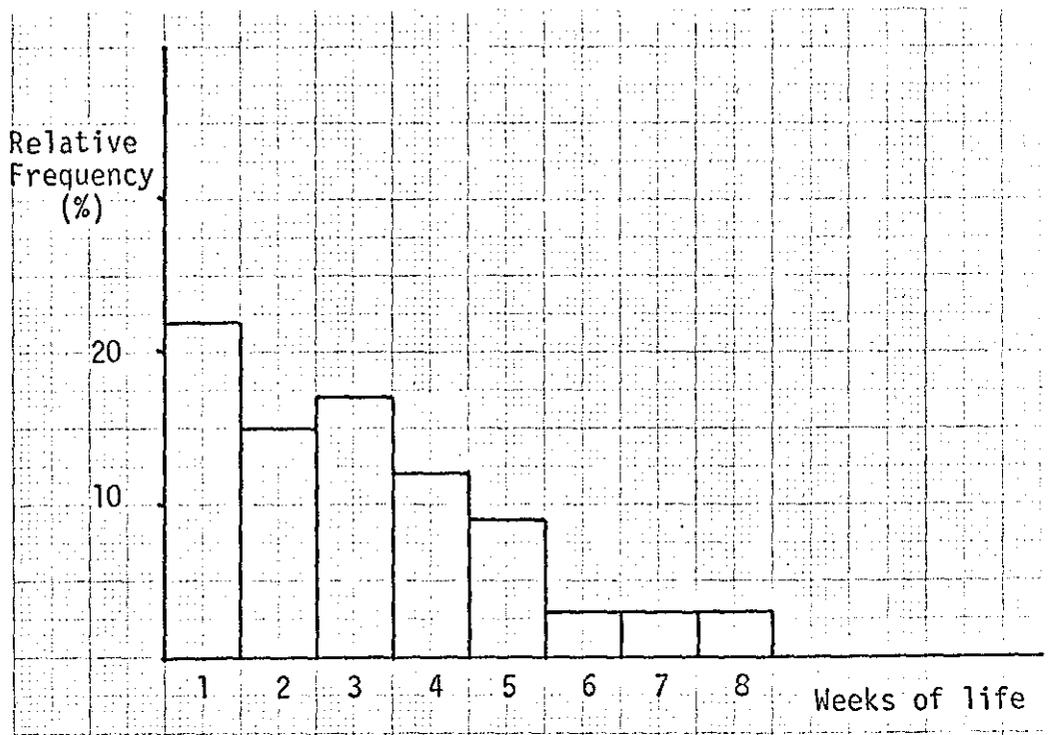


Fig. 3.13. - Distribution of Shortage Lives

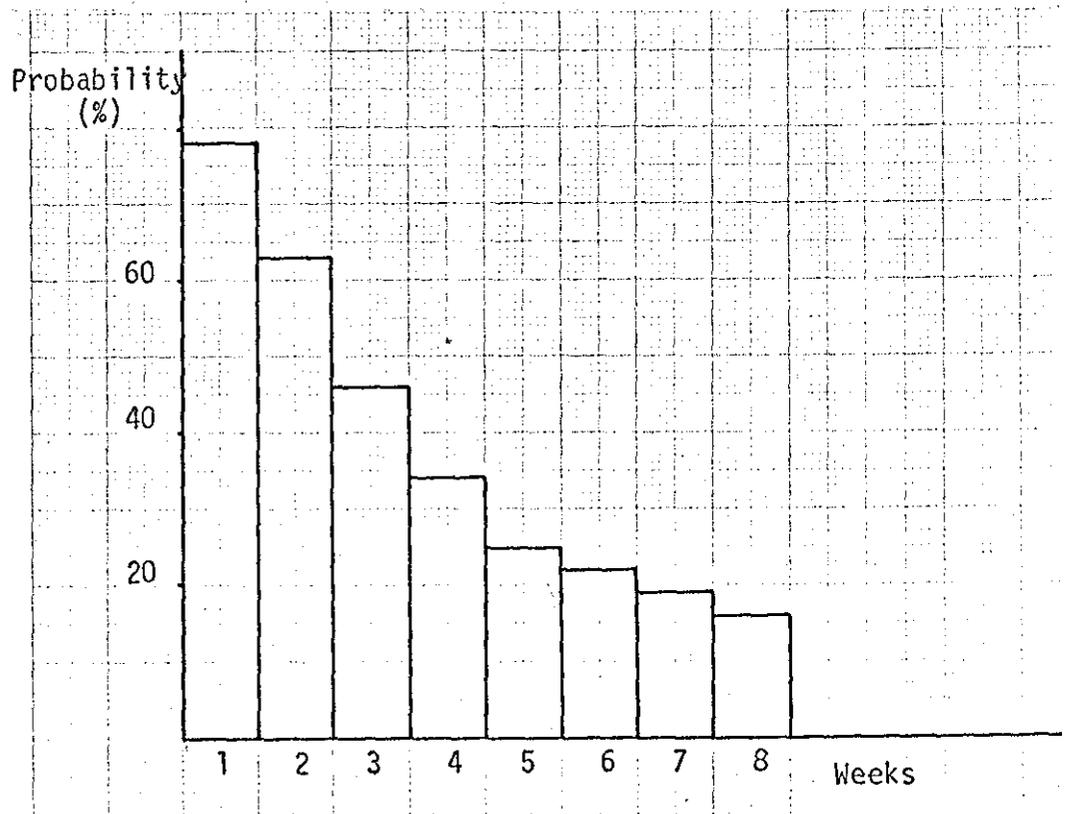


Fig. 3.14. - Probability of Shortage Remaining Longer Than Specified Week

3.3.4.3. Receiving Inspection Lot Rejection

The proportion of batches rejected in goods receiving due to quality failure was recorded as in Table 3.6.

<u>WEEK</u>	<u>PART REJECTION</u>	<u>TOTAL REJECTION</u>	<u>TOTAL FAILED</u>	<u>NO.OF.BATCHES INSPECTED</u>	<u>TOTAL RATIO (%)</u>
5	0	51	51	989	5.1
6	0	47	47	1037	4.5
7	0	25	25	797	3.1
8	4	16	20	775	2.6
9	3	33	36	838	4.3
10	2	22	24	671	3.6
11	2	19	21	733	2.9
12	5	24	29	856	3.4
13	0	18	18	751	2.4
14	4	27	31	618	5.0
15	6	24	30	872	3.5
16	11	23	34	852	4.0
17	8	13	21	670	3.1
18	3	21	24	900	2.7
19	2	23	25	479	5.2
20	5	27	32	828	3.9
21	0	40	40	855	4.7
22	0	10	10	618	1.6
23	5	14	19	509	3.7
24	<u>1</u>	<u>26</u>	<u>27</u>	<u>629</u>	<u>4.3</u>
	61	503	564	15277	3.7

Table 3.6. - Receiving Inspection Lot Rejection

When presented in histogram form as in Fig. 3.15. the profile conforms closely to a normal distribution with a mean of 3.7 and standard deviation of 1.0.

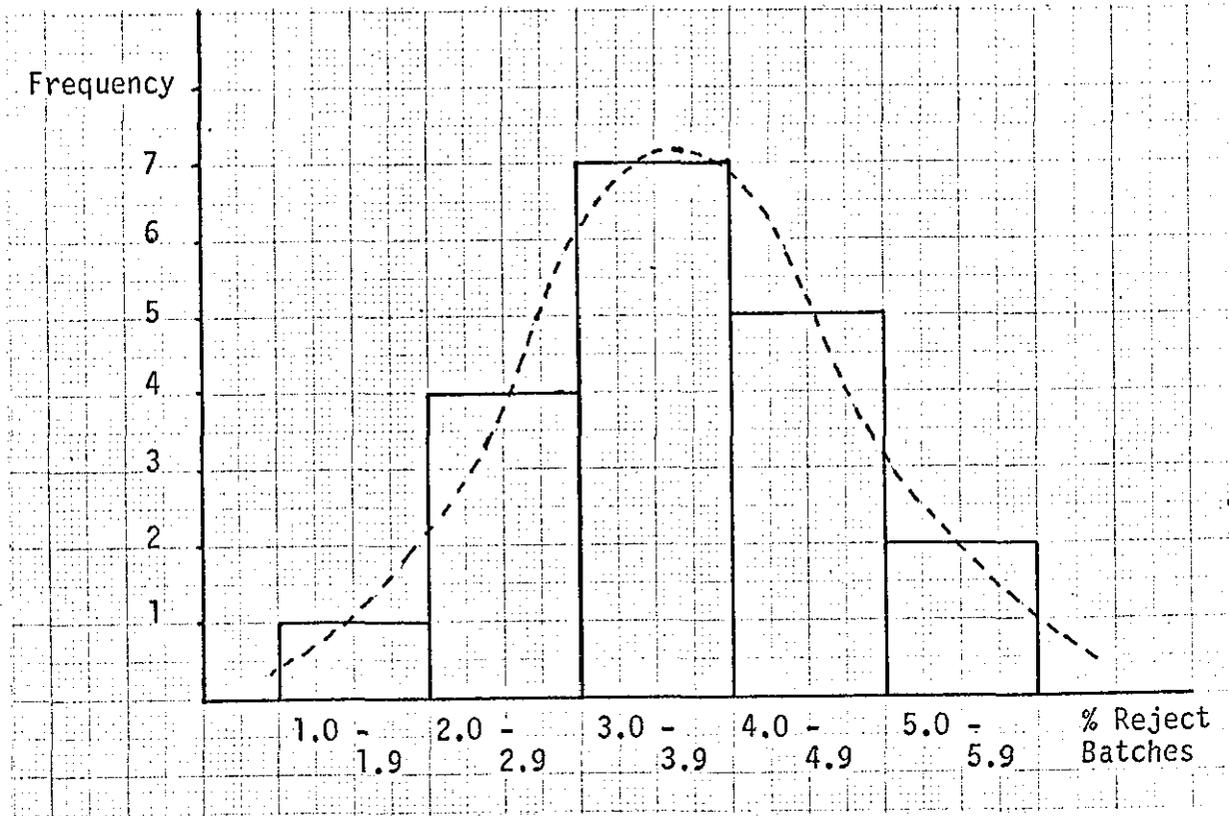


Fig. 3.15. - Reject Batches

Further analysis of the inspection history cards indicated a far lower reject rate on electrical components of 1.6%, suggesting that mechanical parts, which tend to be supplied to company specification, are subject to a far higher production of rejects.

3.3.4.4. Resupply Times

Batches which had been rejected back to suppliers had the re-supply time monitored. The profile observed for a sample of 159 batches was shown in Fig. 3.16.

By observation, the profile may be approximated to a truncated normal distribution with a mean of 6 and co-efficient of variation of 0.3, over the range 0 - 12 weeks.

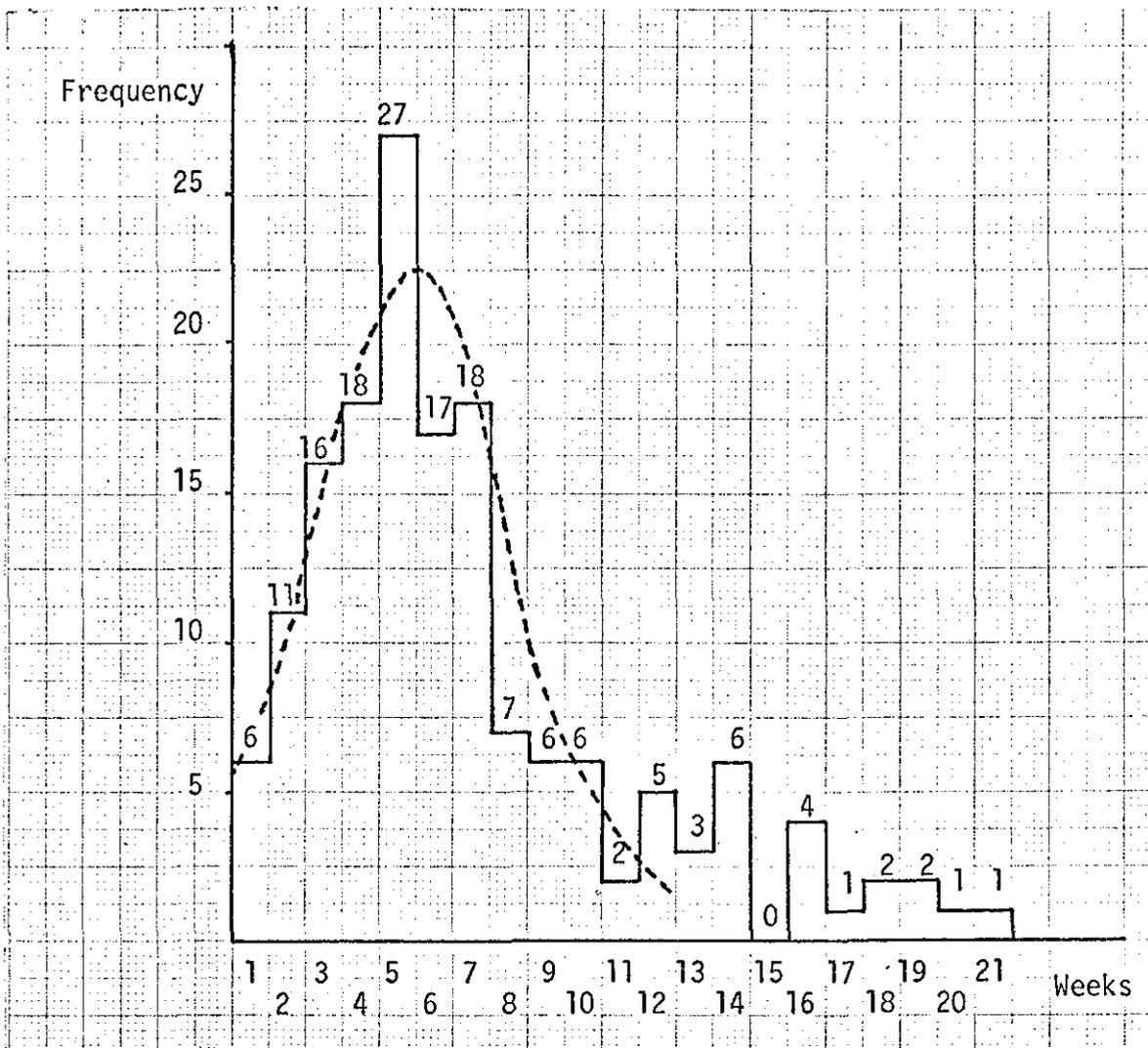


Fig. 3.16. - Re-supply Profile from Suppliers

3.3.4.5. Discussion

The data associated with reject proportion contains a mix of total and part batches. The policy relating to incoming inspection is that any batch which is subject to sample inspection and is found to contain evidence of poor quality is rejected in full. The part batches indicated in the survey are items which, because of their critical nature, have had batches split to clear shortages and keep production flowing. This is not an accepted company policy, more a reflection of the real world attitude towards maintenance of production output.

3.4. SIMULATION MODEL

3.4.1. General Design

The objective in constructing a model which emulates the internal operation of the company is to observe in detail the impact of external factors on the business process and draw conclusions relating to policies, rules and procedures. This implies that the model design should be sufficiently detailed that close comparisons may be drawn between the simulated and the real world. In the extreme situation, the model becomes as complex and difficult to analyse as the actual situation, in which case nothing is gained. The model should, therefore, be constructed to include all the primary processes involved in the business system but should be reduced in scale. Such reduction in scale should still allow positive conclusions to be drawn about the full scale process.

The model may be viewed as comprising three elements; planning routines, execution routines and statistical outputs.

The planning routines must be capable of representing the logic and procedures of the existing systems. This includes the computer facilities, the clerical procedures and the "human evaluation" elements. Each activity or event within the planning cycle is time dependent, in terms of the frequency of occurrence and the sequence in relation to other activities.

The core of the planning routines is the requirements planning logic as described in the Material Support System. The model is required to faithfully emulate this system, since any broad assumptions about the logic may disguise characteristics which significantly influence the total system behaviour.

The most complex parts of the planning process that must be defined are those subject to human evaluation. In this case, the logical thought process must be described and any existing policies or rules stated in systems terms.

The execution routines in the actual situation occur across a continuous time frame. A major consideration in the model design is to determine how this continuous process will be simulated. Three different approaches are possible.

a) Quasi-continuous

The model accepts and processes each transaction as if it were received in real time. This choice is highly complex, since account must be taken of the time to process each transaction, the dependency between transactions and the ability to measure the key parameters. The sampling profiles have to be stated in time rather than quantity format (i.e. inter-arrival times) and such data is often difficult to acquire. A disadvantage in computer modelling terms is that each programme will be accessed so many times that a meaningful simulation experiment may be impossible.

b) Smallest planning increment

The model processes blocks of transactions in batches rather than discrete transactions with a periodicity equal to the smallest planning increment (e.g. 1 week). Since the planning process is also the decision making process, no impact on system performance should result from bypassing a decision point. Operating in batch mode assumes either no dependence between different transactions or, where dependence exists, transactions can be combined in a common batch. The two major advantages of the smallest planning increment approach is that system complexity may be minimised and processing performance optimised.

c) Interim increment

A smaller time increment than the smallest planning increment (e.g. 1 day) is a further alternative. The model complexity is simpler than the quasi-continuous since some form of batching is performed, although some difficulty may still be experienced due to the translation of sampling profiles into very small time increments. The processing time to complete a similar simulation experiment will be considerably greater than the smallest time increment approach, although not necessary a factor of the time ratios (e.g. 5:1 in the examples given)

since not all events occur each period. The main advantage of an interim approach is to obtain more knowledge of the system performance as specific situations develop. This may, however, imply far more detailed examination and emulation of the actual processes than the smallest planning increment option.

Taking account of the above factors and the specific objectives of the simulation model, the decision was taken to design the model in the smallest planning increment mode. This will result in the greatest processing efficiency but should still allow the fundamental problems to be addressed without sacrificing important detail.

Statistical outputs should be in two forms. The first should provide a specific set of results from each simulation experiment such that the effect of changing system parameters may be quantified. The second should allow the behaviour of the system to be observed over the span of the experimental timescale, in order to understand any abnormal conditions, cyclic effects or sub-system inter-actions.

A requirement of the model is that it should not only simulate the present situation, but should also permit alternative procedures to be evaluated. The model should, therefore, be constructed in logical modules to enhance the ease of programming, clarify the procedures and facilitate model validation and testing. Comprehensive diagnostic facilities are required both during initial system design and in later logic changes.

3.4.2. Computer Facilities

The choice of computer facility upon which to develop and run the simulation model was an important decision which significantly influenced the design and effectiveness of the final solution. It is apparent from the description of the business system that should be simulated, that the required model will be complex and almost certainly consume a large amount of computer resource. These considerations led to two important conclusions, Firstly, the facilities should be convenient to use with a fast turn round of submitted jobs, so that the model could be developed in an effective manner. Secondly, the computer facilities should be inexpensive, since the development and execution of a large scale simulation model can potentially consume massive quantities of computer resource.

The choice, in practical terms, was three way.

- (i) Use the local Loughborough University facilities;
- (ii) Use the larger Manchester University facilities which are compatible with Loughborough, for execution but develop as much as possible locally;
- (iii) Choose a larger, more efficient, installation, such as Cambridge University, but forfeit the convenience and support of the local facilities.

Preliminary estimates of the size of the program suggested that the local facilities would be sufficiently large. This factor, with the major advantage of convenience of use, fast program turn-round, experienced local support and probable high execution costs, resulted in the decision to use local Loughborough University facilities. The option to transfer to Manchester University facilities if the size estimates were too low was available if required.

The choice of computer facility limits the availability of simulation programming language, a point which is discussed later in detail.

The computer hardware available for the development and execution of the simulation model were as shown in Fig. 3.17.

The main computer for both the program development and execution was the ICL 1904S*. Programs and data files were stored initially on punched cards, but were subsequently transferred to on-line disk storage due to the increasing risk of read errors as the program volume expanded.

For convenience, when all the programs were on disk file, program editing was performed by using the file edit routines available on the Computer Technology "Modular 1" by linking to the ICL 1904S*. Access to the Modular 1 was either by local terminals or by using remote terminal via a dialled line.

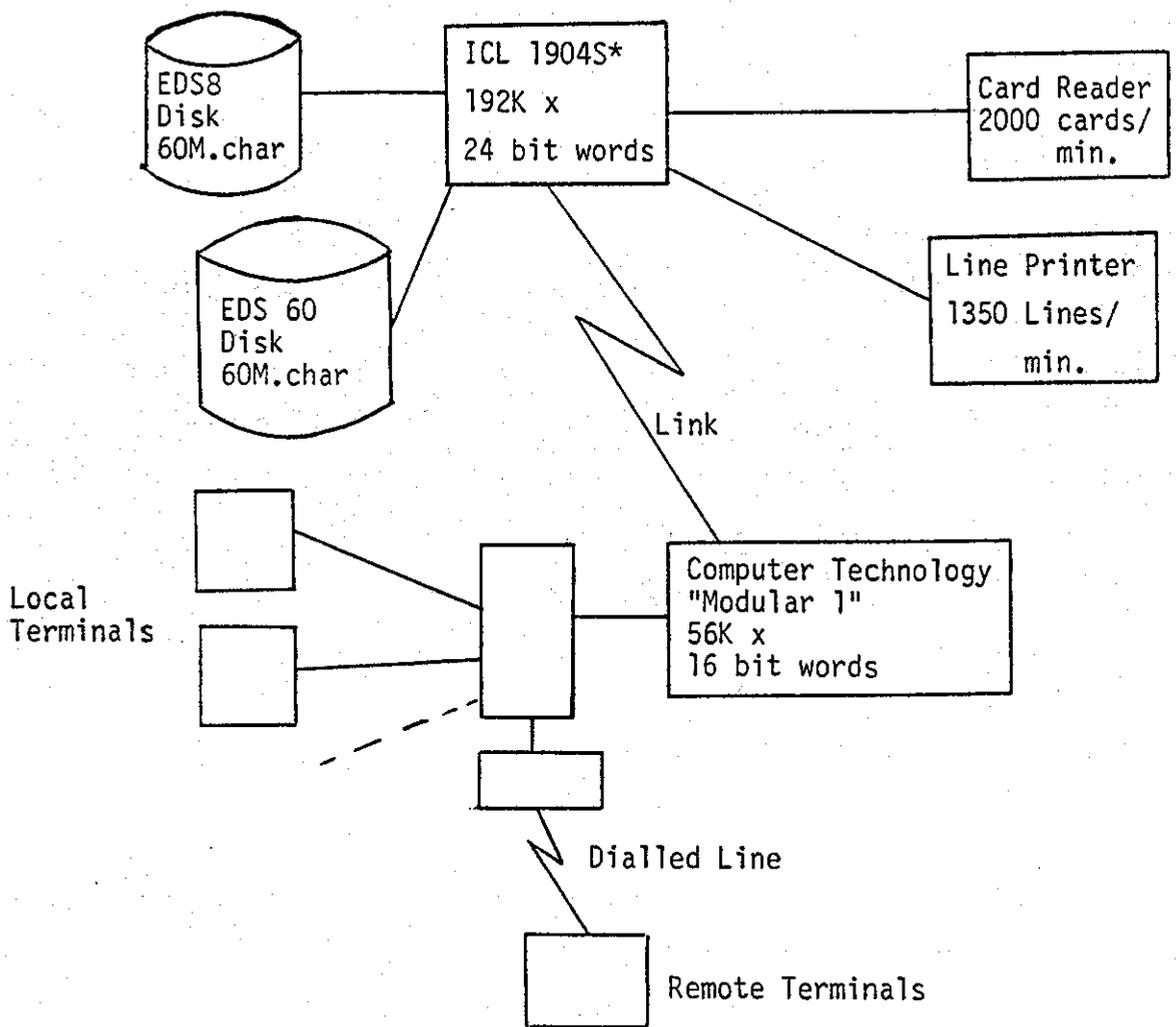


Fig. 3.17. - Computer Hardware Configuration

The programs were written in ICL 1900 Extended Fortran and run under the GEORGE 2L MK4F Operating System. Programs were compiled by the ICL compiler *XFAT MK6C and consolidated by #CPCK.

Details of the execution efficiency are discussed in Section 5.3.3.

3.4.3. Simulation Language

It was evident from the Literature Survey (Section 2.3.) that one of the most significant factors determining the choice of simulation language is the range of simulation software available to the experimenter and the type of computer hardware. This point was raised by Tocher (1965) and subsequently re-inforced by Teichroew and Lubin (1966). The study of simulation language, therefore, embraced only three alternatives.

- a) General Purpose System Simulator (GPSS II)
- b) Control and Simulation Language (CSL)
- c) General Purpose Language (FORTRAN)

The last two were available on the local ICL 1904S* facilities, whilst the first alternative implied the use of an outside computer available to Loughborough University research projects (e.g. Cambridge University).

3.4.3.1. GPSS II

The concepts defining the General Purpose System Simulator are described by Gordon (1962). The principle of GPSS is that entities, defined as "transactions", move through a sequence of "blocks" through simulated clock time. Thus, a transaction may be originated, pass through a sequence of blocks, and finally be terminated. These blocks describe the interaction between the transaction and a facility (e.g. machine, store) through statements such as HOLD: SEIZE: RELEASE: STORE: ENTER: LEAVE

Thus the model may be structured to represent the flow of an element through a sequence of processes or waiting lines. Time is controlled by a clock with equal time increments. Statistics are gathered by observing the contents of a QUEUE block or measuring time elements with MARK or TABULATE blocks. Transaction flow is primarily controlled by a further group of blocks designated LOGIC; GATE; LOOP and COMPARE. Other blocks which control the model execution include INTERRUPT; PREEMT; RETURN; MATCH; SPLIT; ASSEMBLE and SAVEX.

3.4.3.2. C S L

Control and Simulation Language (CSL) described by Buxton and Laski (1962) is a direct descendant of the General Simulation Program (GSP) developed by K.D. Tocher and his colleagues at the United Steel Companies, a later version being described by Tocher and Hopkins (1964).

The CSL language is primarily designed to offer a convenient means of constructing and operating upon sets. The system is described in terms of CLASSES of ENTITIES; SETS OF ENTITIES and ARRAYS. The

operation of the model will move entities, which may be defined as specific members of sets, between the established sets and arrays.

Classes of entities may be provided with T-CELLS, which contain time data. The CSL executive will scan all T-cells to locate the minimum value. All T-cells are then reduced by this amount and control is transferred to the first activity in the program. Thus the time intervals within the model are variable.

The language is particularly powerful when it is required to observe the behaviour of various entities through complex sequences. For example, a TRUCK may be in TRANSIT or LOADING. Conditions may be set such that TRUCK X cannot move into TRANSIT unless a DRIVER is available.

3.4.3.3. Fortran

The use of a general purpose language, such as FORTRAN, for simulation provides a very high degree of flexibility in the model design, but requires very careful and detailed design if logical or sequencing problems are to be minimised. The compiler will include very powerful diagnostic or error checking routines related to the use of the language, but cannot be of use in checking logical errors, or capacity, rule or sequence violations. Any diagnostics related to these points must be recognised and "built-in". In addition, certain facilities available to most special purpose languages, such as distribution sampling and output formatting must be specially written.

3.4.3.4. Discussion

The availability of local facilities which support only FORTRAN or CSL led to a preference for these languages over GPSS II, unless some overriding constraint was evident in the former languages. Thus CSL would be selected in preference to GPSS II, although one of the major logical considerations, the timing mechanism, makes GPSS II a more suitable choice for the specific problem.

It appears, from analysis of the production system, that the model should not relate to specific items, which have to be labelled and progressed. In general, all items, whether component sub-assembly or equipment, should be considered "free" within the system until finally linked to a customer order. We are more concerned with the

manipulation of BATCHES of items and the batch SIZE than with the individual item. Thus, many of the advantages of a special purpose language would be lost in this context.

In addition, it is much easier to emulate the rather complex decisions relating to the setting of, for example, the quarterly plan parameters, with the help of a general purpose language such as Fortran.

A further consideration in the choice of language is that it must be easy to re-structure the model, or parts of the model, in order to experiment on various corporate strategies. A requirement is that the model should adapt itself to the changing nature of the company, and that the experimenter would be able to make use of the model over the passage of time. Thus the language selected should either be simple to understand and adopt, or a generally accepted and widely used example.

The decision to use CSL for the main execution logic augmented with FORTRAN for the planning segments was considered, but eventually rejected due to the incompatibility between the timing mechanisms described in the production process outline and the CSL operating logic.

The final choice was to adopt FORTRAN in preference to the general purpose languages. The main arguments in favour of FORTRAN were:

- (i) the high proportion of complex planning logic required in addition to the execution logic;
- (ii) widespread knowledge and acceptance of the language;
- (iii) the proven efficiency of ICL 1900 extended FORTRAN when used with the GEORGE 2 Operating System.
- (iv) scope for extension of the model or transfer to other computer hardware and operating systems at a later date if required.

3.4.4. Diagnostic Facilities

A large scale simulation model demands a very high level of diagnostic support both during the development and experimental stages, such facilities being a key feature of the model design.

Four diagnostic modes may be identified as shown in Fig. 3.18.

	MODEL DESIGN	MODEL EXECUTION
LIBRARY DIAGNOSTICS	A	B
CUSTOMISED DIAGNOSTICS	C	D

Fig. 3.18. - Diagnostic Modes

The requirements for diagnostic facilities during the design and execution phases are very different. The design phase demands validation of the programming logic and powerful trace facilities to isolate logical errors. Additionally, special routines are required to monitor the "reasonableness" of system variables, particularly where abnormal parameters may lead to program looping. This phenomenon is most likely in the planning routines due to the plan optimisation procedures which require extensive program iteration. Such diagnostic facilities are required both at the initial design phase and for any subsequent logic or parameter changes.

The execution phase requires a different form of diagnostic facility. The modeller must be informed of special circumstances encountered during the execution of a simulation experiment which may invalidate the experimental results. This would include abnormal data streams or inadequate file sizes causing biased performance indicators. The modeller must also be capable of examining the experimental performance both at detail and summary level. For example, a specific simulation experiment may yield results that are significantly at variance with the trend. The capability of increasing the level of definition of the output statistics at the discretion of the experimenter is a benefit in the analysis of such situations.

Diagnostic facilities may be both intrinsic to the programming language, compiler and operating system, or may require development into the application program logic. The former have been arbitrarily

designated as "library diagnostics", whilst the latter have been termed "customised diagnostics". Library diagnostics include the facilities offered with the ICL 1900 FORTRAN IV and the George 2 operating system. These include:

- a) compilation diagnostics, which identify errors in the definition of the Fortran statements;
- b) execution errors, which specify errors encountered during the execution of the Fortran programs. Examples include overflow conditions, illegal variable values and array subscript errors.
- c) diagnostic traces, which enable the program statement conditions immediately preceding an execution error to be analysed in detail. Traces are at two levels. Level 1 identifies the program segments accessed prior to the error condition and Level 2 provides a history of each executable statement and the specific values assigned at the execution time. Trace level 2 has a significant impact on the program execution efficiency, and is normally used only during program development and testing.

Customised diagnostics were developed to accommodate the development and execution conditions previously described.

- a) Error condition diagnostics, which are only activated when an error condition is encountered during execution. Examples of such errors include incompatible data in the system files and out of range system variables. Most error conditions are considered catastrophic and cause the execution to be terminated.
- b) Routine execution diagnostics permit the experimenter to trace the system performance at various levels of detail. The facilities are time dependent, so that the level of detail may be varied at pre-defined times through the simulation experiment. This facility is required to limit the volume of system output without constraining the level of transaction detail available.

The diagnostic levels available for selection are shown in Table 3.7.

<u>LEVEL</u>	<u>DEFINITION</u>	<u>DESCRIPTION</u>
1	Detail diagnostics/ warnings	Warning messages and detailed variable status
2	Transaction details/ warnings	Warning messages and report on every major transaction
3	Weekly summaries/ warnings	Warning messages and summaries of system performance and major file status at weekly intervals
4	Monthly summaries/ warnings	As (3) except monthly rather than weekly intervals
5	Quarterly summaries/ warnings	As (3), except quarterly rather than weekly intervals
6	Run summary/initial conditions	Final summary of run performance and display of initial conditions only
7	Run summary only	Final summary of run performance only

Table 3.7. - Diagnostic Levels

The choice of level is dependent upon the nature of the simulation experiment and the validity of the model. For example, if modifications are made to the model logic, the lowest level diagnostics will be required to validate the changes. General performance may be monitored at a level of 5, but if the dynamic or cyclical performance is being observed, a level of 3 or 4 may be required. Due to the dynamic nature of the model, levels 6 and 7 have limited benefit at the present level of program definition. These levels have been defined to permit the subsequent application of a post-processor at a later date, which would store the periodic performance indices and perform some statistical analysis in summary form. This aspect is discussed further in Section 6 - Recommendations for Further Research.

3.4.5. Summarised Program Description

3.4.5.1. Introduction

The simulation program was developed from the overview described in Section 3.2. - The Production System.

Following the concepts previously described, the programs may be classified as:

- planning segments
- execution segments
- reporting segments

The bounds of the model are shown with reference to Fig. 1.8. and are designated by the ring encompassing the schematic.

Thus, the only exogenous variables (or independent variables) are:

- a) the customer demand (i.e. the receipt of an order), which is basically a "non-controllable" exogenous variable.
- b) the supply of material (including crystals) and labour, both of which are "controllable" within certain definable limits.

A wide variety of status variables describe the state of each element of the system. In this case they relate mainly to the levels of inventory at each stage of the process.

The endogenous variables are the dependent or output variables of the system. In the physical sense, these are sales to a customer (or customers) but in our model we are seeking data also on total inventory investment, production efficiency (or utilisation) and customer service.

The model is completed by the definition of operating characteristics and identities, which define the manner in which the system variables are processed.

The operating characteristics are hypotheses which relate the endogenous and status variables to the exogenous variables. Such characteristics take the form of a probability density function where a stochastic process is involved. One example in the model is the time to process a batch of sub-assemblies. This comprises a fixed element related to the work backlog in the department, and a variable element representing such factors as internal departmental scheduling, processing times, inspection failures, etc.

The identities are the definitive relationships that exist within the system, examples being:

- a) New order book = old order book + orders received - deliveries;
- b) New stock level = old stock level + receipts - issues;
- c) Stock value = quantity x unit value.

3.4.5.2. Planning

The planning segments represent the major difference between the "conventional" simulation model and the approach using MRP logic. The majority of simulation experiments are involved in the execution of a set of conditions pre-defined by the modeller, and such conditions will not vary significantly throughout the life of a single simulation experiment. Examples include simulations of warehouse operation, supermarket check-outs, transportation systems. In such cases, the execution logic is the major part of the program. The objective of this research is to observe the planning process and the results as observed by the execution of the plans. Thus the planning logic is a significant proportion of the simulation program and, since it represents both standard rules and human interpretation of information, is the most difficult to simulate.

The actual production system is based on Material Requirements Planning logic. The model has to reflect the process involved according to the rules and policies governing the real world situation. Table 3.8. indicates the type of rules or relationships to be considered and the degree to which they may be defined.

<u>TYPE OF RULE</u>	<u>DEGREE OF DEFINITION</u>
Coded in MRP Programs	Precisely defined
Program parameters (e.g. lead times)	↑ Discretionary
Planning rules	
Planning policies	

Table 3.8. - Planning Rules

The planning segments of the system comprise the following functions:

- sales forecast
- production plan
- master schedule
- material plans
- capacity plans

The sales forecast is the weakest link in the simulation model since, in the professional electronics industry, a major input to the forecast is known market conditions and large order prospects. It would be feasible to make some attempt to emulate this situation and this is discussed further in Section 6. - Recommendations for Further Research. The decision to derive a sales forecast from the sales history with no adjustment for extrinsic factors was considered acceptable at the first stage of model development, and a simple linear regression algorithm was adopted. The program accepts sales history for the previous twelve monthly periods and projects the forecast sales for the next six quarterly periods.

The sales forecast is the primary input to the Production Plan. Status information concerning the current order commitment, finished equipment stock and work in progress is projected by using the sales forecast, previous production plan and rules governing the permissible changes to plan.

The production planning logic and the relationships involved are described in detail in Section 3.2. - The Production System. The simulation model must prepare the plan as described but is constrained by the inability to overview the full planning horizon. To minimise this constraint, each period is planned consecutively with the planned production rate being increased in steps until the required rate is reached. The model is able to respond to zero demand in any forward period and ensure that stock and work in progress are consumed under these circumstances.

The Master Production Schedule is derived by converting each quarterly period in the Production Plan into weekly periods. The model recognises the gross manufacturing quantity required each quarter and either selects a fixed number of batches in the period or continuous production according to the volume required. Two

schedules are prepared for further processing; the manufacturing plan (i.e. off-line output) which is used as the input to the material planning process, and the delivery plan (i.e. production to be allocated) which forms the basis for customer order promising.

The heart of the planning is the material requirements calculation. The logic employed is a simulation of the actual procedures and programs used and therefore does not fully conform to "standard" MRP program packages. The most significant differences are the treatment of safety stock and open orders, and the netting of intermediate sub-assembly stock. The planned safety stock, specified in number of weeks, is treated as safety lead time, thus the requirements are offset by a factor comprising manufacturing lead time plus safety stock weeks. The "available" on-hand is considered to be free stock plus work in progress (i.e. scheduled receipts) and is not time-phased. The technique is requirements calculation rather than requirements planning, since no facility exists to schedule open manufacturing orders.

Sub-assembly stocks are not in practice included in the requirements calculation but a "nett adjustment" is applied following manual calculation. Since the result is comparable to the normal multi-echelon netting logic, this facility has been included.

The efficiency of the model execution is dependent upon the requirements planning or "explosion" logic adopted. The technique employed is a simple regenerative example using low level codes to facilitate the level by level requirements aggregation.

The model must be capable of reflecting the behaviour of components, sub-assemblies and equipments when considered in terms of product mix variability and component commonality. The product structure is contained in the Item Master file as a "used on" matrix as shown in Fig. 3.18.

The structure is considered sufficiently representative of the real world to permit meaningful conclusions to be drawn from the simulation experiments without excessively complicating the model and resulting in uneconomic computer run costs. (See Section 3.3.2. - Product Definition.)

		SUB-ASSEMBLY					COMPONENTS							
		P1	P2	P3	P4	P5	C1	C2	C3	C4	C5	C6	C7	C8
Product	A Type 1	1	1				1	1	1					
	A Type 2	1		1			1	1	1					
	A Type 3	1			1		1	1	1					
	B		1			1			1	1	1			
Sub-Assembly	P1						2		1					
	P2								1					
	P3								1		1			
	P4								1				1	
	P5										2			1

Fig. 3.18. - Product Structure Matrix

The final stage after calculation of the nett requirements for each item is the preparation of a supplier delivery schedule. The requirements are compared with the existing schedule, noting that no changes are permissible within the supplier reaction time (also called schedule response time).

The complete planning cycle is repeated each quarter, the main outputs being:

- the delivery, or order loading plan
- the manufacturing plan for each product and sub-assembly
- the delivery schedule for each purchased part.

An important assumption in the model relates to the material procurement procedure. It is assumed that the supplier is able to respond to any changes in requirement within the constraints established in the Production Plan. The purchase order, therefore, acts only as a contract and does not influence the vendor's ability to supply, regardless of purchase lead time. This assumption may merit further validation to ascertain the degree of independence associated with a given group of production planning rules.

It has been demonstrated from the treatment of manufacturing orders that the existing procedures do not conform to accepted Material Requirements Planning logic. This is also evident in the treatment of sub-assembly schedules. The requirements calculation is executed each quarter, which, in a relatively short delivery lead time environment (6-10 weeks) demands some form of interim manufacturing schedule adjustment if stock and service level is to be managed. This is accomplished within the procedures for sub-assembly planning, which pre-date the introduction of the Material Support System. A sub-assembly schedule is derived from the gross quarterly requirement of sub-assemblies and "economic" batch sizes are calculated using the "Classical Economic Batch Quantity Formula" described by New (1978) and many other standard inventory control texts. These quantities are recalculated each quarter from the requirements data generated by the material requirements calculation. Each month a sub-assembly schedule is established by using the economic batch quantity and re-order frequency as a base, and adjusting the preliminary schedule to maintain the planned level of safety stock. It should be noted that this procedure does not influence the previously established component delivery schedules.

A further activity which takes place on a monthly cycle is a review of the order loading plan to take account of the level of finished equipment stock and the performance to the manufacturing plan. The model simulates the procedures used to maintain the level of finished equipment stock, but does not, at this stage, compensate for variances in performance to plan.

Summarising the planning procedures, there are two levels of formal planning; quarterly and monthly. The quarterly procedures are the primary planning process and establish the delivery, manufacturing and material plans for the future 18 months. An interim review each month adjusts the sub-assembly program and the delivery plan to maintain the planned level of safety stock and compensates for any back-order situation.

3.4.5.3. Execution

The execution segments of the system can be viewed in two perspectives. The first is the flow of material from supplier to customer, and the second parallel activity is the flow of customer orders through the

system. The two streams merge at the point of customisation of a manufactured equipment.

The order cycle commences with the generation of the customer order. This is effected by "constructing" the order by sampling from a sequence of representative probability density functions. The method chosen was considered more realistic than providing an independent order stream for each equipment and permits observation of the behaviour of the complete order, particularly significant in "no part shipment permissible" conditions. The sequence of order construction is shown in Fig. 3.19.

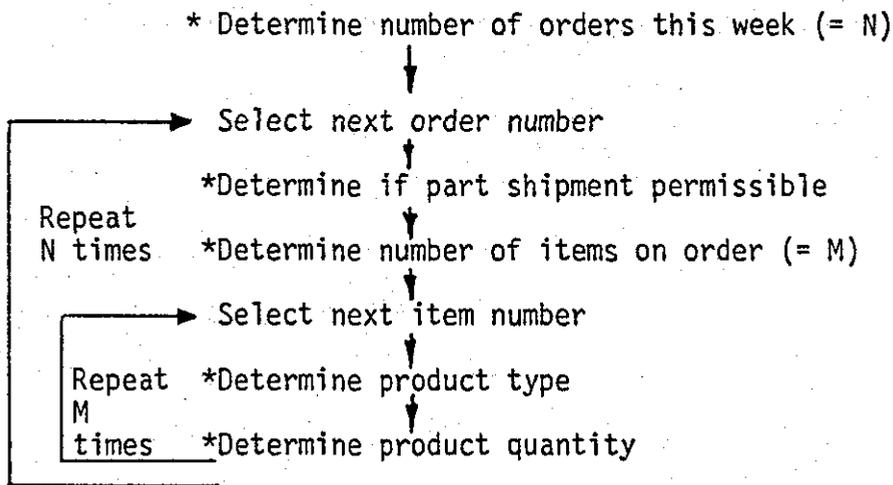


Fig. 3.19. - Construction of Customer Order

Each of the activities marked '*' are supported by a sampling distribution derived from actual observed data.

Generated orders are retained within a file called the order processing "pipeline" prior to the application of the delivery date. The order loading process compares the order requirements with the balance available for sale, taking account of the longest lead time product for "no part shipment" orders. The application of the delivery date completes the order definition and causes two files to be updated; the Order Book which is organised by product and the Order Placed File which is organised by customer order reference.

Orders remain in the files in open status until the normal equipment allocation time. At this point the decision is made to either take a stock equipment to satisfy the order, or to manufacture the product from sub-assemblies and components. The facility is available to select one of three modes of manufacture:

1. Make to customer order only - no stock is planned.
2. Make to stock only - orders are allocated to finished equipment stock.
3. Mixed mode, where the decision at any moment is based on the equipment stock levels.

If sufficient free stock exists, orders will be designated "ex-stock" status and the allocated stock value for the product will be augmented. Orders selected for manufacturing are placed in an allocation file. The batch quantity for allocation is determined as two weeks worth of production, based on current rules. If insufficient customer orders are available for allocation within the allocation horizon, the balance will be made up with a batch of stock products.

Sub-assembly allocations are independent of customer orders, the batch size and timing being dependent only on the manufacturing schedule.

Allocation batches of both products and sub-assemblies cause the comprising components to be allocated in the stock file. If a negative free stock condition arises on any component, the offending delivery batch or batches will be subject to expediting action. The success of the expediting effort is determined from a sampling profile and influences the proportion of outstanding leadtime that is reduced. It is assumed that any subsequent expediting effort will have no effect.

When the allocation has reached the release date, determined by sampling at the time the batch was established, an attempt at issuing the component parts is made. The component service level is measured at this point. If all of the components are available, the physical stock and allocated stock records will be reduced and the comprising customer and stock orders moved into the manufacturing line queue.

Orders, both product and sub-assembly, are moved from the line queue according to:

- a) the minimum process time defined;
- b) the priority rules selected;
- c) the manufacturing rate per week.

Priority rules are either "first in first out" or by due date. The due date option causes the queue to be sorted before processing.

Stock orders, on leaving the line queue, will cause physical stock to be augmented. Customer orders are transferred to the test work in process, or test queue. The test queue is also supplied by orders in "ex-stock" status. Orders which have been given "ex-stock" status will be moved into test if physical stock of the product exists and the time is sufficiently close to the due date.

All orders in test will be moved to "despatch" status according to the same rules as defined in the "on-line" condition, except that the delivery plan rather than the manufacturing plan is used to determine the maximum despatches for the period.

Orders remain in "despatch" status, or commercial stock until the part shipment rules are satisfied. If the conditions are met, the order will be shipped, the delivery performance statistics augmented and the system files reset as appropriate.

The material cycle commences with the supplier schedule derived through the quarterly planning procedures. The actual material receipts are determined by applying the observed supplier delivery performance profile to the unmodified schedule using a sampling histogram. This new schedule is augmented by an estimate of the deliveries associated with the outstanding schedule arrears, again defined by a sampling histogram.

Material receipts are subject to a quality check to determine:

- a) the probability that a reject exists;
- b) the proportion of rejected items, given that a reject is present.

If the rejected proportion is greater than a pre-defined proportion, the complete batch will be returned to the supplier. Alternatively only the reject proportion will be returned. The re-schedule period for returned batches is determined from a sampling histogram.

Items passing the incoming materials quality audit will cause the physical stock to be augmented by the accepted quantity.

The reporting segments permit certain of the system files and performance indices to be output during the execution of a simulation experiment. The volume of output is dependent upon the diagnostic level selected.

The files that are available for reporting include:

- the item master file (PNMF)
- the orders placed file
- the equipment order books
- the system queues
 - allocation
 - on-line
 - test

The standard performance reports relate to:

- stock valuation
- delivery performance
- service level
- delivery lead time

The reports are discussed in detail in Section 3.4.5.6. - System Outputs.

3.4.5.4. Program Control

Program control segments comprise the remainder of the simulation model. The first example is the establishment of initial conditions, at which time the status of certain system variables are defined (e.g. opening order book, previous manufacturing plans), and the experimental parameters are set. The parameters over which the experimenter has control include:

- diagnostic level
- mode of manufacture (stock, order, mixed)
- priority rules
- minimum order book (weeks)
- nominal order book (weeks)
- schedule response time (months)
- planned buffer stock (weeks)
 - finished equipment stock
 - sub-assemblies
 - components
- capacity utilisation factor
- orders received trend parameters by product
- product mix proportions
- the simulation experiment run time

The sampling tables are all established as data segments in the model and can only be changed by modifying the appropriate program statement. The random number streams are, however, available to the experimenter.

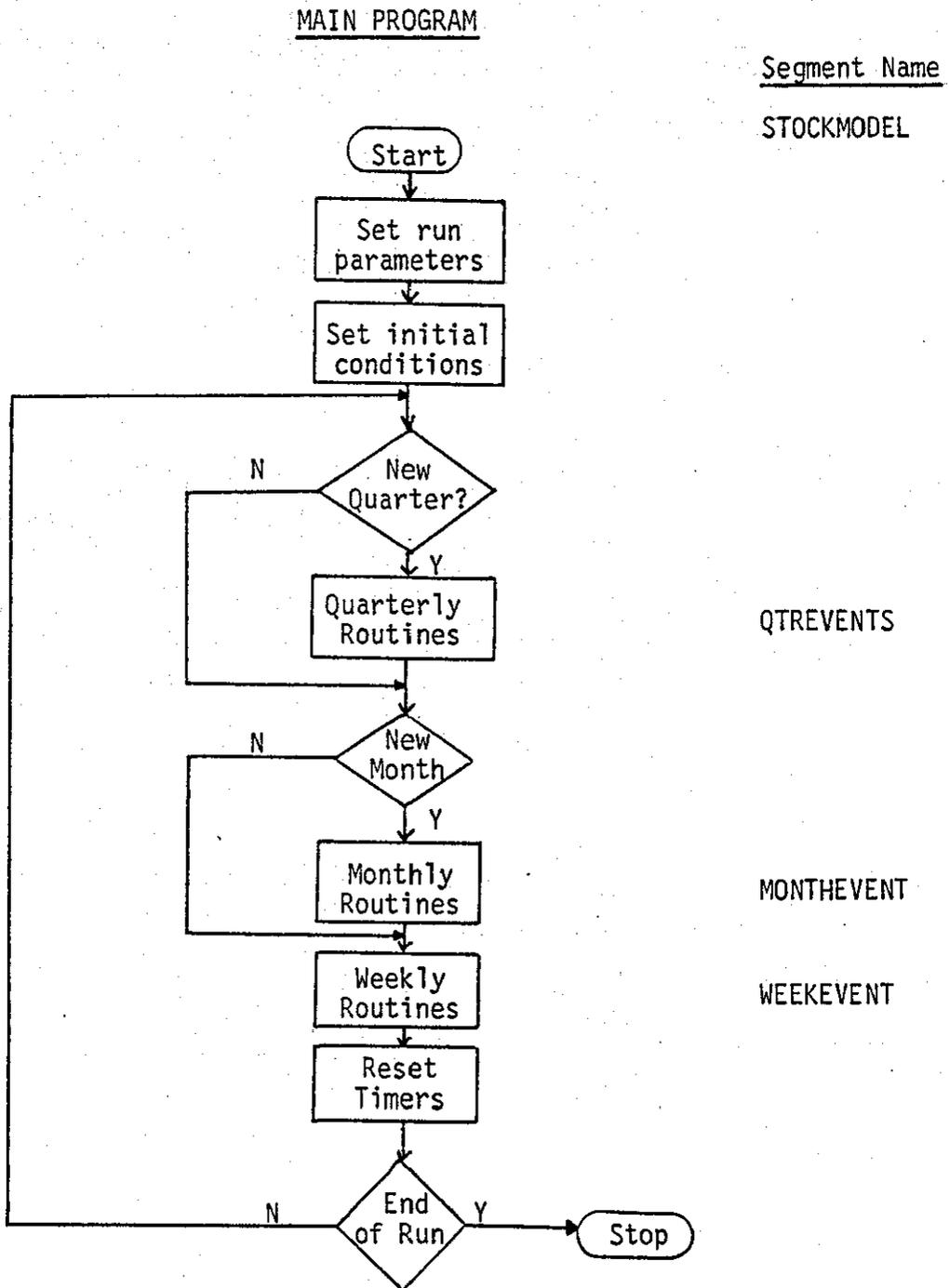
The random number generator adopted is a standard multiplicative congruential example as defined by Naylor et al (1966). Twelve random number seeds are maintained, thus permitting twelve independent random number streams to be generated. The random number generator is capable of offering antithetic streams if desired (see Section 4.3.3.). For certain sampling distributions, the program logic has been modified such that a zero seed will bypass the stochastic process and return a predefined constant.

The initial conditions of the system files are established by reading in the starting order book and building all the dependent files from this data, including status data (e.g. component allocations). This ensures that all files are compatible at the start of the simulation experiment.

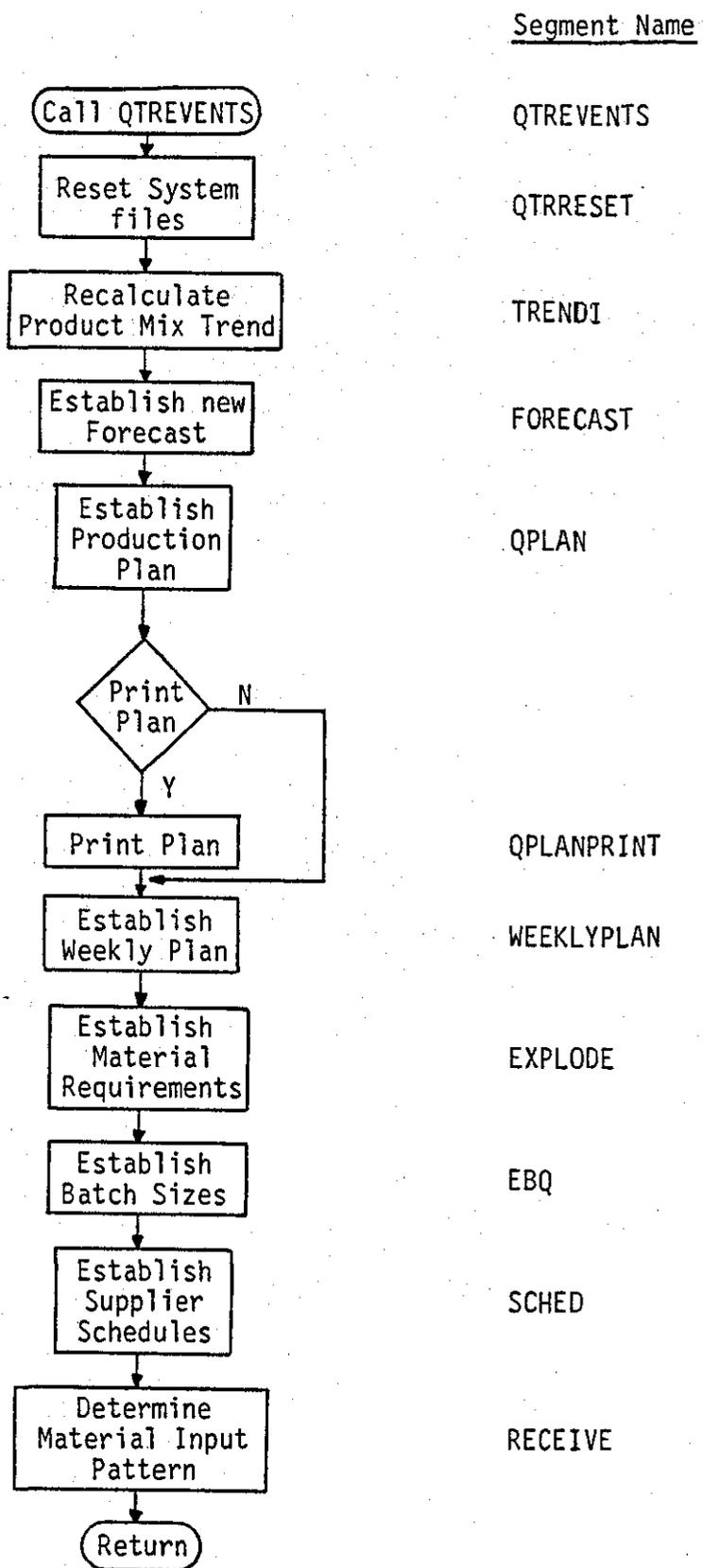
The timing mechanism comprises timing cells which are decremented each logical week. The primary cells are the weekly counter, which defines the simulation period, the monthly counter which initiates the monthly activities and the quarterly counter which initiates the quarterly activities. The secondary cells are contained within the system queues (allocation, line and test) and control the appropriate execution logic.

3.4.5.5. Summarised Flowcharts

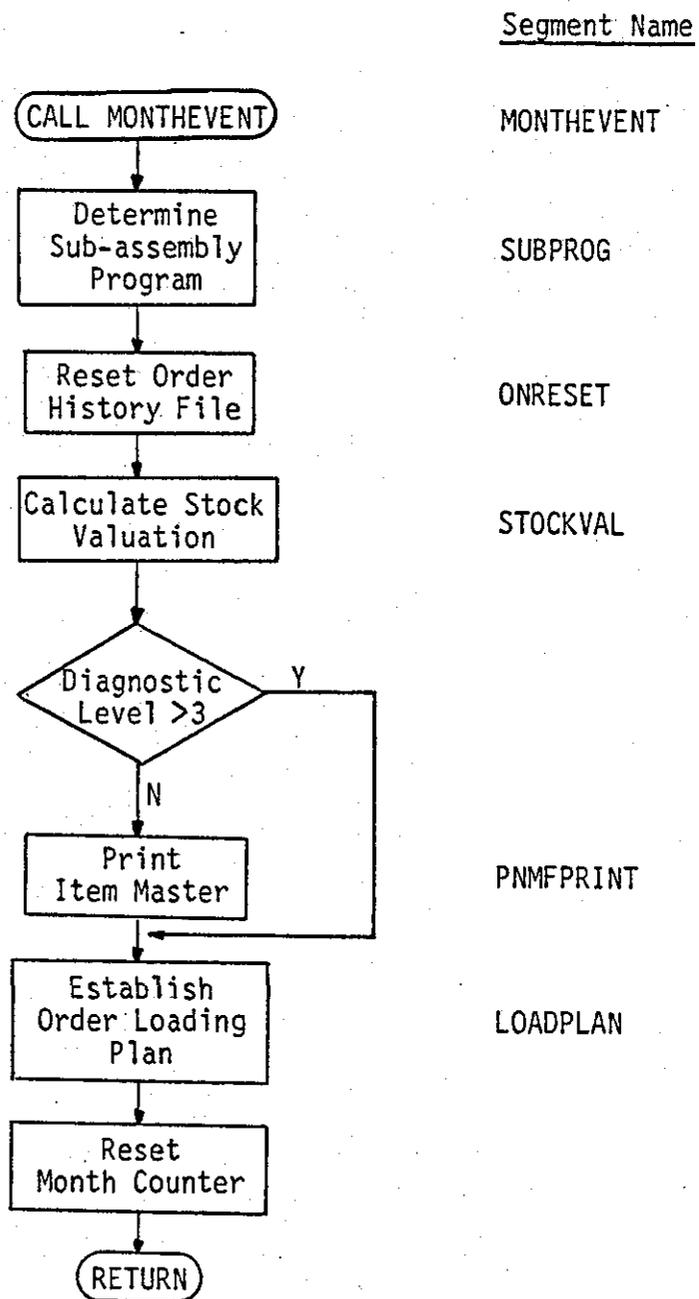
The flowcharts of the primary program segment are indicated with the name of the program module where applicable. Full details of each segment may be found by referencing Appendix B - Program Description.



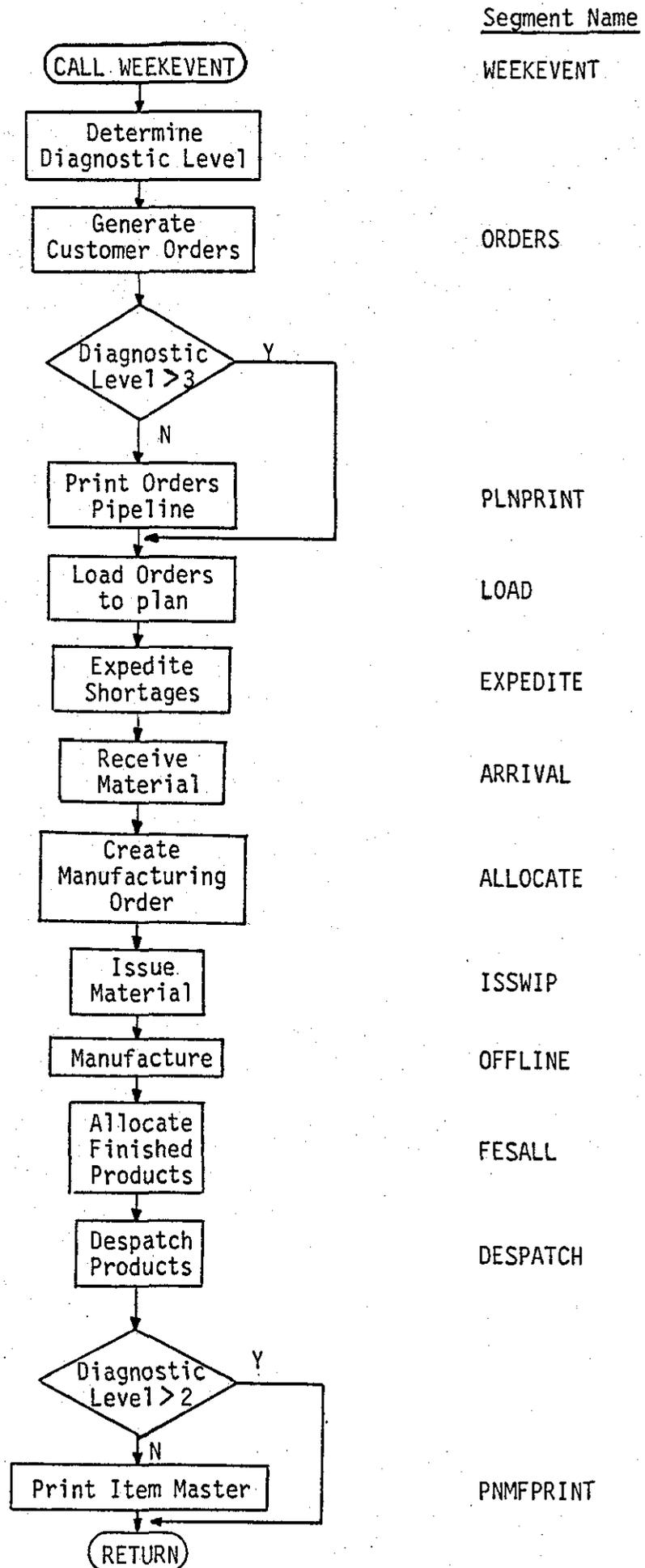
QUARTERLY ROUTINE



MONTHLY ROUTINES



WEEKLY ROUTINES



3.4.5.6. Outputs

The execution of a simulation experiment produces a wide spectrum of output information, dependent upon the diagnostic level selected.

Diagnostic output is in the form of either warning messages or listing of transactions. The efficiency and cost of a simulation experiment is dependent upon the level of diagnostic selected, therefore low levels should only be used by exception.

The experimental output comprises reports on the key performance statistics, the frequency of reporting being also dependent upon the diagnostic level.

a) Stock Valuation

Each stock holding area is valued at the close of each month irrespective of diagnostic level.

The number of components or products in each stock category is derived from the stock status within the Item Master File with the exception of commercial stock. To derive the value of each category, the formulae described in subroutine STOCKVAL are used. Commercial stock units (i.e. products awaiting despatch) are derived by a search of the orders placed file for all items in "despatch" status.

A typical monthly stock valuation report is shown in Fig. 3.20.

STOCK VALUES FOR MONTH	5
COMPONENTS	= £125433
SUB-ASSEMBLIES	= £ 93047
WORK IN PROGRESS	= £ 83892
EQUIPMENT STOCK	= £ 20577
TEST W.I.P.	= £ 29484
COMMERCIAL STOCK	= £ 7633
TOTAL STOCK VALUE	= £ 360066

Fig. 3.20. - Monthly Stock Valuation Report

b) Component Service Level

The frequency of calculation and reporting of service level of components issued from stock to manufacturing is dependent on the diagnostic level selected. Statistics derived within a quarter are cumulative for the period, therefore the most reliable value is the quarter ending statistic.

The service level is defined as the proportion of items available compared with the quantity required at the time an allocation is made.

$$\text{Service level} = \frac{\text{Items required} - \text{Items short}}{\text{Items required}} \times 100\%$$

A sample service level report is shown in Fig. 3.21.

SERVICE LEVEL ACHIEVED

ITEM NUMBER	ITEMS REQUIRED	ITEMS SHORT	SERVICE LEVEL
RW69873	28	0	100.00
RU10034	24	0	100.00
BT49863	5	0	100.00
PP42906	15	0	100.00
PN50006	12	0	100.00
PN10638	3	0	100.00
PN10639	12	0	100.00
PN56043	1	0	100.00
PN69746	24	0	100.00
ET12345	2	0	100.00
FU10000	5	0	100.00
FV25000	5	0	100.00
FS66000	10	0	100.00
TOTAL	146	0	100.00

Fig. 3.21. - Component Service Level Report

c) Delivery Performance

The product delivery performance is measured at three levels.

- (i) Equipment level - the performance of actual delivery date compared with due date is measured and reported.
- (ii) Item level - the performance of the delivery date of the last product despatched against a specific order line/ due date combination is measured and reported.
- (iii) Order level - the performance of the date that the last item on the order is delivered compared with the due date is measured and reported. For part shipment orders it is assumed that all items for a specified due date must be available before delivery may take place.

The delivery performance is presented in three ways:

- the number of deliveries achieved compared with the due date (+/- weeks) is presented for further analysis if required.
- the proportion of deliveries achieved on or before time/ within 3 weeks of due date/within 6 weeks of due date.
- the average lateness, which is defined as

$$\bar{l} = \frac{n_t \times l_t}{N}$$

where \bar{l} = average lateness
 n_t = number of deliveries in week t
 l_t = lateness of week t
N = total deliveries = $\sum_{t=-20}^{t=9} n_t$

Delivery performance is reset and cumulatively calculated through each quarter.

A sample delivery performance report is shown in Fig. 3.22.

DELIVERY PERFORMANCE

	-20	-19	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	
EQUIPMENT																															
MF6AM 01	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.37																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	140	0	0	0	0	0	0	0	0	0	0
MF6AM 02	ON OR BEFORE= 12.50% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.04																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	96	17	0	0	0	0	0	0	0	0	0	0
MF6AM 03	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.82																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	46	17	0	0	0	0	0	0	0	0	0	0	0
AC15PU	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.17																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	60	0	0	0	0	0	0	0	0	0	0	0
TOTAL	ON OR BEFORE= 3.40% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.32																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	165	313	17	0	0	0	0	0	0	0	0	0	0
ITEM																															
MF6AM 01	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.50																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0
MF6AM 02	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.16																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	0	0	0	0	0	0	0	0	0	0	0
MF6AM 03	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 3.00																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
AC15PU	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 2.00																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
ORDERS																															
PART SHIP	ON OR BEFORE= 0.00% WITHIN 3 WEEKS=100.00% WITHIN 6 WEEKS=100.00% LATENESS= 1.73																														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	3	0	0	0	0	0	0	0	0	0	0	0
NO PART SHIP	ON OR BEFORE= 0.00% WITHIN 3 WEEKS= 0.00% WITHIN 6 WEEKS= 0.00% LATENESS= 0.00																														
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

Fig. 3.22. - Delivery Performance Report

d) Lead Time Achieved

The promised delivery lead time at the point of order loading is presented for further analysis if required. A sample lead time report is shown in Fig. 3.23.

This report has been included as the facility is available in the model. However, no conclusions using the lead time information have been drawn.

LEAD TIME ACHIEVED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	
MF6AM 01																										
0	0	0	0	0	0	0	0	0	0	0	0	49	203	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
MF6AM 02																										
0	0	0	0	0	0	0	0	0	0	36	9	88	63	14	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
MF6AM 03																										
0	0	0	0	0	0	0	0	0	0	4	21	0	21	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
AC15PU																										
0	0	0	0	0	0	0	0	0	0	0	0	0	69	30	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

Fig. 3.23. - Lead Time Report

3.4.5.7. Sampling Profiles

The sampling profiles used by the simulation model are derived from the real world data described in Section 3.3. - Data Acquisition.

The range of data within the model has necessarily been scaled down from the actual situation to permit a meaningful analysis of results. This is most apparent in those characteristics which have a direct impact on transaction volumes. Thus, the number of products and components have been substantially reduced, although the rate of orders received for a typical product has been maintained at approximately the actual order of magnitude.

Modification of the sampling profiles to evaluate changes in the environment are feasible but care must be taken since certain changes will cause file size constraints to be exceeded or may result in excessively long experimental run times.

The orders received profile for each product is dependent upon four factors:

- the rate of order input
- the number of item lines per order
- the product specified on each item line
- the quantity of each item line

The observed number of orders per week is 155 with a co-efficient of variation of 0.18. This value is based on a sales catalogue of 354 products, of which some 20% are inactive (or are rarely ordered special variants of products for certain customer groups), leaving approximately 260 active products.

The number of products in the model is only four, but is intended to represent a scaled down view of the actual system. Two views of the scaling factor are possible:

- (i) the ratio of order volume is the same as the ratio of products for the active product range, being a factor of 4:260 or 1:65. This assumption does not take account of the fact that many of the 260 products are rarely ordered.
- (ii) the ratio of order volume is the same as the ratio of products contributing to 80% of the sales volume, being a factor of 4:28 or 1:7. This assumption was considered unrealistic, since it would result in an order volume per product considerably in excess of the actual situation.

A compromise was selected, whereby the order volume was 5.0 per week, being a scaling factor of 5:155 or 1:31, but compensating for the reduced number of products by increasing the co-efficient of variation from 0.18 to 0.30.

This approach, it will be seen, generates data volumes which are within the file size constraints of the model and provides a realistic view of the orders received patterns.

The number of items per order selected for the model is based on the survey proportions but adjusted to reduce the emphasis on single item line orders. This decision was taken because many of the single item orders in practice tend to be the uncommon product types and also because of the adverse effect on model file sizes. The small differences between the model and actual proportions are unlikely to affect the general model performance other than to marginally influence the "no part shipment" order performance.

The comparison between the survey and model proportions is shown in Table 3.9.

<u>NUMBER OF ITEMS</u>	<u>SURVEY PROPORTION</u>	<u>MODEL PROPORTION</u>
1	0.50	0.35
2	0.18	0.30
3	0.13	0.20
4	0.07	0.10
5	0.05	0.05
5	<u>0.07</u>	<u>-</u>
	1.00	1.00

Table 3.9. - Number of Items per Order

The mean for the survey of 2.25 compares with the model mean of 2.10.

The profile is described in the model as a cumulative form of the frequency histogram shown in the table.

The probability that a product will be required for a given order line is dependent upon its relative popularity. This has been described in Fig. 3.10. To obtain a representative profile for

the model, the top 80% volume has been scaled back to the number of products in the model as shown in Fig. 3.24.

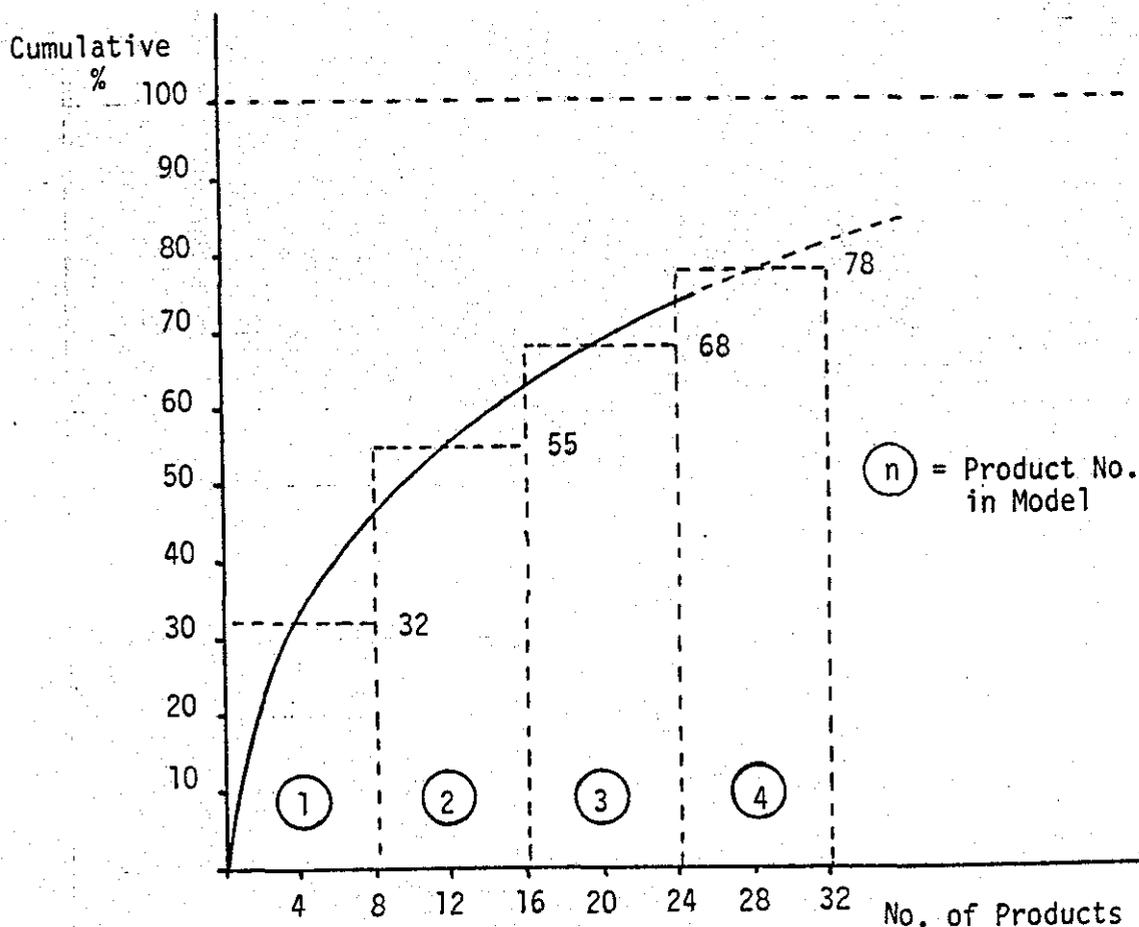


Fig. 3.24. - Product Popularity and Relative Contribution

The contribution of each of the four products has been derived from the relative contribution of each group of eight products as shown and the cumulative values have been derived by observation as indicated. The comparison of these results with the model profile is shown in Table 3.10.

<u>PRODUCT</u>	<u>RELATIVE VALUE</u>	<u>CONTRIBUTION</u>	<u>% CONTRIBUTION</u>	<u>* MODEL</u>
1	32	32	41	40
2	55	23	29	25
3	68	13	17	20
4	78	<u>10</u>	<u>13</u>	<u>15</u>
		78	100	100

* Note that products 3 and 4 are transposed in the program coding within the model.

Table 3.10. - Product Popularity Profile

The profile has been rounded to convenient 5% values and is held in the model as a cumulative frequency histogram.

It has already been shown that the quantity of each item line cannot be described by a continuous distribution, due to the practice of ordering in logical or "rounded" quantities. The decision was, therefore, taken to define the order quantity as a frequency histogram with discrete permissible order quantities. The statistics displayed in Table 3.3. can be restated in ranges of quantity as shown in Table 3.11.

SAMPLE			MODEL	
ORDER QTY RANGE	WEIGHTED MEAN	RELATIVE FREQUENCY	ORDER QUANTITY	RELATIVE FREQUENCY
1	1	32	1	10
2 - 3	2	23	2	15
4 - 7	5	18	5	25
8 - 15	10	13	10	20
16 - 40	25	9	25	15
41 - 80	50	3	50	10
81	100	2	100	5
		100		100

Table 3.11. - Order Quantity Determination

The expected order quantity of the sample is 8.73 compared with the model value of 17.40. The profile in the model has been biased towards higher order quantities because, as previously discussed:

- many of the small order sizes are for the less popular varieties;
- the predominance of small orders in the model would dramatically increase the file space and experimental runtimes.

The final definition of the customer order input is to determine whether part shipment is permissible. The statistic has been derived directly from the Manufacturing Control System survey, where the ratio of part shipment to no part shipment orders was observed as 1:3. This profile is held as a cumulative frequency histogram in the model.

A further group of profiles relate to the supply of material into the receiving department.

The profile of material receipts has been shown in Fig. 3.12. This is compared in Table 3.12. with the profile contained in the model.

	<u>TIME</u>	<u>ACTUAL PROPORTION</u>	<u>MODEL PROPORTION</u>
Late	T - 4	0.4	1
	T - 3	2.0	2
	T - 2	5.4	6
	T - 1	14.0	14
	On Time (T)	41.0	40
Early	T + 1	29.8	30
	T + 2	<u>7.4</u>	<u>7</u>
		100.0	100

Table 3.12. - Material Receipt Profile

The material receipt profile shown is for normal material input and is maintained in the model as a cumulative frequency histogram. Since the model cannot accept actual receipts in "negative" time, all arrears to schedule at the end of each period are re-scheduled into

future periods. This profile is difficult to compare with the real situation, since the duration of actual shortages rather than the arrears to schedule, which often do not materialise as shortages for some weeks, are monitored. The profile adopted in the model, therefore, is based on personal assumptions rather than measured facts. It has the form shown in Table 3.13. and is held in the model as a cumulative frequency histogram.

<u>RESCHEDULE TIME (WEEKS)</u>	<u>RELATIVE FREQUENCY</u>
1	15
2	15
3	50
4	15
5	<u>5</u>
	100

Table 3.13. - Arrears Input Profile

A further profile that was considered impossible to derive from existing data is the effect of expediting on the actual receipt data. An algorithm has been developed to indicate the relative importance of the various factors involved and is explained in the program description (Appendix B). The logic is based on a "success" factor, which is used to determine the proportion of the outstanding lead time which may be reduced through expediting action. This factor is held in the model as a cumulative frequency histogram according to Table 3.14.

<u>FACTOR</u>	<u>RELATIVE FREQUENCY</u>
1	5
2	10
3	15
4	20
5	25
6	15
7	<u>10</u>
	100

Table 3.14. - Expedited Input Factors

Thus, if the outstanding lead time is 8 weeks and the factor 4 is sampled, the due date may be advanced by $8/4$, or 2 weeks.

Goods entering the receiving department are subject to a receiving inspection based on sampling procedures. The actual procedures are dependent upon the supplier, the commodity and other factors, (e.g. the availability of inspection equipment). The information available for the items actually inspected indicates an approximately normal distribution of reject proportion with a mean of 3.7% and a co-efficient of variation of 0.27. The proportion of partly rejected batches was 11%. (Section 3.3.4.3. - Receiving Inspection Lot Rejection).

The logic adopted in the model is a two step process as described in the program summary (Section 3.4.5.3. - Execution). The probability that a reject exists is given by a cumulative frequency histogram with a probability of 20%. The proportion found to be reject is then determined from a normal distribution with a mean of 4% and a co-efficient of variation of 0.3.

When items are rejected, a certain lead time must elapse before they are corrected and re-delivered by the supplier. The re-supply profile as shown in Fig. 3.16. has been approximated to a truncated (i.e. no negative values) normal distribution with a mean of 6 weeks and co-efficient of variation of 0.3. (Section 3.3.4.4. - Resupply Times).

The final profile describes the length of time which elapses between the authorisation of a material request from stores and its delivery to the production department. Due to the limited number of products selected, it was not considered realistic to simulate a queue in this area. A lead time of approximately 8 days is the norm in practice, which has been simulated by a normal distribution with a mean of 8 and an assumed co-efficient of variation of 0.3.

3.4.5.8. Validation Techniques

The problem of model validation is complex, especially in a simulation model with such a scope of planning and executional routines. Naylor et al (1966) states that "the problem of validating computer simulation models is indeed a difficult one because it involves a host of practical, theoretical, statistical and even philosophical complexities". No straight answer is given to this problem other than:

- test how well the simulated values of the endogenous variables compare with known historical data.
- check how accurate are the simulation model's predictions of behaviour of the real system in future time periods.

A number of methods for verification are postulated, including "synthetic apriorism", "ultraempiricism" and "positive economics". All are based on economic models and do not necessarily apply in the case of a specific business model as described.

In the context of the simulation model defined in this chapter, the primary question is whether the processes described are sufficiently close to the real world and the assumptions sufficiently realistic to provide a reasonably high expectation that the model will behave in a manner similar to the real world under the conditions defined.

Validation, therefore, was approached in two steps. The first step was the definition of each program segment, which had to conform both in logic and timing to the actual process. This could only be achieved through a detailed knowledge of the processes involved both through observation and experience.

The second step was the critical evaluation of experimental results, with particular emphasis upon the evolution of results through each planning cycle, to ensure that the outputs were "acceptable". Acceptable in this context means within a range of values that may be considered reasonable to expect under the experimental conditions chosen.

The first step was the most difficult to achieve, especially in those segments emulating the planning process. In this case, Planners in the plant were asked, "would this plan be acceptable to you given the parameters defined". The verdict, without exception, was that the planning procedures were a reasonable and acceptable simulation of the actual process.

The second step embraces both the individual execution transactions and the aggregate effect of all transactions as the model moves through time. Observation of sample simulation results led to a number of conclusions.

- (i) the model is stable under a wide range of parameter changes;
- (ii) experimental results lie well within the range of acceptability of knowledgeable materials management practitioners.

The final confirmation of the verification process was to derive "norms", to which the experimental results should conform. The norms were derived by observing the actual situation and applying the processes, rules and parameters to the data used within the simulation model. This was considered a key quantifiable validation technique and is described in detail in Section 3.4.5.9. - Normative Stock Levels.

3.4.5.9. Normative Stock Levels

The normative levels of stock are based on the current plan obtaining, and will thus be dynamic over a period of time. To enable a simple view of the normative levels to be taken, a theoretical approach based on the simulation model parameters has been adopted.

This argument is based on a steady state condition with zero trend applied to the orders received generator. Given such conditions, the average level of plan will tend to conform to the orders received level over a long period of time.

The expected volume of business for each product type can be derived from the orders generator parameters.

Quantity

The expected quantity of each order is obtained from Table 3.11. as follows:

<u>QUANTITY</u>	<u>PROBABILITY</u>	<u>PRODUCT</u>
1	0.10	0.10
2	0.15	0.30
5	0.25	1.25
10	0.20	2.00
25	0.15	3.75
50	0.10	5.00
100	0.05	<u>5.00</u>

Expected quantity = 17.40
=====

Number of Items

The expected number of order line items is derived from Table 3.9.

<u>NO. OF ITEMS</u>	<u>PROBABILITY</u>	<u>PRODUCT</u>
1	0.35	0.35
2	0.30	0.60
3	0.20	0.60
4	0.10	0.40
5	0.05	<u>0.25</u>
Expected number of items =		<u>2.20</u> =====

Number of Orders

The total number of customer orders generated each week is defined in Section 3.4.5.7. as being normally distributed with a mean of 5.0 and co-efficient of variation of 0.3. Thus the expected number of orders = 5.0.

Total Volume per Week

The total volume of products required each week is the product of the expected quantity per item, the number of item lines per order and the number of orders.

$$\begin{aligned}
 &\text{Expected total volume per week} \\
 &= 17.4 \times 2.2 \times 5.0 \\
 &= 191.4 \\
 &=====
 \end{aligned}$$

Product Mix

The product mix is derived from Table 3.10. and specifies the product type to be assigned to each order item line. Thus, the total volume may be allocated across the product range according to the expected product mix.

<u>PRODUCT</u>	<u>PROBABILITY</u>	<u>EXPECTED VOLUME</u>
MF6AM01	0.40	76.56
MF6AM02	0.25	47.85
MF6AM03	0.15	28.71
AC15PU	0.20	<u>38.28</u>
		<u>191.40</u> =====

It should be noted that the application of trend as defined in the model does not alter the total business level but re-assigns the product mix shown above to the previously determined volume.

Having established the volume of business for each end product, the gross requirement for each comprising sub-assembly and component may be derived by reference to the product structure relationships. This may then be extended by the cost parameters for the various stock categories to determine the base weekly values.

The derivation of unit value is explained in Appendix B. These are summarised below, where

M = basic material cost

L = basic labour cost.

Component value	= M
Sub-assembly w.i.p.	= 1.2M + 2.5L
Sub-assembly stock	= 1.2M + 3.5L
Equipment w.i.p.	= 1.2M + 2.5L
Equipment stock	= 1.2M + 3.0L
Test w.i.p.	= 1.2M + 3.3L
Commercial stock	= 1.2M + 3.5L

The determination of average weekly usage value for each category is illustrated in Table 3.15.

The normative stock levels may be determined as equivalent weeks worth of throughput and subsequently converted into monetary values. The basis for deriving the level for each category is now indicated.

Components

The total component stock can be regarded as the sum of three elements: buffer stock, supplier lot sizing and allocated stock.

The buffer stock is the planned value of safety stock in weeks, input to the model as a run parameter. If "a" is the buffer stock parameter in weeks and "r" is the weekly demand, then the buffer

REF	ITEM	SUMMARISED REQUIREMENT FOR				GROSS REQUIREMENT / WEEK AT EXPECTED VOLUME				GROSS WEEKLY REQ	COST ELEMENTS £		UNIT VALUE £				COMP	AVERAGE WEEKLY USAGE £'000				EQU STOCK	
		MF6AM01	MF6AM02	MF6AM03	AC15PU	MF6AM01	MF6AM02	MF6AM03	AC15PU		MATL	LAB	S/A STOCK	S/A WIP	EQU WIP	TEST WIP		EQU STOCK	S/A STOCK	S/A WIP	EQU WIP		TEST WIP
1	MF6AM01					76.56				76.56	53	12			93.6	103.2	99.6				7166.0	7901.0	7625.4
2	MF6AM02						47.85			47.85	53	12			93.6	103.2	99.6				4478.8	4938.1	4768.9
3	MF6AM03							28.71		28.71	53	12			93.6	103.2	99.6				2687.3	2962.9	2859.5
4	AC15PU								38.28	38.28	25	5			42.5	46.5	45.0				1626.9	1780.0	1722.6
5	AT12345	1	1	1		76.56	47.85	28.71		153.12	25	5	47.5	42.5				7273.2	6507.6				*2
6	AT12347	1				76.56				76.56	25	4	44.0	40.0				3368.6	3062.4				*2
7	AT12801		1				47.85			47.85	25	4	44.0	40.0				2105.4	1914.0				*2
8	AT12802			1				28.71		28.71	25	4	44.0	40.0				1263.2	1148.4				*2
9	AT27896				1				38.28	38.28	12	2	21.4	19.4				819.2	742.6				*3
10	AT22000				1				38.28	38.28	9	1	14.3	13.3				* 1	509.1				*3
11	RK69873	3	3	3		229.68	143.55	86.13		459.36	7									459.4			
12	RU10034	1	1	1		76.56	47.85	28.71		153.12	1									153.1			
13	BT49863	1	1	1		76.56	47.85	28.71		153.12	18									2756.2			
14	PP42906	1	1	1	3	76.56	47.85	28.71	114.84	267.96	1									268.0			
15	PN50006		1		1		47.85		38.28	86.13	1									86.1			
16	PN10638			1				28.71		28.71	1									28.7			
17	PN10639				5				191.40	191.40	1									191.4			
18	PN56043	1				76.56				76.56	1									76.6			
19	PN69746	1	1	1		76.56	47.85	28.71		153.12	1									153.1			
20	ET12345				1				38.28	38.28	6									229.7			
21	FU10000	1	1	1		76.56	47.85	28.71		153.12	22									3368.6			
22	FV25000	2	2	2		153.12	95.70	57.42		306.24	3									918.7			
23	FS66000				1				38.28	38.28	110									382.8			
TOTAL VALUE PER CATEGORY																9072.4	74829.6	13884.1	15959.0	17582.0	16976.4		
GROSS-ASSEMBLY W.I.P.																44672.7							

- *NOTE: 1 Sub-Assembly AT22000 not stocked
2 3 Week Manufacturing Lead Time
3 4 Week Manufacturing Lead Time

Table 3.15. - Calculation of average weekly Usage Value

stock element

$$S_1 = a \times r \dots\dots\dots (1)$$

Supplier batches relate directly to the schedule quantities (except in the case of reject quantities, which may be regarded as relatively insignificant), thus the mean stock level attributable to supplier lot sizing

$$S_2 = 2 \times r \dots\dots\dots (2)$$

The value of allocated stock (note that buffer stock is planned free stock) is related to the frequency of disbursements. Stock disbursements are attributable to demands for equipment manufacture which are scheduled in two week lots each two weeks, and sub-assembly manufacture, which are batched according to "economic batch quantity" rules. It will be shown (cf. Sub-assembly Stock) that the weighted cycle time for sub-assembly batches is 2.6 weeks. Since sub-assemblies consume 1.5 times the component value of equipments, a weighted cycle time for both equipment and sub-assembly demands has been selected as 2.3 weeks. Thus the mean stock level attributable to demand lot sizing

$$S_3 = 1.15 \times r \dots\dots\dots (3)$$

The total component stock is thus the sum of the three elements

$$\begin{aligned} S_c &= S_1 + S_2 + S_3 \\ &= a \times r + 2 \times r + 1.15r \\ &= r(a + 3.15) \end{aligned}$$

Thus, given the weekly demand value, the total component stock may be expressed as a function of the buffer stock weeks selected.

Using the data displayed in Table 3.15. where the usage value of component stock is £9072.4 per week, the stock value for a selection of buffer stock parameters may be derived, as in Table 3.16.

<u>BUFFER PARAMETER</u> <u>(WEEKS)</u>	<u>TOTAL STOCK</u> <u>(WEEKS)</u>	<u>STOCK VALUE</u> <u>(£)</u>
0	3.15	28578
2	5.15	46722
4	7.15	64868
6	9.15	83012
8	11.15	101157

Table 3.16. - Component Buffer Stock Weeks versus Value

Sub-Assembly Stock

The sub-assembly stock level is dependent upon three factors; the lot sizing of input batches, the buffer stock rules, the level of allocated stock.

The lot sizing for each stocked part is dynamic over the life of a simulation experiment, however, the expected lot size and number of batches may be derived from the average demand data in Table 3.15. This may then be interpreted as shown in Table 3.17. below to give the weighted cycle time between batches. The formula used to derive the "economic batch quantity" is that used in the subroutine EBQ and described in Appendix B.

<u>ITEM NUMBER</u>	<u>QUARTERLY DEMAND</u>	<u>NUMBER OF BATCHES</u>	<u>BATCH SIZE</u> (a)	<u>CYCLE TIME (WKS)</u> (b)	<u>a x b</u>
AT12345	1990	13	153	1	153
AT12347	995	6	166	2	332
AT12801	622	4	156	3	468
AT12802	373	4	93	3	279
AT27896	498	3	166	4	664
AT22000	* Non-stocked assembly *				
			$\Sigma a = 734$		$\Sigma(a \cdot b) = 1895$

Table 3.17. - Sub-Assembly Batch Parameters

The weighted cycle time is given by

$$b' = \frac{\sum(a \cdot b)}{\sum a} \dots\dots\dots (5)$$

$$= 2.6$$

Thus, the average stock value in weeks attributable to input batches is $b'/2 = 1.3$ weeks.

Equipment batches are allocated each two weeks, thus the average value of allocated stock is 1 week.

The total sub-assembly stock is, therefore,

$$S_s = r(b + 1 + 1.3)$$

$$= r(b + 2.3)$$

Where r is the demand rate/week and b is the number of weeks of planned buffer stock.

Using the data in Table 3.15., the relationship between planned buffer weeks and stock value may be determined, as shown in Table 3.18. below.

<u>PLANNED BUFFER</u> <u>(WEEKS)</u>	<u>TOTAL STOCK</u> <u>(WEEKS)</u>	<u>STOCK VALUE</u> <u>£</u>
0	2.3	34109
2	4.3	63769
4	6.3	93429
6	8.3	123089

Table 3.18. - Sub-Assembly Planned Buffer Weeks versus Value

Assembly Work in Progress

The normative level of assembly work in progress is the sum of equipment and sub-assembly stock.

The equipment batches are based on two weeks worth of forward requirement expected to be issued at the point at which the work in progress level has dropped to less than the planned lead time. Since the sub-routine is activated weekly, it will not normally fall below the lead time less one week. A mean value of lead time less one half of a week is therefore assumed. The level of work in progress related to equipments is

$$S_E = r(L - 0.5 + 1.0)$$

$$= r(L + 0.5) \dots\dots\dots(6)$$

where L is the manufacturing lead time
r is the production rate per week.

Sub-assembly issues are controlled by the sub-assembly schedule contained within SUBFILE, which in turn is derived from subroutine SUBPROG. The value of work in progress is, as for equipments, the sum of the manufacturing lead time plus one half of the issue cycle time. The weighted issue cycle time (cf. Appendix B) is 2.5 weeks, hence the mean level of sub-assembly related work in progress is

$$S_s = r(1 + 1.25) \dots\dots\dots (7)$$

The normative work in progress stock may now be derived from the data in Table 3.15.

<u>ITEM TYPE</u>	<u>LEAD TIME (WEEKS)</u>	<u>TOTAL STOCK (WEEKS)</u>	<u>USAGE VALUE PER WEEK</u> £	<u>STOCK VALUE</u> £
Equipment	2	2.5	15959	39898
Sub-assembly	3	4.25	12632	53686
Sub-assembly	4	5.25	1252	<u>6573</u>
				<u>100157</u> =====

Table 3.19. - Elements of Assembly Work in Progress

Test Work in Progress

The value of test work in progress is nominally two weeks worth of throughput, but it should be noted that the control exercised by the model is very indirect, the actual level being the result of input from assembly work in progress, allocations from equipment stock and output to the delivery plan.

Based on the above assumption of two weeks worth of throughput, test work in progress value is

$$S_t = 2.r \dots\dots\dots (8)$$

From the data given in Table 3.15. the normative value of test work in progress is 2 x 17582 = £35164.

Finished Equipment Stock

Since production output is a combination of customer orders and stock, the level of finished equipment stock is geared to three factors:

- Production build rate
- Number of customer orders in production build
- Number of customer orders allocated from stock

This is shown pictorially in Fig. 3.24. below.

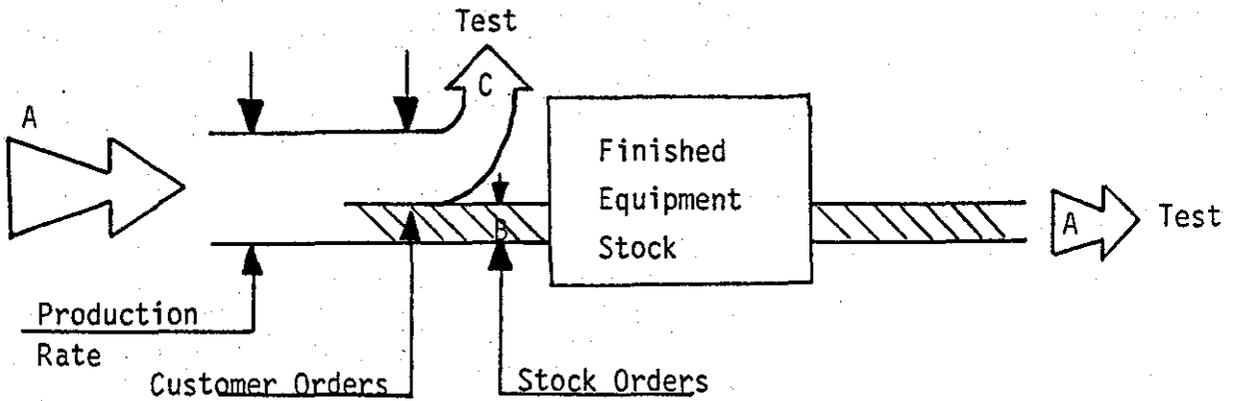


Fig. 3.24. - Finished Equipment Stock Movements

The level of finished equipment stock is determined by the differential rate of stock build to stock withdrawal. If the production rate is 'A', the stock build rate is 'B', the customer order build is 'C' and the allocation rate is 'D', then

$$A = B + C \quad \dots\dots\dots (9)$$

If the customer order loading rate is 'E', then

$$E = C + D \quad \dots\dots\dots (10)$$

Thus

$$B - D = A - E \quad \dots\dots\dots (11)$$

Under steady state conditions, the loading rate is equal to the production rate and the stock input equals stock allocated. Any underload against the production plan will cause stock to increase and conversely, overloads will reduce the stock level. Thus, control of equipment stock is in the order loading mechanism.

The rate of order loading is determined by subroutine LOADPLAN. Two factors are taken into account: overdue orders and excess stock. Assuming that overdue orders and stock excess will not occur simultaneously, the stock level is determined by the stock calculation, where free stock is balanced against the mean authorised stock level. One element of the normative level of finished equipment stock is therefore

$$S_f = r \times f/2 \dots\dots\dots (12)$$

where f is the maximum authorised stock level in weeks.

The second element contributing to the normative finished equipment stock is the number of products allocated to customers but not yet moved into test. Subroutine ALLOCATE searches for orders due up to six weeks ahead when allocating equipment stock (i.e. increasing the number of allocated products and thus reducing free stock). Note that allocated stock is still physical stock. Of the six weeks ahead, three weeks are accounted for by the transfer of products into test work in progress by subroutine FESALL, which searches for orders due up to the current week plus two. The balance of three weeks is the time planned for allocated stock status.

The volume of allocated stock is a function of the proportion of orders being allocated from stock rather than being made to order. This proportion is difficult to determine but, in the extreme, if stock is always available, the mixed mode operation will tend to make to stock mode. The level of allocated stock then tends to four weeks worth of throughput.

It should be noted that, due to lack of formal stock management policy, these procedures cannot be easily validated in the real world.

The relationship between the number of weeks of authorised stock and the resultant stock value may therefore be derived from the data in Table 3.15. and is portrayed below in Table 3.20.

<u>AUTHORISED STOCK (WEEKS)</u>	<u>MEAN LEVEL (WEEKS)</u>	<u>ALLOCATED STOCK (WEEKS)</u>	<u>TOTAL STOCK (WEEKS)</u>	<u>STOCK VALUE (£)</u>
0	0	* 3	3	* 50928
2	1	3	4	67904
4	2	3	5	84880

* NB: In make to order mode, the allocated stock and total stock are zero.

Table 3.20. - Planned Equipment Stock versus Value

Commercial Stock

The normative level of commercial stock is dependent upon the ratio of part shipment to no part shipment orders, the number of weeks of phasing and the delivery performance. Given that the planning is directed towards achieving 100% delivery performance, the normative stock should only be based on items kitted in preparation for despatch.

The derivation of the normative level from the base data is highly complex. To determine the number of weeks of delivery and the expected quantity for each delivery, we have to know

- a) the product type
- b) the rate for each product
- c) the proportion of the delivery plan already committed
- d) whether part or no part shipment
- e) the size of each order item

For ease of analysis, a typical week from the orders placed file was selected for study. The file chosen for analysis was Week 29 of an experiment with mixed mode, 4 weeks equipment and sub-assembly buffer stock and 8 weeks component buffer stock, with

ORD NO.	DELIVERY WK/QTY					ORD NO.	DELIVERY WK/QTY					ORD NO.	DELIVER WK/QTY				
	5	4	3	2	1		5	4	3	2	1		5	4	3	2	1
51				21	4	86					1					2	
66					40						2					5	
					5	87					2					7	
					5						10		18	25		7	
59					25	29					1					25	
					2						10					5	
					25						2					5	
24			3	18	4	30					2				7	18	
				50	50						25		10	11	61	18	
47				10	15						10					1	
82					5						1					50	
					5	32					50					1	
					5						5					1	
39				45	5						5					5	
77					10	33			7		3				2	8	
					2						5				25	18	
43					5	34					1		7			2	
55			13	25	12						10				1	9	
	3	3	3	5	11	35			4		1				7	18	
				10				34	19	46	1					10	
78				5	5	36					2					5	
					25	37			19	25	6					10	
56					5	40					2					2	
					1	41					5					8	
57					25						5				2	40	
				3	22	42					2				10	2	
					2	44					2					5	
67					5		15	15	25	25	20					10	
				16	19						2					2	
					2	45					2					5	
					10	46					25					2	
79				3	7						5				37	63	
58				23	27					10	15					5	
					25	48				75	5					5	
68					2						25					25	
					2	49					1					25	
83					10						25					5	
					2						5					7	
					25	50					5					1	
			30	39	31	52					5		13	40	40	10	
				43	7						25					4	
84				2	8					11	14					1	
85					2	53					1						

TOTAL	18	91	228	771	1330
NUMBER	2	6	12	36	128
MEAN	9.0	15.2	19.0	21.4	10.4

Table 3.21. - Orders Placed File Analysis

zero trend. Order profile characteristics were as described in Section 3.4.5.7.

The data summarised in Table 3.21. indicates for each order the number of items, the number of delivery batches and the quantity per batch.

The weighted mean cost of a product has been derived as shown in Table 3.22. below.

<u>PRODUCT</u>	<u>MATERIAL COST</u>	<u>LABOUR COST</u>	<u>FSP * (£)=x</u>	<u>PROPORTIONAL DEMAND = y</u>	<u>x.y (£)</u>
MF6AM01	53	12	105.6	0.40	42.24
MF6AM02	53	12	105.6	0.25	26.40
MF6AM03	53	12	105.6	0.15	15.84
ACI5PU	25	5	47.5	0.20	<u>9.50</u>
				TOTAL =	<u>£93.98</u> =====

* Note: The FSP, or Commercial Stock Value, is calculated from the relationship given in Appendix B.

Table 3.22. - Weighted Mean Product Cost

The data in Table 3.21. indicates the total quantities due for each delivery week. If these values are now divided by the total number of orders, the profile of a "typical" order may be derived. To arrive at the expected value of commercial stock, each delivery batch must be multiplied by the number of weeks in stock, noting that items with only one delivery week will be despatched immediately. The proportion of part to no part shipment orders must also be considered, since no part shipment orders are despatched in weekly batches and will not be held in despatch status (under 100% order satisfaction conditions). These extensions are summarised in Table 3.23. below.

<u>TOTAL QUANTITY</u> (n)	<u>TYPICAL QUANTITY</u> (n/60)	<u>WEEK OF DELIVERY</u>	<u>TIME IN DESPATCH</u> (WEEKS)	* <u>VALUE IN DESPATCH PER TYPICAL ORDER (£)</u> (t)
18	0.30	5	4	84.59
91	1.52	4	3	321.41
228	3.80	3	2	535.68
771	12.85	2	1	905.73
1330	22.17	1	0	0
TOTAL VALUE =				<u>£ 1847.41</u> =====

* Note: The value in despatch is the product of the typical quantity x the time in despatch extended by the weighted unit value (£93.98) and the proportion of no part shipment orders (0.75).

Table 3.23. - Value in Despatch per Typical Order

The expected value in commercial stock is therefore the product of the typical order value and the expected number of orders per week as given in Section 3.4.5.7.

$$\begin{aligned}
 S_{cs} &= 5.0 \times t && \dots\dots\dots (13) \\
 &= 5.0 \times 1847.41 \\
 &= \underline{\underline{£9237}}
 \end{aligned}$$

The assumptions taken in deriving the normative level of commercial stock are significant, and are restated for clarity.

- a) Deliveries are according to the quoted due dates.
Earlier or later deliveries will result in excess commercial stock costs.
- b) Phased deliveries are over consecutive weeks.
Observation of the model indicates that this is a reasonable assumption.
- c) The order placed file used for analysis is typical.

By observation of item (a) above, it is clear that the "expected" value derived is the minimum achievable level.

3.5. EXPERIMENTAL DESIGN

The definition, construction, validation and execution of the simulation model all contribute towards the search for a solution to the research problem as defined in Section 1.3.

The primary research objective is to establish a deeper understanding of the impact of safety inventories on the customer service level and derive a compromise which would provide an acceptable customer service level with a minimum inventory investment. The simulation experiments were structured to satisfy this main objective while, at the same time, providing secondary indications of the main factors influencing the performance of the system.

The parameters over which the experimenter has direct control are as follows:

- a) Manufacturing mode (make to order, stock, mixed)
- b) Priority rules (due date, FIFO)
- c) Minimum order book (weeks)
- d) Nominal order book (weeks)
- e) Delivery schedule response time (months)
- f) Finished equipment buffer stock
- g) Sub-assembly buffer stock
- h) Component buffer stock
- i) Capacity utilisation
- j) Orders received trend

Additionally, the profiles of each probability distribution function (p.d.f.) used for sampling may be changed by modifying the DATA statements in the Master program.

The profiles concerned include:

- k) Normal (unexpedited) material receipt spread from due date
- l) Expected receipt date for material arrears
- m) Degree of success of expediting effort
- n) Proportion of receipts with reject quantity
- o) Number of items rejected, given a reject exists
- p) Reschedule lead time for rejected quantities
- q) Issue lead time for components (picking time)
- r) Mean number of customer orders per week
- s) Number of item lines per order
- t) Choice of product for an order line
- u) Choice of quantity for an order line
- v) Proportion of "part shipment" to "no part shipment" orders

Experiments may be replicated by repeating a simulation run with identical parameter selection and initial conditions, by substituting one (or more) random number generator seeds. Antithetic sequences may also be generated by repeating runs with negative seeds.

Sample simulation experiments indicated that, if costs were to be contained, a compromise would have to be reached between the number and duration of the experiments and the statistical precision of the results.

The maximum core available to users of the Loughborough University ICL 1904 S* was limited by the Computer Centre management to 100,000 words. The actual resource required by the model as described, including compression of integer and logical values, was 100,096 words. Execution of the model thus resulted in the computer CPU being totally dedicated for the duration of each experiment. For this reason, experiments were scheduled for overnight processing, with a maximum of two experiments each night. Further, the equivalent commercial cost for a simulated five year period exceeded £150, suggesting that, however desirable, replication should be contained to a minimum level.

A priority list, therefore, had to be established to achieve the best compromise between experimental efficiency and benefit.

PHASE 1 was a series of experiments with the twin objectives of

- providing a quantitative answer to the stock location problem;
- testing the ability of the model to perform rigorous, statistically meaningful, experiments.

Thus, the prime interest is the effect of planned buffer stocks at each formal stock point on customer service level and inventory investment. Three factors must be considered:

- planned safety stock of components
- planned safety stock of sub-assemblies
- planned safety stock of finished equipment.

All other parameters must remain constant. This phase was executed as a 3-factor analysis, full factorial but without replication.

The objective of PHASE 2 was to verify that the model was capable of accepting standard variance reduction techniques. Identical experiments were conducted in terms of parameters and initial conditions, firstly with replication and secondly with antithetic sequences.

PHASE 3 was to provide an indicative view of the effect of certain parameter changes, without the same degree of statistical reliability as Phase 1. The experiments chosen were:

- a) Effect of manufacturing mode on delivery performance
- b) Effect of component buffer stock on service level
- c) Effect of different priority rules on inventory investment and delivery performance
- d) Relationship between commercial stock and delivery performance
- e) Effect of changing capacity utilisation factor on inventory investment and delivery performance
- f) Effect of introducing trend into the orders received pattern
- g) Observation of long term cyclic effects.

The experiments described were considered sufficient to prove the validity of the model, satisfy the primary research objectives and provide further insight into the dynamic performance of the model. Many other experiments were considered possible with the existing model design, some of which are discussed in Section 6 - Recommendations for Further Research.

4. RESULTS

4.1. INTRODUCTION

It has been argued in Section 3.5. - Experimental Design, that the structure of the simulation experiments should be such that the maximum results may be obtained with an acceptable expenditure on computer resource. The strategy adopted should support the main research objectives and, as previously discussed, should permit indicative results to be obtained in the secondary interest areas.

It was concluded that, wherever possible, a set of experiments should be structured in such a way that a number of analyses could be conducted on the results according to the specific research parameters selected. It has been assumed that, since all of the secondary experiments are independent, the multiple use of results across different experiments would not introduce any biased conclusions.

The full series of experiments conducted is shown in Table 4.1. - Experimental Parameters, where in each case any specific parameter under investigation is identified for clarity.

The diagnostic level for each experiment was set to provide monthly summaries of all output statistics, although only quarterly values were recorded for further analysis. Each experiment was for approximately five years of simulated time, of which the first 6 - 9 months was discarded to allow for the establishment of a near steady state condition.

Each simulation experiment demonstrated the normal cyclical nature of the business system where the period of the apparent cycle was similar for each instance. It has therefore been assumed that the statistical mean of all observations over the "steady state" horizon is a reasonable means of performance comparison if an integer number of cycles is included. The validity of these assumptions are evaluated in the discussion of results. (Section 4.4.7.).

RP NO.	MODE	PRIORITY	ORDER BOOK		RESP. TIME	BUFFER			UTIL %	TREND				RUN DATE	OBSERVATION
			MIN.	NOM.		EQU.	SUB.	COMP.		PROD.1	PROD.2	PROD.3	PROD.4		
3	S	D	6	10	2	4	4	8	0.95	0.0	0.0	0.0	0.0	05.11.81	Stock mode
6	M	D	6	10	2	4	0	8	0.95	0.0	0.0	0.0	0.0	16.11.81	Buffer
7	M	D	6	10	2	4	4	4	0.95	0.0	0.0	0.0	0.0	30.10.81	Buffer
8	M	D	6	10	2	4	4	8	0.95	0.0	0.0	0.0	0.0	31.10.81	Buffer/RNT/Various
9	M	D	6	10	2	4	2	8	0.95	0.0	0.0	0.0	0.0	13.11.81	Buffer
10	M	D	6	10	2	4	0	4	0.95	0.0	0.0	0.0	0.0	06.11.81	Buffer
11	M	D	6	10	2	4	4	8	1.05	0.0	0.0	0.0	0.0	10.12.81	Utilisation
12	M	D	6	10	2	0	4	8	0.95	0.0	0.0	0.0	0.0	07.11.81	Buffer
13	M	D	6	10	2	0	0	8	0.95	0.0	0.0	0.0	0.0	24.11.81	Buffer
14	M	D	6	10	2	0	0	4	0.95	0.0	0.0	0.0	0.0	25.11.81	Buffer
15	M	D	6	10	2	0	0	0	0.95	0.0	0.0	0.0	0.0	21.11.81	Buffer
16	S	D	6	10	2	0	4	8	0.95	0.0	0.0	0.0	0.0	14.11.81	Stock mode
17	O	D	6	10	2	0	4	8	0.95	0.0	0.0	0.0	0.0	10.12.81	Order mode
18	M	D	6	10	2	4	4	8	1.10	0.0	0.0	0.0	0.0	10.12.81	Utilisation
19	M	D	6	10	2	2	4	8	0.95	0.0	0.0	0.0	0.0	25.11.81	Buffer
20	M	D	6	10	2	2	2	8	0.95	0.0	0.0	0.0	0.0	21.11.81	Buffer
21	M	D	6	10	2	0	2	8	0.95	0.0	0.0	0.0	0.0	25.11.81	Buffer
22	M	D	6	10	2	2	0	8	0.95	0.0	0.0	0.0	0.0	26.11.81	Buffer
23	M	D	6	10	2	2	4	4	0.95	0.0	0.0	0.0	0.0	26.11.81	Buffer
24	M	D	6	10	2	0	4	4	0.95	0.0	0.0	0.0	0.0	26.11.81	Buffer
25	M	D	6	10	2	4	2	4	0.95	0.0	0.0	0.0	0.0	04.12.81	Buffer
26	M	D	6	10	2	2	2	4	0.95	0.0	0.0	0.0	0.0	28.11.81	Buffer
27	M	D	6	10	2	0	2	4	0.95	0.0	0.0	0.0	0.0	27.11.81	Buffer
28	M	D	6	10	2	2	0	4	0.95	0.0	0.0	0.0	0.0	01.12.81	Buffer
29	M	D	6	10	2	4	4	0	0.95	0.0	0.0	0.0	0.0	01.12.81	Buffer
30	M	D	6	10	2	2	4	0	0.95	0.0	0.0	0.0	0.0	30.11.81	Buffer
31	M	D	6	10	2	0	4	0	0.95	0.0	0.0	0.0	0.0	02.12.81	Buffer
32	M	D	6	10	2	4	2	0	0.95	0.0	0.0	0.0	0.0	02.12.81	Buffer
33	M	D	6	10	2	2	2	0	0.95	0.0	0.0	0.0	0.0	01.12.81	Buffer
34	M	D	6	10	2	0	2	0	0.95	0.0	0.0	0.0	0.0	03.12.81	Buffer
35	M	D	6	10	2	4	0	0	0.95	0.0	0.0	0.0	0.0	03.12.81	Buffer
36	M	D	6	10	2	2	0	0	0.95	0.0	0.0	0.0	0.0	04.12.81	Buffer
37	M	D	6	10	2	4	4	8	0.95	0.04	-0.02	0.0	0.0	08.12.81	Trend
38	M	F	6	10	2	4	4	8	0.95	0.0	0.0	0.0	0.0	11.12.81	Priority rule
39	M	D	6	10	2	4	4	8	1.00	0.0	0.0	0.0	0.0	05.12.81	Utilisation
48	M	D	6	10	2	4	4	8	0.95	0.0	0.0	0.0	0.0	11.12.81	RN4--ve RN3
49	M	D	6	10	2	4	4	8	0.95	0.0	0.0	0.0	0.0	11.12.81	RN3
50	M	D	6	10	2	4	4	8	0.95	0.0	0.0	0.0	0.0	05.12.81	RN2--ve RN1

Notes: Mode - M = Mixed
S = Stock
O = Order
Priority - D = Due Date
F = FIFO

Table 4.1. - Experimental Parameters

The detail of the recorded results is included in Appendix A, only the summaries being shown in this section.

4.2. PRIMARY EXPERIMENTS

4.2.1. Effect of planned Buffer Stock on Delivery Performance

A series of 27 experiments was conducted to evaluate the effect of varying the planned buffer stock values of component, sub-assembly and finished equipment stock. All experimental conditions other than buffer stock values were constant across the series.

The results were analysed as a three-way analysis of variance, with each factor having three levels. The analysis was, therefore full factorial without replication.

Analysis of variance is an accepted and widely understood technique for the evaluation of statistical experiments. Further discussion of the theory was not considered appropriate to this test. Analysis of variance theory and application is fully explained by reference to Hoel (1966); Graybill (1961) and Li (1964).

Simulation experiments were evaluated by use of a computer program offered by the Philips time-sharing service - "Call-20". The programme is designated "BPL:ANOVAN" and is described in the Call-20 users manual.

The results from the simulation experiments associated with the buffer stock evaluation were exhibited in preparation for the analysis of variance as shown in Table 4.2.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	*15	36	35	14	28	10	13	22	6
SUB =2	34	33	32	27	26	25	21	20	9
SUB =4	31	30	29	24	23	7	12	19	8

* RP File Number

Table 4.2. - Simulation Experiment in Relation to Analysis of Variance

As defined above, the factors are as follows:

Factor 1 = Planned equipment buffer

Factor 2 = Planned component buffer

Factor 3 = Planned sub-assembly buffer

Six analyses were performed, being the effect of planned buffer levels on delivery performance observed at equipment, part-shipment order and no-part-shipment order detail, each measured by the proportion delivered on or before time and average lateness. Note that, in the following analyses, proportions are shown as percentages.

4.2.1.1. Equipment performance/proportion on or before time

The results observed from the simulation experiments are shown in Table 4.3.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	57.2	57.1	71.5	60.4	64.1	69.8	60.6	62.3	69.6
SUB =2	59.0	66.8	75.3	64.1	65.6	71.6	60.0	67.4	69.0
SUB =4	60.6	70.4	77.2	69.8	77.8	76.9	69.9	75.5	80.7

Table 4.3. - Equipment/Proportion Results Summary

These data were then presented to the analysis of variance program, with the results as in Table 4.4.

<u>LINE NO.</u>	<u>VARIANCE* COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	557.10	2	278.60
2	2	38.78	2	19.39
3	12	57.03	4	14.26
4	3	434.00	2	217.00
5	13	34.33	4	8.58
6	23	45.13	4	11.28
7	123	<u>25.94</u>	<u>8</u>	3.24
	TOTAL	1192.3	26	

GRAND MEAN = 67.79

* 12 means component of factors 1 and 2.

Table 4.4. - Equipment/Proportion Analysis

It is apparent that factors 1 and 3 have a major effect, with some small effect from factor 2. To further analyse the components, a pool was formed of lines 3, 5, 6 and 7, having:

sum of squares = 162.4
 degree of freedom = 20
 mean squares = 8.12

F-Ratios were then computed as follows.

- a) Main effect = line 1 (equipment factors)
 Error term = pool
 F-Ratio = 34.30 (degrees of freedom = 2,20).
 The probability of the F-Ratio being exceeded by chance = 0.00%.
- b) Main effect = line 2 (component factor)
 Error term = pool
 F-Ratio = 2.387 (degrees of freedom = 2,20)
 The probability of the F-Ratio being exceeded by chance = 11.75%.

- c) Main effect = line 4 (sub-assembly factor)
- Error term = pool
- F-Ratio = 26.72 (degrees of freedom = 2,20)
- The probability of the F-Ratio being exceeded by chance = 0.00%.

It can be concluded that both equipment and sub-assembly buffer stocks have a significant effect on equipment delivery performance as measured by the proportion delivered on or before time. There is evidence of some effect of component buffer stocks, but the F-Ratio test does not show it to be statistically significant.

4.2.1.2. Part Shipment Order Performance/Proportion on or before Time.

The results of the simulation experiments are shown in Table 4.5.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	53.7	56.8	72.7	62.5	61.6	68.5	62.2	63.2	68.4
SUB =2	62.0	64.4	74.2	63.8	64.8	67.6	58.5	66.9	66.5
SUB =4	63.4	67.8	69.4	68.3	78.7	73.5	68.1	73.9	77.9

Table 4.5. - Part Shipment Order/Proportion Summary

The analysis of variance indicated the results shown in Table 4.6.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	323.00	2	161.50
2	2	40.12	2	20.06
3	12	62.19	4	15.55
4	3	303.60	2	151.80
5	13	65.54	4	16.39
6	23	80.39	4	20.10
7	123	65.49	8	8.19
	TOTAL	940.4	26	
	Grand Mean = 66.64			

Table 4.6. - Part Shipment Order/Proportion Analysis

Pool created with lines 3, 5, 6, 7 as line 8.

8	Pool	273.6	20	13.68
---	------	-------	----	-------

F-Ratios were then calculated as follows.

a) Main effect = line 1 (equipment factor)
 Error term = pool
 F-Ratio = 11.81 (degrees of freedom = 2,20)
 The probability of the F-Ratio being exceeded by chance = 0.04%.

b) Main effect = line 2 (component factor)
 Error term = pool
 F-Ratio = 1.466 (degrees of freedom = 2,20)
 The probability of the F-Ratio being exceeded by chance = 25.46%

c) Main effect = line 4 (sub-assembly effect)
 Error term = pool
 F-Ratio = 11.10 (degrees of freedom = 2,20)
 The probability of the F-Ratio being exceeded by chance = 0.06%.

Thus, for the part shipment case, both the equipment and sub-assembly factors indicate a highly significant effect, whilst the component effect on delivery performance is not statistically significant.

4.2.1.3. No Part Shipment Performance/Proportion on or before Time.

The simulation results are shown in Table 4.7.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	45.7	45.6	63.4	48.5	55.8	62.8	48.4	51.2	62.3
SUB =2	51.1	57.1	67.9	50.7	54.2	57.7	47.4	58.4	59.1
SUB =4	51.3	61.5	66.4	60.9	67.9	68.8	60.8	64.6	73.6

Table 4.7. - No Part Shipment Performance/Proportion Summary

The analysis of variance of the observations is given in Table 4.8.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	768.10	2	384.00
2	2	20.66	2	10.33
3	12	50.93	4	12.73
4	3	522.30	2	261.10
5	13	49.08	4	12.26
6	23	120.80	4	30.20
7	123	<u>51.98</u>	<u>8</u>	6.50
	Total	1583.8	26	
	Grand Mean = 57.89			

Table 4.8. - No Part Shipment Performance/Proportion Analysis

Pool created with lines 3,5,6, 7 as line 8.

8	Pool	272.8	20	13.64
---	------	-------	----	-------

F-Ratios were calculated as follows:

- a) Main effect = line 1 (equipment factor)
 Error term = pool
 F-Ratio = 28.16 (degrees of freedom = 2,20)
 The probability of the F-Ratio being exceeded by chance = 0.00%.
- b) Main effect = line 2 (component factor)
 Error term = pool
 F-Ratio = 0.7575 (degrees of freedom = 2,20)
 The probability of the F-Ratio being exceeded by chance = 48.18%.
- c) Main effect = line 4 (sub-assembly factor)
 Error term = pool
 F-Ratio = 19.15 (degrees of freedom = 2,20)
 The probability of the F-Ratio being exceeded by chance = 0.00%.

The results when observing no part shipment order performance as measured by the proportion delivered on or before time demonstrate a similar pattern as for both equipment and part shipment performance, except that the component effect shows even less statistical significance.

4.2.1.4. Relationship between Lateness and Proportion delivered on or before Time.

The relationship between the two methods of measuring delivery performance was observed by displaying graphically some sample results from a series of simulation experiments.

To obtain a spread of values, three experiments were selected, with different but overlapping sets of results as shown in Table 4.9.

SET NO.	RUN NO.	RP FILE	STOCK PARAMETERS		
			EQU.	SUB.ASSY.	COMP.
1	4	8	4	4	8
2	7	10	4	0	4
3	11	14	0	0	4

Table 4.9. - Lateness versus Proportion Experimental Parameters

The sample shown on the scatter diagram in Fig. 4.1., showing the "no part shipment" results, was superimposed by a visual "line of best fit". The assumption was made that the % on or before time cannot exceed 100, thus the negative lateness segment is likely to be asymptotic to the 100% limit.

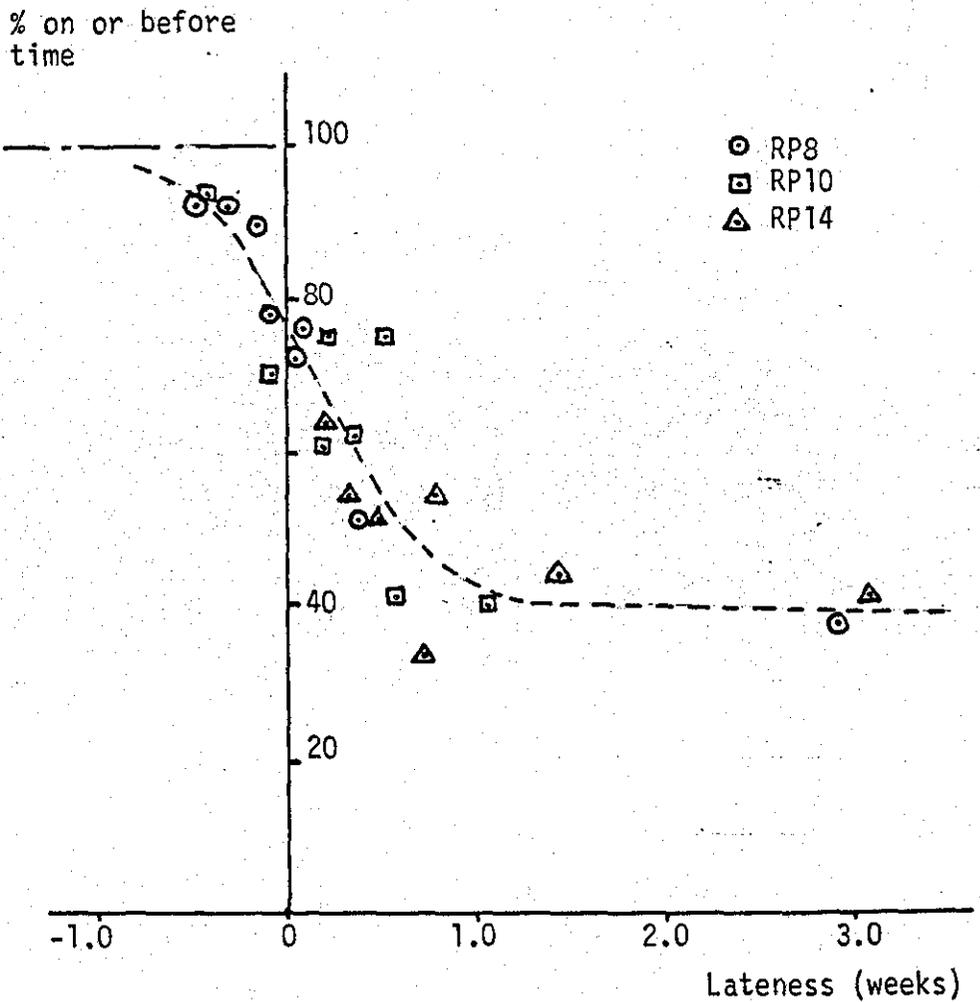


Fig. 4.1. - Relationship between Lateness and Proportion delivered on or before Time.

Two important characteristics are evident from the displayed results. Firstly, there is a large spread around the visual line of best fit, indicating that the confidence intervals around any derived mathematical relationship are likely to be fairly wide, particularly in the area of special interest. Secondly, given extreme conditions such as very early or late deliveries, the curve tends to flatten, thus making any assumed relationship unreliable. It was, therefore, concluded that, to maintain consistency in the main experimental programme, only one measure should be pursued. Since the proportion delivered on or before time is the more widely accepted, this has been selected for all further analysis.

4.2.1.5. Delivery Performance/Buffer Stock Relationship

The results of the preceding analyses of variance each lead to a similar conclusion; that delivery performance is predominantly dependent upon the planned equipment and sub-assembly buffer stocks, and the effect of component buffer stock is comparatively insignificant. This conclusion is consistent with logical reasoning, since the more remote the stock is from the delivery point the more decoupled the interaction between stock and mix fluctuations. This is evident by observation of Fig.1.9. , which demonstrates the theoretical role of each buffer stock. The indications from the theoretical model imply that mix variations resulting from a stochastic orders received pattern will be evident at both the equipment and sub-assembly stock points. Processes further "upstream" are not directly linked to the orders received profile, but are periodically replanned according to the aggregate effect of order mix over a period of time. It can be assumed that order mix has a direct impact on delivery performance, since a regular order mix would result in stable plans and a high delivery performance and conversely, highly unpredictable order mix would result in unstable plans and erratic delivery performance - the degree of instability being a factor of the actual buffer stock and the delivery lead time. It is therefore considered reasonable to assume that, if effects of product mix are absorbed at the delivery end of the process, the influence of buffer stock on delivery performance will behave in a similar manner.

The relative insignificance of the component buffer stock as a contributory factor to delivery performance is an important conclusion and leads to a second level of analysis; the evolution of an approximate mathematical model.

To develop a measure of the absolute contribution of both the equipment and sub-assembly planned buffer stocks on delivery performance, the results at each level of component buffer were considered replications and were pooled, the mean values then being analysed by means of a multiple regression model. The use of this technique assumed that the effects were approximately linear over the observed range of values.

a) Equipment Performance

		Equipment Buffer (weeks)		
		0	2	4
0		57.2	57.2	71.5
		60.4	64.1	69.8
		<u>60.6</u>	<u>62.3</u>	<u>69.6</u>
		$\mu=59.4$	$\mu=61.2$	$\mu=70.3$
2		59.0	66.8	75.3
		64.1	65.6	71.6
		<u>60.0</u>	<u>67.4</u>	<u>69.0</u>
		$\mu=61.0$	$\mu=66.6$	$\mu=72.0$
4		60.6	70.4	77.2
		69.8	77.8	76.9
		<u>69.9</u>	<u>75.5</u>	<u>80.7</u>
		$\mu=66.8$	$\mu=74.6$	$\mu=78.3$

Table 4.10. - Pooled Equipment Performance Results

It can be seen by observation of Fig. 4.2., the assumption of linearity is only valid for the non-extreme cases. For further analysis to be meaningful, only limited ranges of buffer stock parameters may be selected.

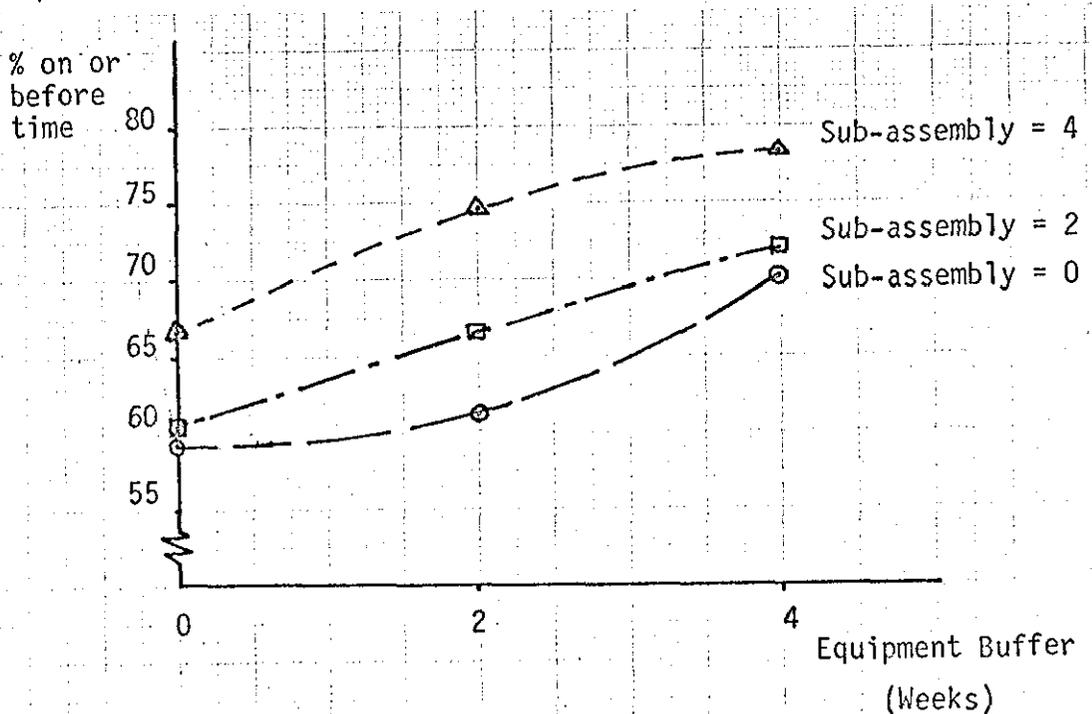


Fig. 4.2. - Equipment Performance Composite Relationship

The mean values were assigned as shown to the multiple regression regression table below, where:

- x_1 = equipment planned buffer
- x_2 = sub-assembly planned buffer
- y = delivery performance value (pooled)

n	1	2	3	4	5	6	7	8	9
x_1	0	0	0	2	2	2	4	4	1
x_2	0	2	4	0	2	4	0	2	4
y	59.4	61.0	66.8	61.2	66.6	74.6	70.3	72.0	78.3

Using the terminology described by Walpole (1968), the sample regression equation for two independent variables may be expressed in the form

$$\bar{y}_{x_1, x_2} = b_0 + b_1x_1 + b_2x_2$$

and each set of observations satisfies the relation

$$y_i = b_0 + b_1x_{1i} + b_2x_{2i} + e_i$$

The least squares estimates of b_0 , b_1 and b_2 are obtained by solving the simultaneous linear equations

$$nb_0 + b_1 \sum_{i=1}^n x_{1i} + b_2 \sum_{i=1}^n x_{2i} = \sum_{i=1}^n y_i$$

$$b_0 \sum_{i=1}^n x_{1i} + b_1 \sum_{i=1}^n x_{1i}^2 + b_2 \sum_{i=1}^n x_{1i}x_{2i} = \sum_{i=1}^n x_{1i}y_i$$

$$b_0 \sum_{i=1}^n x_{2i} + b_1 \sum_{i=1}^n x_{1i}x_{2i} + b_2 \sum_{i=1}^n x_{2i}^2 = \sum_{i=1}^n x_{2i}y_i$$

For the values shown above:

$$\sum_{i=1}^9 x_{1i} = 18 \quad \sum_{i=1}^9 x_{2i} = 18 \quad \sum_{i=1}^9 x_{1i}x_{2i} = 36 \quad \sum_{i=1}^9 x_{1i}^2 = 76$$

$$\sum_{i=1}^9 x_{2i}^2 = 76 \quad \sum_{i=1}^9 y_i = 610.2 \quad \sum_{i=1}^9 x_{1i}y_i = 1287.2$$

$$\sum_{i=1}^9 x_{2i}y_i = 1278.0$$

Substituting these values in the model equations

$$9b_0 + 18b_1 + 18b_2 = 610.2 \quad (1)$$

$$18b_0 + 76b_1 + 36b_2 = 1287.2 \quad (2)$$

$$18b_0 + 36b_1 + 76b_2 = 1278.0 \quad (3)$$

$$(2)-(3) \quad 40b_1 - 40b_2 = 9.2$$

$$b_1 = 0.23 + b_2 \quad (4)$$

$$2x(1) \quad 18b_0 + 36b_1 + 36b_2 = 1220.4 \quad (5)$$

$$(3)-(5) \quad 40b_2 = 57.6$$

$$b_2 = 1.44 \quad (6)$$

$$\text{From (4)} \quad b_1 = 0.23 + 1.44$$

$$b_1 = 1.67 \quad (7)$$

$$\text{From (5)} \quad b_0 + 2(b_1 + b_2) = 67.8$$

$$b_0 = 67.8 - 2(1.44 + 1.67)$$

$$b_0 = 61.58 \quad (8)$$

Thus,

$$\bar{y}_{x_1, x_2} = 61.58 + 1.67x_1 + 1.44x_2$$

where x_1 = equipment buffer stock

x_2 = sub-assembly buffer stock

b) Part Shipment Performance

		Equipment Buffer (weeks)		
		0	2	4
Sub-assembly Buffer (weeks)	0	53.7	56.8	72.7
		62.5	61.6	68.5
		<u>62.2</u>	<u>63.2</u>	<u>68.4</u>
		$\mu=59.5$	$\mu=60.5$	$\mu=69.9$
2	62.0	64.4	74.2	
	63.8	64.8	67.6	
	<u>58.5</u>	<u>66.9</u>	<u>66.5</u>	
	$\mu=61.4$	$\mu=65.4$	$\mu=69.4$	
4	63.4	67.8	69.4	
	68.3	78.7	73.5	
	<u>68.1</u>	<u>73.9</u>	<u>77.9</u>	
	$\mu=66.6$	$\mu=73.5$	$\mu=73.6$	

Table 4.11. - Pooled Part Shipment Performance Results

The composite relationships are shown in Fig. 4.3.

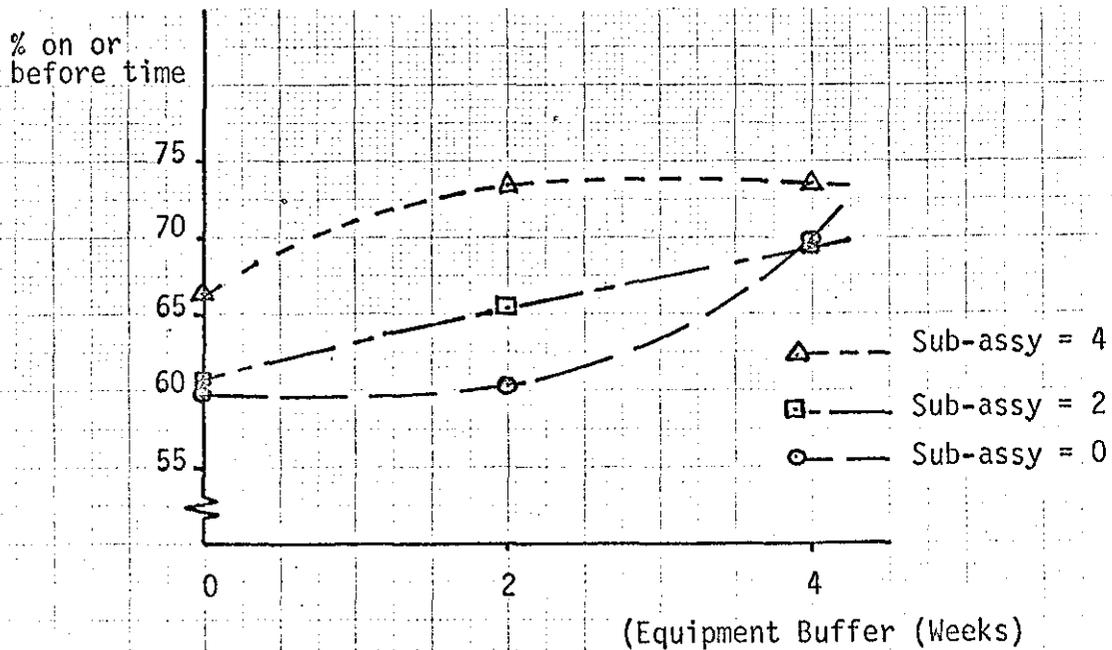


Fig. 4.3. - Part Shipment Performance Composite Relationship

Transforming into the multiple regression table:

n	1	2	3	4	5	6	7	8	9
x ₁	0	0	0	2	2	2	4	4	4
x ₂	0	2	4	0	2	4	0	2	4
y	59.5	61.4	66.6	60.5	65.4	73.5	69.9	69.4	73.6

Thus;

$$\sum_{i=1}^9 x_{1i} = 18 \quad \sum_{i=1}^9 x_{2i} = 18 \quad \sum_{i=1}^9 x_{1i}x_{2i} = 36 \quad \sum_{i=1}^9 x_{1i}^2 = 76$$

$$\sum_{i=1}^9 x_{2i}^2 = 76 \quad \sum_{i=1}^9 y_i = 599.8 \quad \sum_{i=1}^9 x_{1i}y_i = 1250.4 \quad \sum_{i=1}^9 x_{2i}y_i = 1247.2$$

Substituting the values in the model equations:

$$9b_0 + 18b_1 + 18b_2 = 599.8 \quad \dots\dots\dots (1)$$

$$18b_0 + 76b_1 + 36b_2 = 1250.4 \quad \dots\dots\dots (2)$$

$$18b_0 + 36b_1 + 76b_2 = 1247.2 \quad \dots\dots\dots (3)$$

$$(2)-(3) \quad 40b_1 - 40b_2 = 3.2$$

$$b_1 = 0.08 + b_2 \quad \dots\dots\dots (4)$$

$$2x(1) \quad 18b_0 + 36b_1 + 36b_2 = 1199.6 \quad \dots\dots\dots (5)$$

$$(3)-(5) \quad 40b_2 = 47.6$$

$$\underline{\underline{b_2 = 1.19}} \quad \dots\dots\dots (6)$$

From (4) $b_1 = 0.08 + 1.19$

$$\underline{\underline{b_1 = 1.27}} \quad \dots\dots\dots (7)$$

From (5) $b_0 + 2(b_1 + b_2) = 66.6$

$$b_0 = 66.6 - 4.92$$

$$\underline{\underline{b_0 = 61.68}} \quad \dots\dots\dots (8)$$

Thus,

$$\bar{y}_{x_1, x_2} = 61.68 + 1.27x_1 + 1.19x_2$$

where x₁ = equipment buffer stock

x₂ = sub-assembly buffer stock

c) No Part Shipment Performance

		Equipment Buffer (weeks)		
		0	2	4
Sub-assembly Buffer (weeks)	0	45.7	45.6	63.4
		48.5	55.8	62.8
		<u>48.4</u>	<u>51.2</u>	<u>62.3</u>
		u=47.5	u=50.9	u=62.8
2	51.0	57.1	67.9	
	50.7	54.2	57.7	
	<u>47.4</u>	<u>58.4</u>	<u>59.1</u>	
	u=49.7	u=56.6	u=61.6	
4	51.3	61.5	66.4	
	60.9	67.9	68.8	
	<u>60.8</u>	<u>64.6</u>	<u>73.6</u>	
	u=57.7	u=64.7	u=69.6	

Table 4.12. - Pooled No Part Shipment Performance Results

The composite relationship is shown in Fig. 4.4.

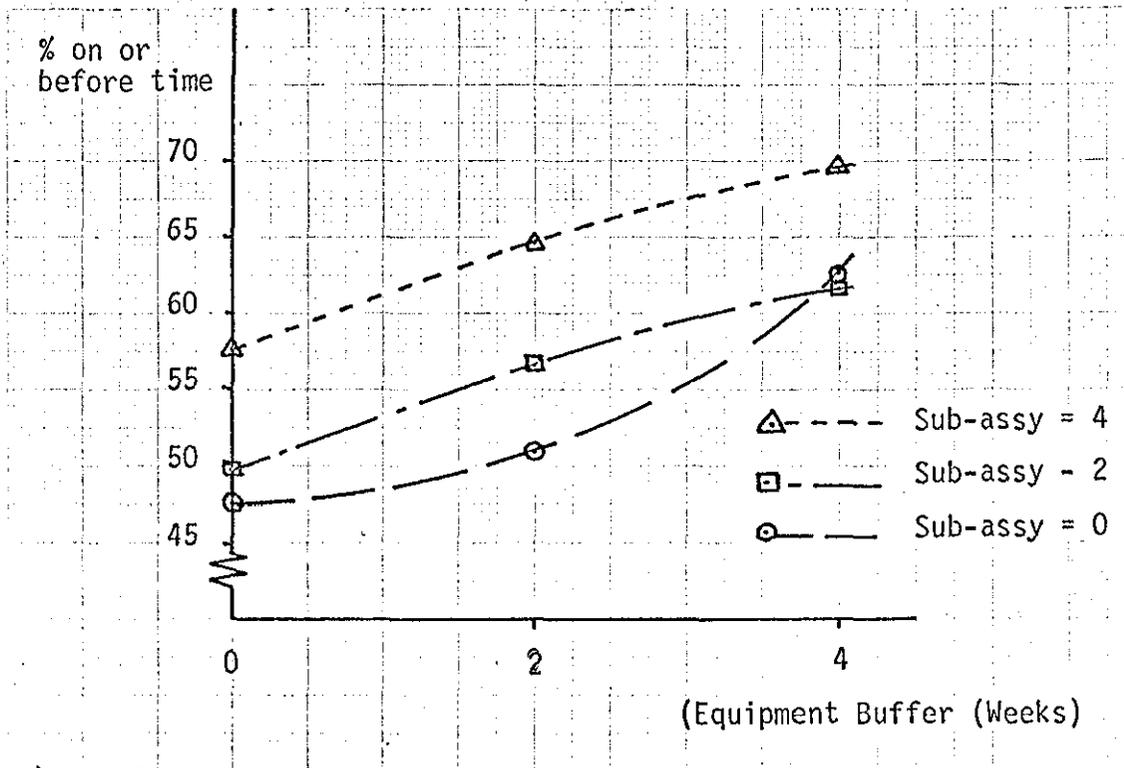


Fig. 4.4. - No Part Shipment Composite Relationship

Transforming into the multiple regression table:

n	1	2	3	4	5	6	7	8	9
x ₁	0	0	0	2	2	2	4	4	4
x ₂	0	2	4	0	2	4	0	2	4
y	47.5	49.7	57.7	50.9	56.6	64.7	62.8	61.6	69.6

Thus;

$$\sum_{i=1}^9 x_{1i} = 18 \quad \sum_{i=1}^9 x_{2i} = 18 \quad \sum_{i=1}^9 x_{1i}x_{2i} = 36 \quad \sum_{i=1}^9 x_{1i}^2 = 76$$

$$\sum_{i=1}^9 x_{2i}^2 = 76 \quad \sum_{i=1}^9 y_i = 521.1 \quad \sum_{i=1}^9 x_{1i}y_i = 1120.4$$

$$\sum_{i=1}^9 x_{2i}y_i = 1103.8$$

Substituting the values in the model equations;

$$9b_0 + 18b_1 + 18b_2 = 521.1 \quad \dots\dots\dots (1)$$

$$18b_0 + 76b_1 + 36b_2 = 1120.4 \quad \dots\dots\dots (2)$$

$$18b_0 + 36b_1 + 76b_2 = 1103.8 \quad \dots\dots\dots (3)$$

$$(2)-(3) \quad 40b_1 - 40b_2 = 16.6$$

$$b_1 = 0.42 + b_2 \quad \dots\dots\dots (4)$$

$$2 \times (1) \quad 18b_0 + 36b_1 + 36b_2 = 1042.2 \quad \dots\dots\dots (5)$$

$$(3)-(5) \quad 40b_2 = 61.6$$

$$b_2 = 1.54 \quad \dots\dots\dots (6)$$

$$\text{From (4)} \quad b_1 = 0.42 + 1.54$$

$$b_1 = 1.96 \quad \dots\dots\dots (7)$$

$$\text{From (5)} \quad b_0 + 2(b_1 + b_2) = 57.90$$

$$b_0 = 57.90 - 7.00$$

$$b_0 = 50.90 \quad \dots\dots\dots (8)$$

Thus,

$$\bar{y}_{x_1, x_2} = 50.90 + 1.96x_1 + 1.54x_2$$

where x_1 = equipment buffer stock
 x_2 = sub-assembly buffer stock

It has been shown from the foregoing analysis that a mathematical relationship between delivery performance and planned buffer stock levels can be derived, but that the relationship is approximately linear over only a limited range of buffer stock values. Extreme conditions, such as zero planned buffer stock, result in an increasingly non-linear relationship, both for equipment and sub-assembly conditions. A probable explanation is that, as the planned buffer stock is decreased, the buffer point becomes "transparent", passing on the task of absorbing mix variations to the "upstream" work in progress processes. Thus, an absolute minimum delivery performance may be observed, being a function of the residual test, main assembly and sub-assembly work in progress.

4.2.2. Effect of planned Buffer Stock on Stock Value.

The same series of experiments used to evaluate the effect of planned buffer stock on delivery performance was further examined to investigate the relationship between the planned buffer stock parameters and the observed stock value. The results as derived from the analyses of variance are now described.

4.2.2.1. Effect of planned buffers on component stock value.

The results obtained from the series of 27 experiments are displayed in Table 4.13.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	41.0	42.2	42.6	74.8	68.6	68.8	101.1	104.1	105.4
SUB =2	44.6	43.2	47.3	71.6	72.9	74.5	109.7	109.6	104.3
SUB =4	45.2	42.5	41.7	71.9	66.3	70.5	106.6	104.7	109.7

Table 4.13. - Planned Buffer/Components Stock Value Results

These data, when presented to the analysis of variance program, yield the results shown in Table 4.14.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	10.04	2	5.02
2	2	17810.00	2	8904.00
3	12	11.65	4	2.91
4	3	48.26	2	24.13
5	13	10.59	4	2.65
6	23	16.23	4	4.06
7	123	<u>72.10</u>	<u>8</u>	9.01
TOTAL		17978.87	26	
GRAND MEAN = 73.53				

Table 4.14. - Planned Buffer/Component Value Analysis

The definition of factors is as for the previous set of analyses.

- Factor 1 = Planned equipment buffer
- Factor 2 = Planned component buffer
- Factor 3 = Planned sub-assembly buffer

It is immediately evident that, as expected, the planned component buffer has a highly significant effect, and that the only other factor with any appreciable significance is possibly the sub-assembly effect. To test the significance, a pool was created of lines 3, 5, 6 and 7.

The pool had the following attributes:

- Sum of squares = 110.6
- Degrees of freedom = 20
- Mean squares = 5.529

F-Ratios were then computed as follows:

- a) Main effect = line 1 (equipment factor)
- Error term = pool
- F-Ratio = 0.9082 (degrees of freedom = 2,20)
- The probability of the R-Ratio being exceeded by chance = 41.93%.

b) Main effect = line 2 (component factor)
Error term = pool
F-Ratio = 1610 (degrees of freedom = 2,20)
The probability of the F-Ratio being exceeded by chance = 0.00%.

c) Main effect = line 4 (sub-assembly factor)
Error term = pool
F-Ratio = 4.364 (degrees of freedom = 2,20)
The probability of the F-Ratio being exceeded by chance is 2.67%.

There is, therefore, evidence that, although no apparent effect of planned equipment buffer exists, there is some influence due to planned sub-assembly buffer, albeit very small when compared to the planned component buffer effect.

Assuming that this planned sub-assembly effect is minimal, the results may be pooled as follows:

	Planned Component Buffer (weeks)		
	0	4	8
Component Stock Value (Mean)	43.4	71.1	106.1

This simulation result may be compared with the theoretical normative component buffer stock value as shown in Fig. 4.5.

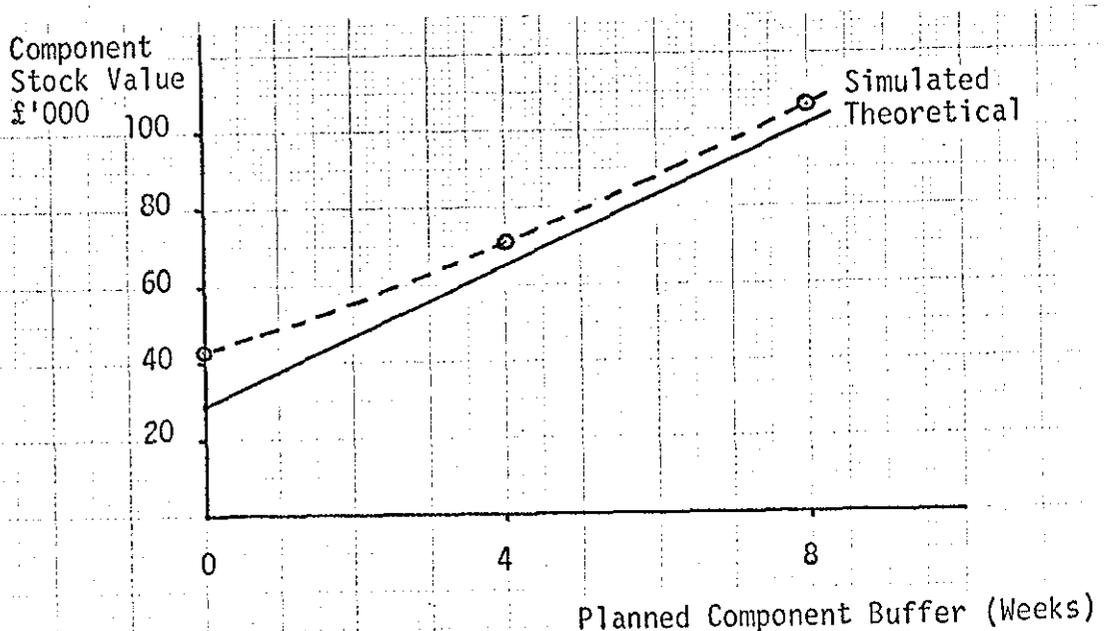


Fig. 4.5. - Planned Component Buffer Effect on Stock Value.

4.2.2.2. Effect of planned Buffers on Sub-Assembly Stock Value.

The simulation results are shown in Table 4.15.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	41.1	42.8	48.5	43.3	44.6	43.7	43.7	40.6	46.2
SUB =2	48.2	50.4	49.4	52.5	56.1	54.0	48.9	51.7	51.8
SUB =4	65.2	68.7	66.5	62.8	70.1	65.9	64.4	72.2	61.0

Table 4.15. - Planned Buffer/Sub-Assembly Stock Value Results

The results from applying these data to the analysis of variance program are shown in Table 4.16.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	41.63	2	20.82
2	2	11.30	2	5.65
3	12	11.17	4	2.79
4	3	2353.00	2	1176.00
5	13	67.85	4	16.96
6	23	28.01	4	7.00
7	123	<u>39.47</u>	<u>8</u>	4.93
	TOTAL	2552.40	26	
	GRAND MEAN = 53.86			

Table 4.16. - Planned Buffer/Sub-Assembly Stock Value Analysis

The F-Ratios were evaluated in two steps. The first was to pool all the interactions to observe the main factors and the second was to observe the two predominant components.

- Pool created of lines 3,5,6 and 7, with
 - Sum of squares = 146.5
 - Degrees of freedom = 20
 - Mean squares = 7.325

F-Ratios were then computed as follows:

- a) Main effect = line 1 (equipment factor)
Error term = pool
F-Ratio = 2.842 (degrees of freedom = 2,20)
The probability of the F-Ratio being exceeded by chance = 8.20%.
- b) Main effect = line 2 (component factor)
Error term = pool
F-Ratio = 0.7716 (degrees of freedom = 2,20)
The probability of the F-Ratio being exceeded by chance = 47.56%.
- c) Main effect = line 4 (sub-assembly factor)
Error term = pool
F-Ratio = 160.6 (degrees of freedom = 2,20)
The probability of the F-Ratio being exceeded by chance = 0.00%.

2. Pool created of lines 2,3,6 and 7, with

- Sum of squares = 89.95
- Degrees of freedom = 18
- Mean squares = 4.997

The F-Ratios computed were as follows:

- a) Main effect = line 1 (equipment factor)
Error term = pool
F-Ratio = 4.165 (degrees of freedom = 2,18)
The probability of the F-Ratio being exceeded by chance = 3.26%.
- b) Main effect = line 5 (equipment/sub-assembly effect)
Error term = pool
F-Ratio = 3.394 (degrees of freedom = 2,18)
The probability of the F-Ratio being exceeded by chance = 3.10%.

There is evidence that the sub-assembly stock value is influenced by both the planned equipment buffer stock and the combined effect of equipment and sub-assembly planned buffers. The most significant effect, however, is the planned sub-assembly buffer.

Assuming that the equipment and combined effects are insignificant when compared with the planned sub-assembly buffer, the results may be pooled as shown.

	Planned Sub-Assembly Buffer (weeks)		
	0	2	4
Sub-assembly stock value (mean)	43.8	51.4	66.3

The simulation result may be compared with the theoretical normative sub-assembly stock value as shown in Fig. 4.6.

Non linearity may be attributed to the fact that the equipment and combined effects may not be totally ignored.

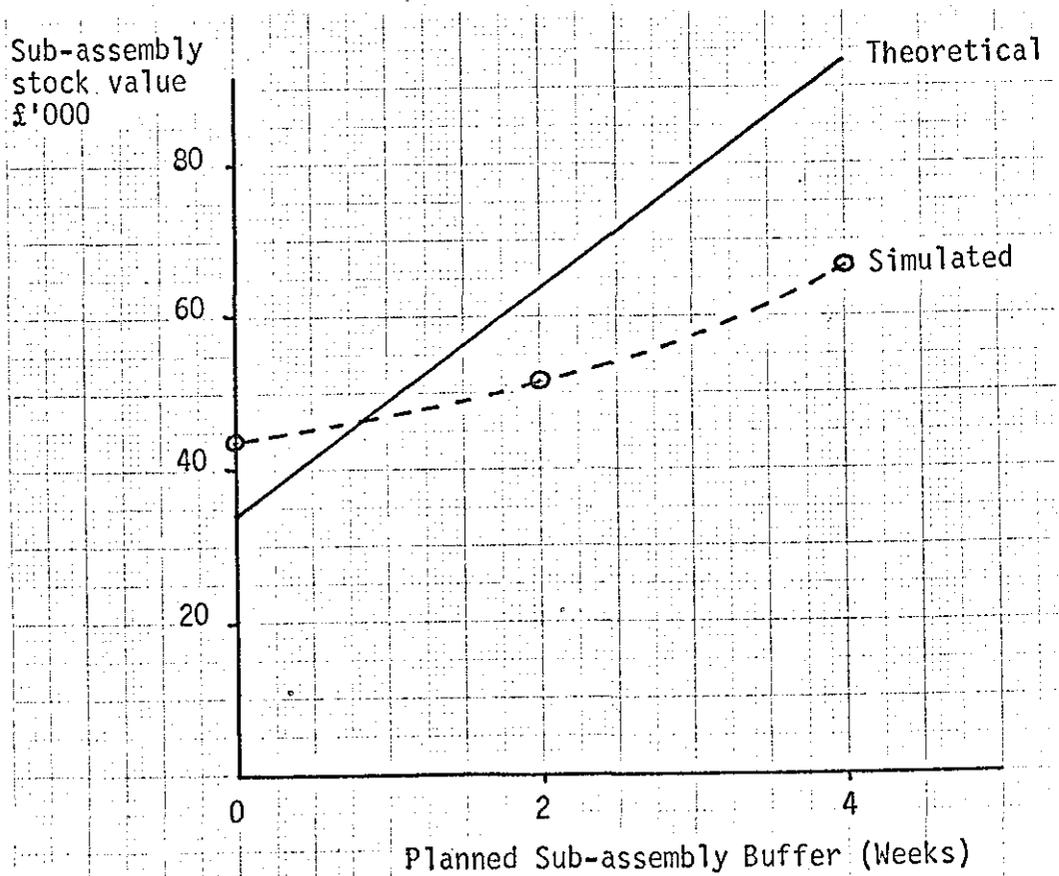


Fig. 4.6. - Planned Sub-assembly Effect on Stock Value

4.2.2.3. Effect of Planned Buffers on Work in Process.

The results of the simulation experiments are shown in Table 4.17.

	COMP = 0			COMP = 4			COMP = 8		
	EQU = 0	EQU = 2	EQU = 4	EQU = 0	EQU = 2	EQU = 4	EQU = 0	EQU = 2	EQU = 4
SUB = 0	85.2	88.6	85.7	86.7	85.2	89.2	86.7	85.8	90.0
SUB = 2	87.8	86.2	90.4	85.3	83.7	83.9	93.6	87.6	86.7
SUB = 4	90.3	95.7	92.5	91.7	87.8	100.0	90.4	87.7	97.7

Table 4.17. - Planned Buffer/W.I.P. Value Results

These data, when presented to the analysis of variance program, yield the results shown in Table 4.18.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	44.44	2	22.22
2	2	9.44	2	4.72
3	12	41.41	4	10.35
4	3	182.80	2	91.42
5	13	53.06	4	13.26
6	23	35.56	4	8.89
7	123	<u>70.35</u>	<u>8</u>	8.79
	TOTAL	437.1	26	
	GRAND MEAN	= 88.97		

Table 4.18. - Planned Buffer/W.I.P. Value Analysis

Where the components are defined as before.

There is evidence of some effect due to both sub-assembly and component buffer stocks. To analyse these further, two pools were created. The first, which has been called pool 1, was created from the interactions; lines 3, 5, 6 and 7. Thus, pool 1 has:

sum of squares = 200.4
degrees of freedom = 20
mean squares = 10.02

F-Ratios were then computed as follows:

- a) Main effect = line 1 (equipment factor)
Error term = pool 1
F-Ratio = 2.218 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 13.49%.

- b) Main effect = line 2 (component factor)
Error term = pool 1
F-Ratio = 0.4712 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 63.10%.

- c) Main effect = line 4 (sub-assembly factor)
Error term = pool 1
F-Ratio = 9.125 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 0.15%.

There is no evidence that the component factor has any effect on the w.i.p. value. This was therefore incorporated into a new pool, to further analyse the interactions, where pool 2 comprises lines 2, 6 & 7, with sum of squares = 115.4
degrees of freedom = 14
mean squares = 8.2

The F-Ratios computed were as follows:

- d) Main effect = line 1 (equipment factor)
Error term = pool 2
F-Ratio = 2.697 (degrees of freedom = 2,14)
Probability of F-Ratio being exceeded by chance = 10.22%.

- e) Main effect = line 3 (component/equipment effect)
Error term = pool 2
F-Ratio = 1.256 (degrees of freedom = 4,14)
Probability of F-Ratio being exceeded by chance = 33.28%.

- f) Main effect = line 4 (sub-assembly factor)
Error term = pool 2
F-Ratio = 11.10 (degrees of freedom = 2,14)
Probability of F-Ratio being exceeded by chance = 0.13%.

- g) Main effect = line 5 (equipment/sub-assembly effect)
- Error term = pool 2
- F-Ratio = 1.610 (degrees of freedom = 4,14)
- Probability of F-Ratio being exceeded by chance = 22.67%.

It can be concluded from the above results that the planned sub-assembly stock has a significant effect on the work in process value. There is some evidence also of an effect from planned equipment buffer stock, but this is not considered significant.

The grand mean of the analysis of variance shows a work in progress value of £88,970. This may be compared with the theoretical normative value of £100,157.

4.2.2.4. Effect of planned Buffers on Equipment Stock.

The results of the simulation experiments are shown in Table 4.19.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	39.1	56.4	60.6	42.9	60.8	64.2	43.2	67.4	72.4
SUB =2	42.6	61.0	68.0	48.7	57.0	71.6	57.2	54.9	83.3
SUB =4	49.4	60.7	84.9	50.4	62.9	88.5	50.5	62.7	84.0

Table 4.19. - Planned Buffer/Equipment Stock Value Results

These data, when presented to the analysis of variance program, yield the results shown in Table 4.20.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	3574.00	2	1787.00
2	2	155.80	2	77.90
3	12	33.43	4	8.36
4	3	423.30	2	211.70
5	13	351.10	4	87.78
6	23	76.37	4	19.09
7	123	<u>149.10</u>	<u>8</u>	18.63
	TOTAL	4763.10	26	
	GRAND MEAN = 60.94			

Table 4.20. - Planned Buffer/Equipment Stock Value Analysis

A pool was then created from line numbers 3, 6 and 7, where:
 the sum of squares = 258.9
 degrees of freedom = 16
 mean squares = 16.18

The F-Ratios were then computed as follows:

- a) Main effect = line 1 (equipment factor)
 Error term = pool
 F-Ratio = 110.4 (degrees of freedom = 2,16)
 Probability of F-Ratio being exceeded by chance = 0.00%.
- b) Main effect = line 2 (component factor)
 Error term = pool
 F-Ratio = 4.815 (degrees of freedom = 2,16)
 Probability of F-Ratio being exceeded by chance = 2.31%.
- c) Main effect = line 4 (sub-assembly factor)
 Error term = pool
 F-Ratio = 13.08 (degrees of freedom = 2,16)
 Probability of F-Ratio being exceeded by chance = 0.04%.
- d) Main effect = line 5 (equipment/sub-assembly effect)
 Error term = pool
 F-Ratio = 5.426 (degrees of freedom = 4,16)
 Probability of F-Ratio being exceeded by chance = 0.59%.

From these results, it can be seen that both the main components of planned equipment, sub-assembly and component buffer stocks, and the combined effect of planned equipment and sub-assembly stocks have a significant influence on equipment stock value.

The degree of significance of the combined effect renders a comparison between the theoretical and observed simulation results relatively invalid. However, the evaluation is shown below given the above limitations.

	Planned Equipment Buffer (Weeks)		
	0	2	4
Sub-Assy =0	41.7	61.5	65.7
Sub-Assy =2	49.5	57.6	74.3
Sub-Assy =4	50.1	62.1	85.8

Table 4.21. - Mean Equipment Stock Value

The simulated results are compared with the theoretical normative equipment stock level as shown in Fig. 4.7.

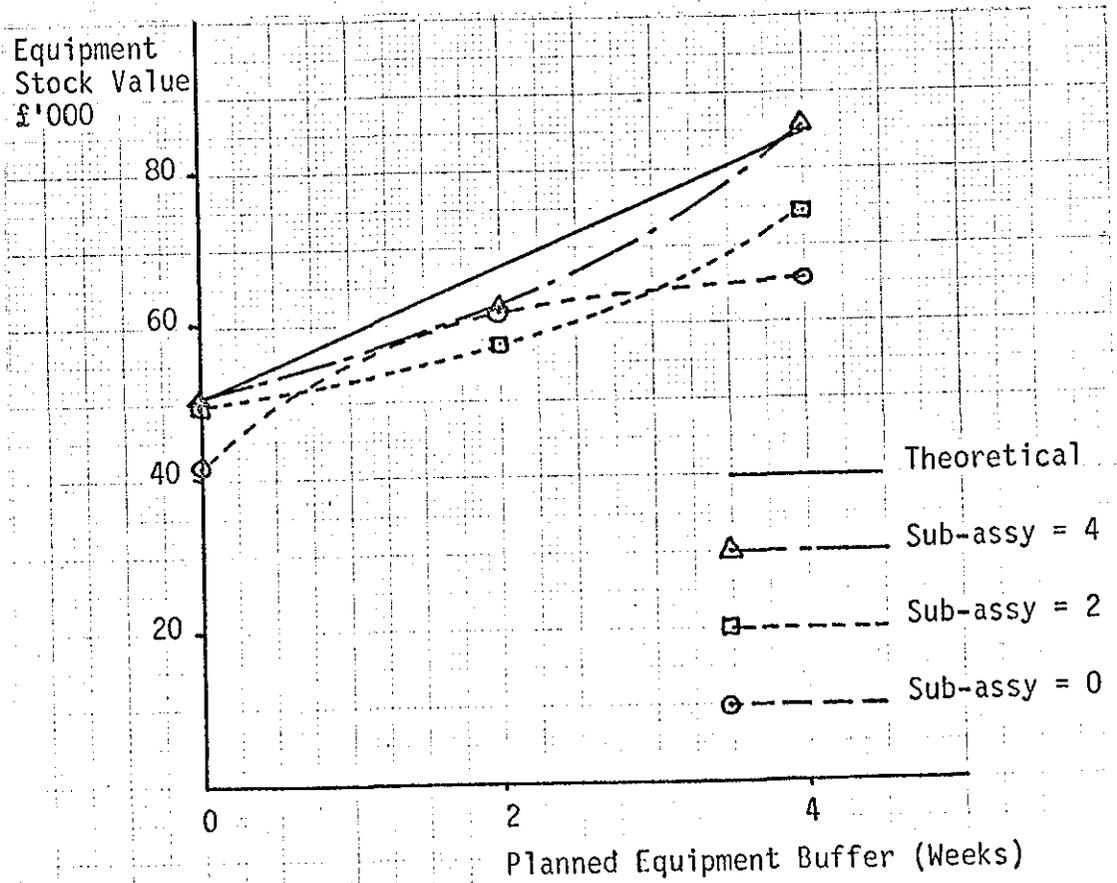


Fig. 4.7. - Planned Equipment Buffer Effect on Stock Value

4.2.2.5. Effect of planned Buffer Stock on Test Work in Progress.

The results obtained from the simulation experiments are shown in Table 4.22.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	19.6	20.7	23.8	20.8	24.0	23.4	20.7	23.7	24.1
SUB =2	24.0	24.1	27.7	22.4	25.9	25.6	23.1	25.6	24.6
SUB =4	22.0	27.1	29.0	25.1	25.1	30.5	24.9	25.5	28.1

Table 4.22. - Planned Buffer/Test W.I.P. Value Results

These data, when presented to the analysis of variance program, yield the results as shown in Table 4.23.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	65.28	2	32.64
2	2	1.28	2	0.64
3	12	5.06	4	1.27
4	3	75.17	2	37.58
5	13	7.24	4	1.81
6	23	5.19	4	1.30
7	123	<u>15.61</u>	<u>8</u>	1.95
	TOTAL	174.83	26	
	GRAND MEAN =	24.49		

Table 4.23. - Planned Buffer/Test W.I.P. Value Analysis

A pool was first created of line numbers 3, 5, 6 and 7. This pool, called pool 1, had

sum of squares = 33.11
degrees of freedom = 20
mean squares = 1.655

To test the component effect, line 2, the following F-Ratio was computed:

Main effect = line 2
Error term = pool 1
F-Ratio = 0.3868 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 68.42%.

Since this factor exhibited no significance, a new pool, pool 2, was created with line numbers 2, 3, 6 and 7, where pool 2 had:

sum of squares = 34.39
degrees of freedom = 22
mean squares = 1.563

F-Ratios were then calculated as follows:

a) Main effect = line 1 (equipment factor)
Error term = pool 2
F-Ratio = 20.88 (degrees of freedom = 2,22)
Probability of F-Ratio being exceeded by chance = 0.00%.

b) Main effect = line 4 (sub-assembly factor)
Error term = pool 2
F-Ratio = 24.05 (degrees of freedom = 2,22)
Probability of F-Ratio being exceeded by chance = 0.00%.

Both planned equipment and sub-assembly buffer stocks show a highly significant effect on test work in progress.

To explore these effects further, the component factors were concluded as insignificant and the experiments pooled as shown in Table 4.24.

	Equ = 0	Equ = 2	Equ = 4
Sub = 0	19.6	20.7	23.8
	20.8	24.0	23.4
	<u>20.7</u>	<u>23.7</u>	<u>24.1</u>
	$\mu=20.4$	$\mu=22.8$	$\mu=23.8$
Sub = 2	24.0	24.1	27.7
	22.4	25.9	25.6
	<u>23.1</u>	<u>25.6</u>	<u>24.6</u>
	$\mu=23.2$	$\mu=25.2$	$\mu=26.0$
Sub = 4	22.0	27.1	29.0
	25.1	25.1	30.5
	<u>24.9</u>	<u>25.5</u>	<u>28.1</u>
	$\mu=24.0$	$\mu=25.9$	$\mu=29.2$

Table 4.24. - Pooled Results of Test w.i.p. Experiments

The mean values were then analysed by multiple regression as shown below, where

- x_1 = equipment planned buffer
- x_2 = sub-assembly planned buffer
- y = test work in progress value

n	1	2	3	4	5	6	7	8	9
x_1	0	0	0	2	2	2	4	4	4
x_2	0	2	4	0	2	4	0	2	4
y	20.4	23.2	24.0	22.8	25.2	25.9	23.8	26.0	29.2

Thus;

$$\sum_{i=1}^9 x_{1i} = 18 \quad \sum_{i=1}^9 x_{2i} = 18 \quad \sum_{i=1}^9 x_{1i}x_{2i} = 36 \quad \sum_{i=1}^9 x_{1i}^2 = 76$$

$$\sum_{i=1}^9 x_{2i}^2 = 76 \quad \sum_{i=1}^9 y_i = 220.5 \quad \sum_{i=1}^9 x_{1i}y_i = 463.8 \quad \sum_{i=1}^9 x_{2i}y_i = 465.2$$

Substituting the values in the model equations:

$$9b_0 + 18b_1 + 18b_2 = 220.5 \quad \dots \dots \dots (1)$$

$$18b_0 + 76b_1 + 36b_2 = 463.8 \quad \dots \dots \dots (2)$$

$$18b_0 + 36b_1 + 76b_2 = 465.2 \quad \dots \dots \dots (3)$$

$$(2)-(3) \quad 40b_1 - 40b_2 = -1.4$$

$$b_1 = b_2 - 0.035 \quad \dots\dots\dots (4)$$

$$2-(1) \quad 18b_0 + 36b_1 + 36b_2 = 441.0 \quad \dots\dots\dots (5)$$

$$40b_2 = 24.2$$

$$b_2 = 0.605 \quad \dots\dots\dots (6)$$

$$\underline{\underline{b_2 = 0.605}}$$

From (4) $b_1 = 0.605 - 0.035$

$$b_1 = 0.570 \quad \dots\dots\dots (7)$$

$$\underline{\underline{b_1 = 0.570}}$$

From (5) $b_0 + 2(b_1 + b_2) = 24.5$

$$b_0 = 24.5 - 2.35$$

$$b_0 = 22.15 \quad \dots\dots\dots (8)$$

$$\underline{\underline{b_0 = 22.15}}$$

Thus, the test work in progress value is given by the relationship

$$\bar{y}_{x_1x_2} = 22.15 + 0.57x_1 + 0.605x_2$$

where x_1 = planned equipment buffer (weeks)
 x_2 = planned sub-assembly buffer (weeks)

The grand mean of the test work in progress as derived from the analysis of variance is £24,490, compared with the theoretical normative level of £35,164 and a base value, assuming no effect of equipment and sub-assembly buffer (as derived above) of £22,150.

4.2.2.6. Effect of Planned Buffers on Commercial Stock.

The results obtained from the simulation experiments are shown in Table 4.25.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	30.2	30.1	19.3	34.5	28.7	18.4	33.3	26.1	20.0
SUB =2	22.0	19.2	19.3	32.3	19.0	20.5	32.0	20.4	26.7
SUB =4	18.6	22.4	20.6	21.0	19.0	20.0	19.6	19.0	19.4

Table 4.25. - Planned Buffer/Commercial Stock Value Results

Applying these data to the analysis of variance program yields the results shown in Table 4.26.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARES</u>
1	1	202.70	2	101.30
2	2	13.54	2	6.77
3	12	59.87	4	14.97
4	3	206.80	2	103.40
5	13	215.00	4	53.76
6	23	48.17	4	12.04
7	123	<u>10.56</u>	<u>8</u>	1.32
	TOTAL	756.64	26	
	GRAND MEAN = 23.39			

Table 4.26. - Planned Buffer/Commercial Stock Value Analysis

Pool 1 was established from the interactions by taking line number 3, 5, 6 and 7. Pool 1 has:

sum of squares = 333.6
degrees of freedom = 20
mean squares = 16.68

F-Ratios were then computed for the main components as follows:

- a) Main effect = line 1 (equipment factor)
- Error term = pool 1
- F-Ratio = 6.076 (degrees of freedom = 2.20)
- Probability of F-Ratio being exceeded by chance = 0.87%.

b) Main effect = line 2 (component factor)
Error term = pool 1
F-Ratio = 0.4058 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 67.18%.

c) Main effect = line 4 (sub-assembly factor)
Error term = pool 1
F-Ratio = 6.200 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 0.80%.

There is evidence, from observation, that the equipment/sub-assembly combination may have some significance. It has also been established from the above results that the component factor has no significance.

Pool 2 was therefore created from lines 2, 3, 6 and 7, where pool 2 has:

sum of squares = 132.1
degrees of freedom = 18
mean squares = 7.340

A further set of F-Ratios was then computed.

d) Main effect = line 1 (equipment factor)
Error term = pool 2
F-Ratio = 13.81 (degrees of freedom = 2,18)
Probability of F-Ratio being exceeded by chance = 0.02%.

e) Main effect = line 4 (sub-assembly factor)
Error term = pool 2
F-Ratio = 14.09 (degrees of freedom = 2,18)
Probability of F-Ratio being exceeded by chance = 0.02%.

f) Main effect = line 5 (equipment/sub-assembly effect)
Error term = pool 2
F-Ratios = 7.324 (degrees of freedom = 4,18)
Probability of F-Ratio being exceeded by chance = 0.11%.

It can be concluded from the above results that the commercial stock is influenced strongly by planned equipment and sub-assembly stocks, and also the combined effect of the two stock categories.

If the two effects above are discarded, the grand mean of the analysis of variance, value £23,390 may be compared with the theoretical minimum value of £9237, based on 100% delivery performance.

4.2.2.7. Effect of planned Buffers on total Stock Value.

The results of the simulation experiments are shown in Table 4.27.

	COMP = 0			COMP = 4			COMP = 8		
	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4	EQU =0	EQU =2	EQU =4
SUB =0	256.2	280.8	280.4	303.1	311.9	313.9	328.8	347.7	358.1
SUB =2	269.2	284.2	302.0	312.8	314.6	330.2	364.5	350.9	377.3
SUB =4	290.8	317.1	335.5	322.8	331.1	375.5	356.4	371.8	399.9

Table 4.27. - Planned Buffer/Total Stock Value Results

The data, when presented to the analysis of variance program, yield the results shown in Table 4.28.

<u>LINE NO.</u>	<u>VARIANCE COMPONENT</u>	<u>SUM OF SQUARES</u>	<u>DEGREES OF FREEDOM</u>	<u>MEAN SQUARE</u>
1	1	4057.0	2	2028.0
2	2	22730.0	2	11360.0
3	12	241.1	4	60.3
4	3	5781.0	2	2890.0
5	13	963.8	4	240.9
6	23	276.5	4	69.1
7	123	<u>301.9</u>	<u>8</u>	37.7
	TOTAL	34351.3	26	
	GRAND MEAN	= 325.5		

Table 4.28. - Planned Buffer/Total Stock Value Analysis

A pool was first created of the interaction components, lines 3, 5, 6 and 7, where pool 1 has;

sum of squares = 1783.0
degrees of freedom = 20
mean squares = 89.16

F-Ratios were then computed for the main components.

a) Main effect = line 1 (equipment factor)
Error term = pool 1
F-Ratio = 22.75 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 0.00%.

b) Main effect = line 2 (component factor)
Error term = pool 1
F-Ratio = 127.5 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 0.00%.

c) Main effect = line 4 (sub-assembly factor)
Error term = pool 1
F-Ratio = 32.42 (degrees of freedom = 2,20)
Probability of F-Ratio being exceeded by chance = 0.00%.

There is evidence, from observation of the computed results, of some effect from the combined equipment/sub-assembly factors. A second pool, pool 2, was therefore created from lines 3, 6 and 7, where;

the sum of squares = 819.5

degrees of freedom = 16

mean squares = 51.22

F-Ratios were then further computed as follows:

d) Main effect = line 1 (equipment factor)
Error term = pool 2
F-Ratio = 39.60 (degrees of freedom = 2,16)
Probability of F-Ratio being exceeded by chance = 0.00%.

e) Main effect = line 2 (component factor)
Error term = pool 2
F-Ratio = 221.9 (degrees of freedom = 2,16)
Probability of F-Ratio being exceeded by chance = 0.00%.

f) Main effect = line 4 (sub-assembly factor)
Error term = pool 2
F-Ratio = 56.43 (degrees of freedom = 2,16)
Probability of F-Ratio being exceeded by chance = 0.00%.

- g) Main effect = line 5 (equipment/sub-assembly effect)
- Error term = pool 2
- F-Ratio = 4.704 (degrees of freedom = 4,16)
- Probability of F-Ratio being exceeded by chance = 1.06%.

The results indicate that, apart from the main effects of each planned stock category, there is a significant contribution due to the combined effect of planned equipment and sub-assembly buffer stocks.

4.2.3. Relationship between Delivery Performance and Stock Investment.

The results of the experiments linking delivery performance and stock value to the planned buffer stock parameters suggest that some relationship between delivery performance and stock investment may be derived, within the bounds set by the stated assumptions.

Firstly, given

- x_1 = equipment planned buffer (weeks)
- x_2 = sub-assembly planned buffer (weeks)
- x_3 = component planned buffer (weeks)

it is possible to derive an expression for the total stock investment.

If linearity can be assumed over the limited ranges stated, the results of the simulation experiments described in Section 4.2.2. may be expressed as follows:

Component stock value,	$V_c = 40.0 + 7.5x_3$
Sub-assembly stock value,	$V_s = 42.5 + 5.6x_2$
Work in progress stock value,	$V_w = 89.0$
Equipment stock value,	$V_e = 47.5 + 6.75x_1$
Test work in progress value,	$V_t = 22.15 + 0.57x_1 + 0.61x_2$
Commercial stock value,	$V_{cm} = 23.4$

Where all values are in £'000. The total stock investment V_{TOT} is the sum of all stock categories, where

$$V_{TOT} = 264.9 + 7.3x_1 + 6.2x_2 + 7.5x_3 \dots\dots\dots (1)$$

Further, the relationship between delivery performance and planned buffer stock weeks has been derived as follows, taking the equipment performance case,

$$\text{Equipment performance (\%), } P_e = 61.58 + 1.67x_1 + 1.44x_2 \dots\dots(2)$$

It has been proven that the effect of planned component buffer stock on delivery performance is insignificant. Equation (1) may therefore be simplified by selecting, for example, $x_3 = 8$ and substituting,

$$V_{TOT} = 324.9 + 6.2x_2 + 7.3x_1 \dots\dots\dots(3)$$

If we now take the two extreme cases, where $x_2 = 0$ and $x_1 = 0$

a) $x_2 = 0$
 $V_{TOT} = 324.9 + 7.3x_1 \dots\dots\dots(4)$

$$P_e = 61.58 + 1.67x_1 \dots\dots\dots(5)$$

From (4)

$$x_1 = \frac{V_{TOT} - 324.9}{7.3}$$

Substituting in (5)

$$P_e = 61.58 + \frac{1.67}{7.3} (V_{TOT} - 324.9)$$

$$P_e = 0.23V_{TOT} - 13.15 \dots\dots\dots(6)$$

or $V_{TOT} = P_e / 0.23 + 57.17$ where V_{TOT} is value in £'000.

=====

b) $x_1 = 0$
 $V_{TOT} = 324.9 + 6.2x_2 \dots\dots\dots(7)$

$$P_e = 61.58 + 1.44x_2 \dots\dots\dots(8)$$

From (7)

$$x_2 = \frac{V_{TOT} - 324.9}{6.2}$$

Substituting in (8)

$$P_e = 61.58 + \frac{1.44}{6.2} (V_{TOT} - 324.9)$$

$$P_e = 0.23V_{TOT} - 13.15 \quad \dots\dots\dots (9)$$

$$\text{or } V_{TOT} = P_e / 0.23 + 57.17 * \quad \dots\dots\dots (10)$$

=====

*Note that the element shown is approximately the value of component stock (i.e. $7.5x_3$)

The equations (2) and (3), substituting the values for x_1 ; x_2 in the range 0-4, are shown in Fig. 4.8.

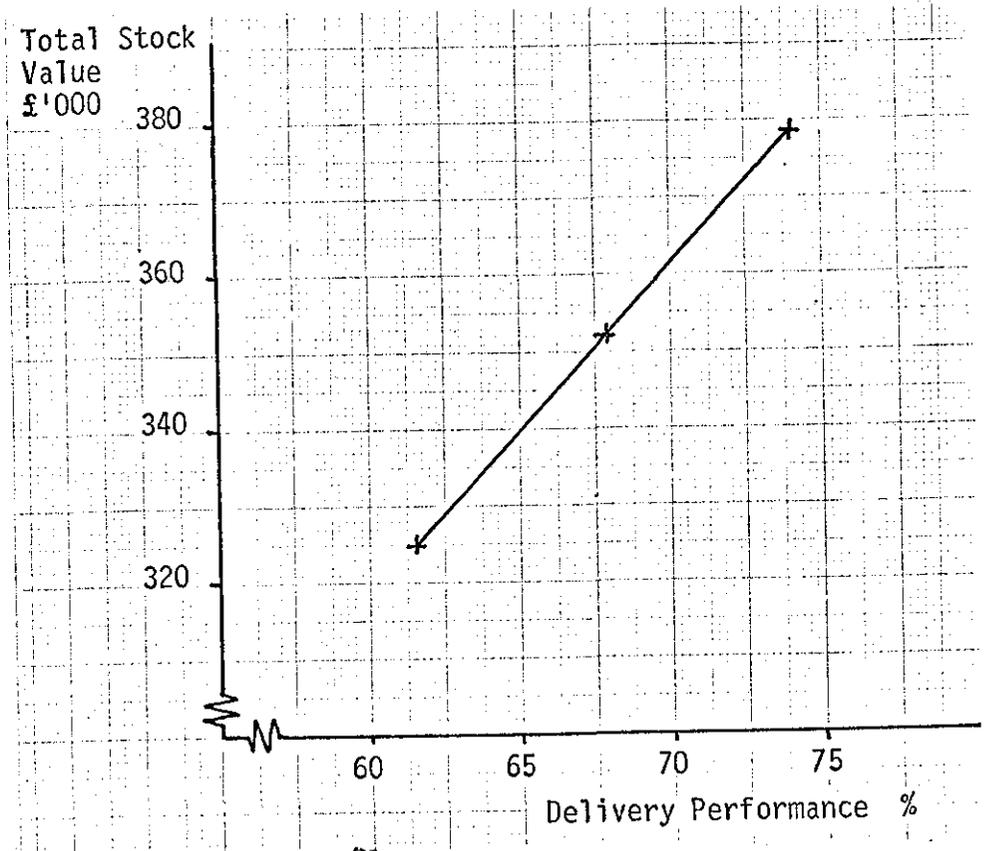


Fig. 4.8. - Total Stock Value vs Delivery Performance

A number of conclusions are apparent from the foregoing results.

- 1) The actual range of delivery performance influenced by the changes in planned buffer stock is limited when compared with the minimum delivery performance with zero planned buffers, i.e.

Minimum equipment delivery performance = 61.58%
Range (for planned sub-assembly/equipment buffers
of 0/0 to 4/4 weeks) = 61.58 - 74.02%

- 2) The residual stock value of £264,900, which is uninfluenced by the planned buffer levels, is substantial compared with the variable element. For example, within the range selected where

$$0 \leq x_1 \leq 4$$

$$0 \leq x_2 \leq 4$$

$$0 \leq x_3 \leq 8$$

the variable element ranges from 0 to £114,000.

- 3) From the observed performance, the cost effectiveness of sub-assembly planned buffers on incremental delivery is exactly the same as for equipment planned buffers.
- 4) The observations are only valid over a limited range due to the assumption of linearity, which is certainly not valid as extremes are approached. Thus, the expression (10) above must not be used to extrapolate the stock investment required to achieve 100% delivery performance.

4.3. VARIANCE REDUCTION TECHNIQUES

4.3.1. Methods

Two variance reduction techniques were introduced for evaluation; replicated experiments using different random number streams, and antithetic experiments performed by introducing negative seeds into the random number generators.

The simulation model is designed to utilise up to twelve random number streams by the introduction of a non-zero seed for each stream. The starting seeds are contained in a series of files named RN*, where the '*' identifies the file number. The inclusion of the selected file number in the initial run parameter definition causes the appropriate seed file to be selected.

4.3.2. Replication

The majority of simulation experiments were conducted with file RN1. To evaluate the effect of replication, a further experiment was concluded using a second file RN3. The random number stream seed values are shown in Table 4.29.

<u>FILE</u>	<u>RN1</u>	<u>RN3</u>
1	36893	69831
2	29431	20963
3	12345	11217
4	62915	43821
5	24671	66095
6	42913	38219
7	24091	16141
8	3967	23843
9	14823	82437
10	33241	64331
11	19629	50047
12	24603	16839

Table 4.29. - Random Number Seeds - Replication

4.3.3. Antithetic Pairs

The application of antithetic pairs is discussed by Taha (1976), who provides some practical arguments for the use of the technique. Antithetic random numbers over the range 0-1 are complementary, such that if x_1 is the first random number, then x_2 , the antithetic partner is given by

$$x_1 + x_2 = 1$$

Thus, if one experiment is conducted with a given random number stream, any bias (e.g. consistently high numbers) may be removed by using a second stream of antithetic numbers and averaging the two experimental results.

The generation of an antithetic stream has been achieved in the model by the introduction of an identical but negative seed into the random number generator. Observation of the program description given in Appendix B will demonstrate this facility.

To estimate the effect of introducing antithetic random number streams, two further experiments were conducted, using negative random number seeds for all twelve streams. The values are as shown in Table 4.30.

<u>FILE</u>	<u>RN2</u> <u>(-ve RN1)</u>	<u>RN4</u> <u>(-ve RN3)</u>
1	-36893	-69831
2	-29431	-20963
3	-12345	-11217
4	-62915	-43821
5	-24671	-66095
6	-42913	-38219
7	-24091	-16141
8	- 3967	-28843
9	-14823	-82437
10	-33241	-64331
11	-19629	-50047
12	-24603	-16839

Table 4.30. - Random Number Seeds - Antithetic Pairs

4.3.4. Results

The summarised results of the four simulation experiments are shown in Table 4.31., in the columns headed "Observed Values". It has been assumed that an analysis of the effect on stock value alone is adequate to demonstrate the effects of variance reduction.

Four secondary results were obtained by pairing the observations into two replicated means and two antithetic means. The group mean, being the mean of all observed values was also calculated.

To provide an estimate of the total variability, the co-efficient of variance of each value from the group mean was calculated to minimise the effect of bias. The sum of the co-efficient of variances was then considered a reasonable estimate of relative variability between sets.

It can be seen that the replicated experiments result in a variability factor considerably lower than the average factor derived from the observed values. It is not, however, less than the best observed set.

The results using antithetic pairs indicate a significantly lower variability factor than achieved through replication and also better than any single observed set.

Stock Values	Observed Values				Mean of Pairs				Group Mean
	RP8 (RN1)	RP49 (RN3)	RP50 (-veRN1)	RP48 (-veRN3)	RP8/RP50 (Antithetic)	RP49/RP48 (Antithetic)	RP8/RP49 (Replicated)	RP50/RP48 (Replicated)	
Component	109.7	96.8	104.2	113.7	107.0	105.3	103.3	109.0	106.1
Sub-assembly	61.0	64.2	75.4	68.0	68.2	66.1	62.6	71.7	67.2
Work in process	97.7	90.1	93.7	92.7	95.7	91.4	93.9	93.2	93.6
Equipment	84.0	88.6	95.3	82.9	89.7	85.8	86.3	89.1	87.7
Test	28.1	29.8	34.4	29.5	31.3	29.7	29.0	32.0	30.5
Commercial	19.4	17.9	27.1	22.4	23.3	20.2	18.7	24.8	21.7
Total	399.9	387.5	430.0	409.1	415.0	398.3	393.7	419.6	406.6
Co-efficient of Variances from Group Mean = z									
Component	0.1221	0.8152	0.0340	0.5444	0.0068	0.0068	0.0765	0.0765	
Sub-assembly	0.5720	0.1339	1.0006	0.0095	0.0164	0.0164	0.3083	0.3083	
Work in process	0.1796	0.1309	0.0001	0.0087	0.0494	0.0494	0.0013	0.0013	
Equipment	0.1561	0.0092	0.6586	0.2627	0.0433	0.0433	0.0223	0.0223	
Test	0.1889	0.0161	0.4987	0.0328	0.0210	0.0210	0.0738	0.0738	
Commercial	0.2438	0.6654	1.3438	0.0226	0.1105	0.1105	0.4277	0.4277	
Total	0.1104	0.8972	1.3467	0.0154	0.1715	0.1715	0.4124	0.4124	
$\sum z$	1.5729	2.6679	4.8825	0.8961	0.4189		1.3223		
Average	2.5049								

Table 4.31. - Results of Variance Reduction Experiments

4.4. SECONDARY EXPERIMENTS

4.4.1. Effect of Manufacturing Mode on Delivery Performance

The group of experiments used to examine the effect of manufacturing mode are shown in Table 4.32.

		FILE NUMBER				
		RP3	RP8	RP16	RP17	RP12
MODE		STOCK	MIXED	STOCK	ORDER	MIXED
Planned Buffers	Equip.	4	4	0	0	0
	Sub-assy	4	4	4	4	4
	Component	8	8	8	8	8
Value	Component	107.1	109.7	101.7	120.6	106.6
	Sub-assy	64.6	61.0	66.1	89.9	64.4
	w i p	96.4	97.7	90.5	83.4	90.4
	Equipment	95.3	84.0	45.3	0.0	50.5
	Test	30.4	28.1	21.9	34.0	24.9
	Commercial	16.4	19.4	14.5	16.6	19.6
	Total	410.2	399.9	339.9	344.5	356.4
Delivery Performance	Equip. % \bar{l}	81.5	80.7	85.9	83.9	69.9
		0.0500	0.0031	-0.2550	-0.3900	0.0063
	Part ship % \bar{l}	77.2	77.9	79.3	74.8	68.1
		0.1763	0.1381	-0.0688	0.0238	0.0781
	No part ship % \bar{l}	74.2	73.6	80.4	79.6	60.8
	0.2544	0.2744	-0.1031	-0.0313	0.2325	
Component Service Level		99.65	99.81	99.91	99.99	99.68

Table 4.32. - Effect of Manufacturing Mode

It should be noted that the term "make to order" in the context of the manufacturing system described implies final assembly to order, since sub-assembly manufacture is decoupled from the actual customer orders.

The experiments were sub-divided into two groups; the first with a planned equipment stock of 4 weeks and the second with a planned equipment stock of zero.

a) Planned equipment stock - 4 weeks.

Only two experiments were conducted, one in make to stock mode and the second in mixed mode. Make to order mode with a finite level of planned equipment buffer is not a valid condition.

Comparison of the two experiments indicates no appreciable differences, either in stock value by category, or in the achieved delivery performances.

b) Planned equipment stock - zero.

All three manufacturing modes were observed with a planned equipment stock of zero; make to order, make to stock and mixed.

A comparison of the effect of each mode on stock value shows no appreciable difference, except in the case of the actual equipment stock value, where in the make to order mode no stock is generated.

The effect on achieved delivery performance in the experiments as recorded are more significant. Although there is no appreciable difference between the "pure" make to order or make to stock examples, the mixed mode indicates a significantly lower performance. This effect is evident when observing either the proportion delivered on or before time, or the average lateness.

It can be seen that the component service level was consistent for all experiments considered, thus indicating similar supply conditions across each example.

4.4.2. Relationship between Component Buffer Stock and Service Level.

The component service level as derived from the delivery performance group of experiments was displayed as in Table 4.33.

	COMP = 0			COMP = 4			COMP = 8		
	EQU = 0	EQU = 2	EQU = 4	EQU = 0	EQU = 2	EQU = 4	EQU = 0	EQU = 2	EQU = 4
SUB = 0	91.67	91.53	88.89	99.18	98.51	99.32	99.90	99.82	99.90
SUB = 2	92.58	90.76	90.94	98.64	98.61	98.88	99.76	99.87	99.85
SUB = 4	90.91	88.51	89.15	98.31	98.40	99.16	99.68	99.73	99.81
	$\mu_0 = 90.55$			$\mu_4 = 98.78$			$\mu_8 = 99.81$		

Table 4.33. - Component Buffer Stock and achieved Service Level (%)

The service levels as shown indicate no discernible interaction between the sub-assembly and equipment planned buffer levels and the achieved component service level. The results were then pooled to provide an estimate of the mean service level for each planned component buffer level. The means were then shown graphically as in Fig. 4.9., the line joining the means being an estimate of the service level profile.

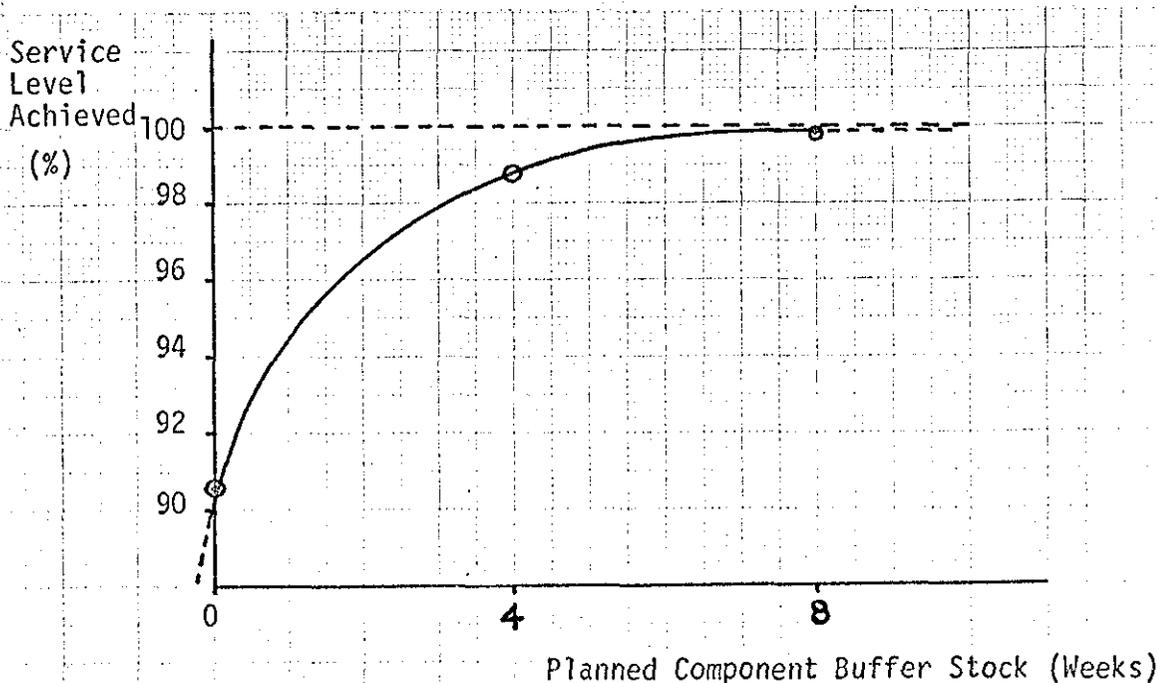


Fig. 4.9. - Service Level/Planned Component Buffer Stock Profile

The profile derived is a typical variation of that discussed in standard inventory control literature, and is referred to by New (1973) as the "service level/inventory trade-off curve".

4.4.3. Effect of Priority Rules

As a standard against which the priority rule effect could be measured, the experiment with RP8 was selected in which the priority rule is set to "due date". The experiment was then repeated with RP38 in which the conditions were identical except for the selection of "first-in-first-out" (FIFO) priority logic.

The results are shown in Table 4.34.

STOCK VALUE £'000			DELIVERY PERFORMANCE		
CATEGORY	DUE DATE	FIFO	CATEGORY	DUE DATE	FIFO
Component	109.7	107.8	Equip. %	80.7	80.6
Sub-assembly	61.0	63.3	" Lateness	0.0031	-0.0006
W.I.P.	97.7	96.3	Part ship %	77.9	78.3
Equipment	84.0	85.3	" Lateness	0.1381	0.1206
Test	28.1	25.8	No part ship %	73.6	73.5
Commercial	19.4	17.1	Lateness	0.2744	0.2625
Total	399.9	395.7			

Table 4.34. - Effect of Priority Rules on Stock and Delivery Performance

The results for all categories for both stock and delivery performance show no discernable differences, with the observations being significantly within the experimental limits established by the variance reduction groups (section 4.3.).

4.4.4. Relationship between Commercial Stock and Delivery Performance

The relationship between commercial stock and delivery performance was observed by selection of the group of experiments relating to delivery performance. These are shown in Table 4.35.

RP No.	Planned Buffer (Weeks)			Commercial Stock	Delivery Performance (%)		
	Comp.	Sub.	Equ.		Equip.	Part Ship	No Part Ship
13	8	0	0	33.3	60.6	62.2	48.4
22	8	0	2	26.1	62.3	63.2	51.2
6	8	0	4	20.0	69.6	68.4	62.3
21	8	2	0	32.0	60.0	58.5	47.4
20	8	2	2	20.4	67.4	66.9	58.4
9	8	2	4	26.7	69.0	66.5	59.1
12	8	4	0	19.6	69.9	68.1	60.8
19	8	4	2	19.0	75.5	73.9	64.6
8	8	4	4	19.4	80.7	77.9	73.6

Table 4.35. - Commercial Stock Relationship with Delivery Performance

The results for the part shipment order performance were selected for graphical presentation against the commercial stock value as shown in Fig. 4.10.

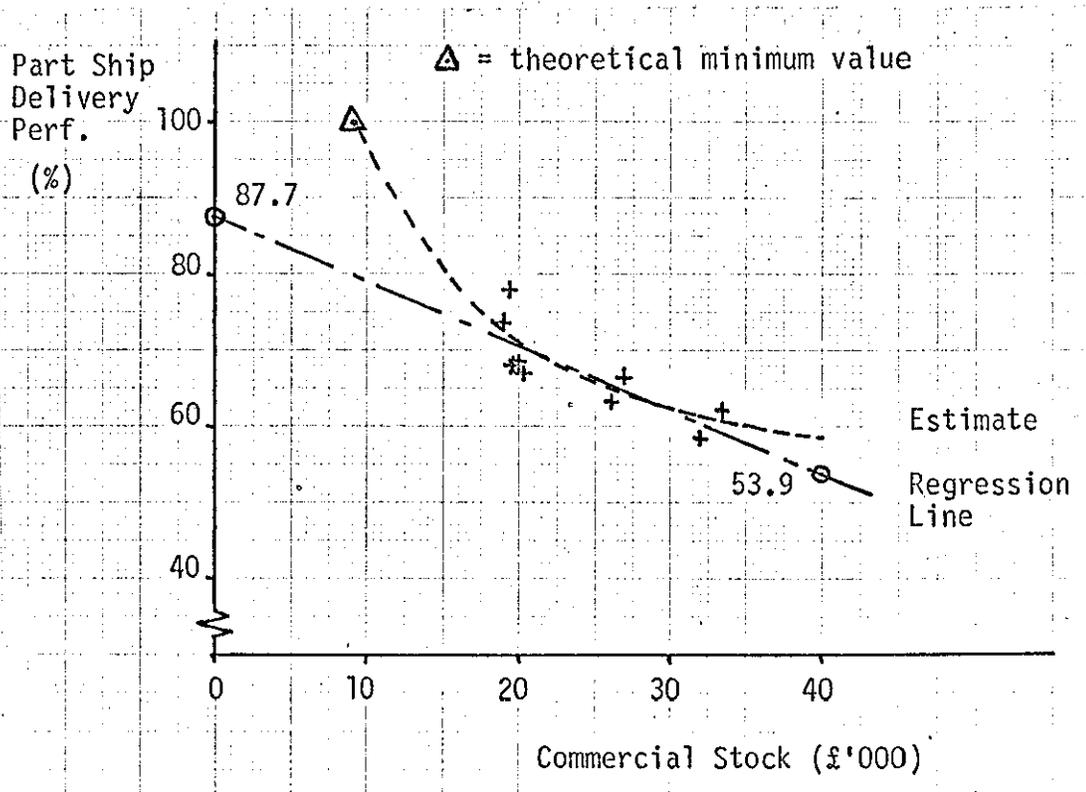


Fig. 4.10. - Estimate of Commercial Stock and Delivery Performance Relationship

Assuming that the relationship is approximately linear over the range shown, the regression line was calculated and plotted as shown.

If an estimate of the regression line is given by:

$$\bar{y}_x = a + bx$$

then,

$$b = \frac{n \sum_{i=1}^n x_i y_i - \left(\sum_{i=1}^n x_i \right) \left(\sum_{i=1}^n y_i \right)}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2}$$

$$a = \bar{y} - b\bar{x}$$

For the data given,

$$\sum_{i=1}^9 x_i y_i = 14351.2 \quad \sum_{i=1}^9 x_i = 216.5 \quad \sum_{i=1}^9 y_i = 605.6$$

$$\sum_{i=1}^9 x_i^2 = 5464.7$$

$$\bar{y} = 67.3 \quad \bar{x} = 24.1$$

$$b = \frac{9 \times 14351.2 - 216.5 \times 605.6}{9 \times 5464.7 - 216.5^2}$$

$$= \frac{129160.8 - 131112.4}{49182.3 - 46872.3}$$

$$= - \frac{1951.6}{2310.0}$$

$$b = -0.845$$

$$a = \bar{y} - b\bar{x}$$

$$= 67.3 + 0.845 \times 24.1$$

$$a = 87.7$$

Thus

$$\bar{y}_x = 87.7 - 0.845x$$

Where \bar{y}_x is the estimated delivery performance as the commercial stock x is varied.

An alternative view of the relationship, where a delivery performance of 100% is assumed to equate to £9.2K commercial stock, (see normative Stock levels - Section 3.4.5.9.), has been shown by the curved line "estimate", which is a visual "best-fit" between the observations. Observation of the two alternative approaches suggest that the visual "best fit" is probably a better estimate than the regression line based on an assumption of linearity.

4.4.5. Effect of changing Capacity Utilisation Factor

The influence of the capacity utilisation factor on the model performance is shown by observing the results of the experiments displayed in Table 4.36.

STOCK EFFECT					DELIVERY PERFORMANCE				
Category	Utilisation Factor				Category	Utilisation Factor			
	0.95	1.00	1.05	1.10		0.95	1.00	1.05	1.10
Component	109.7	107.8	109.2	107.7	Equip. %	80.7	80.2	80.2	76.8
Sub-assy	61.0	61.4	63.8	55.6	"	0.0031	-0.0131	0.0238	0.0550
W.I.P.	97.7	98.0	98.4	99.0	Lateness	77.9	77.0	77.0	71.3
Equipment	84.0	85.1	85.7	80.6	Part ship %	0.1381	0.1544	0.1556	0.3344
Test	28.1	25.9	26.5	27.6	No part ship %	73.6	72.9	70.8	67.6
Commercial	19.4	17.8	19.0	27.4	No part ship lateness	0.2744	0.2438	0.3363	0.5919
Total	399.9	395.9	402.0	398.0	RP NO	8	39	11	18
RP NO	8	39	11	18					

Table 4.36. - Effect of Capacity Utilisation on Stock Value and Delivery Performance

From observation of the recorded values, the result of changing the capacity utilisation has no discernable effect on the stock value, either in total or by category.

The result on delivery performance is, however, a distinct deterioration of performance as the capacity is increasingly constrained, across all categories of performance measurement.

The effect on delivery performance is shown graphically in Fig. 4.11.

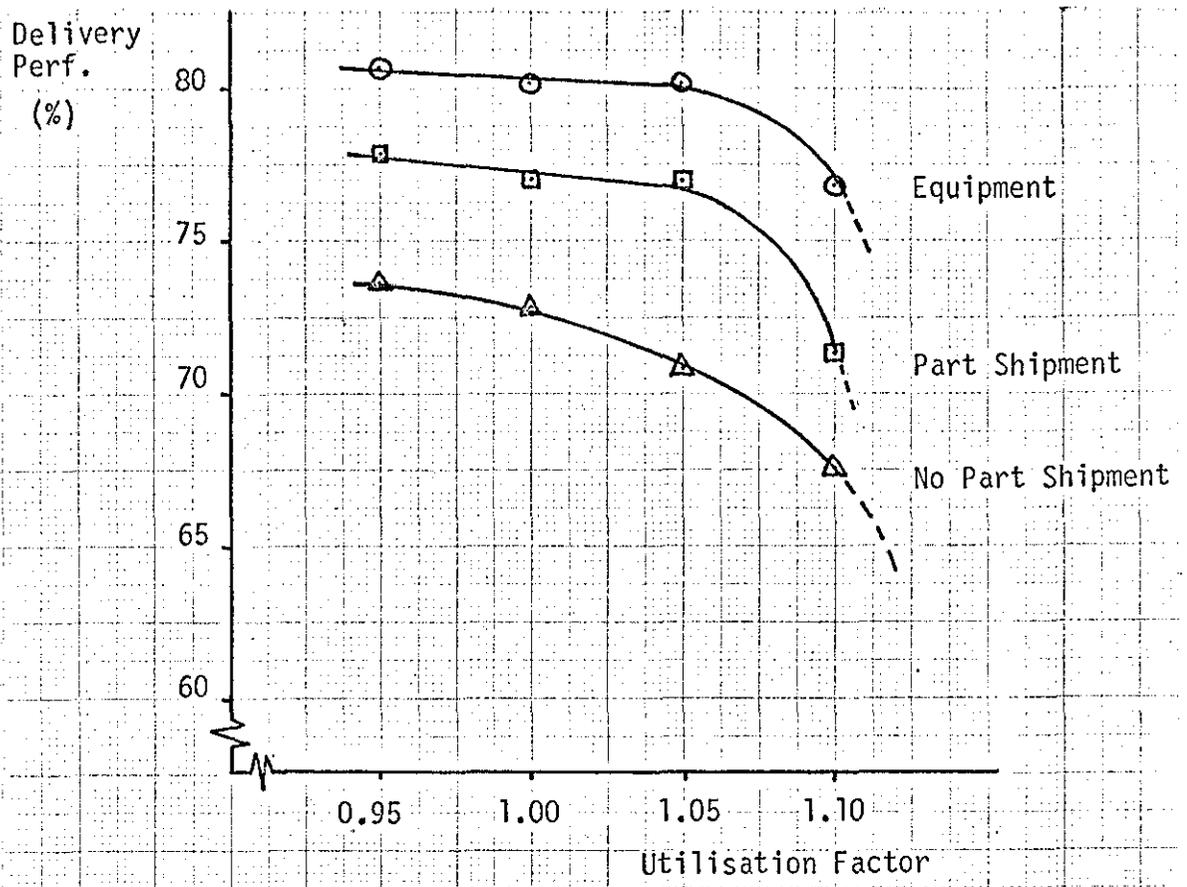


Fig. 4.11. - Effect of Capacity Utilisation on Delivery Performance

The profiles show that the effect is limited up to the point of marginal capacity overload, beyond which there is an apparent abrupt deterioration in delivery performance.

4.4.6. Effect of Orders Received Trend

One experiment was conducted with trend factors introduced into the orders received generator. Two products were selected to observe the effects of trend, one with a positive factor and the second with a negative factor. The results were then compared with the control experiment to evaluate the magnitude of any apparent variations. The results are shown in Table 4.37., where the control experiment was conducted with parameter file RP8 and the trend experiment used RP37, where a trend of +4% per quarter was introduced into Product 1 and -2% per quarter was introduced into Product 2.

It should be noted that, due to the design of the orders generator, the introduction of trend does not alter the aggregate orders received volume, since only the probability of one product being selected in favour of the remaining products is affected.

STOCK VALUE £'000			DELIVERY PERFORMANCE		
CATEGORY	ZERO TREND	TREND	CATEOGRY	ZERO TREND	TREND
Component	109.7	110.8	Equipment %	80.7	77.7
Sub-assy	61.0	62.7	" Lateness	0.0031	0.1131
W.I.P.	97.7	95.7	Part Ship %	77.9	74.4
Equipment	84.0	94.5	" " Lateness	0.1381	0.4531
Test	28.1	25.1	No Part Ship %	73.6	68.8
Commercial	19.4	23.4	" " " Lateness	0.2744	0.6113
Total	399.9	390.3			

Table 4.37. - Orders Received Trend Results

The stock values in all categories but one show no discernable variance between the control experiment and the one conducted with trend introduced. The equipment stock value, however, shows some evidence of an increase, although this is still within the spread experienced in the experiments associated with variance reduction, all of which were subject to identical parameters with the exception of the trend factor.

The delivery performance in all categories does not vary substantially from the control experiment and all observations lie within the extremes recorded in the variance reduction experiments.

4.4.7. Long Term Cyclic Effects

The cost and time required to conduct each simulation experiment required run time restrictions to be placed on the main volume of experiments. To verify that the time horizon selected was not biased and to observe the behaviour of the model over a more extended period an experiment over a ten year simulated time horizon was conducted. The parameters chosen were identical to the control experiment using parameter file RP8.

The results, which are shown fully in Appendix A , have been displayed for clarity in four separate graphs.

Fig. 4.12. - Component and sub-assembly stock value

Fig. 4.13. - Work in process and test value

Fig. 4.14. - Equipment and commercial stock value

Fig. 4.15. - Total stock value.

Observation of the stock value over simulated time provides some useful indicators on the model performance and thus the real world behaviour.

- a) There is no evidence of any long term trends introduced by the model under the specified experimental conditions.
- b) A clear cyclical pattern is apparent in all stock categories. Since the orders received pattern selected was stable, it must be assumed that the cycles are self-induced by some form of positive feedback in the planning procedures.
- c) The time frame selected for the primary and secondary experiments of weeks 53 - 248 inclusive approximates closely to two full cycles, thus supporting a primary experimental assumption.
- d) The component stock appears to be the leading factor in the cyclical series. If the peaks in component stock value are taken as reference, the stock categories are shifted in phase as follows:

Component	= Reference (0)
Work in process	= + 7 weeks
Test	= + 20 weeks
Commercial	= + 20 weeks
Sub-assembly	= + 26 weeks
Equipment	= No regular pattern
Total stock value	= + 13 weeks

An explanation may be that, as component stock becomes plentiful, material issues are released into work in process without

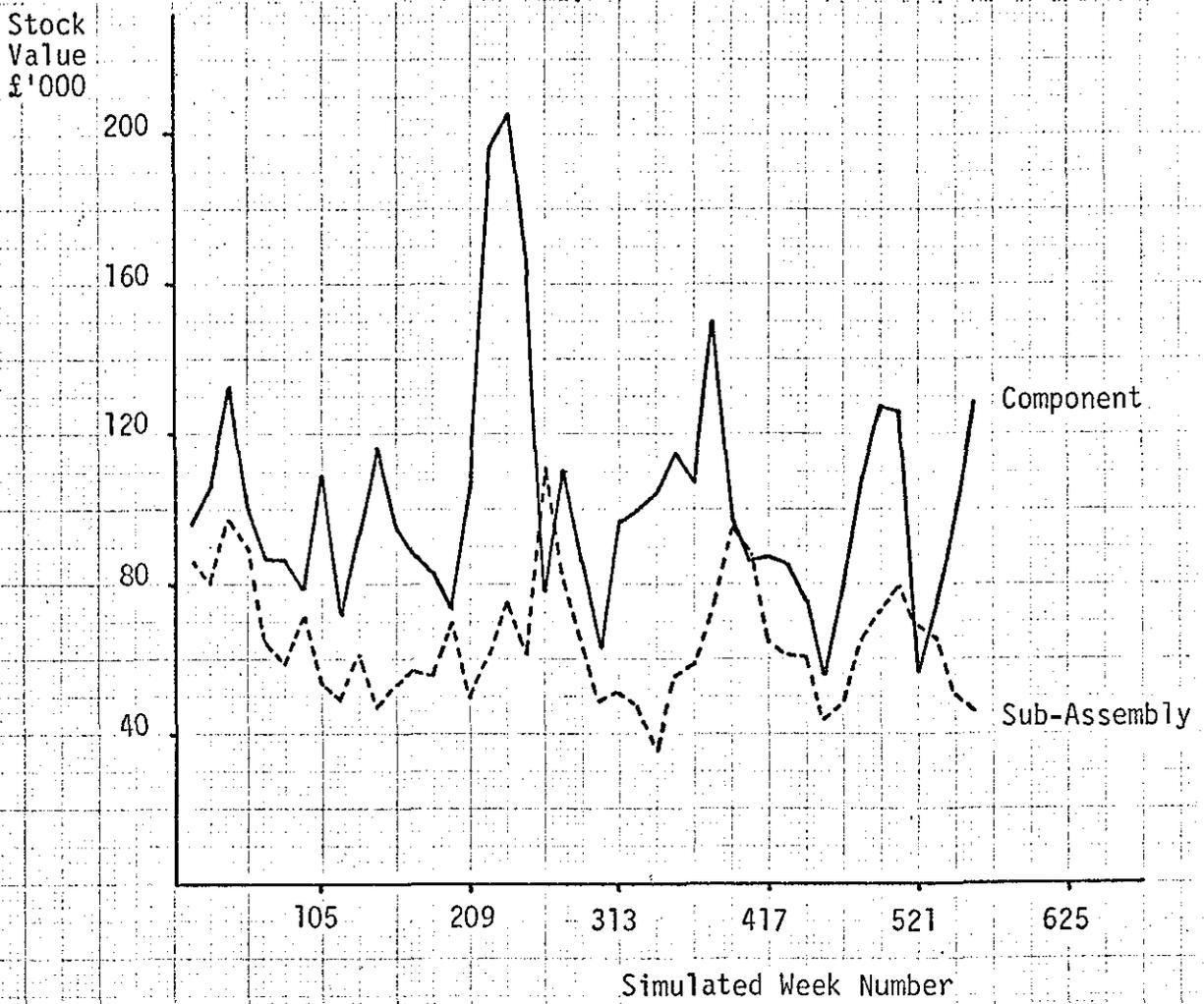


Fig. 4.12. - Component and Sub-Assembly Stock Value

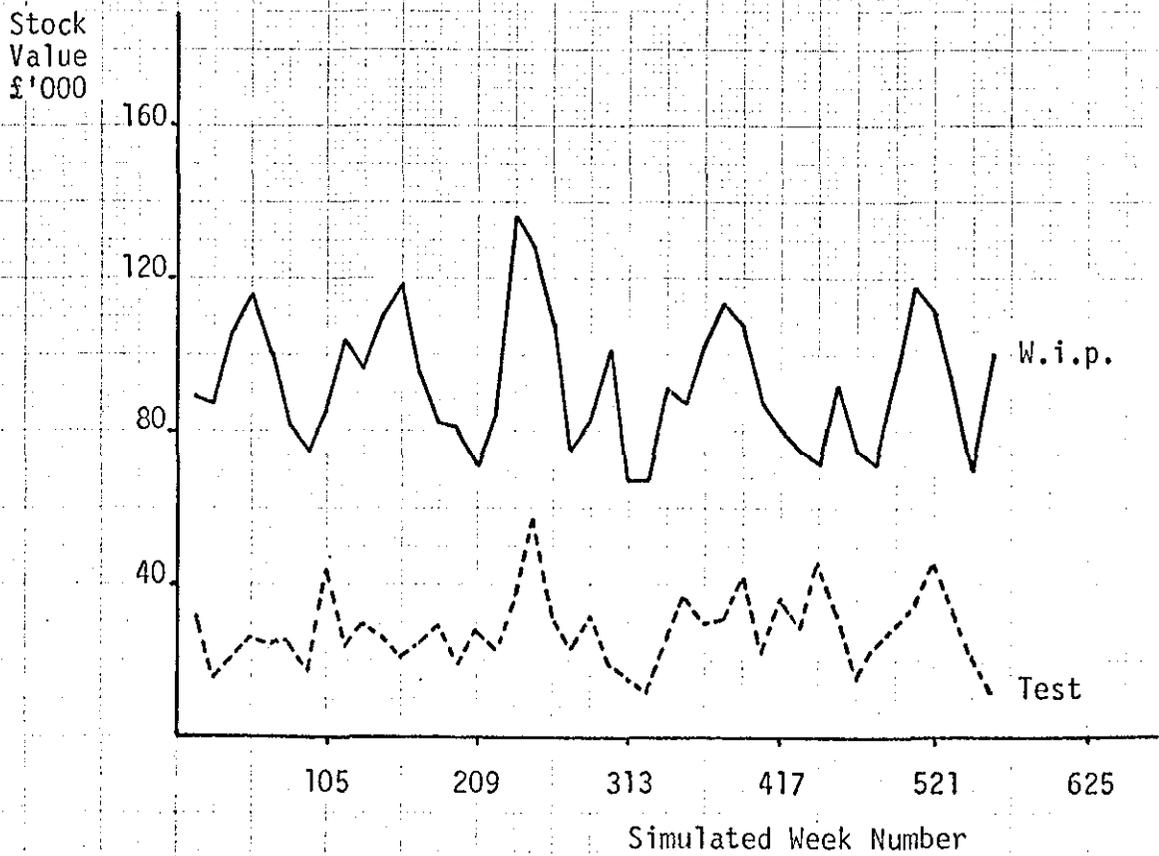


Fig. 4.13. - Work in Process and Test Value

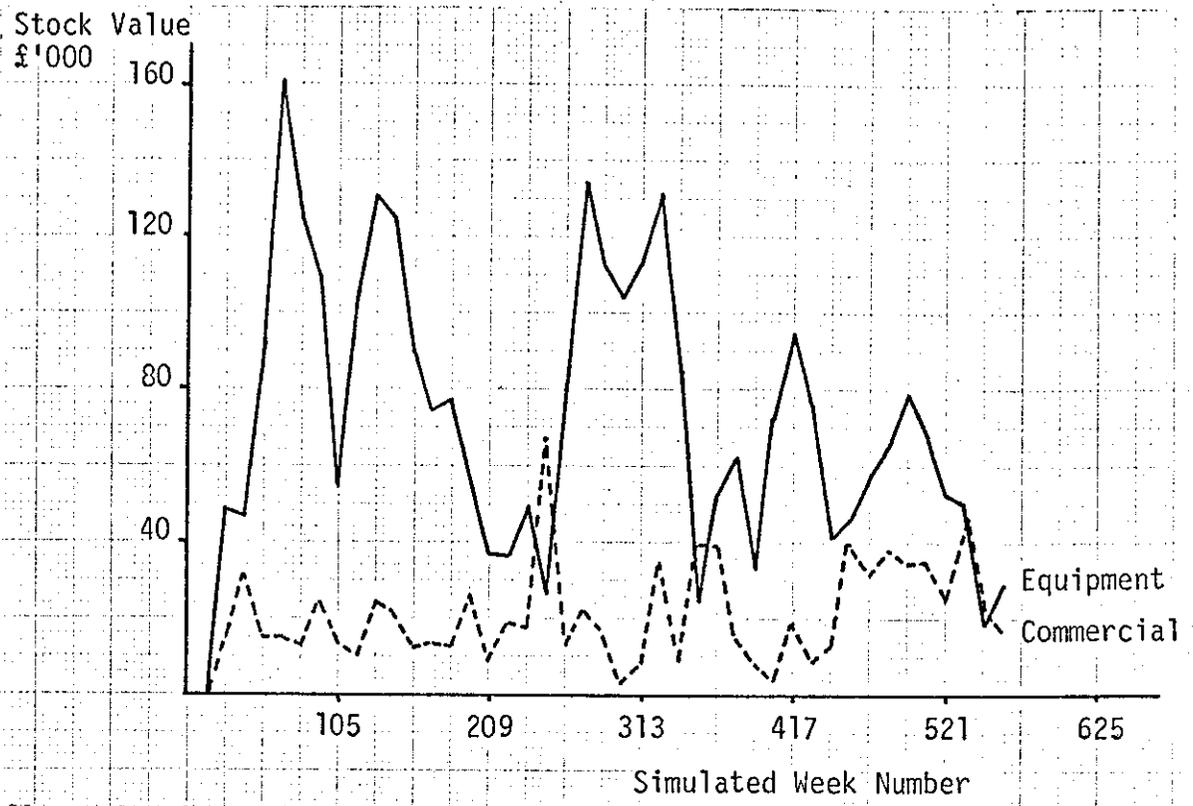


Fig. 4.14. - Equipment and commercial Stock Value

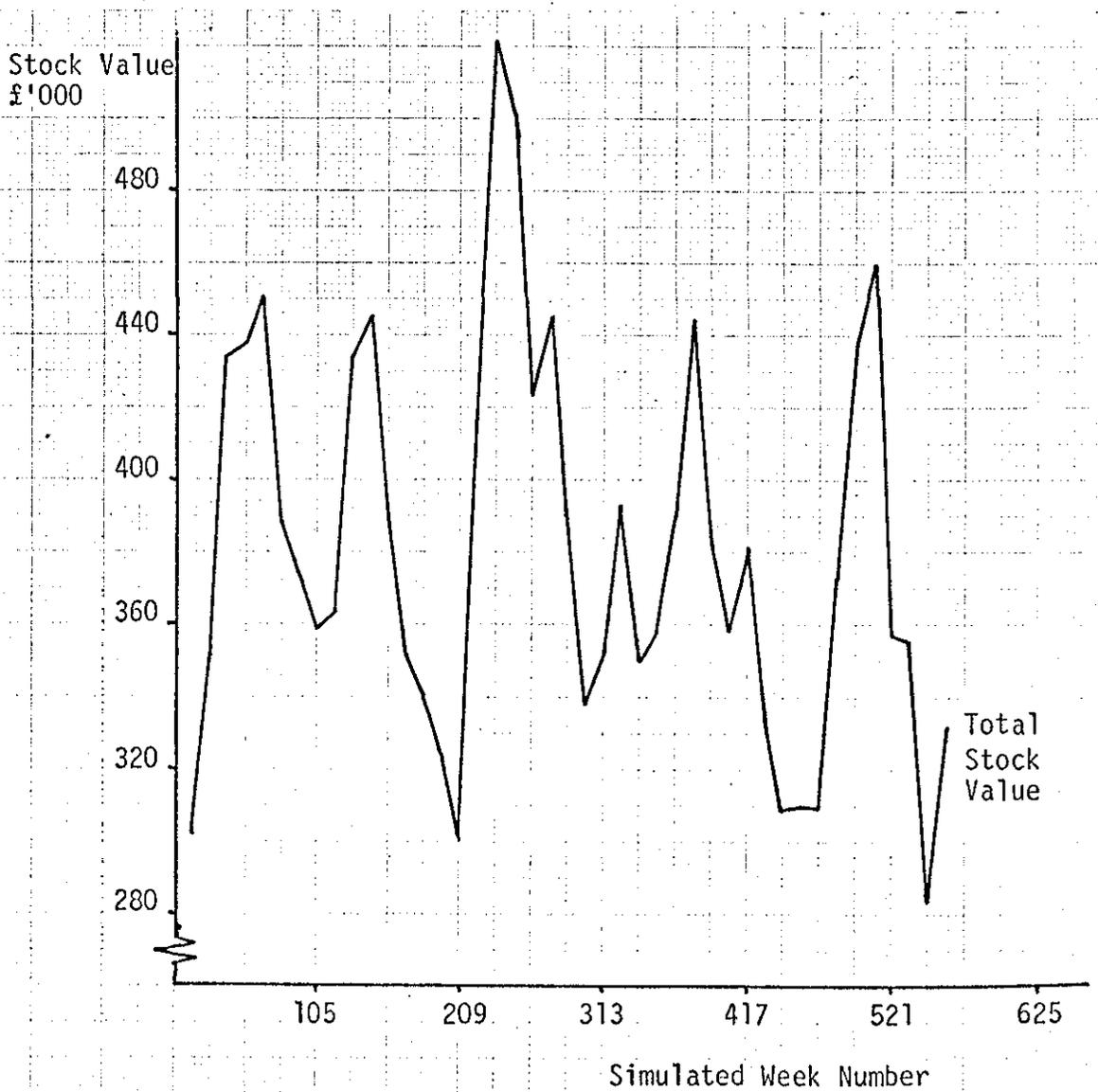


Fig. 4.15. - Total Stock Value

shortages, thus causing a "ripple effect" as the value moves through sub-assembly stock, equipment work in process, test and despatch.

- e) Each stock category indicates certain special characteristics. These have been summarised in Table 4.38.

STOCK CATEGORY	CYCLICAL PATTERN	RELATIVE MAGNITUDE	CONTRIBUTION TO TOTAL
Component	Regular	Very large	Large
Sub-assembly	Regular	Medium	Medium
Work in process	Very regular	Small	Medium
Equipment	Fairly regular	Very large	Large
Test	Irregular	Medium	Low
Commercial	Irregular	Very large	Very low
Total	Regular	Large	N/A

Table 4.38. - Cyclical Attributes

Thus it can be seen that the component and equipment stock categories contribute mainly to the fluctuations in total stock investment and therefore merit further investigation of the causes of the observed variations. The dramatic build up of component stock in the simulated week 235 is particularly significant, being approximately double the normative value. The most likely cause is the abnormally low total stock in week 209, since the planning system attempts to recover the planned buffer levels. As all stock categories are low, the inventory tends to arrive at the component point beyond the schedule reaction time.

The irregularity of the equipment stock value could be explained by the probability that, in the mixed mode condition, products are switching from "make to order" to "make to stock" mode, this causing large variations in allocated stock during the transition.

4.5. MODEL EFFICIENCY

The resources required to execute the described model are shown in Table 4.39.

RP NO.	START TIME (hr/m/s)	END TIME (hr/m/s)	ELAPSED TIME (hr/m/s)	CORE (WORDS)	OFF-LINE OUTPUT (LINES)	RESOURCES USED	RUNNING COST (£)	COMMERCIAL COST (£)
3	00/42/57	02/19/02	1/36/05	100096	7646	85044	72.25	159.45
7	14/37/42	16/00/28	1/22/46	"	7650	84706	71.96	158.82
8	00/14/43	01/25/17	1/10/35	"	7879	84797	72.04	158.99
9	02/57/32	04/00/01	1/02/29	"	7890	83661	71.07	156.86
10	05/28/26	06/56/10	1/27/44	"	7552	80681	68.54	151.27
11	02/12/36	02/58/53	0/46/17	"	7381	80682	68.54	151.27
12	00/50/31	02/12/33	1/22/02	"	7552	80430	68.33	150.80
13	07/05/49	08/34/47	1/28/58	"	7708	81409	69.16	152.64
14	04/07/47	05/55/27	1/47/40	"	7480	81331	69.09	152.49
15	04/10/31	05/31/06	1/27/35	"	7564	80430	68.33	150.80
16	02/43/49	06/49/38	3/05/49	"	7552	81314	69.08	152.46
17	05/26/01	06/49/38	1/23/37	"	7471	87038	73.94	163.19
18	06/49/40	07/44/05	0/54/25	"	7551	80809	68.65	151.51
19	05/17/55	06/51/51	1/33/56	"	7642	84692	71.95	158.79
20	02/45/56	04/10/28	1/24/32	"	7642	84988	72.20	159.35
21	05/55/29	07/33/01	1/37/32	"	8229	86704	76.66	162.57
22	04/26/16	05/54/48	1/28/32	"	7410	80955	68.78	151.79
24	05/54/51	08/03/21	1/09/30	"	7552	81040	68.85	151.95
25	03/47/57	05/17/52	1/29/55	"	7689	81956	69.63	153.66
26	00/41/07	01/40/57	0/59/50	"	7323	81686	69.40	153.16
27	23/12/44	00/41/05	1/28/21	"	8016	82549	70.13	154.77
28	02/41/20	04/32/44	1/51/24	"	7655	84341	71.65	158.13
29	01/21/57	02/41/18	1/19/21	"	7889	84982	72.70	159.34
30	21/48/31	23/41/36	1/53/05	"	7874	85595	72.72	160.49
31	00/50/39	02/24/13	1/33/34	"	7872	84818	72.06	159.03
32	02/24/15	03/58/59	1/34/44	"	7877	84918	72.14	159.22
33	23/27/34	00/50/38	1/23/04	"	7645	84542	71.82	158.51
34	00/19/21	01/38/16	1/18/55	"	7873	85639	72.75	160.57
35	04/08/21	05/36/34	1/28/13	"	7876	84419	71.72	158.28
36	02/09/33	03/47/55	1/38/22	"	7882	83964	71.33	157.43
37	07/02/24	08/32/21	1/29/57	"	7574	81243	69.02	152.33
38	08/01/37	10/14/11	2/12/34	"	7559	81421	69.17	152.66
39	04/15/46	05/03/17	0/47/31	"	7558	81289	60.06	152.41
48	04/41/49	05/33/08	0/51/19	"	7550	81067	68.87	152.00
49	03/04/45	04/41/46	1/37/01	"	7322	81729	69.43	153.24
50	03/27/42	04/15/43	0/48/01	"	7550	82111	69.76	153.95
AVERAGE			1/26/32	100096	7663	83027	70.37	155.67
TOTAL							2533.28	5604.18

Table 4.39. - Computer Resources utilised

The design of the computer programs resulted in a constant main memory requirement of 100096 words. This value is highly significant, since this exceeded the limit set by the Computer Centre management as available for user application programs. This limitation established the maximum dimensions of the data files and subsequently the experimental data volumes. It should be noted that some reduction in main memory requirement could have been achieved by the use of COMMON or EQUIVALENT statements. The decision to maintain the independence of the memory allocation was taken since it was only considered viable to overlay workfiles, and these only represent a very small proportion of the total file space required.

The possibility of reducing the main memory requirement, or alternatively increasing the system file dimensions, by transferring certain files to the secondary storage media (disk storage) was not considered appropriate due to the inevitable impact on run times as result of the input/output accesses.

The actual experimental run time varied from 46 minutes to 3 hours 05 minutes, with a mean of 1 hour 26 minutes. Since the total amount of resources used was substantially constant, it can be concluded that the wide variation in runtime was due to the presence of other conflicting demand on the computer resource.

The off-line output of approximately 7500 lines represents the requirement for a five year simulation experiment at diagnostic level 4 (monthly summaries only). Increasing the diagnostic detail to level 3 or below significantly influences the amount of off-line output generated. For example, when conducting detailed tests at level 1, two boxes of single part listing paper were required for a simulated one year period.

The commercial cost of conducting each experiment averaged £155, resulting in a total of £5600 for the series of the experiments described. This total excludes cumulative cost of developing and testing the program modules. The three factor, three level full factorial group of experiments account for £4185 of the total cost.

5. CONCLUSIONS

5.1. INTRODUCTION

The results obtained from the simulation experiments permit conclusions to be drawn about the business system behaviour, the model performance and the applicability of the techniques employed. This section has been structured into three main discussion areas, in descending order of priority. The first area is the impact of planned buffer stock on the business system behaviour, leading to recommendations on the policies that should be adopted. The second area concentrates on an analysis of the simulation model validity and any general conclusions that may be drawn from the approach adopted. The final discussion includes general conclusions or indications derived from observation of a number of the secondary experiments.

5.2. BUFFER STOCK DISPOSITION

5.2.1. Component Buffer Stock

The results of the simulation experiments have shown that the influence of the planned component buffer stock level on delivery performance observed at the despatch point is insignificant when compared with the influence of the downstream stock points, including test work in process, finished equipment stock, assembly work in process, sub-assembly stock and sub-assembly work in process. The role of the component buffer stock within the business system described can therefore be considered as being predominantly its primary task of minimising the effect of supply disturbances on the production process.

An important distinction at this point is that component buffer stocks are planned to provide protection against predictable, or **recurring**, supplier irregularity. The parameters within the simulation model were selected to demonstrate a reasonable supplier performance profile under normal conditions. No allowance was made in the model for unpredictable supplier failure, for example, the effect of a strike, a tool failure, or lack of capacity. Buffer stock is not

intended to address these problems and may, in some cases, aggravate the underlying cause by increasing the supplier work-load. Such situations are resolved by regular monitoring of supplier performance and manual adjustment of the Master Production Schedule or intermediate Inventory Plans to alleviate the problem.

The isolation of the component buffer stock influence is significant, since it allows further important conclusions to be derived.

It has been shown that the impact of product mix on the component stock within the formal replanning events is negligible. The disbursement of stock to the work in progress areas will, therefore, tend to be predictable, thus minimising the need for buffer stock at the component level to absorb demand uncertainty. The component stock will, thus, represent only the three elements;

- cycle stock dependent upon the frequency of supply (normally monthly);
- reserved stock representing the allocated production orders;
- buffer stock dependent upon the degree of supplier uncertainty.

Analysis of component buffer stock may therefore be directed towards the optimisation of supplier performance as seen from the production interface, and the best compromise between component stock investment and supply system performance may be derived by selectively buffering each component according to the supplier reliability. Such analysis may be executed in isolation of the demand influence, since it has been shown that there is no significant interaction.

5.2.2. Sub-assembly versus Equipment Stock

The discussion and conclusions regarding the impact of sub-assembly and equipment buffer stocks on delivery performance are based, in the first instance, on the simulation model results. A subsequent discussion will establish the validity of the simulation results in the actual business system and argue the practical significance.

The most important result of the simulation experiments is the conclusion that, under the stated experimental conditions, there is no significant difference between the influence of planned sub-assembly and planned equipment buffer stocks on delivery performance, particularly when related to stock investment rather than equivalent weeks of throughput.

This conclusion is valid for the experimental conditions selected, but may differ if other operating parameters are established. Both the planned level of test work in process and assembly work in process will influence the relative importance of each buffer stock, since increased work in process investment will decrease the sensitivity of delivery performance to planned buffer changes, the decreased sensitivity being more apparent the further upstream the stock exists relative to the delivery point. The conditions selected were, however, based on existing policies and were considered representative.

The selection of a buffer stock policy, therefore, is more dependent upon strategic considerations rather than purely financial. The evaluation must include, for example:

- a) the increased obsolescence risk of customised products;
- b) the reduced flexibility to changes in demand pattern as products are completed to a higher level;
- c) the need to offer competitively short delivery lead time to certain customers;
- d) the requirement to achieve a high quality performance by incorporating a number of sub-assemblies into final products for quality control checks with a minimum delay;
- e) the need to provide a constant work flow through the assembly and test departments by storing further added value.

The first two items argue for holding stock of sub-assemblies only, whilst the last three favour finished equipment stock.

A general conclusion which addresses both the financial considerations and includes the strategic arguments is as follows:

- 1) Stock should be held at the sub-assembly point as a general principle, to maximise manufacturing flexibility and reduce obsolescence risk.
- 2) The lead time to finally assemble a customised product must be as short as possible, given the constraints of the manufacturing system. This implies certain investment in assembly and test technology to minimise equipment set-up and reduce "economic batch" sizes. In this way, the final assembly can respond rapidly to mix changes and short delivery lead times can be offered where appropriate.
- 3) The need to store added value in the final assembly and test departments must be minimised. This can be achieved by a number of complementary practices.
 - responsive order promising to achieve a constant delivery plan;
 - short manufacturing lead times and minimal set-up times between batches;
 - reduction of labour intensive activities by improved design and selective automation.
- 4) Where it can be demonstrated that additional sales may be generated by an "ex-stock" delivery of standard products, it may be valid to hold certain items in fully assembled and tested form to take advantage of these opportunities. Experience shows, however, that the need for very short deliveries is limited, since:
 - new customers require a relatively long lead time to establish a frequency allocation from the Telecommunications controlling Authorities.
 - existing large customers generally are sufficiently mature to pre-plan their requirements.
 - agents and group companies are normally able to extend their stock replenishment proposals into the manufacturing planning system.

Present marketing estimates place the volume of business which may benefit from such strategic stock at less than 15% of the total turnover.

Stock of finished products can only be effective if the frequency customisation lead time is very short, a condition which may be achieved by

- final crystal insertion and tuning at the latest possible moment (e.g. the service depot).
- use of synthesisers which may be readily programmed at short notice.
- purchase of crystals on a very short delivery lead time, usually at a premium price.

5.2.3. Cost versus Delivery Performance

It is not reasonable to assume that an absolute measure of the effect of stock investment on delivery performance can be derived from the simulation results. Conclusions may be drawn, however, about the general behaviour, which can provide a better understanding of the actual business system.

An approximate relationship between the total stock value and the equipment delivery performance has been derived according to the experimental assumptions stated.

$$P_e = 0.23V_{TOT} - 13.15$$

for the conditons

$$\begin{aligned} 0 &\leq x_1 \leq 4 \\ 0 &\leq x_2 \leq 4 \\ x_3 &= 8 \end{aligned}$$

where P_e = equipment delivery performance (%)

V_{TOT} = total stock value (£'000)

x_1 = equipment buffer stock (weeks)

x_2 = sub-assembly buffer stock (weeks)

x_3 = component buffer stock (weeks)

Due to the increasing non-linearity of the fundamental relationships, the expression is valid for a limited range of buffer stock values but becomes less valid under extreme conditions.

The experimental results show that an approximately linear relationship can be derived over a limited range, and that an actual value for incremental delivery performance may be derived.

If the results are observed in further detail, it can be seen that, as the planned buffer stock is varied through the two extremes, equipment delivery performance varies from 61.58% to 74.02% and stock value ranges from £324,900 to £378,900. Thus a 1% change in delivery performance is effected by a 1.24% change in total stock investment.

It has been shown in Section 3.4.5. that the model structure and data selection represent a reasonable, scaled down, version of the actual business system. It can, therefore, be concluded that the proportional relationship derived above is an acceptable estimate of the real world stock investment/delivery performance behaviour.

5.2.4. Impact of Human Intervention

The simulation model has been structured to include simple priority rules, such that manufacturing queues will be sorted on either a first-in-first-out, or a due date priority. The real world rules are far more complex and will often vary as either policies or circumstances change. This particular aspect should be considered further, since it has some significance in the interpretation of the simulation results.

Delivery performance has been a highly visible management performance index for the past few years. This visibility, and commitment to a high level of customer satisfaction has yielded dramatic improvements in measured results.

The monitoring of delivery performance is the responsibility of the Order Control department, who constantly review priorities and apply pressure as required to meet their pre-defined objectives. The two primary objectives are:

- (i) maintaining the value of the invoiceable shipments;
- (ii) achieving the delivery performance targets.

The two objectives are, to a large extent, in conflict since maximum invoice value may be attained by concentration on a few large orders, while delivery performance statistics may be enhanced by shipping a large number of small orders.

In practice, a working compromise is struck between the two requirements, the result being that invoice value receives the greatest attention, while delivery performance may still be achieved by the selection of a suitable portfolio of small orders.

The simulation model is not sensitive to order size and thus will not dynamically adjust to maximise the measured delivery performance. The effect of applying selective human intervention of the "unexpedited" business model will be to increase the measured delivery performance, the degree of influence being dependent upon the specific management objectives at any time.

5.2.5. Assumptions/Validity

The value of the conclusions reached is directly influenced by the validity of the simulation model as a true representation of the actual business system and the reasonableness of the assumptions made. The validity of the simulation model is dependent upon the accurate portrayal of the process and the reasonableness of the data, both of which have been addressed in Section 3 - Research Methodology.

It can be concluded that the model does provide an adequate representation of the general business behaviour, given normal operating conditions. The model is unable to portray abnormal conditions, such as catastrophic supply failure or extreme customer behaviour, nor does it address the changes in internal policies or priorities that arise from periodic management intervention in the process. Such limitations do not detract from the value of the model, since such situations may be introduced once a good understanding of the normal situation is obtained.

An evaluation of the data applicability is more complex, since the model is necessarily a scale version of the actual environment. Every attempt has been made to provide consistent scaling factors, whilst maintaining the simplicity required for rational evaluation of the results and remaining within the constraints imposed by the data file sizes and computer run times permitted. Some allowance should, however, be made for the possible bias that may have occurred by increasing the expected product quantity.

5.3. SIMULATION MODEL

It has been shown that general purpose simulation languages were not considered appropriate tools for the evaluation of the stated business problem. A different approach was adopted, taking advantage of the flexibility of a general purpose programming language, FORTRAN, and subsequently emulating the MRP logic. Since the plausibility of the experimental conclusions is influenced directly by the appropriateness of the techniques adopted, some further conclusions on the model performance are now derived.

5.3.1. Statistical Significance

It has been shown that the model is valid and thus able to provide a basis for statistically rigorous experimentation, within the constraints of the computer resource available.

A total of twelve probability density functions are incorporated into the model design, each of which is sampled by use of an independent random number stream. To enable certain influences to be isolated, many of the stochastic processes may be readily converted to deterministic by use of a zero random number seed. (Note: This facility has not been demonstrated in the experiments described).

The most rigorous test for the model was the three factor experiment for the evaluation of buffer stock significance. The results permitted analysis as a full factorial analysis of variance without replication, demonstrating the value of the model as an analytical tool. Further, variance reduction through the use of antithetic random number streams and multiple replication have been demonstrated, both techniques performing as expected.

The validity and statistical significance of the experimental results are also dependent upon the performance of the random number generator. It should be noted that the program was derived from a standard IBM library routine and has been subject to tests and found to be satisfactory. There is no evidence of bias in the experimental results obtained, however, attempts to achieve quantifiable statistical significance should be preceded by a validation of the pseudo-random number streams using, for example, the recommended tests suggested by Naylor et al (1966).

5.3.2. Scope

The model is, necessarily, a simplification of the real world processes. It attempts to provide an accurate representation of the actual business system and in so doing has to compromise between the conflicting considerations.

- the need to emulate the total business system, from supplier to customer;
- the selection of reasonable probability density functions to represent historical observations;
- the requirement to provide a realistic, yet simple, emulation of the human decision making process where rules are not apparent;
- the need to scale data consistently within the constraints imposed by the computer resources.

The primary objective is to provide a comprehensive view of the aggregate system performance, rather than an in-depth analysis of any individual process. However, the structure is such that any sub-process may be isolated if required for further evaluation, examples being the receiving process and the effect of work in process quality performance. Further definition and analysis is easily accommodated, but the need must be weighted against the overhead in computer run time and cost.

The lowest level of definition within the model is a weekly summary of transactions through each business sector. Results are monitored at this level, but normally are not recorded due to the substantial volumes of printed output that would result.

The model may, thus, be used in two quite different ways. The first, by selection of a high diagnostic level, permits the evaluation of the aggregate system in response to parameter or condition changes, where long term results may be readily compared. The second is the ability to perform a detailed study, at transaction level if required, at any pre-selected time during the simulation experiment. The low diagnostic level will cause the reporting of each operational transaction without influencing the model behaviour over the long term.

The structure of the model permits changes to be introduced to any one, or all, of the three significant factors.

1. Environmental changes, either in the form of the supplier or the customer profiles.
2. Parameter changes within the model, reflecting changes in management policy.
3. Process changes within the model, indicating a fundamental change in the business system.

5.3.3. Efficiency

The simulation model as described is relatively inefficient in computer resource terms. The design is such that all programs and files are held in main memory during execution time to avoid the problem of disk access time, and yet a five year simulation experiment requires a dedicated processor for over one hour.

The lack of model efficiency was a significant constraint during both the design and experimentation phases. The limitations in main memory directly determined the file sizes permissible, and hence the scaling factors required to reduce the data volumes.

The run time and thus the cost of each experiment did not permit the range of parameter selection and replication that were required for statistical significance to be attained for any of the "secondary experiments".

The conditions under which the model was executed were, however, less than optimum. The ICL 1904S is, by current standards, a very limited and slow processor. Execution of the experiments on a contemporary processor, for example an IBM 3031, would result in execution times of ten minutes or less with significantly more main memory available for system files if required.

5.3.4. Language

The decision to use a general purpose programming language, FORTRAN, was taken because of the limitations of the specialised simulation languages when working at the detailed level required. It has been shown that FORTRAN is a viable programming language for the type of model considered, albeit with two significant limitations.

The first limitation is the handling of files. The use of FORTRAN led to problems in maintaining consistent data between files, redundant file space and complicated programming logic. The second limitation, compared with the use of specialised simulation languages, was the significantly greater time required to structure a model and the need to design certain logical diagnostics that would be native to a simulation language.

The positive features of FORTRAN, however, outweighed the problems encountered. The main aspects are restated below:

- it would not have been possible to emulate the MRP process conveniently using either a time or event driven simulation language, due to the problems of introducing the product structure.
- FORTRAN was offered on the computer facilities available and permitted an easy transfer to a larger facility had this been required.
- more expertise for the resolution of programming problems was available for FORTRAN than for simulation languages, and subsequently, the model could be more easily adapted by other experimenters if required.
- FORTRAN is well proven and relatively efficient when used under the GEORGE operating system which also offers powerful diagnostics and trace capabilities.

5.3.5. General Applicability

Observation of the simulation model demonstrates the potential to address a more general situation than the specific business area selected. (See Section 1.3.4.)

Conceptually, the modelling technique adopted may be employed to model any complete business system, or sub-system, within the ability to define the rules and processes. The definition and development time-scales would, however, be extremely long and such an approach is unlikely to be cost effective in a commercial environment.

Practically, the model can be considered as representative of a typical multi-echelon manufacturing assembly environment. Thus, with minor changes to the parameters and probability distribution functions, many similar business environments may be simulated. Further small changes to certain rules and procedures can also be easily accommodated, thus increasing the general applicability of the technique.

The modular structure of the simulation programme also allows a further level of differentiation. Replacement of an existing subroutine with an alternative version will permit a completely different process to be emulated, without necessarily impacting on the residual model structure. This facility is of value, not only in adapting the technique to other environments, but also to demonstrate the effect of changing certain processes in the existing simulated environment.

The approach adopted retains the view of the full business system. A similar concept, but with a much more limited scope and ability to tailor to a given environment is discussed by Carlson (1979). The technique, however, of using MRP as a simulator, is supported by his study.

5.4. GENERAL CONCLUSIONS

Observation of the behaviour of the simulation model under certain conditions reveals a number of important characteristics of the business system which, although not always quantified, are sufficiently significant to warrant a critical examination of many of the actual operating policies and procedures.

5.4.1. Cyclic Effects

There is clear evidence that the rules applied to the planning of material requirements, in conjunction with the delay times observed within the business system, lead to a pronounced cyclic behaviour. Although this phenomenon has been displayed only for the inventory values, a similar pattern may be seen in the observed delivery performance.

The cyclic effects may be reduced by a number of complementary changes to the existing policies.

- a) The total planning system should be integrated, such that all elements of inventory, including sub-assembly stocks, are included in the requirements planning.
- b) The planning frequency should be increased from quarterly to weekly, to permit changes in business volume or production effectiveness to be followed more closely.
- c) The requirements planning system should be used as the mechanism for production scheduling in addition to material planning to ensure a single, integrated operating plan.

5.4.2. Manufacturing Mode

There is apparently little difference between the measured delivery performance for the make to order or make to stock modes of manufacture. If the system is operated in mixed mode, however, the achieved delivery performance is significantly lower. This effect is explained by the continual switching between modes as stock is replenished or depleted since, if stock were to continually exist, the "pure" stock mode would result. The effect during the transition is for delivery priorities to be confused at the expense of service level. There is evidence, therefore, that clear guidelines governing the mode of manufacture are required to avoid the mixed mode phenomena.

5.4.3. Priority Rules

There is no evidence from the experimental results that the delivery performance is influenced by the choice of priority rule. This result appears contrary to logical reasoning since, using the "Due Date" rule, overdue orders would be placed at the top of manufacturing priority list and move quickly through the system. The choice of model logic, however, places constraints on the minimum throughput time since the time moves forward in one week increments. Thus, a product cannot pass through both assembly and test in the same week. This effect, therefore, limits the value of the priority rule experiments.

It should also be noted that the same constraint on throughput time may also marginally lower the measured delivery performance.

5.4.4. Relationship between Commercial Stock and Delivery Performance

A relationship between the observed delivery performance and the value of commercial stock has been suggested. This indicates, predictably, that as the delivery performance improves the value of stock awaiting order completion diminishes. It has been proposed that the relationship is non-linear, exhibiting a minimum value of commercial stock at the 100% delivery performance point.

The extrapolation shown, however, assumes ideal conditions. It may be argued that, under normal business conditions, the achievement of a near 100% delivery performance would require a substantial proportion of products to be delivered into commercial stock in advance of the scheduled due date. The effect would be to increase the value of commercial stock as more products are advanced, due to subsequent imbalance in achieved completion dates.

It would, thus, be argued that the value of commercial stock would reach its lowest point at a value in excess of the theoretical minimum, and would then increase as the delivery performance further improves. Observation of the results suggests that this point may have been reached in the simulation model at a value of around £9,200 (see Section 4.4.4.)

Since both the delivery performance achieved and the value of commercial stock are relatively independent, each being the result

of a number of causal influences, the derivation of a definitive relationship is considered inappropriate.

5.4.5. Effect of Capacity Utilisation

There is clear evidence from the experimental results that the availability of excess capacity does not significantly improve delivery performance. The contrary effect, however, of constraining the available capacity indicates a "knee" in the delivery performance/capacity utilisation relationship, beyond which the delivery performance deteriorates rapidly.

The range of capacity utilisation selected for experimentation was limited, therefore further quantification was not attempted. More extensive evaluation, including an estimate of the cost of excess capacity, would certainly be beneficial as a further measure of the cost of delivery performance attainment.

5.4.6. Effect of Orders Received Trend

There is no evidence to suggest, given the experimental conditions of a moderate trend introduced in the product mix within a constant overall volume, that orders received trend has a quantifiable effect on achieved delivery performance.

It is not feasible, given the very limited scope of experimentation involving trend parameters, to draw any general conclusions on the effect of orders received trend. Logical reasoning would indicate that, under more extreme conditions of trend involving both product mix and volume, quantifiable effects should be apparent. Further experimentation into these phenomena is, therefore, recommended.

6. RECOMMENDATIONS FOR FURTHER RESEARCH

6.1. INTRODUCTION

It is evident from the discussions related to the model design and the structuring of experiments that the modelling technique offers enormous potential for further productive research. This section indicates the scope available by organising the potential research areas firstly in priority order to complement the results described earlier, and secondly in ascending complexity from a model modification viewpoint.

6.2. EXPERIMENTAL DESIGN

6.2.1. Variance Reduction Techniques

It has been shown that the simulation model permits the use of both replication, by using alternative random number seeds, and anti-thetic sequences by the introduction of negative seeds.

Many of the secondary experiments were indicative rather than conclusive, due to the limited number of simulation experiments using the variance reduction techniques available. Although the costs for each experiment are not trivial, a number of the secondary experiments certainly warrant more detailed analysis.

6.2.2. Long Term cyclic Effects

A single example of the long term cyclic performance was conducted, again due to the cost and timescale involved. The main consideration was to demonstrate that the model is stable over the long term and that selection of the first simulated five years is a reasonable compromise between the cost of experimentation and validity of the results.

There is, however, scope to examine the long term cyclic effects in more detail. There is evidence to suggest some form of damped oscillation may be present, and if this is so the structure of the planning process may be introducing an element of positive feedback.

Analysis of the model using control theory may lead to certain modifications of the planning procedure to minimise the cyclic nature of the stock profiles.

6.2.3. External Parameters

Of the parameters that are determined by management policy, two are accessible as input parameters; planned order book in weeks and supplier response time. Both were pre-defined in the described simulation experiments to reflect the existing policies.

Management has been reluctant to change these parameters in practice due to the long lead time required to determine the impact. The simulation model will permit the long term effects to be observed without any practical risk involved.

6.2.4. Internal Parameters

A further set of parameters is embedded in the model design, since the specific business problems did not require access to these items and pre-definition at the data input stage would have caused greater complexity. A number of significant internal parameters are worthy of further evaluation, some of which are as follows:

- (i) The planned work in process level in weeks is defined both in the planning rules and in the order release decision process. A series of experiments to demonstrate the effect of modifying the planned work in process levels is indicated, since it has been shown that the "residual" stock investment is far greater than that influenced by planned buffer stocks.
- (ii) The rules applied to the treatment of equipment stock were assumed, since there was evidence in the actual business environment of several different practices. The model offers scope to modify the timing of equipment allocation to customer order and hence to potentially reduce the allocated stock investment. The probable effect of such action on delivery performance and aggregate stock investment may be considered prior to a policy decision.

(iii) The planning constraints used to assist in the preparation of the equipment quarterly plan are heuristic rules which have been developed over time and evolved through experience. An evaluation of the sensitivity of the business system to different planning rules would contribute to the establishment of policies which minimise the response time to forecast changes consistent with acceptable stock investment and delivery performance.

6.2.5. Probability Distribution Functions

The probability distribution functions describing certain business attributes have been selected to represent, as closely as possible, the real world conditions. Scope exists, however, to predict the likely effect of changes in the environment so that remedial action may be considered prior to a trend being observed. The most important characteristics are the customer ordering profile, the supplier delivery profile and the reject re-supply pattern.

The order characteristics permit selection of five parameters; the number of orders per period, the number of items per order, the product selected, the quantity of each product ordered and whether part shipment is permissible. The model permits trend to be introduced on one or all products within a fixed business level. Further evaluation of the effect of trend would be desirable, particularly the reaction of the system to rapid changes in trend under different planning constraints.

Changing the part shipment rules will effect both the stock investment and the measured delivery performance. Any proposed change in policy must, however, be related to the willingness of the customer to pay the invoice, or the result is to move value from stock to debtors.

The material receipt profiles are dependent upon two factors. The first is the supplier reliability and the second is the internal inspection procedure. Supplier reliability can be influenced by careful supplier screening and improving the dialogue between the procurement function and the supplier. Since the supplier unreliability is addressed by component safety stocks, there is scope for an evaluation of the potential benefits that might accrue through more effective procurement policies.

The inspection procedures have been emulated as closely as possible according to rules as available. Inspection policies are, however, subject to regular review as the type of component evolves through technical change and management responds to current thinking. The structure of the model permits a range of policies to be evaluated, but only in terms of component service level. No facility has been introduced to represent quality failure detected at the work in process stage, although this facility could be incorporated with minimum effort.

Vendor re-supply data was difficult to acquire and thus may not be fully reliable. This is because in many instances a rejected batch can lose its identity and be aggregated into other scheduled deliveries. There exists the potential to examine the sensitivity of the system to re-supply leadtimes and evaluate the potential benefits of a more visible form of re-supply control.

6.2.6. Product Definition

The master files accessed by the simulation model include the product definition, which comprises item data (e.g. description, value) and the product structure.

The product definition file as described includes four finished products, which are represented through four structure levels; finished product, two levels of sub-assembly and component. There is no limitation in the model on the number of items at each level or the number of levels apart from the physical file size definition. It should be noted, however, that an increase in the item master file implies a similar increase in many other files, the most significant of which, in terms of volume, is the equipment order book.

The product structures upon which the simulation experiments were based, included a mix of common items to a number of products and unique items to single products. There is, therefore, the possibility to observe the performance at the component level of the common compared to the unique items in response to orders received trends.

Further analysis of the reaction of each type of component may lead to a better understanding of safety stock requirements and the risk of potential stock-outs.

6.3. MODEL DESIGN

The simulation model was constructed essentially to assist in the resolution of a specific business problem. Subsequently, it has been proven that the technique adopted has a far wider application than originally anticipated. The model construction has, however, been constrained to permit some facilities in excess of the basic requirements without moving too far from the main objectives.

There is a great deal of potential in the basic model as described to enhance the operational efficiency and improve the interface between the model and experimenter.

6.3.1. Interactive Analysis of Results

The model presently outputs diagnostics, performance indices and statistics according to the diagnostic level selected. The programs may be easily modified to permit easier interpretation of results in two stages.

The first stage would be to prepare an output file into which all results at detail level would be written. It would then be possible to select a series of programs which could interrogate the file according to the particular needs of the experiment. A second stage would be to create some interactive programs which would permit the experimenter to make enquiries on the output file at any level of detail. Thus, for example, any abnormal condition at summary level could be investigated through on-line interrogation of the output file at successive levels of detail. Such facilities would avoid several costly simulation experiments at different diagnostic levels to isolate a specific event.

Model enhancement as described would require extra file space but would improve the model efficiency since no print statements would be included in the program. The main benefit would, however, be to the experimenter, who would have access to far more performance data than presently available.

6.3.2. Logic Changes

The model was constructed to emulate as closely as possible the actual business system. The modular structure, however, permits modifications to be made to the logic which may be used to evaluate possible changes to the business process.

Examples of modifications that could provide a greater understanding of the process include the following:

a) Increasing the regeneration frequency.

A major limitation of the process is the quarterly regeneration, which is primarily used for material planning. Production scheduling is a largely manual, supporting procedure.

Increasing the regeneration frequency to monthly, or possibly weekly, offers the opportunity to generate the production schedules directly from the planning process and react faster to forecast changes.

b) Master Schedule.

Due to the infrequent replanning periodicity, the Master Schedule is only notional. Changes to the delivery plan and order loading sub-routines could be made which would be closer to the concept of a true Master Schedule. Thus, the production and material schedules would be based on actual orders and forecast as the order load evolves, and order promising would be less speculative.

c) Net-change.

The two changes described above would be sufficient to move the system from a material planning tool to a fairly standard MRP model. The potential improvements in business system performance that might be expected from the introduction of, for example, the Manufacturing Control System, could be evaluated in advance, including sample rules and policies.

A further enhancement would be the modification of the requirements planning logic to observe the net-change planning procedure. It should be noted, however, that major modifications might be required, since the net-change logic assumes that any system change (e.g.s. bill of material change, Master Schedule change, material rejected) would cause a replan.

d) Order Generator.

The orders received generator allows typical customer orders to be presented to the model, but with certain limitations. Two, relatively simple, enhancements to the orders received generator, would permit a wider scope of analysis.

- (i) The facility to introduce trend into the volume of business could be achieved by incrementing the average number of orders to be generated each period.
- (ii) The trend generator at product level presently only accommodates linear trend. Replacement of the linear trend with a pre-defined profile would enable a typical product life cycle to be observed.
- (iii) Large orders are at present inadequately represented. It is possible to provide a separate large order generator, but this should include the possibility to link to the forecasting module according to certain heuristic rules.

6.4. EFFICIENCY

It has been shown that the simulation model is relatively inefficient in its present form. To make best use of the technique, the executional efficiency should be improved by "tuning" the program and selecting a more suitable host computer.

The programs described are logically sound but do not make best use of the computer resource available. Selective reprogramming can potentially increase the utilisation of main memory and significantly reduce the run-time.

Modification of the programs as suggested is, however, an extremely time consuming process, since an intimate knowledge of the logic within each segment is assumed. A safer and faster alternative is to transfer the programs to a more appropriate host computer. The ICL 1904S* is a slow machine by modern standards as can be seen by comparison with, for example, an IBM 370/158.

	<u>ICL 1904S*</u>	<u>IBM 370/158</u>
Main memory	96K words - 256K words **	1024K - 8192K 8 bit bytes
Cycle time	500 nS	80 nS
Full add time	1.90 μ S	0.08 μ S

** one word is 24 bits

Thus, the IBM 370/158 is up to 20 times faster than the ICL 1904S*.

Even greater potential is offered by moving away from the large mainframe to a dedicated personal computer. It would be possible to execute the programs on a 16 bit micro-computer with 256K bytes of internal memory and obtain the advantage of interactive program control and output analysis.

6.5. EDUCATION

Education in a complex logistics environment is always constrained, since it is difficult to experiment in a live situation due to the long lead time before the effects of decisions are observed and the inherent risk.

The modelling technique described offers an excellent vehicle for the observation of the production and logistics processes without risk. In its present form, selection of a low diagnostic level permits a detailed examination of the underlying transactions, and transfer to a micro-computer would provide even greater training potential. Modern MRP packages are normally supplied with a test data base and training aids, but do not facilitate the introduction of sampling distributions or "free running" over an extended time period. A model of the proposed facilities with the sampling and execution logic described, can be developed into a valuable education and training aid to complement the facilities provided with the MRP package.

The use of an MRP model as an educational tool has been shown by Carlson and Glaser (1975) to be a viable technique. The concepts can be exploited more fully by using the model described in this work, since the scope has been extended to the business boundaries with the external environments.

B I B L I O G R A P H Y

=====

- ANDERSON A.D. Inventory Record Accuracy
20th APICS Technical Conference Proceedings
(1977)
- ANDREW C.G. Engineering Changes to the Product Structure -
Opportunity for MRP Users
Production & Inventory Mgt V 16 No 3 23/1975
- ATKIN G. Meeting Delivery Dates May be Easier than You
Think
Works Management, May 1981.
- BELT W. Men, Spindles and Material Requirements
Planning: Enhancing Implementation.
Production & Inventory Mgt, Vol. 20 No 1
Q1/1979
- BERRY W.L. Lot Sizing Procedures for Requirements
Planning Systems: A Framework for Analysis.
Production & Inventory Management.
Vol. 13 No. 2 Q2/1972
- BERRY W.L., Master Production Scheduling - Principles
VOLLMAN T.E. & and Practice;
WHYBARK D.C. APICS 1979
- BLASINGAME J.W. & Behavioural Dimensions of MRP Change:
WEEKS J.K. Assessing your Organisation's Strengths and
Weaknesses.
Production & Inventory Management, Vol. 22
No. 1 Q1/1981
- BOBECK C.J. & The Master Schedule: New Financial Tool
HALL R.W. APICS Conference Proceedings (1976)

- BOLANDER S; &
TAYLOR S.G. A Framework for Manufacturing Resource
Planning in the Process Industries.
Inventories and Production, Vol. 2 No. 2,
March-April 1982
- BOURKE R.W. Bills of Materials - The Key Building Block.
Bourke & Associates 1977
- BRENIZER N.W. The Bottom Line Begins at the Top.
Production and Inventory Management Q1/1977
- BROOKS R.B. Develop Stock Record Accuracy - Create a
Parts Bank.
20th APICS Technical Conference Proceedings
(1977)
- BROWN R.G. Decision Rules for Inventory Management.
Wiley 1965
- BROWN R.G. Statistical Forecasting for Inventory Control.
McGraw-Hill 1959
- BS 1100 Application of Production Control
BIM 1953
- BUFFA F.P. &
BRYANT T.R. Reflecting Logistics Costs in Customer Service
Level Targets.
Production & Inventory Management. Vol. 21
No. 1 Q1/1980
- BURBIDGE J. What is Wrong with Material Requirements
Planning.
The Production Engineer, Oct. 1980.
- BUXTON J.N. &
LASKI J.G. Control and Simulation Language.
The Computer Journal, Vol. 5, 1962
- CALL-20 REFERENCE
MANUAL Philips Information Systems and Automation
February 1981

- CAMPBELL R.J. &
PORCANO T.M. The Contributions of Material Requirements
Planning (MRP) to Budgetting and Cost Control.
Cost and Management Jan/Feb 1979
- CARLSON J.G. Interactive Methods for the Study and Operation
of Material Requirements Planning (MRP)
Engineering & Process Economics; 4 (1979)
- CARLSON J.G. &
GLASER R.B. Interactive Approaches to MRP Instruction
National Conference Proceedings, American
Institute for Decision Sciences, 1976.
- CHANG C. &
INOUE M.S. New Dynamic Ordering Rule for MRP.
AIIE System Engineering Con. No. 1977
- CONLON J.R. Is Your Master Production Schedule Feasible.
Production & Inventory Management 01/1976
- COPICS MANUALS (Communications Oriented Production Information
and Control System)
IBM Corporation 1972
Ref G320-1974/1981 (8 vols)
- CROWCROFT P.K. &
LAURENCE P.D. Advanced Material Requirements Planning -
USA Visit
Pye Telecommunications Ltd., 1978
- CROWCROFT P.K. &
LAURENCE P.D. Manufacturing Control System Feasibility Study
Pye Telecommunications Ltd., 1979
- DESIGNING A NET
CHANGE MRP SYSTEM IBM Corporation (1976) GE20-0534-0
- EDSON N.W. Measuring MRP System Effectiveness.
Software International Corp., Andover, Mass.,
USA, 1978
- EVERDELL R. Time Phasing; The most Potent Tool Yet for
Slashing Inventories.
Modern Materials Handling, Nov. 1968

- EVERDELL R. Master Scheduling: Its New Importance in the Management of Materials.
Modern Materials Handling, Oct. 1972
- FOGARTY D.W. & Customer Service
HOFFMAN T.R. Production & Inventory Mgt., Vol. 21 No. 1 Q1/1980
- FORRESTER J.W. Industrial Dynamics
M.I.T. and Wiley 1961
- FORTUIN L. SIC or MRP? A heuristic Approach.
N.V. Philips Gloeilampenfabrieken, Eindhoven.
IDR-R-For/7608/2009, Sept. 1977
- FORTUIN L. Material Requirements Determination in Industry -
Comparison of SIC and MRP by Analysis of a
Simple Model.
N.V. Philips Gloeilampenfabrieken, Eindhoven.
IDR-R-For/7810/1014, Nov. 1978
- GANGOPADHYAY S., Bills of Material Structuring and Requirement
CHATTERJEE G. & Planning for Items with Multiple Parents.
PA D.K. Journal of the Institute of Engineers (India) -
Mech. Eng. Div., V59, No. 3, Nov. 1978
- GARWOOD D. Stop, Before You Use The Bill Processor.
Production & Inventory Mgt., Vol 11, No. 2 1970
- GAYLORD M.J. Master Schedule in Relation to the Sales Forecast
and Marketing.
Proceedings of the 20th APICS Conf., Nov. 1977
- GORDON G. A General Purpose System Simulator.
IBM System Journal, Vol. I, 1962
- GREENE J.H. Production and Inventory Control Handbook.
McGraw-Hill, 1970
- GRIECO P.L. Monitoring Performance Levels.
Production & Inventory Mgt., Vol 21, No 4,
Q4/1980

- HABLEWITZ M.J. Cycle Counting
20th APICS Technical Conf. Proceedings (1977)
- HAY E.J. Pitfalls to Avoid in Implementing MRP.
Proceedings of 21st APICS Conf. (1978)
- HIGGINS M.J. New Inventory Performance Measures.
Production & Inventory Mgt., Vol 21, No 3,
Q3/1980
- HOFFMAN R.F. Structuring a Product Model Data Base.
20th APICS International Technical Conf., 1977
- HSU J.P. Implementation Considerations for Group
Technology and Material Requirements Planning.
Proceedings of the 15th Numerical Control
Society Technical Conference (1978)
- JAGETIA L.C. &
PATEL D.M. Computerised Production and Inventory Planning
Models.
Production & Inventory Mgt., Vol 20, No 1, Q1/1979
- JONES G.D. Pitfalls to Avoid in Implementing MRP.
Proceedings of 21st APICS Conf. (1978)
- KARIN R. A Uniform Order Quantity (UOQ)
Lot Sizing Technique for Varying Demand Rates.
Production & Inventory Mgt., Vol 21, No 3, Q3/1980
- KIVIAT P.J.,
VILLANUEVA R. &
MARKOVITZ H.M. The SImscript II Programming Language
Prentice-Hall, 1968
- KOHANKIE R.W. &
MORENCY R.R. Master Scheduling: An On-going Analytical Process
APICS Conference Proceedings (1976)
- KROPP D.H.,
CARLSON R.C. &
JUCKER J.V. Use of Dynamic Lot Sizing to Avoid Nervousness
in MRP Systems.
Production & Inventory Mgt., Vol 20, No 3,
Q3/1979

- KRASNOW W.S. &
MERIKALLIO R.A. The Past, Present and Future of Simulation
Languages.
Management Science, Vol. 11, No. 2, Nov. 1964
- LANDY T.M. Production Planning and Control
McGraw-Hill, 1950
- LANGENWALTER D.F. Structuring Complex Products
Production & Inventory Management, Vol. 17,
No. 4, Q4/1976
- LAURENCE P.D. Measuring MRP Effectiveness
International Journal of Operations and
Production Management
Vol. 1, No. 3, (1981)
- LEACH D. Two Stage Forecasting Model for Use in
Conjunction with a Computerised Master
Scheduling System.
AIIE Systems Engineering Conference
Proceedings. Nov. 1977
- LING R.C. &
WIDNER K. Master Scheduling in a Make to Order Plant
APICS Conference Proceedings (1974)
- MAGEE J.F. &
BOODMAN D.M. Production Planning and Inventory Control.
McGraw-Hill, 1967
- MAHANY H.M. &
TOMPKINS J.A. GT and MRP: An Unbeatable Combination
Proceedings of the AIIE Systems Engineering
Conference (1977)
- MALKO R. Master Scheduling; A Key to Results
APICS Conference Proceedings 1976
- MARANKA P. Master Schedule - A User Applies the Theory.
APICS Conference Proceedings (1976)

- MARTIN A. DRP - A Profitable New Corporate Planning Tool
Canadian Transportation and Distribution
Management, Nov. 1980
- MASTER PRODUCTION APICS (1977)
SCHEDULING REPRINTS
- MATHER H.F. & The Master Production Schedule -
PLOSSL G.W. Management's Handle on the Business.
Mather & Plossl Inc. 1978
- McGREGOR D. The Human Side of the Enterprise.
New York: McGraw-Hill (1960)
- MIZE J.H. & Essentials of Simulation
COX J.G. Prentice-Hall, 1968
- NAYLOR T.H., Computer Simulation Techniques.
BALINTFY J.L., Wiley, 1966
BURDICK D.S. &
CHU K.
- NEW C.C. Requirements Planning
Gower 1973
- NEW C.C. Lot Sizing in Multi-Level Requirements
Planning Systems.
Production & Inventory Mgt., Vol. 15, No. 4,
Q4/1974
- NEW C.C. Safety Stocks in Requirements Planning.
Production & Inventory Mgt., Vol. 16, No. 2,
Q2/1975
- NEW C.C. MRP and GT: A New Strategy for Component
Production.
Production & Inventory Mgt., Vol. 18, No. 3,
Q3/1977

- NEW C.C. Managing Manufacturing Operations.
Management Survey Report No. 35,
British Institute of Management, 1976
- NICHOLAS J.M. Developing Effective Teams for Systems
Design and Implementation.
Production & Inventory Mgt., Vol. 21, No. 3,
Q3/1980
- ODUARDO F. How Forecasting Affects an MRP System.
Production & Inventory Mgt., Vol. 19, No. 2,
Q2/1978
- ORLICKY J.A. Material Requirements Planning
McGraw-Hill, 1975
- ORLICKY J.A.,
PLOSSL G.W. &
WIGHT O.W. Material Requirements Planning Systems.
APICS 13th International Conference, 1970
- ORLICKY J.A.,
PLOSSL G.W. &
WIGHT O.W. Structuring the Bill of Material for MRP.
Production & Inventory Mgt., Q4/1972
- ORLICKY J.A. Closing the Loop with Pegged Requirements
and the Firm Planned Order.
Production and Inventory Management, Q1/1975
- ORLICKY J.A. Net Change Material Requirements Planning.
Production and Inventory Management
Vol. 13, No. 1, Q1/1973
- PAULDEN S. How to Deliver on Time
Gower Press 1977
- PLOSSL G.W. Manufacturing Control - The last Frontier
for Profits.
Reston 1973

- PLOSSL G.W. &
WELCH W.E. The Role of Top Management in the Control of
Inventory.
Reston 1979
- PLOSSL G.W. &
WIGHT O.W. Production and Inventory Control:
Principles and Techniques.
Prentice-Hall 1967
- PLOSSL G.W. MRP Yesterday, Today and Tomorrow
Production & Inventory Management, Vol. 21,
No. 3, Q3/1980
- PRICHARD J. &
EAGLE R.H. Modern Inventory Management
Wiley 1965
- ROSE D.J. Craters Along the MRP Road
Proceedings of 21st APICS Conference (1978)
- SATO N.,
IGNIZIO J.P. &
HAM I. Group Technology and Material Requirements
Planning: An Integrated Methodology for
Production Control.
28th General Assembly of CIRP (1978)
- SKELTON T. An Investigation into the Image of the Customer
as seen by a Professional Electronics Company.
M.Sc. Project, Loughborough University of
Technology, 1977.
- SKELTON T. Unpublished Ph.D. Work
- SPAMPANI P.B. Executing the Company Game Plan.
APICS Conference Proceedings (1975)
- STARR M.K. Production Management - Systems & Synthesis
Prentice-Hall 1972
- STEELE D.C. The Nervous MRP System - How to do Battle
Production & Inventory Mgt., Q4/1975

- SURESH N.C. Optimising Intermittant Production Systems through Group Technology and an MRP System. Production and Inventory Mgt., Vol. 20, No. 4, Q4/1979
- STENGER A.J. &
CAIRINATO J.L. Adapting MRP to the Outbound Side - Distribution Requirements Planning. Production & Inventory Mgt., Vol. 20, No. 4, Q4/1979
- TAHA H.A. Operations Research - An Introduction
McMillan, 1976
- TALLMAN J. Practical Approach to Installing a Cycle Counting Programme
Production & Inventory Mgt., Vol 17, No 4, Q4/1970
- TEICHROEW D. &
LUBIN J.F. Computer Simulation - Discussion of the Technique and Comparison of Languages
Communications of the ACM Vol. 9, No. 10, Oct. 1966
- TOCHER K.D. The Art of Simulation
English Universities Press, 1963
- TOCHER K.D. Review of Simulation Languages
Operations Research Quarterly, Vol 16, No 2, 1965
- TOCHER K.D. &
HOPKINS D.A. Handbook of the General Simulation Program MK II; Report No. 118/ORD 10/TECH
United Steel Company Ltd., Sheffield, England, June 22, 1964
- TRUX W.R. Einkauf und Lagerdisposition mit Datenverarbeitung
Deutsches Institut für Betriebswissenschaft, Verlag Moderne Industrie, 1968
- ULBERG M.D. Master Scheduling Technique for Rapistan
APICS Conference Proceedings (1975)

- VISAGIE M.S. Production Control in a Flow Production Plant
APICS Conference Proceedings (1975)
- VOSS A.V. Measuring Make to Order Delivery Performance
Production & Inventory Mgt., Vol 21, No 2,
Q2/1980
- VAZSONYA A. Scientific Programming in Business and Industry
Wiley, 1958
- WACKER J. &
HILLS F.S. The Key to Success or Failure of MRP:
Overcoming Human Resistance.
Production & Inventory Mgt., Vol 18, No 4, Q4/1977
- WHITE E.M. Implementing an MRP System using the Lewin-
Schein Theory of Change.
Production & Inventory Mgt., Vol 18, No 1, Q1/1977
- WHYBARK D.C. MRP: A Profitable Concept for Distribution.
Research Issues in Logistics -
Ohio State Univ. (1975)
- WELCH W.E. Tested Scientific Inventory Control
Management Publishing Co. 1956
- WIGHT O.W. Production and Inventory Management in the
Computer Age.
Cahners 1974
- WIGHT O.W. Designing and Implementing a Material
Requirements Planning System.
APICS 13th International Conference 1970
- WIGHT O.W. To Order Point or Not to Order Point.
Production & Inventory Mgt., Vol 9, No 4, Q3/1968
- WILKERSON D.A. Material Requirements Planning and Manpower
Planning
Production and Inventory Management,
Q2/1976

A P P E N D I X A

=====

EXPERIMENTAL RESULTS

The summarised results of each of the simulation experiments are shown, being extracts from the reports produced during each computer run.

In each case, the header displays the parameters utilised for the particular experiment and the Run Parameter (RP) File containing the externally variable parameters.

A time frame of sixteen periods of thirteen weeks, shown as the RANGE, has been selected to derive the mean values of each observed result over the steady state horizon. (See section 4.4.7.)

The final schedule indicates the results obtained from a selected experiment with RP8 continued over a ten year simulated horizon to observe the nature of the cyclic effects.

DATE: 5.11.81

MODE: MAKE TO STOCK

PRIORITY: DUE DATE

RP FILE: 3

RUN NUMBER: 1

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMPL. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	105.9	80.2	87.2	51.4	15.7	11.0	351.3	17.4	1.39	11.1	1.93	44.4	1.22	100.00	
40	132.4	96.9	106.3	37.7	23.8	14.0	411.0	100.0	-0.83	100.0	-0.84	100.0	-0.88	100.00	
53	100.1	89.4	115.7	98.2	25.6	14.7	443.8	90.7	-0.31	92.1	-0.21	85.1	-0.13	100.00	
66	86.7	64.7	99.9	159.9	22.3	9.5	443.0	98.7	-0.57	87.9	-0.14	100.0	-0.51	99.37	
79	86.4	59.1	81.7	127.4	16.7	16.6	388.0	82.4	-0.32	52.5	0.23	71.4	0.06	100.00	
92	77.0	70.7	74.5	108.8	18.2	32.0	381.3	94.5	-0.52	80.0	0.57	87.8	-0.10	100.00	
105	104.7	61.5	76.5	58.4	46.2	11.1	358.5	59.0	1.95	71.4	1.27	45.5	2.65	100.00	
118	49.5	47.7	111.1	101.0	24.4	5.8	339.5	63.4	1.17	72.3	0.98	53.3	1.63	98.92	
131	103.8	64.4	82.1	110.3	36.1	23.0	419.7	76.9	-0.02	81.0	0.26	68.6	0.20	100.00	
144	127.6	59.3	102.7	120.4	25.7	9.2	444.9	70.1	-0.04	64.4	-0.02	50.0	0.27	99.52	
157	114.9	56.5	113.0	88.0	32.3	14.9	419.5	92.7	-0.34	88.7	-0.28	89.3	-0.21	100.00	
170	97.2	76.0	85.6	63.8	36.6	5.5	364.7	96.0	-0.31	94.4	-0.19	90.6	-0.13	100.00	
183	56.3	61.0	87.3	122.0	28.1	13.4	368.1	77.9	-0.22	80.7	-0.10	81.5	-0.30	99.40	
196	90.1	53.5	69.2	105.8	16.6	30.5	365.7	68.5	0.43	38.5	0.77	46.0	0.92	98.10	
209	120.0	66.3	70.2	80.2	24.8	11.2	372.6	96.8	-0.36	87.2	-0.13	93.6	-0.23	100.00	
222	157.5	59.9	116.5	45.9	36.9	6.7	423.3	75.6	-0.07	69.6	-0.02	78.9	-0.13	100.00	
235	185.0	55.0	135.6	29.6	55.5	31.3	492.8	75.2	-0.03	92.7	-0.11	66.2	0.15	100.00	
248	156.1	89.2	120.5	104.6	40.2	26.7	537.4	84.9	-0.16	81.5	-0.06	79.0	-0.07	99.11	
261															
274															
Σ	1712.9	1034.2	1543.0	1524.3	486.2	262.1	6562.8	1303.3	0.80	1234.9	2.82	1186.7	4.07	1594.4	
μ	107.1	64.6	96.4	95.3	30.4	16.4	410.2	81.5	0.0500	77.2	0.1763	74.2	0.2544	99.65	

NOTES:

DATE: 16.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 6

RUN NUMBER: 2

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 0

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE E'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	106.6	51.0	92.5	47.8	19.1	11.4	328.3	18.5	1.40	14.3	1.82	44.4	1.33	100.00	
40	163.9	41.2	93.4	25.2	27.2	24.7	375.4	88.1	-0.42	92.7	-0.34	93.6	-0.40	100.00	
53	129.4	64.2	77.7	70.3	23.5	17.3	382.3	81.3	-0.17	79.6	-0.11	74.5	0.04	100.00	
66	87.4	62.0	77.5	132.2	21.4	15.3	395.7	76.2	-0.23	73.2	0.02	70.2	-0.06	100.00	
79	84.5	47.0	60.1	106.7	22.0	18.8	339.1	92.4	-0.44	85.1	-0.11	87.2	-0.21	100.00	
92	97.1	36.8	99.5	40.2	32.0	19.5	325.0	74.3	-0.10	66.7	0.18	60.3	0.21	100.00	
105	85.8	36.2	87.2	47.9	11.7	5.6	274.5	65.3	0.19	70.2	0.23	63.2	0.24	100.00	
118	77.9	44.5	94.0	72.9	6.2	7.3	302.9	75.9	0.58	85.0	0.48	75.0	0.57	98.79	
131	78.6	32.0	75.1	83.6	19.6	13.7	302.6	58.8	1.99	21.3	3.06	45.5	2.79	100.00	
144	129.7	41.9	90.6	83.2	16.1	14.2	375.7	45.0	0.87	52.4	0.79	40.0	1.06	100.00	
157	114.1	40.7	101.3	105.4	15.4	14.6	391.5	59.7	0.17	73.8	-0.26	52.9	0.41	100.00	
170	100.5	42.0	97.7	88.2	28.3	32.2	388.9	80.8	-0.01	64.4	0.27	75.5	0.23	100.00	
183	111.3	56.2	85.7	60.2	32.1	29.9	375.4	74.6	-0.01	76.6	0.00	61.9	0.26	100.00	
196	56.5	33.0	98.4	79.9	24.4	30.4	322.6	66.2	0.24	61.9	0.45	62.0	0.38	100.00	
209	91.8	32.7	65.1	51.5	32.5	10.2	283.9	75.8	-0.10	72.1	-0.05	55.2	0.24	100.00	
222	132.3	42.1	85.9	30.3	23.7	21.4	335.7	44.1	0.48	58.0	0.28	40.9	0.59	100.00	
235	178.4	61.7	124.9	48.9	38.0	19.8	471.6	58.0	0.45	62.5	0.38	46.3	0.69	100.00	
248	130.9	66.1	119.9	57.2	38.6	50.2	462.9	85.9	-0.17	92.2	-0.25	86.6	-0.09	99.66	
261															
274															
Σ	1686.2	739.1	1440.6	1158.6	385.5	320.4	5730.3	1114.3	3.74	1095.0	5.36	997.2	7.35	1598.45	
μ	105.4	46.2	90.0	72.4	24.1	20.0	358.1	69.6	0.2338	68.4	0.3350	62.3	0.4594	99.90	

NOTES:

DATE: 30.10.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 7

RUN NUMBER: 3

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 4

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	85.1	80.2	87.2	48.3	15.5	14.4	330.7	19.4	1.34	14.3	1.82	44.4	1.33	99.65	
40	91.5	96.9	106.3	46.9	21.1	30.5	393.2	88.6	-0.46	93.0	-0.49	89.4	-0.34	100.00	
53	84.1	89.4	115.7	92.1	26.0	15.1	422.4	82.5	-0.15	71.8	0.00	75.9	0.09	99.59	
66	53.7	64.4	95.1	160.2	24.2	14.5	412.1	78.4	-0.27	66.0	0.02	68.2	-0.07	99.02	
79	64.7	59.1	81.7	124.1	24.4	12.3	366.3	72.5	-0.12	51.2	0.29	51.0	0.39	100.00	
92	49.5	70.8	74.5	108.9	16.7	24.0	344.4	89.3	-0.21	83.7	0.58	84.2	0.05	99.46	
105	66.4	53.2	85.8	54.2	43.3	13.8	316.7	50.4	2.21	45.1	2.22	37.9	2.91	100.00	
118	57.1	49.0	109.5	104.9	23.5	10.2	354.2	64.1	1.05	71.1	0.93	53.3	1.60	94.69	
131	45.1	59.0	99.1	130.5	27.6	24.1	385.3	83.0	-0.24	82.6	-0.04	75.0	0.03	98.45	
144	77.2	60.4	97.0	126.2	27.3	11.2	399.4	85.3	-0.33	82.1	-0.33	75.6	-0.10	98.80	
157	71.3	47.9	119.2	107.2	31.0	5.8	382.3	90.7	-0.35	91.4	-0.29	90.5	-0.19	99.51	
170	55.8	55.3	91.5	80.9	36.3	29.9	349.8	95.4	-0.50	79.0	-0.08	90.7	-0.26	100.00	
183	41.3	51.5	77.6	85.4	29.0	25.5	310.3	76.6	-0.19	79.3	0.00	63.0	0.33	99.08	
196	70.0	54.1	85.2	61.9	15.3	29.6	316.1	73.1	0.21	55.6	0.47	53.9	0.67	99.04	
209	94.8	68.3	104.6	36.4	37.4	25.8	367.2	92.5	-0.48	100.0	-0.45	85.7	-0.43	100.00	
222	115.7	86.2	107.9	22.7	42.8	23.1	398.3	53.9	0.65	67.7	0.38	55.6	0.76	100.00	
235	102.4	76.4	140.6	62.2	42.3	17.8	441.6	53.7	0.72	54.7	0.64	44.8	1.05	99.69	
248	79.6	109.7	114.9	58.7	41.4	37.5	441.8	89.7	-0.39	94.2	-0.29	95.2	-0.19	99.16	
261															
274															
Σ	1128.7	1054.7	1599.9	1416.5	488.5	320.2	6008.2	1231.1	1.61	1175.5	4.95	1100.5	6.64	1586.49	
μ	70.5	65.9	100.0	88.5	30.5	20.0	375.5	76.9	0.1006	73.5	0.3093	68.8	0.4150	99.16	

NOTES:

DATE: 31.10.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 8

RUN NUMBER: 4

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	105.9	80.2	87.2	48.3	15.5	14.4	351.5	19.4	1.34	14.3	1.82	44.4	1.33	100.00
	40	132.4	96.9	106.3	46.9	21.1	30.5	434.0	88.6	-0.46	93.0	-0.49	89.4	-0.34	100.00
	53	100.1	89.4	115.7	92.0	26.0	15.1	438.4	82.5	-0.15	71.8	0.00	75.9	0.09	100.00
	66	86.7	64.7	99.9	160.2	24.2	14.5	450.2	78.4	-0.27	66.0	0.02	68.2	-0.07	99.51
	79	86.4	59.1	81.7	124.1	24.4	12.3	388.1	72.5	-0.12	51.2	0.29	51.0	0.39	100.00
	92	78.7	70.7	74.5	108.9	16.7	24.0	373.6	89.3	-0.21	83.7	0.58	84.2	0.05	100.00
	105	108.6	53.2	85.8	54.2	43.3	13.8	358.9	50.4	2.21	45.1	2.22	37.9	2.91	100.00
	118	71.8	49.0	103.9	104.9	23.5	10.2	363.3	64.1	1.05	71.1	0.93	53.3	1.60	98.55
	131	93.7	60.6	96.5	130.3	29.1	24.1	434.2	83.0	-0.24	80.4	-0.02	72.2	0.06	100.00
	144	116.8	46.6	110.3	124.5	26.0	20.9	445.2	77.5	-0.23	75.6	-0.24	70.0	0.00	100.00
	157	94.8	53.4	118.3	89.1	20.5	12.1	388.2	91.0	-0.63	96.3	-0.50	92.1	-0.46	100.00
	170	87.6	57.2	94.8	74.1	24.4	13.7	351.8	97.3	-0.60	100.0	-0.43	98.2	-0.48	100.00
	183	83.1	55.8	82.1	77.3	29.2	12.5	340.0	97.2	-0.50	100.0	-0.31	92.3	-0.31	100.00
	196	73.6	69.6	80.4	55.5	19.0	25.8	324.0	84.8	0.00	66.7	0.15	69.6	0.26	100.00
	209	108.1	49.5	70.9	36.8	26.7	8.3	300.3	81.5	-0.28	97.1	-0.40	77.8	-0.07	100.00
	222	197.3	61.0	84.2	36.3	22.5	18.3	419.6	63.3	0.51	68.3	0.20	53.7	0.71	100.00
	235	205.7	75.3	136.1	49.3	36.9	17.5	520.7	87.9	-0.19	87.0	-0.07	89.5	-0.14	100.00
	248	161.9	61.4	127.9	26.2	57.3	66.8	501.5	89.8	-0.30	85.9	-0.21	91.7	-0.15	98.93
	261														
	274														
	Σ	1754.9	976.5	1563.0	1343.7	449.7	309.9	6398.0	1290.5	0.05	1246.2	2.21	1177.6	4.39	1596.99
	μ	109.7	61.0	97.7	84.0	28.1	19.4	399.9	80.7	0.0031	77.9	0.1381	73.6	0.2744	99.81

NOTES:

DATE: 13.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 9

RUN NUMBER: 5

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 2

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	116.5	61.2	87.0	47.8	19.0	11.4	342.9	17.9	1.41	14.3	1.82	44.4	1.33	100.00	
40	160.8	75.6	69.5	35.8	30.5	24.6	396.9	89.7	-0.45	97.7	-0.36	91.5	-0.36	100.00	
53	121.4	65.2	119.7	68.0	26.0	22.2	422.4	85.1	-0.35	88.9	-0.19	78.2	-0.07	100.00	
66	87.2	47.8	91.6	141.8	22.1	14.5	404.9	79.6	-0.24	74.1	-0.05	79.6	-0.07	100.00	
79	79.5	34.6	84.1	101.7	21.3	14.0	335.1	71.2	-0.19	51.3	0.28	49.1	0.28	100.00	
92	84.3	49.1	70.1	91.2	22.0	14.0	330.7	79.4	-0.16	77.5	-0.20	68.8	0.04	100.00	
105	88.4	53.0	69.2	58.1	26.2	8.7	305.6	84.6	-0.42	76.8	-0.20	67.3	-0.04	100.00	
118	54.5	39.4	84.7	53.4	28.4	14.2	274.7	78.8	-0.26	74.6	-0.11	71.1	-0.03	99.42	
131	99.7	29.7	61.7	83.5	9.1	14.3	298.0	99.7	-0.72	100.0	-0.50	100.0	-0.43	100.00	
144	85.9	34.6	72.1	89.2	8.3	31.0	321.1	87.9	0.20	92.9	-0.71	82.4	0.24	99.51	
157	105.1	36.6	79.0	121.7	6.5	13.5	362.4	52.6	6.01	63.2	4.58	50.0	6.39	100.00	
170	133.0	57.5	89.9	115.2	26.2	53.1	475.0	37.5	4.89	30.3	5.73	16.1	7.61	100.00	
183	115.8	75.7	84.9	94.7	39.5	45.4	456.0	63.7	1.21	48.0	2.06	62.9	1.42	100.00	
196	82.5	65.8	112.2	84.3	37.1	10.1	392.0	64.0	0.10	63.2	0.11	62.9	0.18	99.52	
209	77.9	47.9	73.0	60.9	33.2	22.6	315.5	67.7	0.04	46.7	0.60	54.8	0.35	99.45	
222	130.8	56.4	54.1	33.7	28.2	74.0	377.2	52.8	1.59	71.4	1.80	41.5	3.12	100.00	
235	166.4	70.0	116.5	28.7	30.1	34.1	445.8	50.7	1.80	48.6	1.86	35.7	2.93	100.00	
248	155.6	64.8	123.6	107.0	28.7	41.2	520.9	49.0	1.09	56.9	1.10	25.0	2.12	99.75	
261															
274															
Σ	1668.0	828.1	1386.4	1333.1	392.9	426.7	6037.1	1104.3	14.59	1064.4	16.17	945.4	21.04	1597.65	
μ	104.3	51.8	86.7	83.3	24.6	26.7	377.3	69.0	0.9119	66.5	1.0106	59.1	1.3150	99.85	

NOTES:

DATE: 6.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 10

RUN NUMBER: 7

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 0

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	97.5	51.0	92.5	47.8	19.1	11.4	319.1	18.5	1.4	14.3	1.82	44.4	1.33	100.00	
40	109.8	41.2	93.4	25.2	27.2	24.7	321.3	88.1	-0.42	92.7	-0.34	93.6	-0.40	100.00	
53	94.2	62.4	77.7	70.3	23.5	17.3	347.2	81.3	-0.17	79.6	-0.11	74.5	-0.04	100.00	
66	51.8	62.0	77.5	132.2	21.4	15.3	360.1	76.2	-0.23	73.2	0.02	70.2	-0.06	99.51	
79	63.1	47.0	60.1	106.7	22.0	18.8	317.6	92.4	-0.44	85.1	-0.11	87.2	-0.21	100.00	
92	54.9	36.8	99.5	40.1	32.0	19.5	282.8	74.3	-0.10	66.7	0.18	60.3	0.21	99.52	
105	63.4	36.2	87.2	47.9	11.7	5.6	252.1	65.3	0.19	70.2	0.23	63.2	0.24	97.88	
118	41.3	36.8	100.9	72.9	6.2	7.3	265.5	75.9	0.58	85.0	0.48	75.0	0.57	95.97	
131	52.9	32.0	75.1	83.6	19.6	13.7	277.0	58.8	1.99	21.3	3.06	45.5	2.79	99.40	
144	83.5	41.9	90.6	83.2	16.1	14.2	329.5	45.0	0.87	52.4	0.79	40.0	1.06	100.00	
157	64.2	40.7	101.3	105.4	15.4	14.6	341.7	59.7	0.17	73.8	-0.26	52.9	0.41	98.81	
170	69.2	42.0	97.7	88.2	28.3	32.2	357.6	80.8	-0.01	64.4	0.27	75.5	0.23	100.00	
183	70.1	56.2	85.7	60.2	32.1	29.9	334.2	74.6	-0.01	76.6	0.00	61.9	0.26	100.00	
196	49.2	33.0	98.4	79.9	24.4	30.4	315.2	66.2	0.24	61.9	0.45	62.0	0.38	99.08	
209	48.4	32.7	65.1	51.5	32.5	10.2	240.4	75.8	-0.01	72.1	-0.05	55.2	0.24	100.00	
222	80.5	42.1	85.9	30.3	23.7	21.4	283.9	44.1	0.48	58.0	0.28	40.9	0.59	100.00	
235	103.7	54.2	131.6	48.9	38.0	19.8	396.2	58.0	0.45	62.5	0.38	46.3	0.69	98.99	
248															
261															
274															
Σ	1100.2	699.0	1427.7	1026.5	373.8	294.9	5022.3	1116.4	3.49	1095.5	5.89	1004.2	6.96	1589.16	
μ	68.8	43.7	89.2	64.2	23.4	18.4	313.9	69.8	0.2181	68.5	0.3681	62.8	0.4350	99.32	

NOTES:

DATE: 10.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 11

RUN NUMBER: 8

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 4

1.05

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	105.9	80.2	87.2	48.3	15.5	14.4	351.5	19.4	1.34	14.3	1.82	44.4	1.33	100.00	
40	132.4	89.0	113.4	46.9	21.1	30.5	433.3	88.6	-0.46	93.0	-0.49	89.4	-0.34	100.00	
53	101.1	84.9	119.7	92.1	26.0	15.1	437.0	82.5	-0.15	71.8	0.00	75.9	0.09	100.00	
66	86.7	64.7	99.9	160.2	24.2	14.5	450.2	78.4	-0.27	66.0	0.02	68.2	-0.07	99.51	
79	86.4	56.8	83.8	124.1	24.4	12.3	387.9	72.5	-0.12	51.2	0.29	51.0	0.39	100.00	
92	78.7	62.7	81.7	108.9	16.7	24.0	372.8	89.3	-0.21	83.7	0.58	84.2	0.05	100.00	
105	108.6	53.2	85.8	54.2	43.3	13.8	358.9	50.4	2.21	45.1	2.22	37.9	2.91	100.00	
118	72.1	47.5	107.7	100.8	24.0	10.2	362.3	64.1	1.05	71.1	0.93	53.3	1.60	98.55	
131	104.4	64.7	87.1	121.7	27.2	24.8	430.0	87.1	-0.43	90.9	-0.36	83.3	-0.22	100.00	
144	113.1	42.5	116.1	129.6	22.3	16.6	440.1	90.7	-0.35	86.1	-0.35	78.6	-0.10	100.00	
157	112.7	51.3	105.1	94.5	28.2	12.1	403.7	91.4	-0.37	91.2	-0.32	83.3	-0.17	99.02	
170	93.0	79.2	65.7	68.8	34.7	13.4	354.9	94.9	-0.36	91.8	-0.20	92.9	-0.43	100.00	
183	83.1	62.9	85.9	73.3	26.5	11.6	343.3	95.7	-0.47	92.9	-0.29	89.3	-0.25	100.00	
196	83.0	63.8	84.1	57.5	21.9	29.9	340.3	79.6	0.09	63.4	0.32	69.2	0.46	100.00	
209	115.9	60.2	79.6	37.9	24.8	20.0	338.4	87.8	-0.42	82.9	-0.23	78.1	-0.09	100.00	
222	173.3	70.0	106.7	22.4	28.9	20.5	421.9	66.3	0.25	89.8	-0.06	50.0	0.67	100.00	
235	203.8	66.8	152.7	78.4	29.3	25.3	556.3	64.2	0.39	60.8	0.43	48.5	0.88	99.04	
248															
261															
274															
Σ	1747.3	1020.2	1575.0	1371.3	423.5	303.6	6432.2	1283.5	0.38	1231.7	2.49	1133.1	5.38	1596.12	
μ	109.2	63.8	98.4	85.7	26.5	19.0	402.0	80.2	0.0238	77.0	0.1556	70.8	0.3363	99.76	

NOTES:

DATE: 7.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 12

RUN NUMBER: 9

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	122.1	80.2	87.2	11.2	25.0	8.8	334.4	34.2	0.70	22.2	1.30	61.1	0.44	100.00	
40	104.7	96.9	106.3	15.0	24.1	29.5	376.5	68.4	0.03	79.4	-0.12	67.4	0.26	100.00	
53	80.4	88.1	102.2	93.0	20.1	6.3	390.0	73.9	-0.14	71.9	0.03	63.3	0.18	100.00	
66	110.9	61.7	56.7	96.8	20.2	27.2	373.5	74.3	0.01	60.0	0.28	57.5	0.40	100.00	
79	95.3	54.9	81.0	66.6	16.3	17.9	331.9	80.6	-0.30	72.3	-0.02	71.2	-0.04	100.00	
92	74.8	62.8	78.9	55.5	26.0	24.3	322.3	80.0	-0.19	78.1	-0.12	74.5	-0.04	100.00	
105	84.1	65.8	76.1	31.0	25.2	14.0	296.2	79.6	-0.32	69.8	-0.04	65.4	0.00	100.00	
118	77.6	58.9	95.0	28.9	22.0	24.7	307.2	75.7	-0.15	80.7	-0.11	75.7	-0.03	100.00	
131	129.3	47.3	95.2	49.2	17.5	6.3	344.7	65.8	0.22	84.6	0.03	54.8	0.39	100.00	
144	120.1	52.8	98.8	54.9	12.7	9.9	349.2	69.4	-0.06	74.1	-0.09	61.0	0.12	100.00	
157	108.2	64.8	93.0	42.8	30.2	22.6	361.5	66.6	0.01	70.8	-0.02	50.8	0.40	100.00	
170	87.4	79.5	67.3	52.5	27.9	9.7	324.3	93.8	-0.47	89.4	-0.21	97.8	-0.47	100.00	
183	62.5	44.5	74.2	86.0	28.6	9.5	305.3	78.4	-0.25	73.5	-0.09	67.9	0.00	97.20	
196	99.5	66.3	78.6	48.4	24.5	23.0	340.3	62.5	0.32	29.8	0.70	37.8	0.70	97.93	
209	145.9	62.3	90.1	34.1	32.0	30.7	395.0	76.6	-0.08	85.7	-0.29	56.7	0.27	99.70	
222	159.3	61.9	125.8	15.4	34.9	25.5	422.8	33.2	0.80	38.6	0.57	25.9	0.97	100.00	
235	165.9	61.1	126.8	38.1	36.8	33.0	461.6	40.3	0.67	31.3	0.75	44.3	0.61	100.00	
248															
261															
274															
Σ	1705.9	1029.6	1446.0	808.1	399.0	314.1	5702.3	1118.0	0.10	1090.0	1.25	972.0	3.72	1594.83	
μ	106.6	64.4	90.4	50.5	24.9	19.6	356.4	69.9	0.0063	68.1	0.0781	60.8	0.2325	99.68	

NOTES:

DATE: 24.11.81.

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 13

RUN NUMBER: 10

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 0

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	106.6	51.0	92.5	11.2	25.0	8.8	295.1	34.2	0.70	22.2	1.30	61.1	0.44	100.00	
40	137.8	41.2	93.4	5.2	22.5	23.7	323.7	66.8	0.10	85.3	-0.12	58.1	0.37	100.00	
53	102.6	44.4	86.0	72.4	13.8	18.0	337.2	67.1	0.07	66.7	0.11	54.4	0.37	100.00	
66	93.5	28.3	69.4	66.9	23.0	24.6	305.7	64.1	0.24	56.0	0.40	52.1	0.63	100.00	
79	121.2	30.4	81.6	13.3	20.1	16.1	282.6	66.0	0.05	52.3	0.52	51.0	0.49	100.00	
92	76.2	30.7	105.3	19.6	25.1	36.1	293.0	66.7	0.00	63.8	0.40	56.9	0.35	100.00	
105	84.1	62.6	74.4	34.7	15.1	7.5	278.4	71.5	-0.06	74.5	0.04	64.0	0.22	100.00	
118	66.9	46.3	86.0	35.6	24.1	19.8	278.8	73.7	-0.09	69.2	0.08	65.6	0.31	99.31	
131	71.5	41.3	61.8	77.3	10.9	14.6	277.5	64.8	0.21	85.7	-0.09	54.6	0.79	100.00	
144	102.3	19.6	76.5	83.7	11.5	5.2	298.9	65.9	1.38	70.6	1.29	47.8	2.00	100.00	
157	126.6	33.9	97.0	83.0	13.1	26.5	380.1	56.9	2.22	52.6	2.79	41.7	3.08	99.48	
170	100.5	39.2	103.8	58.8	29.7	54.9	386.9	40.3	2.35	45.1	2.24	27.6	2.93	100.00	
183	60.7	43.3	82.7	37.1	30.1	26.4	280.3	49.3	0.46	70.9	0.09	33.3	0.76	100.00	
196	72.7	36.3	94.2	32.1	21.2	36.9	293.4	68.5	0.48	59.5	0.78	58.8	0.97	99.62	
209	100.7	51.6	70.6	19.5	29.6	28.5	300.5	65.3	0.62	55.6	0.89	44.0	1.44	100.00	
222	156.2	74.9	74.9	9.7	25.8	80.2	421.6	39.5	1.45	37.5	2.87	29.4	2.79	100.00	
235	144.3	75.7	129.0	42.8	16.1	113.7	521.6	43.8	2.65	50.0	5.94	34.7	4.49	100.00	
248															
261															
274															
Σ	1617.8	699.7	1386.6	691.7	331.7	532.7	5260.2	970.2	12.13	995.3	18.23	774.0	21.99	1598.41	
μ	101.1	43.7	86.7	43.2	20.7	33.3	328.8	60.6	0.7581	62.2	1.1394	48.4	1.3744	99.90	

NOTES:

DATE: 25.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 14

RUN NUMBER: 11

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 0

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE E'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%	LATENESS	
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	98.0	51.0	92.5	11.2	25.0	8.8	286.4	34.2	0.70	22.2	1.30	61.1	0.44	100.00	
40	114.0	41.2	93.4	5.2	22.5	23.7	300.0	66.8	0.10	85.3	-0.12	58.1	0.37	100.00	
53	68.7	44.4	86.0	72.4	13.8	18.0	303.2	67.1	0.07	66.7	0.11	54.4	0.37	99.60	
66	67.9	28.3	69.4	66.9	23.0	24.6	280.1	64.1	0.24	56.0	2.12	52.1	0.63	100.00	
79	68.7	30.4	81.6	13.3	20.1	16.1	230.1	66.0	0.05	52.3	0.52	51.0	0.49	99.11	
92	57.5	30.7	105.3	19.6	25.1	36.1	274.4	66.7	0.00	63.8	0.40	56.9	0.35	99.15	
105	55.9	62.6	74.4	34.7	15.1	7.5	250.2	71.5	-0.06	74.5	0.04	64.0	0.22	98.50	
118	41.0	40.4	91.3	35.6	24.1	19.8	252.3	73.7	-0.09	69.2	0.08	65.6	0.31	98.62	
131	51.1	41.3	61.8	77.3	10.9	14.6	257.2	64.8	0.21	85.7	-0.09	54.6	0.79	96.17	
144	79.1	19.6	76.5	83.7	11.5	5.2	275.7	65.9	1.38	70.6	1.29	47.8	2.00	99.43	
157	93.0	33.9	92.7	83.0	13.1	26.5	342.2	56.9	2.22	52.6	2.79	41.7	3.08	99.48	
170	116.3	39.2	103.8	58.8	29.7	54.9	402.7	40.3	2.35	45.1	2.24	27.6	2.93	99.82	
183	58.3	43.3	82.7	37.1	30.1	26.4	277.9	49.3	0.46	70.9	0.09	33.3	0.76	99.39	
196	55.1	36.3	94.2	32.1	21.2	36.9	275.8	68.5	0.48	59.5	0.78	58.8	0.97	98.11	
209	60.0	51.6	70.5	19.5	29.7	28.5	259.8	65.3	0.62	55.6	0.89	44.0	1.44	99.63	
222	110.6	75.0	75.0	9.7	25.7	79.4	375.3	37.9	1.50	34.4	2.91	29.4	2.85	100.00	
235	99.0	75.3	128.9	37.8	16.5	134.5	492.1	41.4	2.62	58.3	5.14	36.5	4.33	99.82	
248															
261															
274															
Σ	1196.2	693.5	1387.5	686.7	332.1	552.7	4849.0	966.2	12.15	1000.5	19.19	775.8	21.89	1586.83	
μ	74.8	43.3	86.7	42.9	20.8	34.5	303.1	60.4	0.7594	62.5	1.1994	48.5	1.3681	99.18	

NOTES:

DATE: 21.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 15

RUN NUMBER: 12

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 0

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	95.6	51.0	92.5	11.2	25.0	8.8	285.1	34.2	0.70	22.2	1.30	61.1	0.44	99.69	
40	50.9	41.2	93.4	5.2	22.5	23.7	236.9	66.8	0.10	85.3	-0.12	58.1	0.37	95.22	
53	53.4	57.4	72.7	72.4	13.8	18.0	287.7	67.1	0.07	66.7	0.11	54.4	0.37	88.98	
66	57.0	23.9	72.2	69.0	23.0	24.6	269.6	61.1	0.27	52.0	0.44	45.8	0.69	99.33	
79	37.5	45.7	69.9	21.3	22.3	11.6	208.5	65.4	0.14	53.3	0.51	51.0	0.49	89.25	
92	30.5	36.9	100.2	33.1	18.3	31.9	250.9	61.6	0.14	63.0	0.30	48.0	0.44	87.40	
105	39.9	53.8	83.1	41.4	15.3	22.9	256.5	56.9	0.69	66.7	0.60	51.0	0.76	92.55	
118	21.1	46.1	72.8	57.0	11.9	7.2	216.0	68.1	0.40	69.1	0.55	55.2	0.83	91.35	
131	29.0	44.3	65.1	79.5	14.2	11.8	243.9	65.2	0.61	71.1	0.71	52.9	1.18	89.87	
144	36.7	44.2	82.6	79.5	17.7	10.4	271.2	46.0	1.04	47.4	0.89	36.4	1.39	84.24	
157	67.9	40.0	91.9	45.3	17.5	42.1	304.7	44.8	1.13	49.0	1.20	31.4	1.71	97.95	
170	45.9	32.1	94.9	34.1	26.1	11.8	244.9	61.4	0.56	72.7	0.36	56.1	0.83	94.52	
183	36.7	46.5	77.8	28.9	19.9	23.2	233.0	66.2	0.26	66.7	0.27	47.2	0.69	95.38	
196	33.3	29.6	90.2	13.9	27.1	24.3	218.4	40.9	0.67	26.7	1.07	16.1	1.13	91.22	
209	15.0	41.4	81.4	9.6	22.5	46.8	216.7	66.6	0.14	67.7	0.12	48.0	0.76	85.78	
222	38.9	28.4	91.8	10.5	19.7	64.7	253.9	41.6	1.43	31.4	2.77	45.7	2.60	88.99	
235	61.7	46.8	122.9	25.0	22.1	107.5	386.0	36.2	2.67	38.7	4.97	33.3	4.75	94.67	
248															
261															
274															
Σ	655.4	658.3	1362.9	625.7	313.9	482.5	4098.8	915.9	10.32	859.8	14.75	730.6	18.99	1466.70	
μ	41.0	41.1	85.2	39.1	19.6	30.2	256.2	57.2	0.6450	53.7	0.9219	45.7	1.1869	91.67	

NOTES:

DATE: 14.11.81

MODE: MAKE TO STOCK

PRIORITY: DUE DATE

RP FILE: 16

RUN NUMBER: 13

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	122.1	80.2	87.2	9.5	26.7	11.3	336.9	39.0	0.69	18.5	1.30	55.6	0.67	100.00	
40	104.7	96.9	106.3	7.9	26.5	10.9	353.1	91.5	-0.21	96.9	-0.34	87.2	-0.06	100.00	
53	80.4	88.1	102.2	91.2	20.0	7.7	389.5	92.6	-0.38	67.7	0.12	87.0	-0.22	100.00	
66	108.0	61.7	56.7	98.5	19.0	22.7	366.7	86.5	-0.37	75.5	-0.02	72.3	-0.19	100.00	
79	91.2	53.2	80.8	65.6	15.7	18.5	325.1	95.2	-0.43	84.9	-0.09	96.2	-0.33	100.00	
92	74.9	56.5	81.7	42.8	24.6	19.7	300.2	95.0	-0.55	90.2	-0.41	94.0	-0.46	100.00	
105	80.5	65.0	79.9	22.9	20.7	3.6	272.5	97.1	-0.49	91.7	-0.25	95.8	-0.40	100.00	
118	73.3	55.1	98.9	23.1	20.3	6.3	277.2	91.2	-0.48	90.9	-0.35	86.5	-0.27	99.42	
131	110.2	64.7	80.9	58.4	14.7	12.4	341.4	77.5	-0.19	92.1	-0.13	66.7	0.03	100.00	
144	118.0	83.7	88.4	54.9	16.2	6.2	367.3	81.3	-0.09	60.4	0.19	74.3	0.06	100.00	
157	80.9	52.4	98.4	30.3	29.2	21.5	312.7	89.3	-0.29	84.9	-0.26	85.5	-0.07	99.49	
170	110.4	64.8	78.0	50.5	18.2	8.5	330.4	99.8	-0.70	100.0	-0.50	100.0	-0.51	100.00	
183	67.5	65.1	93.4	42.4	24.5	6.2	299.0	95.4	-0.46	81.8	-0.12	96.7	-0.40	100.00	
196	75.7	56.5	93.2	54.9	18.6	28.7	327.5	85.7	-0.02	72.3	0.21	62.8	0.30	100.00	
209	108.9	41.7	88.7	28.2	27.1	21.8	316.3	94.3	-0.43	89.7	-0.24	85.2	-0.22	100.00	
222	146.0	72.0	96.4	15.2	24.5	8.1	362.2	58.4	0.41	58.2	0.33	58.8	0.37	100.00	
235	197.0	79.6	123.7	37.2	30.9	28.4	496.7	43.5	0.60	31.7	0.76	37.0	0.72	99.59	
248															
261															
274															
Σ	1627.6	1057.0	1447.6	724.0	350.7	231.2	5437.8	1374.3	-4.08	1268.9	-1.10	1286.0	-1.65	1598.50	
μ	101.7	66.1	90.5	45.3	21.9	14.5	339.9	85.9	-0.2550	79.3	-0.0688	80.4	-0.1031	99.91	

NOTES:

DATE: 10.12.81

MODE: MAKE TO ORDER

PRIORITY: DUE DATE

RP FILE: 17

RUN NUMBER: 14

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	129.8	67.3	92.6	0.0	25.6	14.6	330.0	41.7	0.57	25.9	1.22	61.1	0.61	100.00
	40	125.1	92.2	100.3	0.0	24.4	12.6	354.7	89.1	-0.25	96.8	-0.32	82.6	0.02	100.00
	53	101.3	108.4	70.6	0.0	53.9	13.3	347.5	82.6	-0.43	66.7	0.08	73.1	-0.08	100.00
	66	129.9	72.5	60.6	0.0	31.6	13.6	308.3	94.9	-1.49	85.7	-0.20	90.2	-0.63	100.00
	79	96.3	69.0	90.0	0.0	27.0	29.6	311.9	94.7	-0.21	76.1	0.22	92.5	-0.23	100.00
	92	94.0	80.8	85.6	0.0	27.8	18.2	306.4	96.1	-0.79	83.7	-0.21	92.2	-0.43	100.00
	105	103.5	91.8	78.3	0.0	24.7	11.6	309.9	87.6	-0.35	79.3	0.04	75.9	-0.04	100.00
	118	78.5	83.6	74.9	0.0	24.4	22.7	284.0	71.3	-0.22	64.3	0.23	69.2	0.05	100.00
	131	86.3	68.3	64.7	0.0	31.0	5.4	255.7	91.7	-0.58	78.1	-0.13	83.3	-0.22	100.00
	144	104.8	81.7	76.4	0.0	23.7	15.8	302.3	91.8	-0.80	81.3	-0.15	96.9	-0.41	100.00
	157	123.7	90.4	75.5	0.0	22.0	15.6	327.3	80.0	-0.75	83.3	-0.42	77.3	-0.07	100.00
	170	130.6	89.4	105.0	0.0	29.1	18.9	373.0	60.5	0.16	54.2	0.56	49.2	0.51	100.00
	183	102.2	103.6	74.8	0.0	27.1	18.3	326.0	85.6	-0.49	55.6	0.24	73.1	0.04	100.00
	196	127.0	99.0	68.6	0.0	27.4	27.4	349.5	73.9	-0.27	67.4	0.16	70.8	0.46	100.00
	209	177.5	94.8	89.0	0.0	43.0	14.7	419.1	72.3	0.29	85.2	0.07	65.9	0.55	100.00
	222	202.8	97.9	98.4	0.0	51.0	8.4	458.4	89.3	-0.06	66.7	0.25	96.4	-0.07	100.00
	235	146.2	115.5	121.5	0.0	76.1	18.9	478.3	81.5	0.00	72.9	-0.04	85.7	0.05	99.91
	248														
	261														
	274														
	Σ	1929.7	1438.9	1334.2	0.0	544.2	265.0	5512.5	1342.9	-6.24	1197.3	0.38	1274.3	-0.50	1559.91
	μ	120.6	89.9	83.4	0.0	34.0	16.6	344.5	83.9	-0.3900	74.8	0.0238	79.6	-0.0313	99.99

NOTES:

DATE: 10.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 18

RUN NUMBER: 15

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 4

1.10

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	105.9	80.2	87.7	47.1	16.2	14.4	351.5	19.4	1.34	14.3	1.82	44.4	1.22	100.00	
40	138.0	79.5	112.3	47.8	20.6	25.5	423.7	89.3	-0.48	93.2	-0.50	89.4	-0.34	100.00	
53	107.8	79.1	112.0	92.6	27.5	16.5	435.6	81.9	-0.13	70.7	-0.02	77.8	0.02	100.00	
66	86.0	66.6	97.1	163.0	21.7	17.2	451.7	84.3	-0.39	78.0	-0.20	77.8	-0.02	99.50	
79	85.8	52.1	84.8	129.3	14.8	17.3	384.1	72.7	-0.19	46.5	0.35	49.0	0.39	100.00	
92	67.5	51.0	90.7	76.5	42.7	30.2	358.7	81.0	-0.27	77.8	-0.03	74.5	-0.02	100.00	
105	97.2	50.6	86.8	55.3	24.0	4.3	318.3	57.7	0.21	61.1	0.33	50.0	0.38	100.00	
118	69.9	45.5	106.8	91.6	15.8	1.6	331.2	69.5	0.28	81.4	0.09	58.1	0.61	99.19	
131	105.5	64.6	78.0	105.2	29.6	15.5	398.4	72.5	-0.02	55.3	0.16	60.5	0.32	100.00	
144	122.9	39.4	113.8	117.3	24.2	8.9	426.5	80.2	0.01	51.0	0.63	73.0	0.05	99.62	
157	107.3	52.8	101.6	90.3	27.8	26.1	406.0	93.3	-0.58	100.0	-0.65	90.0	-0.40	100.00	
170	75.5	50.4	103.7	89.7	26.5	10.1	356.0	97.3	-0.59	100.0	-0.41	91.7	-0.50	100.00	
183	76.6	53.4	72.3	102.8	30.0	11.8	346.9	96.8	-0.48	89.5	-0.18	96.2	-0.38	97.83	
196	104.2	48.5	79.4	40.9	35.8	26.7	335.5	45.6	0.53	33.3	0.87	22.5	1.05	100.00	
209	143.3	68.2	78.0	21.6	26.8	58.0	396.0	75.6	0.05	81.3	0.19	65.6	0.78	100.00	
222	155.6	40.6	116.8	19.3	32.1	75.6	440.0	81.0	0.56	82.4	0.75	73.9	2.13	100.00	
235	180.6	46.6	149.8	46.8	42.2	93.7	559.6	50.4	2.37	40.0	3.97	31.9	5.40	100.00	
248															
261															
274															
<i>M</i>	1723.7	888.9	1583.9	1290.0	442.1	439.0	6368.2	1229.1	0.88	1141.5	5.35	1081.9	9.47	1596.14	
<i>u</i>	107.7	55.6	99.0	80.6	27.6	27.4	398.0	76.8	0.0550	71.3	0.3344	67.6	0.5919	99.76	

NOTES:

DATE: 25.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 19

RUN NUMBER: 16

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE E'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	89.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	122.7	80.2	87.2	31.8	17.2	19.1	351.8	31.0	0.90	24.1	1.34	53.9	0.54	100.00	
40	112.2	96.9	106.3	38.5	14.9	32.7	401.5	77.0	-0.20	88.9	-0.36	71.1	0.11	100.00	
53	85.2	106.7	88.6	83.8	31.3	24.0	419.7	62.0	0.16	66.7	0.14	40.8	0.52	100.00	
66	97.1	53.2	77.9	120.6	16.1	17.5	382.5	71.3	0.12	59.6	0.54	58.7	0.43	99.52	
79	82.1	63.2	83.5	58.3	21.3	29.6	338.0	86.4	-0.33	86.1	-0.05	80.8	-0.13	100.00	
92	99.6	54.2	81.7	62.0	18.5	13.0	328.9	79.6	-0.26	72.1	-0.02	69.4	-0.02	100.00	
105	88.1	59.1	82.7	36.6	20.7	3.3	290.5	92.4	-0.45	93.8	-0.25	87.5	-0.25	100.00	
118	73.2	62.1	97.7	45.2	24.7	20.0	322.9	82.9	-0.30	83.3	-0.26	70.0	0.07	99.51	
131	78.4	64.2	77.3	81.2	20.4	12.4	333.9	84.1	-0.37	97.1	-0.34	76.7	-0.10	100.00	
144	59.4	50.5	103.0	90.5	21.4	9.0	333.7	93.6	-0.45	92.2	-0.39	89.7	-0.31	99.54	
157	88.3	49.8	75.6	82.3	10.9	10.1	317.1	91.9	-0.57	94.3	-0.60	94.7	-0.42	100.00	
170	155.0	71.2	68.1	60.3	24.8	26.6	406.1	75.6	-0.11	83.3	-0.02	70.0	0.10	100.00	
183	71.3	62.7	104.1	54.0	33.8	7.7	333.6	87.8	-0.18	89.1	-0.11	76.5	0.06	97.82	
196	98.6	69.6	75.7	66.0	22.8	24.7	357.3	65.3	0.20	64.7	0.38	35.9	0.67	100.00	
209	143.8	81.6	76.2	45.1	29.7	13.7	390.1	72.2	-0.11	54.1	0.32	45.5	0.42	100.00	
222	153.2	80.1	106.8	18.3	42.6	24.7	425.8	49.0	0.41	51.0	0.35	47.7	0.49	100.00	
235	162.6	107.9	91.4	40.1	43.3	15.8	461.1	39.0	0.68	23.7	1.11	33.3	0.78	100.00	
248	138.7	119.0	112.6	59.6	26.0	51.5	507.4	75.5	-0.09	71.4	0.12	57.1	0.31	99.28	
261															
274															
Σ	1674.6	1155.1	1402.9	1003.9	409.3	303.6	5948.6	1208.6	-1.65	1182.5	0.92	1034.3	2.62	1595.67	
μ	104.7	72.2	87.7	62.7	25.5	19.0	371.8	75.5	-0.1031	73.9	0.0575	64.6	0.1638	99.73	

NOTES:

DATE: 21.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 20

RUN NUMBER: 17

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 2

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	116.2	61.2	87.0	31.3	17.7	19.1	332.4	31.0	0.90	24.1	1.34	53.9	0.54	100.00	
40	149.0	75.6	69.5	27.0	27.6	29.8	378.5	72.5	0.02	82.9	-0.03	68.1	0.23	100.00	
53	101.9	60.7	118.2	59.1	31.7	7.1	378.6	64.7	0.06	73.0	0.03	46.6	0.45	99.56	
66	103.8	38.1	73.1	83.9	23.8	17.1	339.7	79.0	-0.20	73.6	0.00	81.4	-0.19	99.54	
79	99.2	46.5	64.1	43.6	27.8	19.9	301.1	49.2	0.49	59.4	0.44	23.1	1.08	100.00	
92	97.7	51.0	80.4	28.0	20.4	10.8	288.4	78.0	-0.04	59.6	0.19	63.3	0.33	100.00	
105	99.1	55.7	78.9	35.9	18.9	8.8	297.4	92.1	-0.52	94.3	-0.40	91.7	-0.46	100.00	
118	66.8	46.4	83.5	63.1	22.1	19.9	301.7	80.9	-0.30	82.4	-0.18	64.7	-0.06	99.07	
131	85.5	37.3	62.5	88.8	11.3	17.9	303.3	70.9	0.14	62.1	0.21	62.5	0.34	100.00	
144	117.0	33.5	81.3	88.1	16.9	5.9	342.8	51.6	0.76	40.5	0.88	52.2	0.91	100.00	
157	128.7	41.7	84.6	68.3	15.4	18.3	356.9	55.5	0.21	56.3	0.38	50.0	0.41	100.00	
170	138.9	67.1	71.8	47.9	32.7	29.6	388.1	55.4	0.27	59.6	0.30	54.1	0.41	100.00	
183	71.8	45.1	110.7	50.1	30.5	18.3	326.5	77.1	-0.04	79.0	0.02	72.7	0.11	100.00	
196	107.6	42.4	81.6	48.3	36.1	42.8	358.8	76.5	-0.02	59.5	0.35	66.7	0.33	100.00	
209	110.0	49.2	86.5	53.7	26.0	17.5	342.9	78.9	-0.15	70.0	0.10	62.9	0.29	100.00	
222	159.4	61.4	88.5	15.4	38.3	25.5	388.6	50.9	0.41	55.3	0.32	49.0	0.35	100.00	
235	139.1	72.9	114.1	33.0	32.0	44.9	436.0	60.0	0.81	74.4	0.07	51.1	1.33	100.00	
248	127.7	77.8	122.4	70.6	25.8	38.7	462.9	57.3	0.77	71.7	0.23	42.6	1.50	99.72	
261															
274															
Σ	1754.2	826.8	1402.2	877.8	409.7	325.9	5613.7	1078.0	2.65	1070.7	3.30	934.6	7.13	1597.89	
μ	109.6	51.7	87.6	54.9	25.6	20.4	350.9	67.4	0.1656	66.9	0.2063	58.4	0.4456	99.87	

NOTES:

DATE: 25.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 21

RUN NUMBER: 18

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 2

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	116.2	61.2	87.0	11.2	25.0	8.8	309.4	34.2	0.70	22.2	1.30	61.1	0.44	100.00
	40	142.6	75.6	69.5	13.8	18.9	33.4	353.8	73.6	-0.01	82.4	-0.09	73.9	0.15	100.00
	53	97.9	56.3	115.3	66.4	24.1	10.2	370.3	78.3	-0.21	83.3	-0.17	63.5	0.13	99.62
	66	105.2	42.4	68.2	70.4	21.2	8.7	317.1	75.8	-0.11	75.9	0.10	57.8	0.22	100.00
	79	85.5	49.4	73.1	29.7	16.9	14.2	268.8	75.2	-0.09	62.2	0.22	72.6	0.04	100.00
	92	94.3	46.7	86.3	21.5	24.5	14.8	288.1	69.5	-0.12	75.7	-0.19	62.5	0.10	100.00
	105	88.8	51.3	86.4	28.7	22.9	18.8	297.1	78.5	-0.25	76.9	0.00	57.5	0.15	99.55
	118	67.9	45.0	82.2	32.6	18.6	14.1	260.3	76.6	-0.11	72.7	0.05	67.5	0.13	99.17
	131	96.4	37.0	61.4	73.9	9.0	15.9	293.6	77.8	0.31	94.3	-0.23	71.4	0.57	100.00
	144	113.2	29.7	93.4	78.4	12.4	30.9	358.0	51.7	2.19	45.5	1.48	43.5	2.87	100.00
	157	145.8	56.5	81.1	108.0	11.6	23.8	426.9	40.2	2.98	47.1	2.71	27.0	3.76	100.00
	170	150.8	69.9	79.5	87.3	25.1	18.7	431.3	44.3	2.12	35.3	2.73	25.0	3.12	100.00
	183	75.6	56.1	113.0	43.1	34.5	36.9	359.2	42.9	0.76	46.0	0.74	21.0	1.37	99.57
	196	61.7	48.8	90.7	68.7	23.0	37.4	330.3	52.9	0.56	37.5	0.92	42.5	0.88	99.05
	209	112.7	43.3	82.7	42.1	26.3	48.7	355.8	75.8	0.07	68.6	0.34	53.6	0.89	100.00
	222	176.9	50.4	105.2	11.8	26.5	82.0	452.7	63.8	1.28	61.7	1.02	54.0	2.66	100.00
	235	146.7	53.8	125.4	43.1	46.4	98.0	513.3	26.9	2.55	28.1	4.12	25.5	4.66	99.71
	248	134.1	45.7	153.1	110.2	26.8	39.5	509.3	30.5	1.78	25.0	2.81	12.9	3.69	99.41
	261														
	274														
	Σ	1754.5	782.3	1497.0	915.9	369.8	512.6	5832.1	960.7	13.71	935.8	16.65	757.9	25.24	1596.08
	μ	109.7	48.9	93.6	57.2	23.1	32.0	364.5	60.0	0.8569	58.5	1.0406	47.4	1.5775	99.76

NOTES:

DATE: 26.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 22

RUN NUMBER: 19

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 0

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	106.6	51.0	92.5	31.8	17.2	19.1	318.1	31.0	0.90	24.1	1.34	53.9	0.54	100.00	
40	141.3	41.2	93.4	20.1	19.7	29.9	345.6	74.6	-0.02	86.1	-0.06	70.5	0.20	100.00	
53	108.6	46.5	90.2	59.8	30.7	25.4	361.1	63.1	0.27	65.7	0.13	47.3	0.51	100.00	
66	87.0	28.5	85.3	96.5	21.1	28.1	346.5	77.1	0.14	68.9	0.60	56.8	0.77	99.15	
79	100.7	40.7	74.3	53.0	20.3	39.9	328.9	82.9	-0.26	89.1	-0.20	71.2	0.00	100.00	
92	77.7	32.6	106.1	41.0	22.7	20.6	300.7	78.6	-0.39	70.7	-0.12	72.9	-0.15	100.00	
105	89.3	44.3	88.8	47.6	18.4	7.8	296.2	71.9	-0.07	78.7	-0.02	71.8	-0.08	100.00	
118	60.6	33.8	93.0	76.6	13.0	2.7	279.6	76.3	-0.10	72.7	0.14	64.5	0.13	98.77	
131	66.2	36.6	57.3	110.4	10.1	19.4	299.9	95.5	-0.57	97.2	-0.31	85.7	-0.24	100.00	
144	101.5	34.2	66.9	105.0	13.6	23.6	344.7	76.4	2.65	71.9	2.56	59.1	4.64	100.00	
157	132.6	48.8	77.2	143.0	11.9	34.3	447.8	40.3	6.36	42.9	6.43	38.7	6.16	100.00	
170	163.1	44.1	91.0	126.9	30.7	28.9	484.6	21.7	5.10	9.4	5.25	12.5	5.96	100.00	
183	71.1	34.9	98.9	55.7	48.7	48.7	358.0	32.1	1.50	35.5	1.98	13.6	2.46	100.00	
196	70.9	42.7	57.9	46.3	39.3	28.7	285.8	34.2	1.57	18.4	1.63	20.8	2.56	99.61	
209	93.5	23.6	73.8	32.6	28.4	22.1	274.1	61.9	1.57	67.4	1.00	40.7	2.67	99.62	
222	144.9	57.5	87.3	24.1	22.6	29.0	365.3	56.7	0.74	75.6	-0.22	57.5	0.93	100.00	
235	156.3	59.4	131.8	40.5	27.2	28.8	444.1	53.3	1.27	61.5	0.82	35.6	2.12	100.00	
248															
261															
274															
Σ	1665.3	649.4	1373.2	1079.1	378.4	417.9	5562.9	996.6	19.76	1011.7	19.61	819.2	28.64	1597.15	
μ	104.1	40.6	85.8	67.4	23.7	26.1	347.7	62.3	1.2350	63.2	1.2256	51.2	1.7900	99.82	

NOTES:

DATE: 26.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 23

RUN NUMBER: 20

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 4

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	92.4	80.2	87.2	31.8	17.2	19.1	327.8	31.0	0.90	24.1	1.34	53.9	0.54	99.68
	40	71.0	96.9	106.3	38.5	14.9	32.7	360.3	77.0	-0.20	88.9	0.25	71.1	0.11	100.00
	53	70.4	106.7	88.6	83.8	31.3	24.0	404.9	62.0	0.16	66.7	0.14	40.7	0.52	99.11
	66	75.9	53.2	77.9	120.6	16.1	17.5	361.3	71.3	0.12	59.6	1.51	58.7	0.43	99.04
	79	46.2	63.2	83.5	58.3	21.3	29.6	302.1	86.4	-0.33	86.1	-0.05	80.8	-0.13	98.25
	92	35.5	54.2	81.7	62.0	18.5	13.0	264.7	79.6	-0.26	72.1	-0.02	69.4	-0.02	97.39
	105	76.2	67.3	74.2	36.6	20.7	3.3	278.4	92.4	-0.45	93.8	-0.25	87.5	-0.25	97.45
	118	39.2	64.1	95.8	45.2	24.7	20.1	289.0	82.9	-0.30	83.3	-0.26	70.0	0.07	97.06
	131	45.1	64.1	81.7	81.4	18.9	21.2	312.3	81.6	-0.32	100.0	-0.38	76.7	-0.03	96.87
	144	47.8	57.3	98.9	84.8	22.8	7.4	319.0	85.0	-0.38	85.2	-0.30	83.3	-0.31	95.41
	157	65.2	49.6	81.4	78.9	16.7	12.7	304.5	86.4	-0.44	87.1	-0.52	82.9	-0.14	100.00
	170	95.2	65.6	81.3	59.4	33.4	25.4	360.2	90.5	-0.28	87.5	-0.05	86.5	-0.08	98.53
	183	44.9	71.9	89.7	59.7	33.9	13.5	313.6	80.7	-0.09	86.2	-0.07	74.0	0.20	96.55
	196	66.3	55.0	85.0	67.6	21.7	22.4	318.0	73.7	0.04	69.7	0.21	44.7	0.53	99.14
	209	86.9	76.7	87.8	41.2	33.7	6.7	332.9	77.7	-0.12	67.4	0.14	58.8	0.24	99.66
	222	102.7	84.3	98.3	31.7	35.9	22.5	375.3	64.0	0.13	75.9	0.00	61.5	0.11	100.00
	235	91.9	91.9	92.6	57.2	36.6	31.5	401.7	54.0	0.59	50.0	0.67	39.1	0.80	100.00
	248														
	261														
	274														
	Σ	1060.4	1122.0	1404.7	1006.9	401.1	303.5	5298.2	1245.2	-2.13	1259.5	1.02	1085.7	2.05	1574.50
	μ	66.3	70.1	87.8	62.9	25.1	19.0	331.1	77.8	-0.1331	78.7	0.0638	67.9	0.1281	98.40

NOTES:

DATE: 26.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 24

RUN NUMBER: 21

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 4

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	92.4	80.2	87.2	11.2	25.0	8.8	304.8	34.2	0.70	22.2	1.30	61.1	0.44	99.71
	40	67.4	96.9	106.3	15.0	24.1	29.5	339.2	68.4	0.03	79.4	-0.12	67.4	0.26	99.73
	53	65.6	88.1	102.2	93.0	20.1	6.3	375.2	73.9	-0.14	71.9	0.03	63.3	0.18	99.60
	66	89.1	61.7	56.7	96.8	20.2	27.2	351.7	74.3	0.01	60.0	0.28	57.5	0.40	100.00
	79	55.3	54.9	81.0	66.6	16.3	17.9	292.0	80.6	-0.30	72.3	-0.02	71.2	-0.04	98.97
	92	51.7	62.8	78.9	55.5	26.0	24.3	299.1	80.0	-0.19	78.1	-0.12	74.5	-0.04	98.60
	105	76.6	65.8	76.1	31.0	25.2	14.0	288.7	79.6	-0.32	69.8	-0.49	65.4	0.00	99.17
	118	47.9	58.9	90.1	28.9	22.0	24.7	272.4	75.7	-0.15	80.7	-0.11	75.7	-0.03	98.08
	131	64.9	47.3	95.2	49.2	17.5	6.3	280.4	65.8	0.22	84.6	0.03	54.8	0.39	97.58
	144	86.0	52.8	98.8	54.9	12.7	9.9	315.1	69.4	-0.06	74.1	-0.09	61.0	0.12	99.47
	157	59.3	64.8	93.0	42.8	30.2	22.6	312.6	66.6	0.01	70.8	-0.02	50.8	0.40	97.97
	170	57.0	73.1	73.0	52.5	27.9	9.7	293.2	93.8	-0.47	89.4	-0.21	97.8	-0.47	98.57
	183	41.7	40.9	77.5	86.0	28.6	9.5	284.2	78.4	-0.25	73.5	-0.09	67.9	0.00	89.72
	196	56.0	59.8	84.5	47.5	25.4	23.0	296.2	62.7	0.32	29.8	0.70	37.8	0.70	96.28
	209	102.0	62.3	90.1	34.1	32.0	30.6	351.1	77.5	-0.11	85.7	-0.29	60.0	0.20	99.70
	222	115.2	61.9	128.8	15.4	34.9	25.5	381.8	32.8	0.81	40.0	0.02	27.1	0.95	99.80
	235	114.3	52.0	135.1	36.4	38.8	55.3	431.8	37.8	0.71	33.3	0.74	41.7	0.63	99.79
	248														
	261														
	274														
Σ		1150.0	1004.0	1467.3	805.6	401.9	336.3	5164.7	1117.3	0.12	1093.4	0.24	973.9	3.65	1573.0
μ		71.9	62.8	91.7	50.4	25.1	21.0	322.8	69.8	0.0075	68.3	0.0150	60.9	0.2281	98.31

NOTES:

DATE: 4.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 25

RUN NUMBER: 22

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 2

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	96.1	61.2	87.0	47.8	19.0	11.4	322.5	17.9	1.41	14.3	1.82	44.4	1.33	100.00	
40	120.7	75.6	69.5	35.8	30.5	24.6	356.8	89.7	-0.45	97.7	-0.36	91.5	-0.36	100.00	
53	85.9	65.2	119.7	68.0	26.0	22.2	386.9	85.1	-0.35	88.9	-0.19	78.2	-0.07	97.99	
66	75.9	47.8	91.6	141.8	22.1	14.5	393.6	79.6	-0.24	74.1	-0.05	79.6	-0.07	99.01	
79	45.8	34.6	84.1	101.7	21.3	14.0	301.5	71.2	-0.19	51.3	0.28	49.1	0.28	100.00	
92	58.9	47.1	72.4	90.7	22.0	14.0	305.2	79.4	-0.16	77.5	-0.20	68.8	0.04	96.95	
105	66.2	52.9	69.6	57.6	26.2	8.7	281.2	84.6	-0.42	76.8	-0.20	67.3	-0.04	99.53	
118	40.5	37.2	85.1	51.3	28.4	14.2	256.8	78.8	-0.26	74.6	-0.11	71.1	-0.03	99.40	
131	58.9	26.9	60.7	82.9	11.1	21.2	261.6	92.9	-0.52	100.0	-0.45	86.4	-0.18	100.00	
144	81.4	40.4	71.4	90.1	5.4	22.5	311.2	74.6	0.26	89.7	-0.31	56.5	0.87	100.00	
157	95.3	59.9	81.0	108.5	12.6	8.4	365.7	37.7	3.36	50.0	3.37	20.0	4.07	99.73	
170	124.9	64.1	85.4	101.3	22.5	17.0	415.1	32.6	2.79	18.9	2.98	11.4	3.70	100.00	
183	58.0	73.4	97.2	46.3	49.6	46.9	371.3	49.5	0.58	51.0	0.76	24.6	1.25	99.66	
196	30.8	69.3	80.0	36.7	50.6	30.3	297.7	71.4	0.36	68.8	0.33	47.2	0.98	93.12	
209	57.6	44.9	69.1	52.9	28.0	15.3	267.7	74.7	0.27	55.6	0.92	43.5	1.52	98.73	
222	63.9	49.5	96.0	32.2	24.8	12.2	278.6	70.4	0.19	60.9	0.33	67.3	0.24	98.90	
235	127.9	75.2	110.2	47.1	29.2	42.1	431.8	73.3	-0.02	46.0	0.51	60.9	0.28	99.06	
248															
261															
274															
Σ	1192.6	864.0	1343.0	1144.9	410.3	328.1	5282.7	1145.5	5.20	1081.8	7.61	923.4	12.48	1582.08	
μ	74.5	54.0	83.9	71.6	25.6	20.5	330.2	71.6	0.3250	67.6	0.4756	57.7	0.7800	98.88	

NOTES:

DATE: 28.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 26

RUN NUMBER: 23

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 2

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000								DELIVERY PERFORMANCE						COMP. SERV. LEVEL
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%	LATENESS	
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	96.1	61.2	87.0	31.3	17.7	19.2	312.3	31.0	0.90	24.1	1.34	53.9	0.54	100.00	
40	114.7	75.6	69.5	27.0	27.6	29.8	344.2	72.5	0.02	82.9	-0.03	68.1	0.23	100.00	
53	68.3	60.7	118.2	59.1	31.7	7.1	345.0	64.7	0.06	73.0	0.03	46.6	0.45	96.93	
66	92.5	38.1	73.1	83.9	23.8	17.1	328.4	79.0	-0.20	73.6	0.00	81.4	-0.19	99.08	
79	44.7	46.5	64.1	43.6	27.8	19.9	246.5	49.2	0.49	59.4	0.44	23.1	1.08	98.88	
92	55.3	51.0	80.4	28.0	20.4	10.8	246.0	78.0	-0.04	59.6	0.19	63.3	0.33	100.00	
105	74.4	55.7	78.9	35.9	18.9	8.8	272.6	92.1	-0.52	94.3	-0.40	91.7	-0.46	100.00	
118	49.2	40.5	88.9	63.1	22.1	19.9	283.5	80.8	-0.30	82.0	-0.18	64.7	-0.06	97.12	
131	44.4	37.2	51.1	87.9	18.3	15.9	254.7	69.3	0.32	66.7	0.27	56.3	0.66	97.75	
144	77.1	32.8	74.1	85.1	10.7	12.7	292.5	56.9	1.34	46.5	1.12	59.1	1.23	99.31	
157	95.7	49.8	76.8	88.1	12.9	14.1	337.5	46.9	1.98	45.2	2.17	34.2	2.61	100.00	
170	95.4	61.3	99.2	67.3	28.9	15.5	367.5	48.1	1.22	42.9	1.29	26.4	1.89	99.45	
183	58.7	89.0	94.0	36.3	38.9	38.0	354.9	72.9	0.06	75.9	0.02	59.0	0.36	99.62	
196	34.9	77.5	89.3	70.7	29.9	32.5	334.9	69.9	0.24	71.4	0.29	60.4	0.60	93.48	
209	53.8	58.9	74.3	59.0	34.3	26.0	306.4	68.4	0.16	36.7	1.00	45.2	0.81	97.94	
222	88.5	51.1	90.0	28.7	36.2	25.1	319.7	43.8	0.43	47.3	0.35	39.2	0.49	99.37	
235	119.0	71.7	118.3	48.4	32.0	10.6	400.0	57.7	0.52	78.6	0.26	49.1	0.81	98.86	
248															
261															
274															
Σ	1166.6	897.4	1340.2	912.1	414.4	303.8	5034.3	1050.2	5.78	1036.0	6.82	867.8	10.84	1577.79	
μ	72.9	56.1	83.7	57.0	25.9	19.0	314.6	65.6	0.3613	64.8	0.4263	54.2	0.6775	98.61	

NOTES:

DATE: 27.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 27

RUN NUMBER: 24

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 2

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	96.1	61.2	87.0	11.2	25.0	8.8	289.3	34.2	0.70	22.2	1.30	61.1	0.44	100.00
	40	111.6	75.6	69.5	13.8	18.9	33.4	322.8	73.6	-0.01	82.4	-0.09	73.9	0.15	100.00
	53	63.8	56.3	115.3	66.4	24.1	10.2	336.2	78.3	-0.21	83.3	-0.17	63.5	0.13	95.40
	66	91.1	42.4	68.2	70.4	21.2	8.7	302.0	75.8	-0.11	75.9	0.10	57.8	0.22	99.62
	79	29.8	49.4	73.1	29.7	16.9	14.2	213.1	75.2	-0.09	62.2	0.22	72.6	0.04	97.42
	92	57.5	46.7	86.3	21.5	24.5	14.8	251.3	69.5	-0.12	75.7	-0.19	62.5	0.10	99.27
	105	58.7	51.5	86.4	28.7	22.9	18.8	267.0	78.5	-0.25	76.9	0.00	57.5	0.15	97.29
	118	54.1	39.1	87.5	32.6	18.6	14.1	246.0	76.6	-0.11	72.7	0.05	67.5	0.13	98.76
	131	45.8	35.8	59.0	73.9	9.0	15.3	238.8	78.2	0.21	94.3	-0.26	71.4	0.52	98.85
	144	55.9	33.7	93.2	78.4	12.8	20.0	294.0	51.0	2.30	48.4	1.16	43.5	3.00	99.74
	157	97.0	49.7	83.1	109.0	10.6	27.8	377.1	39.8	2.62	47.1	2.24	25.0	3.44	99.76
	170	89.5	71.8	79.9	90.5	23.7	15.9	371.3	45.9	2.11	38.8	2.61	24.5	3.14	100.00
	183	49.6	46.7	95.0	42.4	35.3	25.2	294.2	42.9	0.87	51.0	0.71	25.0	1.47	97.18
	196	55.7	46.9	84.4	30.8	29.5	25.3	272.7	55.3	0.65	56.1	0.61	35.0	1.20	95.73
	209	82.8	62.6	81.8	21.1	28.5	48.1	324.8	62.4	0.69	55.6	1.22	38.7	1.94	100.00
	222	122.3	68.3	100.6	11.1	25.6	99.3	427.3	70.3	0.37	62.0	1.26	56.4	0.28	100.00
	235	79.8	63.3	101.9	59.6	36.7	125.4	466.7	53.0	2.82	38.7	4.97	36.8	6.25	99.23
	248														
	261														
	274														
	M	1145.0	839.8	1365.2	779.9	358.8	516.5	5005.3	1026.3	11.74	1021.1	14.44	811.6	22.16	1578.25
	μ	71.6	52.5	85.3	48.7	22.4	32.3	312.8	64.1	0.7338	63.8	0.9025	50.7	1.3850	98.64

NOTES:

DATE: 01.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 28

RUN NUMBER: 25

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 4

BUFFER: 0

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	98.0	51.0	92.5	31.8	17.2	19.1	309.5	31.0	0.90	24.1	1.34	53.9	0.54	100.00	
40	114.1	41.2	93.4	20.1	19.7	29.9	318.3	74.6	-0.02	86.1	-0.06	70.5	0.20	100.00	
53	74.4	46.5	90.2	59.8	30.7	25.4	326.8	63.1	0.27	67.5	0.13	47.3	0.51	100.00	
66	57.7	28.5	80.2	96.5	21.1	28.1	312.0	77.1	0.14	68.9	0.60	56.8	0.77	99.15	
79	40.1	44.7	60.1	44.3	30.7	42.3	262.1	78.6	-0.07	68.9	0.20	65.3	0.18	97.93	
92	62.6	38.3	88.9	50.1	18.3	17.8	276.0	66.4	-0.04	60.0	0.09	52.7	0.31	98.02	
105	67.2	59.1	76.5	47.8	17.9	8.8	277.3	72.9	-0.04	61.4	0.30	77.8	-0.11	98.02	
118	52.7	49.6	88.0	68.2	8.2	12.2	279.0	70.5	0.05	63.3	0.37	61.3	0.32	97.49	
131	29.7	36.5	71.2	95.9	14.7	16.3	264.4	62.1	0.47	67.5	0.82	54.6	0.76	99.38	
144	79.3	43.4	90.7	92.2	16.0	29.0	350.5	55.4	0.54	63.2	0.61	45.7	0.86	98.42	
157	61.1	41.7	100.5	87.9	19.4	5.5	316.0	62.5	0.04	70.4	-0.07	71.7	0.02	98.86	
170	66.3	44.0	83.9	55.3	39.0	51.0	339.5	86.6	-0.23	84.0	-0.06	79.4	0.04	97.40	
183	40.4	46.1	67.1	85.0	29.5	13.4	281.5	77.8	-0.16	78.1	-0.03	71.4	0.07	97.56	
196	55.9	27.7	76.1	35.1	27.8	14.7	237.3	70.3	0.11	57.1	0.31	50.0	0.63	97.09	
209	55.3	48.2	89.4	19.5	20.9	49.8	283.1	66.2	0.46	76.7	0.00	75.0	-0.33	99.48	
222	86.7	44.2	78.3	24.7	16.8	65.7	316.4	19.1	5.24	28.6	5.29	12.8	7.23	99.80	
235	136.3	66.6	106.6	43.1	24.6	64.7	442.0	42.1	3.36	22.2	7.14	22.6	6.23	98.42	
248	131.4	49.1	115.3	67.6	48.3	14.1	425.8	55.0	1.38	47.1	1.71	47.8	2.85	99.21	
261															
274															
Σ	1097.1	712.2	1363.0	973.0	383.9	458.8	4989.7	1025.7	11.52	984.9	17.41	892.2	20.34	1576.23	
μ	68.6	44.6	85.2	60.8	24.0	28.7	311.9	64.1	0.7200	61.6	1.0881	55.8	1.2713	98.51	

NOTES:

DATE: 01.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 29

RUN NUMBER: 26

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 4

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	83.6	80.2	87.2	48.3	15.5	14.4	329.3	19.4	1.34	14.3	1.82	44.4	1.33	99.33
	40	39.2	96.9	106.3	46.9	21.1	30.5	340.9	88.6	-0.46	93.0	-0.49	89.4	-0.34	95.50
	53	47.1	89.4	115.7	92.1	26.0	15.1	385.4	82.5	-0.15	71.8	0.35	75.9	0.09	86.18
	66	40.5	64.7	94.9	160.2	24.2	14.5	399.0	78.4	-0.27	66.0	0.02	68.2	-0.07	95.61
	79	20.5	56.2	84.4	124.1	24.4	12.3	322.0	72.5	-0.12	51.2	0.29	51.0	-0.39	94.14
	92	26.1	69.3	69.3	108.9	16.7	24.0	314.2	89.3	-0.18	83.7	0.58	84.2	0.05	83.87
	105	49.6	59.0	84.9	47.3	42.0	13.8	296.7	52.2	2.21	49.0	2.16	41.4	2.88	97.64
	118	23.2	64.3	93.4	102.9	19.1	12.2	315.3	63.1	0.81	68.8	0.69	50.0	1.22	78.47
	131	25.0	63.6	80.8	104.4	35.2	30.8	339.7	92.1	-0.32	75.8	-0.18	87.5	-0.06	85.09
	144	42.2	47.3	100.9	111.3	21.3	7.8	330.8	85.0	-0.07	62.8	0.41	74.5	0.09	84.73
	157	48.4	44.7	109.4	73.9	24.5	17.5	320.4	82.9	-0.34	85.5	-0.38	73.5	-0.09	85.64
	170	52.8	53.8	69.8	68.7	23.0	12.2	280.4	88.4	-0.34	95.7	-0.33	80.5	-0.24	98.36
	183	42.5	59.4	85.8	61.2	26.7	7.6	283.1	97.7	-0.45	93.2	-0.30	100.0	-0.35	91.82
	196	30.9	64.2	80.5	36.4	36.6	29.3	277.8	85.1	-0.15	75.0	0.02	79.1	-0.05	85.33
	209	54.8	69.4	88.4	60.3	32.5	13.8	319.1	72.2	-0.09	51.9	0.33	50.0	0.29	92.78
	222	50.8	70.4	100.5	36.6	43.8	46.9	349.2	63.8	0.15	70.9	0.04	50.0	0.53	91.82
	235	65.7	84.4	120.8	65.7	37.0	21.8	395.4	56.2	1.12	63.6	0.52	42.0	1.54	82.98
	248	47.5	104.5	100.8	105.1	30.6	50.2	438.7	74.3	-0.01	45.0	0.70	54.1	0.84	91.98
	261														
	274														
	Σ	667.6	1064.6	1480.3	1359.1	463.6	329.8	5367.2	1235.7	1.80	1109.9	4.92	1061.9	7.54	1426.44
	μ	41.7	66.5	92.5	84.9	29.0	20.6	335.5	77.2	0.1125	69.4	0.3075	66.4	0.4713	89.15

NOTES:

DATE: 30.11.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 30

RUN NUMBER: 27

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 4

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	83.6	80.2	87.2	31.8	17.2	19.1	319.0	31.0	0.90	24.1	1.34	53.9	0.54	99.37	
40	40.5	96.9	106.3	38.5	14.9	32.7	329.8	77.0	-0.20	88.9	-0.36	71.1	0.11	94.06	
53	31.9	76.1	118.7	83.8	31.3	24.0	365.9	62.0	0.16	66.7	0.14	40.7	0.52	77.97	
66	53.5	64.6	67.6	119.5	17.2	17.5	340.0	78.9	-0.02	69.2	0.37	67.4	0.28	98.54	
79	20.7	55.7	85.8	50.5	22.6	29.6	264.9	86.4	-0.23	86.1	0.00	80.8	0.00	92.00	
92	13.7	51.4	86.0	58.9	18.5	13.0	241.4	79.6	-0.26	72.1	-0.02	69.4	-0.02	78.22	
105	41.5	64.7	84.2	29.1	15.1	4.8	239.3	93.2	-0.35	89.1	-0.13	87.0	-0.20	85.54	
118	39.9	53.6	92.6	38.3	25.4	11.8	261.7	63.2	0.24	62.5	0.33	66.7	0.25	87.68	
131	23.0	61.3	95.2	70.8	19.0	15.7	285.0	89.3	-0.24	90.6	-0.16	83.9	-0.10	85.65	
144	52.5	75.8	110.1	69.5	14.4	10.8	333.0	53.1	0.79	51.0	0.69	44.1	1.00	96.22	
157	58.8	79.2	110.1	91.6	12.3	10.7	362.7	45.2	0.95	57.1	0.67	26.5	1.47	98.02	
170	37.2	70.0	104.9	48.9	41.2	43.2	345.5	90.8	-0.19	80.9	0.13	89.2	-0.09	91.44	
183	28.0	54.8	68.5	69.5	30.6	17.3	268.7	70.6	-0.06	73.9	0.09	63.6	0.21	83.52	
196	35.1	64.0	73.2	44.1	24.7	17.5	258.6	75.7	0.17	58.5	0.46	66.7	0.46	83.49	
209	65.7	52.9	99.2	61.1	32.9	20.6	332.4	83.4	-0.11	86.1	-0.28	71.4	0.21	85.14	
222	68.2	86.9	73.8	27.2	48.8	64.0	369.1	43.7	1.14	37.8	1.35	32.7	2.02	95.45	
235	80.3	95.1	131.9	37.9	36.7	29.2	411.1	37.3	1.42	27.9	1.60	24.1	2.07	89.31	
248	30.1	92.8	129.0	70.5	43.3	29.4	395.0	73.6	0.09	75.0	0.08	70.3	0.16	87.98	
261															
274															
Σ	680.1	1098.9	1530.8	971.2	434.0	359.1	5074.3	1126.0	3.50	1084.5	5.32	984.5	8.24	1416.17	
μ	42.5	68.7	95.7	60.7	27.1	22.4	317.1	70.4	0.2188	67.8	0.3325	61.5	0.5150	88.51	

NOTES:

DATE: 02.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 31

RUN NUMBER: 28

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 4

BUFFER: 0

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	83.6	80.2	87.2	11.2	25.0	8.8	296.0	34.2	0.70	22.2	1.30	61.1	0.44	99.42	
40	38.9	96.9	106.3	15.0	24.1	29.5	310.6	68.4	0.03	79.4	-0.12	67.4	0.26	93.50	
53	29.4	101.1	87.9	93.0	20.1	6.3	337.6	73.9	-0.14	71.9	0.03	63.3	0.18	78.05	
66	58.6	59.3	66.3	89.5	20.2	27.2	321.2	74.3	0.01	60.0	0.28	57.5	0.40	99.18	
79	42.4	54.5	70.1	45.6	15.9	17.9	246.3	80.5	-0.23	72.3	0.11	73.1	0.04	88.81	
92	50.6	56.8	87.2	34.9	14.7	21.1	265.3	75.3	-0.24	76.2	-0.28	72.3	-0.17	95.30	
105	38.0	71.4	77.2	30.9	13.1	10.2	240.8	82.6	-0.33	83.7	-0.20	81.3	-0.21	94.98	
118	20.5	45.0	118.0	46.5	15.9	8.3	254.2	54.2	0.12	56.1	0.16	60.0	0.17	83.84	
131	47.8	65.8	93.1	57.2	14.9	13.4	292.3	56.6	0.54	63.2	0.37	42.1	0.82	93.92	
144	55.8	46.7	102.7	82.0	16.8	6.6	310.7	59.4	0.13	67.2	0.10	59.1	0.11	92.72	
157	40.6	56.1	103.5	63.5	12.1	19.7	295.5	65.1	-0.05	74.1	-0.22	50.0	0.27	91.22	
170	48.2	44.9	81.0	46.5	22.7	14.4	257.8	53.3	0.63	68.9	0.22	53.5	0.63	96.20	
183	22.0	59.5	82.3	33.2	25.5	7.5	230.1	63.8	0.17	63.6	0.23	61.8	0.29	96.36	
196	28.6	69.0	70.5	44.2	27.6	24.3	264.1	57.3	0.41	56.4	0.54	24.2	1.00	83.64	
209	43.4	50.8	104.6	60.0	28.6	32.1	319.7	61.4	0.46	54.8	0.97	36.1	1.67	89.30	
222	62.0	85.1	90.6	20.3	36.0	32.4	326.4	41.0	0.56	44.0	0.46	44.8	0.43	95.45	
235	82.6	70.3	117.6	17.8	35.0	45.9	369.2	42.8	0.82	62.0	0.26	34.0	1.13	80.33	
248	52.8	107.5	92.5	25.8	32.8	10.0	321.4	27.3	1.61	40.0	0.92	7.3	2.22	95.20	
261															
274															
Σ	723.3	1043.8	1445.1	790.9	351.9	297.3	4652.6	968.8	4.47	1014.4	3.95	820.4	8.98	1454.50	
μ	45.2	65.2	90.3	49.4	22.0	18.6	290.8	60.6	0.2794	63.4	0.2469	51.3	0.5613	90.91	

NOTES:

DATE: 02.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 32

RUN NUMBER: 29

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 2

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	94.4	61.2	87.0	47.8	19.0	11.4	320.8	17.9	1.41	14.3	1.82	44.4	1.33	99.65	
40	58.0	75.6	69.5	35.8	30.5	24.6	294.1	89.7	-0.45	97.7	-0.36	91.5	-0.36	96.01	
53	56.2	65.2	119.7	68.0	26.0	22.2	357.3	85.1	-0.35	88.9	-0.19	78.2	-0.07	90.76	
66	37.2	46.7	88.7	142.2	21.7	13.6	350.1	70.0	-0.11	64.9	0.09	77.3	0.02	95.96	
79	27.9	45.1	70.5	94.0	22.8	49.8	309.9	83.4	-0.34	73.8	-0.02	73.6	-0.04	94.96	
92	43.1	28.4	80.6	80.2	27.4	11.0	270.8	73.8	-0.02	74.4	-0.08	52.3	0.52	81.59	
105	50.7	51.0	68.6	45.5	32.5	13.5	261.7	56.9	0.21	54.7	0.32	44.0	0.56	93.52	
118	19.9	54.0	67.6	55.3	27.4	10.0	234.2	68.3	0.30	67.3	0.38	65.7	0.29	87.83	
131	28.7	38.0	83.9	86.7	25.4	15.8	278.5	83.3	-0.19	85.3	0.03	71.9	0.06	89.04	
144	64.4	38.4	101.7	105.4	17.4	10.0	337.3	66.3	-0.01	73.2	0.02	55.3	0.08	92.77	
157	54.3	64.0	80.3	89.3	20.3	10.4	318.5	92.0	-0.30	94.4	-0.39	81.5	-0.17	97.07	
170	40.9	66.3	95.6	46.2	41.4	42.6	332.9	77.9	-0.02	81.0	0.14	72.4	0.14	91.34	
183	32.0	40.9	78.5	95.6	27.9	6.1	281.0	65.6	0.32	64.3	0.48	50.0	0.85	88.15	
196	36.0	40.7	63.0	49.1	25.6	24.2	238.6	93.2	-0.40	78.6	0.00	87.2	-0.18	78.29	
209	66.5	34.5	71.5	25.6	22.6	20.2	241.0	85.2	-0.22	81.4	-0.14	78.3	-0.13	98.74	
222	63.7	42.9	98.9	21.3	18.8	11.0	256.6	60.3	0.33	53.6	0.39	60.4	0.27	94.61	
235	71.3	68.5	146.5	38.1	27.7	24.6	376.5	60.8	0.31	74.1	-0.04	53.3	0.38	91.67	
248	64.4	65.0	130.0	45.2	58.3	23.5	386.5	82.7	-0.13	77.9	-0.04	84.5	0.00	88.70	
261															
274															
Σ	757.2	789.6	1445.6	1087.7	443.2	308.5	4831.4	1204.8	-0.62	1187.8	0.95	1085.9	2.58	1455.00	
μ	47.3	49.4	90.4	68.0	27.7	19.3	302.0	75.3	-0.0388	74.2	0.0594	67.9	0.1613	90.94	

NOTES:

DATE: 01.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 33

RUN NUMBER: 30

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 2

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	94.4	61.2	87.0	31.3	17.7	19.1	310.6	31.0	0.90	24.1	1.34	53.9	0.54	99.67	
40	57.3	75.6	69.5	27.0	27.6	29.8	286.8	72.5	0.02	82.9	-0.03	68.1	0.23	96.67	
53	40.2	60.7	118.2	59.1	31.7	7.1	316.9	64.7	0.06	73.0	0.03	46.6	0.45	89.47	
66	49.2	38.1	73.1	83.9	23.8	17.1	285.1	79.0	-0.20	73.6	0.00	81.4	-0.19	98.16	
79	32.1	46.5	64.1	43.6	27.8	19.9	225.0	49.2	0.49	59.4	0.44	23.1	1.08	89.89	
92	24.2	51.0	80.4	28.0	20.4	10.8	214.9	78.0	-0.04	59.6	0.19	63.3	0.33	84.10	
105	46.4	53.0	81.3	31.8	23.2	7.4	243.2	91.3	-0.51	94.3	-0.38	93.8	-0.46	85.77	
118	20.9	44.5	77.7	65.9	19.4	19.3	247.7	80.0	-0.34	80.0	-0.16	67.7	-0.18	79.44	
131	32.5	41.5	57.7	88.8	11.3	18.1	249.8	70.9	0.14	58.6	0.24	59.4	0.38	94.37	
144	29.4	39.3	72.5	88.1	19.6	6.0	254.9	50.9	0.81	40.5	0.90	52.2	0.87	89.18	
157	53.6	34.4	96.5	68.3	13.9	17.1	283.8	58.4	0.28	56.0	0.48	62.2	0.24	96.54	
170	59.7	74.1	62.4	46.2	32.3	36.8	311.6	50.9	0.56	50.0	0.58	39.7	0.84	97.55	
183	23.3	37.3	104.5	54.6	29.4	13.2	262.4	55.2	0.43	61.2	0.27	42.9	0.71	89.29	
196	36.4	29.6	82.2	76.8	17.2	38.5	280.5	74.3	-0.05	58.6	0.38	47.1	0.50	83.58	
209	77.7	46.9	68.6	35.1	25.9	17.0	271.2	75.1	-0.06	63.4	0.32	63.6	0.24	97.13	
222	71.9	49.7	114.0	23.1	25.1	33.9	317.8	60.3	0.24	76.1	-0.02	57.1	0.27	95.24	
235	44.9	73.5	120.1	51.1	28.3	23.6	341.6	74.0	0.56	74.3	0.46	60.0	1.20	92.86	
248	57.4	86.8	106.4	131.1	36.7	21.8	440.2	56.2	0.37	51.2	0.78	53.1	0.69	89.56	
261															
274															
Σ	690.6	806.9	1379.7	975.5	386.0	307.6	4546.6	1068.4	2.74	1029.8	4.51	913.2	6.97	1452.13	
μ	43.2	50.4	86.2	61.0	24.1	19.2	284.2	66.8	0.1713	64.4	0.2819	57.1	0.4356	90.76	

NOTES:

DATE: 03.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 34

RUN NUMBER: 31

PARAMETERS

COMPONENT
BUFFER: 0

SUB-ASSY
BUFFER: 2

EQUIPMENT
BUFFER: 0

UTILISATION:
0.95

TREND:
0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	94.4	61.2	87.0	11.2	25.0	8.8	287.6	34.2	0.70	22.2	1.30	61.1	0.44	99.70	
40	57.3	75.6	69.5	13.8	18.9	33.4	268.5	73.6	-0.01	82.4	-0.09	73.9	0.15	99.66	
53	36.6	56.3	115.3	66.4	24.1	10.2	308.9	78.3	-0.21	83.3	-0.17	63.5	0.13	86.97	
66	48.8	41.5	66.5	69.4	22.2	22.2	270.6	73.6	0.04	72.2	0.30	53.5	0.42	97.58	
79	30.7	37.6	78.3	35.0	16.4	16.5	214.5	74.9	-0.04	60.0	0.31	64.7	0.25	88.89	
92	34.2	48.5	84.0	18.9	19.2	14.5	219.3	71.9	-0.08	76.6	-0.13	65.2	0.09	88.49	
105	43.3	55.4	91.9	20.7	17.9	8.7	237.9	71.5	0.07	58.3	0.29	77.4	0.00	88.70	
118	21.8	39.2	77.7	40.1	22.5	13.0	214.3	67.9	0.09	66.7	0.30	71.0	0.10	88.36	
131	25.9	32.2	59.3	72.0	16.3	14.9	220.6	61.7	0.65	79.3	0.21	51.5	1.12	94.43	
144	42.6	33.5	78.6	65.5	11.9	6.2	238.3	62.8	1.60	65.0	0.95	52.4	1.67	92.00	
157	59.9	46.0	80.5	57.8	10.8	21.3	276.4	48.5	1.78	47.6	1.64	39.0	2.37	97.97	
170	43.8	48.9	98.8	50.0	31.2	29.8	302.6	53.1	0.83	40.4	1.08	42.4	1.15	93.37	
183	32.6	48.5	82.2	27.4	37.7	39.1	267.5	45.6	0.48	68.0	0.14	36.7	0.76	95.90	
196	38.9	52.4	82.6	27.8	27.4	39.5	268.6	61.2	0.42	55.3	0.95	56.8	0.57	91.70	
209	33.3	45.1	72.4	33.4	32.2	6.1	222.4	61.5	0.32	73.2	0.10	48.2	0.63	95.90	
222	79.5	49.0	77.9	19.3	33.0	23.9	282.7	36.0	1.40	52.0	1.00	32.6	1.65	96.83	
235	71.9	62.5	145.2	40.2	22.4	52.6	394.7	33.2	1.40	38.2	1.32	26.9	1.75	93.35	
248	70.0	74.2	113.7	38.1	38.0	33.0	367.9	42.5	0.66	56.5	0.35	34.3	0.82	90.88	
261															
274															
Σ	713.8	771.8	1404.9	682.0	383.2	351.5	4307.2	944.2	9.41	992.6	8.64	816.1	13.48	1481.32	
μ	44.6	48.2	87.8	42.6	24.0	22.0	269.2	59.0	0.5881	62.0	0.5400	51.0	0.8425	92.58	

NOTES:

DATE: 03.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 35

RUN NUMBER: 32

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 0

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE E'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%	LATENESS	
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	96.6	51.0	92.5	47.8	19.1	11.4	318.3	18.5	1.40	14.3	1.82	44.4	1.33	99.64
	40	52.9	41.2	93.4	25.2	27.2	24.7	264.5	88.1	-0.42	92.7	-0.34	93.6	-0.40	95.29
	53	59.4	64.2	77.7	70.3	23.5	17.3	312.3	81.3	-0.17	79.6	-0.11	74.5	0.04	91.63
	66	39.1	60.2	79.1	132.2	21.4	15.3	347.3	76.2	-0.23	73.2	0.02	70.2	-0.06	96.59
	79	41.4	45.3	70.0	97.3	22.0	18.8	294.5	92.4	-0.41	85.1	-0.11	87.2	-0.19	89.22
	92	33.1	32.8	110.1	31.5	29.9	24.2	261.6	77.2	-0.17	67.3	0.17	63.5	0.17	83.89
	105	45.0	45.0	73.1	40.1	11.6	5.2	220.0	76.3	-0.02	84.8	-0.15	70.0	0.20	97.44
	118	20.5	47.0	75.9	66.0	11.7	8.7	229.7	68.2	0.30	77.8	0.07	76.7	0.23	83.68
	131	28.0	29.0	73.9	77.0	10.0	9.7	227.5	59.3	0.47	37.0	0.78	50.0	0.75	84.58
	144	36.8	37.3	92.7	79.4	22.0	16.0	284.1	62.3	0.26	83.3	-0.22	42.4	0.61	83.22
	157	48.5	53.9	87.0	63.9	15.5	26.3	295.1	91.8	-0.57	95.7	-0.55	89.4	-0.35	88.70
	170	33.7	59.7	80.8	58.9	30.8	21.6	285.6	82.2	-0.19	90.9	-0.32	77.6	-0.09	84.00
	183	29.5	33.1	54.8	67.5	29.2	9.1	223.2	72.7	0.04	75.6	0.18	73.3	0.20	83.02
	196	50.6	43.7	70.4	30.8	24.3	17.7	237.4	29.7	1.59	22.6	2.29	15.4	2.19	93.89
	209	48.6	44.3	73.3	40.3	26.1	26.6	259.1	74.6	0.07	75.0	0.10	50.0	0.80	97.41
	222	66.2	43.6	98.5	23.5	31.7	28.3	291.7	58.6	0.28	51.3	0.49	44.4	0.56	88.69
	235	51.8	59.6	139.2	51.1	31.6	45.3	378.5	58.9	0.39	69.2	0.26	51.6	0.56	86.25
	248	49.2	77.7	114.9	40.0	38.7	18.6	339.2	82.0	-0.21	95.3	-0.48	77.4	-0.10	89.96
	261														
	274														
	W	681.4	776.4	1371.4	969.8	380.0	308.7	4486.8	1143.7	1.43	1163.7	2.42	1013.6	5.52	1422.17
	u	42.6	48.5	85.7	60.6	23.8	19.3	280.4	71.5	0.0894	72.7	0.1513	63.4	0.3450	88.89

NOTES:

DATE: 04.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 36

RUN NUMBER: 33

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 0

BUFFER: 0

BUFFER: 2

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%	LATENESS	
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	96.6	51.0	92.5	31.8	17.2	19.1	308.1	31.0	0.90	24.1	1.34	53.9	0.54	99.66
	40	50.9	41.2	93.4	20.1	19.7	29.9	255.2	74.6	-0.02	86.1	-0.06	70.5	0.20	94.51
	53	57.2	59.5	76.9	59.8	30.7	25.4	309.4	62.9	0.27	66.7	0.15	46.3	0.54	89.70
	66	53.5	31.0	68.7	94.4	21.2	28.2	296.9	70.9	0.27	58.7	0.83	51.1	0.89	98.70
	79	36.4	18.1	86.9	42.0	27.9	51.7	263.0	65.6	0.13	67.5	0.27	52.4	0.50	90.31
	92	31.2	40.5	94.4	56.0	8.5	0.0	230.6	67.6	-0.05	62.8	0.26	54.6	0.33	86.46
	105	48.4	41.6	78.7	44.5	20.7	14.9	248.9	59.1	0.23	60.0	0.29	68.6	0.04	82.68
	118	22.8	46.8	84.2	52.9	17.9	9.2	233.9	63.2	0.75	53.2	0.89	51.6	1.58	90.00
	131	43.0	31.2	82.4	88.3	13.5	23.2	281.5	89.9	-0.34	85.0	0.02	75.0	0.13	77.55
	144	31.5	39.4	103.5	92.7	19.3	11.1	297.5	57.6	0.76	75.8	0.09	50.0	1.03	88.80
	157	51.6	46.7	98.8	73.0	19.6	48.3	338.0	44.5	0.80	40.7	0.97	29.8	1.35	93.78
	170	55.2	34.5	79.9	45.8	32.5	15.2	263.1	55.3	0.58	71.4	0.40	33.9	1.03	93.06
	183	13.0	41.2	75.8	37.5	20.6	11.3	199.4	93.6	-0.41	85.7	-0.29	91.7	-0.17	94.57
	196	30.2	36.8	69.3	19.1	19.0	27.3	201.7	37.2	0.86	27.3	0.91	22.9	1.34	95.10
	209	55.7	36.5	96.3	6.9	18.5	26.8	240.7	42.1	0.87	33.3	1.67	19.2	1.77	93.04
	222	48.0	61.9	93.9	14.3	14.2	69.5	301.8	39.9	1.13	63.6	1.00	46.0	1.14	98.66
	235	37.5	42.0	131.2	45.9	26.0	101.4	384.1	34.1	2.90	33.3	3.72	21.4	5.14	95.92
	248	60.5	77.2	96.9	130.0	20.4	17.9	402.8	30.8	3.40	24.4	3.38	14.6	6.80	96.19
	261														
	274														
	Σ	675.7	684.9	1417.8	903.1	330.5	481.4	4493.3	914.3	12.15	909.4	14.56	729.1	23.44	1464.52
	μ	42.2	42.8	88.6	56.4	20.7	30.1	280.8	57.1	0.7594	56.8	0.9100	45.6	1.4650	91.53

NOTES:

DATE: 08.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 37

RUN NUMBER: 34

PARAMETERS

COMPONENT
BUFFER: 8SUB-ASSY
BUFFER: 4EQUIPMENT
BUFFER: 4UTILISATION:
0.95TREND:
0.04/-0.02/0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	105.9	80.2	87.2	48.3	16.4	19.8	357.8	18.9	1.36	14.3	1.82	37.5	1.37	100.00
	40	132.4	96.9	106.3	48.5	21.4	23.3	428.7	89.4	-0.43	90.9	-0.50	85.4	-0.35	100.00
	53	100.1	89.4	115.7	100.9	24.1	17.5	447.7	81.1	-0.14	72.5	-0.02	75.0	0.00	100.00
	66	84.7	64.7	99.9	158.5	24.6	18.1	450.5	89.5	-0.35	72.6	0.04	79.2	-0.19	99.51
	79	89.6	60.6	83.6	100.7	14.3	7.6	356.3	77.8	-0.22	66.6	0.14	65.5	0.18	100.00
	92	84.7	49.1	90.8	90.5	19.7	12.4	347.2	78.1	-0.30	60.0	0.15	77.8	-0.17	100.00
	105	87.2	59.3	72.6	106.9	21.0	3.5	350.5	83.2	-0.15	80.4	-0.13	75.0	-0.03	100.00
	118	78.1	54.5	79.6	124.1	14.0	0.7	351.1	56.4	0.30	62.8	0.21	37.5	0.53	100.00
	131	103.4	47.2	81.5	111.2	26.1	16.1	385.5	81.5	-0.08	74.5	0.11	75.0	0.19	100.00
	144	129.9	41.7	92.8	122.7	13.3	11.1	411.5	81.2	-0.26	78.6	-0.14	76.5	-0.15	100.00
	157	128.6	56.1	79.4	75.4	29.7	12.8	382.0	96.9	-0.41	98.0	-0.47	96.5	-0.35	99.53
	170	115.2	48.5	105.0	74.5	33.9	7.8	384.9	78.9	-0.02	83.3	0.10	70.6	0.10	98.79
	183	84.5	54.9	106.4	78.5	38.3	21.6	384.2	88.3	-0.47	94.2	-0.50	91.1	-0.31	100.00
	196	107.2	65.7	89.8	55.7	23.7	24.6	366.7	72.4	0.23	71.8	0.31	61.9	0.36	100.00
	209	121.6	54.6	94.9	79.9	22.2	46.9	420.1	39.5	0.89	59.1	0.36	21.7	1.61	99.56
	222	176.4	73.0	102.8	85.9	30.7	93.5	562.2	84.4	1.05	75.9	3.10	64.9	3.49	99.72
	235	149.0	87.2	130.6	97.4	45.3	56.2	565.7	64.1	2.17	48.8	4.49	47.5	4.87	100.00
	248														
	261														
	274														
	M	1772.6	1003.4	1531.7	1511.3	402.3	373.7	6244.3	1242.7	1.81	1190.0	7.25	1101.1	9.78	1597.11
	u	110.8	62.7	95.7	94.5	25.1	23.4	390.3	77.7	0.1131	74.4	0.4531	68.8	0.6113	99.82

NOTES:

DATE: 11.12.81

MODE: MIXED

PRIORITY: FIFO

RP FILE: 38

RUN NUMBER: 35

PARAMETERS

COMPONENT
BUFFER: 8

SUB-ASSY
BUFFER: 4

EQUIPMENT
BUFFER: 4

UTILISATION:
0.95

TREND:
0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000						DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	105.9	80.2	87.2	48.3	15.5	14.4	351.5	19.4	1.34	14.3	1.82	44.4	1.33	100.00
	40	132.4	96.9	106.3	46.9	21.1	30.5	434.0	88.6	-0.46	93.0	-0.49	89.4	-0.34	100.00
	53	100.1	89.4	115.7	92.1	26.0	15.1	438.4	82.5	-0.15	71.8	0.00	75.9	0.09	100.00
	66	86.7	64.7	99.9	160.2	24.2	14.5	450.2	78.4	-0.27	66.0	0.02	68.2	-0.07	99.51
	79	89.4	59.1	81.7	124.1	24.4	12.3	388.1	72.5	-0.12	51.2	0.29	51.0	0.39	100.00
	92	78.7	70.8	74.5	108.9	16.7	24.0	373.6	89.3	-0.21	83.7	0.58	84.2	0.05	100.00
	105	108.6	53.2	85.8	54.2	43.3	13.8	358.9	50.4	2.21	45.1	2.22	37.9	2.91	100.00
	118	71.8	49.0	103.9	104.9	23.5	10.2	363.3	64.1	1.05	71.1	0.93	53.3	1.60	98.55
	131	93.7	60.6	96.5	130.3	29.1	24.1	434.2	83.0	-0.24	80.4	-0.02	72.2	0.06	100.00
	144	116.8	46.6	110.3	124.5	26.0	20.9	445.2	77.5	-0.23	75.6	-0.24	70.0	0.00	100.00
	157	94.8	53.4	118.3	89.1	20.5	12.1	388.2	91.0	-0.53	96.3	-0.50	92.1	-0.46	100.00
	170	87.6	57.2	94.8	74.1	24.4	13.7	351.8	97.3	-0.60	100.00	-0.43	98.2	-0.48	100.00
	183	83.1	55.8	82.1	77.3	29.2	12.5	340.0	97.2	-0.50	100.00	-0.31	92.3	-0.31	100.00
	196	73.6	69.6	80.4	55.5	19.0	25.8	324.0	84.8	0.00	66.7	0.15	69.6	0.26	100.00
	209	108.1	49.5	70.9	36.8	26.7	8.3	300.3	81.5	-0.28	97.1	-0.40	77.8	-0.07	100.00
	222	197.3	61.0	84.2	36.3	22.5	18.3	419.6	63.3	0.51	68.3	0.20	53.7	0.71	100.00
	235	205.7	75.3	136.1	49.3	36.9	17.5	520.7	87.9	-0.19	87.0	-0.07	89.5	-0.14	100.00
	248														
	261														
	274														
	Σ	1725.4	1012.1	1541.4	1364.5	413.5	273.6	6330.5	1289.3	-0.01	1253.3	1.93	1175.3	4.20	1598.06
	μ	107.8	63.3	96.3	85.3	25.8	17.1	395.7	80.6	-0.0006	78.3	0.1206	73.5	0.2625	99.88

NOTES:

DATE: 05.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 39

RUN NUMBER: 36

PARAMETERS

COMPONENT
BUFFER: 8SUB-ASSY
BUFFER: 4EQUIPMENT
BUFFER: 4UTILISATION:
1.00TREND:
0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT % LATENESS	PART SHIP % LATENESS	NO PART SHIP % LATENESS				
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	105.9	80.2	87.2	48.3	15.5	14.4	351.5	19.4	1.34	14.3	1.82	44.4	1.33	100.00
	40	132.4	93.0	109.8	46.9	21.1	30.5	433.7	88.6	-0.46	93.0	-0.49	89.4	-0.34	100.00
	53	100.1	87.0	117.8	92.1	26.0	15.1	438.1	82.5	-0.15	71.8	0.00	75.9	0.09	100.00
	66	85.7	64.7	99.9	160.2	24.2	14.5	450.2	78.4	-0.27	66.0	0.02	68.2	-0.07	99.51
	79	86.4	57.9	82.8	124.1	24.4	12.3	388.0	72.5	-0.12	51.2	0.29	51.0	0.39	100.00
	92	78.7	66.5	78.3	108.9	16.7	24.0	373.1	89.3	-0.21	83.7	0.58	84.2	0.05	100.00
	105	108.6	53.2	85.8	54.2	43.3	13.8	358.9	50.4	2.21	45.1	2.22	37.9	2.91	100.00
	118	71.8	45.2	107.4	104.7	23.7	10.2	363.0	64.1	1.05	71.1	0.93	53.3	1.60	98.55
	131	93.7	60.6	96.5	130.5	28.9	24.8	434.9	83.7	-0.25	84.4	-0.07	75.0	0.03	100.00
	144	116.8	45.5	111.3	131.1	20.4	15.6	440.8	76.6	-0.22	75.6	-0.27	74.4	-0.05	100.00
	157	94.8	53.4	118.3	88.8	28.0	11.1	394.5	95.6	-0.42	94.3	-0.36	90.2	-0.26	100.00
	170	87.6	57.2	94.8	77.5	28.0	6.5	351.6	94.5	-0.56	95.9	-0.31	98.2	-0.67	100.00
	183	83.1	53.2	84.4	79.5	25.1	13.3	338.5	97.8	-0.51	100.00	-0.25	92.6	-0.26	100.00
	196	73.6	66.7	83.1	42.2	22.3	41.6	329.4	82.2	-0.25	72.7	0.05	60.0	0.22	100.00
	209	108.1	49.3	71.1	40.2	19.9	20.9	309.5	80.7	-0.25	90.0	-0.17	78.6	-0.04	100.00
	222	197.3	57.5	87.4	36.6	23.0	17.5	419.3	64.2	0.21	52.9	0.20	59.5	0.19	100.00
	235	205.7	71.5	139.5	43.4	38.7	12.5	511.2	82.7	-0.01	84.0	0.10	77.4	0.11	100.00
	248														
	261														
	274														
	Σ	1725.4	982.4	1568.2	1360.9	413.7	284.2	6334.7	1283.8	-0.21	1231.7	2.47	1165.8	3.90	1598.06
	μ	107.8	61.4	98.0	85.1	25.9	17.8	395.9	80.2	-0.0131	77.0	0.1544	72.9	0.2438	99.88

NOTES:

DATE: 11.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 48

RUN NUMBER: 37

PARAMETERS

COMPONENT
BUFFER: 8

SUB-ASSY
BUFFER: 4

EQUIPMENT
BUFFER: 4

UTILISATION:
0.95

TREND:
0.0/ 0.0/ 0.0/ 0.0

R A N G E	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL	
	WEEK	COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%		LATENESS
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	118.8	79.5	90.7	62.5	9.6	6.3	367.5	15.2	1.41	26.5	1.29	20.0	2.20	99.67	
40	138.1	98.0	92.7	46.2	26.4	20.8	422.1	94.2	-0.48	85.7	-0.14	88.0	-0.28	100.00	
53	108.9	82.9	118.3	54.0	27.0	16.9	407.9	81.6	-0.20	64.4	0.18	70.2	0.19	100.00	
66	75.4	71.9	91.0	101.7	27.0	19.4	386.3	76.7	-0.07	74.3	0.14	65.9	0.09	96.55	
79	102.7	70.4	79.6	72.1	28.6	47.9	401.3	78.1	-0.17	57.9	0.34	79.6	-0.05	100.00	
92	132.8	58.7	79.3	110.7	13.9	16.7	412.0	63.3	0.22	51.6	0.48	42.9	0.76	100.00	
105	113.9	51.1	96.2	110.9	35.6	23.4	431.1	83.0	-0.24	93.6	-0.39	94.7	-0.39	100.00	
118	68.4	62.8	84.0	103.3	30.2	22.5	371.0	87.4	-0.32	93.0	-0.33	86.5	-0.31	99.52	
131	87.2	44.2	60.8	76.0	27.6	8.5	304.3	87.8	-0.08	55.2	0.43	62.5	0.31	98.21	
144	132.7	47.8	82.0	56.0	19.6	15.8	354.0	47.3	0.58	31.1	0.76	25.0	1.04	100.00	
157	169.3	44.5	107.7	43.4	40.1	19.7	424.8	84.3	-0.06	69.1	0.18	81.8	0.02	100.00	
170	221.9	56.2	118.1	27.5	30.6	37.6	491.9	75.8	-0.09	70.4	0.09	75.5	0.00	100.00	
183	159.7	97.4	101.1	57.4	42.1	36.3	493.9	87.9	-0.38	89.8	-0.36	83.6	-0.22	99.32	
196	76.7	93.9	132.2	106.8	39.3	23.8	472.7	45.8	0.49	28.1	0.88	37.0	0.77	100.00	
209	52.1	81.7	105.3	164.2	35.2	14.2	452.8	81.7	-0.10	76.5	0.15	68.8	0.08	100.00	
222	62.8	65.9	73.5	129.8	32.2	17.0	381.2	91.9	-0.44	89.8	-0.24	85.1	-0.32	97.02	
235	116.5	60.2	61.0	66.4	15.9	18.4	338.3	74.4	-0.03	58.6	0.34	66.7	0.00	100.00	
248															
261															
274															
Σ	1819.1	1087.6	1482.8	1326.4	471.3	358.9	6545.6	1241.2	-1.37	1089.1	2.51	1113.8	1.69	1590.62	
μ	113.7	68.0	92.7	82.9	29.5	22.4	409.1	77.6	-0.0856	68.1	0.1569	69.6	0.1056	99.41	

NOTES: As run number 4 (RP8) with different and antithetic random number streams - taken from RN4 which is negative RN3.

DATE: 11.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 49

RUN NUMBER: 38

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE E'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%	LATENESS	
	14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
	27	90.6	85.3	85.5	52.6	16.1	2.7	332.7	19.3	1.33	14.3	1.71	45.5	1.00	99.67
	40	62.0	69.8	91.2	66.4	33.0	14.6	337.0	75.7	0.04	80.7	-0.03	57.4	0.30	100.00
	53	69.7	68.7	77.6	86.8	23.7	35.7	362.2	89.9	-0.36	76.3	0.08	85.4	-0.32	100.00
	66	80.2	54.7	76.4	69.9	27.4	16.6	325.3	92.0	-0.45	89.8	-0.27	80.5	-0.02	100.00
	79	94.0	56.0	79.3	37.7	29.4	17.7	314.2	86.7	-0.21	85.1	-0.19	78.4	-0.06	100.00
	92	105.7	69.7	74.8	21.9	36.7	16.0	324.8	62.5	0.19	67.7	0.13	54.8	0.36	100.00
	105	108.5	51.0	105.5	32.4	32.8	17.6	347.8	76.9	0.06	78.3	0.02	63.5	0.25	100.00
	118	166.6	60.5	98.4	43.5	27.6	26.3	422.9	89.9	-0.26	89.8	-0.22	95.1	-0.37	99.28
	131	144.5	65.9	121.6	47.9	47.7	30.9	458.6	72.7	0.18	77.1	0.11	53.9	0.48	100.00
	144	97.6	76.8	123.1	54.4	48.9	13.9	414.6	73.4	0.01	67.4	0.19	66.3	0.15	100.00
	157	83.4	86.3	94.2	158.2	19.4	5.2	446.7	92.4	-0.42	88.9	-0.08	82.4	-0.24	99.48
	170	87.4	68.4	84.1	151.3	26.6	25.2	443.1	95.1	-0.50	88.9	-0.11	84.9	-0.15	100.00
	183	49.8	73.0	77.0	99.5	31.1	15.1	345.5	90.3	-0.45	100.0	-0.39	93.9	-0.47	99.03
	196	72.3	54.6	70.3	124.1	20.0	14.9	356.2	70.2	0.19	80.7	0.00	69.2	0.19	99.50
	209	102.8	54.9	76.6	137.4	9.1	5.1	386.0	62.7	0.77	64.4	0.96	47.2	1.25	100.00
	222	135.8	53.2	95.6	152.3	18.1	15.9	470.9	77.9	-0.22	70.8	0.00	83.7	-0.28	99.57
	235	88.5	63.3	96.5	133.6	45.7	15.7	443.4	75.6	0.01	56.8	0.35	66.7	0.27	100.00
	248														
	261														
	274														
	Σ	1548.8	1026.9	1442.2	1417.3	477.2	286.4	6199.2	1283.9	-1.42	1262.7	0.55	1163.3	1.34	1596.86
	μ	96.8	64.2	90.1	88.6	29.8	17.9	387.5	80.2	-0.0888	78.9	0.0344	72.7	0.0838	99.80

NOTES: As run number 4 (RP8) with different random number streams - taken from RN3.

DATE: 05.12.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 50

RUN NUMBER: 39

PARAMETERS

COMPONENT
BUFFER: 8SUB-ASSY
BUFFER: 4EQUIPMENT
BUFFER: 4UTILISATION:
0.95TREND:
0.0/ 0.0/ 0.0/ 0.0

R A N G E	WEEK	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL
		COMP	SUB STK	WIP	EQU STK	TEST	COM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
									%	LATENESS	%	LATENESS	%	LATENESS	
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00	
27	84.0	71.9	107.3	42.5	15.4	5.3	326.4	23.6	1.00	34.2	1.05	60.0	0.40	99.69	
40	84.0	90.4	88.0	49.7	30.4	37.5	380.2	93.4	-0.58	94.6	-0.32	88.5	-0.37	100.00	
53	101.5	80.1	68.3	35.1	32.7	23.8	341.5	78.1	0.03	60.4	0.26	64.3	0.36	100.00	
66	144.9	61.6	88.1	47.0	15.8	17.9	375.2	70.4	0.01	86.1	-0.14	77.8	0.14	100.00	
79	116.5	96.6	85.3	102.5	31.5	15.0	447.4	63.3	0.16	62.5	0.13	54.3	0.46	99.18	
92	107.8	95.9	95.9	75.3	52.5	40.7	468.1	78.9	-0.23	66.7	0.02	80.7	-0.16	99.16	
105	84.7	84.6	104.8	91.9	25.6	19.7	411.2	63.4	0.18	76.3	-0.16	48.3	0.66	96.60	
118	74.6	66.2	91.5	93.2	35.3	23.7	384.5	84.6	-0.11	70.8	0.19	73.2	0.07	97.11	
131	121.7	64.0	103.2	88.5	31.0	16.4	424.8	52.8	0.97	35.4	1.37	43.3	1.40	99.59	
144	122.1	62.4	94.7	166.2	20.5	69.5	535.4	59.8	0.59	61.5	0.72	46.2	0.82	99.29	
157	108.0	74.1	100.0	102.7	41.6	31.7	458.7	70.2	1.37	61.2	2.21	58.1	3.45	100.00	
170	141.1	50.0	106.6	91.9	35.7	25.0	450.3	63.7	1.40	54.8	2.23	54.6	2.22	100.00	
183	138.7	98.9	100.3	62.4	54.2	27.7	482.2	68.0	0.33	82.1	0.13	54.2	0.77	100.00	
196	98.7	75.2	132.8	111.3	44.8	26.1	488.9	40.7	0.83	38.5	0.97	22.0	1.26	99.18	
209	83.8	87.1	84.2	142.6	31.5	21.6	450.8	70.0	0.05	60.0	0.27	72.7	0.13	100.00	
222	76.3	57.8	89.0	143.6	30.8	26.6	424.1	63.1	0.07	76.5	-0.24	51.2	0.28	95.93	
235	62.3	61.0	65.8	121.2	36.7	10.1	357.2	49.5	0.74	57.7	0.58	29.0	1.11	98.46	
248															
261															
274															
Σ	1666.7	1205.9	1498.5	1525.1	550.6	433.0	6880.5	1069.9	5.81	1045.1	8.22	918.4	12.60	1584.50	
μ	104.2	75.4	93.7	95.3	34.4	27.1	430.0	66.9	0.3631	65.3	0.5138	57.4	0.7875	99.03	

NOTES: As run number 4 (RP8) with antithetic random number streams - taken from RN2 (negative RN1).

DATE: 31.10.81

MODE: MIXED

PRIORITY: DUE DATE

RP FILE: 8

RUN NUMBER: 4

PARAMETERS

COMPONENT

SUB-ASSY

EQUIPMENT

UTILISATION:

TREND:

BUFFER: 8

BUFFER: 4

BUFFER: 4

0.95

0.0/ 0.0/ 0.0/ 0.0

WEEK	STOCK VALUE £'000							DELIVERY PERFORMANCE						COMP. SERV. LEVEL
	COMP	SUB STK	WIP	EQU STK	TEST	CCM STK	TOTAL	EQUIPMENT		PART SHIP		NO PART SHIP		
								%	LATENESS	%	LATENESS	%	LATENESS	
14	96.2	85.8	88.8	0.0	31.3	0.0	302.0	0.0	0.00	0.0	0.00	0.0	0.00	100.00
27	105.9	80.2	87.2	48.3	15.5	14.4	351.5	19.4	1.34	14.3	1.82	44.4	1.33	100.00
40	132.4	96.9	106.3	46.9	21.1	30.5	434.0	88.6	-0.46	93.0	-0.49	89.4	-0.34	100.00
53	100.1	89.4	115.7	92.0	26.0	15.1	438.4	82.5	-0.15	71.8	0.00	75.9	0.09	100.00
66	86.7	64.7	99.9	160.2	24.2	14.5	450.2	78.4	-0.27	66.0	0.02	68.2	-0.07	99.51
79	86.4	59.1	81.7	124.1	24.4	12.3	388.1	72.5	-0.12	51.2	0.29	51.0	0.39	100.00
92	78.7	70.7	74.5	108.9	16.7	24.0	373.6	69.3	-0.21	83.7	0.58	84.2	0.05	100.00
105	108.6	53.2	85.8	54.2	43.3	13.8	358.9	50.4	2.21	45.1	2.22	37.9	2.91	100.00
118	71.8	49.0	103.9	104.9	23.5	10.2	363.3	64.1	1.05	71.1	0.93	53.3	1.60	98.55
131	93.7	60.6	96.5	130.3	29.1	24.1	434.2	83.0	-0.24	80.4	-0.02	72.2	0.06	100.00
144	116.8	46.6	110.3	124.5	26.0	20.9	445.2	77.5	-0.23	75.6	-0.24	70.0	0.00	100.00
157	94.8	53.4	118.3	89.1	20.5	12.1	388.2	91.0	-0.63	96.3	-0.50	92.1	-0.46	100.00
170	87.6	57.2	94.8	74.1	24.4	13.7	351.8	97.3	-0.60	100.0	-0.43	98.2	-0.48	100.00
183	83.1	55.8	82.1	77.3	29.2	12.5	340.0	97.2	-0.50	100.0	-0.31	92.3	-0.31	100.00
196	73.6	69.6	80.4	55.5	19.0	25.8	324.0	84.8	0.00	66.7	0.15	69.6	0.26	100.00
209	108.1	49.5	70.9	36.8	26.7	8.3	300.3	81.5	-0.28	97.1	-3.40	77.8	-0.07	100.00
222	197.3	61.0	84.2	36.3	22.5	18.3	419.6	63.3	0.51	68.3	0.20	53.7	0.71	100.00
235	205.7	75.3	136.1	49.3	36.9	17.5	520.7	87.9	-0.19	87.0	-0.07	89.5	-0.14	100.00
248	161.9	61.4	127.9	26.2	57.3	66.8	501.5	89.8	-0.30	85.9	-0.21	91.7	-0.15	98.93
261	78.4	111.4	107.8	81.1	31.7	13.2	423.7	83.1	-0.25	70.0	-0.05	80.0	-0.09	100.00
274	110.0	80.6	75.3	134.1	23.4	21.7	445.2	83.6	-0.05	76.5	0.12	63.6	0.67	100.00
287	85.6	62.7	82.6	112.2	30.8	15.1	389.0	79.6	-0.10	55.6	0.27	73.3	0.09	100.00
300	63.0	48.4	100.7	104.0	19.2	3.1	338.4	88.6	-0.57	89.1	-0.54	85.7	-0.49	98.38
313	96.9	50.4	67.6	113.5	15.6	8.4	352.4	97.9	-0.52	96.4	-0.25	97.9	-0.34	99.46
326	100.0	47.5	67.7	131.0	11.8	34.5	392.5	64.5	0.52	68.0	0.24	61.5	0.92	100.00
339	104.5	35.6	90.2	84.9	25.8	8.8	349.8	68.4	0.51	71.9	0.19	52.0	0.74	99.60
352	115.0	55.3	87.2	24.7	35.9	39.6	357.8	63.8	0.52	55.3	1.57	55.8	0.67	100.00
365	107.7	59.1	102.4	52.5	30.0	38.2	390.0	53.8	1.90	59.5	2.35	34.2	4.54	98.26
378	149.9	74.2	112.6	62.0	31.1	14.3	444.0	51.6	1.19	57.9	2.58	51.1	1.76	98.48
391	97.3	95.0	107.0	33.2	41.7	8.0	382.1	72.3	0.07	74.3	0.09	53.1	0.34	99.61
404	86.1	87.1	86.9	72.5	21.9	3.9	358.4	81.3	-0.01	62.5	0.42	69.0	0.19	98.55
417	86.7	64.5	80.2	94.3	36.1	19.4	381.3	80.0	-0.10	56.4	0.36	74.2	0.03	100.00
430	85.2	60.9	74.8	75.7	28.4	8.7	333.7	68.0	0.11	69.4	0.18	54.9	0.33	100.00
443	75.7	60.5	71.8	41.4	45.3	13.3	308.1	77.3	0.05	63.6	0.27	71.1	0.24	100.00
456	55.8	44.0	91.4	47.0	31.7	39.9	309.7	71.8	0.21	70.6	0.25	74.4	0.36	98.00
469	80.4	48.9	75.2	57.7	14.9	31.9	309.1	76.3	0.88	51.6	2.10	63.4	1.66	99.62
482	109.2	64.7	71.8	65.0	23.9	38.0	372.7	62.1	3.49	77.4	0.58	40.5	5.51	100.00
495	127.0	72.9	95.5	78.7	29.4	34.5	438.1	71.8	3.86	54.8	3.71	56.0	5.86	100.00
508	125.6	79.2	117.2	67.3	34.9	34.4	458.5	38.1	3.69	41.5	4.85	26.5	6.37	99.73
521	57.4	68.1	110.1	52.4	44.4	24.7	357.2	85.6	-0.30	78.5	-0.09	81.3	-0.16	98.83
534	75.4	65.0	90.4	50.0	33.7	40.7	355.3	84.5	-0.32	83.0	-0.26	71.7	0.02	98.51
547	101.0	50.1	70.0	18.7	21.2	22.2	283.2	42.5	0.76	27.3	1.00	26.2	1.19	100.00
560	128.2	45.3	100.00	29.0	11.7	16.6	331.2	70.8	0.41	62.9	-0.28	62.2	0.96	100.00

EXPERIMENT WITH RP8 OVER 10 SIMULATED YEARS

