THE DEVELOPMENT OF A COMPUTER SIMULATION MODEL OF THE INTERACTION BETWEEN THE SUPPLY AND USAGE OF MAJOR COMPONENTS IN CAR ASSEMBLY FOR USE IN STOCK CONTROL -

A Thesis Presented to

THE UNIVERSITY OF ASTON IN BIRMINGHAM

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by

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SUMMARY

The assembly of a motor car is the most capitally intensive part of its manufacture because there is high capital investment both in the stocks of expensive major components and in the fully automated assembly factories needed to produce cars. Control of major component stocks can therefore play a significant part in keeping overall manufacturing costs down.

The nature of volume car manufacture does not permit any direct control of major component stocks, but a measure of indirect control can be achieved by fixing ceiling levels up to which stocks will be allowed to rise before supplies are stopped.

At present these ceiling levels are not fixed in any scientific way at the Austin-Morris Division of the British Leyland Motor Corporation. This thesis describes the development of a probabilistic computer simulation model of the inter-action between the supply and usage of major components in order to review major component stocking policy to the Company's best advantage.

Part I of the thesis describes motor car manufacture and methods of production and inventory control of major components presently emplyed by the Company. The contribution of existing literature is also reviewed in this section of the thesis.

A simulation model of the inter-action between the supply and usage of major components is developed in the second part of the thesis. Part III deals with a feasibility study undertaken to validate, and experiment with, the model.

The results obtained indicate that

1) The model used is sufficiently valid for its intended purpose;

2) The use of a ceiling level of about 2,000 sets of major components can be recommended for conditions specified in the feasibility study;

3) Maintaining a low ceiling level of about 700 sets of major components would cost over £170,000 more than the recommended level under similar conditions.

ACKNOWLEDGMENTS

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The writer wishes to thank B.L.M.C. (Austin-Morris) Ltd. for the complete support, both financial and moral, which has been given to the project described in this thesis.

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PREFACE

The project described in this thesis is rather unusual in the sense that it is one of the first applied research projects to be supervised by the Inter-disciplinary Higher Degrees Scheme of the University of Aston. For this reason a preface to this thesis has been written in an attempt to explain what the scheme, and its aims, are.

The IHD scheme was started up towards the end of 1968 in response to a growing demand for longer term and deeper joint ventures by industry and universities. Prior to 1968 a number of universities, polytechnics and technical colleges had maintained a link with industry mainly through the undergraduate sandwich course, the short course and the day release course. But the purpose of these courses was, and still is, to teach students certain skills, which could be exploited by industry only after the students had either left or completed the course. Short projects are carried out in industry by the students on some of these courses, but the time set aside is usually not long enough for any useful results to be obtained from them.

In the 1960's, however, the Science Research Council, several universities and a few companies all thought that there was room for the longer term post-graduate research project in industry. The University of Aston was one of the first universities to start up a scheme on these lines, with backing from the Science Research Council and industry, and the project described in this thesis was one of the first to be started on the scheme. The IHD scheme is now running more than 40 projects and a number of other universities have started up similar schemes.

The aim of the IHD scheme is, in a nutshell, the solution of industrial problems by applied research; to provide a means for solving those important and complex problems in industry, which are always just beneath the surface. By doing this the scheme aims to show that ivory tower and factory floor do have areas of common interest, to which a joint approach, that will be advantageous to all concerned, can be applied.

The project described by the report was started because the management at Austin-Morris had for some time had the idea of developing a method of reviewing major component stocking policy. But more important jobs were taking up all the time, resources and energy available. On the other hand the problem was not a copy-book stock control problem and it was thought that some advantage could be gained from setting up a research project within the IHD scheme to deal with it.

Any joint approach to a problem must involve compromises on both sides, and the research undertaken for this project is no exception. On the one hand the theory and statistics used are not analysed in such great depth as they might be, because the real life problem would not benefit from such deep analysis. On the other hand the analysis used and the methods suggested would not satisfy the manager who wants a quick answer to a problem and who is not too concerned about the longer term. In reading this thesis therefore, the basic reason for this project being undertaken and the aims of the IHD scheme must be kept in mind.

GLOSSARY

Term		Definition
Part		Any finished item used in building a car before it is put together with other parts in any form of sub-assembly or assembly process. E.g. A windscreen, a screw etc.
Component		As 'Part'.
Sub-assembly	(1)	A unit made up from several parts and/or sub-assemblies. E.g. Pedal sub-assembly made up from pedals, connecting bars, screws, nuts and washers.
	(2)	The process of building a sub-assembly.
Major Sub-assembly		The largest sub-assemblies to be built before the final assembly of a car. For the purposes of this thesis these have been defined as: (a) Body shell - Empty car body frame (b) Power unit[1] - Engine and Transmission sub-assemblies joined together. (c) Pair of front suspension units.[2] (d) Pair of rear suspension units.[2]

1. (Sometimes referred to as just 'Engine')
2. Suspension units are delivered in pairs. One pair controls the driving wheels whilst the other pair does not, hence the difference.

Term	Definition
Major Component	As 'Major Sub-assembly'.
Sub-assembly Plant	Factory where the sub-assembly of major components takes place.
Assembly	Final assembly - the process of assembling major components, sub-assemblies and parts into a finished car.
Main Assembly Plant	Factory where assembly takes place.
Trim	Any part or sub-assembly which goes into the empty body shell and turns it into a finished car interior. E.g. Seats, carpets, headlights.
Car Range	Any group of cars having a particular design and marketed under one name. E.g. Mini, Maxi.
Variant	Any combination of body style and power unit within a car range. E.g. 1100 2-door automatic, 1300 4-door manual and 1300 GT all come within the 1100/1300 car range.
Option	As 'Variant'
Volume Car Manufacture	Production of large numbers of relatively low cost cars.

Term	Definition
Vertical Integration	The establishment of direct control, usually through ownership, of all the processes of manufacture leading to a finished product.
Shift	A scheduled period of work or duty so arranged that if the need arises more than one such period can be worked within 24 hours by different groups of people.
Float	Another term for stock, but one which includes stocks in transit and work in progress.
Scheduling	Material scheduling - sending notice of material requirements to suppliers.
B.L.M.C. (Austin-Morris)	Abbreviation for British Leyland Motor Corporation (Austin-Morris & Manufacturing) Ltd. - the largest part of B.L.M.C. Also referred to as the Company in this thesis.
PSF	Abbreviation for Pressed Steel Fisher, the Company's body building division.
Sales Requirement Forecast (SRF)	The Company's short-term sales forecast for production mix, issued monthly.

Term	Definition
Production Programme	The Company's long-term production plan. Also referred to in this thesis as Programme or Programme Level.
449/204 or 500/230	In Part III of this thesis production programme figures are referred to daily, one day being a 24 hour period or 12 hour period depending on the number of shifts worked. In a standard working week there are 4 complete 24 hour periods (2 shifts) and one 12 hour period (one shift). So the production programme for a week is written as two figures, 449/204 etc, indicating that the week contains 4 daily production programmes for 449 vehicles each, and one daily programme for 204 vehicles.
Vehicle Build Programme (VBP)	The Company's short-term production plan determining production mix, issued monthly.
Built Up (BU)	Cars that are completely assembled in the U.K. and either sold in the home market or exported complete.

Term	Definition
Knocked Down (KD)	Cars that are assembled abroad, either by foreign subsidiaries or under licence, from sets of sub-assemblies produced in the UK.
CAB 1 and CAB 2	One of the Company's assembly plants has two Car Assembly Buildings in it. These are referred to as Car Assembly Buildings, or CAB 1 and 2.

TERMS OF REFERENCE

"To investigate, with a view to improvement, the interaction of the supply of major components with main production." *

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* For the purposes of this thesis major components are as defined in the Glossary.

PART I - BACKGROUND

CHAPTER 1 - MOTOR MANUFACTURE AT AUSTIN-MORRIS

1.1. Introduction - Car Manufacture.

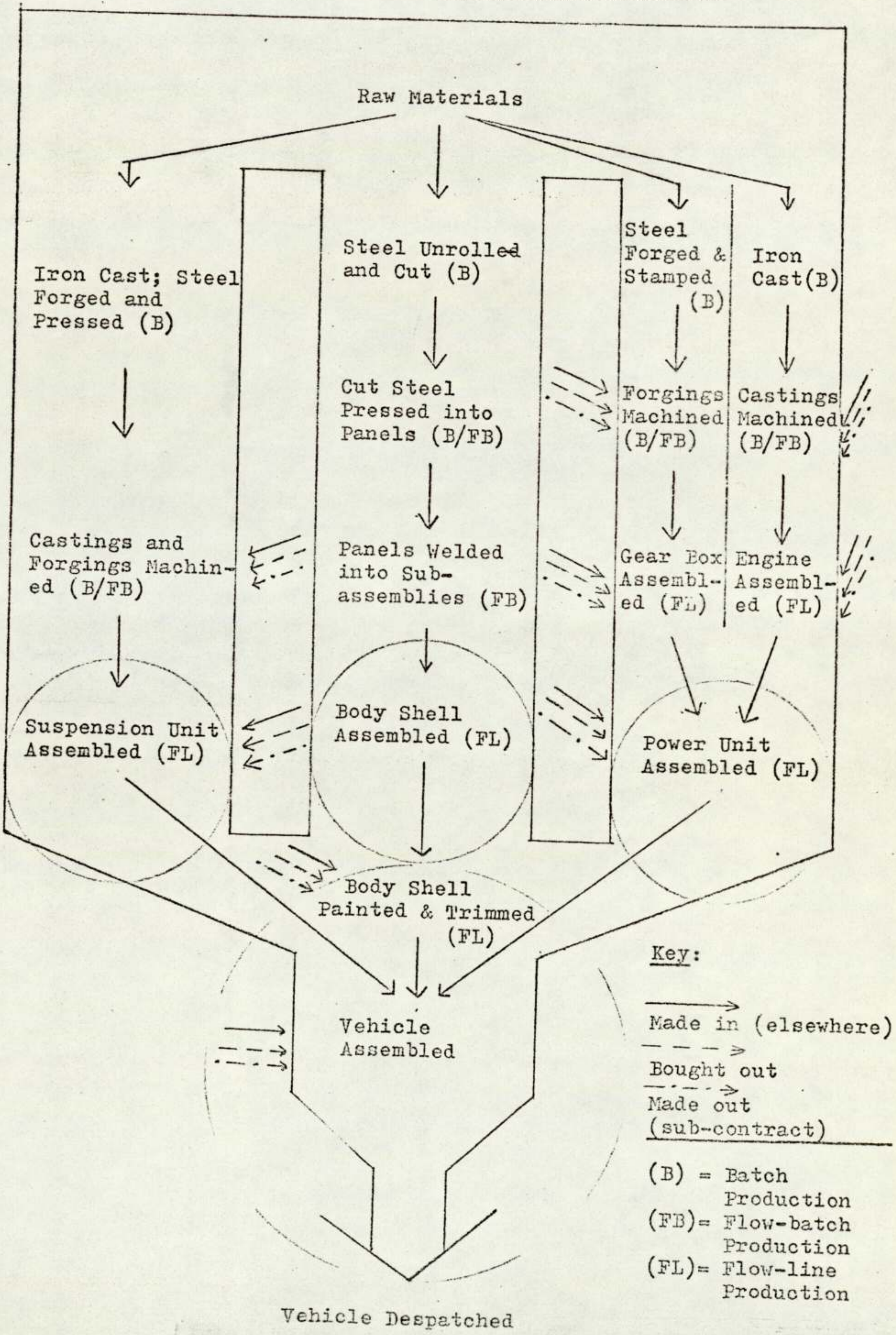
The manufacturing processes involved in building a motor car appear at first to be very complex. The average family car is built up from at least 5,000 individual parts. Yet the final assembly of a car involves the putting together of only a handful of major components, sub-assemblies and parts.

The discrepancy is explained by the additive process of car manufacture, which is illustrated on the flow chart in Figure 1.1.a on page 10. In general there are three distinct stages of manufacture. First there is the processing of raw materials, such as steel, iron and aluminium, into processed or finished parts. These processes do not involve the addition of any other parts and they are usually batch production operations, such as casting, forging, pressing and machining.

The second stage is the assembly of processed parts, bought in parts and any existing sub-assemblies into increasingly larger sub-assemblies as final assembly is approached. Each successive sub-assembly has its own part number and exists as a single unit in its own right for a time. The largest sub-assemblies to be built are the major components, which are surrounded by the continuous circles in the flow chart. Together they contain about one half of the total number of individual parts that go into a car.

Figure 1.1.a

PRODUCTION PROCESSES IN THE MANUFACTURE OF A MOTOR CAR



All that has to be done in the last stage of manufacture is the painting and trimming of the body shell and the final assembly operation.

The flow chart has been drawn up in terms of the major components defined for this thesis in order to stress the important part they play in the manufacture of a motor car. On the one hand they are extremely expensive items, accounting for about one half of the total labour and material costs of a car, as well as a large slice of the overhead costs. On the other hand each major component is essential to the production of any motor car. Stocks of major components therefore form the final, most expensive, and most vital inventory station in a series of stations.

1.2. Integration and Location of Sub-assembly and Main Assembly Plants in the Company.

The flow chart in Figure 1.1.a shows that a certain degree of vertical integration has been achieved in the motor industry, but the degree of this integration is not as complete as is sometimes imagined.

The broken line arrows on the chart indicate that many parts and sub-assemblies used to build a car are still either bought 'outside' the companies controlling car assembly, or processed and built up by independent sub-contractors. In fact the sector of the motor industry which is not owned by the car assembly companies employs more people than the sector which is owned by them. At the top end of the scale in this independent sector are companies which exercise monopolistic or oligopolistic control over supplies of such components as tyres, toughened glass and brakes. The dependency of the motor car assembly companies on the supplies of such components has been demonstrated several times over the past few years when industrial action has affected delivery.

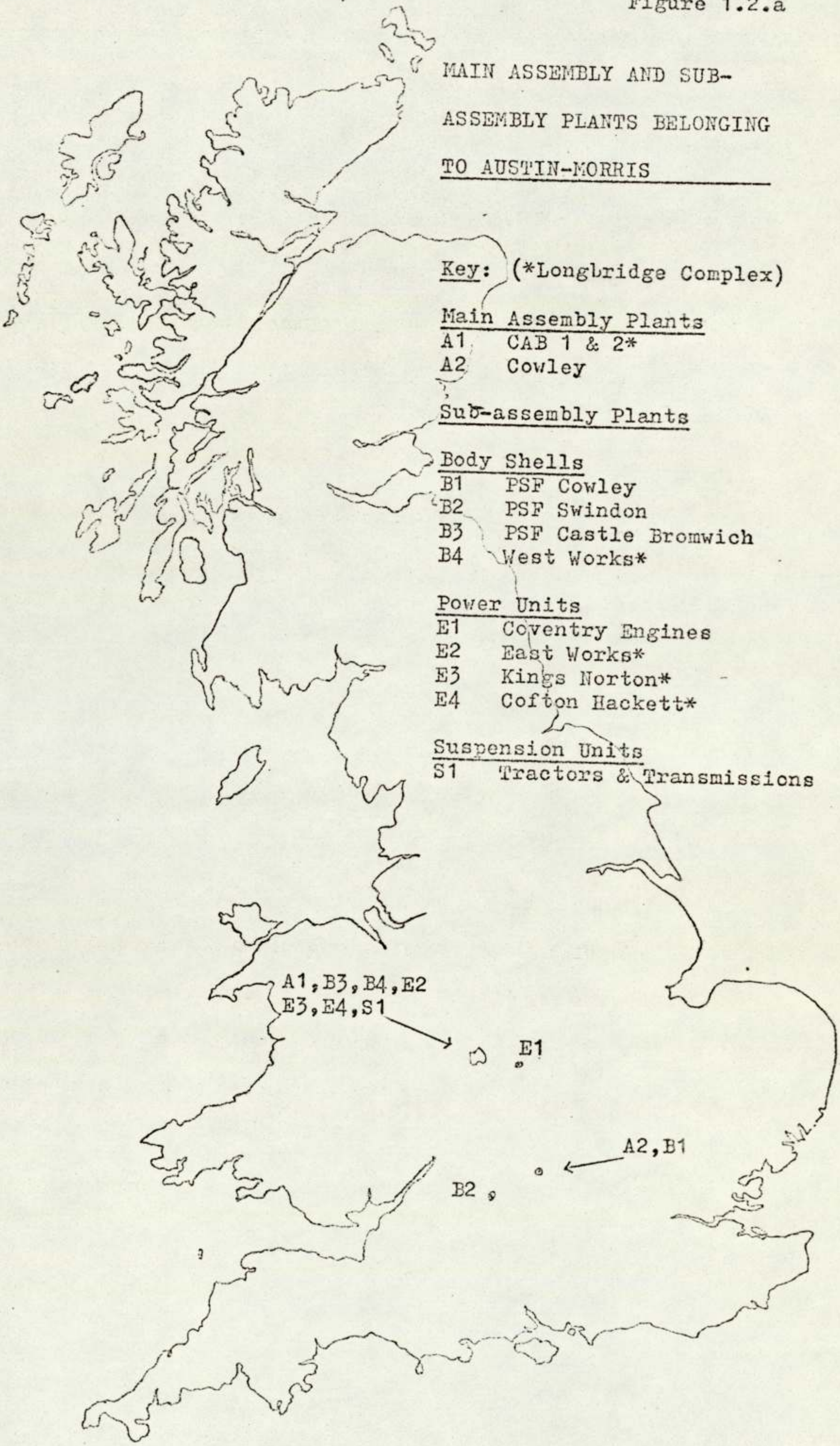
It would, however, be true to say that the closer the production process is to final assembly, the higher the degree of vertical integration there is. By the time major components are assembled and supplied to final assembly this integration is complete. Two consequences follow from this. Firstly the motor car assembly company has complete control over the supply of major components for final assembly. But, secondly, it is not possible to obtain a major component from anywhere else when stocks run out.

Vertical integration in the U.K. Motor industry has been the result of a logical progression of events rather than a planned process. Before the Second World War it was the exception rather than the rule and even some of the companies producing major components were independent from those assembling the cars. Since the war it has come about gradually through a series of takeovers and mergers. So gradually, in fact, that the Pressed Steel Company, now a part of Austin-Morris, was still an independent supplier of body shells less than ten years ago.

The gradual process of integration to some extent explains the dispersal of factories belonging to the motor car assembly companies throughout the country, although since the war, successive governments have also succeeded in getting the companies to build factories in development areas. It also explains the arrow labelled 'made in (elsewhere)' on the flow chart in Figure 1.1.a, which can now be seen to mean that a part or sub-assembly used in a particular process has been supplied from another factory within the same company.

Austin-Morris is one result of this gradual process of integration and consequently some of its sub-assembly plants are located at some distance from the main assembly plants, as illustrated on the map in Figure 1.2.a on page 14. Any attempt to closely integrate the production at factories in different locations is bound to create some problems, especially when flow-line operations are involved. Those sub-assembly plants in Austin-Morris which are not located in or near the main assembly plant complexes to which they send their products are connected to the assembly plant by road or rail transport. The flow of transport from sub-assembly plants to main assembly plants is therefore an integral part of the production system, which must be maintained almost continuously if the system is not to break down.

Figure 1.2.a



MAIN ASSEMBLY AND SUB-ASSEMBLY PLANTS BELONGING TO AUSTIN-MORRIS

Key: (*Longbridge Complex)

Main Assembly Plants

A1	CAB 1 & 2*
A2	Cowley

Sub-assembly Plants

Body Shells

B1	PSF Cowley
B2	PSF Swindon
B3	PSF Castle Bromwich
B4	West Works*

Power Units

E1	Coventry Engines
E2	East Works*
E3	Kings Norton*
E4	Cofton Hackett*

Suspension Units

S1	Tractors & Transmissions

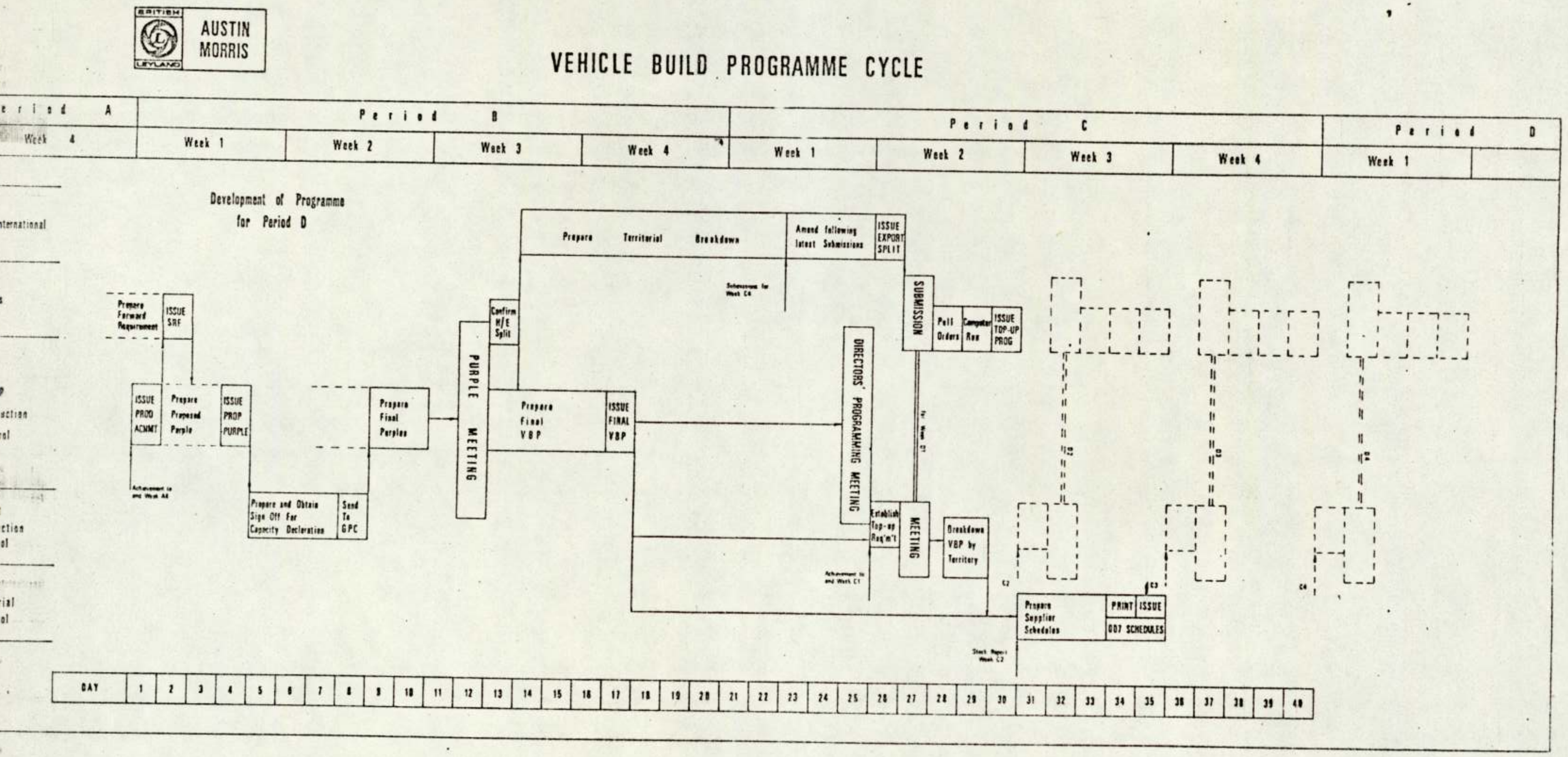
1.3 Planning Production in the Company

There are two levels of production planning in the Company, The first covers long-term planning. The cost of altering machines and flow-line tracks every time total production levels for a car range are changed can be very high. Not only are the machine and track alterations expensive to carry out, but the equipment involved must remain idle for days, or even weeks, at a time. The Company also covers the costs incurred by independent suppliers setting up their machines to satisfy a particular production level whether the parts are ordered or not. And finally total production levels are subject to union negotiations from which labour tries to obtain long production runs at a steady level in order to obtain regular wages. For all these reasons it is impracticable to let short-term demand for finished cars be the sole factor to influence total production levels for car ranges. Some compromise between sales and production must be reached. This compromise is a production programme which is based on long-term forecasts of sales and productivity. The duration of a production programme is never usually less than six months and once it has been set it will only be altered if a serious error in forecasts has been made. It effectively keeps production levels for each car range steady over a fairly long period of time and so allows the investment costs in production facilities to be recovered.

The second level of production planning in the Company is controlled by the Vehicle Build Programme. The VBP is a short-term plan which fixes the production of one month ahead firmly, and the production of two further months tentatively, in more precise detail within the constraints laid down by the production programme. Just as the total number of cars to be produced in each car range is determined by long-term planning, the mix of options within any range is controlled by the VBP from month to month. As such the second level of production planning is more closely related to sales forecasts and the Company's Sales Requirement Forecast always forms the basis for the VBP. Figure 1.3.a on page 17 illustrates the present procedure for determining the VBP and a specimen copy of the document which is issued as the result is contained in Appendix D1.

The integration of production at sub-assembly and main assembly plants is affected by both levels of planning. Both types of factory operate on a flow-line principle and therefore their track speeds and the distances between operations on the lines are fixed in accordance with the production programme. Manning up levels - the amount of labour and the number of skills necessary for any production level - are also controlled by long-term plans. But none of these factors are affected by what major component or car options within any range are produced and so production mix is governed by the VBP. In the short term, therefore, the production of major components and their usage at the assembly plants can only be controlled in content, and not in number.

Figure 1.3.a



A Couchman
Nov '71.

Figure 1.3.a

1.4 Major Component Stock Control in the Company.

One of the basic ingredients of standard stock control systems is the ability to order more supplies and, within a reasonable lead time, to receive all or most of those supplies. That ingredient is not, however, present in the production system connecting major components with final assembly.

Stocks of major components occur as a result of any variability between their supply from the sub-assembly plants and their usage at the assembly plants. In theory the integration between the two types of plants should be so close that any variability between supply and usage of major components is negligible and control of stocks is unnecessary. In practice, however, the system may not always work so perfectly. Men and machines are fallible, and transport, although an integral part of the production system, is not always under the Company's control. Moreover, in volume car assembly even small variability between supply and usage of major components can result in large surpluses of stock occuring or a large amount of production at the assembly plants being lost through shortages.

In the latter case there would be a need for some form of stock control. But major components cannot be scheduled and so safety stocks cannot be maintained. One form of control available is the fixing of ceiling levels up to which the stocks of any major component will be permitted to rise.

Company records, examined in the early stages of the research project, indicated that large surpluses of major component stocks do occur quite frequently, as do losses to production caused by shortages of major components. A list of weekly opening stock figures for the body shells of a particular car range that were recorded during the financial year 1968/69 appear in Appendix C1. During the same year 46,340 cars were lost from total Austin-Morris production because of shortages of major components.

Further investigation established that there are two ways in which the ceiling levels for major component stocks can be fixed in the Company. The first method is to tie the ceiling levels to the production programme currently in force by fixing them at the planned production levels for two or three shifts. This is, however, only a rough guide.

Ceiling levels can also be fixed by using a calculation contained in the 049 procedure for selective parts control in the Company. 049 is the standard scheduling and float control procedure used by the Company. It was primarily designed for use in scheduling materials and, as such, assumes some degree of control over levels of supply in the short term in order to maintain safety stocks. That control does not exist in the case of major components and enquiries established that 049 was not really designed for use with major components. But 049 does have a calculation to fix ceiling levels for stocks, which appears in Figure 1.4.a on page 21 and which can be used for major components.

The two elements of that calculation are Stores Buffer and Delivery Quantity. The Stores Buffer is itself the sum of the elements set out in the centre of Figure 1.4b on page 22 which turns out to be a negligible figure for major components because of the continuous nature of the way in which they are delivered, and can therefore be safely ignored. The Delivery Quantity for major components is the production programme for the time interval over which delivery is considered to take place. The ceiling level chosen will therefore depend on this time interval. If a small one is used ceiling levels will be low and if a large one is used they will be high. It is interesting to note that if the 049 calculation were applied over time intervals of one shift and two shifts, the ceiling levels would be one and a half shifts and three shifts of planned production respectively, which are almost the same as suggested by the rough guide described above.

1.5 Need for some Method of Review established.

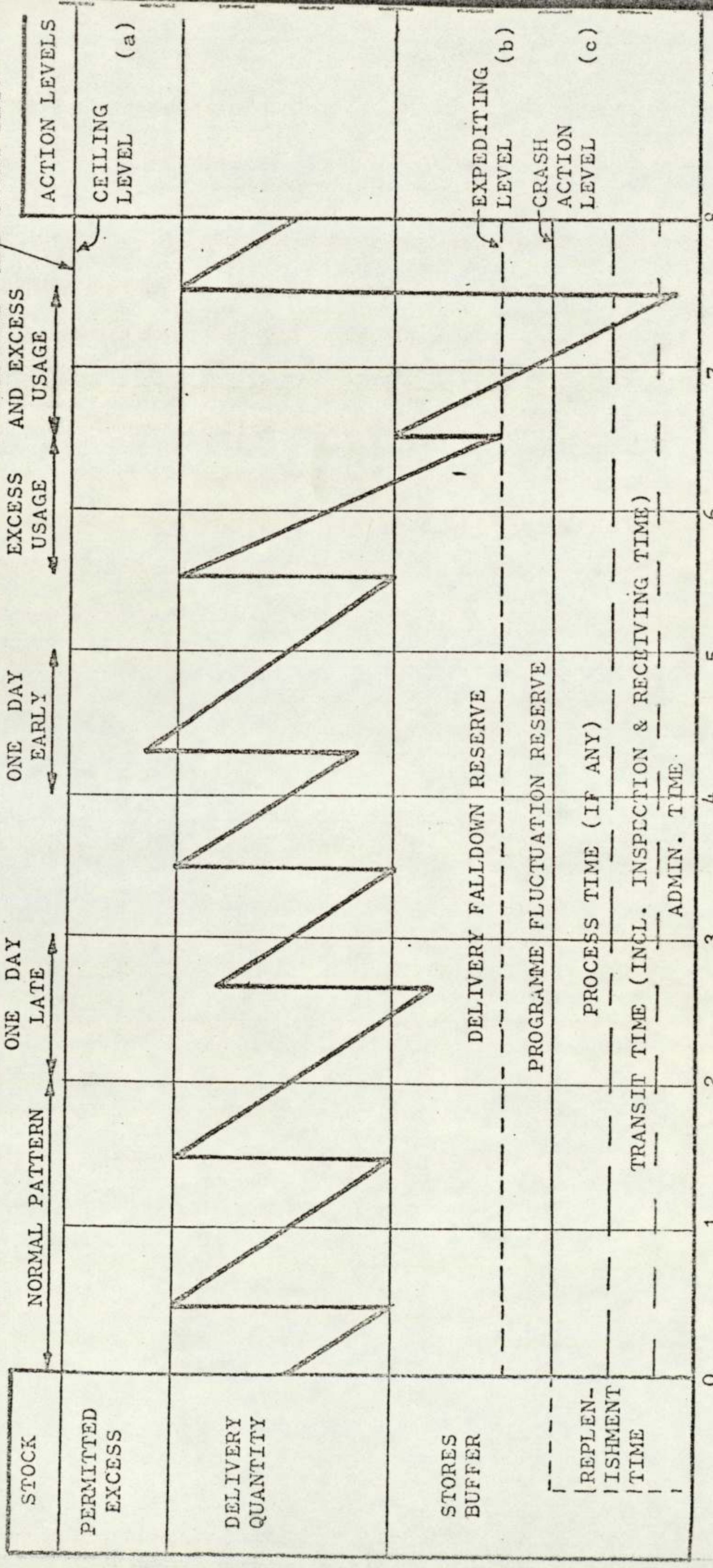
Both methods of fixing ceiling levels for major component stocks in the Company are arbitrary. They include no method of evaluating the effects of the chosen levels on the Company, neither do they have any means of comparing the chosen levels against other potential ceiling level policies. This does not mean to say that the ceiling levels chosen by those methods are not the best available. It just means that the Company has no means of knowing whether or not they are the best. In order to be sure of choosing

Figure 1.4.a

Appendix'A' illustrates the elements which make up Action Points :-

(a)	Ceiling Level		Stores Buffer
		plus	Delivery Quantity
		plus	Permitted Excess (up to 50% of delivery quantity subject to stores capacity)
(b)	Expediting Level		Stores Buffer Level
		minus	Delivery Falldown Reserve
(c)	Crash Action Level (Replenishment Time)		Admin. Time
		plus	Transit Time (inc. Receiving and Inspection)
		plus	Process Time

Figure 1.4.b


STOCK
PERMITTED EXCESS
DELIVERY QUANTITY
STORES BUFFER
REPLENISHMENT TIME
NORMAL PATTERN
DELIVERY ONE DAY LATE
DELIVERY ONE DAY EARLY
EXCESS USAGE
SHORT DELIVERY AND EXCESS USAGE
TO COMPENSATE EXCESS USAGE AND SHORT DLY.
ACTION LEVELS
CEILING LEVEL
(a)
EXPEDITING LEVEL
(b)
CRASH ACTION LEVEL
(c)
DELIVERY FALLDOWN RESERVE
PROGRAMME FLUCTUATION RESERVE
PROCESS TIME (IF ANY)
TRANSIT TIME (INCL. INSPECTION & RECEIVING TIME)
ADMIN. TIME
0
1
2
3
4
5
6
7
8
week numbers

the best ceiling level policy for major components, however that policy is calculated, it is necessary to use some scientific method of reviewing major component stocking policy. Such a method would fix ceiling levels in such a way as to minimise the combined cost of holding large stocks and losing production because of shortages. In other words the variability between the supply and usage of major components would be the determining factor in any scientific method of review. It was therefore decided to try and establish such a method of review.

CHAPTER 2 - CONTRIBUTION OF LITERATURE AND RESEARCH

2.1 The Review of Literature and Research.

A review of existing literature and contemporary research was undertaken once the problem area had been defined. The primary purpose of the review was to find an existing method of ceiling level control for major in-process stocks, which could be applied directly to major components in the motor industry. Failing this a secondary purpose was to find some existing work in the field of stock control that could be adapted for the development of a major component stocking model. Three approaches to the literature and research survey were taken.

2.1.1. References from the following bibliographies were followed up.

- (a) The APICS Bibliography[1].
- (b) 'Operations Research in Production and Inventory Control'[2].
- (c) 'Inventory Control Research: A Survey'[3].
- (d) The Austin-Morris Inventory Control Bibliography[4].*

2.1.2. Abstracts from specialised abstract publications in the fields of industrial scheduling[5] and inventory control[6] were read and potentially useful references were followed up.

2.1.3. A survey of contemporary research into in-process stock control, based on the latest available edition of 'Scientific Research in British Universities and Colleges, Volume III (The Social Sciences)'[7], was carried out. A copy of the circular letter sent out in connection with the survey appears in Figure 2.1.a on page 26 , and a schedule containing details of research that was followed up is contained in Figure 2.1.b on page 27 .

2.2 The Contribution of the Review.

The review yielded mixed results. Because of the nature of the stock control problem involved and its peculiarity to the motor industry no immediately applicable methods of reviewing major component stocking policy were found. The few useful references that were found, however, did provide a basis for the development of a major component stocking model.

2.2.1. The production system described in 'The Effects of Breakdowns and Interstage Storage on Production Line Capacity'[8] bears a close resemblance to the system linking major component sub-assembly with final assembly. The automated production line model described in the article has the following main features:

(a) It is defined as "...a network of automatic (machine controlled) production stages through which parts are successively fed." Attention is restricted to production lines of a simple linear flow with n stages.

Figure 2.1.a

**The University of Aston
in Birmingham
Department of
Industrial Administration**

Head of Department:
Professor I F Gibson

Postgraduate Room

Maple House, 158 Corporation Street,
Birmingham 4
Telephone 021-359 3611
Extension:

Dear

I am a research student at the University of Aston doing some work on production and inventory control for major components in the motor and heavy engineering industries. The research is concerned with major in-process stocks and supplies rather than finished products.

I understand from the latest edition of "Scientific Research in British Universities and Colleges" Volume 3, that you are carrying out research into some aspect of production and inventory control. If your research is in any way connected with in-process stocks (the industry or product is not important at this stage), or with computer applications for in-process stock control, I would be obliged if you could let me know a little about the work you are doing.

Should I discover that we have some common ground in the research we are doing I would be very pleased to start a correspondence with you and, should the need occur, come and see you.

Yours faithfully,

CONTEMPORARY RESEARCH PROJECTS FOLLOWED UP

NAME	UNIVERSITY ETC.	RESEARCH TOPIC
S.J. Morrison.	Hull	"Production scheduling and in-process stock control problems"
D.C. Spencer.	Leicester Coll. of Technology	"Development of ultra-stable production and stock control systems: examination of the role of stocks as a casual factor in generating economic instability."
K. Hilton.	Southampton	"Inventory model of U.K. by sector" (1966-1968). "Cross-section analysis of stocks in British manufacturing industry" (1966-1968).
Dr. G. Gregory.	Lancaster	"Layout problems of sales forecasting, production planning and stock control." (1968-1969).
M.J. Sargeaunt.	Loughborough	"Overall optimisation of complete industrial systems as against sub-optimisation of the individual parts, with particular reference to stock and production control." (1966-).
D.J. Jugwell.	Swansea (U.of W.)	"Systems for inventory control in instrument manufacturing company" (1966-1968 Marconi Ltd.).
G.A.B. Edwards.	UMIST	"Inventory control in engineering firms." (1967-).
R. Shanks.	Warwick	"Production planning in the motor industry." (1967-1970).

(b) " A production line is considered to be producing whenever the last stage is turning out finished pieces. Otherwise it is said that the line is "down"."

(c) Each stage in the line is subject to random stoppages resulting from mechanical breakdowns or adjustments, and a stage in this condition is considered to be "down". A working stage is referred to as being "up".

(d) " A third state is possible for a stage. That is, it is physically able to produce......but it either has no parts on which to work or it has no place to eject the part on which it has just completed work." Such a stage is said to be "forced down".

(e) " A storage facility between two successive stages is called the buffer capacity. Under the postulates of breakdowns, the number of parts found in a buffer at any time is a chance variable. A stage will build up the number of parts in a buffer whenever that stage is up and the succeeding stage is down or forced down. A stage will decrease the number of parts in a buffer whenever that stage is up and the preceeding stage is down or forced down. The buffers are not preloaded with parts at the beginning of a production run."

At first sight it may appear that the two production systems have so much in common that the method set out in the article for determining how much buffer storage capacity to provide for an automated production line could be directly applied for determining optimum ceiling levels for major component stocks. Closer inspection of the contents, however, indicate a number of important differences, which are listed below.

(a) Mr Freeman's interest is not restricted to storage policy alone. He is concerned with the major factors relating to the design of automated production lines, and in the article referred to he seeks to determine:

" 1. How many stages to employ in the line.
2. In which order to place the stages.
3. How much interstage storage capacity to provide.
4. How to allocate the storage capacity among the stages."

(b) The production line defined in the article is not strictly comparable to the production system under study in this thesis. The article refers to a production line separated into production stages by buffer storage facilities, each stage carrying out a distinct operation on a part. Such a production process is referred to as flow-batch in Figure 1.1.a on page 10 , and it is used mainly for machining operations in the motor industry. The system described in Chapter One can be defined as two continuous flow-lines connected by a major component storage facility. Furthermore, whereas Mr Freeman is only considering one n-stage line, the system under study contains three or four parallel sub-assembly lines feeding one final assembly line.

(c) Only fixed capacity buffer storage facilities are considered in the article, and once the line is built these capacities cannot be altered. Control of major component stocks, however, must involve some degree of flexibility in the ceiling levels used, in order to cater for varying conditions.

(d) Finally, the analysis used in the article is confined to the mechanical behaviour of production stages in the production line. Transport between stages is discounted and human factors are ignored. The assumptions used in this respect are critical to the solutions arrived at in the article, as the following paragraph illustrates:

" The last assumptions to be made about the production line concern the breakdown characteristics of the individual stages. In this investigation it is assumed that the mean up time between successive breakdowns of a stage, and the duration of a breakdown, are each independent random variables described by exponential distributions. ......The basis for choosing the exponential model is the empirical evidence that actual production facilities behave in that manner. Such evidence is cited in Koenigsberg* and Feller*."

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* References given in the article.

The differences between the two production systems bar the way to any direct application of the work in the article being reviewed to the problem under study in this thesis. If, however, the sub-assembly and main assembly processes of car manufacture are considered as two stages of one continuous flow-line, separated by buffer stock facilities, it is possible to adapt the method of simulating the behaviour of the production stages to determine optimum ceiling levels for major component stocks, as set out in the article.

2.2.2. A basis for developing a major component stocking model had been provided by the article discussed above. The arbitrary assumption about the distribution of production stage breakdowns, however, did mean that some other way of describing the behaviour of the production 'stages' concerned had to be found. Once again the literature provided no direct answer. But there appeared to be some connection between the system under study and a dam storage model.

The use of dam storage theory in stock control is not a new phenomenon as the following passage from 'The Theory of Storage'[9] illustrates:

"Dams and inventories having essentially different structures it is not at first sight obvious that a very close connection exists between the two types of situation. In the above simple model we have a dam of finite capacity K, input X_t, content after release

Z_{t+1} and amount released equal to min $(M, X_t + Z_t)$. Consider the deficit, $D_t = K - Z_t$, which is a random quantity and may be interpreted as the stock in a store. During successive intervals of time random demands, X_t, are made on the store. If $X_t \leq K - Z_t$ the demand can be completely satisfied and the final amount of stock is $K - X_t - Z_t$. If $X_t > K - Z_t$ the whole demand cannot be satisfied and the final content of the store is zero. This corresponds to an overflow. At the end of each interval of time, the store is again stocked with an amount M or $K - X_t - Z_t$, whichever is less (since the store is finite). This corresponds to the release rule in the dam. Unsatisfied demand remains unsatisfied and does not occur again in the next interval. The equations of this system are thus exactly the same as those of the dam, whether the quantity being stored is continuous or discrete."

Closer inspection of the above passage, however, demonstrates that it is an inverted dam storage model which is being used to describe a stock control situation. The input of water into the dam, X_t, is used to describe demand on the store, the release rule, or flow of water out of the dam, is used to describe the flow of stock into the store, and an overflow is used to describe a stockout.

The literature reviewed did not contain any case in which a dam storage model is applied to a stocking situation the 'right way up'. Yet the dam storage model referred to in this section is closely related, as it stands, to the production system linking major components to final assembly. In both cases the supply of a particular commodity flow into a storage space of finite capacity, from where it is taken to help produce another commodity. The long term nature of the supply of both water and major components can be estimated from distributions of rainfall in a given season and deliveries against a given production programme respectively. But the exact level of supply in any one time interval is largely a matter of chance for both.

One difference between the dam storage and major component stocking situations is that the flow of major components out of stock is also a chance variable in the short term, whereas the release rule for water in a dam can be fairly accurately forecast for a time interval. This difference is, however, only one of detail. The dam storage model provides an even better basis for a major component stocking model than the interstage storage model, described in 2.2.1, does. The production system being considered is still one of two 'stages' separated by a buffer storage facility, but the resulting stock is no longer being determined by the behaviour of the production stages themselves. It is now being determined by the flows of major components being supplied to, and used from, a stock reservoir. The model developed in Part II of the thesis is therefore essentially concerned with the interaction between the supply and usage flows of major components.

The dam storage model is by no means the complete solution. It can only have two dimensions whereas a major component stocking model must have at least four or five dimensions, one for the supply of each major component and one for usage. Moreover, once built, the dam has a fixed physical capacity, whereas ceiling levels for major component stocks need to be more flexible. The way in which the basic two dimensional supply/usage model is adapted to the major component stocking situation is described in Chapters 3 and 4.

2.3 The Longbridge Engine Storage Exercise.

During the project described in this thesis a small engine storage simulation exercise was carried out by the Operational Research Department of the Longbridge complex. That exercise was also based on a supply/usage model, but it is not directly applicable for the following reasons:

(a) The Longbridge exercise was a one-off study of the supply and usage of just power units. The interdependency of the supplies of all major components was not considered.

(b) The time interval in that simulation was one week.

In order to approximate to continuous supply and usage flows the interval needs to be much smaller.

The engine storage exercise is mentioned here because, although it is not directly comparable with the major component stocking model described in Part II, it does provide partial confirmation for the supply/usage model approach, since both projects were carried-out independently. The results obtained during the Longbridge exercise also confirm the trend of results obtained from the major component stocking model, as will be seen in Chapter 9.

PART II - DEVELOPMENT OF THE COMPUTER SIMULATION MODEL

CHAPTER 3 - A MAJOR COMPONENT STOCKING MODEL

3.1. The basic Model

It has already been established in 1.4 that the sole reason for any change in the stock level of a major component is the variability, or inter-action, between its supply and usage. A change in stock level can therefore be defined as the difference between supply and usage, and the basic major component stocking model can be expressed in terms of the following closing stock equation:

Figure A

$$CS_t = OS_t + REC_t - USE_t$$

Key: CS = Opening Stock; CS = Closing Stock; REC = Supply;
USE = Usage; t = A Time Interval.

The exact nature of supply and usage for any one time interval are not known. But the pattern of supply and usage for any particular programme level can be estimated. These estimates can be made from probability density functions set up from distributions describing the supply and usage of any major component. In the model, therefore, supply and usage will depend on estimates and the equation should be defined as:

Figure B

$$CS_t = OS_t + REC_t - USE_t$$

where $REC_t = Pr(REC)_t$

$USE_t = Pr(USE)_t$

Key: Pr(-) = An event estimated from the relevant density function.

Assuming for the moment that there are no constraints whatsoever on CS, then the model will be affected solely by the inter-action between Pr(REC) and Pr(USE). In this case supply and usage will be acting quite independently of each other in the short term described by t. As they are independent variables the results of their inter-action can be described by their joint distribution, giving estimated changes in stock level, set out below

Figure C

$$Pr(\Delta\ STOCK)_t = Pr(REC)_t - Pr(USE)_t$$

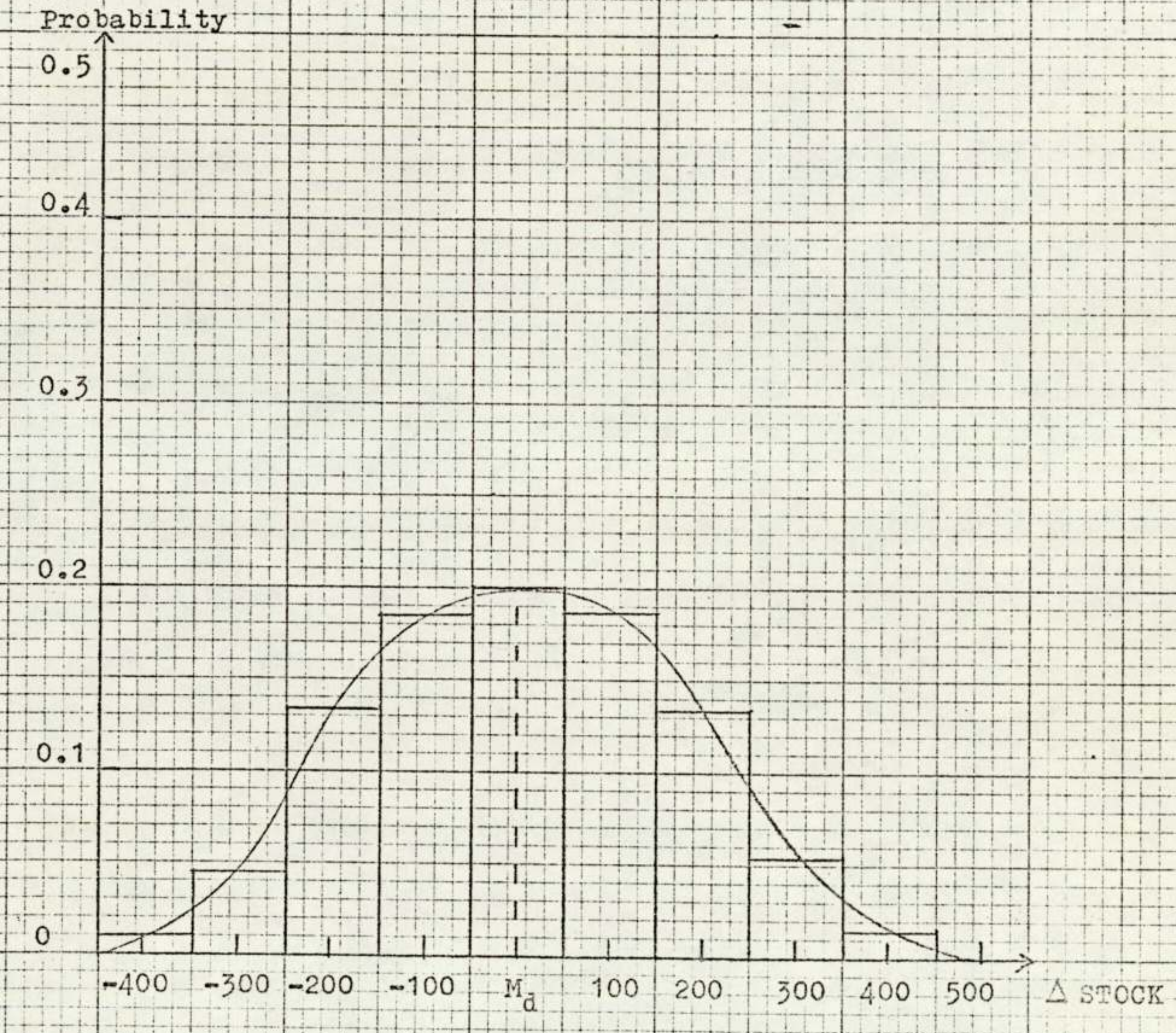
with $CS_t = OS_t + Pr(\Delta\ STOCK)_t$

Key: Δ STOCK = A change in stock level.

An example of a probability density function built up from the joint distribution Pr(ΔSTOCK) is shown in Figure 3.1.a on page 38. Both the continuous and discrete cases have been included in the example. Given such a density function and an opening stock figure it is possible to estimate the probabilities of various closing stock figures.

Figure 3.1.a

EXAMPLE OF A PROBABILITY DENSITY FUNCTION f(Δ STOCK)



3.2. Availability.

In the model developed so far CS has three possible states. It can be positive, zero or negative. But in any real stocking situation negative closing stocks cannot occur and a restriction must therefore be placed on the model to prevent their occurrence there. At the same time the real effect of a negative stock, a loss to production caused by shortage of the major component, must be recorded. This loss will amount to the absolute value of the negative stock generated by the model. Hence the following relationship can be defined:

Figure D

$$LOSS_t = |CS_t| \qquad \text{for } CS_t < 0$$

CS can only be negative if the estimated availability of the major component is less than its estimated usage, where estimated availability is the sum of the opening stock and estimated supply. The value of the negative closing stock will then be the difference between estimated usage and estimated availability, and the usage generated by the model will be restricted to the estimated availability resulting in a zero closing stock figure. Taking the availability restriction into account the model can be expressed as follows:

Figure E

$$CS_t = OS_t + REC_t - USE_t$$

where $REC_t = Pr(REC)_t$

$$USE_t = Pr(USE)_t \;;\; LOSS_t = 0 \quad \text{for } OS_t + Pr(REC)_t \geq Pr(USE)_t$$

$$\begin{cases} USE_t = OS_t + Pr(REC)_t & \text{for } OS_t + Pr(REC)_t < Pr(USE)_t \\ LOSS_t = Pr(USE)_t - (OS_t + Pr(REC)_t) & \end{cases}$$

3.3. Ceiling Levels

Another assumption underlying the model developed so far is that there is no restriction on the size of a positive CS. But in real situations there is a space constraint on the amount of stock that can be held in any one time interval. Moreover, in the major component stocking situation, as in dam storage, the restrictions on size for any positive CS constitute one method of controlling stocks. The dam storage problem is to optimise the physical size of a dam. This is a once and for all exercise because geographical and climatic conditions, controlling the supply of water are unlikely to change during the life-span of any dam and the growth of the use of electricity in any area can be fairly accurately forecast. The behaviour of the supply and usage of major components, however, will change at least each time the production programme is changed. It is therefore not practicable to invest in a physical storage space to cater for just one supply/usage condition. There must, of course, be a physical limit to any storage space, and the considerations involved in fixing such a limit are discussed in the concluding chapter of this thesis. The major component stocking problem is therefore to optimise ceiling levels, within any storage space limit, for given supply/usage conditions.

The effect of a ceiling level restriction in the real situation is to stop the supply of the major component in the following time interval, thus causing a disruption to production at the sub-assembly plant for the duration of a time interval, whenever it is reached. In the model this can be expressed as:

Figure F

$$CS_t = OS_t + REC_t - USE_t$$

where $REC_t = Pr(REC)_t$ for $OS_t < MAX$

$REC_t = 0;\ DIS = t$ for $OS_t \geq MAX$

(for USE see Figure E)

Key: MAX = Ceiling level; DIS = Disruptions to Production at the Sub-assembly Plant.

3.4. Explaining Losses to Production in Assembly, and Disruptions to Production in Sub-assembly.

The basis of the major component stocking model is the unconstrained inter-action between supply and usage, which is described by their joint distribution of likely changes in stock level. The effects of introducing the availability and ceiling level constraints into the model can therefore be explained by reference to the example in Figure 3.1.a.

There are two ways in which losses to production in assembly and disruptions to production at sub-assembly can occur. The first is when average levels of efficiency at the two types of factory are out of equilibrium. M_d is the mean likely change in stock. If M_d is significantly different from zero, there will be either a cumulative increase in stocks or a cumulative decrease in stocks, and the inter-action between supply and usage will be constantly subjected to a constraint. Consequently there will be either large losses to production in final assembly, or frequent disruptions to production at the sub-assembly plant. It is possible to find an optimum ceiling level restriction for this supply/usage condition. But to do so would be to solve for a second best situation and thus imply that such a situation had been accepted as normal. Depending on how large a value M_d is, it it also unlikely that any optimum solution would make much difference to the situation in this case.

When M_d is not significantly different from zero, the supply and usage of any major component are in balance. But the model is probabilistic, and the order of events is unknown. It is therefore possible for either a decrease in stocks to occur in a time interval with a low opening stock, or for an increase in stocks to occur in a time interval with a high opening stock. These combinations of circumstances would also result in the inter-action between supply and usage being subjected to the restrictions, causing either losses to production in final assembly or disruptions to production at sub-assembly to occur.

In the first case the mean likely change in stocks is the determining factor in the model. But in the second case it is the variance of the joint distribution that determines how many times the constraints need to be used. The flatter the distribution, for instance, the greater is the chance of any large change in stocks, and consequently the greater is the chance of any loss to production at final assembly or disruption to production at sub-assembly. In a balanced supply/usage situation, therefore, a useful optimum solution, in terms of ceiling level restriction, can be found, and it will always be related to the variance of the joint distribution. The higher the variability between supply and usage is, the larger the variance of their joint distribution will be and the higher the ceiling level needs to be set.

Two further considerations arise from the explanations given in this section. The first concerns the independence of the supply and usage variables. These variables are only independent when their inter-action is not subject to any restrictions. In the model the inter-action takes place <u>before</u> the restrictions are introduced, and the model itself then determines the effects of any restrictions. The supply/usage information used for the model must therefore be independent.

Recorded supply and usage information will have already been subject to the restrictions in the real situation, and therefore some of it will not be independent. If recorded information is used extreme care must be taken to eliminate any dependent data.

The second consideration concerns the time interval. In the basic model, with no restrictions on supply or usage, negative stocks and very large stocks have no effect whatsoever. Providing M_d is not significantly different from zero, cumulative increases in stock will off-set any cumulative decreases in stock almost exactly over a reasonable length of time, and the time interval chosen is not of much consequence. When the restrictions are introduced that is no longer the case. The moment the inter-action is subjected to a constraint its results are affected, and whatever the result of the inter-action in the following time interval is, it cannot off-set that effect. A loss to production at final assembly during one time interval, for instance, cannot be made good by an increase in stocks during the following time interval. The model is therefore very sensitive to the time interval used, which must be small to approximate to the real situation. If a time interval of, say, one week were to be used, any actual increase or decrease in stocks generated by the model may well conceal any losses to production at final assembly or disruptions to production at sub-assembly that might have occurred during that week.

3.5. Interdependency of the Supplies of all Major Components.

Including both the availability and ceiling level restrictions introduced, the model developed so far has been expressed as:

Figure G

$$OS_t = OS_t + REC_t - USE_t$$

$$\begin{array}{lll} \underline{\text{where}} & REC_t = Pr(REC)_t & \text{for } OS_t < MAX \\ & REC_t = 0;\ DIS = t & \text{for } OS_t \geq MAX \\ & USE_t = Pr(USE)_t\ ;\ LOSS_t = 0 & \text{for } OS_t + Pr(REC)_t \geq Pr(USE)_t \\ & \left\{\begin{array}{l} USE_t = OS_t + Pr(REC)_t \\ LOSS_t = Pr(USE)_t - (OS + Pr(REC)_t) \end{array}\right. & \text{for } OS_t + Pr(REC)_t < Pr(USE)_t \end{array}$$

As it stands the model is only two-dimensional, describing the inter-action between the supply of just one major component and its usage, whereas all four major components are needed to produce a car. The supplies of all major components are therefore inter-dependent, and, as such, can only be described by a five dimensional model, which must contain four supply variables and one usage variable. There will also be four ceiling level restrictions, and the purpose of the model will be to find not an optimum ceiling level, but an optimum combination of the four ceiling levels. There will still only be one availability restriction, which will be determined by the major component with the lowest availability in any time interval. The model should therefore be expressed as follows:

Figure H

$$CS_{t,j} = OS_{t,j} + REC_{t,j} - USE_t$$

where

$$\begin{array}{ll}
REC_{t,j} = Pr(REC)_{t,j} & \text{for } OS_{t,j} < MAX_j \\
REC_{t,j} = 0;\ DIS_j = t & \text{for } OS_{t,j} \geq MAX_j \\
USE_t = Pr(USE)_t\ ;\ LOSS_t = 0 & \text{for } MINAV_t \geq Pr(USE)_t \\
\left.\begin{array}{l} USE_t = MINAV_t \\ LOSS_t = Pr(USE)_t - MINAV_t \end{array}\right\} & \text{for } MINAV_t < Pr(USE)_t
\end{array}$$

Key MINAV = Minimum availability amongst major components - i.e. Minimum $(OS_{t,j} + Pr(REC)_{t,j})$; j = A Major Component.

3.6. The Production Programme.

It has already been pointed out that the model depends on the supply/usage condition for which an optimum ceiling level policy is being sought, and that this condition will change at least each time there is a programme change. Consequently if a review of major component stocking policy over a period to include more than one programme level is contemplated, the model will have to include one distribution for each of the five variables (four for supply and one for usage) at each programme level to be included. Strictly speaking, therefore, estimated supply and usage should be written as; $Pr(REC)_j / PROG_i$ and $Pr(USE)/PROG_i$ respectively, where $PROG_i$ is any one programme level. In order to avoid too much visual complexity, however, this has not been done, and references to production programmes are made just with the symbol PROG. The dependency of the supply and usage variables on programme levels is taken as understood from now on.

The production programme also affects losses to production at final assembly. A loss has so far been defined as $Pr(USE)_t - MINAV_t$, when $MINAV_t < Pr(USE)_t$. But losses are really calculated from the production programme, and it is possible for more production than planned to be achieved. It is therefore important to ensure that any potential usage (i.e. estimated usage) over and above programme level, that has not been taken up because of a shortage of major components, is not regarded as a loss.

On the other hand, when usage is below the programme level (i.e. estimated usage again) and a loss occurs, that loss is covered by the existing loss relationship in Figure H, because factors local to the assembly plant would have caused usage to be below programme level, even if there had been enough major components to satisfy the complete production programme. Taking the production programme into account the model should be expressed as follows:

Figure I

$$CS_{t,j} = OS_{t,j} + REC_{t,j} - USE_t$$

where

$$REC_{t,j} = Pr(REC)_{t,j} \qquad \text{for } OS_{t,j} < MAX_j$$

$$REC_{t,j} = 0; \quad DIS_j = t \qquad \text{for } CS_{t,j} \geq MAX\ j$$

$$\left.\begin{array}{ll} USE_t = Pr(USE)_t\ ;\ LOSS_t = 0 & \text{for } MINAV_t \geq Pr(USE)_t \\ USE_t = MINAV_t;\ LOSS_t = 0 & \text{for } MINAV_t < Pr(USE)_t \end{array}\right\} \begin{array}{l}\text{for } MINAV_t \\ \geq PROG_t\end{array}$$

$$\left.\begin{array}{l} \left.\begin{array}{l} USE_t = MINAV_t \\ LOSS_t = PROG_t - MINAV_t \end{array}\right\} \text{for } PROG_t < Pr(USE)_t \\ \left.\begin{array}{l} USE_t = MINAV_t \\ LOSS_t = Pr(USE)_t - MINAV_t \end{array}\right\} \begin{array}{l}\text{for } PROG_t \geq Pr(USE)_t \\ \geq MINAV_t\end{array} \end{array}\right\} \begin{array}{l}\text{for } MINAV_t \\ < PROG_t\end{array}$$

Key: CS = Closing Stock; OS = Opening Stock; REC = Supply; USE = Usage; t = Time Interval; j = A Major Component; Pr(-) = An Estimated Event; MAX = Ceiling Level; DIS = Disruption to Production at Sub-Assembly; LOSS = Loss to Production at Final Assembly; MINAV = Minimum Availability.

A flow chart of this model can be seen on Figure 3.6a. on page 50 .

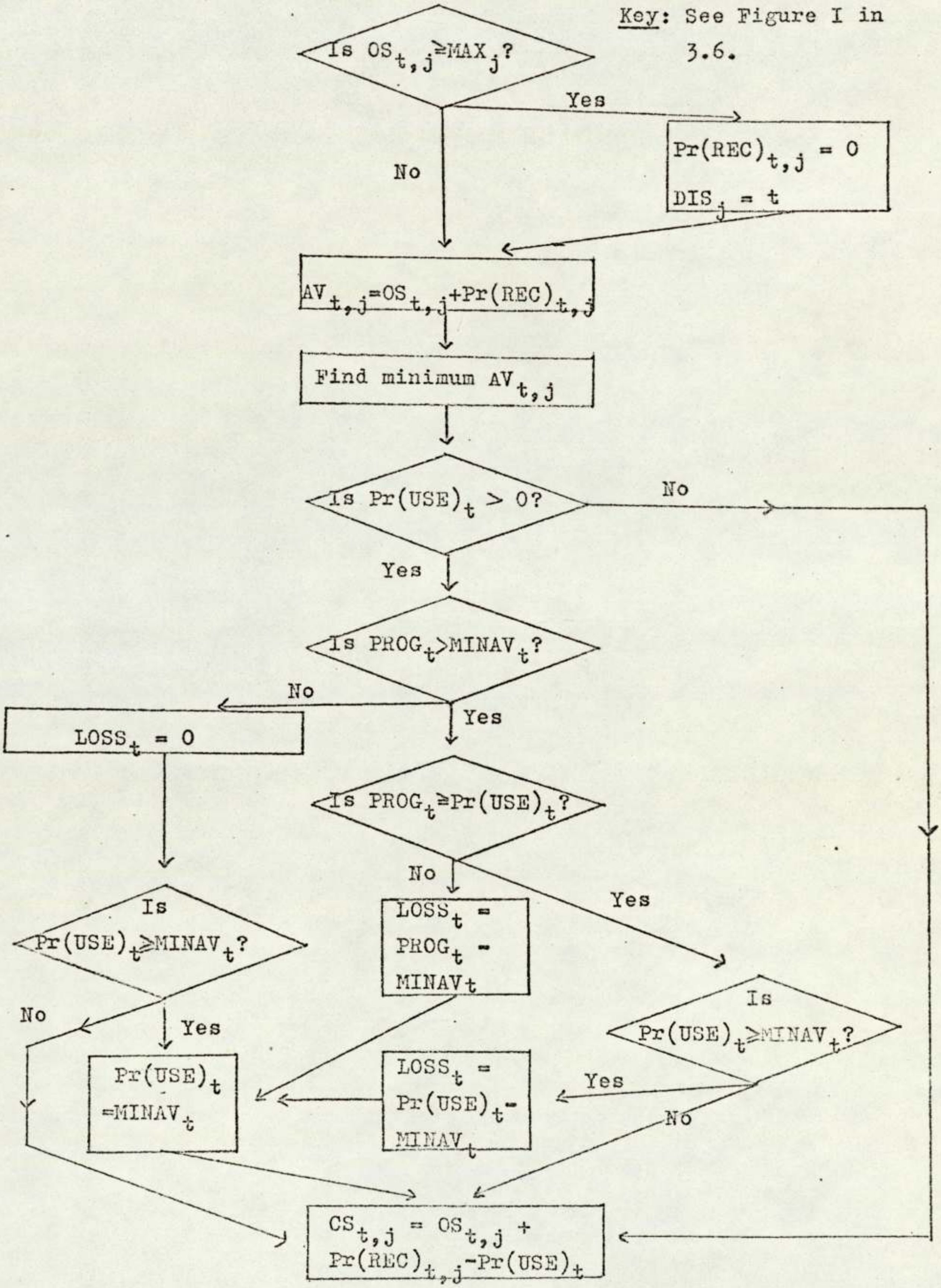
3.7 Accuracy of the Model.

The model set out in Figure I is the one which has been used for all the practical work carried out during this research project. It is, however, a simplified model. Greater accuracy could still be achieved. A more accurate and complex model is described in Chapter Four. But, for reasons that are given at the end of that chapter, it was not possible to put the more complex model to any practical use at this stage. The description of the more complex model has been included in this thesis so that it can be used immediately the practical difficulties involved are overcome, without any further work being necessary.

Figure 3.6.a

FLOW-CHART OF SIMPLIFIED MAJOR COMPONENT STOCKING MODEL

Key: See Figure I in 3.6.



N.B In Figures 3.6.a and 4.4.a actual supply and usage in the final equation are also defined by Pr(REC) and Pr (USE).

CHAPTER 4 - A MORE COMPLEX MODEL

4.1 Towards a more complex Model.

No Company policy concerning the production at main assembly and sub-assembly plants has been included in the model developed so far. Production stops when a constraint has been reached and only starts again in the following time interval providing that the constraints are no longer applicable. In other words the model assumes that there is no cost attached to spasmodic production.

This is, of course, unrealistic. There is a cost attached to any production process that is frequently disrupted, especially when production is supposed to be more or less continuous, as in the case of the production and usage of major components. The Company does have a policy to cover possible disruptions to production at assembly and sub-assembly plants. This policy has been introduced into the model, in the form of restrictions, in order to try to make the model more realistic. It will also make the model more complex.

4.2. Usage Restrictions.

The important relationship between sub-assembly and main assembly plants has resulted in a good communications system between them. Advance knowledge of certain events is therefore available to management. Given this knowledge, it is Company policy not to start production in any shift if there is a good chance that most of the shift will not be worked for one reason or another. This is because the moment any shift begins labour costs for the whole shift are incurred whether it is worked or not.

In the model it can be assumed that advance knowledge of estimated supply levels for all time intervals within any shift is available at the beginning of each shift. In order to ensure that most of any shift will be worked and that there will not be too many disruptions to final assembly because of shortages of major components, the minimum availability figure is compared against a fairly high percentage of the production programme for that shift. If the minimum availability for the shift is lower than the chosen percentage of programme the shift is not begun and lost production amounting to the whole shift programme is attributed to the shortage of the major component with the minimum availability. The part of the model relating to production loss can therefore be expressed as follows:

FIGURE J

$$USE_{t_1 \ldots t_n} = 0 \qquad \text{for } X < Y$$

$$LOSS_{t_1 \ldots t_n} = PROG_t$$

(and then as for FigureI)

Key: $X = MINAV_s$ - i.e. Minimum $(OS_{s,j} + Pr(REC)_{s,j})$; s = Shift

Y = Chosen Percentage of Production Programme; n = Number of time Intervals in a Shift.

4.3. Supply Restrictions.

If t is less than a shift disruptions to production can also occur in the middle of any shift at the sub-assembly plants and similar restrictions must be applied to the supply of major components.

The model again assumes prior knowledge of events that may lead to this situation, and if it is known that the ceiling level will be exceeded during the shift to come, production at the sub-assembly plant concerned will be stopped for that shift.

Whether or not the ceiling level will be exceeded in the next shift depends on the interaction between supply and usage. But usage itself may depend either on the estimated level of usage input into the model, or on a low availability of another major component. In the case of each major component, therefore, the chances of their respective ceiling levels being reached depend on the size of existing stock levels and on either a low usage being estimated or a low minimum availability being estimated.

The additional supply restrictions can therefore be written as:

Figure K

$$REC_{t_1 \ldots t_n, j} = 0; \quad DIS_j = s \qquad \text{for } OS_{s,j} \geq MAX_j$$

$$\underline{\text{and}} \quad (OS_{s,j} + REC_{s,j} - U) \geq MAX_j$$

Key: $U = Pr(USE)_s$ for $Pr(USE)_s \leq X$

$U = X$ for $Pr(USE)_s > X$

4.4. The more complex Model.

The more complex model is formed by applying the extended restrictions set out in Figures J and K to the closing stock equation:

$$CS_{t,j} = OS_{t,j} + \dot{REC}_{t,j} - USE_t$$

An illustration of this model appears on the flow-chart in Figure 4.4.a on page 56.

4.5. The Time Interval in the more complex Model.

It would be generally agreed that the additional restrictions introduced into the model in this chapter make for greater accuracy on two counts. Firstly the good communications and the production policy on which they are based do exist. And secondly time intervals of one shift or less must be used with the more complex model. It will therefore be more representative of the real situation.

Yet it was this restriction on time intervals that can be used in the more complex model that caused it to be abandoned for the feasibility study described in Part III of this thesis. A model is only as good as the information that can be fed into it. After the model had been built records of supply and usage were examined. It was found that it would be impracticable to collect the necessary supply and usage information over time intervals of one shift or less for the experimental work to be carried out during the research project for two reasons.

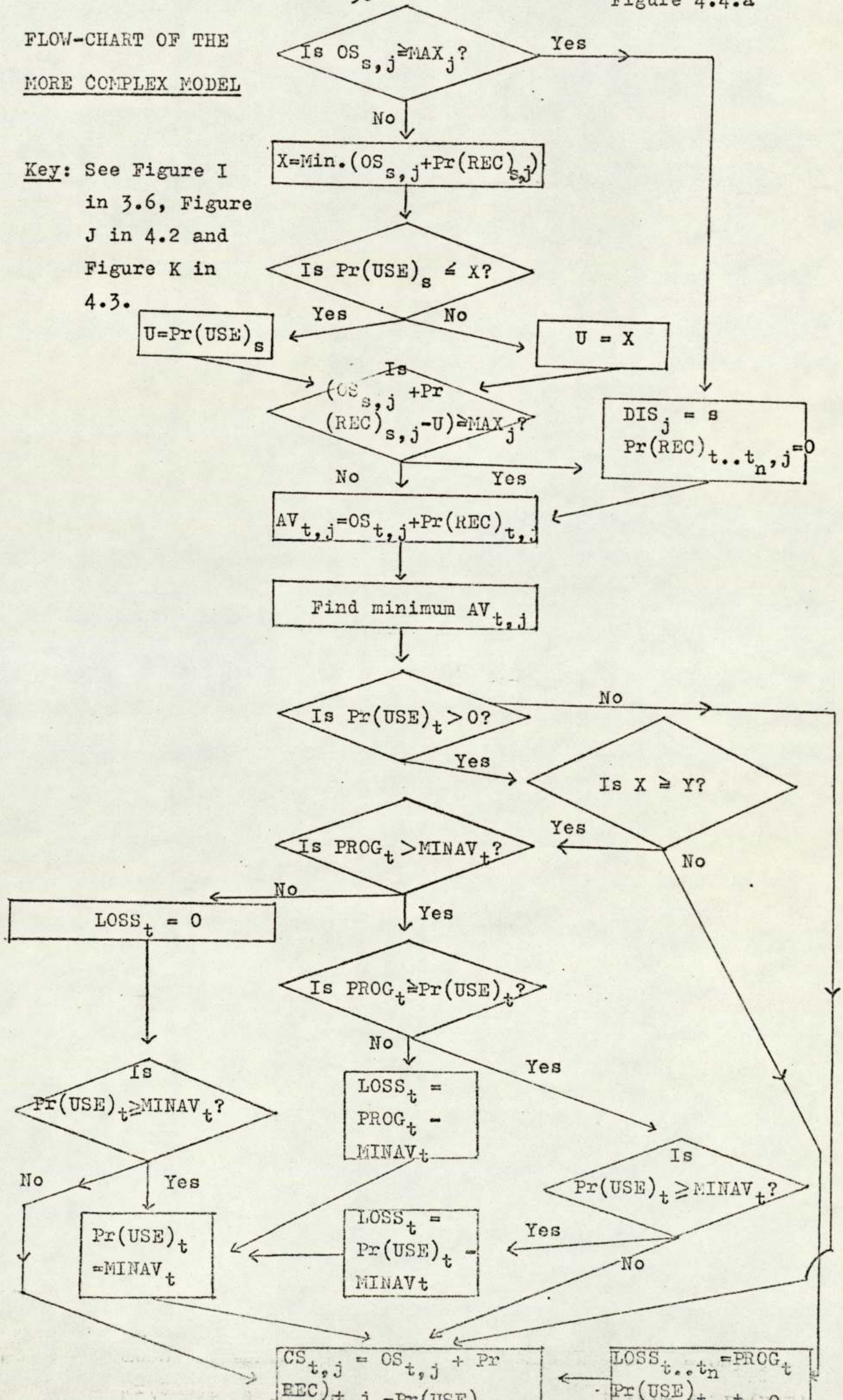
Firstly, although supply and usage information is available, over small time intervals from Company records of one sort or another, the necessary records are not easily accessible and they also contain a fairly large number of gaps. Secondly, any information collected for use in the model must also be investigated in order to eliminate any dependent data (see section 4 of Chapter Three). The work of investigating the information collected over small time intervals turned out to be too complicated and time-consuming to be successfully undertaken by one person in the time available.

It was therefore decided to collect daily supply and usage information for any experimental work. But that meant that the more complex model could not be used, and that all practical work would have to be done on the simplified model in Figure I. It should be stressed that the work done is none the less valid because the simpler model was used as the results obtained in validating the model, described in Chapter Seven, indicate.

Figure 4.4.a

FLOW-CHART OF THE MORE COMPLEX MODEL

<u>Key</u>: See Figure I in 3.6, Figure J in 4.2 and Figure K in 4.3.



CHAPTER 5 - THE COSTS

5.1. A Measure of Performance.

The development of a major component stocking model, and some refinements to it, have been described in the last two chapters. But in order to use the model for reviewing various ceiling level stocking policies it is necessary to introduce a measure of performance, by which the effects of different policies can be compared so that an optimum policy can be chosen. The cost involved in fixing a given ceiling level is used as that measure of performance, and the elements of that cost are introduced into the model in this chapter.

5.2. A Storage Policy.

The use of a ceiling level stocking policy for major components implies a storage policy, even if that policy were to leave stocks lying around in any available open spaces. The storage policy used will obviously affect the cost of maintaining any particular ceiling level in one way or another. If no storage facilities are to be provided there will be a high cost of maintenance and deterioration. If facilities are to be provided there will be an investment cost, but the maintenance and obsolescence costs will be much lower. It should therefore be the purpose of any major component stocking review to compare the optimum ceiling levels for different storage policies, in order to choose the storage policy with the minimum cost, as well as comparing different ceiling levels for just one storage policy.

Storage policy in the model has three elements. They are:

5.2.1 The investment cost. It can vary from nothing to thousands of pounds, but if there is to be an investment cost it will be discounted over a number of years and appear as an annual cost in the model.

5.2.2 Storage facility capacity. If investment in storage facilities does take place it must be remembered that each facility will have a different capacity for each type of major component. More space will be required for storing body shells, for instance, than storing suspension units. The investment cost attributable to each type of major component must therefore be related to the amount of the storage facility taken up by it.

5.2.3 Factory Floor Storage Space. In the assembly plants there is usually provision for buffering a limited amount of major component stocks, resulting from the variability between supply and usage, within the factory building itself. In CAB 2, for instance, there is a balcony capable of holding some 200 body shells. A small proportion of any major component stocks can therefore be accommodated in these existing storage facilities at no extra investment cost.

Any storage policy can thus be expressed as follows:

Figure L

$$\left\{ \left(\left(MAX_j - XY_j \right) / DIV_j \right) \times TC_j \right\}$$

Key: MAX = Ceiling Level; XY = Factory Floor Storage Space;
DIV = Storage Facility Capacity; TC = Investment Cost;
j = Any Major Component.

5.3. Cost of holding Stock.

The cost of holding stock is the opportunity cost of keeping capital tied up in stocks instead of investing the capital and getting a return, plus the cost of maintaining stocks. This cost is usually calculated by applying a holding rate of percentage to the cost of the materials being held in stock. As the cost of maintaining stocks (or failing to maintain them in terms of wear and tear) is included in the cost of holding, the cost of holding will usually be inversely proportional to the investment cost, as explained in 5.2. The cost of holding is expressed below.

Figure M

$$CH_j = CM_j \times R$$

Key: CH = Cost of Holding; CM = Cost of Labour and Materials;
R = Holding Rate.

5.4 Cost of Shortage.

The shortage of any major component results in a loss to production and a cost is incurred by the Company each time this happens. The overhead costs of every car are calculated on the basis of the production programme. If a car is not built that overhead must be absorbed by the Company. The cost of shortage is therefore the unabsorbed overhead cost.

5.5. The Total Cost.

The total cost for any major component stocking policy can thus be expressed as follows:

Figure N

$$\mathrm{TCOST} = \sum_{j=1}^{4} \left[\left\{ \left((\mathrm{MAX}_j - \mathrm{XY}_j)/\mathrm{DIV}_j \right) \times \mathrm{TC}_j \right\} + \mathrm{CH}_j \right] + \mathrm{COS} \qquad \text{for } \mathrm{XY}_j < \mathrm{MAX}_j$$

$$\mathrm{TCOST} = \sum_{j=1}^{4} \mathrm{CH}_j + \mathrm{COS} \qquad \text{for } \mathrm{XY}_j \geq \mathrm{MAX}_j$$

Key: TCOST = Total Cost; CCS = Cost of Shortage

5.6. The Total Cost Introduced into the Model.

The total cost is introduced into the model by multiplying the cost of holding stocks by an average stock figure generated by the model for any time period, and by multiplying the cost of shortage by a figure which is the sum of all the losses to production generated by the model for the same time period. These figures are derived from the model in Figure O.

Figure O

$$AS_j = \left(\sum_{t=1}^{n} CS_{t,j}\right)/n$$

$$TLOSS = \sum_{t=1}^{n} LOSS_t$$

Key: CS, LOSS, t and j are as defined in Figure I, Chapter Three; AS = Average Stock; TLOSS = Total Loss; n = number of Time Intervals in Period of Review.

The measure of performance of each ceiling level policy can therefore be expressed by the following equation:

Figure P

$$TCOST = \sum_{j=1}^{4}\left[\left\{\left((MAX_j - XY_j)/DIV_j\right) x TC_j\right\} + (AS_j \; x CH_j)\right] + COS \; x \; TLOSS \qquad \text{for } XY_j < MAX_j$$

$$TCOST = \sum_{j=1}^{4} (AS_j \; x \; CH_j) + (COS \; x \; TLOSS) \qquad \text{for } XY_j \geq MAX_j$$

and the purpose of any review would be to find the policy which minimises TCOST.

5.7. Disruptions to Production.

One effect of the inter-action between supply and usage of major components is that losses to assembly will occur if there is any variability, and so a cost has been attached to it. But another effect is that disruptions to production at sub-assembly plants will also occur whenever ceiling levels are reached.

It is extremely difficult to attach a cost to such disruptions, even when the information relating to them is correct, and the information generated by the simple model would not be an accurate reflection of disruptions likely to occur in the real situation. Since the simple model had to be used for all practical work in the research, it was decided to make no attempt to cost disruptions to production at sub-assembly plants generated by the model. Provision was made, however, for the number of disruptions that were generated to be recorded so that some idea of their extent could be gained.

CHAPTER 6 - SIMULATION

6.1. Getting Results.

It has been demonstrated in Chapter Five that various ceiling level policies can be evaluated by solving for TCOST (Figure P) in each case. A review of policies can then be carried out by simply comparing the costs, and the policy with the minimum cost can be deemed optimum. A method of reviewing major component stocking policy has therefore been developed. But the evaluation of TCOST depends, in turn, on finding realistic estimates of the average stock and the total loss for each ceiling level policy. As it is not possible to find these estimates by implementing various policies and waiting for the results, a model has been constructed to obtain them instead. It is therefore necessary to find some means of obtaining the results from the model that are necessary for the evaluation of the stocking policies.

There are two ways in which results can be obtained from models. The first is by using an analytical technique and the second is by simulation. Analytical techniques usually take the form of equation(s) or rule(s) of thumb that can be applied to the model. Simulation is a technique by which results are obtained from models by a process of imitation.

All models can be defined by relationships of one sort or another, and therefore it is always better to try and find solutions analytically. The only reason for resorting to a simulation is, according to F. Hannsman,[2] "......the complexity of the model which prevents one from writing down the desired measure of performance in closed "analytical" form."

The relationships in the major component stocking model all depend on Pr(△STOCK) - the joint distribution of supply and usage. If the parameters of that distribution can be calculated it will be possible to find the average stock and total loss from the model analytically. But the real major component stocking model is not the two-dimensional model portrayed in Figure 3.1.a on page 38, but a five-dimensional model. The calculation of the parameters of the joint distribution would therefore be quite complex, and it was decided to use simulation in order to obtain the results from the model.

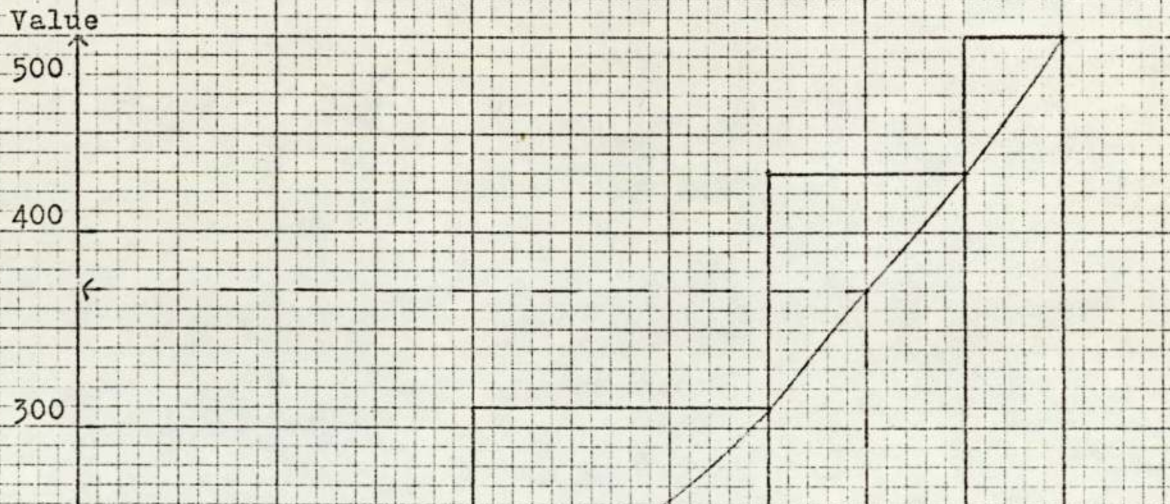
6.2. Generating Events.

Whereas analytical solutions are found directly from a model, simulation involves the imitation of what happens, or has happened, in any situation described by a model. This is done by generating events in some predetermined order or pattern. If the model is probabilistic events will be generated in a pattern determined by a probability or frequency distribution.

The method by which events are generated for a probabilistic model is described in this section. Any distributions to be used are turned into cumulative distributions as illustrated in the example in Figure 6.2.a. on page 65. The figure contains examples of cumulative distributions for both the continuous and the discrete case. Use of the continuous distribution implies that any value, between 0 and 500 in this case, has a chance of

Figure 6.2.a

EXAMPLE OF A CUMULATIVE DISTRIBUTION



occuring. If only specific values have a chance of occurring, such as 140, 200, 310, 430 and 500 in the example, the discrete distribution must be used. The supply of body shells and power units, for instance, approximate to a continuous distribution because there is a chance of almost any number of those major components being supplied in a given time interval within a specific range. Suspension units, however, are smaller and can be delivered in greater numbers. Supply of suspension units therefore tends to be confined to specific batches and is best described by a discrete distribution. In both cases the pattern of likely events in maintained by the shape of the distribution.

The generation of events or values depends on random occurrence. It is known that there is only a small chance of obtaining a value of less than 100 on the continuous distribution, but when a value less than 100 will occur is not known. Random occurrence is ensured by means of generating a pseudo-random number, which has an equal chance of turning up as any number between 0 and 1 in the example. Once a pseudo-random number has been generated the process of generating an event from the continuous distribution is simply one of reading off from the curve the value corresponding to the pseudo-random number on the probability axis. This is illustrated by the broken lines in the example. In the discrete distribution the random number will fall into one of the boxes formed by the histogram, and as each box, or range of probabilities, corresponds to just one discrete value, that value will be generated. If, for instance, a random number of between 0.21 and 0.4 were generated, the corresponding value of 200 would be generated from the distribution.

6.3 A Computer Simulation Model.

Simulation can be done by hand, with the help of random number tables and a calculating machine. The time, effort and cost of using a computer for simulation are such that it should be done by hand whenever possible. In the major component stocking model, however, there are at least five distributions from which events need to be generated (four for supply and one for usage) and there are also a large number of policies that need to be simulated because a policy is any combination of four ceiling levels, not just one set of ceiling levels. Use of a computer is therefore essential to the model. But this also means that the cost of using a computer must be borne in mind when considering how useful the simulation model is to the Company.

The size of this section in the thesis belies the time and effort spent on computer systems and programming. Although an understanding of computers and computing is not necessary for the reading and understanding of the thesis, because a computer is only the means of evaluating and comparing different major component stocking policies, any appreciation of the work involved must take the computing done into account. Instructions and advice on how to use the computer simulation model can be found in Appendix B, together with details of the computer programs used.

There are, in fact, two programs. The first builds up frequency distributions of supply and usage. The second is the simulation program proper, which generates the events, puts them through the model and evaluates and compares the costs of various ceiling level policies. If the behaviour of any supply variable or usage can be shown to be compatible with a known probability distribution it may not be necessary to build up a frequency distribution for it, in which case the first program does not have to be used.

All the programming has been done in FORTRAN IV. Courses in the specialist simulation languages of GPSS and CSL were attended, but so much of the programming was involved in building up frequency distributions and sorting, neither of which could be done by those languages, that it was decided not to use them at all.

The computer used was the ICL 1905 installation at Aston University. It is much smaller and slower than some of the Company's machines and therefore the costs and running times discussed in Chapter 9 may not be applicable. The Aston Computer, however, was much more adaptable to research work because of the software available, in terms of statistical packages and scientific sub-routines, and because of the faster turn-round of work.

PART III - THE FEASIBILITY STUDY

CHAPTER 7 - VALIDATION

7.1. Purpose of Feasibility Study.

The terms of reference for this research project require the inter-action between the supply of major components and main assembly to be investigated with a view to improvement. Those terms have partly been satisfied by the development of a computer simulation model for the purpose of reviewing major component stocking policy, which is based on the inter-action between supply and usage of major components, and which has been described in Part II of this thesis.

So far, however, all the work described has been theoretical. In order to carry out the terms of reference to their full extent it was necessary to undertake a feasibility study in order to:

1) Establish that the model being used is a reasonable approximation of the real situation - i.e. to validate the model.

2) Carry out experimental work to assess the computer simulation model as a means of periodically reviewing major component stocking policy, in terms of practicability and cost.

7.2. Scope of the Investigation.

In order to validate the model an investigation of the supply and usage of major components for a particular car range over a past period had to be undertaken, and the actual results from that period had to be compared with the results generated by the simulation model. Although practical considerations had caused the simple model to be used, with time intervals of one day, for all practical work, it was not thought that validation of the model would prove to be impossible.

The car range chosen had to be one of volume car manufacture, because only when production levels were high would the stocks resulting from the variability between supply and usage become large enough to merit serious consideration and review. The range chosen for the investigation was therefore the ADO 16 (1100/1300) car range, which represented approximately 36% of the Company's total planned production at the time. The period chosen was the latest complete financial year at the time, 1969/70, and the time interval to be used was one day.

The ADO 16 car range was, however, being assembled at both the Company's assembly plants (see map in Figure 1.2.a on page 14) during 1969/70. It was realised that the data collection involved in trying to carry out the investigation at both assembly plants could not be carried out in the time available, and the investigation was further restricted to a sub-set of the car range. The sub-set chosen was the standard four door ADO 16 saloon, which represented a still substantial 18% of the Company's total planned production at the time, and which was built at the Longbridge assembly plant during 1969/70.

The scope of the investigation to be undertaken can therefore be summed up as follows: to investigate in detail the supply and usage of major components for the standard four door ADO 16 saloon during the financial year 1969/70, and to apply the information collected to the simulation model described in this thesis in order to validate it and then experiment with it.

7.3. The Production System Investigated.

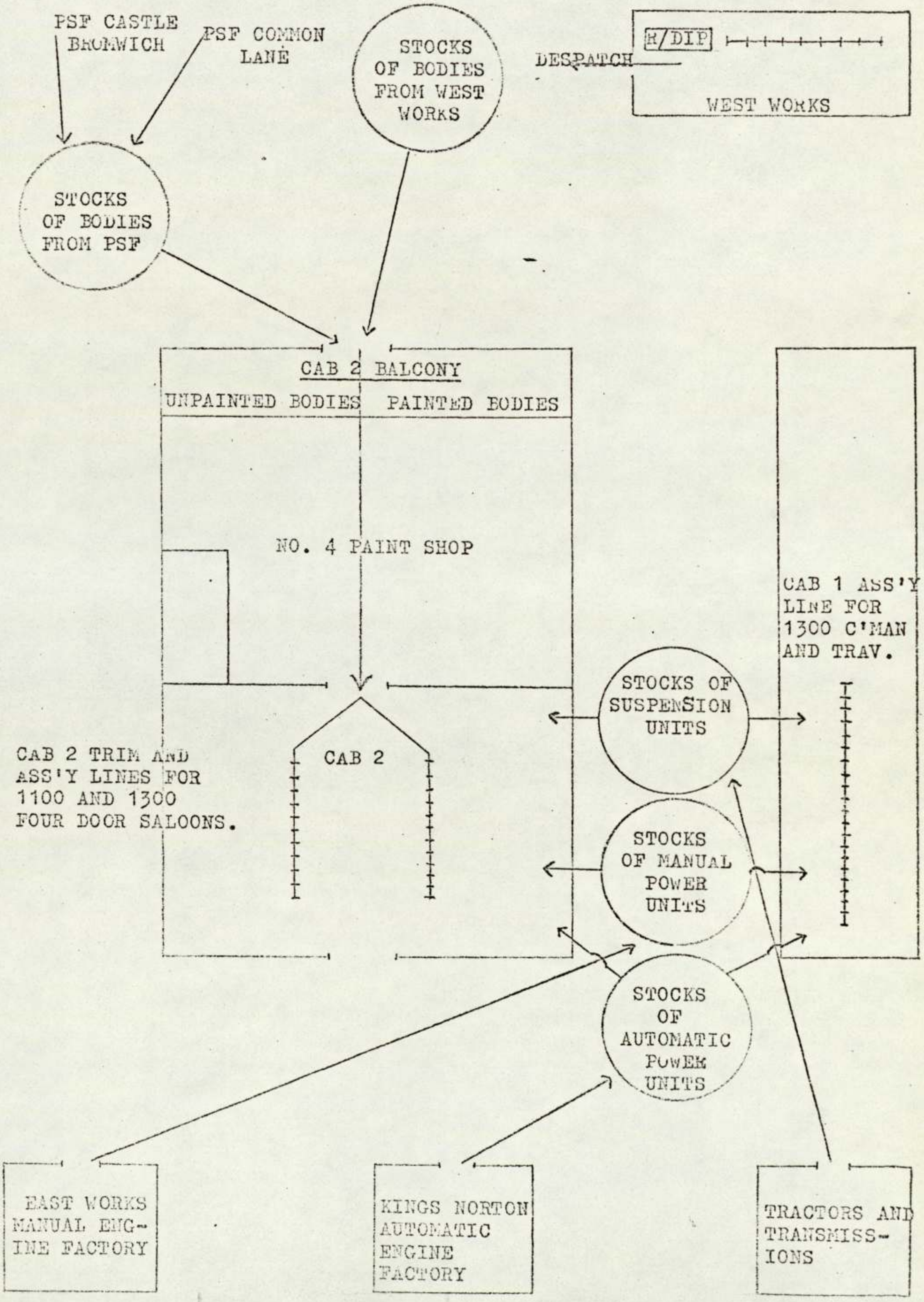
Figure 7.3.a on page 72 illustrates details of the supply and usage of major components in the system investigated. Body shells were received from three sources; West Works (within the Longbridge assembly plant complex) and the two Pressed Steel Fisher factories indicated. Stocks of body shells received from the PSF factories were kept separate from those received from West Works, when possible, for accounting purposes. Supplies of power units were received from either of two factories, both within the assembly plant complex, depending on whether they were manual or automatic units. Supplies of all suspension units came from one factory outside the assembly plant complex. All the factories concerned are, in fact, in the Birmingham area.

7.4. Data Collected.

Information relating to the supply and usage of major components and production programmes was required in order to validate the model. But in the case of supply and usage information it was not only necessary to collect the correct

Figure 7.3.a

THE PRODUTION SYSTEM INVESTIGATED



information for the time interval chosen, but it was also essential to have the necessary background knowledge to be able to eliminate dependent data in the five distributions. It will be recalled that it was the difficulty of obtaining this background knowledge, coupled with the difficulty of obtaining necessary records, for small time intervals of one shift or less that caused the complex model to be abandoned.

7.4.1. Supply information was collected from daily advice note records, if the supplying plant was outside the Longbridge assembly plant complex, or from daily internal factory records if it was inside the complex. Data actually used for the model, after elimination of any dependent data had taken place, is contained in the computer printouts in Appendix B1. Specimens of the documents used in collecting the supply information appear in Appendix D2. As has been mentioned in Chapter 6.2, the supply of body shells and power units was considered to be continuous, whilst the supply of suspension units was taken to be discrete.

One additional factor had to be taken into account, in the case of power unit and suspension unit supplies. Another sub-set of the ADO16 car range was being built at Longbridge during the year 1969/70, in the other Car Assembly Building, as indicated in Figure 7.3.a. Although the production involved was only low volume, averaging about 60 per day as opposed to the 500 odd per day of the four door saloon, the same power units and suspension units were used for both types of car. This problem was overcome by subtracting the average daily production of the ADO16 Countryman from daily supplies of power units and suspension units.

7.4.2. Usage information was collected from a daily production report, which gave figures for production achieved and for production falldown. It also gave reasons for production falldown, although these often had to be further investigated. Usage information actually input into the model, after the elimination of dependent data, also appears in the printouts in Appendix B1. A specimen copy of the daily production report can be found in Appendix D3.

7.4.3. Daily opening and closing stock information was collected, but there were too many gaps in the records to prove useful.

7.4.4. During the year investigated there was a change in production programme. Moreover, as the time interval being used was one day, each full week consisted of four days with two shifts and one day with one shift. Consequently it was necessary to use four distributions for the supply of each major component and for usage.

The daily production programmes involved were 449/204 (for two shifts and one shift respectively) during the first 43 production days of the year, and 500/230 for the remaining 196 days (see Glossary.) Some daily programmes did differ from those set out above. But not sufficiently for separate account of them to be taken (e.g. 447 instead of 449 and 209 instead of 204).

7.4.5. The ceiling levels used for the major components under investigation were estimated from the stocking information that had been collected. There had been a strike at the assembly plant during the year and stocks of body shells, pairs of front suspension units and pairs of rear suspension units had risen to 1200, 1400 and 1200 respectively before supplies had been stopped. During the same year there was a large surplus of power units of all types in the Company and these stocks were stored in rented storage space. It was therefore difficult to establish a realistic estimate for a ceiling level, and a figure of 2000 was used.

7.5. Validation Results.

In theory any attempt to validate the model should have taken average stocks, losses to production at final assembly and disruptions to production at sub-assembly into account. But it had been established that only the more complex model could generate accurate results about disruptions to production at sub-assembly. And insufficient stock data had been collected for comparison of average stocks generated with those actually recorded. That left only losses to production as a means of validating the model.

Although the pattern of losses to production generated by the simple model using one day as the time interval would obviously not be as accurate as the pattern generated by the complex model, there was no reason to suppose that the total losses generated by the model for the year should not be a good approximation of the actual losses to production caused by shortages during the year. It was therefore decided that the model could be declared valid if the total loss generated by the model was a reasonable approximation of the actual loss. This meant that the mean total loss calculated from a number of simulation runs would have to have a good confidence of being close to the actual total loss incurred.

The actual figure for total loss caused by shortages of major components in the year was 7860, all of which had been caused by shortages of body shells. But a strike during the year which affected the body shell supplying plants was responsible for 4000 of that loss. The total loss for purposes of comparison was therefore considered to be 3860, all caused by shortages of body shells.

The mean total loss generated by the model was 4083, 3892 of which were caused by shortages of body shells. A good confidence for these average figures being not more than 3½ or 4% out was also obtained. It was therefore considered that the model was sufficiently valid for use in further experimental work, although it is strongly recommended that further validation of the model, using better recorded data, is undertaken before it is put to regular use.

CHAPTER 8 - EXPERIMENTAL WORK

8.1 Purpose.

Once the model had been validated experimental work had to be carried out to assess the viability of the computer simulation model as a method of reviewing major component stocking policy. It was decided that the best way of doing this would be to actually use the model to review and compare various ceiling level combinations under a supply/usage condition specified by management. The finding of an optimum solution, although required if possible, was not considered to be of as much importance as the general trends that could be determined by the results.

8.2. Assumptions.

Using a time interval of one day meant that ceiling levels could be exceeded by amounts almost as large as one day's planned production under exceptional circumstances (i.e. if $OS_{t,j} = 950$, $MAX_j = 1000$, $Pr(REC)_{t,j} = 450$, $USE_t = 0$ and $PROG_t = 500$). Investment costs for storage facilities in the model are calculated on the ceiling level imposed less any factory floor storage capacity. If the ceiling level is exceeded, the cost of holding stock will increase, but the investment cost will not. In the more complex model this cannot happen. Therefore, rather than trying to adapt the total cost equation for exceptional circumstances, which could be avoided by using a more realistic model, it was decided to assume that the excess stock could be accommodated at no extra investment cost.

The main assumption that has to be made before costs can be input into the model is that of storage policy. The traditional method of storing major components is on trailers, which are specially built for the transport and storage of specific major components. In order to make the experimental work as realistic as possible this same method of storage was chosen. Another consideration was that trailer costs and capacities were readily available.

Normally a total storage space restriction would be available and ceiling levels above a certain figure could not be considered. Some points to be considered in choosing this total space restriction are discussed in the concluding chapter of this thesis. But for the experimental work an attempt was made to establish the current space restriction in terms of total numbers. The restriction would, of course, depend on the storage facility used, which were trailers in this case.

Up till now it has been tacitly assumed that all storage of major components takes place at the assembly plant. But that is not the case, and stocks of major components are held at the sub-assembly plants too. The choice of a total space restriction did not really warrant a number of detailed calculations at each sub-assembly plant concerned, and therefore a total restriction of 2000 for each major component was assumed. This high figure, involving at least 400 trailers, was chosen so that a reasonable range of ceiling levels could be reviewed without the results being too unrealistic.

8.3 Supply and Usage.

A great deal of time had been spent in collecting and investigating the supply and usage information used for validating the model. It was therefore agreed that the same data should be used for the experimental work. But, the long strike involving body shell plants apart, body shell supply had still been considerably out of balance with the other supply variables and usage, as was demonstrated during validation of the model. Management therefore specified that the supply/usage conditions for the experimental work should be the same as existed during the financial year 1969/70, save that certain body shell data should be removed in order to establish a balanced situation. The data removed for the experimental work is marked with an asterisk on the printouts in Appendix B1.

8.4 Cost and Capacity Information.

Having defined the nature of the experimental work in detail, cost and capacity information was collected as follows:

<u>8.4.1.</u> The cost of labour and material for each major component was obtained from the Longbridge cost office and is set out under item one of Appendix C2. The Company surprisingly did not appear to have a holding rate, and therefore a conservative figure of 25% was chosen.

<u>8.4.2.</u> Trailer capacities and costs are set out under items two and three of Appendix C2. Their source was the factory planning department at Longbridge. A series of new trailers was being purchased by the Company at the time and two sets of capacities and costs are given for power units and suspension units. The first set in each case was used for the model.

<u>8.4.3.</u> The factory floor storage space for body shells in CAB 2 was known because there is a balcony in the building specifically designed for holding body shells and it has a capacity of 200. The space for the other major components was estimated at 200, 360 and 360 respectively for power units, front suspension units and rear suspension units.

<u>8.4.4.</u> The cost of shortage has been defined as the unabsorbed overhead incurred each time a programmed car was not built because of the shortage of a major component. The Longbridge Operational Research Department had used

a figure of £200 to cover this cost in a project on engine storage. But the lower "economic profit" figure of £150, suggested by the Group Production Control department, was chosen in order to keep costs conservative.

8.5 Opening Stocks.

The starting point for all simulation runs in the experimental work was to be the same as the actual opening stock figures for 1969/70 used in validating the model.

8.6 Period of Review.

Any implementation of a major component stocking policy would probably involve some storage policy decision and some investment cost. It is therefore unrealistic to assume that any review of major component stocking policy could be operated at short intervals, even if it is anticipated that supply and usage alter their behaviour significantly in the short term. Considerations in choosing the period of review are discussed in Chapter Ten. In the experimental work, however, management wanted the period of review to correspond to a given programme level. As there was one change in production programme during the year from which the data base for the model had been taken, two periods of review were involved.

CHAPTER 9 - THE RESULTS

9.1 Variation in Results.

The viability of using the computer simulation model for reviewing major component stocking policy depends on the number of samples, or simulation runs, that have to be taken for each ceiling level policy in order to ensure reasonable accuracy for the results obtained. The number of samples that have to be taken depend, in turn, on the variance of the results generated by the model.

The validation runs of the simulation model had already shown that the results for any one major component stocking policy took some time to settle down, and even then varied by between 10% and 12% about the mean. The slight modification made to the data base for the experimental work, described in section 3 of Chapter Eight, was not expected to affect this variation a great deal. But the validation runs were carried out over a period of one year involving a change in production programme, and hence using four different distributions for each supply variable and usage. A separate review for each programme level was to be carried out during the experimental work, and therefore only two distributions would be used for each variable. Consequently further tests were carried out to establish the variation in results to be expected. One test was carried out for each programme level.

Five simulation runs of one ceiling level policy were carried out for periods of between one and five years length, and variation as a percentage of mean total cost was a follows:

TABLE 1

Programme Level: 500/230		449/204	
Year Length	s	Year Length	s
1	50.79	1	58.31
2	35.67	2	36.02
3	26.19	3	18.63
4	8.69	4	13.16
5	12.48	5	7.03

s = estimated standard deviation.

An extra run of six years length was carried out for the 449/204 level to discover whether any further decrease in variation could be expected, but the variation recorded was 9.33%. It was therefore concluded that the results would settle down after about four years at the 500/230 level, and after about five years at the 449/204 level. The actual variation in both cases was expected to be in the region of 10%, but more precise calculations were to be carried out later.

The long time taken for the results to settle down, and the large variation in results even then, were thus confirmed. Applying an estimated standard deviation of 10% to the sampling formula $C \times s/\sqrt{n} = A$ (where C = statistical confidence required in terms of numbers of standard deviations;[1] s = estimated standard deviation; n = sample size; A = a degree of accuracy), it turned out that at least 16 to 25 simulation runs would be needed for each policy in order to achieve a .975 confidence[2] that the mean total cost generated would be within 4% to 5% of the true mean.

[1] This is based on the Normal Distribution, but in order to obtain greater accuracy with small samples C should be chosen from the Student's 't' Distribution.

[2] Confidence limits are usually referred to as .95 and .99. But these only apply to two-tail tests, in which variation both above and below the mean is taken into account. The purpose of the simulation model is to find the ceiling level policy with the minimum total cost. An error will only occur if the total cost of the optimum policy found by the model is underestimated. Therefore it is only necessary to use a one-tail test.

It followed that every policy to be reviewed would have to be run for four or five years at least 16 times. If, for instance, any four combinations of just ten ceiling levels were to be reviewed, 10^4 policies (or 10,000 policies) would have to be run 16 times over a number of years. Even the speed of a computer has its limits, and the one being used was comparatively slow as computers go. It was therefore expected that it would prove impracticable, in terms of both time and cost, for an optimum solution to be found merely by attempting to carry out the necessary number of runs for all the policies to be reviewed.

The first attempt at obtaining results only served to confirm these fears. An attempt was made to review all policies between 900 and 1400, at steps of 100, for just one of the programme levels. That range was chosen because it contained the ceiling levels estimated to have been used during 1969/70. 1296 policies were involved and a fairly long time on the computer was set aside for the run, but the run was not completed. Not even when the number of policies was cut to 4^4 or 256 was the run completed. It was estimated that it would take about 3 hours for the computer to complete one run of 1296 policies. The cost of leasing time on the Aston University computer was £50 an hour. If a minimum of 20 runs was needed at each programme level, the cost of completing the review would be 3 x 20 x £50 x 2 or £6000, (20 runs of 3 hours each @ £50 an hour for both programme levels).

9.2 The Extract Routine.

The problem encountered was by no means insuperable. A faster computer could be used and if this were done the running time for the model would be cut, although a cut in costs would not necessarily follow as faster computers cost more for the time used on them. But it was not even necessary to consider switching computers at that stage. There are methods ~~of~~ designing experiments such that only a small number of results, which are likely to be optimum, have to be analysed. A secondary literature review was undertaken, but unfortunately no applicable method of experimental design was found. Sufficient knowledge was gained, however, to develop the basis of an experimental design which would cut down the amount of computing work to be done. For the purposes of this thesis it has been called the Extract Routine.

The underlying assumption of the extract routine is that there is some relationship between the bottom area of the total cost curve and the ranking of policies being reviewed according to minimum cost. Within that area the variation in results will make it difficult to distinguish the optimum solution from a number of near optimum solutions. But it is highly unlikely for the most expensive policy ever to be placed near the optimum policy, even in any single simulation run. If, therefore, a good estimate of the bottom area of the true total cost curve can be obtained in terms of a percentage of ranked policies for any one run, it will only be necessary to carry out one complete simulation run of all the policies to be reviewed. Further runs of only the likely optimum solutions need then be carried out.

There was not sufficient time to develop the extract routine properly and carry it to its logical conclusion by determining the relationship between the optimum area of the total cost curve and the ranking of policies. Experiments were carried out, however, and their results indicated that the use of the extract routine would ensure the choice of at least a near optimum solution. The results of those experiments appear in Appendix C3, and on the basis of those results it was decided to carry out the review of major component stocking policy by extracting the first 12½% of policies, ranked according to minimum cost, and then by simulating the extracted policies the correct number of times. Only one run would be needed to extract the best 12½% of policies. The results from the extract routine experiments were also used to obtain a better estimate of standard deviation, and estimates of 11.0% and 11.5% were calculated. It was found that there was a .9995 confidence of their not being exceeded. Using the sampling formula described in section 1 of this chapter it was decided to run 30 simulation runs of the extracted policies for both programme levels in order to achieve an accuracy of about 4%.

9.3 Results from the Extract Routine.

In order to avoid making the initial extract run too large at the same time as trying to cover as wide a range of ceiling levels as possible, it was decided to test all combinations of ceiling levels between 1000 and 2000 at steps of 250. This meant that 625 policies were to be initially reviewed, but only the best 12½%, or 78, from the first run were to be examined in detail, Appendices C4 and C5 contain the 78 extracted policies, together with their mean total costs estimated from 30 simulation runs, for the 449/204 and 500/230 programme levels respectively. The ten optimum policies in each case are also marked in the appendices. As can be seen there is not much to choose between any of the total costs relating to the best thirty or so policies shown, and it can be concluded that the bottom area of the total cost curve is not very sensitive.

9.4 Comparison of Results.

Once an optimum, or near optimum, policy for each programme level had been found, the effect of using them both together during a period of one year could be compared with the effects of other policies, chosen by arbitrary methods. Three other such policies were chosen.

The first was the ceiling level policy suggested in section 4 of Chapter One - tying all ceiling levels to three shifts of production programme. This policy also involved a change of ceiling levels during the year to be simulated because of the change in programme.

A second policy used in the comparison was to fix all ceiling levels at their highest possible point, which was 2000. And the last policy was the policy used in the validation runs, and estimated to have been used during 1969/70. Changes in programme would affect neither of the last two policies.

The results of the 30 comparison runs appear in Appendix C6. The immediate lesson to be drawn from this comparison is that setting ceiling levels too high is always better than setting them too low. The cost of losses to production outweigh the costs of stocking quite heavily.

9.5 Computer Costs and Time.

Using the extract routine involved running the computer simulation model four times at each programme level, and once for the comparison of policies described in section 4. The first run at each programme level was to determine the optimum run length, the second was to try and find a range of policies approximating to the bottom area of the total cost curve, the third was to apply the extract routine to the policies under review and the last run, or rather series of runs, was to carry out the necessary 30 simulation runs on the extracted policies. A full break-down of the running times and costs for each stage are contained in Appendix C7.

At first the total cost of £1440 appears to be still quite high, although it has been cut to a quarter of what it might have been (see 9.1). But compared with the security the model affords against making a wrong decision, which is highlighted by the £150,000 difference in costs between the three shift ceiling levels and any of the other policies, the £1400 computing cost fades into insignificance.

9.6 Individual Component Simulation

The influence of the cost of losses to production was so pronounced in the results of the comparison run that management wished to develop some means of illustrating the point. A graphical illustration was suggested, but the results of the model are expressed in terms of one total cost for any combination of four ceiling levels, which would involve an illustration of five dimensions.

For the purpose of illustration, therefore, the computer programs were adapted to review a two dimensional case of the interaction between the supply and usage of any one major component. It was fully realised that optimum results could not be obtained by solving for each individual type of major component in this way. No details on how the computer programs were adapted have been included in this thesis because the work involved was specific to this once and for all exercise.

Ceiling levels of between 400 and 2000, at steps of 100, were simulated over the same one year period which still included the programme change. Five simulation runs were carried out for each major component, but no real attempt to obtain statistically correct averages for the results was made because it was the comparison between the influence of the cost of stocking and the cost of lost production on the total cost curve that was of central interest.

Graphs showing smoothed total cost curves for two of the simulation runs carried out appear in Appendices C8 and C9. One curve relates to pairs of front suspension units, and the other to pairs of rear suspension units. The predominant feature in both graphs is the steep rise in costs as the ceiling level decreases from the optimum as opposed to the very gradual rise in costs as the ceiling level increases from the optimum. The results of all the individual major component simulation runs appeared to confirm that the lesser evil lay in setting ceiling levels too high rather than too low.

Another feature management required to be illustrated is the way in which ceiling levels can be lowered from the levels for which investment in storage facilities has been made, thus reducing the amount of capital tied up in stocks at the same time as allowing a reduction of efficiency at the assembly plant. At certain times of the year the demand for stocks of finished cars falls off considerably and there is not such a great need for efficiency at the assembly plant. Management wanted to know if there was a way of discovering how much could be saved, in terms of a decrease in capital tied up in stocks of major components, by a limited reduction in the efficiency of the assembly plant caused by lowering the ceiling levels. There would, of course, be no reduction in the annual investment cost for storage facilities.

It was found that an Efficiency/Cost curve could be constructed from the results already being generated by the model.

Examples of the two Efficiency/Cost curves, constructed from information generated by the same simulation runs as were used for the total cost curves in Appendices C8 and C9, can be seen in Appendices C10 and C11.

First of all losses to production caused by shortages are plotted against the ceiling levels at which they occur. The losses to production are then expressed as decreasing rates of production efficiency. This is done by calculating loss as a percentage of total planned production for the year and by then subtracting that percentage from 100. The cost of capital tied up in average stockholdings at the various ceiling levels is then added as the second set of values for the 'x' axis. From this curve it is possible to estimate the effects of lowering a ceiling level on both efficiency at the assembly plant and average stocks of major components. Once again it is not possible to illustrate this process for the five-dimensional model, but a similar exercise can be undertaken by simulating the desired drop in ceiling level and comparing results.

One last interesting feature of the Efficiency/Cost curves is that they confirm the almost total influence of losses to production on the total cost curve, which is almost identical to the Efficiency/Cost curve cum. Shortage/Ceiling Level curve.

The individual component simulation exercises carried out were to some extent similar to the Longbridge engine storage simulation exercise referred to in Chapter 2. There were still differences in time interval and method of control assumed for the two exercises. But the results proved to be strikingly similar, as is shown by the graph in Appendix C12, which has been reproduced from the report on engine storage issued by the Longbridge Operational Research Department. The very strong influence of the cost/risk of shortages of major components on the total cost curve is thus further confirmed by an independent source.

CHAPTER 10 - CONCLUSIONS

10.1 Results.

On the whole the results obtained from the computer simulation model are very encouraging. They can be summarised as follows:

1. Validation. Even the simple model, used with time intervals of one day, has been shown to be a reasonable approximation of the real situation. The more complex model should therefore prove to be even better.

2. Experimental work. The major component stocking policy review carried out during the experimental work established two important points. Firstly, losses to production caused by shortages of major components is by far the most influential factor on the total cost of any policy. Consequently it is always better to overestimate, rather than underestimate, the ceiling levels required. The results of the comparison run, contained in Appendix C6, show that the arbitrarily chosen policy of stocking right up to the limit, whenever the system allowed, costs only £3000 more than the optimum policy derived from the model, whereas the arbitrarily chosen policy of maintaining ceiling levels amounting to only three shifts of planned production costs over £170,000 more than the optimum policy. A ceiling level policy of 2000 sets of

major components can therefore be recommended under the specified conditions. The second point established by the results obtained from the model during the experimental work was that the bottom area of the total cost curve is probably not very sensitive.

3. Viability.

The amount of work involved in any major component stocking review will depend on the variability of the results generated by the model. But if there is a large variability the basis for an experimental design, which could cut the amount of work to be done quite considerably, is available.

4. Cost. The cost of running a simulation model is usually high because of the very nature of simulation. The cost involved must be considered against the background of major component supply, usage and stocks. The cost of any stocking policy for major components is going to be high. The cost of choosing the wrong policy will also be high. The simulation model practically eliminates the risk of choosing a wrong policy and is able to review far more policies, with scientific precision, than any one person would be able to review. For reasons that will be given later in this chapter it is not anticipated that the model will be used very frequently.

For these reasons it is felt that the relatively small cost of running the model would be more than justified by the savings that would result from its use.

On the basis of the experimental work carried out on the model so far, there is every reason to suppose that it will become a very useful management tool.

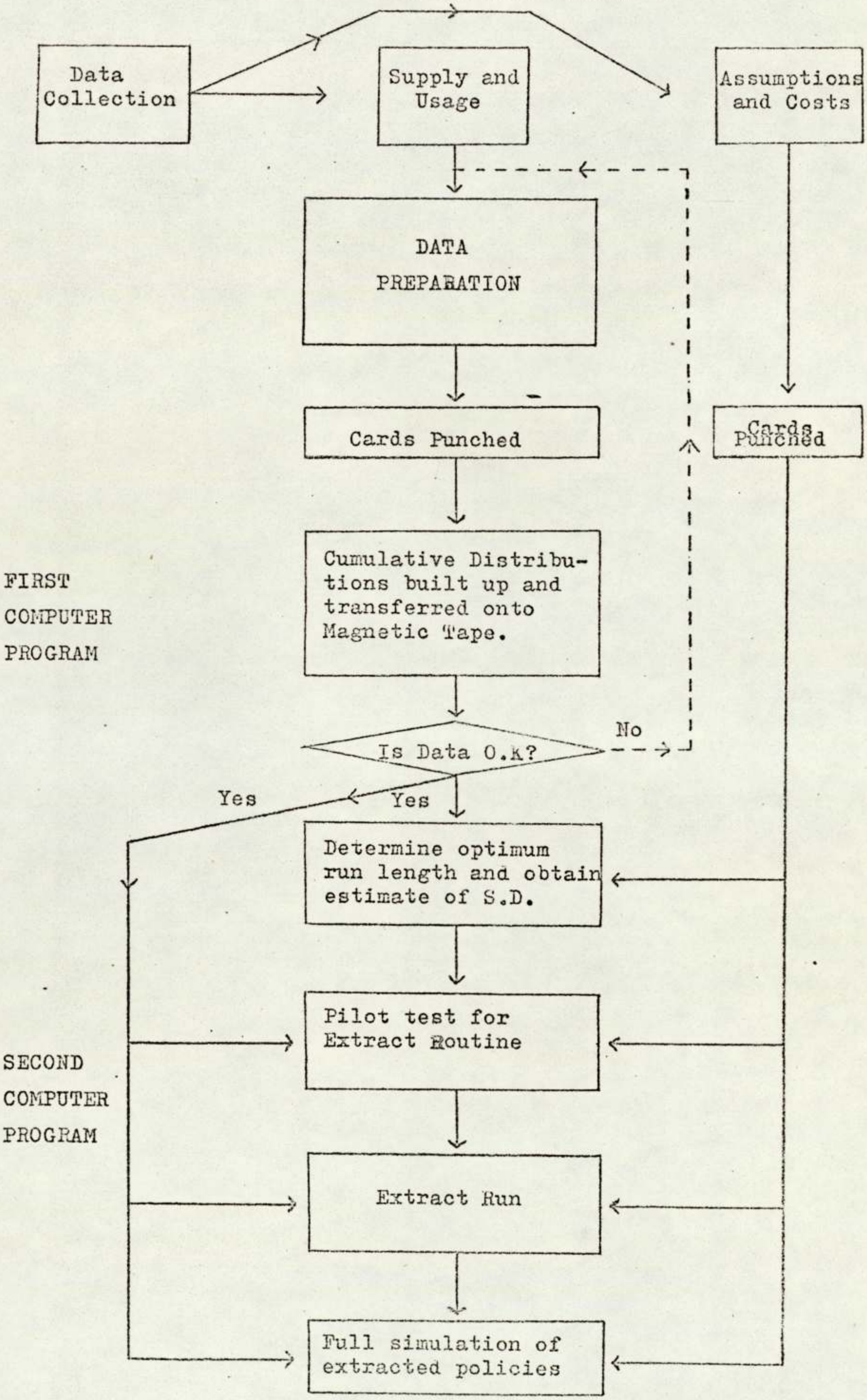
10.2 Summary of Review Procedure.

The procedure for using the computer simulation model to review major component stocking policy and to choose an optimum policy is set out in the form of a flow-chart in Figure 10.2.a. on page 98. Detailed instructions on how to use the computer model are contained in Appendix B.

The first stage is the data collection. Two types of data have to be collected; supply and usage information is needed as the data base for the model, and cost information is needed as the measure of performance in the model. The supply and usage information collected can either be historical, if it is thought likely that a particular supply/usage condition is going to repeat itself, or it can be a forecast of likely events obtained from management.

Figure 10.2.a

FLOW-CHART OF REVIEW PROCEEDURE



The second stage is the data processing or preparation. This involves the elimination of all dependent supply and usage data. It also involves ensuring that the data used for the model describes a balanced supply/usage condition (i.e. where M_d in Figure 3.1.a. on page 38 is not significantly different from zero.)

Once the data has been prepared the cards are punched and the supply and usage information is fed into the first computer program. This program builds up all the necessary cumulative distributions for each supply variable and usage. It also prints out the mean and standard deviation of each distribution so that the data can be checked a second time before it is fed into the simulation program. The first program then transfers all the cumulative probability distributions onto magnetic tape.

The cycle of simulation runs then begins. A first run is carried out to determine the optimum run length, and also to obtain an estimate of the standard deviation of generated results. The second run is a pilot test to determine what range of ranked policies to extract. This is followed by the extract run, and finally the full simulation of extracted policies takes place.

10.3 Information.

It will be clear by now that the usefulness of the major component stocking model which has been developed for the Company depends on the accuracy with which the supply and usage conditions can be estimated. In the early stages all the possible ways in which supply and usage can behave will have to be determined from analysis of past records. Experience during this project has demonstrated that the collection of the necessary information is a long and complicated procedure as things stand. Even the collection of supply and usage information for time intervals of one day took over two months of full time work to complete. As it is the difficulty of getting access to available information, rather than any lack of available information, which seems to be the problem, it is recommended that provision be made for the collection of supply and usage information, together with any background information needed in preparing the data, at a central point. The information should, of course, be collected for the smallest possible time intervals so that the more accurate model can be used (providing it can be validated.) The collection of data at a central point is essential for the model and would involve a negligible amount of work.

10.4 The Assembly Plant as a Unit.

The simulation model that has been develcped will review major component stocking policy for any one car range. Investment in storage facilities will therefore be calculated for each car range separately. But this is not very realistic. Firstly, because car ranges are sometimes built at both the Company's assembly plants, and secondly because it is most unlikely that ceiling levels for stocks of major components of all car ranges will be reached at the same time, and consequently the Company will be left with a large amount of spare storage capacity most of the time. Any investment in storage facilities should therefore be made for the assembly plant as a unit, and the necessary investment will depend on a calculation combining the ceiling levels chosen for all car ranges produced in the assembly plant with an analysis of the probabilities of stocks of the same type of major component from different car ranges reaching their various ceiling levels at one and the same time. These probabilities can be derived by carrying out a number of simulation runs of the optimum policy for each car range and then comparing the closing stock figures generated for the same type of major component in each car range. Calculation of total storage facility capacity for the assembly plant in this way assumes that the storage facilities needed for the major components of different car ranges are all identical. Investment cost in the model can then be expressed as rental charges incurred by any major component.

10.5 Period of Review.

Investment in storage facilities for all major components used at one assembly plant will come to a very high figure. It will probably also be necessary to acquire a site near the assembly plant for storage purposes. It is therefore totally impracticable to carry out frequent reviews of major component stocking policy with a view to altering investment. Accordingly any investment in a storage site and storage facilities will be a long-term corporate planning decision. The considerations in reaching the investment decisions will, however, still be supply and usage of major components and the simulation model can be used to help determine optimum investment decisions. The difference is that the period of review will have to be over a much longer period, say five years or so, and all expected supply/usage conditions for that period will have to be input into the model. The cost of running the model for these corporate planning decisions will be much higher, but it would only be incurred once in a number of years.

At a lower level of decision making the standard period of review will usually be tied to the length of any particular production programme, and the purpose of the model will be to find optimum ceiling levels for major components of all car ranges in the way that has been described in this thesis.

SOME CONSIDERATIONS IN CONTROLLING STOCKS OF MAJOR COMPONENT OPTIONS

In Part I of this thesis it was established that, although there could be no direct control over the total levels of major components in any car range being supplied and used in the short term, control of the mix of major component options being supplied and used in the short term is possible. Some ideas on how to tie in the control of stocks of major component options with an overall ceiling policy are discussed in this Appendix.

The basic idea is to fix a number of option levels within any major component ceiling level, so that when too high a surplus of one option occurs production at the sub-assembly plant can be switched to another option at short notice. The problem, therefore, is to develop the best means of fixing these option levels.

The normal method of stocking for production mix is to stock according to demand. It is therefore possible to develop a method of fixing option levels according to some kind of demand analysis, like Pareto. But the assumption underlying any such analysis of demand is that the cost of not being able to build a popular car is greater than the cost of not being able to produce a car with a lower demand. It is a logical assumption, but no proof for it exists. It was therefore decided to develop the basis for a method of fixing option levels which is more closely tied to the costs involved in not being able to produce a particular option.

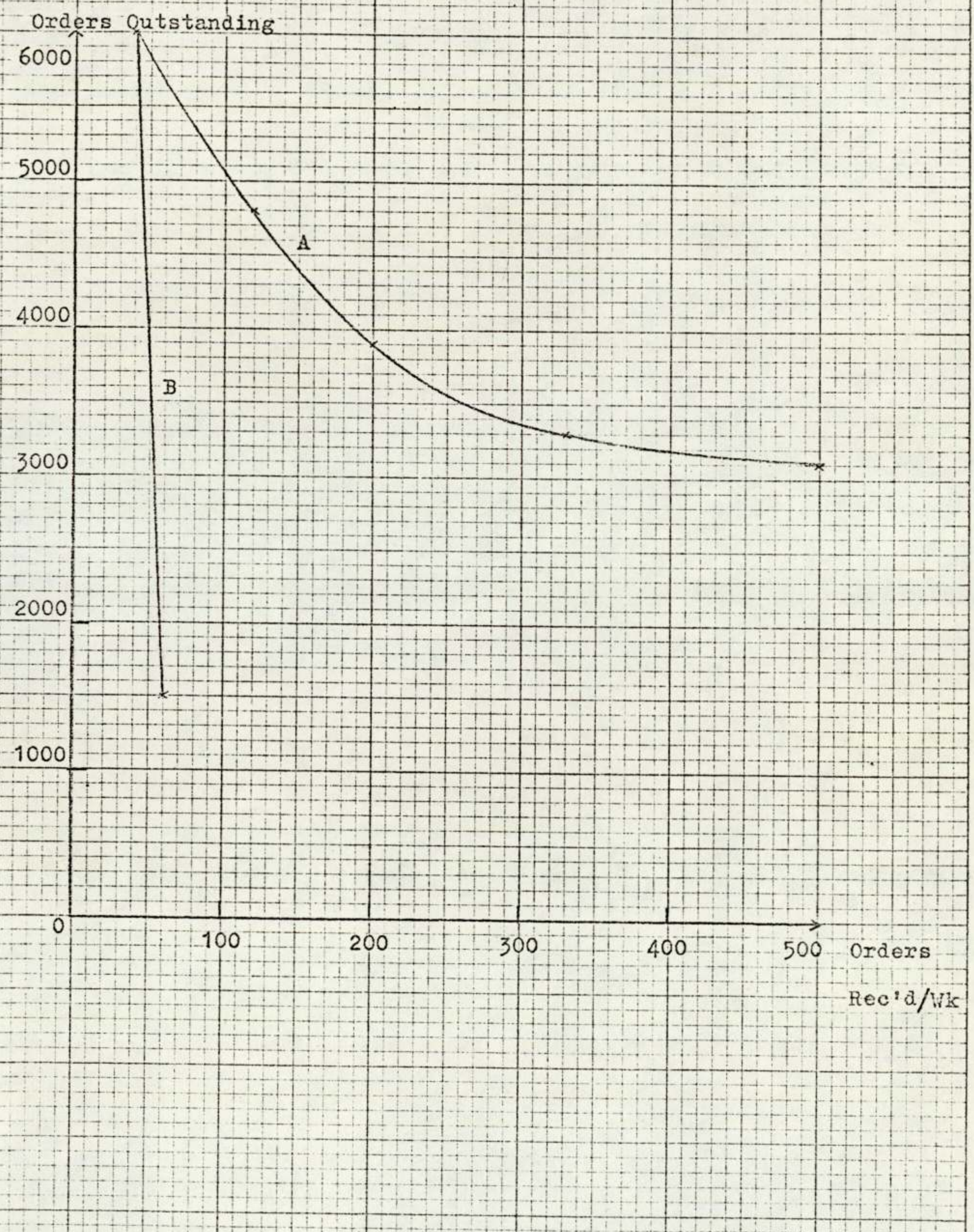
The cost of not being able to produce an option can, to some extent, be expressed in terms of the amount of time a customer is prepared to wait for his car. If he is prepared to wait a long time there is little chance of the 'cost' of losing him as a customer being incurred if the particular car he is waiting for cannot be built for the lack of a major component option. If he is not prepared to wait, however, this cost will be incurred. The likelihood of a customer willing to wait for a particular car option can be determined by the relationship between the orders outstanding for that car and the orders received for it in any time interval. If the curve of this relationship is elastic it can be concluded that customers are not prepared to wait a long time, and if it is inelastic it can be concluded that customers are prepared to wait. It should therefore be possible to fix option levels according to the elasticity of the 'Waiting Time Cost' curve of the car(s) containing the particular major component option.

Examples of elastic (A) and inelastic (B) waiting time cost curves are shown in Appendix A1. Using the waiting time elasticity of demand to control stock levels of major component options will ensure that options used for cars with a low demand but high sensitivity to waiting time will be stocked.

Some analysis of waiting time curves for all car options in the ADO 16 range was carried out during this research project and two of these curves appear in Appendices A2 and A3. Lack of time, however, did not permit any further progress in this direction.

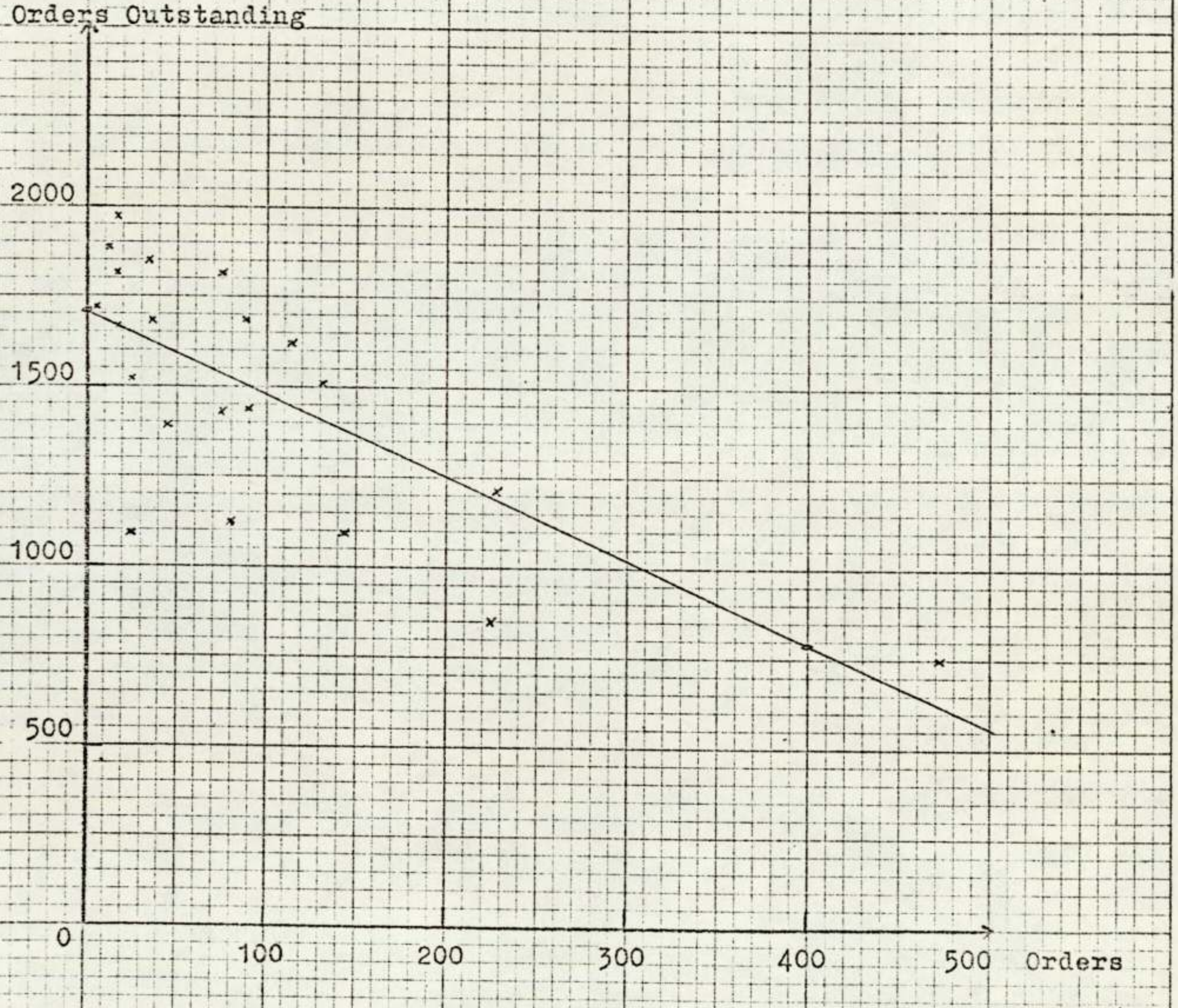
APPENDIX - A1

WAITING TIME ELASTICITY OF DEMAND

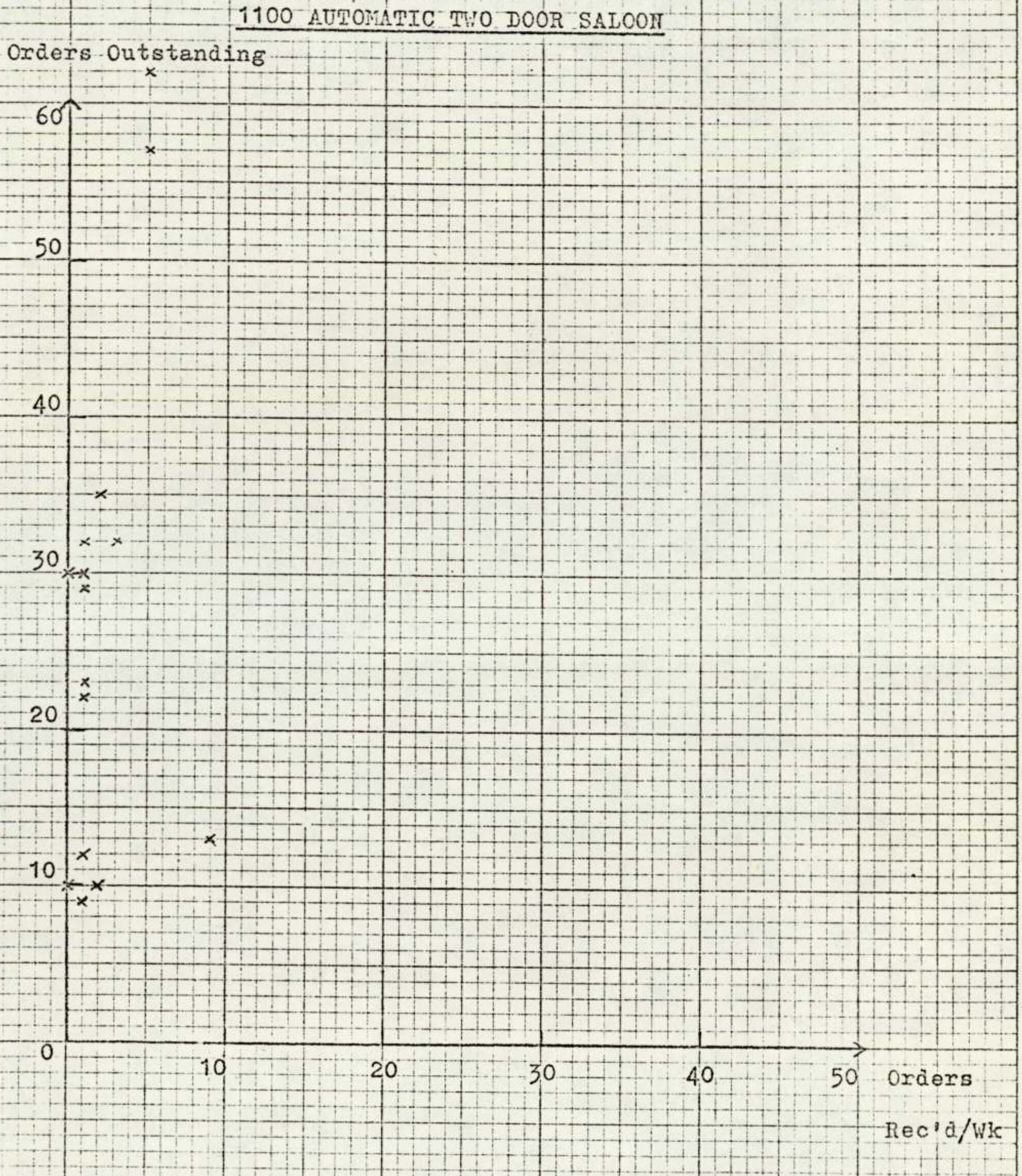


APPENDIX - A2

1300 MANUAL TWO DOOR SALOON



APPENDIX - A3


1100 AUTOMATIC TWO DOOR SALOON
Orders Outstanding
60
50
40
30
20
10
0
10
20
30
40
50
Orders
Rec'd/Wk

INSTRUCTIONS FOR USING THE COMPUTER PROGRAMS

The review procedure for major component stocking policy in Chapter 10.2 involves the use of two computer programs. The first program builds up the cumulative distributions of supply and usage from which events for the second program, the simulation program, are generated. Copies of both programs that were used for the experimental work described in this thesis are contained in Appendix B3. All the programming has been done in Fortran IV. Neither of the programs is very complex, nor are they as efficient as they might be since the overriding consideration in the programming was the relatively small core capacity of the computer being used. Except where changes are recommended, the programs themselves will not be discussed in this appendix.

THE FIRST PROGRAM

Instructions for Input.

The base supply and usage information for the simulation model is input into the first program. The data pack for that program currently contains one control card and data cards containing the raw supply and usage data already sorted into data sets. A data set is defined as either usage figures or supply figures for any one major component relating to a specific production programme - i.e. supplies of body shells during the period when production programme was 449 per day.

Input instructions are as follows:

1) Prepare data - i.e. eliminate dependent data;

2) Sort data into data sets;

3) Punch data onto cards, remembering that
    (a) Only whole numbers may be used
    (b) At least one blank column must be left after each number on any one card
    (c) Each new data set must be started on a completely new card;

4) The order in which the numbers within each data set are punched is not important, but for the program as presently written the data sets themselves must be placed in the data pack in the following order -
    (a) Usage - Programme level A to D* respectively
    (b) Body Supply - Programme level A to D respectively
    (c) Engine Supply - " " " " " "
    (d) Front Suspension Unit Supply - As for (a), (b) and (c)
    (e) Rear " " " - " " " " " "

    * See Key on cover page of Appendix B1;

Printouts of supply and usage data actually read into the first program can be found in Appendix B1.

5) A control card, or set of control cards, which contain the number of values in each data set, must then be punched in the same order as set out in 4) above. The control card(s) must be the first card(s) in the data pack.

The number of data sets to be input will always be the number of major components being analysed plus one for usage, times the number of programme levels involved. This figure will obviously vary with both the number of major components and the number of programme levels involved. At present control of the total number of data sets to be processed is achieved by setting a program control variable, M4 (circled in the copy of the program listing in Appendix B3), equal to the required figure at the start of each program run. This means that it is necessary to change a program source card each time it is desired to process a different number of data sets. This is unnecessary and can easily be changed. It is therefore recommended that the total number of data sets to be processed is read in from a data card, which will then become the first card in the data pack. The necessary adjustment to the program has been added to the program listing in Appendix B3.

Interpretation of Output.

The first program just does all the basic data processing for the main simulation program. The two programs could therefore be linked without much difficulty. They have been kept separate so that a check on the cumulative distributions built up by the first program is available. Results from the first program are therefore output to both magnetic tape, as an indirect link to the second program, and lineprinter, as a visual check.

1) Magnetic Tape: A cumulative distribution is built up for each data set read into the program. These distributions are defined in terms of data blocks, each containing three segments as follows

   (a) Ranked values

   (b) Cumulative probabilities

(c) Number of values.

The data blocks are output to magnetic tape in the same order as their respective data sets are read in. An illustrated example of a data block, together with an example of how the blocks are stored on magnetic tape, is shown at the beginning of Appendix B2.

2) Lineprinter: The same data blocks are also output to the lineprinter in the same order as they are written to magnetic tape. Additionally the corresponding data sets are printed out, exactly as they were read in from the data cards, before each data block and the mean and estimated standard deviation of each distribution are printed out. A specimen printout of results from the first program can be found in Appendix B2.

THE SECOND PROGRAM

Instructions for Input.

The data blocks describing the supply and usage distributions which are output to magnetic tape by the first program are automatically input into the second program from the same magnetic tape. Consequently no further instructions regarding supply and usage information are necessary. Nevertheless the data pack for the second program is still quite large because there are a number of different types of simulation run that can be carried out during any major component stocking review.

Operating instructions are given by listing below the details of data cards that need to be punched in the order in which they must be placed in the data pack.

Order	Card	Card Type	Program Variable	Setting
1	Run Type	Facility	KØDE (Integer)	Extract Run = 0 Simulation of Extracted Policies = 1 Simulation of Restricted Number of Policies = 2
2	Change in Ceiling Level	Facility	ITIME* (Integer)	No Change = 0 Time Interval at which Change in Level is required = t
3	Number of Data Blocks	Control	M5 (Integer)	1 to 4. The program can handle up to 4 distributions.
4	Number of Simulation Runs	Control	NSC (Integer)	Must be > 0. Maximum limit depends on time available.

* NB ITIME is also the name of a time checking routine in ICL Fortran. This has already caused some errors in execution and it is therefore strongly recommended that the variable name is changed.

Order	Card	Card Type	Program Variable	Setting
5	Run Length	Control	YEARC (Integer)	Any multiple of a Run Period. Usually Optimum Run Length.
6	Number of Policies	Control	KØUNTC (Integer)	Number of policies to be extracted - for KØDE = 0; OR to be reviewed - for KØDE $\neq$ 0
7	Number of Major Components	Control	M2 (Integer)	1 to 4
8	Number of Time Intervals	Control	M8 (Integer)	Number of time intervals within any single period of review.
9	Data Block Indicator	Control	KZ (Integer)	Set in conjunction with M5. For M5 $<$ 4, KZ = 1 or 2.* For M5 = 4, KZ = 0.

* NB At present the program is designed to accommodate dual level production programmes (e.g. 449/204 and 500/230 - see Glossary). From the magnetic tape storage diagram in Appendix B2 it can be seen that the relevant distributions are stored in positions 1 and 3, and 2 and 4 respectively. Set KZ at 1 if the distributions stored in positions 1 and 3 are not required, and at 2 if the distributions in positions 2 and 4 are not required. The

relevant programming instructions are missing from the program listing in Appendix B3, but they have been inserted in the correct place by hand.

Order	Card	Card Type	Program Variable	Setting
10	Programme Limits	Control	LH1, LL1 LH2, LL2 LH3, LL3 (Integer)	The range of small fluctuations in programme levels must be set in pairs (LH = high, LL = low) for each specified programme (see 7.4.4).*

* NB These limits ensure that events generated from the correct distribution are attributed to programme levels which deviate slightly from the generalised level specified. The three sets of limits must be set for the first three programme levels in the same order as their corresponding distributions , or data blocks, are stored on magnetic tape. The last programme level is catered for automatically. All limits must always be set. If $M5 < 4$ superfluous limits can be set at 0.

11	Factory Floor Storage	Data	XY(M2) (Integer)	One value for each major component. See 5.2.3.
12	Opening Stocks	Data	STØCK(M2) (Integer)	One value for each major component.
13	Programme Levels	Data	P(M8) (Integer)	One value for each time interval.

Order	Card	Card Type	Program Variable	Setting
14	Ceiling Levels	Data	MAXHI, MAXS, MAXC (Integer)	For KØDE = 0: The highest and lowest levels to be simulated plus the steps between them, in that order.
			MAX(M2) (Integer)	For KØDE ≠ 0: Either the paper tape output by the Extract Program (see under 1(b) of Interpretation of Output) must be handed over with the data pack and no card(s) are inserted (KØDE = 1). Or card(s) containing all policies to be reviewed must be inserted (KØDE = 2).*

* NB When KØDE = 2 each policy, consisting of a combination of M2 ceiling levels, must be punched on a different card. If ITIME ≠ 0 each policy must be defined by 2 ceiling level combinations, also punched on different cards. In this case the 2 cards defining the policy must be placed together in the data pack in the order in which the ceiling levels are to be put into effect.

Order	Card	Card Type	Program Variable	Setting
15	Random Number Seed	Data	RNS (Real)	Any decimal number between .00001 and .0001 under normal circumstances. The card should be changed for each new computer run.*
16	Cost of Holding Rate	Data	R (Real)	See 5.3
17	Cost of Shortage	Data	CØS (Real)	See 5.4
18	Cost of Material	Data	C(M2) (Real)	One value for each major component. See 5.3
19	Cost of Investment	Data	TC(M2) (Real)	One value for each major component. See 5.2.1
20	Storage Facility Capacity	Data	DIV(M2) (Real)	One value for each major component. See 5.2.2

* NB In generating random numbers for simulation the program is linked up to an ICL package. If this facility is not available some program source instructions will have to be changed.

Each variable listed must be punched on a separate card or set of cards in addition to any specific instructions already given. Once again a blank column must be left between all the figures on any one card.

Interpretation of Output.

The simulation program outputs the six most relevant results for assessing any major component stocking policy. A specimen printout of these results is shown in Appendix B2. The information it provides is, reading from left to right, as follows:

(a) Major component code: 1 = Body Shells
2 = Power Units
3 = Front Suspension Units
4 = Rear Suspension Units;

(b) Ceiling level combination. Hence the major component stocking policy being analysed is always defined by the first 2 columns on the printout;

(c) Simulated average stocks per period;

(d) Simulated average losses to final assembly production caused by shortages of each major component per period;

(e) Simulated average number of disruptions recorded at each sub-assembly plant per period;

(f) Simulated total cost of the policy;

(g) Simulated average total loss to final assembly production caused by shortages of all major components (which will usually differ from the sum of (d));

(h) Simulated average number of disruptions recorded at the final assembly plant.

The results listed above are output regardless of run type (i.e. KØDE setting). But the method of output and additional output facilities will vary according to run type chosen as follows:

1) Extract Run (KØDE = 0)

   (a) Lineprinter: The results of the number of lowest cost policies specified by the input variable KØUNTC are printed out in <u>descending</u> order of total cost. This form of output is merely a visual check on the first main stage of the whole stocking review (Chapter 10.2) The only information of any importance to be output from an Extract Run are the extracted policies themselves, which form part of the input into the next stage of the review proceedure (Chapter 10.2 and Input Instruction 14)

   (b) Paper Tape: The transfer of data with respect to the extracted policies from run type 0 to run type 1 is achieved by a second output from the Extract Run to paper tape in the same order as they are printed out. The same paper tape is then used as input into the next run. If a separate visual record of the extracted policies alone is required the paper tape can be put through a reader and printed out, as has been done for Appendices C4 and C5;

2) Simulation of Extracted Policies (KØDE = 1): As presently written the program will print out results for each policy and for each simulation run. A vast amount of

printout would therefore accumulate as the result of a modest number of runs. It is therefore necessary to

(a) Average the simulation results for each policy. At present a special routine at the end of the program averages the total costs of all the required runs for each policy. A specimen printout of the results obtained by the routine is shown in Appendix B2. The limited core size of the computer being used did not permit the averaging of all the results without basic changes to the program. But if a computer with larger core size is used it is recommended that the routine is expanded to cater for the averaging of all required results

(b) Suppress the results from each individual simulation run. In the past this has been done by inserting a special program source card. Those instructions are not included in the program listing, and it is recommended that a general output suppression routine is added to the program;

3) Simulation of Restricted Number of Policies (KØDE = 2): The same output is obtained for this type of run as is obtained for run type 1 (see above). The only difference is that the number of policies to be simulated will be far less, and failure to suppress printouts for each separate run will result in less superfluous printout.

4) Finally, for simulation runs where KØDE ≠ 0, it is possible to get a full simulation listing for any policy on the lineprinter. A specimen listing is contained in Appendix B2. The key to the column headings is as follows:

PRØG = Daily production programme

Ø/S = Opening stock

C/S = Closing stock

REC = Supply received

B = Body shells

E = Power units

FS = Front suspension units

RS = Rear suspension units

USAGE = Major component usage

LØSS = Loss to final assembly production

CØDE = Major component shortage responsible for the loss

At present this facility is limited to the first simulation run only. But if a large number of policies are being simulated, full simulation listings, even for just one run, will again result in a great deal of unwanted printout. It is therefore recommended that a general output suppression routine for the simulation listings is also added to the program.

GENERAL

A general word of warning needs to be added in concluding this appendix. Both programs have been written specifically for the ICL 1905 computer at the University of Aston in Birmingham. Consequently certain ICL packages and conventions have been used. If the programs are to be used on other installations great care must be taken to discover what changes need to be made.

APPENDIX - B1

PRINTOUTS OF SUPPLY AND USAGE DATA

NB: In the first computer program supply and usage is read into arrays of 150 elements each. In the printouts in this appendix the whole array has been printed out. Consequently all the zeros which appear after the last value in each array refer to empty array elements and are not zero values of supply or usage.

KEY:

A = Data collected for specified 449 programme level
B = " " " " 500 " "
C = " " " " 204 " "
D = " " " " 230 " "

USAGE

```
  454   471   470   444   238   467   476   462   459   452   439   445   375   452   445   439   372   443   446   355
  431   451   450   373   447   425   451   388   456   450   449   449   444   456   451   402   449   460   328   424
  291   408   412   332   311   327   312   427   410   450   450   450   450   459   450   447   484     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓐ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     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

  450   402   442   450   453   450   450   450   430   450   416   448   438   241   447   453   454   493   439   505
  486   504   496   510   508   502     0   350   330   390   436   436   446   406   394   464   504   517   515   474
  455   501   494   510   488   494   503   474   505   505   515   403   514   497   498   514   521   498   488   513
  520   323   494   329   395   464   443   480   508   513   464   514   492   424   485   227     0   201   409   459
  494   502     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓑ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0

  206   215   200    20   205   194   206   190   170   191   103   188   196   219   209     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓒ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0

  208   211   206   204   213   241   237   160   200   180   234   238   236   242   220   199   180   180   219   212
  213    88     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓓ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0
```

SUPPLY - BODY SHELLS

```
  459   469   452   436   418   385   451   442   417   456   383   325   417   436   475   413   353   477   329   304
  409   387   371*   74*  343*  414   411   434   409*  437   328   258*  402*  413   444   502   457   441   460   415
  449   430   436   467   458   417   435   445   428   374   449   399   376   266   324   269*  377*  457*  494   462
  459   448   479   469   440   406     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓐ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0


  427   486   474   414   438*  447*  456*  447   466   478   469   449   460   486   522   510   397   319   217*  405
  433   505   324   191   446   387   315   459   471   395*  468*  482*  490*  492   434*  386   357   379   383   381
  376   317   241*  382   442*  411*  371*  386*  365*  366   403*  396*  412*  467*  464   497   464   471   493   503
  459   506   470   478   520   484   433   527   498   505   483   450   531   554   524   536   496   549   501   479
  455   355   445   338   412   459*  451   525   485   484   406   522   465   499   501   401   425   458   282   251
  271*  377*  480*  445*  115*  403*  405*  386*    0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓑ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0
```

* DATA OMMITTED FOR EXPERIMENTAL WORK

```
  191   187   189   135   127     0*  188   116*  189   170   177   207   120    44   202   191   218     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓒ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0


  153   196   213   245   203   189   221   225*  196   166   107*  159*  172   213*  284   231   235   241   202   227
  151   280   266   210   195    92   178*  187*    0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0  Ⓓ  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0
```

SUPPLY - POWER UNITS

Ⓐ

```
368  426  423  384  469  467  545  515  466  421  458  532  518  609  452  394  574  589  401  577
512  414  432  433  492  479  455  446  458  421  540  502  405  488  401  417  393  411  527  492
505  534  546  526  517  567    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    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
```

Ⓑ

```
602  448  451  504  475  515  565  530  595  459  485  480  463  481  479  453  508  429  578  513
501  521  479  530  599  525  467  439  478  485  467  549  568  506  413  530  414  482  417  506
599  473  541  519  602  518  634  506  533  552  567  504  640  508  493  558  568  532  533  523
571  579  558  462  530  610  576  468  445  452  551  433  542  675  486  506  486  484  489  464
501  394  579  530  472  434  482  508    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0
```

Ⓒ

```
204  180  211  192  188  370  276  228    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0
```

Ⓓ

```
277  253  234  214  209  220  260  347  340  275  409  238  181  232  288  324  209    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0
```

SUPPLY – FRONT SUSPENSION UNITS

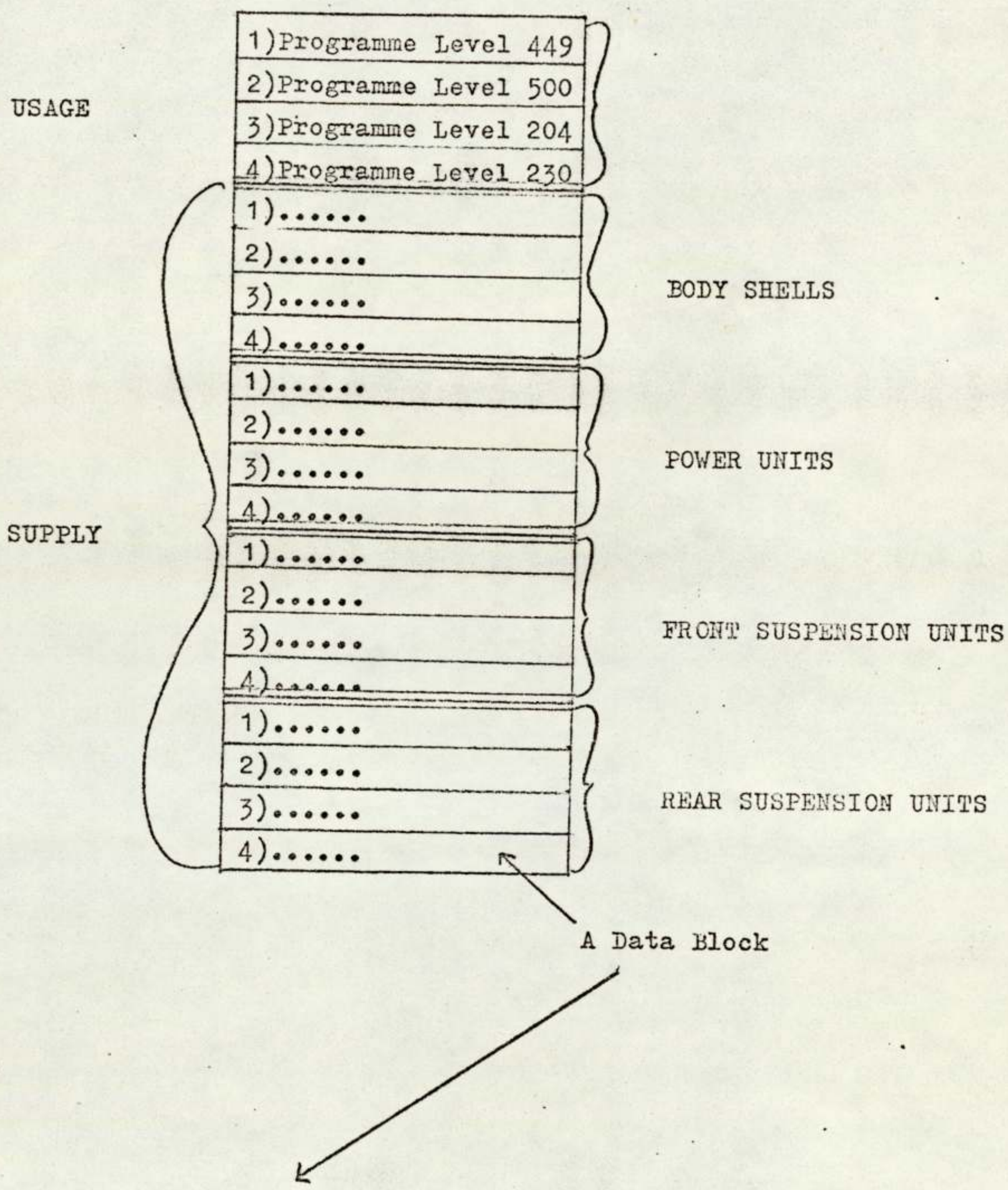
```
432  432  468  468  468  840  504  612  612  828  432  432  324  648  432  504  468  552  468  432
462  432  648  468  684  612  324  468  432  633  576  432  468  468  432  415  378  648  468  504
504  324  612  468  612  432  432  432  468    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0 Ⓐ  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    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

576  432  432  468  432  468  684  432  612  468  468  468  468  468  576  504  312  432  612  612
360  612  504  756  468  408  384  612  432  468  324  432  432  612  324  504  531  612  600  576
504  648  432  504  384  612  432  648  432  504  648  432  432  564  432  636  468  468  468  612
432  432  900  528  432  741  576  468  492  504  468  360  468  468  540  360    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0 Ⓑ  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0

576  468  324  468  288  288  288  432  432  288  432  144  324  432  144  144    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0 Ⓒ  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0

288  432  504  468  168  432  468  144  288  324  288  344  504  468  504  888  504  180  576  468
576  573  144  468  360    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0 Ⓓ  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0
```

DATA BLOCKS STORED ON MAGNETIC TAPE



Example of a data block describing a distribution.

RANKED VALUES	CUMULATIVE PROBABILITIES	NUMBER OF VALUES

```
DATA SET AS READ IN                                         RANKED VALUES                          CUMULATIVE PROBABILITY
  540   435   510   360   360   360   510   420   360   345   480   435   180   345   480   315   705   435   435   420
  435   330   315   465   360   480   345     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0   150   265   300   315   330   390   405   435   450   480   510   675   390   405   405   405   405   405   435
  450   450   450   450   480   510   675     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 0.00  3.67 11.00 14.67 25.67 44.00 51.33 69.67 73.33 84.33 91.67 95.33 99.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 MEAN  383.333    STANDARD DEVIATION  565.674  (13) ← N
```

SPECIMEN RESULTS FROM FIRST COMPUTER PROGRAM

SPECIMEN RESULTS FROM SECOND COMPUTER PROGRAM

```
   MAXIMUM STOCK     AVERAGE STOCK     LOSS CAUSED     MM     COST     TOTAL LOSS     NN
   =============     =============     ===========     ==     ====     ==========     ==

1           1000              560.             130     21
2           1500              472.            1030      1
3           1250              871.              33     82
4           2000             1437.               0     50   242002.           1193    117

   MAXIMUM STOCK     AVERAGE STOCK     LOSS CAUSED     MM     COST     TOTAL LOSS     NN
   =============     =============     ===========     ==     ====     ==========     ==

1           1000              553.             130     21
2           1500              466.            1057      1
3           1500             1102.               0     82
4           1750             1174.               0     49   241559.           1187    119

   MAXIMUM STOCK     AVERAGE STOCK     LOSS CAUSED     MM     COST     TOTAL LOSS     NN
   =============     =============     ===========     ==     ====     ==========     ==

1           1000              560.             130     21
2           1500              472.            1030      1
3           1250              871.              33     82
4           1750             1171.               0     49   240821.           1193    117
```

```
 472144.
      1250      1250      1000      1750
 483236.
      1250      1500      1750      2000
 475339.
      1500      1250      2000      2000
 456560.
      1500      1250      2000      1750
 463172.
      2000      1000      1750      1750
 455422.
      1500      1500      1000      2000
 470255.
      1750      1250      1250      2000
 455534.
      1000      1250      1250      2000
 482410.
      2000      1000      1750      2000
 452951.
      1750      1250      1250      1500
 475208.
      1750      1250      1250      1750
 463810.
      1250      1000      1750      1750
 464040.
      2000      1000      1500      1500
 471810.
      1750      1250      1000      1500
 487307.
      1250      1500      1500      2000
 474373.
      1500      1250      1750      2000
 455198.
      1500      1250      1750      1750
 461249.
      2000      1000      1500      1750
 457967.
      1750      1000      2000      1500
 469376.
      2000      1000      1500      2000
 452982.
      2000      1000      1250      1500
 473426.
      2000      1000      1000      1750
```

– SPECIMEN PRINTOUT OF TOTAL COST AVERAGES FOR A GIVEN NUMBER OF POLICIES OVER A SPECIFIED NUMBER OF SIMULATION RUNS.

SPECIMEN SIMULATION LISTING

```
PROC  O/S B  REC B  C/S B  O/S E  REC E  C/S E  O/S FS  REC FS  C/S FS  O/S RS  REC RS  C/S RS  USAGE  LOSS  CODE
====  =====  =====  =====  =====  =====  =====  ======  ======  ======  ======  ======  ======  =====  ====  ====

 451   201    328    105   1540    408   1524   1598       0    1174     698     480     754    424     0     0
 449   105    407     87   1524    461   1560   1174     588    1337     754     480     809    425     0     0
 449    87    459    143   1560    480   1637   1337     372    1306     809     480     886    403     0     0
 449   143    324     21   1637    382   1573   1306     552    1412     886     300     740    446     0     0
 204    21    188     25   1573    228   1617   1412       0    1228     740     330     886    184     0     0
 449    25    476     31   1617    446   1593   1228     444    1202     886     480     896    470     0     0
 449    31    456    350   1593    431   1887   1202     552    1617     896     435    1194    137     0     0
 449   350    328    229   1887    464   1902   1617       0    1168    1194     390    1135    449     0     0
 449   229    451    235   1902    339   1796   1168     402    1125    1135     570    1260    445     0     0
 204   235    188    230   1796     96   1699   1125     546    1478    1260       0    1067    193     0     0
 449   230    412    199   1699    518   1774   1478       0    1035    1067     480    1104    443     0     0
 449   199    436    246   1774    430   1815   1035     264     910    1104     480    1195    389     0     0
 449   246    269     72   1815    514   1886    910     408     875    1195     300    1052    443     0     0
 449    72    267      0   1886    367   1914    875     408     944    1052     300    1013    339   109     1
 204     0    204     14   1914     34   1808    944     402    1156    1013     330    1153    190     0     0
 449    14    449     14   1808    387   1746   1156     408    1115    1153     615    1319    449     0     0
 449    14    460     25   1746    423   1720   1115     552    1218    1319       0     870    449     0     0
 449    25    444    140   1720    508   1899   1218     492    1381     870     300     841    329     0     0
 449   140    333    126   1899    406   1908   1381     408    1392     841     435     879    397     0     0
 204   126    135     77   1908    185   1909   1392     114    1322     879     645    1340    184     0     0
 449    77    412     69   1909    457   1946   1322     552    1454    1340       0     920    420     0     0
 449    69    328      0   1946    516   2063   1454       0    1057     920     580    1103    397    52     1
 449     0    402      6   2063      0   1663   1057     264     919    1103     480    1181    402    47     1
 449     0    440      4   1663    472   1699    919     372     855    1181     300    1045    436     0     0
 204     4    216    145   1699    158   1782    855     294    1074    1045     330    1300     75     0     0
 449   145    267      0   1782    366   1736   1074     372    1034    1300       0     888    412    36     1
 449     0    444      0   1736    428   1720   1034     372     962     888     435     879    444     5     1
 449     0    435      0   1720    466   1751    962     552    1079     879     300     744    435    10     1
 449     0    406      0   1751    397   1742   1079     408    1081     744     300     638    406    43     1
 204     0    188      0   1742    189   1743   1031     402    1295     638     330     780    188     3     1
 447     0    458      9   1743    466   1760   1295     372    1218     780     300     631    449     0     0
 449     9    267      0   1760    419   1903   1218     408    1350     631     435     790    276   121     1
 449     0    462    133   1903    392   1966   1350     372    1393     790     300     761    329     0     0
 449   133    454    138   1966    397   1914   1393     355    1299     761     300     612    449     0     0
 204   138     97     41   1914    200   1920   1299     258    1363     612     420     838    194     0     0
 449    41    454     43   1920    350   1818   1363     444    1555     838     480     866    452     0     0
 449    43    448    354   1818    518   2199   1355     372    1590     866     300    1029    137     0     0
 449   354    400    275   2199      0   1720   1590       0    1111    1029     300     850    479     0     0
 449   275    416    241   1720    455   1725   1111     552    1213     850     300     700    450     0     0
 204   241    365    475   1725    163   1757   1213     258    1340     700     330     899    131     0     0
 447   475    333    368   1757    330   1667   1340     444    1344     899     480     939    440     0     0
 447   368    444    504   1667    470   1829   1344     588    1624     939     525    1156    308     0     0
 447   504    452    505   1829    354   1732   1624       0    1173    1156     480    1165    451     0     0
 447   505    413    642   1732    143   1599   1173     402    1299    1165     525    1434    276     0     0
 213   642    179    622   1599    178   1578   1299     402    1502    1434       0    1235    199     0     0
 447   622    444    623   1578    363   1498   1502       0    1059    1235       0     797    443     0     0
 447   623    411    662   1498    419   1545   1059     408    1095     792     300     720    372     0     0
 447   662    343    578   1545    466   1584   1095     264     932     720     435     728    427     0     0
 447   578    435    569   1584    456   1596    932     588    1076     728     480     764    444     0     0
 213   569    365    872   1596    271   1805   1076     402    1416     764     330    1032     62     0     0
 447   872    292    715   1805    393   1749   1416       0     967    1032     300     883    449     0     0
 447   715    371    765   1749    548   1976    967     372    1018     883     300     862    321     0     0
 447   765    415    783   1976    372   1951   1018     372     993     862     300     765    397     0     0
```

```
RTRAN COMPILATION BY #XFAE MK 4D    DATE 28/10/71  TIME  01/02/14

    LIST(LP)
    SEND TO (ED,ASTD-DEFAULT(0))
    WORK(ED,WORK FILE    (0))
    PROGRAM(PD02)
    COMPRESS INTEGER AND LOGICAL
    INPUT 5=CR0
    OUTPUT 6=LP0
    OUTPUT 7=MT0/(STOREDUPDATE)
    NO TRACE
    END
```

FIRST COMPUTER PROGRAM

```
   MASTER(PROBDISTS)
   DIMENSION ROM(150),CUMNOM(150),M(50)
   INTEGER RR(150),SP1(150),SP2(150)
   REAL NOM(150),NAM(150),MEA
  (M4=20)- - - - - - - - - - - - - - Change to: READ(5,I00)M4
   K0=0
   READ(5,100)(M(I),I=1,M4)
00 FORMAT(250I0)
   MC AND M1 ARE SPARE INTEGERS.SP1 AND SP2 ARE SPARE INTEGER ARRAYS.
03 M1=M(K0+1)
   DO 108 I=1,150
   CUMNOM(I)=0
   SP1(I)=0
05 SP2(I)=0
   READ(5,100)(RR(I),I=1,M1)
   DO 101 I=1,M1
01 SP1(I)=RR(I)
 - WRITE(6,898)SP1 - - - - - - - - - - - - - - - - - - - - - -
   IF((K0+1)-8)104,104,0
   IF((K0+1).EQ.11.OR.(K0+1).EQ.12)GO TO 110
   IF((K0+1).EQ.15.OR.(K0+1).EQ.16)GO TO 110
   IF((K0+1).EQ.19.OR.(K0+1).EQ.20)GO TO 110
   DO 107 I=1,M1                                     Special routine
   SP1(I)=SP1(I)-60
   IF(SP1(I)-0)0,0,107                               to accommodate
   SP1(I)=0
07 CONTINUE                                          data problem
   GO TO 104
10 DO 111 I=1,M1                                     specified in 2nd
   SP1(I)=SP1(I)-30
   IF(SP1(I)-0)0,0,111                               paragraph of 7.4.I
   SP1(I)=0
11 CONTINUE
 - RANK DATA - - - - - - - - - - - - - - - - - - - - - - - - - -
04 DO 102 I=1,M1
02 SP2(I)=SP1(I)
   SM=SP2(1)
   DO 105 I=1,M1
   DO 106 L=1,M1
   IF(SP2(L)-SM)0,0,106
   SM=SP2(L)
   NO=L
06 CONTINUE
   SP1(I)=SM
   SP2(NO)=1000000
05 SM=1000000
   GENERATE CUM. PROBABILITY DISTRIBUTIONS
   N=0
   L=1
   M9=M1-1
   DO 15 J=1,M9
   IF(SP1(J)-SP1(J+1))16,0,0
   L=L+1
   GO TO 15
16 N=N+1
   SP1(N)=SP1(J)
   NOM(N)=L
   L=1
 5 CONTINUE
   N=N+1
   SP1(N)=SP1(M1)
   NOM(N)=L
   IF(SP1(1)-0)600,600,0
   N=N+1
```

```
      SP2(1)=0
      NAM(1)=0.0
      DO 610 I=2,N
      NAM(I)=NOM(I-1)
  610 SP2(I)=SP1(I-1)
      DO 620 I=1,N
      NOM(I)=NAM(I)
  620 SP1(I)=SP2(I)
      ROM(1)=0.0
      DO 630 I=2,N
  650 ROM(I)=(NOM(I)/M1)*99.0
      GO TO 640
  600 DO 23 I=1,N
   23 ROM(I)=(NOM(I)/M1)*99.0
  640 CUMNOM(1)=ROM(1)
      DO 25 I=2,N
   25 CUMNOM(I)=CUMNOM(I-1)+ROM(I)
      WRITE(6,898)SP1
  898 FORMAT(20I6)
      WRITE(6,998)CUMNOM
  998 FORMAT(20F6.2)
      MEAN=0.0
      VAR=0.0
      DO 27 I=1,N
      MEAN=MEAN+(NOM(I)*SP1(I))/M1
   27 VAR=VAR+(NOM(I)*SP1(I)-MEAN)**2/M1
      SD=SQRT(VAR)
      WRITE(6,29)MEAN,SD,N
   29 FORMAT(1H0,10X,F10.3,10X,F10.3,I4)
      WRITE(7)N
      WRITE(7)(SP1(I),I=1,N)
      WRITE(7)(CUMNUM(I),I=1,N)
      K0=K0+1
      IF(K0-M4)103,0,0
      ENDFILE 7
      STOP
      END

END OF SEGMENT, LENGTH   741, NAME  NONM
```

```
ON BY #XFAT MK 4C     DATE 15/12/71  TIME  00/52/35


      LIST(LP)
      SEND TO (ED,ASTD-DEFAULT(0))
      WORK(ED,WORK FILE   (0))
      LIBRARY(SUBGROUPSRF7)
      LIBRARY(SUBGROUPFSCE)
      PROGRAM(JCS2)
      COMPRESS INTEGER AND LOGICAL
      INPUT 4=TR0
      INPUT 5=CR0
      OUTPUT 6=LP0
      INPUT 7=MT0/(UPDATEDTORED)
      OUTPUT 9=TP0
      NO TRACE
      END
```

SECOND COMPUTER PROGRAM

```
  MASTER(INTERACT)
  DIMENSION LOSS(250),MAX(4),C(4),MM(4),MX(4),AS(4),ASZ(160,4
 1),LC(250),S(4),DIV(4),TC(4),CH(4),CUMNOM(160),COST(4),TCOSTZ(160)
  INTEGER RB(250,4),RE(250.4),RTF(250,4),RTR(250,4),U(250,4),RO(250.
 14),U0(250),P(250),OS(250,4).AV(4),CS(250,4),SP1(250)
 2.SP2(250),XY(4),STOCK(4),TLC(4),TLX(4),YEAR,YEARC,DN,DD,PROG
  CALL WORKFILE(8,2HED,15000)
  CALL WORKFILE(3,2HED,1000)
  CALL WORKFILE(2,2HED,1000)
  NS=0
  READ(5,100)KODE(ITIME)- - - - - - - - Change variable name.
  READ(5,100)M5,NSC,YEARC,KOUNTC,M2,M8,KZ,LH1,LL1,LH2,LL2,LH3,LL3
 1,(XY(I),I=1,M2),(STOCK(I),I=1,M2),(P(I),I=1,M8).
0 FORMAT(100I0)
HIS LARGE A REPEAT COUNT INTENDED AT ABOUT COLUMN 16, LINE 0028

  IF(KODE-1)0,800,800
  READ(5,100)MAXHI,MAXS,MAXC
  GO TO 801
0 KY1=1
  IF(KODE-1)0,0,802
  DO 803 I=1,KOUNTC
  READ(4,100)(MAX(J),J=1,M2)
  CALL PUTARRAY(3,KY1,MAX)
3 CONTINUE
  GO TO 801
2 DO 99 I=1,KOUNTC*2
  READ(5,100)(MAX(J),J=1,M2)
  CALL PUTARRAY(3,KY1,MAX)
9 CONTINUE
1 READ(5,10)RNS
  READ(5,10)R,COS,(C(I),I=1,M2),(TC(I),I=1,M2),(DIV(I),I=1,M2)
0 FORMAT(250F0.0)
HIS LARGE A REPEAT COUNT INTENDED AT ABOUT COLUMN 15, LINE 0045

  KY2=1
  DO 90 I=1,KOUNTC
0 SP2(I)=0
  CALL PUTARRAY(2,KY2,SP2)
  M4=M5*(M2+1)
  DO 11 J=1,M2
1 CH(J)=C(J)*R
3 K0=0
  KOUNT=0
  KY=1
  KY1=1
  KY2=1
  YEAR=0
1 DO 110 K=1,M2
  READ(7)(N)
  READ(7)(SP1(I),I=1,N)
  READ(7)(CUMNOM(I),I=1,N)
  ~~DO 50 I=1,M8~~ - - - - - - - - - - IF(K.EQ.KZ.OR.K.EQ.(KZ+2))GO TO 110
8 IS=FPMCRV(RNS)*100
  IF(IS-0)58,58,0
  IF((K0+1)-(M5*3))33,33,0
  DO 31 J=1,N
  IF(IS-CUMNOM(J))32,32,0
1 CONTINUE
2 SP2(I)=SP1(J)
  GO TO 50
3 IF(IS-CUMNOM(1))58,0,53
  SP2(I)=SP1(1)
  GO TO 50
```

```
 55 DO 51 J=2,N
    IF(CUMNOM(J)-IS)0,52,56
 51 CONTINUE
 52 SP2(I)=SP1(J)
    GO TO 50
 56 SP2(I)=((IS-CUMNOM(J-1))/(CUMNOM(J)-CUMNOM(J-1)))*(SP1(J)-SP1(J-1
   1)+SP1(J-1)
 50 CONTINUE
    RNS=RNS+0.0003
    IF(RNS-0)22,22,0
    IF(RNS-0.50)21,0,21
 22 RNS=0.02
 21 K0=K0+1
    IF(K0-M5)60,60,0
    IF(K0-(M5*2))61,61,0
    IF(K0-(M5*3))62,62,0
    IF(K0-(M5*4))63,63,0
    DO 76 I=1,M8
 76 RTR(I,K)=SP2(I)
    GO TO 110
 60 DO 970 I=1,M8
970 U(I,K)=SP2(I)
    GO TO 110
 61 DO 70 I=1,M8
 70 RB(I,K)=SP2(I)
    GO TO 110
 62 DO 72 I=1,M8
 72 RE(I,K)=SP2(I)
    GO TO 110
 63 DO 74 I=1,M8
 74 RTF(I,K)=SP2(I)
110 CONTINUE
    IF(K0-M4)101,0,0
    J1=1
    J2=1
    J3=1
    J4=1
    DO 200 I=1,M8
    IF(P(I).LE.LH1.AND.P(I).GE.LL1)GO TO 910
    IF(P(I).LE.LH2.AND.P(I).GE.LL2)GO TO 911
    IF(P(I).LE.LH3.AND.P(I).GE.LL3)GO TO 912
    R0(I,1)=RB(J4,4)
    R0(I,2)=RE(J4,4)
    R0(I,3)=RTF(J4,4)
    R0(I,4)=RTR(J4,4)
    U0(I)=U(J4,4)
    J4=J4+1
    GO TO 200
910 R0(I,1)=RB(J1,1)
    R0(I,2)=RE(J1,1)
    R0(I,3)=RTF(J1,1)
    R0(I,4)=RTR(J1,1)
    U0(I)=U(J1,1)
    J1=J1+1
    GO TO 200
911 R0(I,1)=RB(J2,2)
    R0(I,2)=RE(J2,2)
    R0(I,3)=RTF(J2,2)
    R0(I,4)=RTR(J2,2)
    U0(I)=U(J2,2)
    J2=J2+1
    GO TO 200
912 R0(I,1)=RB(J3,3)
    R0(I,2)=RE(J3,3)
    R0(I,3)=RTF(J3,3)
    R0(I,4)=RTR(J3,3)
```

```
     UV(I)=U(J3,3)
     J3=J3+1
 200 CONTINUE
     CALL PUTARRAY(8,KY,R0)
     CALL PUTARRAY(8,KY,U0)
     YEAR=YEAR+1
     IF(YEAR-YEARC)0,401,401
     K0=0
     REWIND 7
     GO TO 101
 401 IF(KODE-1)400,0,0
     CALL GETARRAY(2,KY2,SP2)
 400 DO 250 J=1,M2
     OS(1,J)=STOCK(J)
     MM(J)=0
     S(J)=0.0
     TLC(J)=0
 250 AS(J)=0.0
     NN=0
     L1=0
     YEAR=0
     KY=1
  12 DO 14 I=1,M8
  14 LC(I)=0
     IF(KODE-1)840,0,0
     CALL GETARRAY(3,KY1,MAX)
 840 CALL GETARRAY(8,KY,R0)
     CALL GETARRAY(8,KY,U0)
     DO 15 J=1,M2
     DO 15 I=1,M8
     RB(I,J)=R0(I,J)
  15 SP1(I)=U0(I)
     DO 330 I=1,M8
     IF(I-ITIME)900,0,900
     CALL GETARRAY(3,KY1,MAX)
     IF((YEAR+1)-YEARC)0,900,900
     KY1=KY1-M2*2
 900 DO 300 J=1,M2
     IF(OS(I,J)-MAX(J))300,0,0
     R0(I,J)=0
 300 CONTINUE
     DO 260 J=1,M2
 260 AV(J)=OS(I,J)+R0(I,J)
     MINAV=AV(1)
     DO 270 J=1,M2
     IF(AV(J)-MINAV)0,0,270
     MINAV=AV(J)
     J1=J
 270 CONTINUE
     IF(U0(I)-0)0,0,601
     LC(I)=0
     GO TO 320
 601 IF(P(I)-MINAV)0,0,371
     LOSS(I)=0
     LC(I)=0
     IF(U0(I)-MINAV)320,372,372
 371 IF(P(I)-U0(I))0,102,102
     LOSS(I)=P(I)-MINAV
     GO TO 103
 102 IF(U0(I)-MINAV)320,320,0
     LOSS(I)=U0(I)-MINAV
 103 LC(I)=J1
     TLC(J1)=TLC(J1)+LOSS(I).
 372 U0(I)=MINAV
 320 DO 330 J=1,M2
     OS(I,J)=AV(J)-U0(I)
```

```
      IF(RO(I,J)-RB(I,J))0,395,395
      MM(J)=MM(J)+1
  395 S(J)=S(J)+CS(I,J)
  330 CS(I+1,J)=CS(I,J)
      DO 390 I=1,M8
      L1=L1+LOSS(I)
      IF(UO(I)-SP1(I))0,390,390
      NN=NN+1
  390 CONTINUE
      L=L1/(YEAR+1)
      NX=NN/(YEAR+1)
      DO 500 J=1,M2
      AS(J)=S(J)/(M8*(YEAR+1))
      MX(J)=MM(J)/(YEAR+1)
      TLX(J)=TLC(J)/(YEAR+1)
      IF(MAX(J)-XY(J))515,515,0
      COST(J)=((MAX(J)-XY(J))/DIV(J))*TC(J)+AS(J)*CH(J)
      GO TO 500
  515 COST(J)=AS(J)*CH(J)
  500 CONTINUE
      TCOST=0.0
      DO 516 J=1,M2
  516 TCOST=TCOST+COST(J)
      TCOST=TCOST+L*COS
      YEAR=YEAR+1
      IF(YEAR-YEARC)0,13,13
      DO 20 J=1,M2
   20 CS(1,J)=CS(M8,J)
      GO TO 12
   13 KOUNT=KOUNT+1
      IF(KODE-0)810,0,810
```

```
   18 IF(KOUNT-KOUNTC)0,0,520
      NO=KOUNT
      GO TO 545
  520 IF(TCOST-HI)0,525,525
  545 DO 530 J=1,M2
      RTF(NO,J)=MAX(J)
      ASZ(NO,J)=AS(J)
      RTR(NO,J)=TLX(J)
  530 RE(NO,J)=MM(J)
      CUMNOM(NO)=TCOST
      U(NO,2)=L
      U(NO,3)=NN
      IF(KOUNT-KOUNTC)525,0,0
      HI=CUMNOM(1)
      DO 541 K=1,KOUNTC
      IF(CUMNOM(K)-HI)541,0,0
      HI=CUMNOM(K)
      NO=K
  541 CONTINUE
  525 MAX(4)=MAX(4)-MAXS
      IF(MAX(4)-MAXC)0,400,400
      MAX(4)=MAXHI
      MAX(3)=MAX(3)-MAXS
      IF(MAX(3)-MAXC)0,400,400
      MAX(3)=MAXHI
      MAX(4)=MAXHI
      MAX(2)=MAX(2)-MAXS
      IF(MAX(2)-MAXC)0,400,400
      MAX(2)=MAXHI
      MAX(3)=MAXHI
      MAX(4)=MAXHI
      MAX(1)=MAX(1)-MAXS
      IF(MAX(1)-MAXC)0,400,400
      DO 16 J=1,M2
   16 MAX(J)=MAXHI
      HI=CUMNOM(1)
      DO 540 I=1,KOUNTC
      DO 542 K=1,KOUNTC
      IF(CUMNOM(K)-HI)542,0,0
      HI=CUMNOM(K)
      NO=K
   42 CONTINUE
      TCOSTZ(I)=HI
      U(I,1)=NO
      CUMNOM(NO)=-1000000
   40 HI=-1000000
      DO 17 I=1,KOUNTC
      WRITE(9,1005)(RTF(U(I,1),J),J=1,M2)
   05 FORMAT(4I10/)
      WRITE(6,350)(J,RTF(U(I,1),J),ASZ(U(I,1),J),RTR(U(I,1),J),RE(U(I,1)
     1,J),I=1,M2),TCOSTZ(I),U(U(I,1),2),U(U(I,1),3)
   17 CONTINUE
      NS=NS+1
```

```
  GO TO 820
0 WRITE(6,350)(J,MAX(J),AS(J),TLX(J),MX(J),J=1,M2),TCOST,L,NX
0 FORMAT(1H0,2(/),6X,13HMAXIMUM STOCK,6X,13HAVERAGE STOCK,6X,11HLOSS
  1 CAUSED,6X,2HMM,6X,4HCOST,6X,10HTOTAL LOSS,6X,2HNN/6X,13(1H=),6X,
  213(1H=),6X,11(1H=),6X,2(1H=),6X,4(1H=),6X,10(1H=),6X,2(1H=)/4(//2X
  3,I3,9X,I5,13X,F6.0,13X,I4,4X,I4),1X,F9.0,11X,I5,4X,I4)
   IF(NS-1)0,902,902
03 WRITE(6,340)(P(I),(OS(I,J),RO(I,J),CS(I,J),J=1,M2),UO(I),LOSS(I),
  1LC(I),I=1,M8)
40 FORMAT(1H1//2X,4HPROG,2X,5HO/S B,2X,5HREC B,2X,5HC/S B,2X,5HO/S E,
  12X,5HREC E,2X,5HC/S E,2X,6HO/S FS,2X,6HREC FS,2X,6HC/S FS,2X,
  26HO/S RS,2X,6HREC RS,2X,6HC/S RS,2X,5HUSAGE,2X,4HLOSS,2X,4HCODE/
  32X,4(1H=),2X,5(1H=),2X,5(1H=),2X,5(1H=),2X,5(1H=),2X,5(1H=),2X,
  45(1H=),2X,6(1H=),2X,6(1H=),2X,6(1H=),2X,6(1H=),2X,6(1H=),2X,6(1H=)
  5,2X,5(1H=),2X,4(1H=),2X,4(1H=)///250(2X,I4,3X,I4,3X,I4,3X,I4,3X,
  6I4,3X,I4,3X,I4,4X,I4,4X,I4,4X,I4,4X,I4,4X,I4,4X,I4,3X,I4,2X,I4,
  72X,I4/))
THIS LARGE A REPEAT COUNT INTENDED AT ABOUT COLUMN 41, LINE 0252

02 SP2(KOUNT)=SP2(KOUNT)+L
    IF(KOUNT-KOUNTC)400,0,0
    KY2=1
    CALL PUTARRAY(2,KY2,SP2)
    NS=NS+1
    IF(NS-NSC)0,414,414
    REWIND 7
    GO TO 443
414 KY2=1
    CALL GETARRAY(2,KY2,SP2)
    DO 91 I=1,KOUNTC
 91 SP2(I)=SP2(I)/NSC
    KY1=1
    DO 92 I=1,KOUNTC
    CALL GETARRAY(3,KY1,MAX)
    WRITE(6,93)(MAX(J),J=1,M2)
 93 FORMAT(1H0,10X,4I10)
    WRITE(6,94)SP2(I)
 94 FORMAT(10X,I10)
    KY1=KY1+M2
 92 CONTINUE
    GO TO 814
820 NS=NS+1
    IF(NS-NSC)0,814,814
    REWIND 7
    GO TO 443
814 STOP
    END

ENGTH  1501, NAME  NONM      - COMMENTS
```

APPENDIX - C1

ANALYSIS OF ADO 16 FOUR DOOR BODY SHELL STOCKS, LONGBRIDGE 1968/69.

WEEK No.	OPENING STOCK.	WEEK No.	OPENING STOCK.
1)	N/A[1]	27	112
2)		28	149
3	485	29	-17
4	449	30	-
5	410	31	455
6	183	32	613
7	121	33	772
8	167	34	504
9	262	35	560
10	274	36	194
11	415	37	335
12	558	38	258
13	624	39	180
14	613	40	321
15	529	41	319
16	442	42	320
17	257	43)	HOLIDAYS
18	23	44)	
19	18	45	63
20	118	46	161
21	309	47	399
22	190	48	523
23	328	49	623
24	158	50	468
25	113	51	470
26	198	52	HOLIDAYS
		52A	746

[1] N/A = Figures Not Available.

APPENDIX C2

LIST OF COST INFORMATION

1) Cost of Material and Labour.

Body shell (ADO 16 four door)	£80-55[1]
Power unit (1100/1300)	£100-57[2]
Front Suspension units	£28-74 per pair[3]
Rear Suspension units	£13-72 per pair

[1] Weighted average of the costs of material and labour from West Works and PSF.

[2] Weighted average of the costs of all relevant power units.

[3] Weighted average of the costs of manual and automatic units.

2) Trailer and Pallet Capacities.

For body shells		Trailer capacity - 6
For power units		Trailer capacity 26 (on trolleys)
	OR	Trailer capacity 96 (in pallets holding 4)
For suspension units		Trailer capacity - 180 prs. (in pallets holding 15 singles each.)
	OR	Trailer capacity - 300 prs. (in pallets holding 15 singles each.)

3) Cost of Trailers and Accessories.*

For body shells		£1250
For power units		£1400 plus £468 for trolleys
	OR	£2200 plus £720 for pallets
For suspension units		£1800 plus £132 for pallets
	OR	£2200 plus £440 for pallets.

* The cost of trailers used for the model include trolley or pallet costs where applicable.

APPENDIX - C3

PILOT TESTS FOR EXTRACT ROUTINE

In order to establish some relationship between the ranking of policies according to minimum cost in any one run and the bottom area of the true total cost curves, pilot tests were carried out in which 81 policies were simulated over the optimum run length five times. The best 30 policies from each run were extracted and the top 10 policies of each run were then analysed with respect to their ranking in other runs. This was carried out for both the 449/204 programme level and the 500/230 level. The results of these tests were as follows:

Programme Level: 449/204

Run No.	Policy.	Ranking.	Ranking in other Runs.			
			Run No.			
1			2	3	4	5
	1000/1500/1500/2000[1]	1	6	12	23	7
	1000/2000/1500/2000	2	5	3	2	4
	1000/1500/2000/2000	3	11	15	27	3
	1000/1500/1000/2000	4	-	19	-	24
	1000/2000/2000/2000	5	2	5	4	8
	1000/1500/1500/1500	6	4	29	24	14
	1000/2000/1000/2000	7	-	1	10	-
	1000/1500/2000/1500	8	9	30	29	1
	1000/2000/1500/1500	9	3	8	1	2
	1500/1500/1500/2000	10	18	10	11	27

[1] The ceiling levels for Body Shells, Power Units, Front Suspension Units and Rear Suspension Units are always given in that order for each policy.

APPENDIX - C3 (Cont'd)

Programme Level: 449/204

Run No.	Policy.	Ranking.	Ranking in other Runs.			
			Run No.			
			1	3	4	5
2						
	1000/2000/2000/1500	1	11	11	3	5
	1000/2000/2000/2000	2	5	5	4	8
	1000/2000/1500/1500	3	9	8	1	2
	1000/1500/1500/1500	4	6	29	24	14
	1000/2000/1500/2000	5	2	3	2	4
	1000/1500/1500/2000	6	1	12	23	17
	1500/2000/1500/1500	7	20	9	7	10
	1500/2000/1500/2000	8	14	2	8	11
	1000/1500/2000/1500	9	8	30	29	1
	1000/2000/2000/1000	10	-	-	-	7

Run No.	Policy.	Ranking.	Run No.			
3			1	2	4	5
	1000/2000/1000/2000	1	7	-	10	-
	1500/2000/1500/2000	2	14	8	8	11
	1000/2000/1500/2000	3	2	5	2	4
	1500/2000/2000/2000	4	16	13	6	9
	1000/2000/2000/2000	5	5	2	4	8
	1500/2000/1000/2000	6	22	-	15	-
	1000/2000/1000/1500	7	17	-	9	22
	1000/2000/1500/1500	8	9	3	1	2
	1500/2000/1500/1500	9	20	7	7	10
	1500/1500/1500/2000	10	10	18	11	27

APPENDIX - C3 (Cont'd)

Programme Level: 449/204

Run No.	Policy	Ranking.	Ranking in other Runs.			
			Run No.			
4			1	2	3	5
	1000/2000/1500/1500	1	9	3	8	2
	1000/2000/1500/2000	2	2	5	3	4
	1000/2000/2000/1500	3	11	1	11	5
	1000/2000/2000/2000	4	5	2	5	8
	1500/2000/2000/1500	5	21	12	13	6
	1500/2000/2000/2000	6	16	13	4	9
	1500/2000/1500/1500	7	20	7	9	10
	1500/2000/1500/2000	8	14	8	2	11
	1000/2000/1000/1500	9	17	-	7	22
	1000/2000/1000/2000	10	7	-	1	-
			Run No.			
5			1	2	3	4
	1000/1500/2000/1500	1	8	9	30	29
	1000/2000/1500/1500	2	9	3	8	1
	1000/1500/2000/2000	3	3	11	15	27
	1000/2000/1500/2000	4	2	5	3	2
	1000/2000/2000/1500	5	11	1	11	3
	1500/2000/2000/1500	6	21	12	13	6
	1000/2000/2000/1000	7	-	10	-	-
	1000/2000/2000/2000	8	5	2	5	4
	1500/2000/2000/2000	9	16	13	4	9
	1500/2000/1500/1500	10	20	7	9	7

APPENDIX - C3 (Cont'd)

Programme Level: 500/230

Run No.	Policy.	Ranking	Ranking in other Runs.			
			Run No.			
1			2	3	4	5
	1500/1000/1000/2000	1	–	19	5	6
	1500/1000/1500/2000	2	4	5	8	1
	1500/1000/2000/2000	3	2	12	10	3
	2000/1000/1000/2000	4	–	17	2	20
	2000/1000/1500/2000	5	12	1	4	9
	2000/1000/1500/1500	6	10	2	3	–
	1500/1500/1000/2000	7	–	8	21	12
	2000/1000/2000/2000	8	6	3	7	13
	1500/1000/1500/1500	9	3	9	9	29
	2000/1000/1000/1500	10	–	–	1	–
			Run No.			
2			1	3	4	5
	1500/1000/2000/1500	1	14	25	11	–
	1500/1000/2000/2000	2	3	12	10	3
	1500/1000/1500/1500	3	9	9	9	29
	1500/1000/1500/2000	4	2	5	8	1
	2000/1000/2000/1500	5	11	10	6	–
	2000/1000/2000/2000	6	8	3	7	13
	1500/1000/2000/1000	7	–	–	–	–
	1500/1500/2000/1500	8	–	–	29	–
	1500/1500/2000/2000	9	15	16	26	4
	2000/1000/1500/1500	10	6	2	3	–

APPENDIX C3 (Cont'd)

Programme Level: 500/230

Run No.	Policy	Ranking.	Ranking in other Runs.			
			Run No.			
3			1	2	4	5
	2000/1000/1500/2000	1	5	12	4	9
	2000/1000/1500/1500	2	6	10	3	–
	2000/1000/2000/2000	3	8	6	7	13
	2000/1500/1500/2000	4	23	26	17	14
	1500/1000/1500/2000	5	2	4	8	1
	2000/1500/2000/2000	6	27	15	22	17
	2000/1500/1500/1500	7	24	22	18	–
	1500/1500/1000/2000	8	7	–	21	12
	1500/1000/1500/1500	9	9	3	9	29
	2000/1000/2000/1500	10	11	5	6	–

Run No.	Policy	Ranking.	Ranking in other Runs.			
			Run No.			
4			1	2	3	5
	2000/1000/1000/1500	1	10	–	–	–
	2000/1000/1000/2000	2	4	–	17	20
	2000/1000/1500/1500	3	6	10	2	–
	2000/1000/1500/2000	4	5	12	1	9
	1500/1000/1000/2000	5	1	–	19	6
	2000/1000/2000/1500	6	11	5	10	–
	2000/1000/2000/2000	7	8	6	3	13
	1500/1000/1500/2000	8	2	4	5	1
	1500/1000/1500/1500	9	9	3	9	29
	1500/1000/2000/2000	10	3	2	12	3

APPENDIX - C3 (Cont'd)

Programme Level: 500/230

Run No.	Policy.	Ranking	Ranking in other Runs.			
			Run No.			
5			1	2	3	4
	1500/1000/1500/2000	1	2	4	5	8
	1500/1500/1500/2000	2	12	18	13	23
	1500/1000/2000/2000	3	3	2	12	10
	1500/1500/2000/2000	4	15	9	16	26
	1000/1000/1500/2000	5	17	-	27	15
	1500/1000/1000/2000	6	1	-	19	5
	1000/1000/2000/2000	7	22	16	-	20
	1000/1000/1000/2000	8	13	-	-	-
	2000/1000/1500/2000	9	5	12	1	4
	2000/1500/1000/2000	10	19	-	11	12

In order to obtain some measure of how good an approximation to the policies at the bottom of the true total cost curve the top ten policies of any one run were, the mean number of policies out of the best ten of any one run that appeared amongst the top ten of any of the other runs was calculated. The higher this average is, the closer the top ten policies of any run will be to the true best ten policies. The five runs yielded 20 samples and the results showed that there was a .975 confidence of means of 4 and 5 (for programme levels of 500/230 and 449/204 respectively), or higher, occurring. This was considered to be accurate enough for the experimental work, and so it was decided to extract the best 10/81, or 12½%, policies from the first simulation of the full review to be carried out.

APPENDIX C4

Programme Level: 449/204

STOCKING POLICY Bodies;	Power Units;	Ft. Susps;	Rr. Susp.	MEAN TOTAL COST(£'s)	
1250	1750	1250	1500	284396	
1000	2000	1500	1500	286729	
1250	1250	1750	1750	293862	
1250	1250	1500	2000	291651	
1000	1750	1750	1500	291197	
1250	1250	1250	2000	295200	
1000	2000	1500	1250	298866	
1000	1250	2000	1750	302537	
1000	2000	1250	1250	301127	
1000	1500	2000	1500	297766	
1250	2000	1250	1750	274429	(8th Position)
1000	2000	1250	1500	287122	
1250	1250	1500	1750	293471	
1000	1250	1750	2000	296895	
1250	2000	2000	2000	280363	
1250	1500	1250	1500	291492	
1000	1750	1500	1500	283248	
1250	2000	2000	1750	275459	(10th Position)
1000	1250	1750	1750	301322	
1250	1750	1250	1750	280113	
1000	1500	1750	1500	297019	
1000	1750	1500	1250	302762	
1000	1750	1250	1250	303774	
1250	2000	1750	2000	271614	(2nd Position)
1250	1750	2000	2000	296905	
1000	1750	1250	1500	291308	
1000	1250	1500	2000	297855	
1000	2000	1000	2000	288694	
1250	1750	2000	1750	270563	(1st Position)
1250	2000	1250	2000	273039	(4th Position)
1250	2000	1750	1750	273710	(6th Position)
1250	2000	1500	2000	271681	(3rd Position)
1000	1250	1500	1750	301158	
1000	1500	1500	1500	297216	
1250	1750	1750	2000	274263	(7th Position)

APPENDIX
C4 (Cont'd)

STOCKING POLICY				MEAN TOTAL COST(£'s)	
1250	1500	2000	2000	282185	
1250	1500	1250	1750	283674	Programme
1000	1500	1500	1250	306752	Level: 449/204
1250	2000	1500	1750	273291	(5th Position)
1000	1250	1250	1750	302114	
1000	1500	1250	1250	309427	
1000	1500	1250	1500	297693	
1250	1500	2000	1750	284999	
1250	1750	1250	2000	277631	
1250	1750	1750	1750	277149	
1250	1750	1500	2000	275071	(9th Position)
1000	1750	1000	2000	293776	
1250	1500	1750	2000	280495	
1250	1750	1500	1750	277382	
1000	2000	2000	2000	278040	
1250	1500	1250	2000	282704	
1250	1500	1750	1750	283301	
1250	1500	1500	2000	281232	
1000	1500	1000	2000	297100	
1000	2000	2000	1750	280210	
1250	1500	1500	1750	283269	
1000	1750	2000	2000	282627	
1000	2000	1750	2000	276345	
1000	1750	2000	1750	285247	
1000	2000	1750	1750	278665	
1000	1750	1750	2000	281241	
1000	1500	2000	2000	288468	
1000	2000	1500	2000	276807	
1000	2000	1250	2000	278575	
1000	1750	1750	1750	283897	
1000	1500	2000	1750	292263	
1000	2000	1500	1750	278370	
1000	1500	1750	2000	287130	
1000	1750	1500	2000	281122	
1000	2000	1250	x1750	280383	
1000	1750	1250	2000	281063	

APPENDIX
C4 (Cont'd)

STOCKING POLICY				MEAN TOTAL COST(£'s)
1000	1500	1750	1750	291011
1000	1750	1500	1750	283485
1000	1750	1250	1750	284403
1000	1500	1500	2000	287280
1000	1500	1250	2000	288090
1000	1500	1500	1750	291835
1000	1500	1250	1750	290751

Programme
Level: 449/204

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APPENDIX C5

Programme Level: 500/230

STOCKING POLICIES				MEAN TOTAL COST (£'s)	
2000	1000	1750	1500	494339	
1750	1250	1500	2000	482053	
1750	1250	1500	1750	488959	
1750	1250	1000	1750	502416	
1250	1250	1000	2000	500596	
1000	1250	1500	2000	504141	
1250	1000	2000	1750	493316	
1750	1000	1000	1500	509005	
1750	1250	1500	1500	498261	
2000	1250	1000	2000	494196	
1500	1000	1250	1500	498808	
1250	1250	1000	1750	509654	
1250	1500	1750	2000	495049	
1500	1250	2000	2000	481948	
1500	1250	2000	1750	489067	
2000	1000	1750	1750	485045	
1500	1500	1000	2000	500956	
1750	1250	1250	2000	483133	
1000	1250	1250	2000	507238	
2000	1000	1750	2000	478633	(8th Position)
1750	1250	1250	1500	502711	
1750	1250	1250	1750	490723	
1250	1000	1750	1750	492117	
2000	1000	1500	1500	495382	
1750	1250	1000	1500	512551	
1250	1500	1500	2000	494024	
1500	1250	1750	2000	480673	
1500	1250	1750	1750	488280	
2000	1000	1500	1750	485684	
1750	1000	2000	1500	494103	
2000	1000	1500	2000	478212	(7th Position)
2000	1000	1250	1500	493626	
2000	1000	1000	1750	497934	
1250	1500	1250	2000	496748	
1250	1000	1500	1750	491598	

APPENDIX

C5 (Cont'd)

STOCKING POLICIES				MEAN TOTAL COST(£'s)	
1750	1000	2000	1750	484337	
1750	1000	2000	2000	478104	(6th Position)
1750	1000	1750	1500	492676	Programme Level: 500/230
1500	1250	1500	2000	480332	
1500	1250	1500	1750	488416	
2000	1000	1000	2000	492096	
2000	1000	1250	1750	488445	
1750	1250	1000	2000	493765	
2000	1000	1250	2000	481037	
1250	1250	2000	2000	489029	
1250	1000	1250	1750	496436	
1750	1000	1750	1750	483216	
1500	1250	1250	2000	483753	
1250	1000	1000	2000	499067	
1750	1000	1750	2000	477279	(4th Position)
1500	1250	1250	1750	487974	
1750	1000	1500	1500	493617	
1250	1000	1000	1750	508976	
1250	1250	1750	2000	487359	
1750	1000	1500	1750	483728	
1750	1000	1500	2000	477026	(3rd Position)
1750	1000	1250	1500	498265	
1750	1000	1000	1750	498171	
1500	1000	2000	1750	484534	
1500	1000	2000	2000	477284	(5th Position)
1250	1250	1500	2000	487250	
1750	1000	1000	2000	490447	
1750	1000	1250	1750	485497	
1500	1250	1000	2000	495455	
1750	1000	1250	2000	479725	(10th Position)
1500	1000	1750	1750	483010	
1250	1250	1250	2000	490372	
1500	1000	1750	2000	476048	(1st Position)
1250	1000	2000	2000	486204	

APPENDIX

C5(Cont'd)

STOCKING POLICIES				MEAN TOTAL COST(£'s)	
1500	1000	1500	1750	483210	
1500	1000	1500	2000	476696	(2nd Position)
1250	1000	1750	2000	484681	Programme Level: 500/230
1500	1000	1000	1750	497242	
1500	1000	1000	2000	490600	
1500	1000	1250	1750	485625	
1500	1000	1250	2000	479087	(9th Position)
1250	1000	1500	2000	485226	
1250	1000	1250	2000	488346	

****

APPENDIX - C6

RESULTS OF COMPARISON RUNS

	Body Shells	Power Units	Ft. Susp. Units	Rr. Susp. Units	
Mean Total Costs from 1st Group of 15 Comparison Runs	1250 £355370.	1750	2000	1750*	- Near optimum policy computed
	2000 £357416.	2000	2000	2000	- Arbitrary high level policy
	675 £537830.	675	675	675*	- Arbitrary low level policy
	1200 £371947.	2000	1400	1200	- Estimated 1969/70 policy
Mean Total Costs from 2nd Group of 15 Comparison Runs.	1250 £372292.	1750	2000	1750*	- Near optimum policy
	2000 £375405.	2000	2000	2000	- High level policy
	675 £541357.	675	675	675*	- Low level policy
	1200 £399103.	2000	1400	1200	- 1969/70 policy

COMBINED RESULTS FROM 30 COMPARISON RUNS

1250 £363381	1750	2000	1750*	- Near optimum policy
2000 £366410	2000	2000	2000	- High level policy
675 £539593	675	675	675*	- Low level policy
1200 £385525	2000	1400	1200	- 1969/70 policy

---

* These policies have involved a change in ceiling level during the year and only the first combination of ceiling levels is shown here. The second combinations used are 1500/1000/1750/2000 and 750/750/750/750 respectively.

APPENDIX - C7

COMPUTER COSTS AND RUNNING TIMES*

Type of Simulation Run	Running Time.	Cost	Total Cost.
Determining optimum run length for:			
a) 449/204 Programme Level.	30 Minutes	£25	
b) 500/230 " "	" "	£25	
Experimental work for the extract routine:			
a) 449/204 Programme Level.**	87 Minutes	£90-10	
b) 500/230 " "	70 "	£75-30	
The extract run:			
a) 449/204 Programme Level.	120 Minutes	£134-30	
b) 500/230 " "	100 "	£112-30	
30 runs of the extracted policies:			
a) 449/204 Programme Level.	600 Minutes	£508-26	
b) 500/230 " "	500 Minutes	£390	
Comparison Run.	120 Minutes	£80	
			£1440-26

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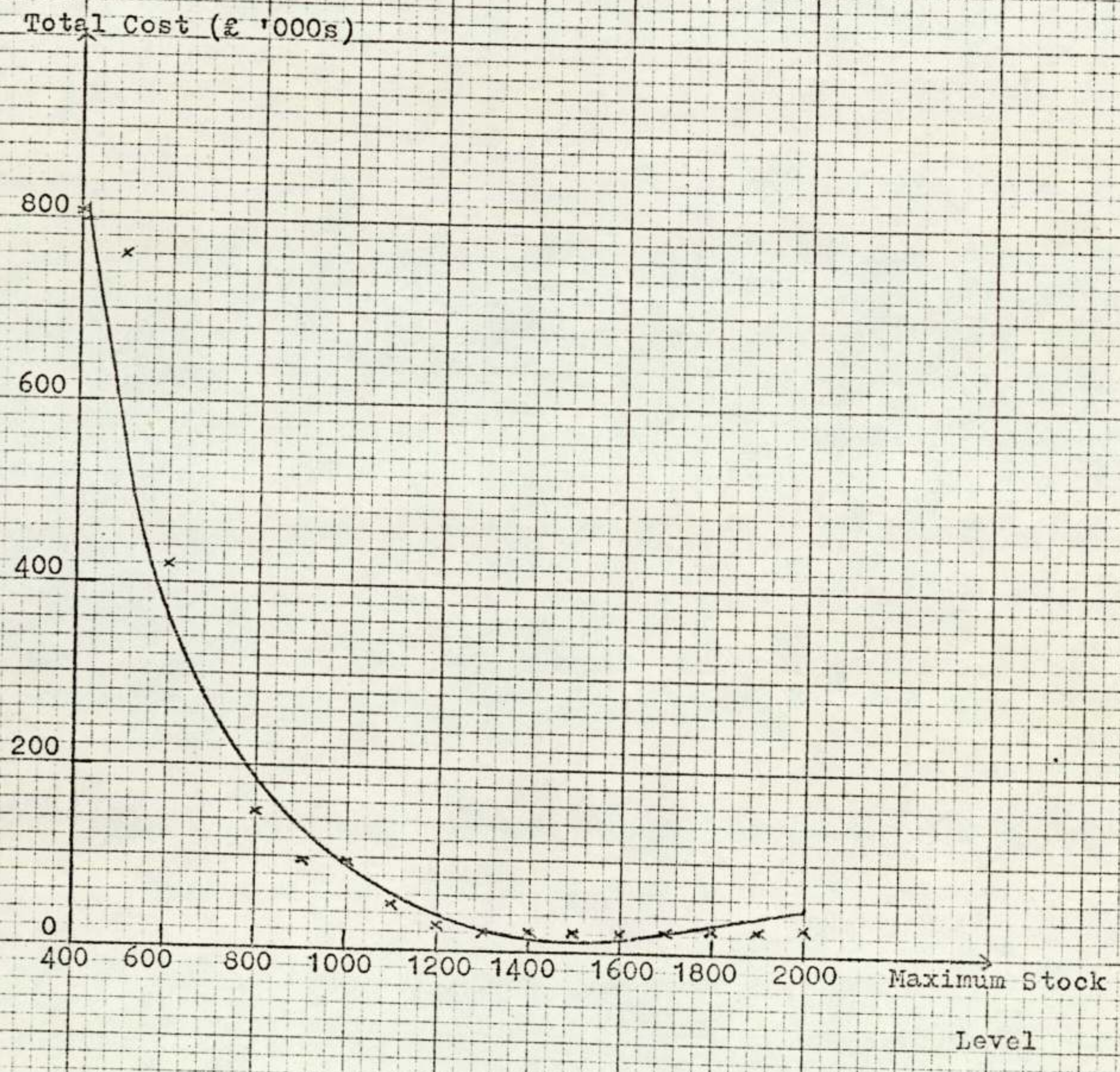
* Based on the scale of charges for external users of the University of Aston computer.

** The 449/204 level had an optimum run length longer than that used for the 500/230 level, so running times for the 449/204 level will be longer and charges will be higher.

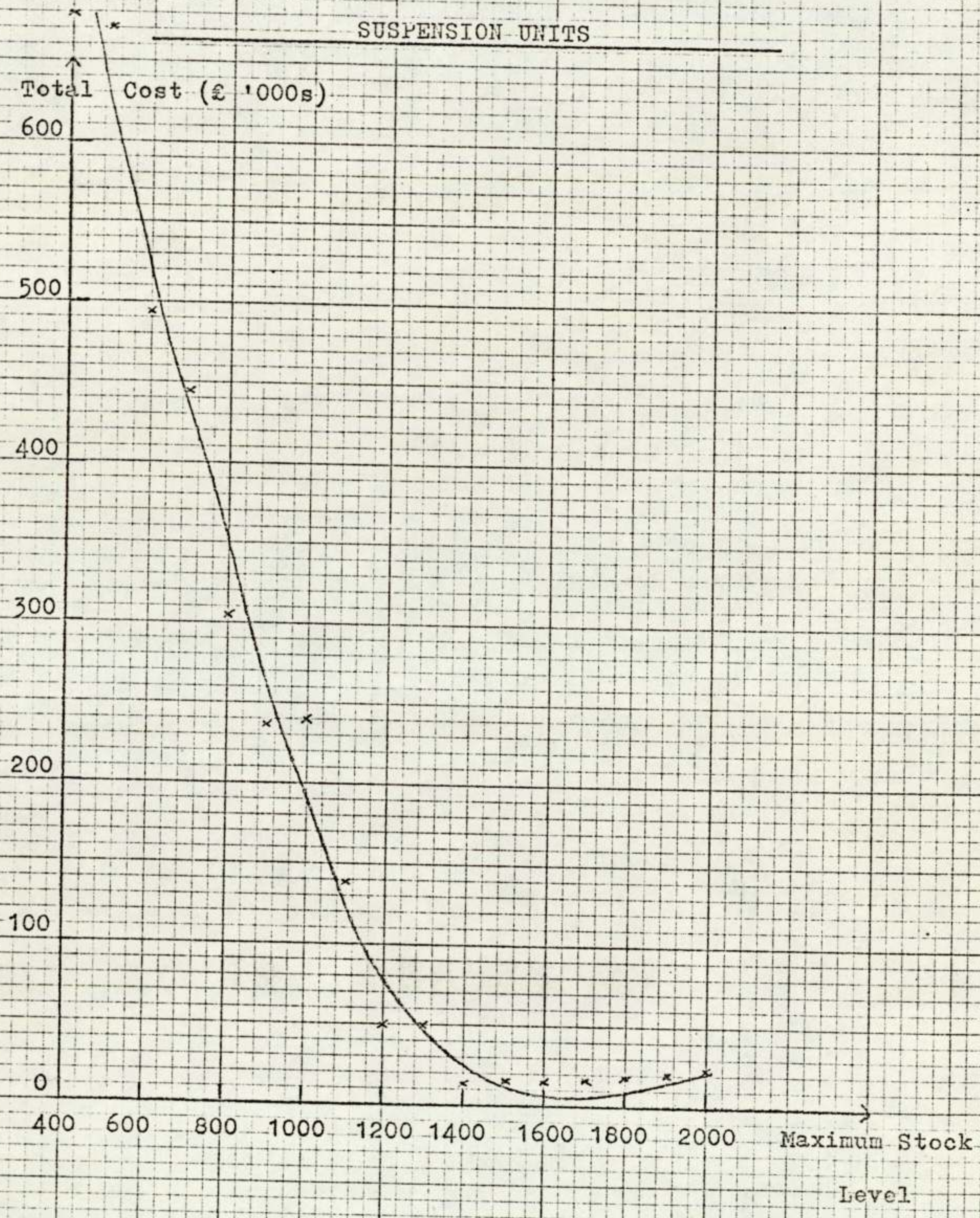
APPENDIX - C8

TOTAL COST CURVE FOR INDIVIDUAL COMPONENT SIMULATION OF FRONT SUSPENSION UNITS



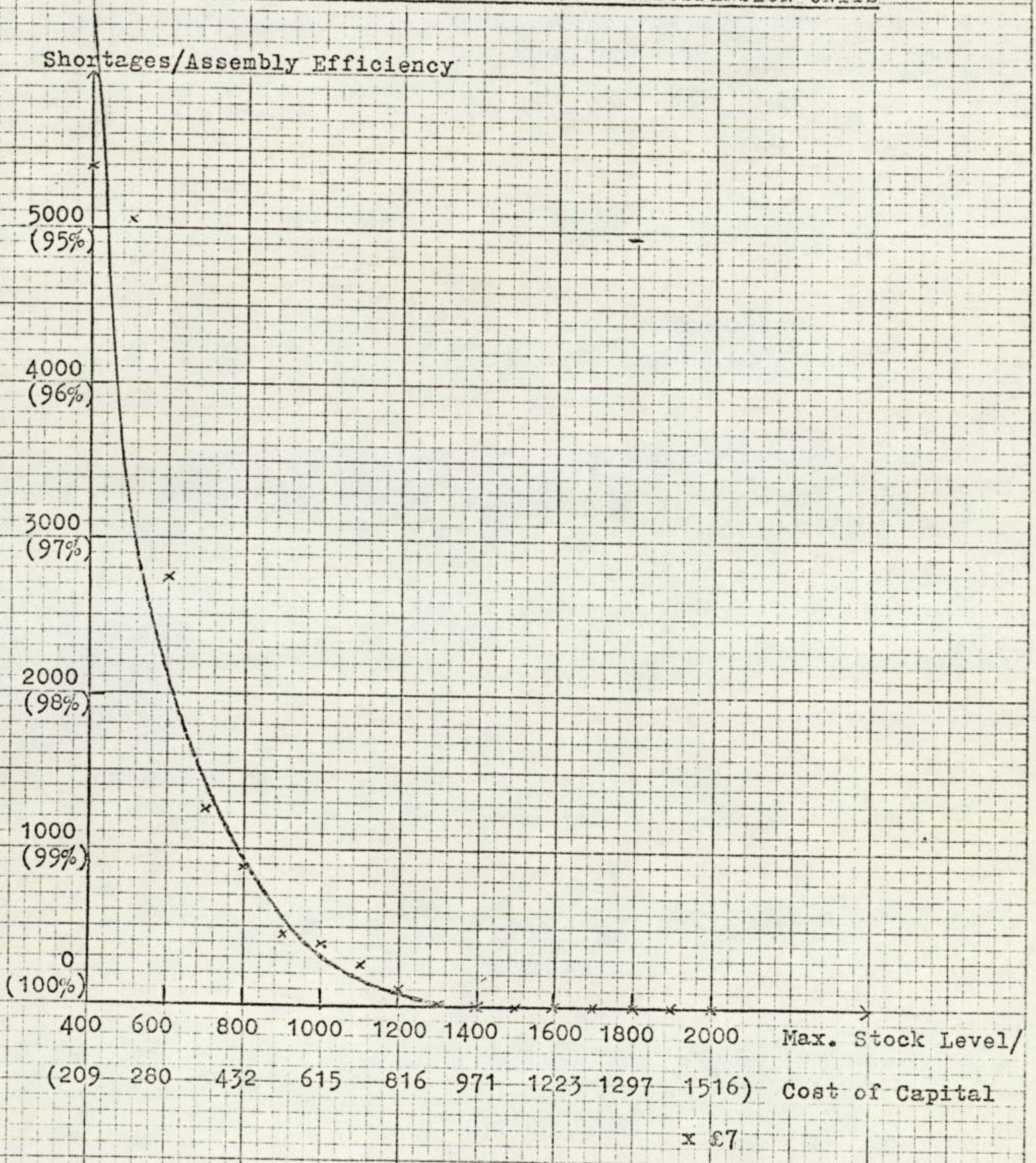
APPENDIX - C9

TOTAL COST CURVE FOR INDIVIDUAL COMPONENT SIMULATION OF REAR SUSPENSION UNITS



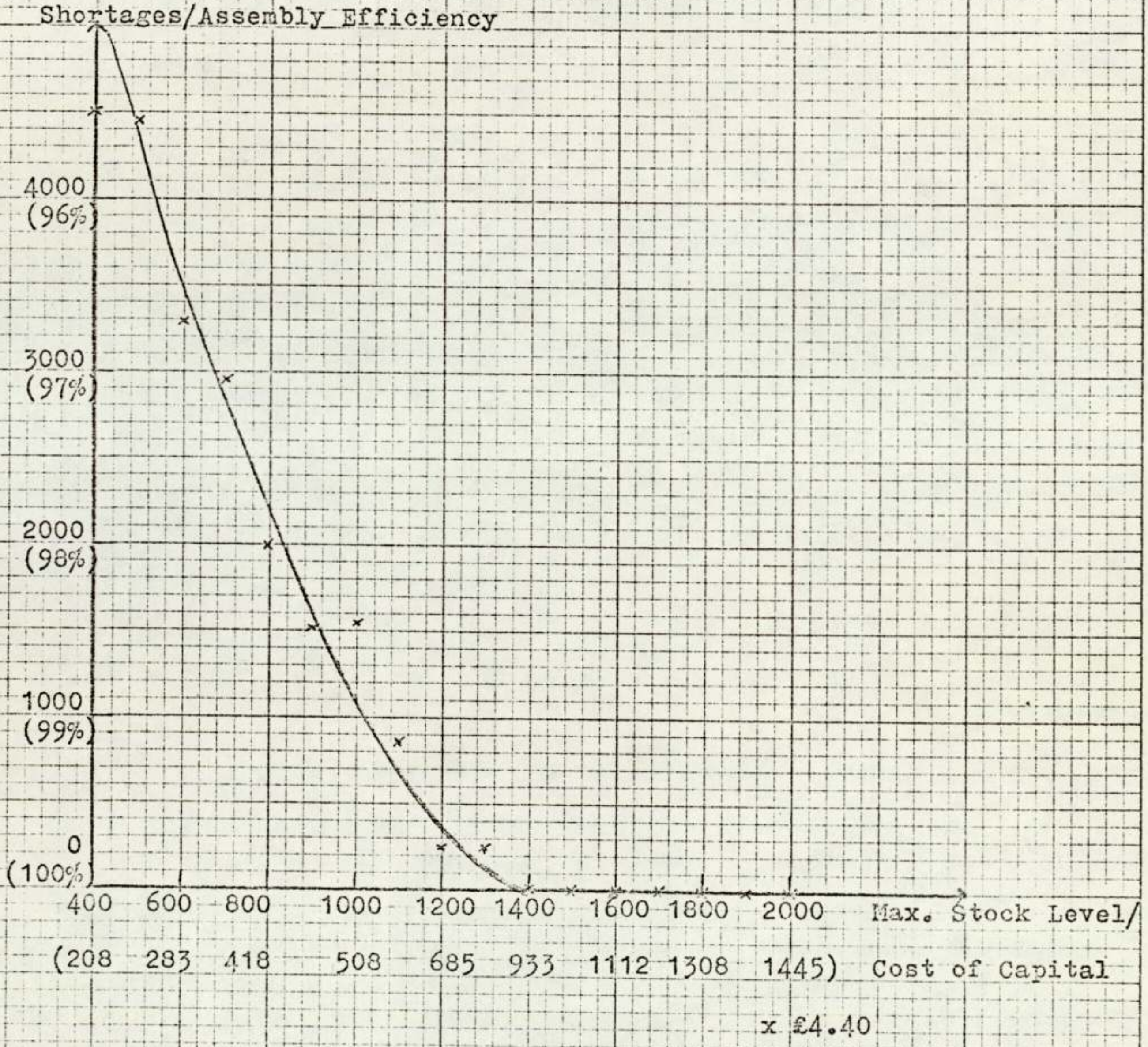
APPENDIX - C10

EFFICIENCY/COST CURVE FOR FRONT SUSPENSION UNITS



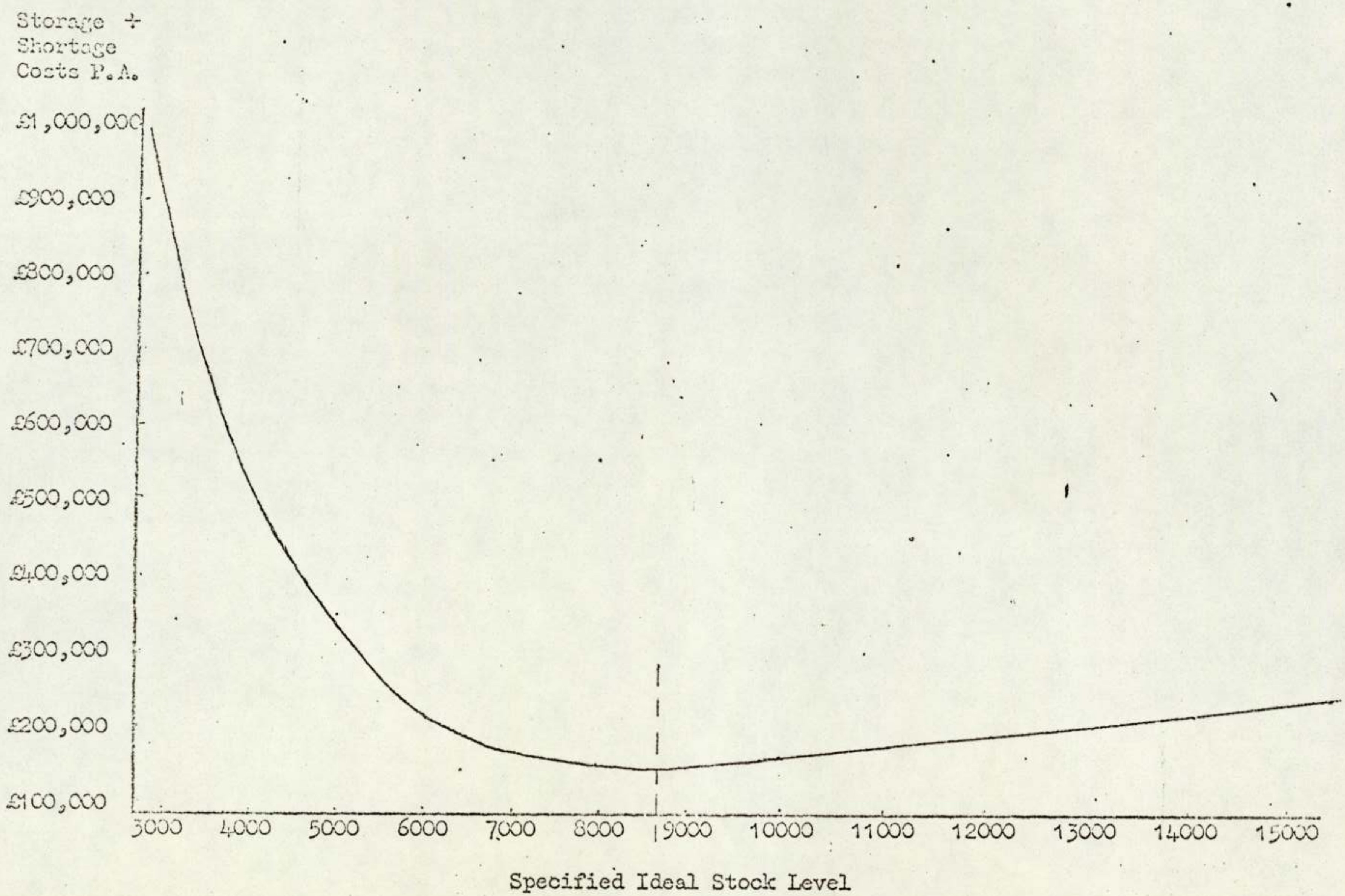
APPENDIX - C11

EFFICIENCY/COST CURVE FOR REAR SUSPENSION UNITS



APPENDIX - C12

EFFECT OF DIFFERENT IDEAL STOCK LEVELS ON TOTAL COSTS



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