AN INVESTIGATION INTO STOCK LEVELS WITHIN A GROUP TECHNOLOGY MANUFACTURING SYSTEM

A THESIS SUBMITTED TO
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FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BY

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SUMMARY OF Ph.D. THESIS ENTITLED "AN INVESTIGATION INTO STOCK LEVELS WITHIN A GROUP TECHNOLOGY MANUFACTURING SYSTEM"

In this thesis, work in progress in a manufacturing system is discussed, highlighting the function of buffer stocks and the factors which determine their operating levels. A particular manufacturing system is analysed, half of which operates on a group technology system and this is used as a basis for studying the mechanism of work in progress and its raison d'être.

Factors such as the method of production planning and control, product variety, transportation, space availability, cost of machine set-ups, cost of interest, have been found to affect work in progress (w.i.p.) levels. These factors are discussed and evaluated in economic terms where possible.

An optimum operating level of work in progress is recommended for the particular system under investigation and the problems of implementing such recommendations are discussed.

Following the investigation into w.i.p. levels within a specific manufacturing system, the importance of being able to determine the approximate optimum w.i.p. levels is emphasised and a methodology is developed for determining this in the general case of any batch manufacturing industry.

DECLARATION

None of the work presented in this thesis has been submitted in support of an application for another degree or other qualification of this or any other institution.

J. M. Gibson.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the following people -
To Professor R. H. Thornley for his enthusiasm in launching the project in the initial stages; to Mr. S. C. Clifford, former Production Director at Ferodo; to Dr. A. J. P. Sabberwal, former Engineering Director at Ferodo and to the late Dr. R. Connolly, Chief Engineer at Ferodo, for supporting the project and for their guidance and helpful criticism.

I am indebted to many people at Ferodo for helping with data collection and also for the enlightening discussions that have transpired. These people are too numerous to mention by name except perhaps for Mr. P. B. Owen and Mr. D. M. Love, with whom I have spent many hours discussing particular points. Their keen and logical criticism has been particularly helpful.

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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction

1.1 The Industry Studied

1.1.1 The Company and its Products

Ferodo is concerned with manufacturing friction material, the principal products being brake linings, disc brake pads and clutch facings.
Fig. 1.1 is a photograph of the product range.
The company is peculiar in that almost exclusively the customer designs and specifies the product as regards its physical shape. However, as regards material type, Ferodo is able to offer a range of materials according to the duty to be performed. The head office and main factory is situated at Chapel-en-le-Frith in Derbyshire, with subsidiary companies throughout the world.
This investigation was carried out at the Chapel-en-le-Frith factory and was mainly concerned with the product group manufacturing moulded drum brake linings (MDBL), but reference will also be made to the disc brake pad manufacturing group (DBP) for comparison purposes.

Ferodo can be said to be a process industry in that it manufactures its own material compound

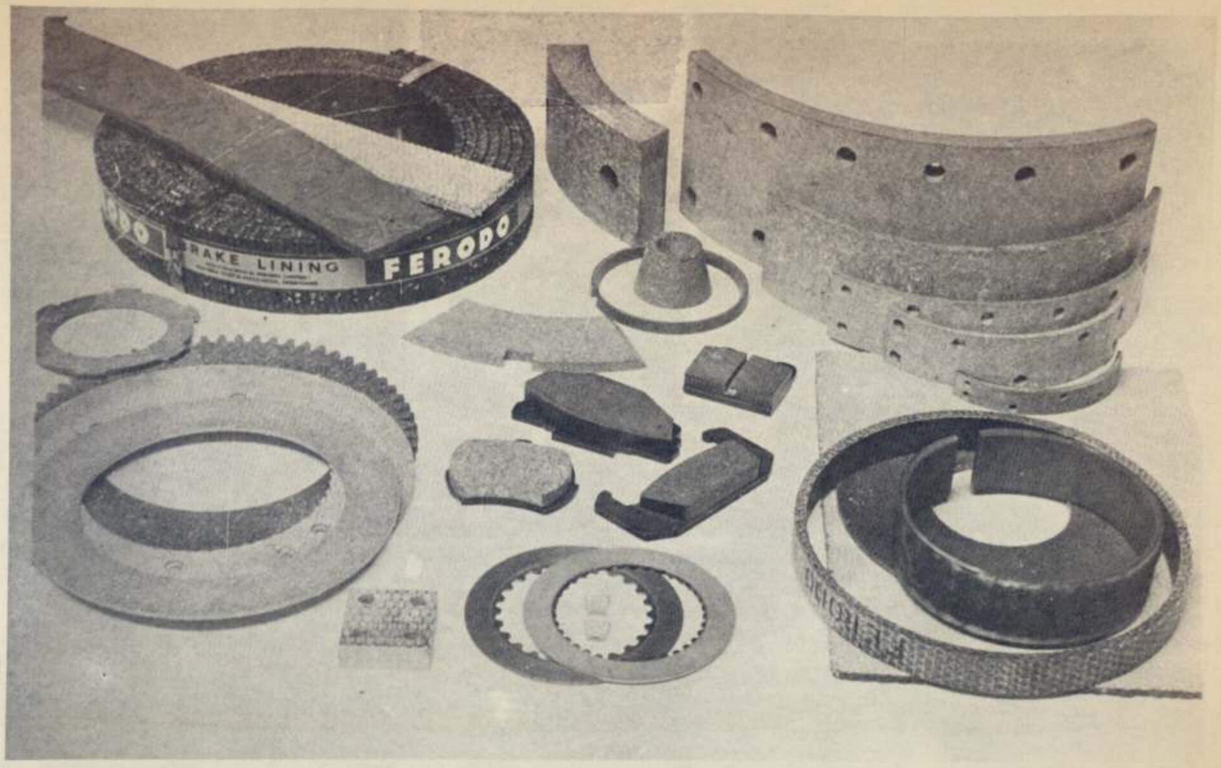


Fig.1.1a A SELECTION OF FERODO PRODUCTS

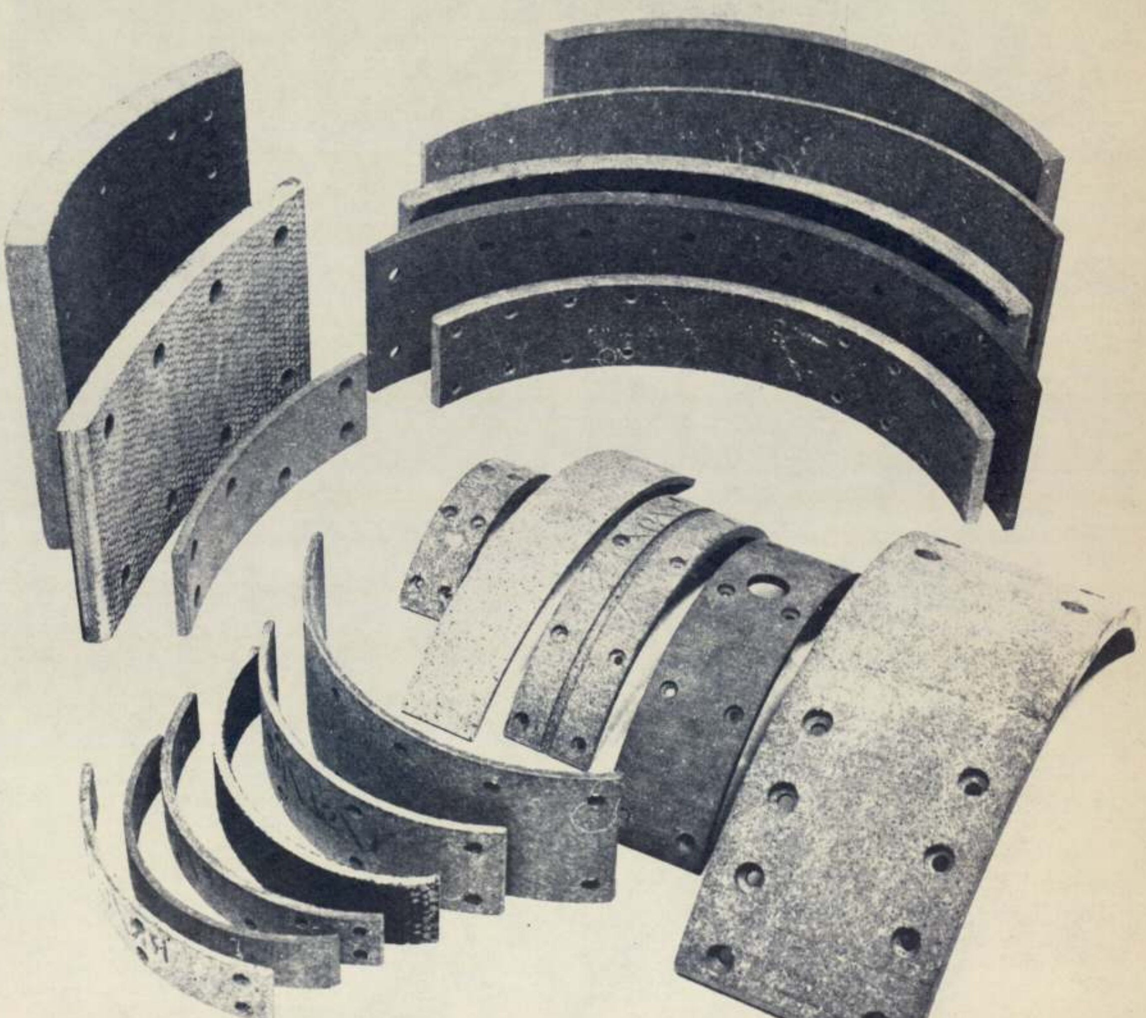


Fig.1.1b A SELECTION OF MOULDED DRUM BRAKE LININGS

from which the final product is machined. The MDBL manufacturing system is divided into two distinct stages, the initial stage operating with a functional layout system and the final stage operating on a group technology (GT) system. The disc brake pad manufacturing system operates on a functional layout principle.

1.1.2 Company Structure

The company is controlled by a Board of Directors, one of whom is responsible for the activity of the Works Division, the main function of this Division being to manufacture. The Manufacturing Division at Chapel-en-le-Frith is composed of four product groups, each of these manufacturing groups being controlled by a Product Manufacturing Manager. Fig. 1.2 shows a detailed breakdown of the MDBL reporting structure. The five production sections are operated on a 3 shift, 24 hour day basis, 5 days per week, thus each section has three section managers associated with it, each manager being responsible for the output on his shift. To give some idea of scale, each of these section managers controls approximately 20 direct operatives and 5 indirect operatives on each shift and the Planning Manager has a department of approximately 40 people working on days only.

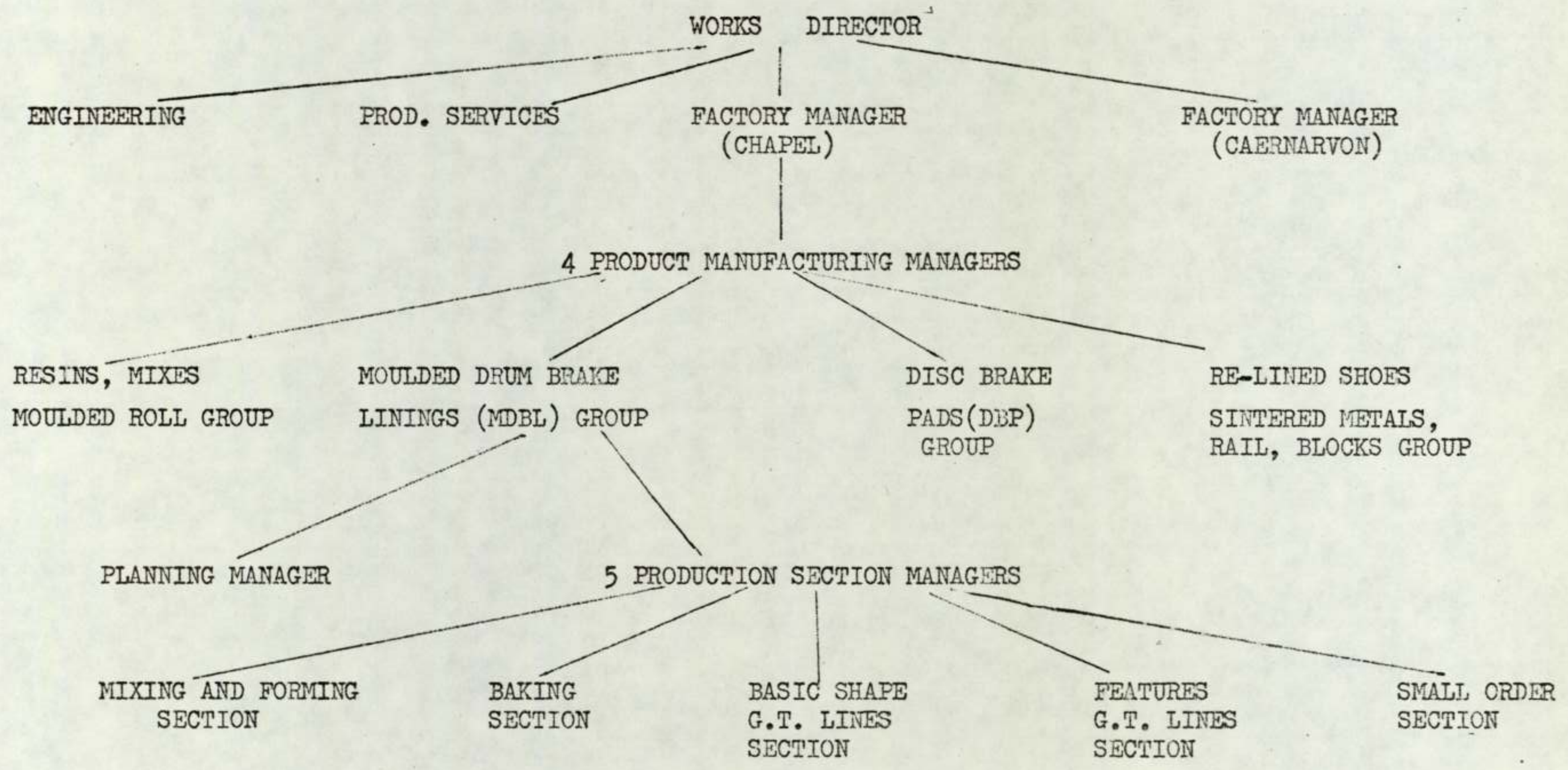


FIG. 1.2 FERODO MANAGEMENT STRUCTURE (1974)

1.1.3 The Author's Involvement with the Industry

The author started his career with Ferodo as a Project Engineer, being concerned with plant design, specification, procurement, installation and cost reduction exercises related to manufacture. He then joined a team of Research Engineers in 1970, working under Dr. R. H. Thornley at UMIST, engaged on a brief to 'Investigate Production Methods of Making Brake Linings from Pads, to Introduce Mechanical Aids to Production and Inspection of Linings'. After two years he was awarded an M.Sc. Degree for his thesis entitled 'Investigation into the Rationalisation of Semi-Finished Products with Reference to a Group Technology Manufacturing System'.(1)Subsequently a paper(2) was produced embodying the principles outlined in the thesis.

The author was then appointed to the position of Planning Manager for the MDBL product group at Ferodo, see Fig. 1.2 and it was during this period that the problem as defined below in 1.3 evolved. He is now employed by Ferodo in the position of Engineering Systems Manager.

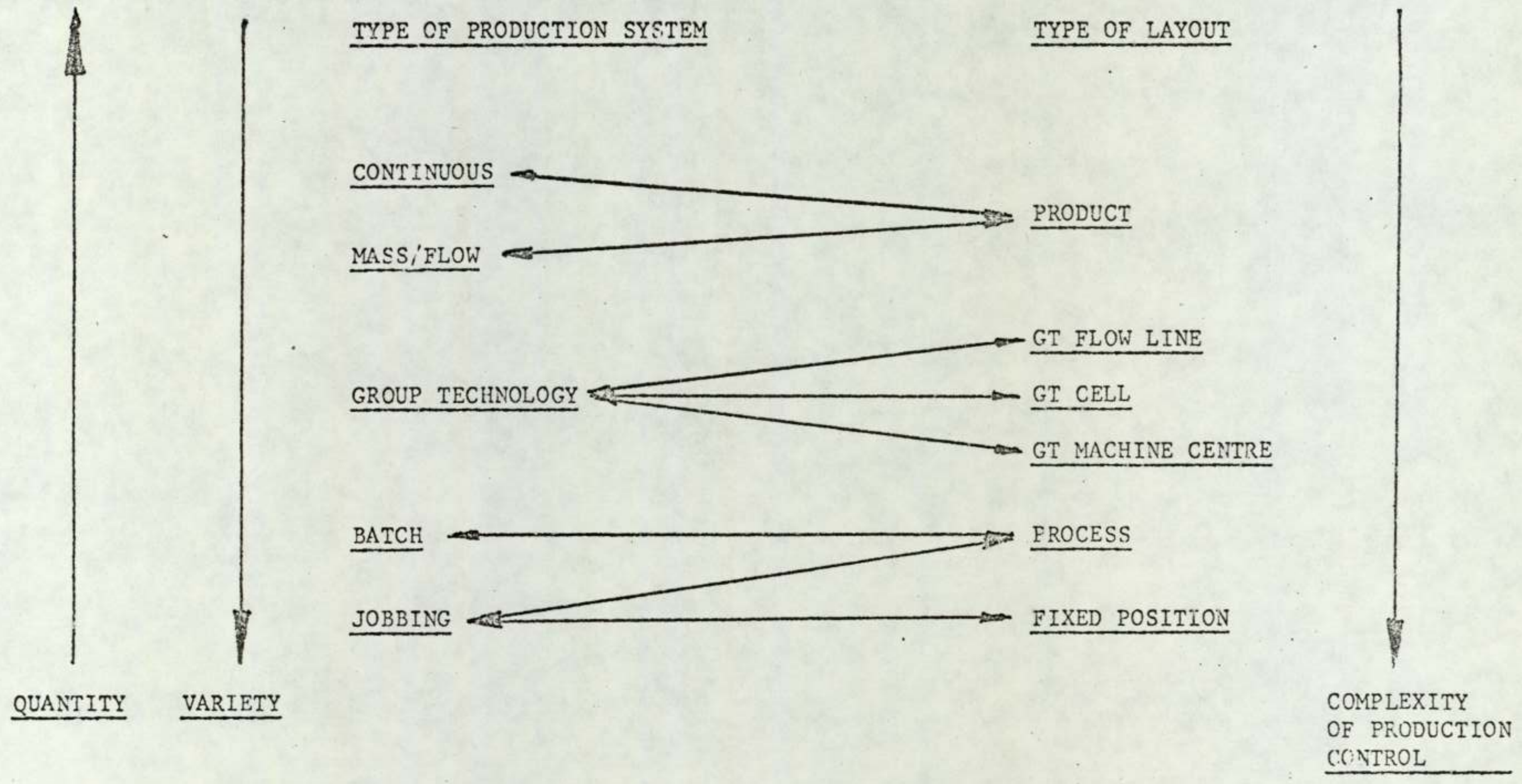
1.2.1 Production Systems

A production system converts materials from one form to another such that a desired product emerges. Production systems have developed over the years, based upon customer demand and are designed principally round the quantities involved. One off, or 'tailor made' items are usually made in a jobbing shop where variety is high and conversely, if items are required in large quantities, they are usually *manufactured in a continuous or mass/flow production system.

Fig. 1.3 shows the interaction between system layout and control of a production unit. A group technology manufacturing system can be employed when small batches are called for by the customer, which lend themselves to grouping such that the advantages of a mass/flow system can be achieved.

It is not within the scope of the thesis to discuss the relative merits of each type of production system since this topic is adequately covered in standard textbooks. (3) (4) (5) (6)

*The terms 'production' and 'manufacture' are considered to be synonymous.



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INTERACTION BETWEEN SYSTEM,
LAYOUT AND CONTROL
(INCLUDING FAMILY PRODUCTION)

FIG. 1.3

DEPARTMENT OF
PRODUCTION ENG.

J.H.F. SAWYER

1.2.2 The Definition of W.I.P.

Most manufacturing systems contain both raw material stocks and component part stores. As soon as items are issued from either of these stores they become classed as w.i.p. and continue to be thus classed until they enter the finished goods stores.

Accountants are usually critical regarding the precise location of these transfer points and are also concerned to ensure that double accounting does not take place and that material does not end up in 'no man's land'. To avoid these anomalies, systems are devised, based on a double entry system so that when material is discounted from stores and it is transferred into the manufacturing system, it must appear as w.i.p. and similarly when w.i.p. is transferred from the manufacturing system into finished goods stores, it is discounted from the manufacturing system and credited to the finished goods stores. The choice of transfer point, both in terms of physical location and time can affect the w.i.p. level and hence the stock valuation. A low valuation can occur when items have completed all operations in the manufacturing system and are waiting to be transferred into the finished goods area when the stock check is taken. These items will usually have a lower value than identical items in the finished stores.
Fig. 1.4 is a schematic diagram of a manufacturing

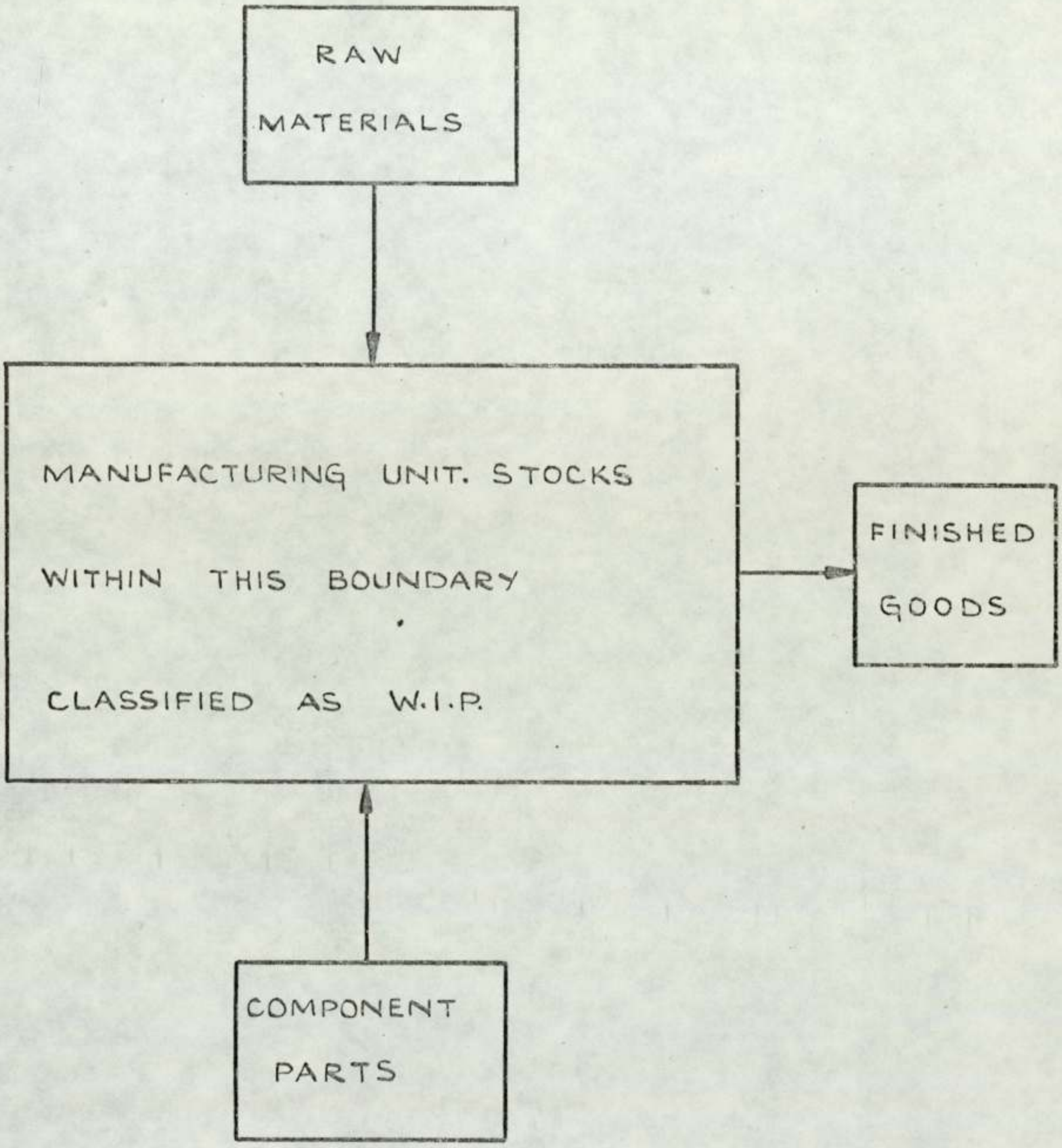


FIG. 1.4. DIAGRAMMATIC REPRESENTATION OF A MANUFACTURING SYSTEM SHOWING THE DEFINITION OF WORK IN PROGRESS (W.I.P.)

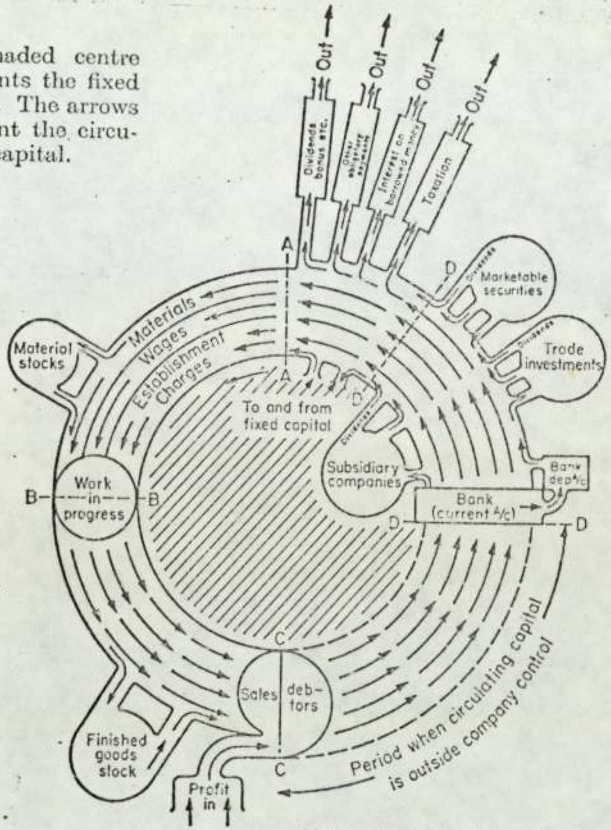
system, i.e. a manufacturing unit with its peripheral stocks. Referring to this diagram, w.i.p is the material confined within the boundary of the manufacturing unit. This unit may have intermediate buffer stocks and semi-finished component stores, all of which would be classified as w.i.p.

1.2.3 The Role of W.I.P. in the Capital of a Company

Fig. 1.5 shows the circulation of capital (cash flow) of a manufacturing enterprise operating in a capitalist environment. It is assumed in this thesis that one of the main company objectives is to produce a profit.

Referring to Fig. 1.5, w.i.p. is shown to have a significant effect although the diagram is limited in that the time factor is ignored. The diagram is particularly significant at the time of writing, since nearly all companies have an acute cash flow problem. They are desperately trying to cut w.i.p. levels and stocks and attempting to reduce the gap C.D. to a minimum, i.e. the period when the circulating capital is outside the company's control. However, indiscriminate action on w.i.p. levels can cost more than the action is designed to save, if all factors are not taken into account. For example, a severe cut in w.i.p. level will reduce

The shaded centre represents the fixed capital. The arrows represent the circulating capital.



[Courtesy Sir Isaac Pitman & Sons, Ltd.

Fig. 1.5 *The capital of a company: a Ring Chart*

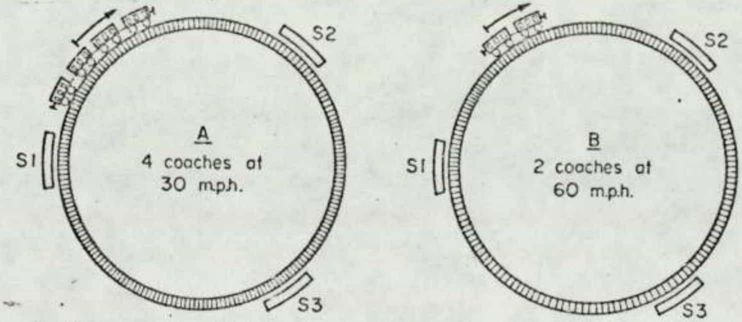


Fig. 1.6 *Railway analogy: rate of capital turnover*

FIGS. TAKEN FROM 'THE PRINCIPLES OF PRODUCTION CONTROL'
J. L. BURBIDGE

the amount of capital invested, thus saving the associated interest being paid but it could result in increased machine set-ups or operatives being idle, which in turn increases the factory cost and reduces the overall profit. Fig. 1.6 is an interesting analogy and attempts to indicate the importance of time in capital turnover. In terms of w.i.p. this suggests that if the level is halved, then to sustain the same cash flow, the lead time must be halved, i.e. the flow rate doubled. Unfortunately, this simple action is usually costly to perform since very rarely is the control system good enough to enable this action to take place without undesirable side effects, two of which have already been mentioned above, resulting in increased costs.

1.3 The Problem Defined

1.3.1 Identification of the Problem

The problem was identified by the author when working in the position of Production Planning Manager on the moulded drum brake lining (MDBL) product group at Ferodo Limited, see Fig. 1.2. The author had been in the position for about two months and being new to production planning, began asking certain basic questions. What should the w.i.p. level be? What is an acceptable manufacturing lead time? What factors influence the level of w.i.p.? The more experienced members of the department, including the previous production controller, could not give any acceptable answer and can be summarised by 'it has always been at that level and people will be out of work if it is any lower'. Clearly the problem had never been examined and recourse to standard textbooks gave little assistance.

The first two questions posed above cannot be answered in isolation since the two factors, w.i.p. level and manufacturing lead time are interdependent. One symptom of a system having too much w.i.p. is a very inconsistent manufacturing lead time. This can be caused by work being delayed on the factory floor due to physical overcrowding which leads to queue jumping, pockets of work being inevitably left hanging about for many weeks in some cases. Another symptom is a manufacturing lead time which is too long. One symptom of too little w.i.p. is inefficient use of labour, plant and tooling.

The w.i.p. level was running at approximately 2.6 million products when the author decided to carry out an exercise over a prolonged period, this being to gradually reduce the w.i.p. level until adverse effects were detected. The experiment was commenced at week 4,(1971) see Fig. 1.7. At this point, the author was convinced that the level was far too high since the arrears were considerable and the manufacturing lead time was very erratic. The experiment was continued until week 26, see Fig. 1.7, i.e. when the w.i.p. level was at 1.5 million products. At this stage it was felt that the minimum acceptable level had been achieved under the conditions prevailing at the time, since each section was in danger of running out of work if flow from the previous section was interrupted for more than a day. Thus, a further reduction in the w.i.p. level would perhaps have resulted in minor breakdowns affecting the following section, indicating that the buffer of work between the sections was failing in one of its main functions, i.e. to smooth out day-to-day irregularities.

The total reduction of w.i.p. was approximately one million products and it was felt that this was possible because of the inherent discipline imposed by the G.T. flowline concept. Since the manufacturing lead time on the G.T. lines is fairly consistent, this gives greater scope for reducing the buffer stocks to an absolute minimum, without running the risk of completely depleting the buffer stock due to erratic manufacturing times. Fig. 1.8 shows

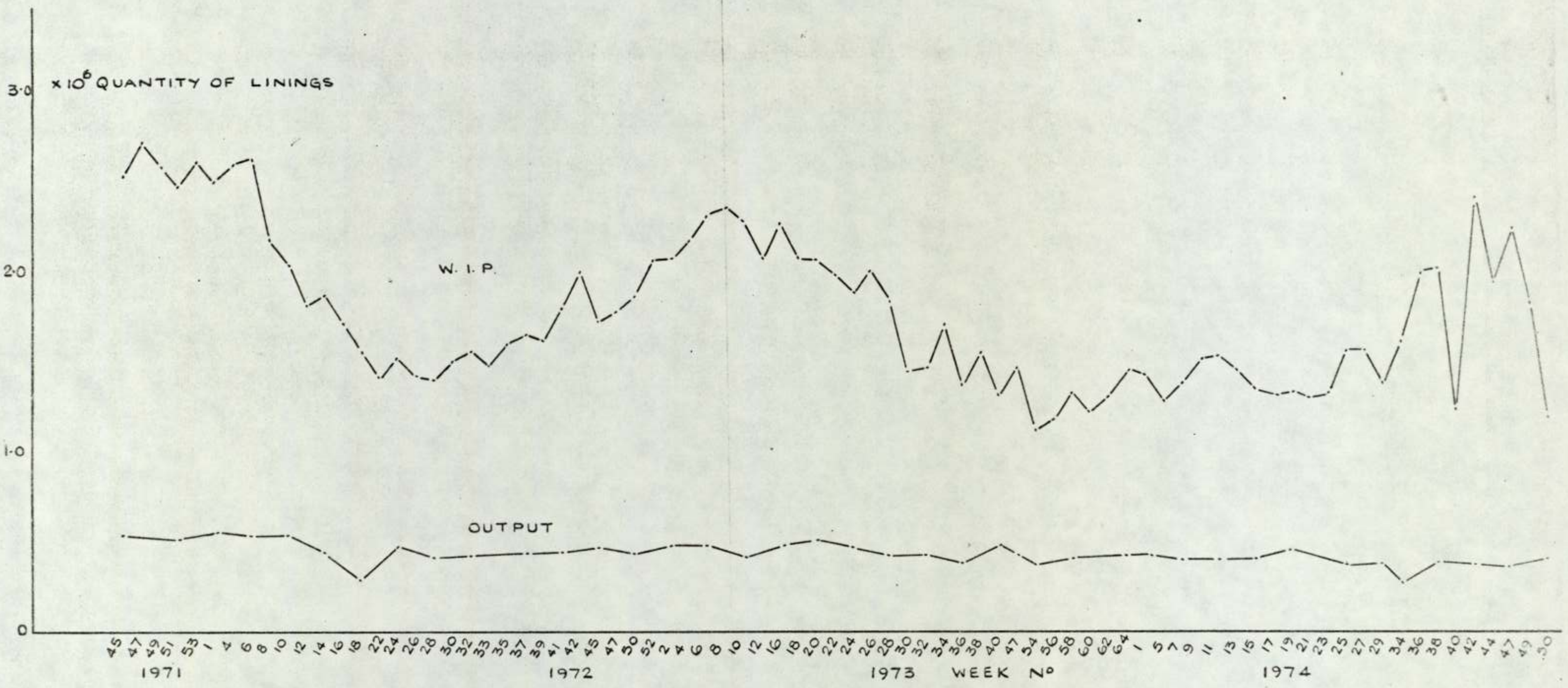


FIG. 1.7 GRAPH SHOWING OUTPUT & W.I.P. FOR THE MOULDED DRUM BRAKE LINING MANUFACTURING UNIT.

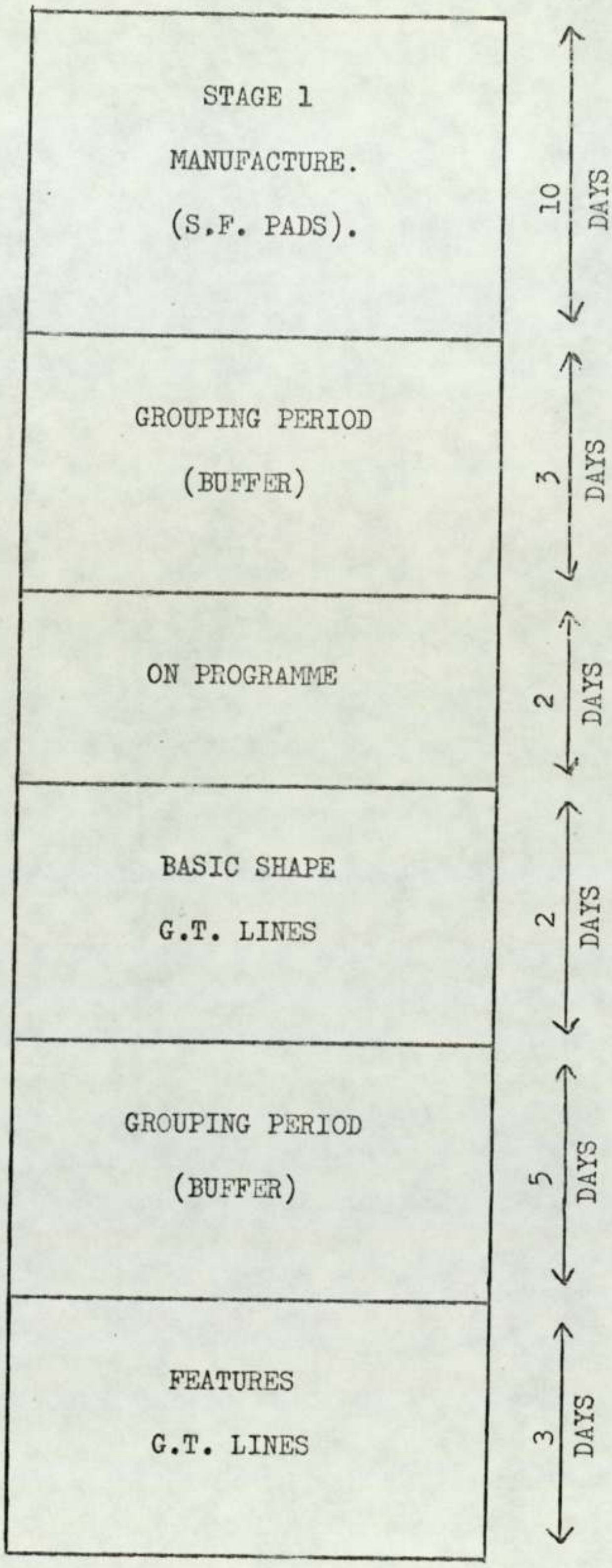


FIG. 1.8 BREAKDOWN OF MANUFACTURING LEAD TIME - M.D.B.L. PRODUCT GROUP.

the manufacturing lead time split up into its various constituent elements and Table 1.1 shows the changes in w.i.p. levels between week 53 and week 26. As can be seen from Table 1.1, the bulk of the w.i.p. reduction occurred at the two principal buffer stocks, i.e. between stage 1 and the G.T. basic shape lines and between the basic shape lines and the feature lines. It is felt that these two buffer stocks were at a minimum level consistent with tool availability and 100% labour utilisation during weeks 25 to 28.

1.3.2 Advantages and Disadvantages due to W.I.P. Reduction of approximately One Million Products

(a) Advantages

Apart from the advantage that £45 000 capital had been released, other advantages were attendant. The estimated number of cages that the million linings were contained in is about 400 (approximate value £7.50 each). This was evident from the fact that the age-old permanent problem of cage shortage completely disappeared. The manufacturing lead time was reduced by one week, for example, from 4 to 3 weeks on undrilled car sizes and from 6½ to 5½ weeks on drilled commercial sizes. By reducing w.i.p., the likelihood of work being left hanging about on the factory floor was

LINING TYPE	CHANGE IN W.I.P. - QUANTITY OF LININGS				
	STAGE 1 (INITIAL PROCESS)	STAGE 2 - (FINISHING PROCESS)			
		BASIC SHAPES		FEATURES	
		AWAITING LOADING	LOADED	AWAITING LOADING	LOADED
Car Sizes	- 487,000	- 292,000	+ 20,000	- 241,000	+ 1,000
Commercial Sizes	- 23,000	+ 32,000	+ 1,000	- 38,000	- 37,000

TABLE 1.1 CHANGE IN W.I.P. LEVELS IN THE MOULDED DRUM BRAKE LINING PRODUCT GROUP BETWEEN WEEK 53 AND WEEK 26 (1972).

greatly reduced. The factory floor was relatively free from stagnant work and this greatly simplified any 'chasing' that became necessary when a customer suddenly required work earlier than originally.

(b) <u>Disadvantages</u>

By considerably reducing the buffer stocks the manufacturing system became very sensitive to any hold ups due to breakdowns, lack of tooling, disputes, etc. Thus, accurate, detailed planning was essential. As the size of the buffer stocks prior to the G.T. lines decreases, so the efficiency of grouping tends to decrease, i.e. the average number of linings/batch decreases and the number of machine set ups increases.

1.3.3 General Comments

It is thought that a minimum acceptable level of the buffer stocks was reached at approximately 1.5 million; this is probably not the optimum economic level. To determine this optimum level, the cost of the w.i.p. should be balanced against machine set-ups and other relevant factors taken into account. However, it is interesting to note that since week 33 the w.i.p. level rose again to approximately 2.3 million and the symptoms as outlined above reappeared, in particular, ground space was scarce, which impeded the smooth flow of work, resulting in work being held in certain areas for longer periods than planned. In consequence, work was late at subsequent sections which lead to late orders and 'chasing' became a necessary, expensive evil.

The w.i.p. level was allowed to rise again above the 1.5 million level mainly to overcome erratic delivery of material from the initial processing sections and also because of a lack of confidence by middle management and unions when operating at such a low level.

After this experiment, the author was convinced that a w.i.p. level of 2.6 million products was too much and felt that 1.5 million products was probably of the right order of magnitude. It was felt that the system characteristics did not allow smooth operation when the level dropped below 1.5 million products.

The object of this thesis is to investigate the factors which determine the level of w.i.p. in the moulded drum brake lining manufacturing system in particular and a batch manufacturing system in general such that an optimal level can be specified.

CHAPTER 2

Literature Survey

An extensive survey on literature relating to the subject of work in progress in a manufacturing system has revealed that little seems to have been published, particularly regarding comment on practical applications. There are many references (7), (8), (9), (10), (11), which advocate w.i.p. reduction, assuming that a reduction automatically reduces the overall cost, when in fact, by reducing the w.i.p. level, the overall cost can rise. Indeed, only one reference has indicated that w.i.p. reduction can be a disadvantage and result in an increase in cost. Belcher, (12), considers the effect of buffer storage on production achievement and evaluates the loss of production due to buffer depletion (i.e. buffer failure) in the previous section in a car assembly plant. This clearly emphasises that in some cases, w.i.p. reduction can cause an increase in overall costs, but it must be borne in mind that the work reported in (12) was carried out in a continous flow production system. However, speaking more generally, manufacturing systems do seem to operate at work in progress levels which are too high. Quoting from (9), 'The biggest item in the balance sheet of many engineering companies is investment in stocks .....

The bigger area of inventory cost for most engineering companies is work in progress'. This indicates the need to define clearly what the optimum work in progress level should be in any manufacturing system.

(13) discusses measures of effectiveness of cellular production systems and cites w.i.p. as being one such measure. Clearly w.i.p. level can be used as a measure of effectiveness when two types of system manufacturing the same product are to be compared or when comparing before and after situations. However, the problem still remains of defining what the optimum level should be, having decided which is the most effective system. In this article, a production cell is simulated and w.i.p. within the cell is analysed, but no reference is made to the inter-relation between cells, i.e. buffer stock sizes. Although this article was based on a production machine shop, there is no comment on either the problems of implementation or the results.

Total company appraisal for group technology is discussed in (10) and says, 'Raw material supply is of significance when contemplating group technology. Coupled with a reduced throughput time group technology is attributed with the advantage of less w.i.p. Whilst this claim is borne out in practice, gaining the benefits of reduced w.i.p. puts a much greater dependence upon raw material supply. The physical weight of components is significant, for the concept of group production implies an efficient transfer of components such that queueing or stock-piling between processes is reduced. Although this may be overcome by handling equipment, it is clear that light components present fewer problems'. Raw material supply is significant in any type of manufacturing system and is particularly evident in the car industry when production is frequently brought to a standstill by a failure in delivery of component parts. Regarding the comment on transport, the frequency of service is more significant than the weight of products, this point is expanded later in the thesis under the section on transportation.

(14) entitled 'Production Systems Audit' says 'The size of stocks and w.i.p. relative to turnover is not an invariable indicator of the health of a company, as the ratio will be quite different from industry to industry'.

This statement is generally true and inter-company comparison is made even more difficult when the company is a mixture of industries as Ferodo is. It can be classed as an asbestos industry, a textile industry, a process industry or an automobile component industry. However, the ratio can be a useful guide to the relative health of a company if a comparison is made of the value at two different time periods, e.g. this year compared with last year.

W.i.p. reduction due to the application of G.T. would seem to be the common advantage claimed by companies who have introduced it. (7) summarises several industrial applications which make such claims and it would be interesting to know if these firms are now considering what the optimum level should be, having converted to the new technique.

The interconnection between w.i.p. levels and production control is indicated in (15). The authors say, 'In an attempt to cope with the variations in work content required from each functional department it is necessary either to continually shuffle the order in which batches are operated upon, or, alternatively, to increase the level of work in progress reservoir. With the former, the shuffling of the order in which batches are processed quite clearly affects the overall delivery time in that it is unreliable. It has been shown (see below*) that the latter alternative of carrying a higher level of work in progress so as to maintain the scheduled

*Iredale, R. 'Shop floor congestion delays deliveries' Metalworking Production - January 1971 order of batches does not work. The variability of manufacturing time increases as the level of work in progress increases due to increased congestion on the shop floor and the difficulty of controlling disassociated operations which are the responsibility of different people'. The importance of production control is not explicitly indicated but if one assumes that a reliable lead time is a fundamental requirement of a production system, then one can infer that the production control system is important since this is the principal mechanism in achieving a stable lead time. The authors conclude that, 'for a given product range and output level, the investment in work in progress and stock is generally inversely related to the investment in plant'.

This relationship would seem to be generally true since as plant investment increases, the degree of sophistication increases, resulting in one machine replacing several (n) operations, which in turn results in one buffer of w.i.p. instead of n buffers. Similarly one would expect investment in stock to decrease as w.i.p. decreases because the factory response time (manufacturing lead time) decreases, thus allowing safety stocks to be reduced. It is felt that the relationship as outlined in (15) could be extended to include investment in the production planning and control system. One would expect that an increase in production planning and control costs would be offset by a corresponding reduction in w.i.p. and finished stock levels.

(16) is a thesis entitled 'Manufacturing Cost and Batch Quantity Equations with Reference to Functional Group Layouts'. In this thesis, the author develops sophisticated formulae to determine optimum batch sizes and attempts to take account of all factors. It is doubtful whether the equations would be utilised in practice because of their complexity; however, they would be useful for comparison purposes of two distinct manufacturing methods, e.g. functional layout and group technology. The author says, 'Work in progress is an aspect of material control which has received much attention. Functional layout is continually charged with providing too large an incentive to building up excessive stocks of work awaiting transit between machine types, in stockpiling against slack periods. In fact, some work has been on the shop floor for years - there

are instances brought to the notice of the author where this has occurred and where work has been lost en route, necessitating replacement batches'. Although no reference has been found in the literature survey, it is suggested that it is not solely the fault of the type of layout used, but that the payment system and production control system are probably more the cause of 'lost' work than the type of layout. The payment system adopted (for direct and indirect labour in particular) can have a dramatic effect on both direct production costs and w.i.p. levels, the author has seen no reference to this factor in his literature survey. This aspect is discussed later in Chapters 6 and 8.

In conclusion, one can say that little has been written on the subject of w.i.p. in a manufacturing system. What little has been written concentrates on section analysis rather than analysis of the overall system and there is virtually no comment on either the results of implementation or the difficulties associated with it. In none of the articles are the problems of implementation discussed, and in particular, Union problems are not mentioned. Perhaps the lack of comment on application is due to the fact that many of the references are badly written in that they are full of mathematical jargon, without any reference to a practical situation. It is felt that this purely theoretical approach causes the Industrialist to be suspicious and anxious of the analysis to such an extent that he is loth to apply the results to a practical situation. It must be borne in mind that first the Industrialist may not be capable of checking the mathematics, and second, have the time to spend translating mathematical concepts into a practical situation. (8) is an article describing how a team of Research Engineers within a University collaborated with Ferodo to design and implement a group technology system at Ferodo and the author says of the Research Engineers, 'The UMIST team have likewise gained through having to implement their ideas in an industrial environment. They have met new problems of delegation and in obtaining agreement for their ideas from all levels of staff, they have needed to modify, or sometimes to improve their plans. They have also needed considerable patience and tact to deal with the reactions from Management and Unions to entirely new modes of thought'.

This article by one of the directors on the Ferodo Board clearly indicates that the Research team spent much time explaining and translating their theoretical, academic ideas into industrial jargon and not merely relying on the Industrialists to accept the concepts via theoretical, mathematical reports or papers.

CHAPTER 3

The Product Group Under Consideration

3.1 The Overall System

Ferodo can be said to be a process industry and is peculiar in that it manufactures its own material from which the final product is machined. Thus, as regards the MDBL product group, the factory can be split up into two sections - Stage 1 manufacture and Stage 2 manufacture, see Fig. 3.1. Stage 1 deals with manufacture of basic material up to and including the baking stage, the material at this juncture being in semi-finished pad form. The function of the semi-finished pad is to serve as a sheet of friction material from which the brake linings are machined in Stage 2. Fig. 3.2 shows a typical semi-finished pad (S.F. pad) showing the resultant linings (automotive size) after the second machining operation within Stage 2.

Stage 1 and Stage 2 are effectively de-coupled by the semi-finished pad store, this being the input buffer stock to the G.T. basic shape lines. Fig. 3.3 gives some idea of the physical size of this buffer stock.

Fig. 3 4 shows the order-flow through the total system. A limited range of linings is stocked in the central warehouse at Chapel-en-le-Frith, supported by depots throughout the country. Orders are generated by the central warehouse to replenish the stock levels, these orders accounting for approximately 30% of the total factory demand.

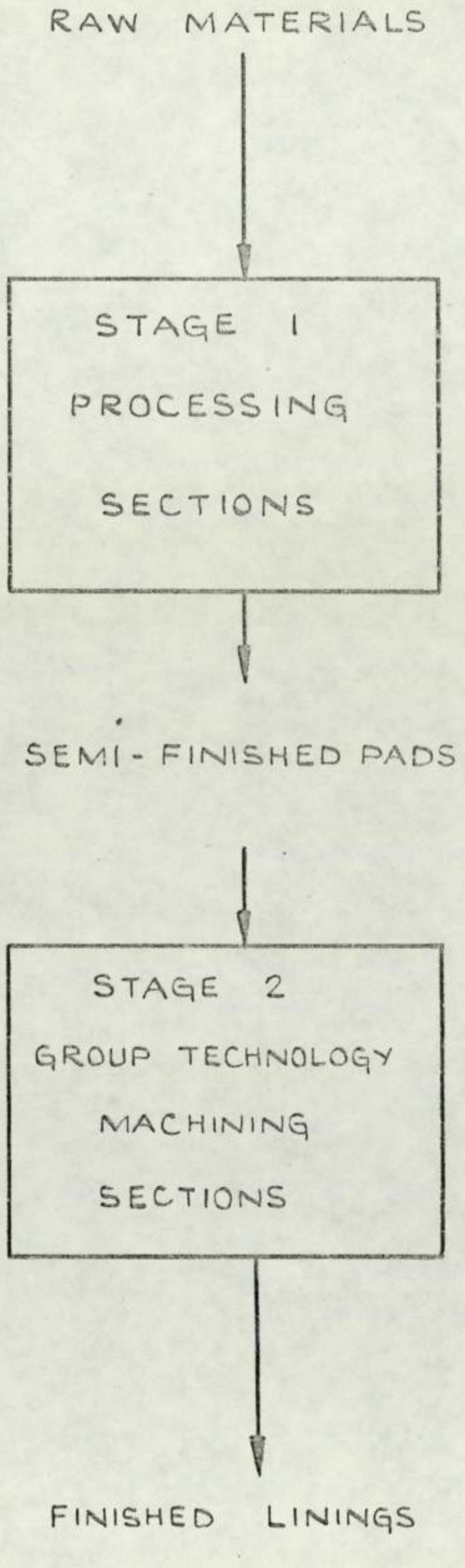


FIG. 3.1. DIAGRAMMATIC REPRESENTATION OF THE M.D.B.L MANUFACTURING UNIT.

Fig. 4.1

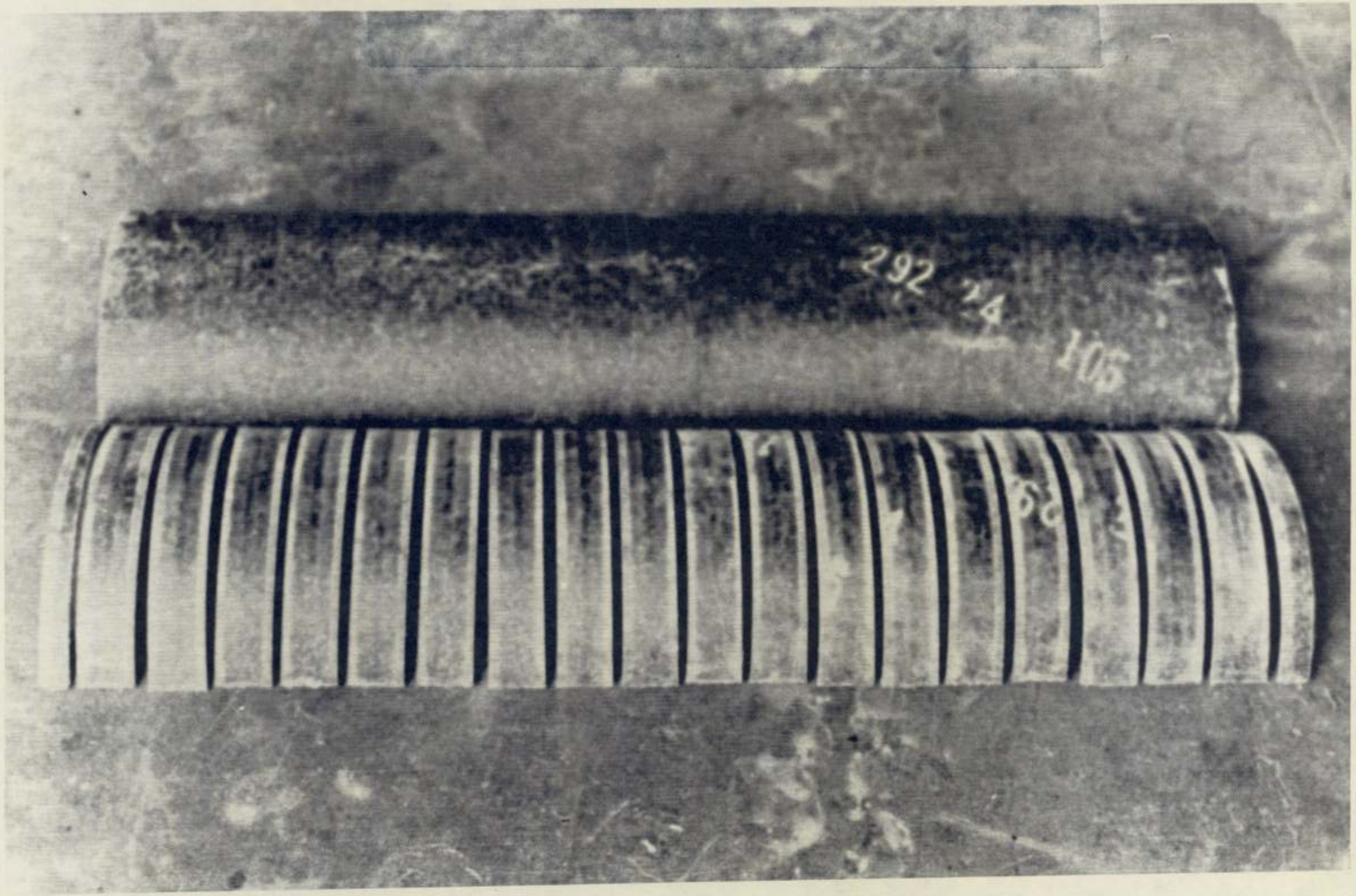


FIG 3.2 PHOTOGRAPH SHOWING ONE SPECIFIC LINING SIZE CUT FROM A SF PAD

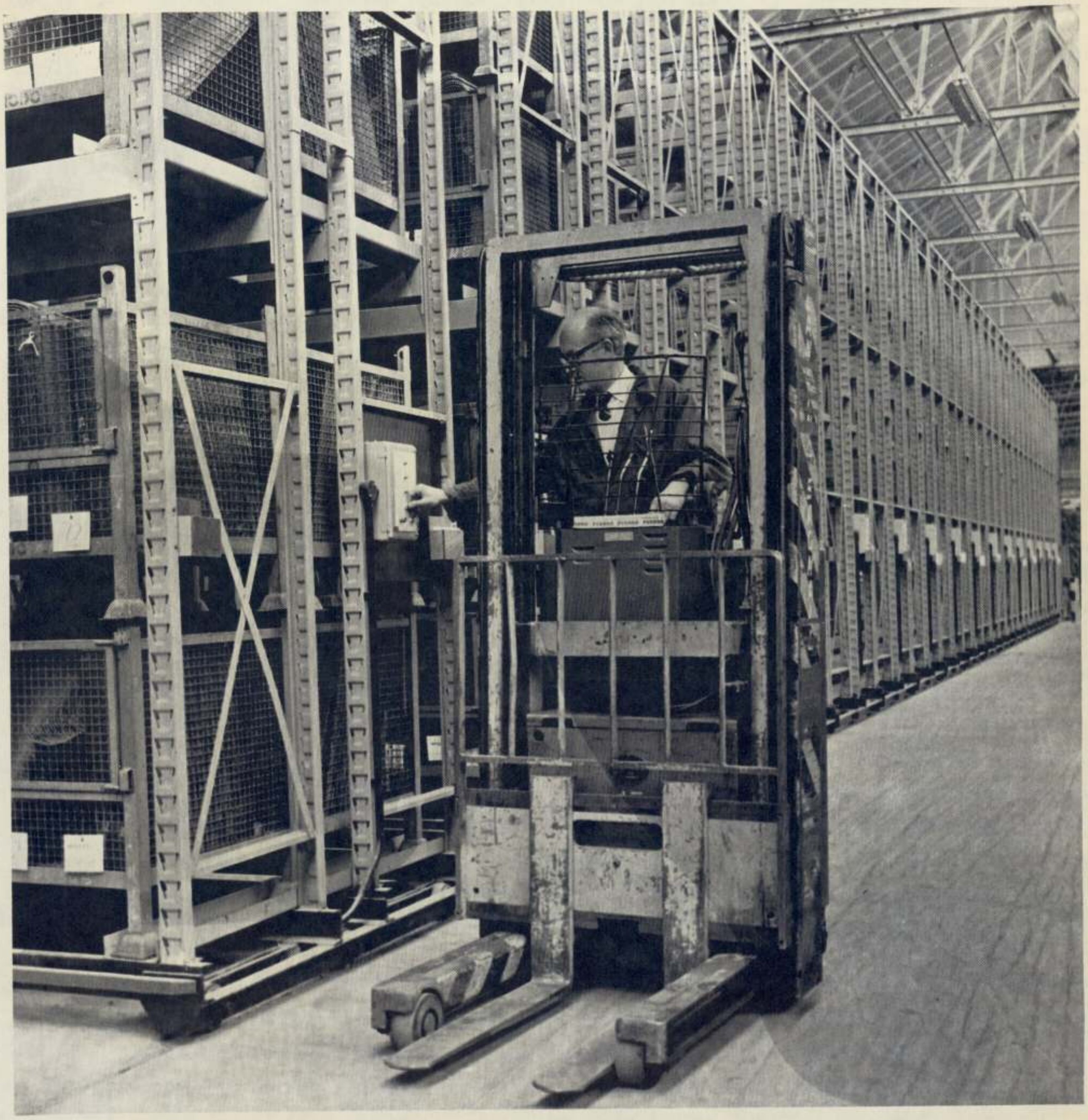


FIG 3.3 S.F. PAD STORE ~ INPUT BUFFER TO BASIC SHAPE C.T. LINES

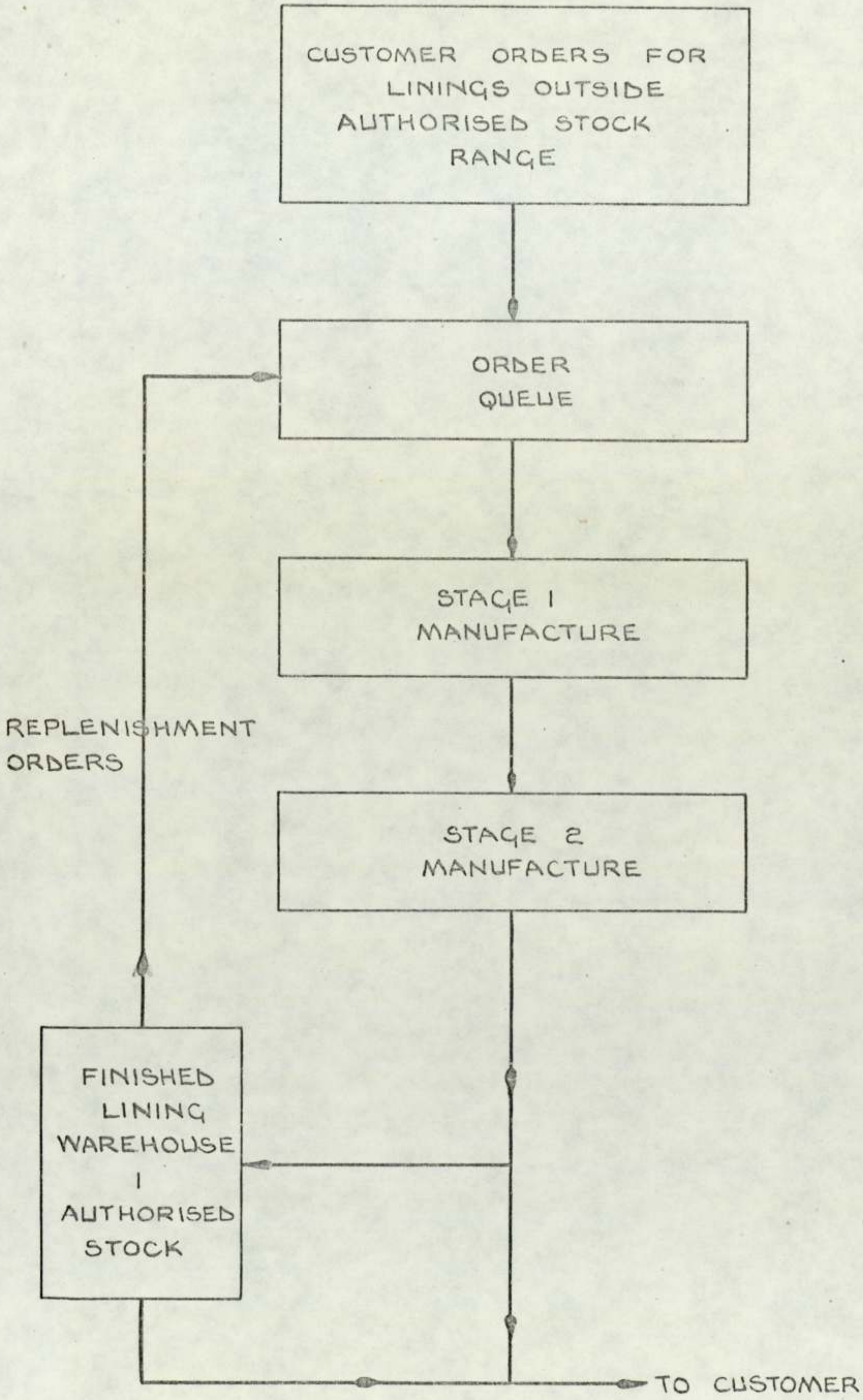


FIG. 3.4. DIAGRAM SHOWING ORDER FLOW THROUGH THE SYSTEM

The remaining 70% of the orders are manufactured for specific customers; these can range from large orders for new vehicles to very small orders for replacing worn linings on old equipment. It is the Company's policy to manufacture linings for almost any type of vehicle or machine in any quantity, although in some cases, minimum order quantities are imposed. This policy results in the factory having to cope with a large product variety, the current quantity of specifications amounting to approximately 8500 and the batch size varies from 2 to 5,000 linings. Table 3.1 is an analysis of order intake and indicates clearly that Ferodo can be classified as a small batch industry. It was for this reason that group technology was introduced in 1968, see (8), (17), (18), (19).

The group technology cells were designed to cater for 95% of the total throughput in terms of volume. The remaining 5% is manufactured in what is termed a 'small order section'. This section not only deals with very small orders which are uneconomical to manufacture on the G.T. lines, but also with orders which are dimensionally outside the capabilities of the machines on the G.T. lines. For the purposes of this investigation, the small order section has been ignored.

	NO. OF LININGS/ORDER					
Week No. 1972	1 - 5 incl. (Avg. No.3)	6 - 10 incl. (Avg. No.8)	11 - 15 incl. (Avg. No.13)	16 - 20 incl. (Avg. No.18)	21 - 50 incl. (Avg. No.36)	Total No. of Orders received
26	13	6	5	6	39	221
27	13	17	9	15	18	128
28	10	14	7	14	37	240
29	10	17	8	20	57	229
30	24	39	15	29	104	239
31	23	35	15	23	101	378
32	10	16	7	14	70	447
33	11	16	7	14	42	265
34	Nil	8	14	12	30	220
35	7	10	6	10	28	106
36	9	15	13	17	32	262
Total	130	193	106	174	558	2,735

TABLE 3.1 Order Intake Analysis Over 11 Week Period (M.D.B.L.)

3.2 Production Planning and Control of the MDBL Manufacturing Unit

There are two main aspects of planning and control in the MDBL manufacturing system, one being the overall method of loading work into the system on a weekly basis and the other being that of section scheduling, both of which are important factors in determining the optimum economic operating levels of w.i.p.

3.2.1 Overall Method of Factory Loading

The factory operates a three shift, five day week manufacturing cycle, closing down at 6 a.m. Saturday morning and starting up again at 6 a.m. Monday morning. Five days from Monday to Friday therefore presents itself as a natural and convenient planning cycle and this has been used in determining the Stage 1 input load for many years. Each week, Planning Department calculates what work is required to be launched into Stage 1 in the following week, this being based on a feedback from the factory regarding w.i.p. levels, production achievements, breakdowns, tooling hold-ups and customer requirements. One of the main objectives when calculating this load is to keep the w.i.p. constant, the underlying assumption being that this is a basic requirement if one is to achieve a constant lead time (assuming a constant output). For purposes of calculating the weekly load, w.i.p. is measured in numbers of linings. Since the product mix does not vary much from week to week and the work content of linings grouped into broad categories is almost identical, then the above assumption is valid. However, it would be dangerous to assume this to be so for any manufacturing system without analysing the product mix and work content initially.

Fig. 3.5 shows the weekly workload sheet which gives an overall picture of the workload both within the Planning Department and within the factory. The information is collated from all points in the system at a specific time during the week and using this information, the objective is to prepare a balanced load working within all the constraints imposed. Referring to Fig. 3.5 it is noticed that the workload is categorised in terms of work types, for example:-

*(a) G.T.1 type is a lining which should be manufactured (in Stage 2) within the G.T.1 cell.

(b) Small Pollard type is a lining which requires drilling on the small Pollard multi-spindle drill situated on the light feature lines. The small Pollard machine is isolated since it is the key

---

* A G.T. code was designed to enable a lining to be quickly categorised - see (19).

machine (for definition see Appendix 1) in the cell in terms of both set-up time and volume limitation.

The overall plan is prepared by determining what issues are required to maintain the w.i.p. level constant (in terms of work types). Column 19 indicates what quantities should be issued into Stage 1 to meet this objective and is obtained as follows:-

issues required = 'target' w.i.p. - actual w.i.p.

It should be noted that the term 'target' w.i.p. is merely used for calculation purposes and it is not the intention to raise the physical w.i.p. on the factory floor to this level. When the system is perfectly balanced the 'issues required' is equal to the current production capacity.

Column 19 gives the ideal Stage 1 issue requirement in terms of Stage 2 manufacturing work types. Having determined the overall quantity of linings to be issued to Stage 1, this must then be considered in terms of specific customers' orders and Stage 1 constraints (e.g. baking tooling constraints, machine capacity limitations). In this manner, a weekly load is calculated which is in effect, a compromise to meet the many constraints of the system.

Although the weekly workload sheet is essentially a planning document, it is also a simple but very effective control device. If the figure in the 'issues required' column is less than the target production figure, this indicates an excess w.i.p. for the particular work type. The excess w.i.p. can be located from the workload sheet and appropriate action taken to reduce it, for example, by working overtime. Similarly, if the system is deficient in w.i.p., the document acts as an early-warning system, enabling appropriate action to be taken.

3.2.2 Section Scheduling

The overall weekly plan can be considered to be a macro plan and does not attempt to minimise individual machine set-ups even though it takes into account critical machine capacities. In order to reduce set-ups and stabilise the lead time it is necessary to support the overall plan with section schedules, these being produced at much more frequent intervals, i.e. one or two days. Stage 2 has clearly defined buffers and work flows into these at a fairly constant rate (equal to the section output). The orders are then grouped to minimise the key machine set-up and issued strictly in sequential order; a typical schedule is shown in Fig. 3.6. The scheduling system is considered to be a vital element in the production control system and the establishment of an effective control system is a

(637)

G.T. 2

SHEET 2.

LINER SIZE.				PAD GRIND.			PAD CUT.			FRAY WIPE.		
LENGTH.	WIDTH.	THICK.	RAD.	M/C TIME	SETTING TIME.	TOTAL.	M/C TIME	SETTING TIME.	TOTAL.	M/C TIME	SETTING TIME.	TOTAL.
6343	1.445	202	3797	39	0	39	70	0	70			
7781	1470	187	3813	3	4	7	6	47	53			
"	"	"	"	2	0	2	3	0	3			
8184	2574	221	4328	13	5	18	20	48	68			
9.779	1590	162	4.370	49	4	53	75	47	122			
"	"	"	"	9	0	9	14	0	14			
9.546	"	182	4343	4	4	8	6	20	26			
"	"	"	"	1	0	1	2	0	2			
9345	"	190	4.331	6	4	10	9	0	9	7	1	8
9869	"	202	4291	15	4	19	23	0	23	28	1	29
"	"	"	"	16	0	16	25	0	25	30	0	30.
7.259	"	"	4055	5	2	7	9	20	29			
8062	1765	192	4062	64	5	69	104	33	137			
"	"	"	"	64	0	64	104	0	104			
9.716	2720	213	4.810	49	5	54	70	48	118			
"	"	"	"	49	0	49	70	0	70			
"	"	"	"	49	0	49	70	0	70			
"	"	"	"	49	0	49	70	0	70			
"	"	"	"	49	0	49	70	0	70			
"	"	"	"	51	0	51	73	0	73			
9719	"	192	"	44	4	48	63	0	63			
11066	"	237	"	33	4	37	52	0	52			
"	2220	"	"	27	0	27	43	33	76			
9719	"	192	"	44	4	48	65	0	65			
9687	"	197	"	30	4	34	44	0	44			
8164	1984	241	4291	7	5	12	12	48	60			
"	"	"	"	13	0	13	20	0	20			
"	"	"	"	13	0	13	20	0	20			
8716	1720	203	4310	46	4	50	75	33	108			
"	"	"	"	46	0	46	75	0	75			
				889	62	951	1362	377	1739	65	2	67

$$\% \text{ set up of key machine} = \frac{377}{1739} \times 100\% = 21.7\%$$

FIG. 3.6 G.T.2 PROGRAMME (PART ONLY)

necessary prerequisite to optimising w.i.p. levels. Buffer stocks are necessary to absorb fluctuations between processes, but if control is poor, the buffer stocks must be sufficiently large to absorb the resulting severe fluctuations in flow. At the beginning of this project, no section scheduling occurred in Stage 1, hence the determination of optimum buffer stock levels was impossible until, as discussed in Chapter 4, a satisfactory section scheduling system was installed.

3.2.3 Material Flow

Stage 1 has not been subjected to the same attention as Stage 2 from a production engineering viewpoint, and it was also considered to be an important prerequisite to the optimisation of buffer stock levels to look at material flow routes and section definitions. Poor section definition leading to poor accountability and irrational material flow routes can be the cause of severe buffer size fluctuations. Thus, before attempting to optimise w.i.p. levels, it is essential to reduce buffer stock fluctuations to a minimum and this aspect is considered in Chapter 4.

A further important difference between Stage 1 and Stage 2 is the nature of the plant. Stage 2 consists of small, light machines and any modification to the plant layout can be easily carried out, whereas the Stage 1 plant is heavy machinery requiring costly foundations. Thus, any plant re-layout would be difficult to justify economically since many of the advantages associated with material flow rationalisation are unquantifiable.

CHAPTER 4

Analysis of the Stage 1 Manufacturing System

4.1 Introduction

The Stage 1 Manufacturing System was observed from the viewpoint of buffer stocks and the critical ones were analysed in detail to determine the factors relevant to their efficient operation. The material flow through Stage 1 was examined and rationalised where necessary.

The production planning and control aspects (including scheduling) were carefully examined since it was felt that this is probably the major cause of severe buffer size fluctuation. Since Stage 1 has undergone changes quite recently, scheduling systems had to be developed (by the author) for certain buffers since it was thought necessary for the satisfactory operation of the system. In developing these scheduling systems the author gained a greater understanding of the system as a whole and of the role that production control plays in the operation of a manufacturing system.

4.2 Existing Situation

Fig. 4.1 shows a diagrammatic representation of material flow within Stage 1. While an attempt has been made to show all materials for which the MDBL Product Manager is responsible, materials and machines are also shown which are the responsibility of the Resins, Mixes and Moulded Roll Manager, but have an impact on the MDBL Product Manager. Fig. 4.1 indicates that the responsibility for some materials fluctuates between these managers before arriving at the H.T. baking section. However, it is true to say that approximately 80% of the volume is within the four materials AM238, 14, 15 and 2626F, the flow of these being straightforward and contained within the domain of one manager (MDBL). This fluctutation of responsibility is one of the causes of material being delayed in arriving into the H.T. Bake buffer. In particular it is well known that materials such as MS3, MS21, AM4, AM6 and HG2 are nearly always late in arriving on the baking section, with the consequent disruption to the production plan, although these materials in total probably only consititute approximately 10% of the throughput. Another cause of the delay is the low temperature drying facility (Stordy Oven). Materials which require low temperature drying prior to H.T. bake, e.g. HG2 seem to spend far too long waiting to go into the oven. The possible reasons for this are as follows:-

(1) Operatives load ovens according to their own priority, probably attempting to work within allowable standing times. There is no system for scheduling the ovens.

(2) Most work that the operatives load is required by the next section within their own product group - therefore this will tend to take priority.

(3) Possible labour shortage, therefore everything has to wait longer than should be necessary.

After discussions with section management, it was felt that (3) can be discounted and that (1) and (2) are almost certainly the reasons for delays on these particular materials.

There would seem to be an anomaly concerning a guillotine, **Plant No. 149-048**, see (1) fig. 4.1. The diagram does not show an assortment of low volume materials which are solely within the resins, mixes and moulded roll product group, e.g. stairtile, RU, 1481 which go through this machine. The anomaly is that 90% of the material the machine deals with is the responsibility of the Resins, Mixes and Moulded Roll Manager. It is located on his area and yet the machine and the associated labour is the responsibility of the MDBL manager.

4.3 Rationalisation of the Existing System

The following materials pertinent to this project are in the obsolescent category and will cease to be produced in December 1975.

MS21 MB1
AM9 2625F
VG97

All these materials fluctuate between the two production managers in Stage 1. This latest material rationalisation will go far towards resolving the variation of lead time in Stage 1, provided that they are not replaced by materials which also fluctuate their responsibility. Fig. 4.2 shows the recommended material flow after the materials listed above have been eliminated and the following actions taken.

(1) Transfer the responsibility for the guillotine, Plant No. 149-048 see (1) fig. 4.1 from the MDBL Product Manager to the Resins, Mixes and Moulded Roll Manager - physically this will remain where it is.

(2) One bank of low temperature drying ovens (3 compartments Stordy type) to be transferred to the H.T. baking section. MDBL product group, see (2) figs. 4.1 and 4.2. Physically

it will remain where it is.

(3) The transferred low temperature ovens to be scheduled on a daily basis in a similar manner to the H.T. baking ovens and the scheduling to be carried out by the H.T. bake scheduling clerk.

Regarding action (1) this would remove the anomaly already mentioned. Actions (2) and (3) would jointly eliminate any delay at the L.T. ovens. Furthermore, it would give the scheduler accurate advance warning of material due to arrive from the low temperature ovens.

A case could be made out for transferring the press to radius facility, Plant No. 252-075 from the resins, mixes and moulded roll product group to the Workshop Section within the MDBL product group. However, since this facility also deals with some materials which remain solely within the resins, mixes and moulded roll product group, and because this transfer would entail increased transportation, not to mention the cost of re-siting, it is felt that this should remain where it is.

While looking at the problem of rationalising the material flow within Stage 1, one has been conscious of the need to keep plant movement down to a minimum since this is always a costly business and is particularly so in an environment of heavy machinery. Furthermore, although the benefits associated with smooth material flow are generally recognised, e.g. quicker throughput, clear accountability etc., it is always extremely difficult to quantify such advantages and furthermore it is difficult to justify expenditure to effect such improvements.

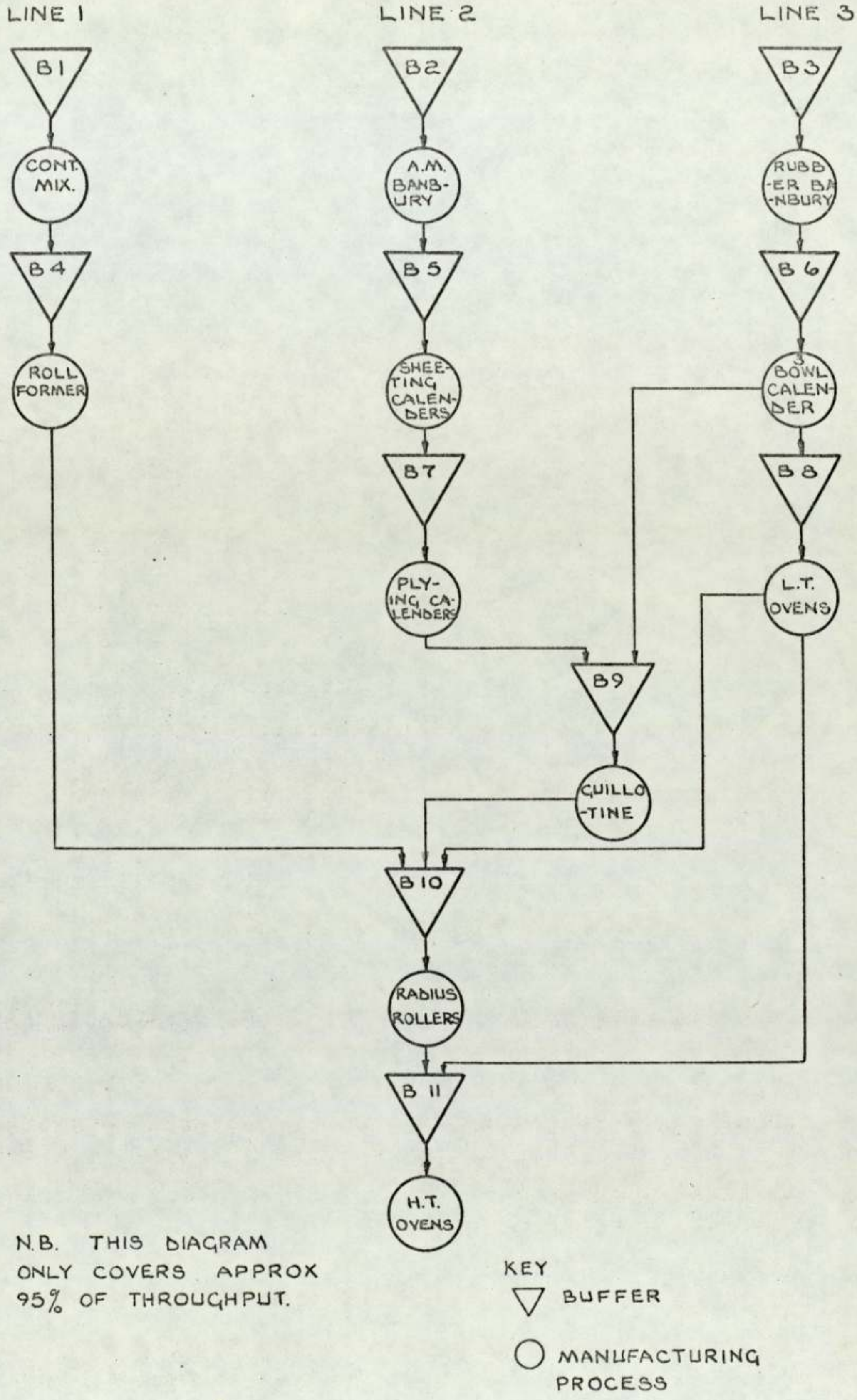
It is with this in mind that the above recommendations were arrived at. The cost of implementation will be virtually nil since no re-siting of plant is necessary. However, it should be pointed out that this is a compromise solution and there is still interaction between the MDBL product group and the resins, mixes and moulded roll product group.

Complete segregation into effectively a high volume (low variety) product group and a low volume (high variety) product group was suggested in (20) but was unacceptable on the basis of cost. This scheme would have involved re-siting plant and increasing the number of section managers but would have completely eliminated any cross flow between product groups. The above recommendations were accepted in principle by the management but there are problems to be resolved before implementation regarding labour allocation. For example, it was recommended that a three compartment oven be transferred from the resins, mixes and moulded roll product group to the MDBL product group.

However, one operative services nine oven compartments, thus the MDBL product group would only theoretically need one third of a man. This can be resolved by the RMMR product group retaining all the labour and the MDBL product group being responsible for defining what is to be loaded into the three compartment oven.

.4 Definition of Buffer Stocks

Stage 1 can be simplified into three production lines as shown in Fig. 4.3, Line (1) being the principal. Raw materials are held in buffers B_1, B_2 and B_3, these being the source of input to the mixing machines. Thereafter, all three lines produce a flat sheet which arrives into buffer B_{10}; line (1) differs from the other two lines in that several handling processes have been eliminated by the use of a roll former. The flat sheet is in a plastic state and is converted into a radiused sheet by the radius rolling machine which in turn feeds into the principal stage 1 buffer B_{11}. Thus buffer B_{11} contains a variety of sizes of radiused sheets awaiting baking. It must be emphasised that throughout the Stage 1 manufacturing process, the material is in a plastic state, and as such, is in an unstable form. This presents quality control problems and these are minimised by imposing maximum allowable standing times between the various processes which are usually dependent upon the material type but can also be dependent upon the



N.B. THIS DIAGRAM
ONLY COVERS APPROX
95% OF THROUGHPUT.

FIG. 4.3. SIMPLIFIED WORKFLOW DIAGRAM SHOWING BUFFER STOCKS IN STAGE 1.

physical dimensions. While the variety of raw material ingredients is very large, the variety of blended materials input into B_{11} is quite small and is usually about 12. The approximation stems from the fact that old materials are being made obsolete and new materials are being developed on a continuous basis.

When the radiused sheets leave B_{11}, they are baked on cast iron formers, cooled and then removed from the formers. The product is then in a stable state and is classed as a semi-finished pad which passes from the baking section into the semi-finished pad stores where it is recognised as being part of the Stage 2 buffer stocks and is available for planning into the G.T. system.

Stage 1 is operated on a three shift basis and is controlled by two production managers on each shift. One manager is responsible for material from B_1 to delivery into B_{11} and the other for controlling B_{11}, for production through the H.T. ovens and for delivery into the S.F. pad stores. Although B_{11} is shown as one buffer stock, in fact the baking ovens can be considered to be three separate facilities, one of which is physically removed from the other two. Furthermore, the tooling problems and control problems are far greater on the baking section than any other in stage 1 and this is the reason for the apparent imbalance in responsibility. B_1, B_2 and B_3 are basically raw material ingredients and are issued from stores as demanded. Generally speaking the size of the remaining buffers can fluctuate between zero and the maximum allowable standing time as indicated in the Manufacturing Instructions. This standing time is frequently a function of material and product dimensions. Quality Control personnel patrol these buffers to ensure that material is not allowed to exceed the maximum allowable standing times. This practice is quite adequate for some of the buffers but four buffers in particular are critical, these being B_4, B_9, B_{10} and B_{14}. It is intended to analyse these buffers in some detail to determine their method of operation, effectiveness and constraints. Line 1 (fig. 4.3) is still under development and B_4 is a hopper of material with a maximum capacity of 1200lbs. This buffer can be exhausted in a matter of minutes and is very sensitive to flows both in and out. Since there is a large labour force on both sides of this buffer which depends on the correct operation of the buffer, it is essential that it is controlled to a very fine degree. A scheduling system has been developed by the author to ensure this and it will be outlined below in 4.9.

B_9, B_{10} and B_{11} cause problems because of their physical size and sources of input coupled with the need to process material within the allowable standing times.

No specific area is allocated for B_9 and B_{10}, but there is for B_{11}. There appeared to be no rules laid down as to what size the buffers should be, either by design in terms of number of hours work, or by area. B_{11} is perhaps the exception in that Planning Department arbitrarily plan to have two days work available for baking at all times. However, no attempt has ever been made to convert this into area required for storage purposes. Acute congestion is one of the prime elements contributing to poor control since in many cases the operative has no choice but to work on the wrong cage, from the sequence point of view.

5 Determination of Buffer Stock Sizes for B_9 and B_{10}

5.1 There are two major developments imminent in Stage 1. One is the introduction of incentive working conditions on the H. T. baking facility (Ballard ovens Block 'L'), the main effect of this will be to increase production to a maximum of 19 200 drum loads per week (38 400 pads). The second is the introduction of *product group 11 (PG 11) AM2, 14 and 15 materials onto the roll former. It is anticipated that the transfer of the whole of PG 11 for these three materials will not be completed for some time and for calculation of buffer sizes it has been assumed that products with $T < .690$in will be roll formed. The buffer sizes have therefore been

*Product Group 11 defined as materials thicker than .285" i.e. $T > .285$"

determined assuming:-

(a) a maximum output from the Ballard 'L' ovens of 38 400 pads

(b) AM2, 14, 15, 2626F and 2629F will be roll formed up to a thickness of .690in.

(c) production according to 1976 S.F. figs. (+ 10% reject allowance)

(d) a maximum output from Spooner No. 2 of 12 000 drum loads (24 000 pads)

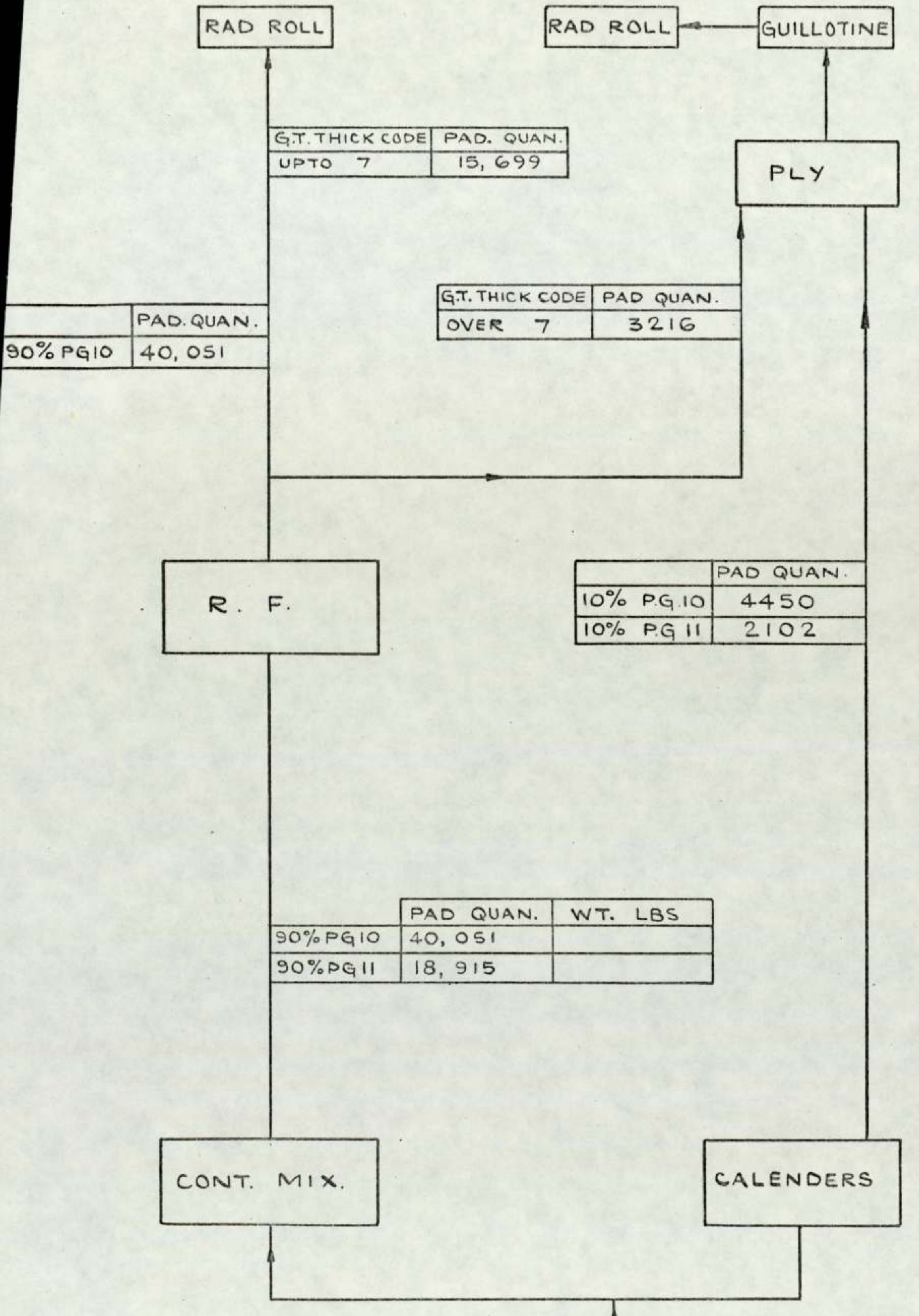
On the basis of these four assumptions it was then necessary to estimate how many pads would be roll formed and how many would be produced by the calendered technique. Invoiced quantities of PG 11 over 1973 were analysed using the computer to determine the % in each G.T. code thickness category. The pad quantities to be manufactured by each technique were then estimated as shown in Fig. 4.4. This defines the flow of work in Stage 1, any surplus above the maximum capacity of the Spooner No. 2 oven and the Ballard 'L' ovens will be baked in Block 'B', which is not considered in this thesis.

.5.2 Analysis of B_9 (Buffer Stock for Guillotines)

Below is a list of maximum allowable standing times for AM materials relative to B_9.

Material Type	Waiting Period	Max. Allowable Standing Time (hours)
AM1	Ply to Radius Roll	12
AM8, 14 15	Calender to Radius Roll	36
AM6	Calender to Radius Roll	24
AM4	Ply to Radius Roll	6 days

As can be seen from the above table, the allowable standing time in the buffer is variable. The total throughput during a week will be small, see Fig. 4.4 and will be approximately 45 pallets. One guillotine working on one shift only will easily cope with this throughput and it is felt that 9 pallets (PG 11) should be the maximum buffer size, this being equivalent to one shift's work. This is in fact the maximum space available within the area until one of the guillotines is removed (which could take place within a year). Fig. 4.5 shows a layout of the buffer area.



G.T. THICK CODE	PAD. QUAN.
UPTO 7	15, 699

G.T. THICK CODE	PAD QUAN.
OVER 7	3216

	PAD. QUAN.
90% PG10	40, 051

	PAD QUAN.
10% P.G.10	4450
10% P.G 11	2102

	PAD QUAN.	WT. LBS
90% PG10	40, 051	
90% PG11	18, 915	

INPUT
1976 S.F. FIGS + 10%
IN WEEKLY QUANTITIES.

G.T. CODE	THICKNESS RANGE UPTO
7 IN	·690

FIG. 4·4 ANALYSIS OF S.F. PAD FLOW IN STAGE I UPTO RADIUS ROLL.

3-7-74.

4.5.3 Analysis of B_{10} (Buffer Stock for Radius Roll)

There are two main flow lines for S.F. pads as indicated in Fig. 4.4. The weekly output quantities, based on 1976 S.F. Figs (+ 10%) are given below.

S.F. Pads requiring Roll Forming only

	Pad Quantity	Output/ Shift	Required No. of Shifts/Week
PG10	40 051	2500	16.0
PG11	15 699	2200	7.1
		Total	23.1

S.F. Pads requiring Plying

	Pad Quantity	Output/ Shift	Required No. of Shifts/Week
PG10	4450	2500	1.8
PG11	5318	2200	2.4
		Total	4.2

Three radius rollers are available at the moment but it has been recommended (and accepted) that one be moved so that two machines are available to deal with the roll formed element of the work and the remaining machine for plied work. The recommended flow is shown in Fig. 4.5. By moving the radius roller from its existing site, extra space is created for the H.T. bake buffer (the need is defined later under 'space considerations'), and the flow is rationalised. Thus, the problem is defined as what space is required to accommodate the buffer stock for

(a) two radius rollers dealing with R.F. work only and

(b) one radius roller dealing with plied work.

The minimum size of the buffers must be zero since it is often necessary to complete all work prior to a shutdown period (e.g. weekends) because of standing time limitations.

Similarly the maximum size is constrained because the maximum allowable standing time between forming and radius rolling is 8 hours. The calculation below to determine the maximum number of pallets required to be held in the buffer is thus based on the latter constraint.

4.5.3.1 Buffer Stock Size for Roll Formed Work

	Radius Rolling machine output/8 hour shift	No. of pads/ pallet
PG10	2500	500
PG11	2200	200

The worst possible case would occur when all PG 11 type work is being produced, the radius rolling capacity being 2200 pads/8 hours shift. Thus, 8 hours work required $\frac{2 \times 2200}{200}$ pallets

= 22 pallets.

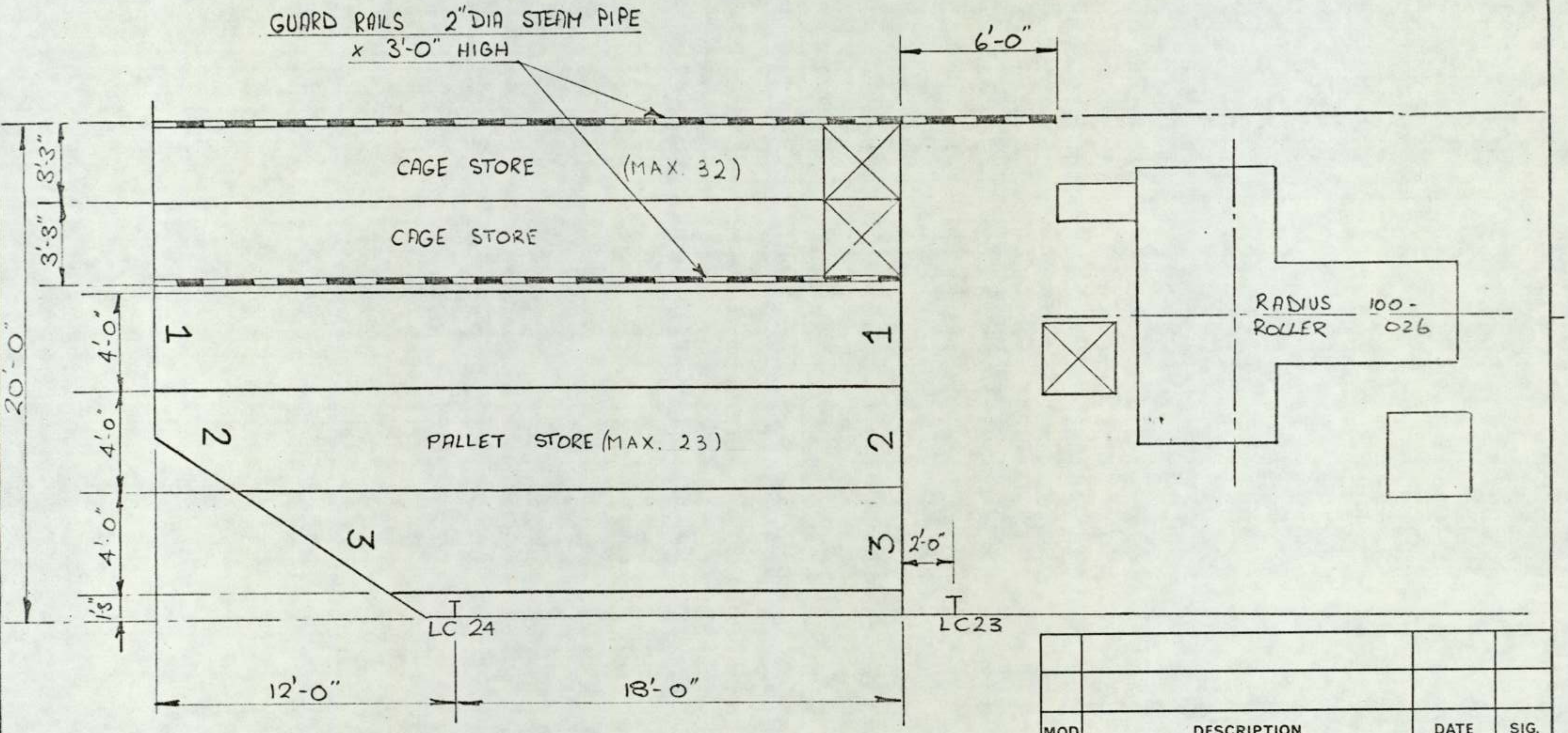
4.5.3.2 Buffer Stock Size for Plied Work

Working on the same assumptions as above, the area should cater for a maximum of 11 pallets. However, bearing in mind that tapered work must be radius rolled on this machine and the time limit between taper planing and radius rolling is only 2 hours, the recommended buffer stock has been reduced to 9 pallets, this then allows for taper planed work to pass directly from the taper planer to the front of the radius rolling queue. The recommended buffer stock areas are shown in the general layout, Fig. 4.5. Fig. 4.6 shows details of the buffer stock for the radius rollers dealing with the R.F. element. This area has been cleared, the area marked out and the buffer is now fully operational. The method of operation has been defined, a brief description of which is given below.

4.5.3.3 Method of operating R.F. Radius Roll Buffer

Three lanes are to be used, see Fig. 4.6. The lanes are filled in sequence by the service man from the roll forming machine, i.e. fill lane 1 first, then lane 2, then lane 3, by which time lane 1 will be empty again. The radius rolling team work similarly in sequence from lane to lane this being essential to

DRG. No.



MOD.	DESCRIPTION	DATE	SIG.

FERODO LTD. CHAPEL-EN-LE-FRITH.
ENGINEERING DIVISION

DATE 14/6/74
DRAWN D Brookes
SCALE 1/4" TO 1 FT
CHECKED
REF.

TITLE BUFFER STOCK AREA FOR R.F. RADIUS ROLLERS

DRG. No. FIG. 4.6

MY T03125 D

ensure material does not exceed the allowable standing time. The method of controlling this buffer was discussed at great length and it was initially proposed to have floor mounted conveyors so that the cages could be fed to the end of the lane. It was also proposed to have gates on each end of the lanes to eliminate any possibility of operative choice. This initial system would have been virtually fool-proof, but might have been expensive to operate, since the operatives would require payment for opening and closing the gates. The final system is easy to operate, but is equally open to abuse by operatives. The section managers were consulted on this issue and they favoured the latter method. In their opinion, this would give them an adequate mechanism to enable them to control the activities of the operatives concerned. They felt that the main reason for work being operated on out of sequence at the present time was lack of space, thus causing the operative to choose either the nearest cage or the only accessible cage in some cases.

4.5.4 Analysis of B_{11} (Buffer Stock for H.T. Bake)

Planning Department attempt to arrange a buffer stock on the H.T. baking section of 48 hours work for each baking drum size which is in circulation. This level is checked weekly and work fed into the mixing facility, generally on a daily basis to control the level at two days.

One of the difficulties on the baking section is ensuring that both the tooling and the correct material are available when indicated on the schedule. It is thus an important requirement to limit the movement of drums in and out of stores to a minimum. In order to meet this requirement it is not sufficient to plan to have 48 hours work of the same baking drum radius type, since work requiring identical baking drums may require different thickness stops or number of bands. It is considered that work should be queued (and planned) in work types on the H.T. bake section, a work type being defined below.

4.5.4.1 Work Type Definition

H. T. bake work type is defined by

B. D. Radius	Thickness Stop	No. of Bands

Thus one work type may be composed of several different semi-finished pads, provided they all require the same B.D. radius, thickness stop and number of bands.

4.5.4.2 Function of the Buffer

In designing the size of a buffer stock, one must analyse why it is necessary to hold such a stock. The following are the major reasons for holding a buffer stock in this particular case.

(a) Work flows into the buffer in an intermittent manner mainly because the previous sections do not work three shifts continuously as do the H. T. bake section and also work flows non-sequentially, thus it is necessary to have a buffer stock to work on when the supply sections are not working.

(b) To safeguard against minor machine breakdowns or labour absenteeism on the supply sections.

(c) To enable time for tooling to be delivered from stores (where necessary).

(d) To enable larger batches to be mixed than would be possible with a zero size buffer.

Regarding point (d), Fig. 4.7 shows the approximate relationship between the continuous mixer set ups and the H. T. bake buffer size. Fig. 4.7 indicates only an approximation because of the uncertainty

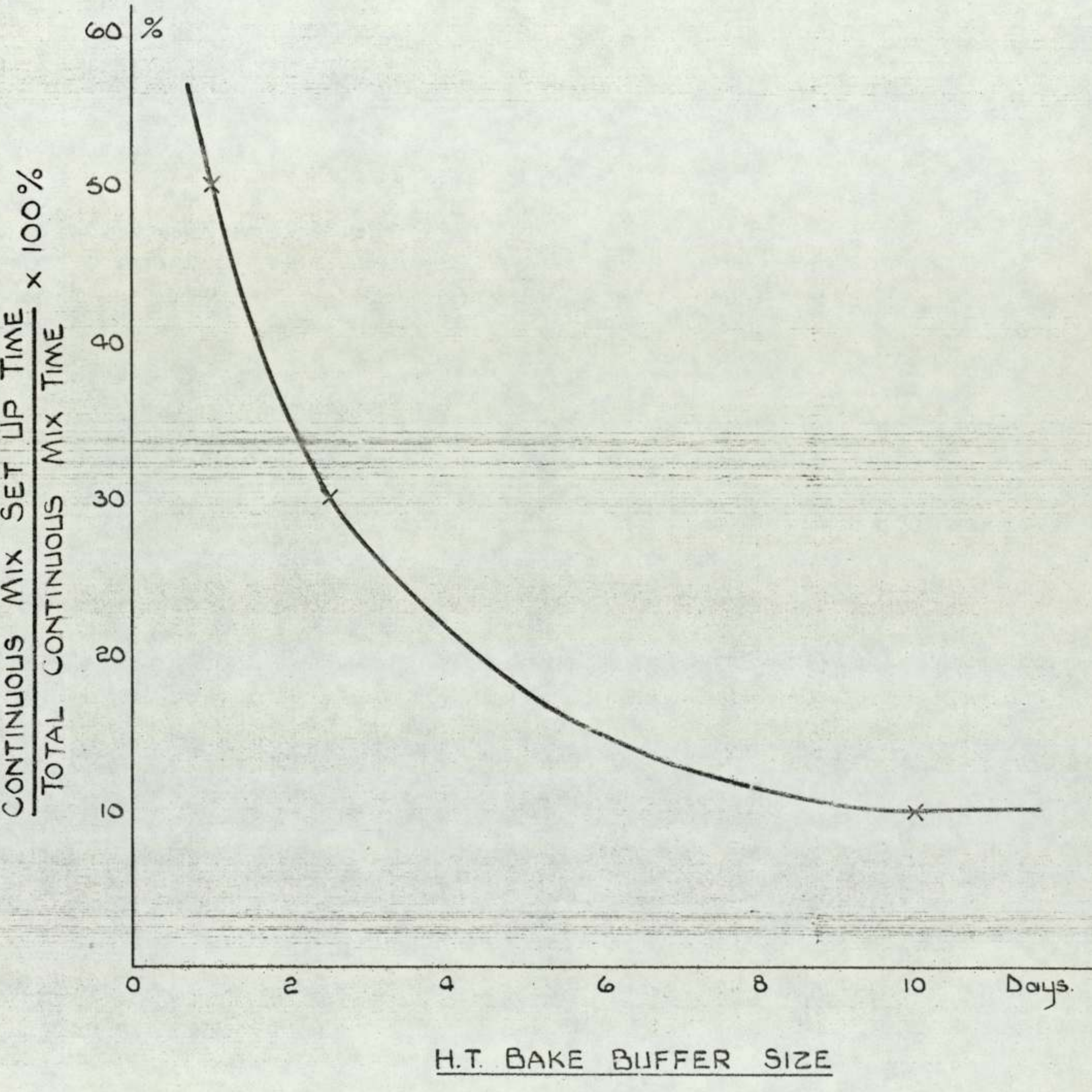


FIG. 4.7 APPROXIMATE RELATIONSHIP BETWEEN CONTINUOUS MIXER SET UPS. & H.T. BAKE BUFFER SIZE

associated with correlating H. T.bake buffer size with continuous mix set up times in a period of plant development. However, the three points on Fig. 4.7 have been determined from discussions with line management and Planning Department. It is well known that the set ups are of the order of 50% when the H. T. bake buffer is as low as one day and similarly when the H. T. bake buffer is at approximately 2½ days the set ups are of the order of 30%. The third point at 10% set ups and a buffer size of three days is a hypothetical one but gives the shape of the curve. This was determined by estimating the buffer size necessary to achieve the minimum possible set up time of 10%.

4.5.4.3 Time Constraints

For $T > .355"$ 7 days is the maximum time allowed from entrance to the H. T. bake buffer to completion of baking. A maximum of two days is allowed for scheduling and tooling delivery, but if tooling is already in use on the section, then one day is sufficient to prepare the schedule. For $T \leqslant .355"$ there is no limitation on the allowable standing time.

Buffer size for $T > .355"$ with constraint of 7 days allowable standing time (generally Ballard type work)

The buffer operates in the following manner. Work flows into the section from the supply sections (radius rolling) and after checking and receiving, it is located into what can be termed the 'reserve stock' area. This work is then scheduled and a programme produced. Work is then transferred in a sequential manner, according to the schedule, into the 'working stock' area. This area contains approximately 24 hours work and as the wording suggests, contains cages from which work is removed, loaded onto drums and thus via trays into the ovens. To summarise:

Buffer stock = Reserve stock + Working stock

Theoretically, the buffer stock could be five days and would just come within the allowable standing time provided production is maintained at the pre-planned level. One has thus got to balance the disadvantages of exceeding the allowable standing time against the advantages of being able to reduce the continuous mixer set ups as indicated in Fig. 4.7. As a compromise, it is suggested that four days be taken as the maximum buffer stock level and to achieve this, batches should be ordered in three-day quantities at the mixing stage as indicated in Fig. 4.8 instead of the present system of daily ordering. Fig 4.9 compares the

		M	T	W	T	F	S	S	M	T	W	T
BAKING BUFFER	MIXING	1 2 3				4 5 6					7 8 9	
	RESERVE STOCK		1 2 3	1 2 3	2 3	3			4 5 6	5 6	6	7 8 9
	WORKING STOCK				1	2			3	4	5	6

FIG.4.8a. DIAGRAM SHOWING FLOW SEQUENCE OF ONE WORK TYPE (T > ·355) THROUGH STAGE ONE MANUFACTURE.

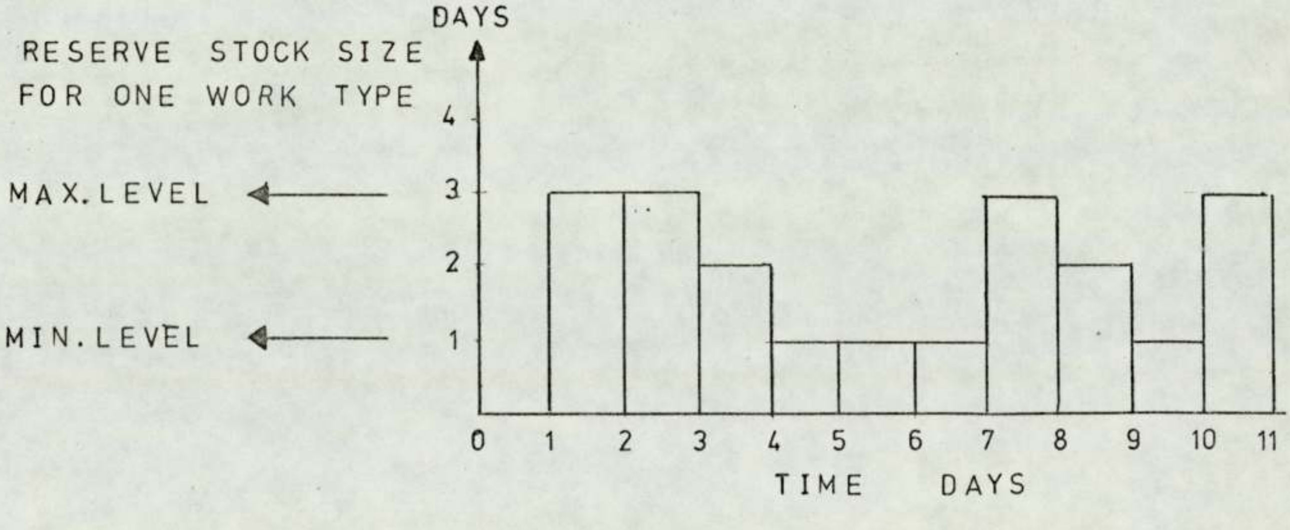


FIG.4.8b. DIAGRAM SHOWING BUFFER SIZE VARIATION FOR ONE WORK TYPE.

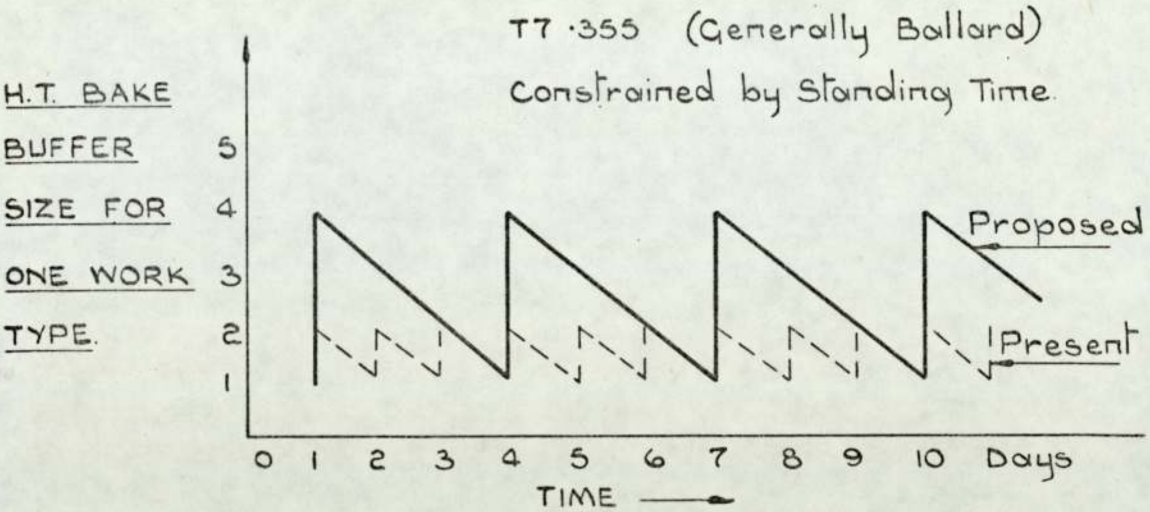


FIG. 4.9.A

N.B. WEEKENDS OMITTED

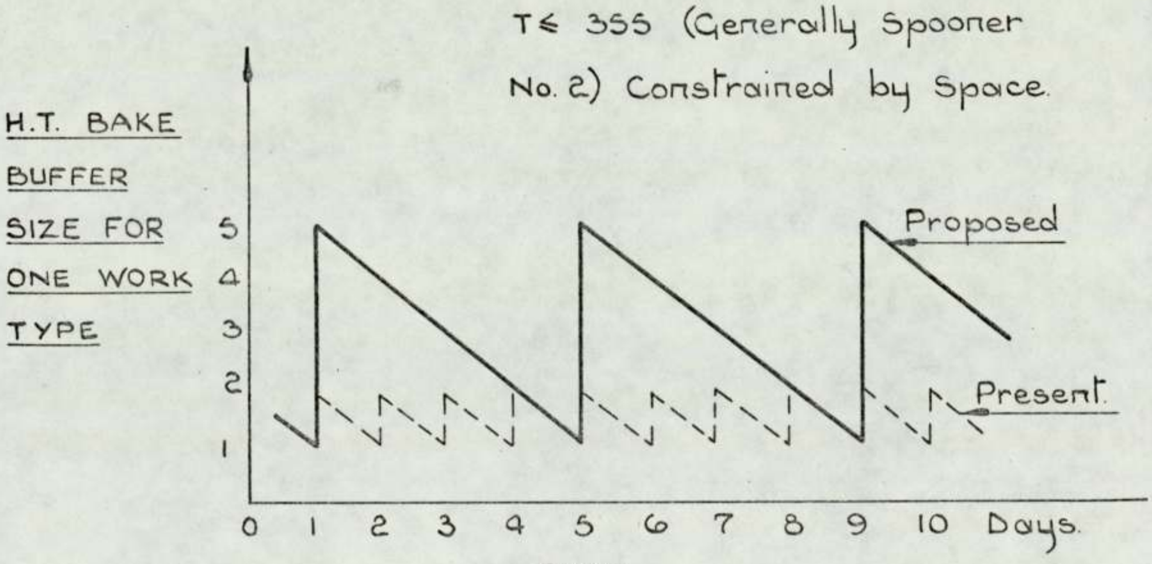


FIG. 4.9.B

FIG. 4.9 COMPARISON OF PRESENT & RECOMMENDED BUFFER STOCK LEVELS FOR H.T. BAKE present and proposed buffer stock levels: however, the comparison is not strictly true since the present stocks at H. T. bake are grouped in terms of B. D. radius only, whereas in the proposed system, the work would be grouped into work types as previously defined. Fig. 4.9b indicates a larger buffer for $T \leqslant .355''$ but this group of work is constrained by space and not by standing time - this will be explained under 'space considerations'. It is estimated that by adopting the method of planning mixing loads in three-day batches instead of the present daily method, see Fig. 4.9, the continuous mixer set ups can be reduced to 66% of their present value, thus releasing production capacity.

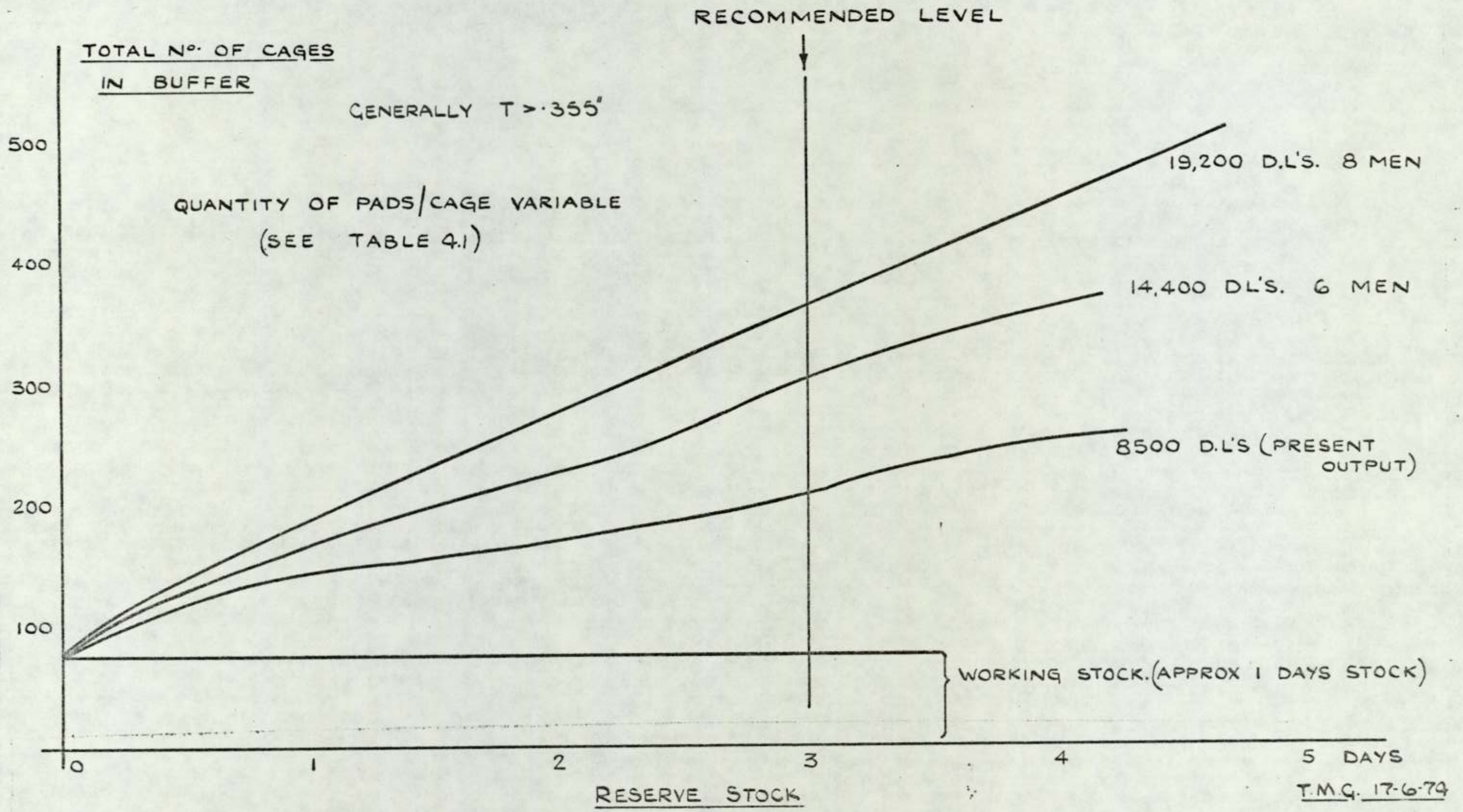
4.5.4.4 Space Considerations

Spooner No. 2 oven handles only car sizes, i.e. $T \leqslant .355''$ and the Ballard ovens in Block 'L' deal mainly with $T > .355''$ although any excess of car sizes that is surplus to the Spooner No. 2 capacity is baked on the Ballard ovens. It is convenient therefore to consider the space requirements of these two facilities individually. Generally speaking, the area required for the working stock is directly proportional to the variety of work types that are being processed and the reserve stock is proportional to the throughput. This will be illustrated below.

Ballard 'L' Space Requirements

Work is transferred from the 'reserve stock' area into the 'working stock' area according to the schedule. One of the objectives in scheduling the H. T bake ovens is to minimise drum movement from the section to the stores, thus the working stock area must cater for all the variety that has been planned for production during any particular week. It is possible for a cage of each work type to be in the working stock area at any time and it is therefore necessary to cater for this eventuality. The number of cages required in the working stock area is thus directly proportional to the number of work types requiring baking. Table 4.1 is an analysis of a typical Ballard programme and indicates the cages required in the working stock area, assuming one cage is required for each work type. The variety in this case was 67 work types. Table 4.1a shows the number of cages required in the reserve stock to support n days production. Tables 4.1b and 4.1c are similar analyses assuming increased production, but with the same variety of work types, hence the working stock area remains constant.

The results are presented in graphical form, see Fig. 4.10. Regarding the Ballard buffer stock,



T.M.G. 17-6-74

FIG. 4.10 BUFFER STOCK SIZE FOR BALLARD "L" OVENS (BLOCK "L") the recommended level is 4 days (3 days reserve + 1 working): Fig. 4.10 indicates that 360 cages should cater for this level. Fig. 4.11 shows the proposed layout which is designed to cater for 439. This extra space has been designed because of the following reasons.

(a) In arriving at 360 cages it has been assumed that the variety will be the same as the Ballard programme chosen as an example (67 work types). At the moment, there is no attempt to control the amount of variety programmed to Stage 1 on a weekly basis and the variety will certainly exceed 67 in some cases, similarly overlap from one week's programme to the next effectively increases the variety.

(b) There are many cases of material exceeding the allowable standing time, the buffer size exceeding four days. This is mainly caused by time lost due to a tackle change which is not catered for when the weekly programme is produced or tackle is not available. A tackle check has been carried out which will enable a computer file to be established in readiness for computerisation of the scheduling system in the future.

DRG. No.

Fig. 4.11

(c) It has been assumed that planned quantities are in units of full cages and that planned quantities are manufactured. There are errors in the planned quantities resulting in inefficient cage utilisation: similarly, overmakes can cause poor cage utilisation if the planned quantity is equivalent to a full cage.

Plans are in hand to eradicate the above faults, but, since this involves much documentation amendment, it could take many months to complete, hence it is necessary to allow a contingency above the theoretical level of cages required (or cage spaces).

The space available within the working stock area on the baking section, thus imposes a limit on the variety of products that the baking section can handle at any one time. The variety of work types in the working stock area cannot exceed 89 and therefore this constraint must be taken into account when loading the mixing facility. This point was not appreciated by Planning Department staff until explained by the author. It is felt that this buffer congestion is the major cause of material being held up and hence going outside the allowable standing time. Fig. 4.11 shows the Ballard 'L' working stock area.

Spooner No. 2 Requirements

The work types required to be baked on Spooner No. 2 are fixed over a monthly period and the variety never exceeds 18 (6 drum sizes and 3 thickness stops associated with each drum size). The buffer stock can be split into two elements in a similar manner to the Ballard facility, i.e. Buffer stock = Reserve stock + working stock.

In the working stock, it is necessary to hold a minimum of 18 cages in the working stock area. Since there are no time constraints on this type of work, subject to other limitations the buffer should be made as large as space permits, which in this case is 90 cages, see Figs. 4.5 and 4.12.

4.5.4.5 Optimum Buffer Size for B_{11}

The question of what is the optimum buffer size can now be considered - optimum being defined as that size which yields minimum operating costs. Fig. 4.13 shows the variable cost elements of the buffer, line (a) being determined from Fig. 4.7 and is the cost of direct labour associated with machine set ups. It is assumed that output is constant at 50 000 pads/week, hence as the buffer size diminishes from 10 days, more hours are

ANNUAL OUTPUT ASSUMED TO BE 50,000 S.F. PADS/WK.

Line A ~ Total Variable Cost Curve

a ~ Cost of Labour Associated with Continuous Mix Set Ups.

b ~ Cost of Labour Required to Compensate for Loss of Production due to increased Set Ups.

c ~ Cost of Interest on H.T. Bake Buffer Stock.

d ~ Cost of Cages used in H.T. Bake Buffer.

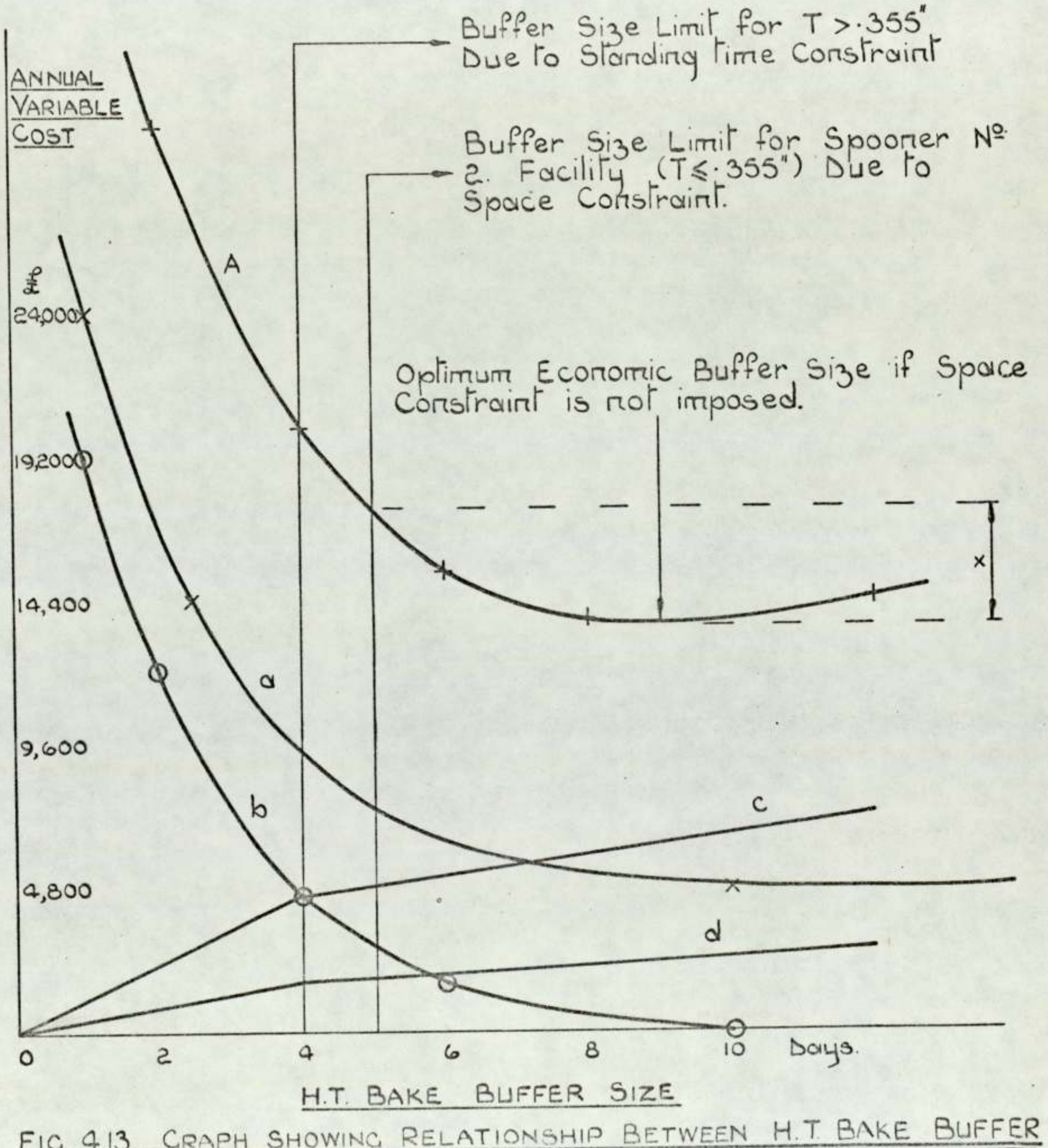


FIG. 4.13 GRAPH SHOWING RELATIONSHIP BETWEEN H.T. BAKE BUFFER SIZE & ANNUAL VARIABLE COST

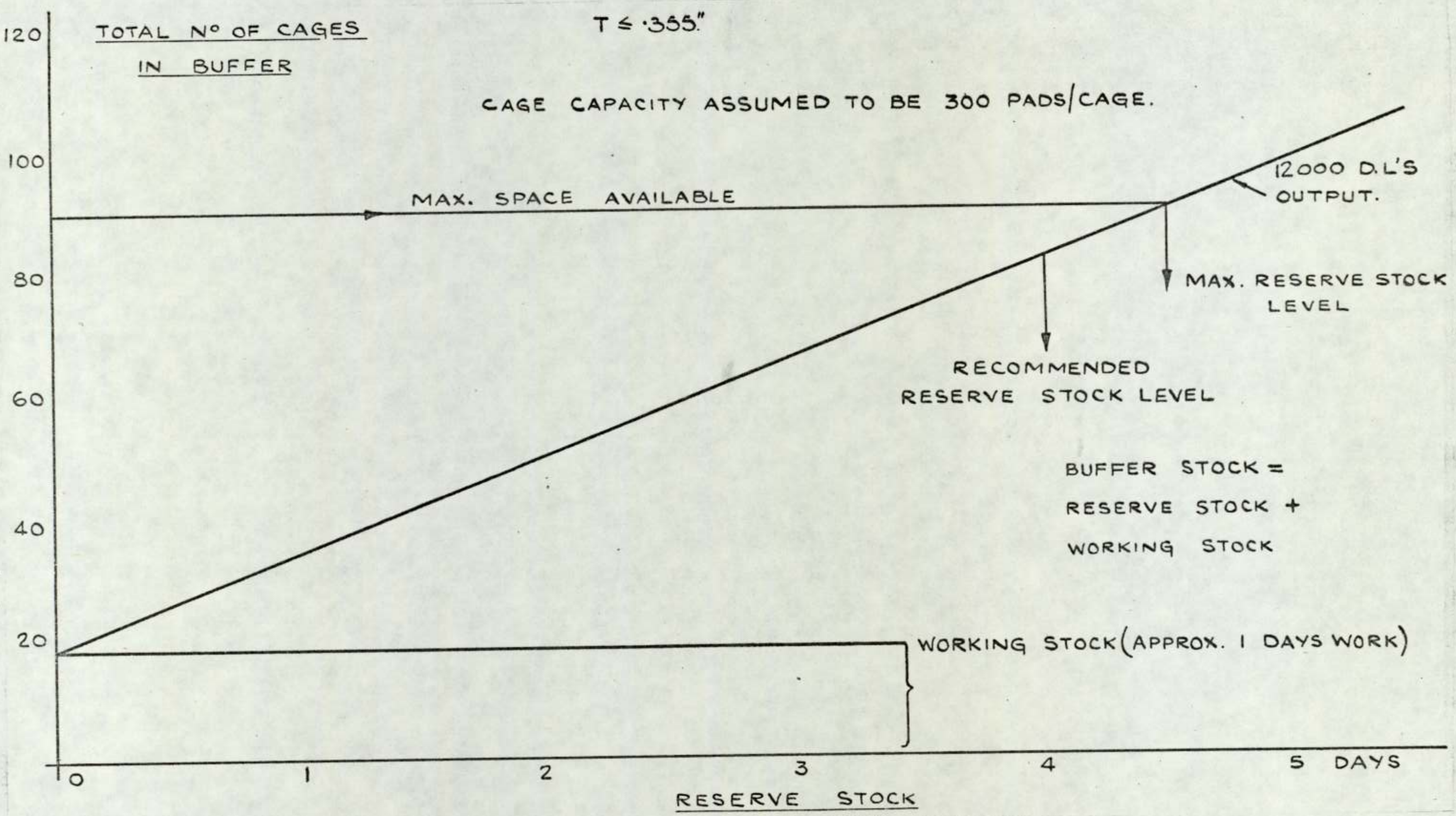


FIG. 4.12 BUFFER SIZE FOR SPOONER NO. 2 OVEN.

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required to be worked to replace the hours lost due to increased set up time. This compensation is shown as line (b) in Fig. 4.13. Line (c) is the cost of interest associated with the capital value of the stock in the buffer and similarly line (d) is the cost of cages used in the buffer, (a 10 year life has been assumed). The slope of both lines (c) and (d) alters at 4 days due to the time constraint imposed for T $>$ .355". Line A indicates the optimum buffer size if the space constraint is removed. The optimum buffer size for T $>$.355" is 4 days and that for T $\leqslant$.355" is 5 days under present operating conditions.

There are many difficult (if not impossible) technological barriers to overcome in order to either remove or increase the time constraint. However, it is possible and practical to consider more space for work types for T $\leqslant$.355". From Fig. 4.13 it can be deduced that in order to operate at the optimal point the buffer size would have to increase to 9 days (for T $\leqslant$.355") and the savings to be achieved in so doing would be approximately £4000 per annum. ('x' see fig. 4.13). Thus it would be a fairly simple exercise to balance this cost against the cost of extra space to accommodate the extra buffer, taking into account, associated running costs, e.g. transport, labour and rent.

However, it is true to say that the composite variable cost curve is very shallow and therefore the minimum point is not critical and the allowable tolerance could be as much as ± 2 days without affecting the total cost appreciably.

4.6 Transportation

Throughout Stage 1, work is transfered from buffer to buffer either by means of a fork lift truck or a hand-operated truck, the work being contained either on a flat pallet or in a cage. In no case is work transported on conveyors between buffers and therefore this means that the flow is intermittent and dependent on the availability of a service function, i.e. service operator and truck. The latter is an important point, since this means there is a queueing time associated with the transport service at each buffer and furthermore, in some cases the transport service is only available on two out of the three shifts. Thus, work may be waiting to be transferred into another buffer stock for as long as eight hours. There is a gradual trend towards each work section being autonomous regarding its own transport requirements instead of relying on a central service for work movement. This has probably been brought about by poor service from a central servicing facility and is demonstrated by the fact that the number of fork lift trucks used for internal transport has increased by 170% in the last ten years, see Fig. 4.14 while production has risen by only 50%.

4.7 Development of a Scheduling System for B_4

The continuous mixer feeds material into the roll former hopper (B_4) at a constant rate. This rate can be varied between runs but not during a run. However, in order to reduce quality control problems, initially it has been decided to restrict the continuous mixer rate to four speeds. The rate of production from the continuous mixer is such that the hopper is capable of being completely filled in a matter of a few minutes (approximately 6 minutes) if the roll former is not producing.

Fig. 4.15 shows a schematic diagram of the arrangement and it is essential that during the production run the hopper level fluctuates between the minimum and maximum levels of 200lbs or 1200lbs. If the level drops below 200lbs., then the roll former must be stopped, since malforming could occur: similarly the mixer must be stopped if the maximum

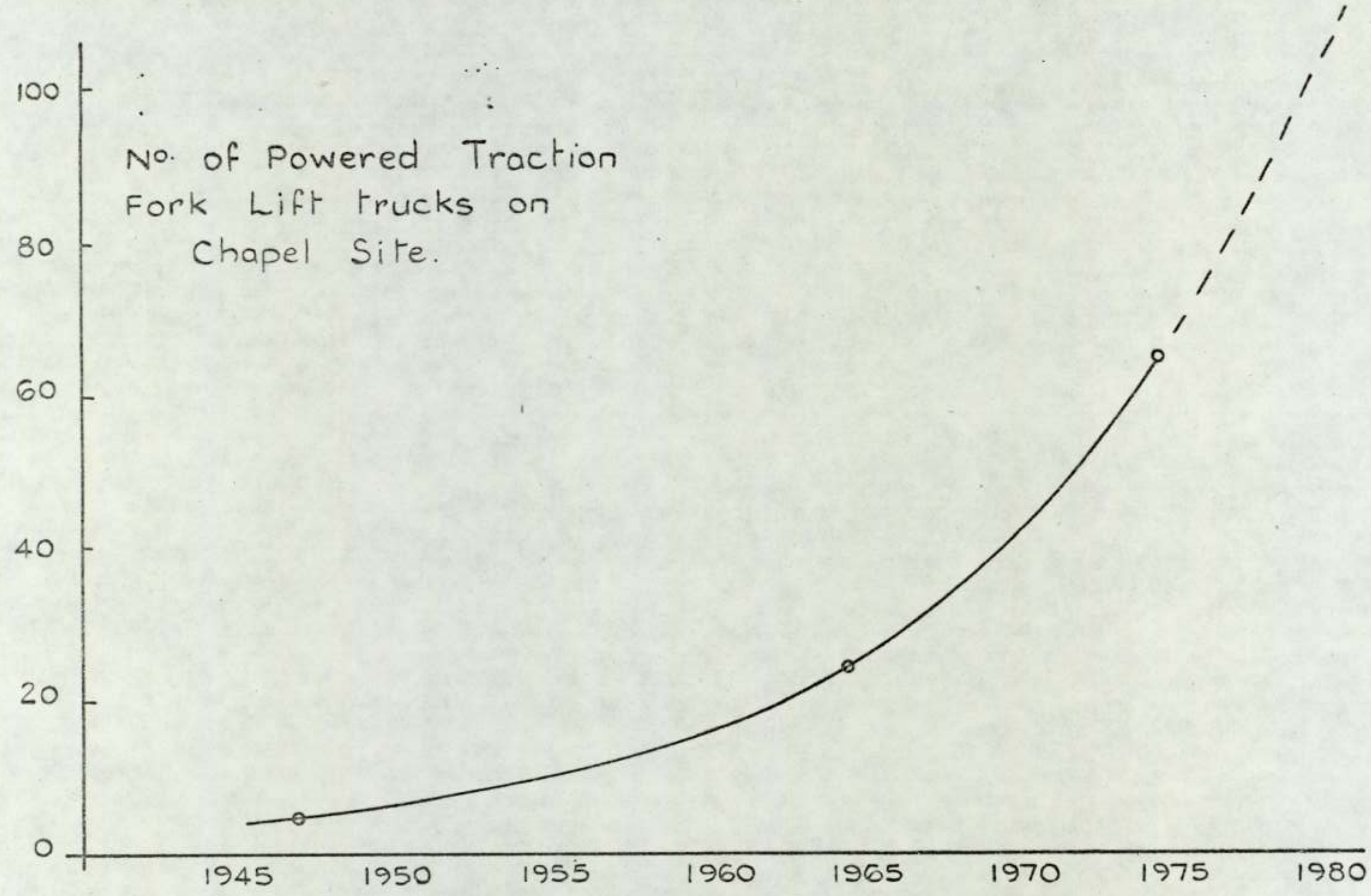
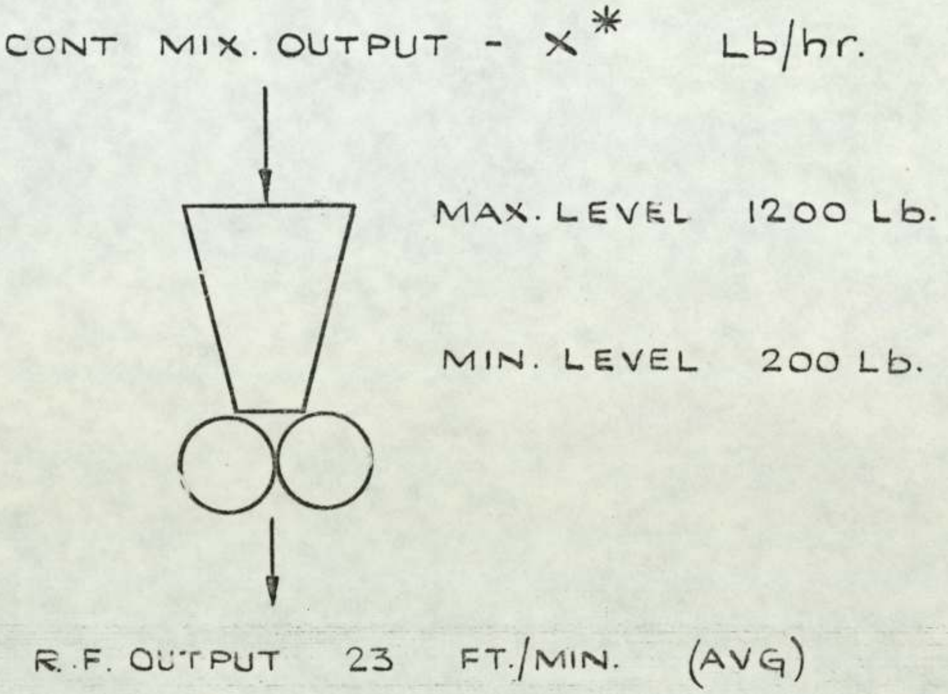


FIG. 4.14 GRAPH SHOWING ESCALATION OF FORK LIFT TRUCKS AT THE CHAPEL SITE



MATERIAL TYPE	X
AM2 - CHOICE OF TWO SPEEDS	5500 7070
AM 14 & 15	6900 - 12½% REBATCH.
AM 15	7800 - 25% REBATCH.

FIG 4.15 SCHEMATIC DIAGRAM OF CONTINUOUS MIXER/ROLL FORMER PRODUCTION LINE.

level is exceeded. (In practice, material is diverted to a bin garage before the mixer is stopped). Thus, in order to ensure that the hopper level is always between the minimum and maximum levels during the production run, it is necessary to schedule the individual orders, since order sequence is extremely important.

A method of scheduling has been evolved and is detailed in Appendix 2. Any delay in roll forming during a production run is critical since the mixer feeds continuously into the hopper. Thus, if any delay occurs, e.g. a hold-up during dimensional changes on the roll former or a minor breakdown (saw blockage), it is necessary to re-schedule the orders. It is therefore recommended that the scheduling sequence should be determined by a mini-computer, since speed in calculating the desired sequence is necessary.

The computer would have to be situated on the factory floor, either adjacent to the roll forming machine or in the clerk's office. All trials so far have been carried out on a Hewlett Packard 9820A machine and it would be necessary to either hire or purchase a calculating machine to carry out this exercise on site.

4.8 Development of a Scheduling System for B_{11} (Ballard 'L' only)

4.8.1 Problem Definition

Fig. 4.3 shows a simplified flow diagram of materials in Stage 1. Under the present organisational structure, the material undergoes a responsibility change when it moves from B_{10} to B_{11}. This would seem to be a logical break, since the maximum allowable standing times at operations prior to radius rolling are often of the order of a few hours only, whereas the maximum allowable standing time in B_{11} is generally seven days. Thus, it is very desirable for buffers B_1 - B_{10} to be controlled by one manager, since he has a concern to progress the orders through all the buffers and not merely some of them. This is particularly important when the maximum permissible standing time is of the order of only a few hours.

The problems on the H. T. baking section can be summarised as follows:-

(a) Lack of material for the baking drums (B. D.'s) planned.

(b) Lack of B. D. 's (according to weekly programme).

(c) Material out of standing time due to (b).

(d) Erratic throughput time - i.e. unreliable material delivery from the baking section.

A weekly programme is issued by Planning Department to the baking section indicating the quantity of drums required for each size. The work is then launched according to this programme into the forming section - i.e. buffers B_1 B_2 and B_3; Fig. 4.3. However, since the work is not controlled through buffers B_4 to B_{10} inclusive, the work arrives into buffer B_{11} in the wrong sequence. Planning Department attempts to control the size of B_{11} so that it is equivalent to 48 hours work; ideally this should be distributed throughout each drum size. Thus the problems as indicated in (a), (b), (c) and (d) arise. The drum setter, who is responsible for ordering drums from drum stores, attempts to work to the weekly programme but usually orders drums on an ad hoc basis, relying more on past experience than anything else.

It was decided to treat the baking section in a similar fashion to the G. T. system in Stage 2 where work flows into a buffer in a more-or-less arbitrary manner, whence after location it is scheduled to the G. T. lines. This system has worked extremely well and is excellent from the control point of view. If one applies the same principle to the mixing and forming section, then the MDBL manufacturing system can be considered to be composed of four cells as shown in Fig. 4.16.

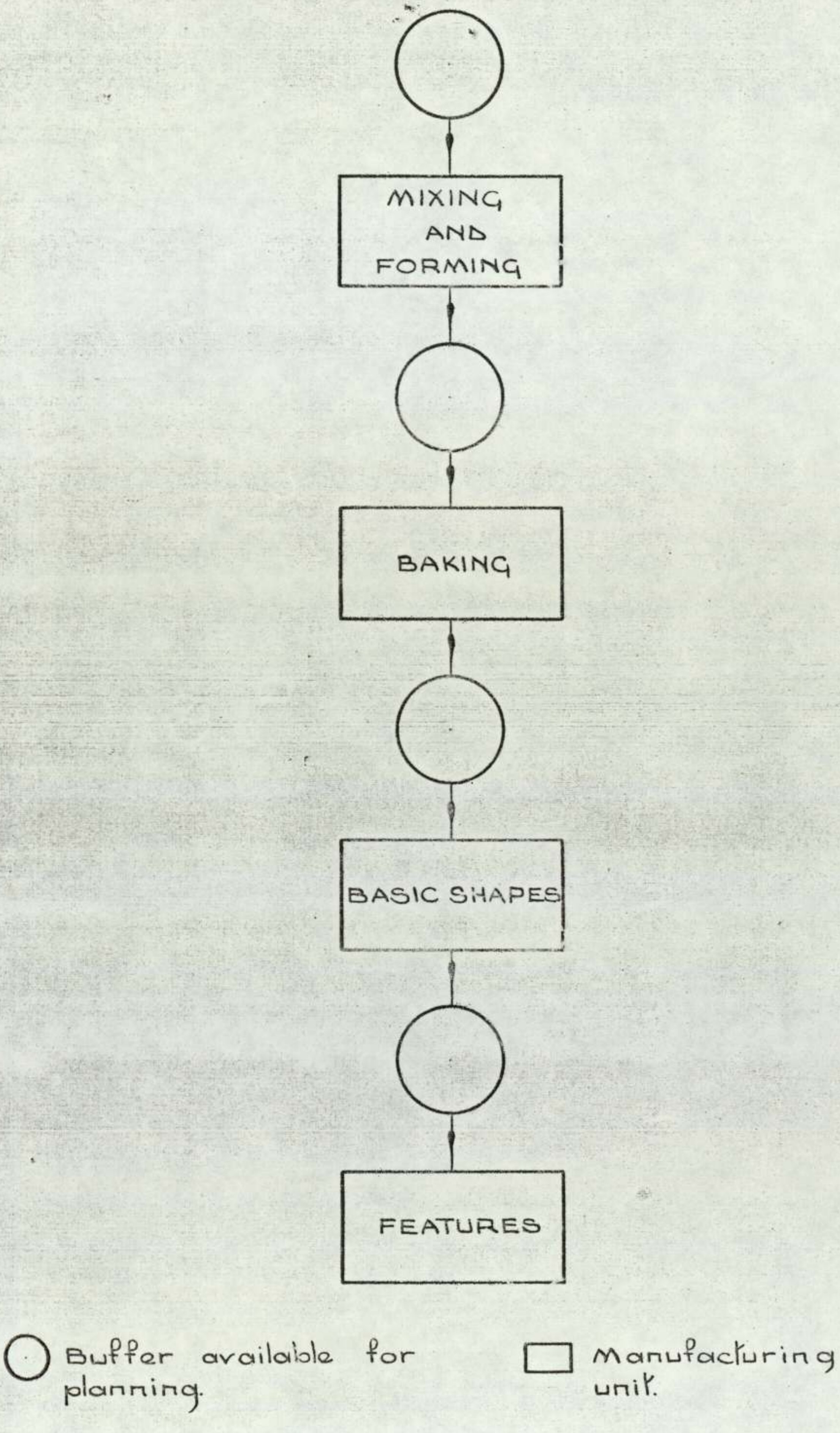
By adopting this approach on all sections, the problem becomes standard - i.e.

(a) How to schedule the section as a manufacturing unit.

(b) How to control the flow of work within the unit.

It is felt that this principle of scheduling sections containing several machines is very important, since many attempts in other companies have been made to schedule each individual machine with very unsatisfactory results. Indeed most computer scheduling systems have failed because of this basic fault. Individual machine scheduling is attractive to computer application because of the ability to cope with masses of data in a short space of time. Looking to the future, when it is quite possible that the four sections outlined in Fig. 4.16 will be scheduled by computer, it is felt that far greater benefit will ensue by scheduling merely four sections rather than the 88 machines that are within the sections.

Considerable experience has already been gained in scheduling the G. T. lines and the flow of work is controlled by means of roller conveyors. It is felt that the problem of flow control within a



M.D.B.L MANUFACTURING SYSTEM

FIG.4.16

manufacturing unit is probably more difficult than the scheduling problem itself, since interference with payment systems can considerably constrain the method adopted.

4.8.2 Development of a Scheduling System

The H. T. baking facility consists of three distinct units:-

(a) Spooner No. 2 continuous oven
(b) Ballard ovens Block 'L' (batch type)
(c) Ballard ovens Block 'B' (batch type)

The Spooner No. 2 oven has a constant heating and cooling period whereas the Ballard type is variable. Mainly large batch automotive sizes (PG10) are baked on the Spooner No. 2 oven which is relatively easy to plan. Therefore it was decided to develop a scheduling system for the Ballard Block 'L' ovens, the principles developed on this facility being applicable to the other two. This was designed and implemented in Week Four (28.1.74). Full details of the scheme are given in (21) but a brief resumé of the scheme is given here.

Work flows into buffer B_{11}, see Fig. 4.3 and is located. The scheduler then prepares a programme from the work available for baking, see Fig. 4. 17.

SCHEDULE 25 BALLARD 'L'

WEEK Nº 10 MON DAY

QUALITY	DRUM RADIUS	THICKNESS	DRUM LOADS	DRUMS REQ.	LOCATION	BANDS	SLEEVES	STOPS	CARD Nº	PAD R Nº
AM2	6·187	·443	60	6	C6				40	31033
2	6·625	·501	28	3	C3				56	632
14	6·687	·414	30	2	F12	2 ND.			16	3048
2	"	·510	6	2	B8				7	[illegible]
	6·312									
2	6·875	·291	38)	3	E10				54	3103
2	"	"	25)		D12				55	"
14	7·157	·748	25	4	F1	4 ND			90	2106
	7·250									
	7·312									
2	7·343	·510	15)	5	D11				51	3102
2	"	"	25)		D9				52	
14	"	·515	22	2	D13	681				2097
14	7·375	807 - 558 T	15	22	C10				128	30471
14	"	"	15		C10				[illegible]	"
14	"	"	15		D1				210	"
14	"	"	15		D4				211	"
14	"	"	15		D4				224	"
14	"	"	15		C6				314	"
14	"	"	15		D7				[illegible]	"
14	"	"	15		[illegible]				316	"
14	"	"	15		D7				[illegible]	"
			15		E4				318	"
14	7·500	·409	18	4	D4				94	3047
14	"	·494	20	3	B14				157	3043
14	7·625	515	14	1	E13				13	2130

FIG.4.17 BALLARD "L" PROGRAMME (BUFFER B_{11})

In preparing this programme, he attempts to minimise the drum changes by working to rules laid down, details of which are given in (21). In order to do this, he has a copy operation card of all work scheduled into the forming section during the current week. It is intended eventually to include details of drum tackle, i.e. stops, sleeves and bands. The present weekly programme ignores these because of the complexity of including them and therefore the situation can arise when there is no tackle available. A schedule is prepared each day, covering approximately 24 hours work and a minimum of 24 hours is allowed for the drum stores to deliver drums and tackle where necessary.

4.8.3 Problems associated with Introducing the New Scheme

There were surprisingly few problems when this was introduced onto the factory floor, the only resistance coming from the section leaders within Planning Department, who were not convinced that the existing system was inadequate. Regarding factory personnel, the scheme was welcomed not only by the section managers, but also by the clerks and drum setters. It is felt that it was welcomed because all these people have, at one time or another, been blamed for lack of delivery when the cause was beyond their control. The drum setter was often blamed by the operatives because drums were available with no material, but under the new scheme this cannot happen. Many meetings were held to acquaint the people concerned with the principle of scheduling from a known amount of work and also to discuss the details. It is felt that although this was time-consuming, it was vital to the success of the scheme and is principally the reason for its smooth introduction.

4.8.4 Comments on the Scheme

4.8.4.1 The scheduling system devised, attempts to take cognisance of all but the first of the following factors.

(1) All tooling available
(2) Material available
(3) Baking times
(4) Cooling times
(5) Total number of drums in service
(6) Labour utilisation on baking section
(7) Labour utilisation within drum stores

The reason why it does not take account of the first is because it is not known what tackle exists.

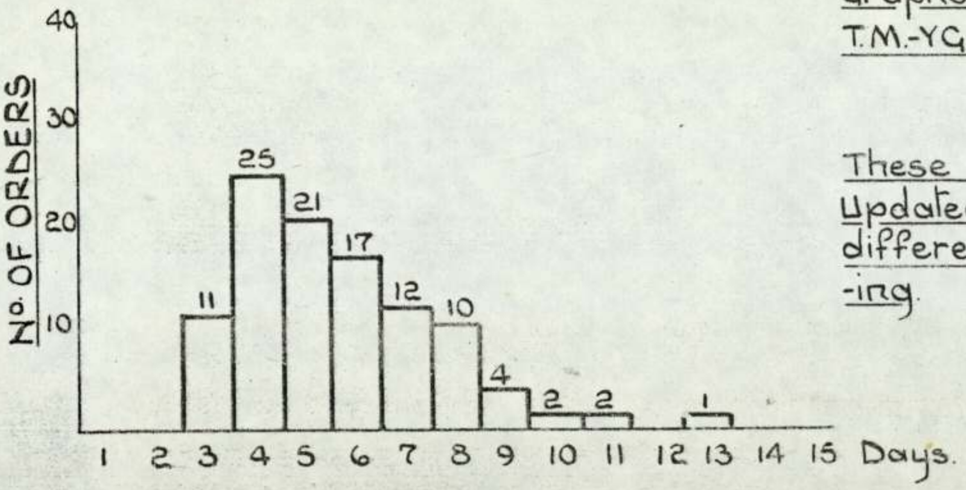
It is beyond the capabilities of a manual system to optimise all the above factors, even if all the information appertaining to the factors was available, time would not be available to carry out the optimisation exercise, since the schedule must be prepared in approximately four hours. Thus, looking to the future, one must seriously consider computerising the scheduling system.

.8.4.2 The scheduling scheme has been introduced without increasing the number of staff employed. Each section manager (on three shifts) has one clerk reporting to him. One of these has been given the job of scheduling, thus releasing the other two clerks from part of their normal work. This arrangement obviously causes problems when the scheduler is absent from work, since there is no relief clerk. Furthermore, the scheduler should be responsible to the Planning Manager and not to the Section Manager. This is in line with the practice in Stage 2 where the Planning Manager is responsible for preparing the schedule and the Section Manager for effecting the plan. Referring to Fig. 4.16, the Planning Manager is reponsible for the work in the buffer (unplanned) and the Section Manager for the work in the manufacturing unit. By transferring the scheduler to the Planning Manager, the problem of relief when he is absent is solved since there is a relief clerk available within the Planning Department. Because of the nature of the scheduler's job, it is felt that he should be located on the H. T. baking section.

.8.4.3 Figs 4.18 and 4.19 are taken from (21) and indicate the delivery situation from the baking section before and after implementing the scheme. Comparing Figs. 4.18 and 4.19, it can be seen that the longest time to complete an order has been reduced from 13 days to 10 days - a reduction of 23%, an order being defined as one operation card for purpose of comparison. The % number of orders completed within 7 days is given below, taken from Figs. 4.18 and 4.19.

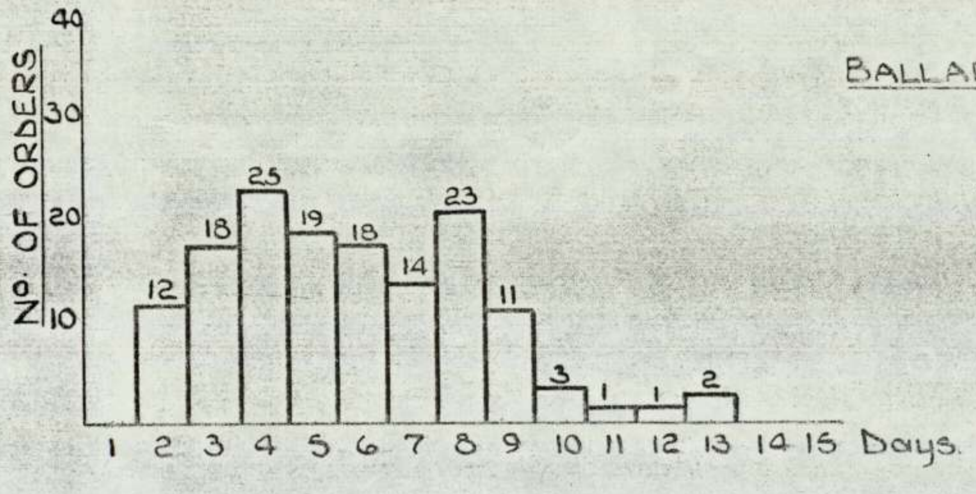
Before the scheme	81.8%) 71.6%)	average 76.7%
After the scheme	85.0%) 91.2%)	average 88.1%

Seven days has been chosen for comparison purposes since in nearly all cases this is the maximum allowable time. Thus, it would seem that the scheme has not only made the lead time more consistent, but the number of orders being completed outside the maximum allowable standing time has also been reduced.



Graphs Reproduced from T.M.-YG ~1210. Jan.'73.

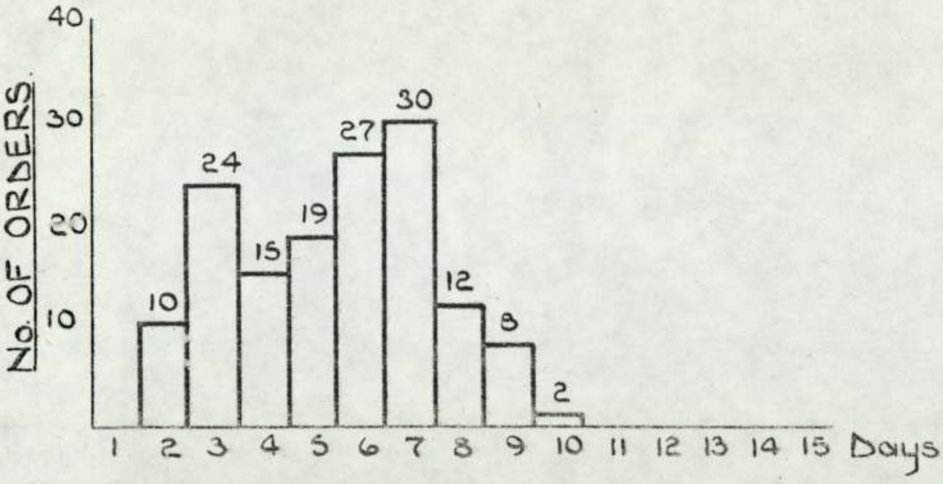
These Graphs have been Updated, because of differences in Date Stamping.



BALLARD 'L' OVENS ONLY

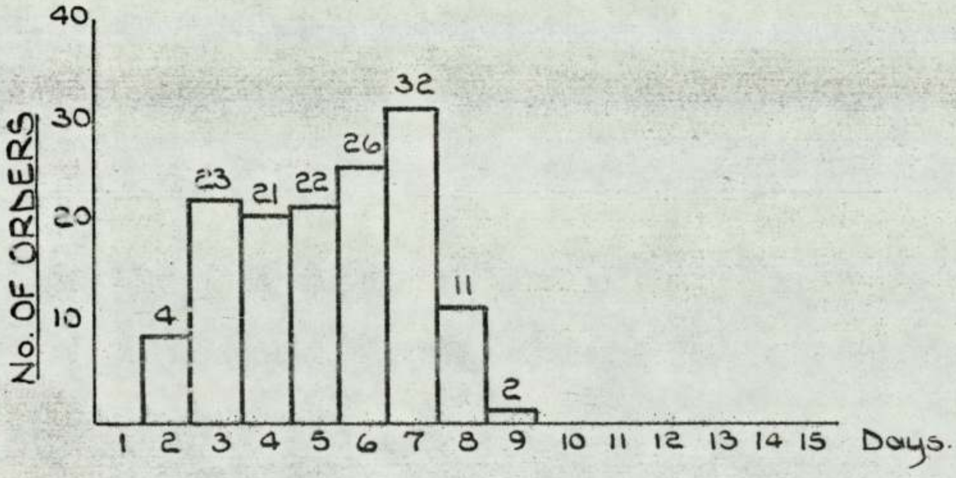
Pattern of orders completed before the introduction of the scheduling System.

FIG. 4.18 FREQUENCY DIAGRAM SHOWING LEAD TIME DISTRIBUTION THROUGH BAKING SECTION BEFORE IMPLEMENTING THE SCHEDULING SYSTEM.



WEEK No. 8.

BALLARD 'L' OVENS ONLY



WEEK No. 9.

Pattern of orders completed
after the introduction of
the scheduling system.

FIG. 4.19 FREQUENCY DIAGRAMS SHOWING LEAD TIME DISTRIBUTION THROUGH BAKING SECTION AFTER IMPLEMENTING THE SCHEDULING SYSTEM

4.9 Comments

In this chapter, the Stage 1 manufacturing system has been analysed and the critical buffers observed to determine the factors which govern their operating level. The important factors have been found to be space, rational material flow, production planning and control, time constraints and machine set ups. Observations on these factors are given in Chapter 6.

CHAPTER 5

Analysis of the Stage 2 Manufacturing System (Group Technology Cells)

5.1 Introduction

Stage 2 consists of two distinct sections, one being for the conversion of S.F. pads into basic shape linings and the other for adding special features to the basic shape lining - for example, drilling or chamfering. Fig. 5.1 is a schematic diagram of Stage 2 showing the product flow and the associated buffer stocks. The buffers for GT1, GT2, GT7 and GT8 are fed from the baking section in Stage 1 and are thus sensitive to any major disruption on the baking section or earlier operations. The light and heavy feature buffers rely on their supply from the basic shape sections and are similarly sensitive to disruptions in these sections.

It was decided to concentrate on the automotive production lines only in Stage 2 - i.e. GT1, GT2 and the light feature lines. This was because all these production lines are in a stable condition and have been for some time. However, the commercial lines have been under a state of re-development recently due to the introduction of new types of equipment and also due to the need to

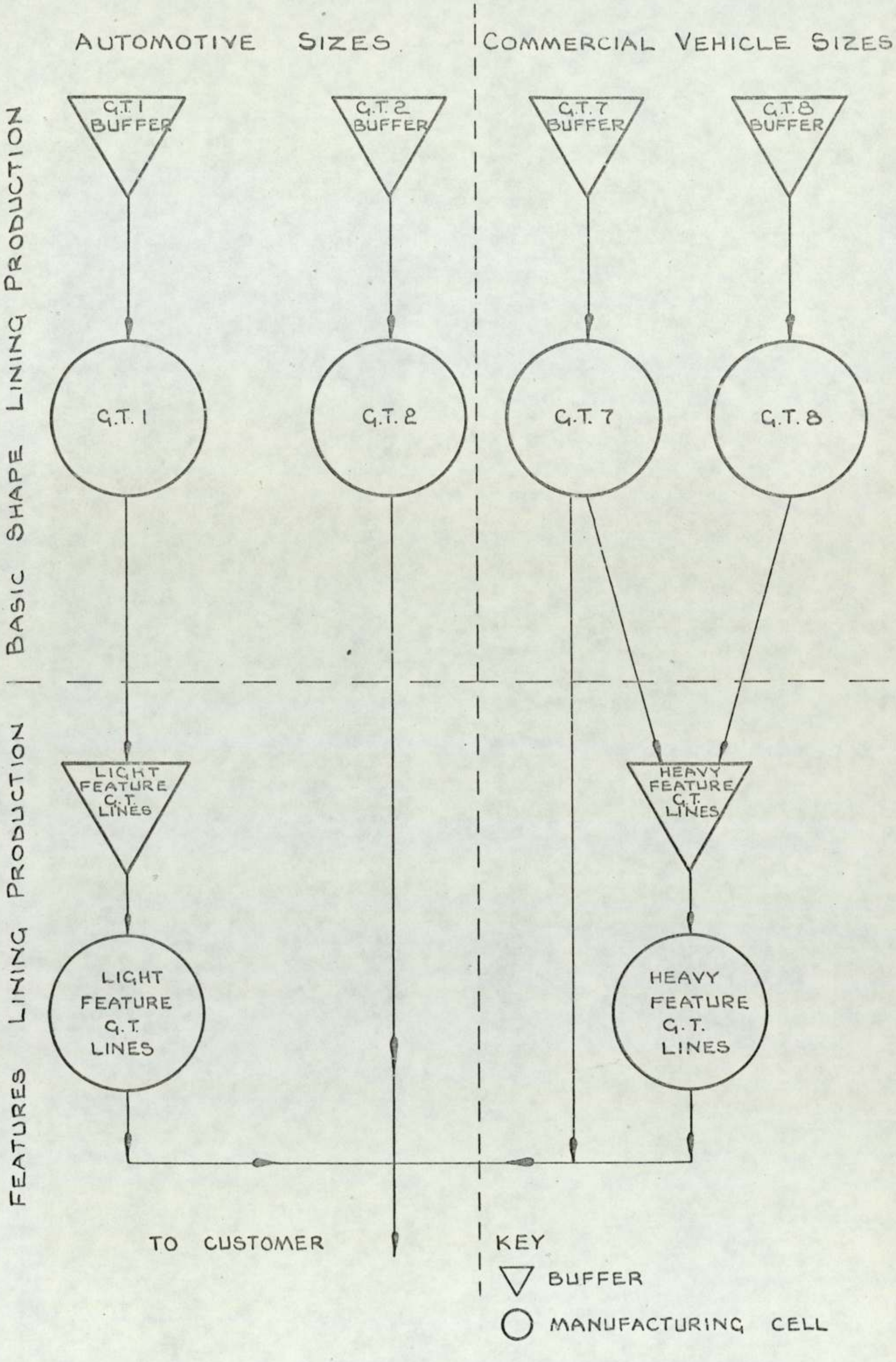


FIG.5.1 SCHEMATIC DIAGRAM SHOWING BUFFER STOCKS WITHIN STAGE 2

increase the available capacity. It was felt that too much unreliable data would have been collected from the commercial lines, since many of the operatives are not working under incentive conditions.

Each cell can be considered to be composed of two discrete elements as shown in Fig. 5.2. The GT cells in Stage 2 were designed to physically accommodate a maximum of approximately three days work, the actual value being dependent on the desired output; furthermore the amount of w.i.p. within the cells is almost constant, probably due to labour flexibility, thus as a backlog occurs, it is quickly diminished by transferring labour. With the exception of the light feature GT lines the lead time through the cells is extremely stable and because of this instability, special attention was paid to this cell and it is analysed under 5.3. The remaining cells were not examined internally, firstly because the cells function so well that Ferodo would not accept any interference to the internal cell mechanism (e.g. re-designed plant layout), this attitude is mainly because such interference would upset current payment and incentive conditions, an area which is particularly troublesome at the present time. This was effectively a constraint imposed by management. Secondly the author felt that there is probably little scope for reducing the amount of w.i.p. within the cells since the operatives are at present paid a 7%

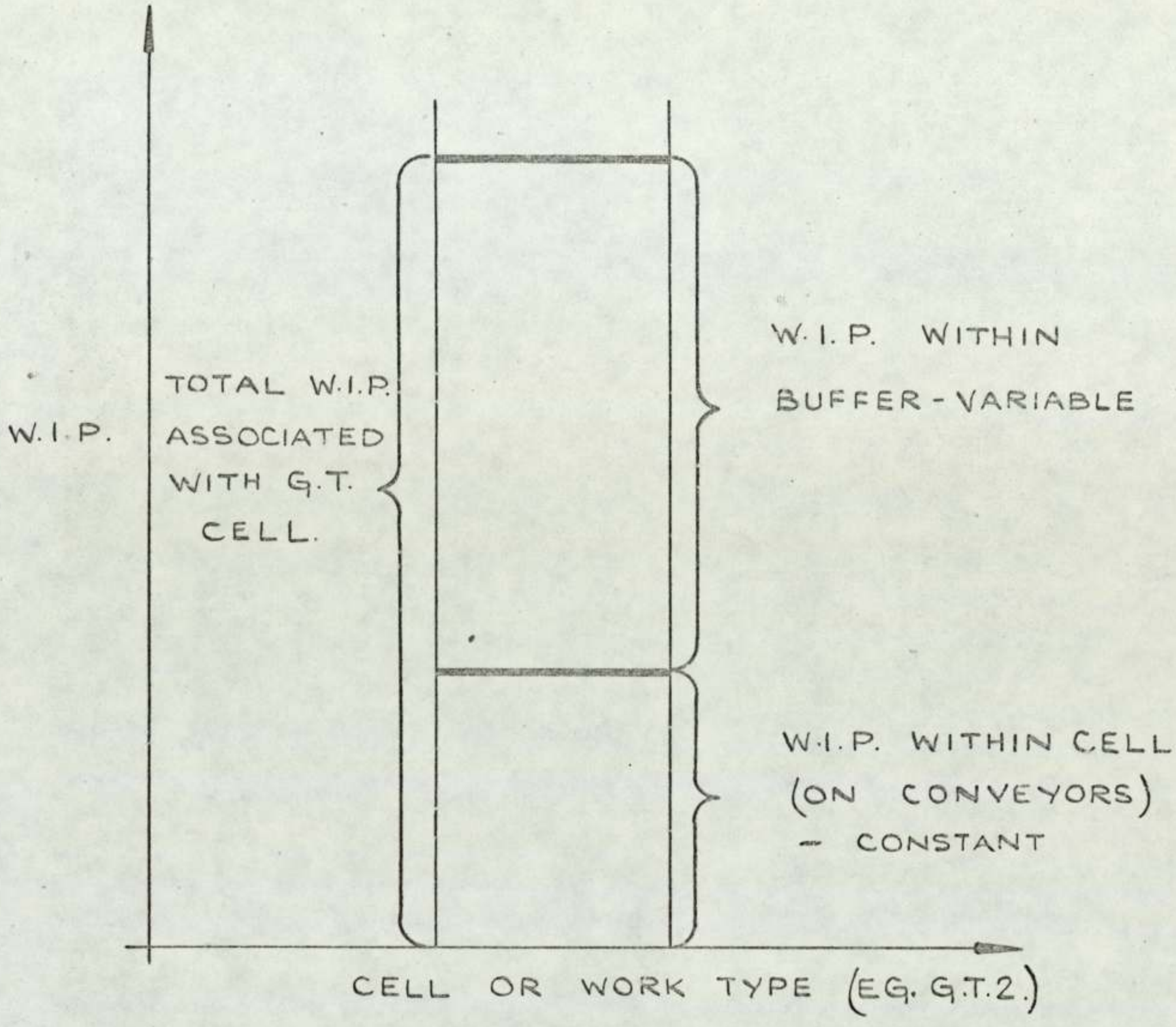


FIG 5·2 DIVISION OF G.T. CELL W.I.P.

allowance for moving from one machine to another in order to balance the workload. If the w.i.p. is reduced from the present level, operative movement will increase, thus increasing the interference allowance. The 'interference allowance' that is paid to operatives is to compensate for loss of rhythm when moving to a different machine. This allowance was negotiated with the Unions and after prolonged discussions over several months, agreement was reached at 7%. It is felt that any further increase in labour movement brought about by reduced storage space on the conveyors would be extremely costly, but very difficult to quantify. This is a point which designers must be very wary of. Theoretically, one can calculate from the learning curve, the loss of output associated with labour movement, but finally this must be negotiated and agreed with the Unions. The outcome of the final agreement may have little relevance to the theoretical interference but may be associated with the political pressures of the day within the company. Thus in designing a system which is to be operated in an industrial environment, it is important that economics associated with such a system are of the right order of magnitude but academic refinement is often eliminated upon implementation by management/union negotiations.

Thus the main area of analysis within the Stage 2 manufacturing system was concentrated on the buffers external to the cells, see Fig. 5.2. The size of these buffers can be specified by the production planning department and apart from determining the factors which affect these buffer sizes, the author has attempted to find the optimum operating level.

5.2 Analysis of Basic Shape G.T. Lines

5.2.1 Analysis of G.T.2

In Section 1.3.2 it was suggested that one of the disadvantages of reducing w.i.p. could be the increase of machine set ups and hence reduced machine efficiency. The Stage 2 manufacturing system is split into discrete manufacturing cells, each cell containing several machines - see Fig. 5.1. Prior to each of these cells, there is a buffer from which work is chosen and scheduled onto the section. The work flows into the buffer in an arbitrary manner, the only pre-planning that has taken place is to ensure that there are sufficient linings of the correct work type in progress through Stage 1 such that there is a continuous flow into the buffer equal to the output of the section.

Thus, before work arrives at the buffer, no planning has taken place to consider the economics of the section as an individual unit. When the GT system was designed originally, the size of the buffer prior to the basic shape GT lines was arbitrarily chosen to be one week (five days). This was the situation corresponding to a total w.i.p. level of 2.6 million linings, see Fig. 1.7. When the w.i.p. had been reduced to 1.6 million, the basic shape buffer (automotive linings only) had reduced to three days.

5.2.1.1 Determination of the Relationship between Buffer Size and Machine Set ups

It is reasonable to suggest that as the buffer size increases, the grouping efficiency increases, the average grouped batch size increases and machine utilisation increases (% time spent on setting up decreases). Thus, the question arose - what effect did the reduction in buffer size from five to three days have on machine efficiency? In this respect, shop floor management seemed to think that the reduction had been too drastic and that machine utilisation had deteriorated considerably although no figures were available to support this suspicion. It was decided to analyse the relationship between buffer size and key machine set up for GT2 types. The key machine in this case is the multi-pad cutter, the set up time being approximately 45 minutes. Since the set up time of all other machines on the line is very small in comparison with that of the key machine, it was decided to ignore the effect of the set ups on the other machines.

Another reason for only considering the key (set up) machine is because the manual planning system is designed round the key (set up) machine and ignores all other machines as regards set ups. In the manual scheduling system adopted, the cell is planned to minimise the key (set up) machine set up time and to fully utilise the key (volume) machine. If the machine cell was scheduled such that the total machine set ups were minimsed, then the scheduling problem would be extremely complicated and would certainly require computer assistance. Since the key(set up) machine set up time is so much greater than the other machines, it is extremely doubtful whether computer scheduling would be viable, particularly since the computer response time would have to be short. In the author's experience, unless computer terminals are employed on the factory floor, the response time is usually too long for section scheduling purposes or conversely, it is too expensive to achieve the desired turn-round of information (bearing in mind the problems of data validation). Thus it was assumed that the present manual scheduling system is adequate and will continue.

The GT2 daily programmes and weekly workload sheets (see Figs. 3.6 & 3.5) were analysed over the period October 1972 to October 1973. In the GT2 cell, the key (set up) machine is the pad cutting machine and the % set up was calculated as shown in Fig. 3.6 and an average weekly figure determined.

The buffer size was determined from the weekly workload sheet, see Fig. 3.5 by dividing the quantity of linings awaiting loading by the daily production target - this gives the buffer size in days. Fig. 5.3 shows the result of plotting buffer size against key machine set up.

Although the points on the graph are somewhat scattered, the trend is unmistakable and it would seem that there is little to be gained (except as a reserve against failure to deliver) by having a buffer stock greater than three days, the machine set up being constant at approximately 17% thereafter. This is equivalent to a machine utilisation of 83% which would seem to be a very acceptable average. It is difficult to compare specific machine utilisation but table 5.1 is reproduced from a report by MTIRA entitled 'The utilisation of machine tools' - Report No. 23. If one compares a multi-part off machine with a centre or turret lathe, then the following comparison figures can be determined.

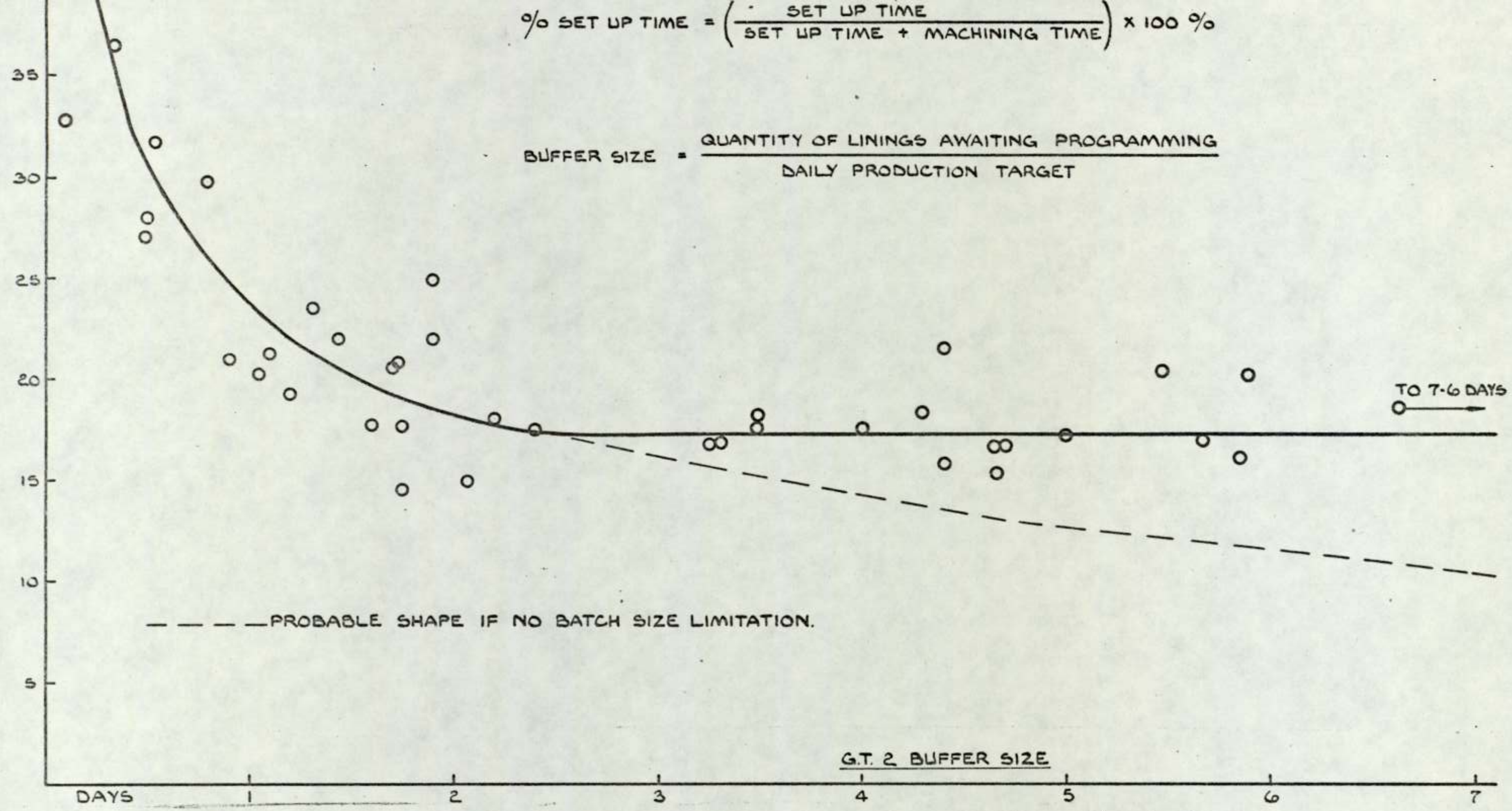
$$\begin{array}{l}\%\text{ set up time}\\\text{(and handling)}\end{array} = \frac{\text{set up time (and handling)}}{\text{set up time (and handling + cutting time)}} \times 100\%$$

Using Figs. from Table 5.1

(a) Centre lathes

$$\%\text{ set up time (and handling)} = \left(\frac{25.4}{25.4 + 40.9}\right) \times 100\%$$

$$= \underline{38.4\%}$$



$$\% \text{ SET UP TIME} = \left(\frac{\text{SET UP TIME}}{\text{SET UP TIME + MACHINING TIME}}\right) \times 100\ \%$$

$$\text{BUFFER SIZE} = \frac{\text{QUANTITY OF LININGS AWAITING PROGRAMMING}}{\text{DAILY PRODUCTION TARGET}}$$

FIG. 5.3 GRAPH SHOWING RELATIONSHIP BETWEEN SIZE OF BUFFER & % SET UP TIME OF KEY MACHINE (MULTI-PART OFF). G.T. 2 LINE ONLY. WEEKS 1-56 (OCT. '72-OCT. 73)

	PERCENTAGES										
	Milling M/Cs	Centre Lathes	Turret Lathes	Planing M/Cs	Drilling M/Cs	Cap. Lathes	Horizontal boring M/Cs	Vertical boring M/Cs	Cylind. grinding M/Cs	Surface grind. M/Cs	Total
Loading & unloading	9.1	7.4	7.3	9.3	16.9	7.7	12.7	12.8	18.1	14.4	10.7
Idle, loaded, operator absent	16.2	17.9	16.0	12.0	12.1	16.7	17.9	14.8	11.2	11.9	15.1
Idle, operator receiving instructions	1.3	2.1	1.2	1.2	1.1	1.3	1.4	1.0	2.8	1.0	1.4
Miscellaneous	0.7	0.3	1.1	0.7	1.1	1.2	0.7	0.4	0.4	0.6	0.8
Gauging	2.8	6.0	4.2	2.7	1.2	3.6	2.7	5.6	7.5	6.4	3.9
Setting & handling	24.2	25.4	27.8	26.8	32.5	32.0	28.6	24.3	15.0	21.0	26.7
Cutting	45.7	40.9	42.4	47.3	35.1	37.5	36.0	41.1	45.0	44.7	41.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Proportion of M/C time usefully employed	84.0	76.8	82.9	89.2	69.2	79.8	80.7	88.8	64.3	68.7	78.7
Total no. of observations see Appendix III	1 867	1 638	1 353	1 241	1 551	1 317	998	580	787	709	12 041

TABLE 5.1 - REPRODUCED FROM M.T.I.R.A. REPORT NO. 23 - 'THE UTILISATION OF MACHINE TOOLS'

(b) Turret lathes

$$\% \text{ set up time (and handling)} = \left(\frac{27.8}{(27.8 + 42.4)}\right) \times 100\%$$

$$= \underline{39.6\%}$$

It is a pity that the handling figure is not segregated from the setting time in the report. However, it would seem that in the case of GT2 a low ratio setting time to machine time is being achieved.

It is interesting to note Connolly's predictions of machine utilisation after the introduction of the GT system. Table 5.2 is reproduced from (17). Group 1, see table 5.2, corresponds to GT2 type work, the prediction of 85.3% corresponds very closely to the actual over the last year of 83%. The utilisation prior to the GT systems was 65.9%.

Referring to Fig. 5 .3, it is interesting to observe why the graph is not asymptotic. With no limitation on grouped batch size the % set up time would certainly continue to decrease as the buffer size increases, as shown dotted in Fig. 5.3. When scheduling the work to the section, due cognisance must be taken of storage capacity on the conveyors between the machines, thus the available storage capacity imposes a constraint in terms of the maximum batch quantity that can be scheduled at one time. This is an important basic design consideration and should be taken into account in any future design calculations.

Group No.	Total operation time (Std. mins.)	Total machining time	Total setting time (Std. mins.)	% Potential Utilisation under G.T. conditions	% Existing Utilisation in 1969
* 1	6982	5962	1020	85.3	65.9
2	6397	3649	2748	57.1	30.3
3	6389	2917	3472	45.7	28.0
TOTALS	19767	12528	7240	—	—

* Equivalent to G.T. 2

** Ph. D. thesis: "The integration of Group Technology Principles into a manufacturing system." - Ref. 17

TABLE 5.2 EXISTING AND POTENTIAL MACHINE UTILISATION AS STATED BY CONNOLLY IN 1969**

.2.1.2 *Optimum size of G.T.2 buffer

In determining the optimum buffer size, the variable operating costs were considered, see Fig. 5.4. Fixed costs relating to buffer running costs have been ignored since although these alter the actual running cost, they do not affect the optimum. An example of such a fixed cost would be the cost of a serviceman (paid a fixed wage) to move cages in and out of the buffer, this being independent of buffer size.

Referring to Fig. 5.4 line (a) is Fig. 5.3 quantified into annual cost, i.e. the multi-parting off set-up costs. Line (b) is the correction factor that must be applied in conjunction with line (a) and is the cost of labour to compensate for loss of production due to increased set-ups. The output was assumed to be constant at 191 000 linings per week and that normal manning achieved this when the buffer size was at three days (the point at which buffer size becomes independent of set-up cost). Thus, it has been assumed that if the buffer operates at less than three days,overtime must be worked to maintain output. Line (c) is the cost of interest associated with the material held in the buffer, the interest rate being taken at 10% and line (d) is the cost of cages used to hold the material in the buffer (assuming a 10-year life). Insurance cost associated with the material in the buffer was found to be negligible. Combining all these costs

* The word 'optimum' will be discussed in Chapter 8

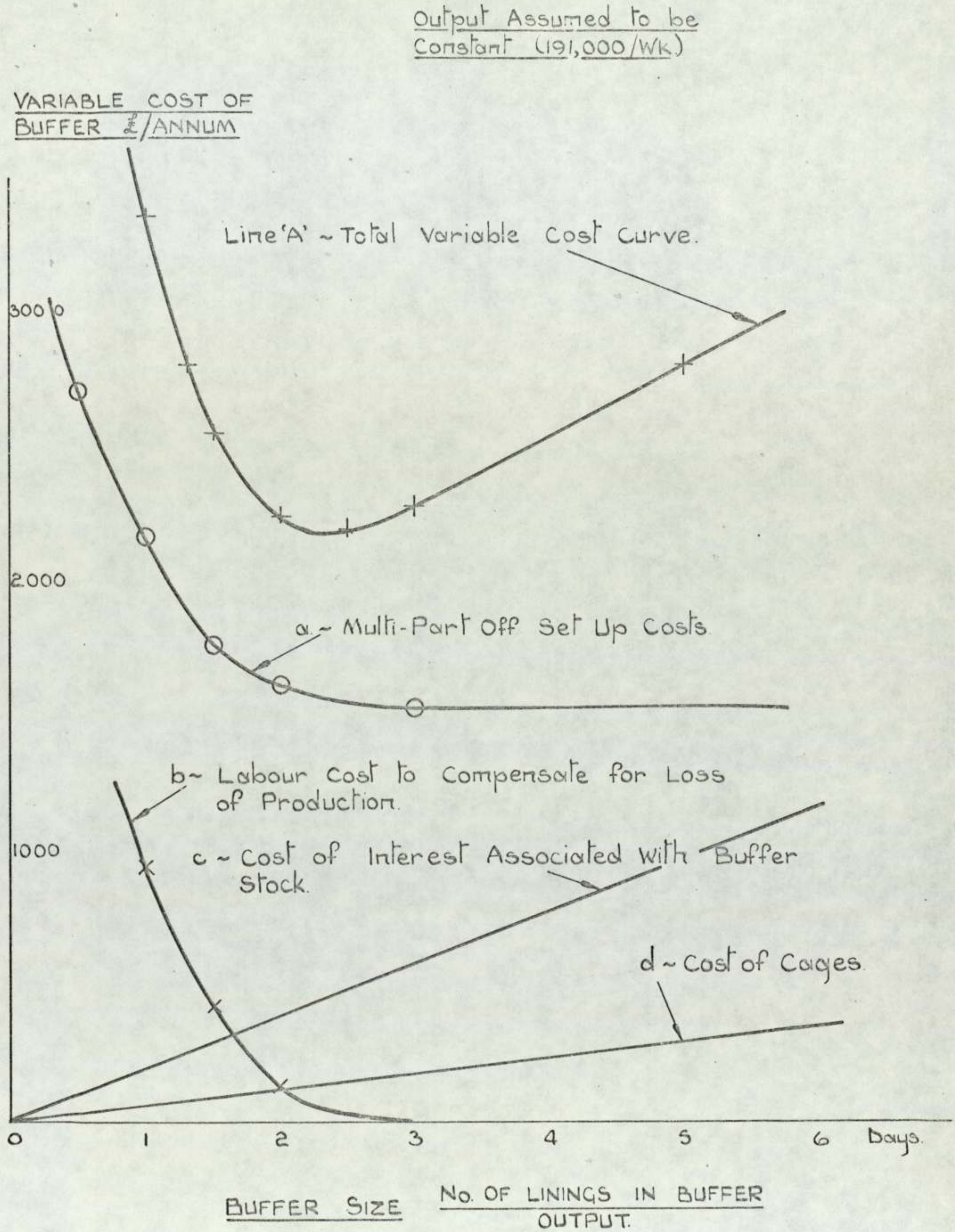


FIG. 5.4 TOTAL VARIABLE COST CURVE FOR G.T 2 BUFFER

yields a sharp minimum value at approximately 2.3 days. It is interesting to note that a reduction of the buffer by one day to 1.3 days results in an increased annual cost of £630 whereas an increase in buffer size from 2.3 days to 3.3 days only results in an increased running cost of £180. A practical top and bottom limit could therefore be recommended as being 4 days and 2 days.

5.2.2 Analysis of G.T.1

A similar exercise to that above was carried out with G.T.1 and the results are given below.

5.2.2.1 Relationship between buffer size and machine set-ups

In the G.T.1 cell, as in the G.T.2 cell, the key (set-up) machine is the multi-pad cutter and the set-up time for this is far greater than any other machine. The relationship between the buffer size and the key machine set-up time is shown in Fig. 5.5. This curve is far more shallow than the G.T.2 curve and is probably due to the fact that G.T.2 deals with a small variety of large orders whereas G.T.1 deals with a large variety of small orders. One would therefore expect to reach saturation point (minimum set-up time imposed by line design) far quicker on G.T. 2 than on G.T.1.

5.2.2.2 Optimum Buffer

All the variable costs associated with the buffer size have been determined in a similar manner to the G.T.2 case and the total variable cost curve is shown in Fig. 5.6. This indicates that the optimum buffer size is at 4 days and

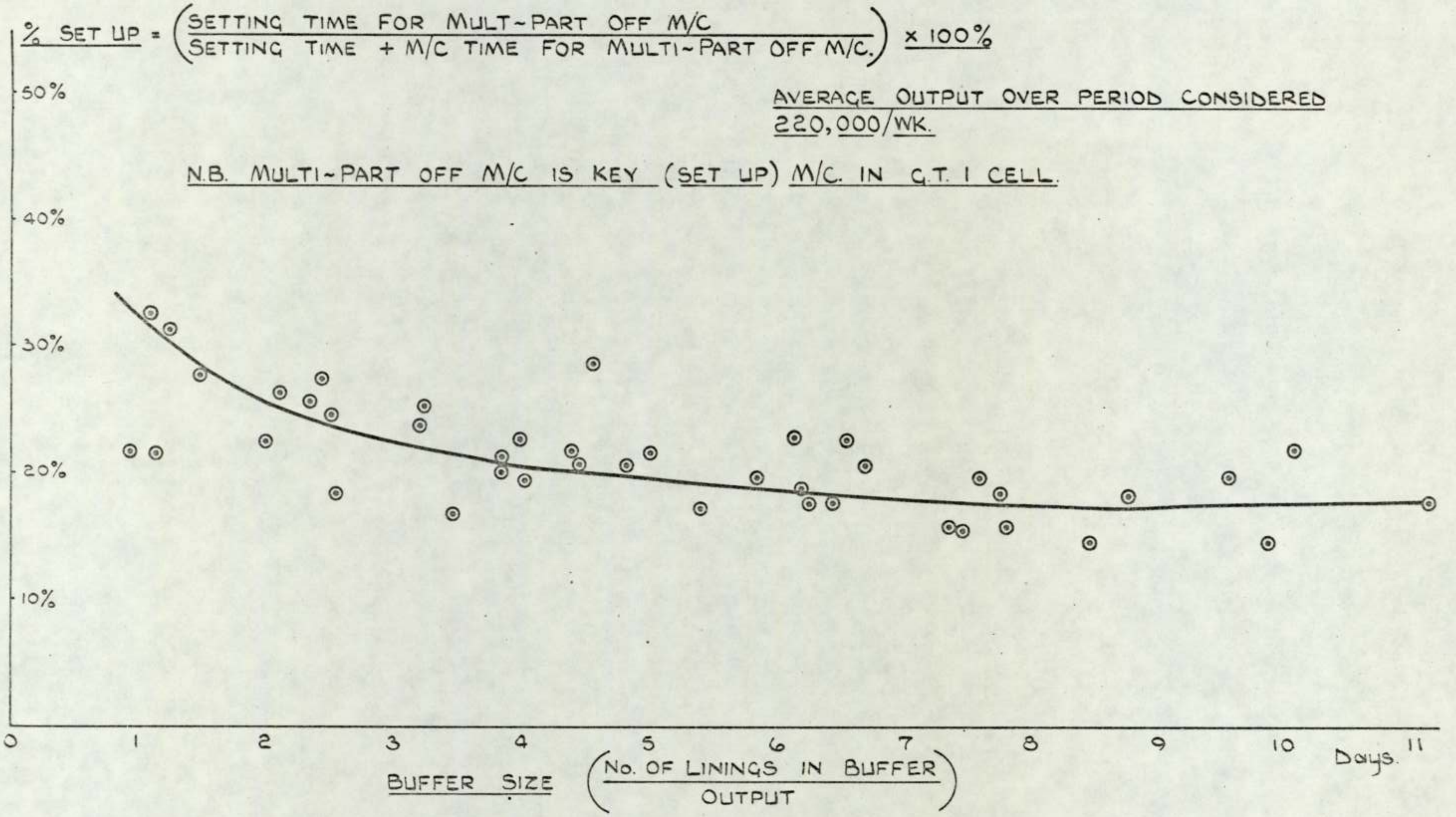


FIG. 5.5. GRAPH SHOWING RELATIONSHIP BETWEEN BUFFER SIZE & KEY M/C SET UP TIME FOR G.T.I

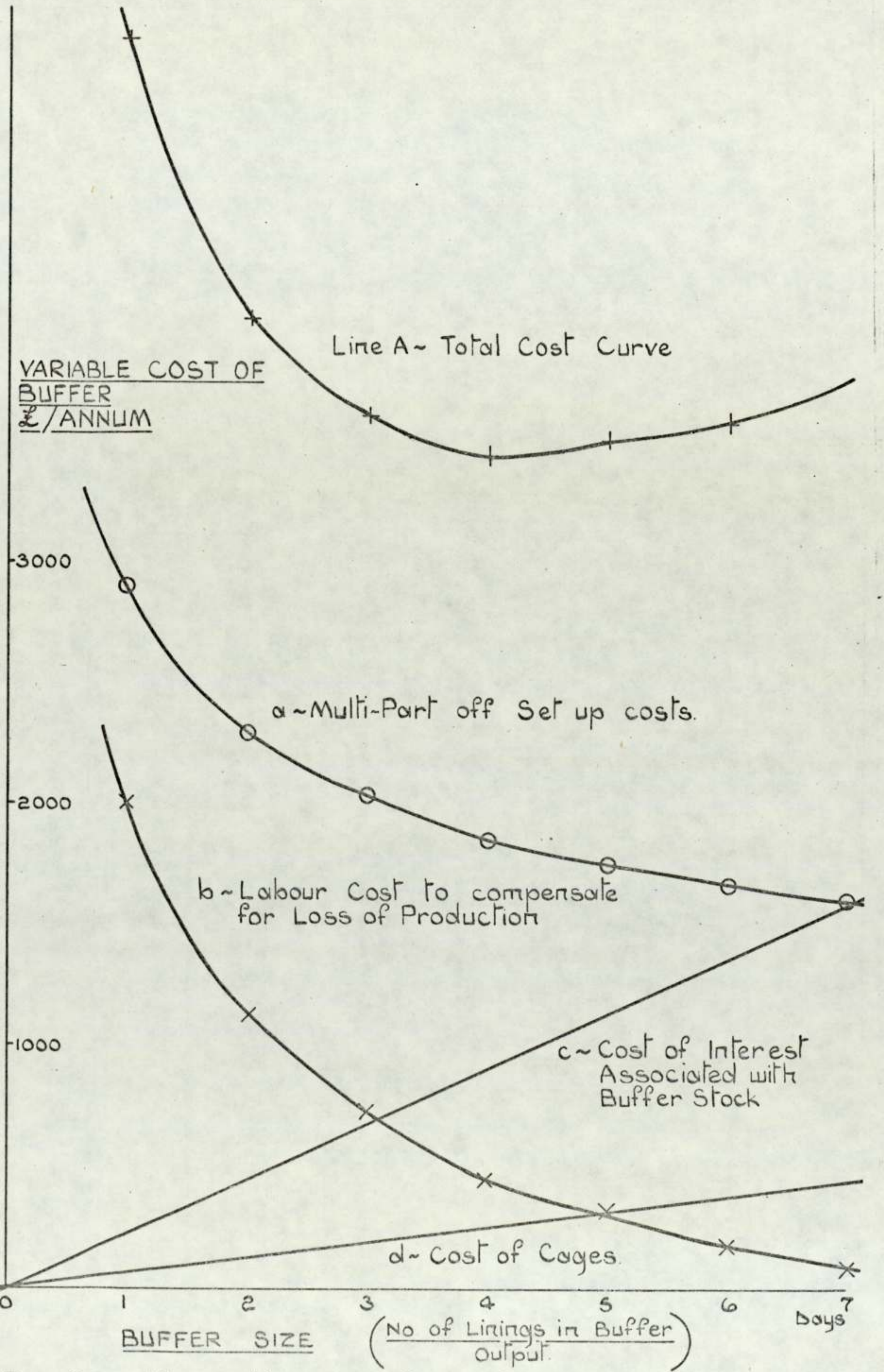


FIG. 5·6 TOTAL VARIABLE COST CURVE FOR G.T.I.

it is recommended that the operating limits are between 3 and 5 days.

5.3 Analysis of Light Feature G.T. Lines

5.3.1 Introduction

The light feature section differs from GT1 and GT2 in that it is composed of several distinct lines which are interconnected - see Fig. 5.7. Work flows into the buffer where it is analysed and segregated into work types ready for scheduling to the various lines. The buffer size is only recorded in total and is not recorded weekly in terms of work types. This necessitated analysing operative day cards in order to determine set up time which could be meaningfully compared with the buffer size.

5.3.2 Analysis of Light Feature Buffer

5.3.2.1 Relationship between buffer size and machine set up for the light feature line

In 5.2.1, a relationship was established between the buffer size and the key machine set up time (expressed as a % of key machine set up time + machining time), for the GT2 basic shape line. A similar relationship has been shown to exist for the light feature key machine, that is the small Pollard multispindle drill. Fig. 5.8

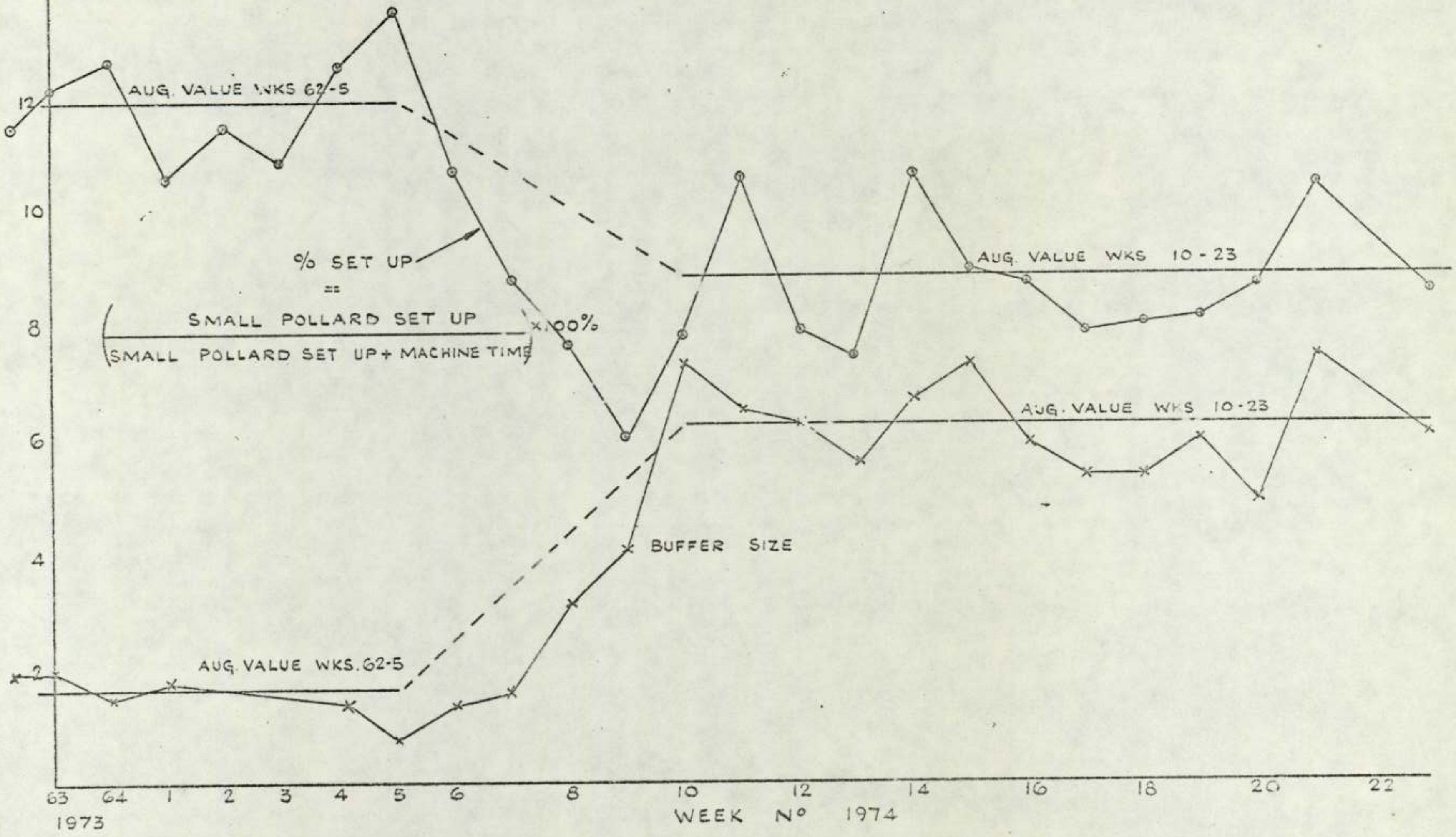


FIG.5.8 GRAPHS SHOWING VARIATION OF SMALL POLLARD SET UP & BUFFER SIZE WITH TIME

was derived by analysing day cards and the weekly workload sheet issued by Planning Department, the former documents being used to determine the set-up time (actually booked) and the latter to determine the buffer size. This graph indicates a definite correlation between buffer size and set up, generally speaking as the buffer size increases, the percentage time spent on machine setting decreases. The points are too scattered to derive any positive relationship and so average values were derived from Fig. 5.8 to produce Fig. 5.9. The two extreme points on the graph can be assumed to be very accurate. The relationship between these two points has been assumed to be linear, although, as will be seen later, the actual relationship in this region is not very important, what is important is that if the buffer size is changed from 6.2 days to 1.6 days, then the % set up will alter by 3% from 8.8% to 11.8%.

5.3.2.2 Relationship between buffer size and annual cost for the light feature line

It should be noted that the small Pollard buffer and the light feature buffer are identical. Line (a) in Fig. 5.10 shows the variable cost of set ups for the multispindle drills (small Pollard) as a function of buffer size, obtained from Fig. 5.9. Fig. 5.10 has been constructed assuming a constant output of 225 000 linings/week. As the buffer size reduces, the set ups increase and output reduces if one assumes that

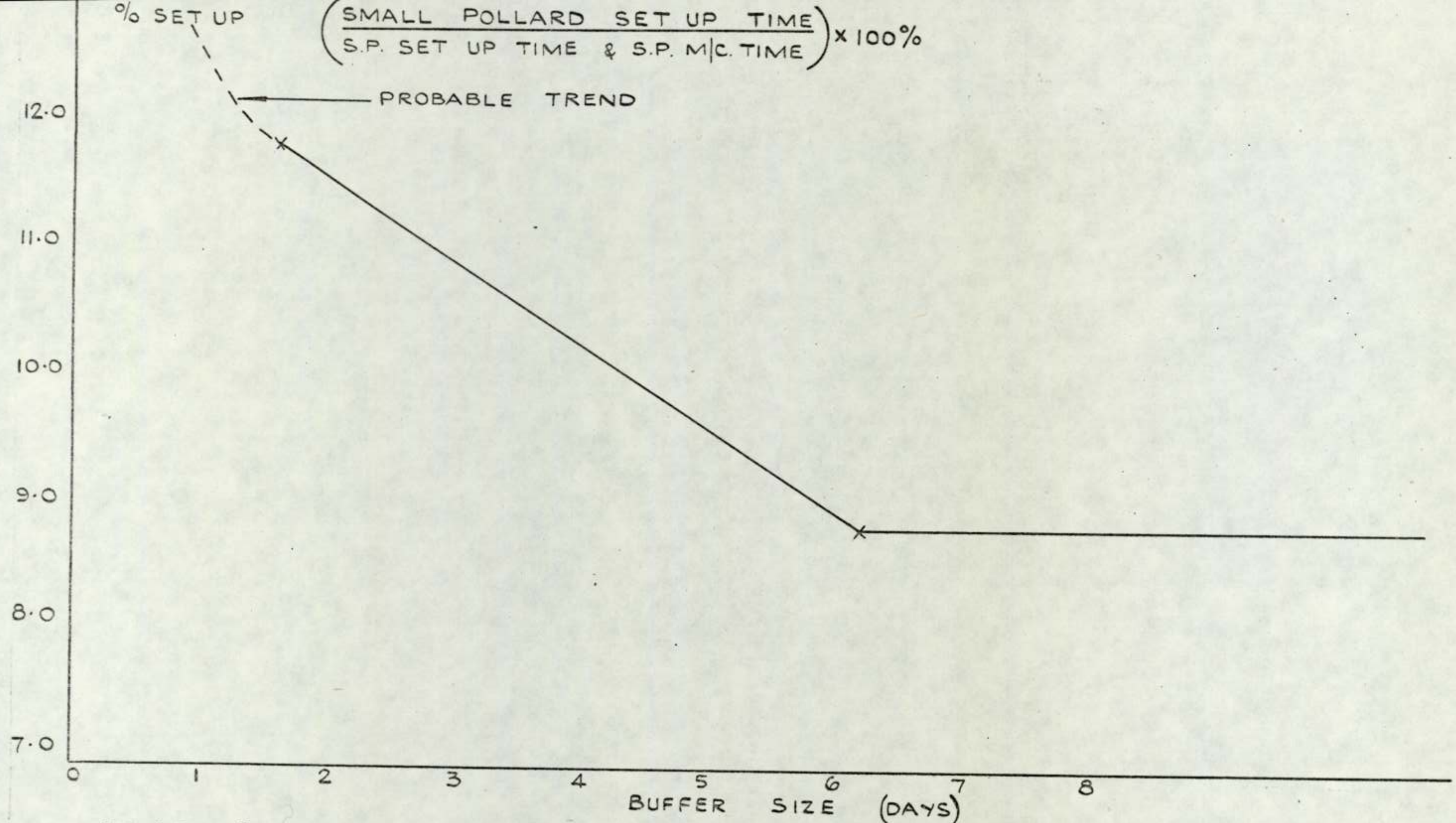


FIG. 59 RELATIONSHIP BETWEEN SMALL POLLARD SET UP TIME & BUFFER SIZE.

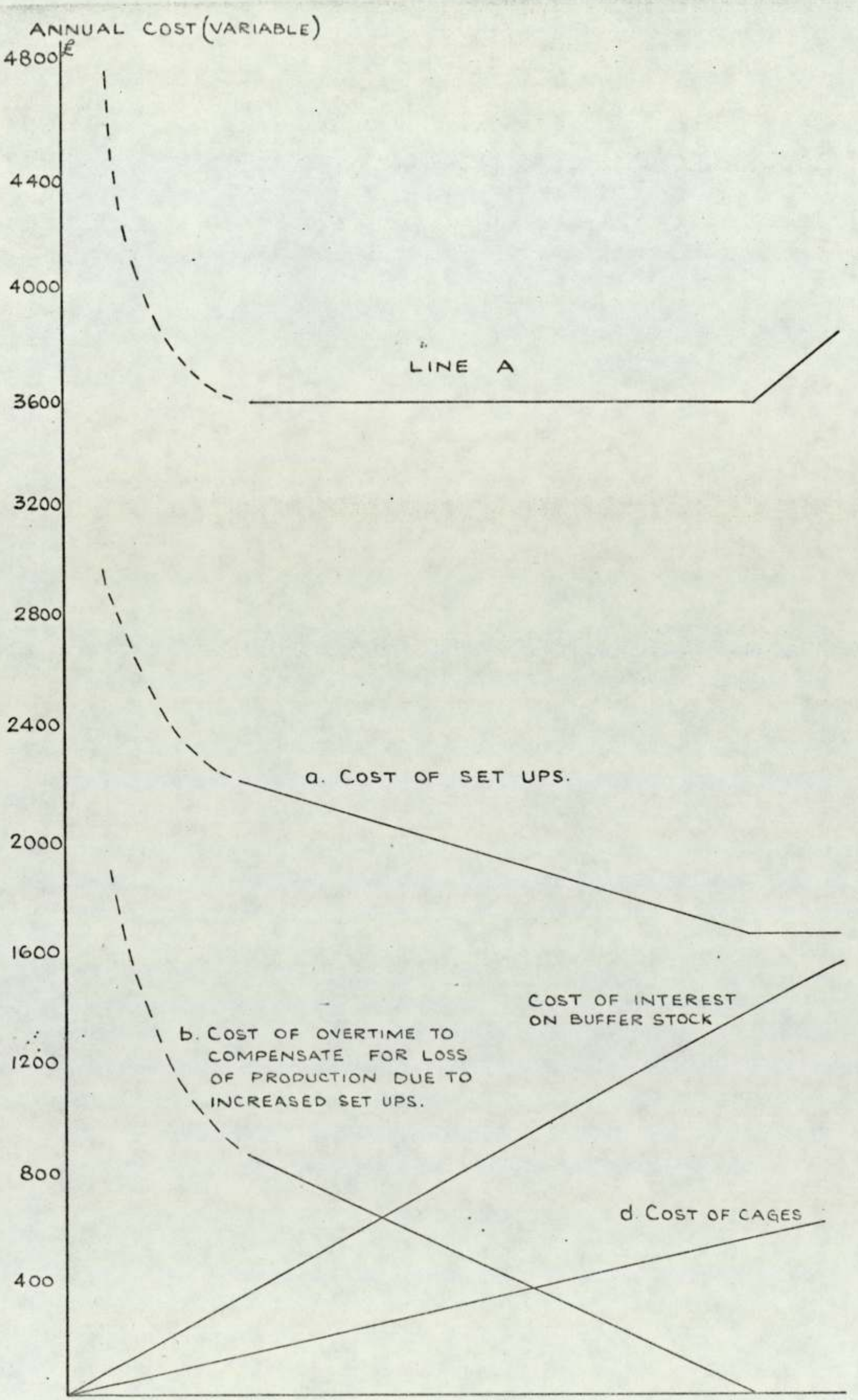


FIG. 5.10 GRAPH SHOWING RELATIONSHIP BETWEEN SMALL POLLARD BUFFER SIZE & ANNUAL COST (VARIABLE)

a constant time is available for set ups plus machining time. Thus overtime must be worked to compensate for loss of production due to increased set ups and the cost is shown by curve (b) in Fig. 5.10. In deriving this curve, it is assumed that the labour level is adjusted to produce 225 000 products within normal working time when the buffer level is at 6.2 days; this assumption merely establishes a datum from which to work. It is reasonable to assume that any loss of production due to increased set ups will be recovered by overtime working since in determining labour levels, under manning tends to take place because it is easier (and probably cheaper) to work overtime and boost output rather than re-deploy labour to reduce output.

Line (c) in Fig. 5.10 is the cost of interest associated with the value of the buffer stock, the value being taken as the material, labour and variable overhead costs. The fixed overheads associated with maintaining the buffer stock, e.g. serviceman and truck are independent of the buffer size and although they contribute towards the total cost of running the buffer, they do not affect the optimum size.

Line (d) in Fig. 5.10 shows the cost of cages depreciated over five years. The cost of insuring the buffer stock was also calculated and found to be insignificant. Appendix 3 gives the data, assumptions and calculations used to determine Fig. 5.10.

5.3.2.3 Optimum buffer size

Line (A) in Fig. 5.10 is the result of combining the variable costs shown in lines (a), (b), (c) and (d).

Since the cost is virtually constant and at a minimum when the buffer size lies between 1.6 and 6.2 days, theoretically the operating level could be anywhere between these two points. In determining Fig. 5.9 a linear relationship was assumed but if a non-linear relationship had been assumed, the effect would probably be a very shallow minimum on Fig. 5.10 having little effect on the optimum buffer size.

It is recommended that the average buffer size should be designed to be three days and that under normal conditions should fluctuate between 2 and 4 days. However, action should be taken when it reaches 2 and 4 days as follows:-

(a) when it falls to 2 days, Management should look critically at the flow into the buffer, the ensuing action could be to work overtime on the previous section.

(b) when it rises to 4 days, Management should look critically at the flow into the buffer and consider working overtime - it should not be allowed to escalate beyond 4 days.

The action in the latter case is probably more critical because when the buffer is more than three days the lead time is increasing above the standard which is clearly undesirable whereas in the former case the lead time is reduced which is quite acceptable.

5.3.3 Analysis of lead time within the light feature cell

During the Spring Shutdown of 1973, all orders were checked on the Features area, details taken of the orders, including location and elapsed time since being loaded onto the first machine on the line. The results revealed a wide variation of lead time as shown in Fig. 5.7 and Table 5.3. The theoretical throughput time was approximately three days and at the time of the survey, there was a severe shortage of work available for planning.

Referring to Table 5.3, the survey showed that 41.8% of the orders had been on the section for five days or more: this is disturbingly high in a system which is conveyorised and is relatively easy to control. Column 4, Table 5.3 indicates that there is a relationship between the size of order and the lead time; the smaller the order, the longer it takes. One explanation for this is that work study values for machining are probably more acceptable to the operatives than those for machine setting and another could be the effect of the learning curve.

NO. OF DAYS ON LINE	NO. OF ORDERS	% NO. OF ORDERS	AVG. SIZE OF ORDERS	TOTAL NO. OF LININGS	% NO. OF LININGS
2 DAYS OR LESS	24	29.7	2388	57,325	36.4
3 OR 4 DAYS	23	28.5	1657	38,133	24.2
5 TO 9 DAYS	33	40.6	1857	61,307	38.9
10 DAYS OR MORE	1	1.2	905	905	.5
	81	100		157,670	100

TABLE 5.3 Analysis of orders on Light Feature G.T. Lines

Referring to Fig.5.7, the following comments can be made. Orders are allowed to jump the queue. There are many examples of older orders being behind newer ones on the same piece of roller tracking.

It is felt that there are two distinct causes for the above occurrences. The first is poor layout of the section, resulting in the operator having freedom of choice from several conveyors, see Y on Fig. 5.7 This could be the result of trying to design a section which could cope with too many variables. The second is insufficient operator supervision. Bearing in mind that the section is relatively small and no order can remain hidden away in a corner, it should be a relatively easy matter to ensure that work flows through in sequence.

The results of this analysis were brought to the attention of management at Ferodo and regarding the cell design, the Industrial Engineering Department is investigating the layout with the object of reducing the lead time variability due to the operatives having too much choice of work (without affecting existing work study values). The variation in lead time through the cell is probably the price the company has had to pay for flexibility within the cell. The author is of the opinion that the layout is acceptable and that the lead time variation could virtually be eliminated if the production section managers were more vigilant. Thus, while is was recommended that the layout of the cell should be looked at, it was also recommended that the production section managers be set a target to complete all orders through the cell within three days, the results being monitored and reported to the Product Manager on a weekly basis. The latter action was implemented but was not entirely successful, probably because three managers were held responsible instead of one (i.e. one on each shift). Furthermore, the attitude of the production section managers seemed to be that the GT cell should work as an automatic machine and that the solution is to re-design the layout. What they do not appreciate is that in designing a machine cell (or machine tool) it is not always possible to meet all the constraints and compromises often have to be made. In the case of the light feature cell design, by allowing several lines to fuse together at certain machines, fewer machines are needed. Thus, flexibility is achieved within the cell at the expense of variable lead time, unless close supervision occurs at critical points within the cell. The attitude of the section managers was probably the result of 'over-selling' the GT concept in the initial introductory stages, since they quote that the cell is an automatic unit. Perhaps a re-education programme is required, since it is vital that all production first line management understand not only the principles of the production system employed, but also its limitations. If these people are ignored the efficiency of the system will be seriously impaired and no amount of engineering design work can compensate.

5.4 Effect of S. F. Pad Stock Policy on Buffer Size and Customer Service

S. F. pads flow into the S. F. pad store which is effectively the buffer stock for the basic shape G.T. lines and generally speaking they only remain there for a few days before being scheduled to the G.T. lines. However, a small stock of slow-moving items is held in the S. F. pad store which covers a wide range of sizes. This policy was developed by the author, (1) and designed to cater for small orders, enabling a quicker customer service to be achieved without incurring expensive set-ups in Stage 1. The effect of this stock on the buffer size is nominal and it can be considered to act as a small source of S. F. pads in the same way as the baking ovens are the main source (97% by volume). Thus the small stock of special sizes remains dormant in the S. F. pad store until required to manufacture a small order, whence the required number of pads are issued and they become part of the buffer of work awaiting manufacture on the G.T. basic shape lines. Fig. 5.11 is taken from (2) and indicates the advantages attendant in holding such a stock of S. F. pads. It attempts to indicate the cash benefits attendant with a reduction in lead time, without any factual cost figures being used. The shape of the curve is

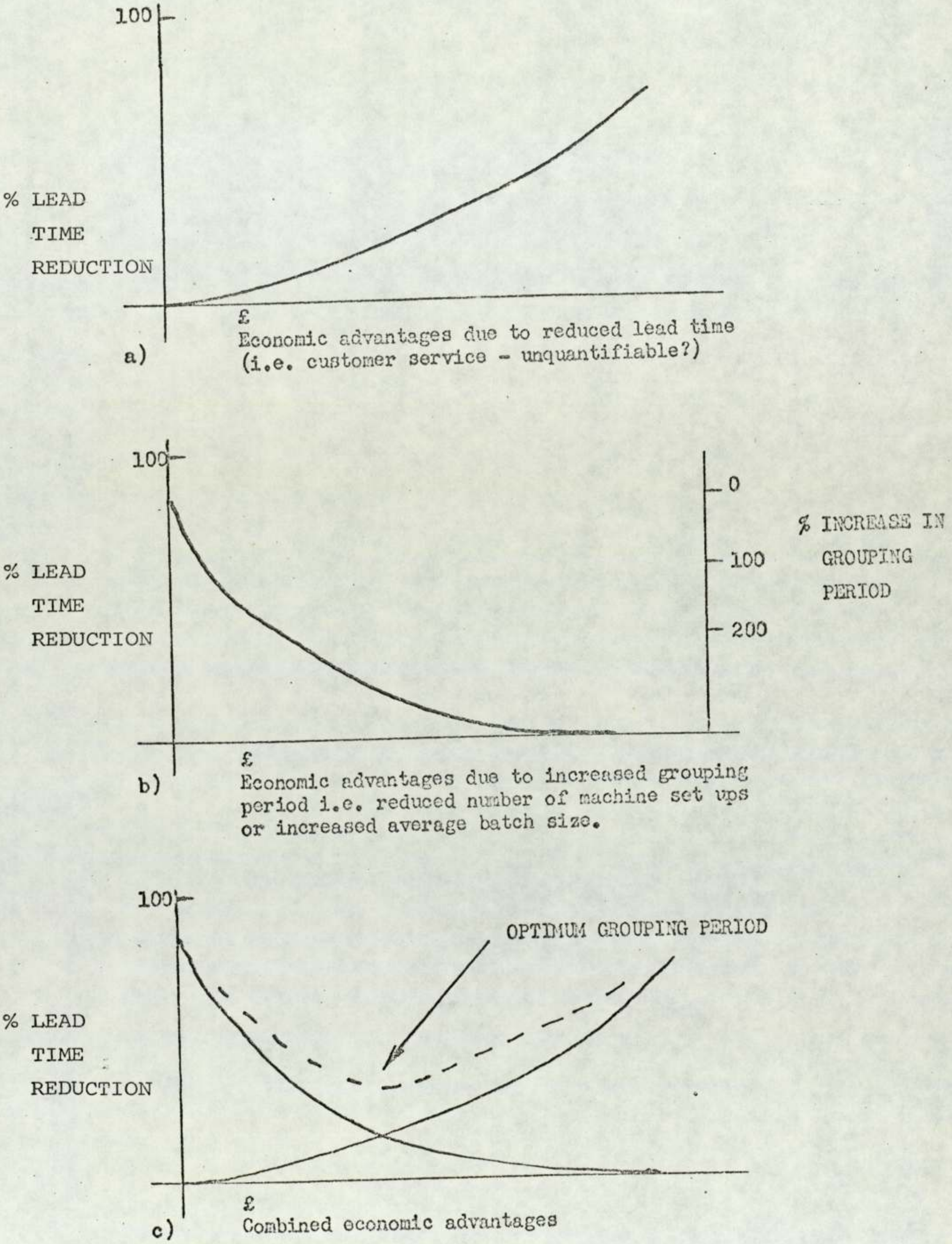


FIG. 5.11 GRAPHS SHOWING THE EFFECT OF HOLDING S. F. PAD STOCKS FOR SMALL ORDERS ('C' TYPE PADS) ON (a) LEAD TIME (b) CUSTOMER SERVICE & (c) MACHINE SET UPS

debatable and may not be as indicated in Fig. 5.11. However, a minimum point would certainly be formed but it is uncertain as to how shallow the minimum point would be. One must pose the question - What is it worth to reduce the standard lead time by one week? This is an almost impossible question to answer bearing in mind the amount of new business such an action may attract. Fig. 5.11b indicates the advantages associated with machine set ups. When S. F. stock is available, it is possible to hold the order in the buffer for much longer than the normal three days: the longer it stays in the buffer, the larger the chance of grouping with other orders. Fig. 5.11c indicates a combination of Fig. 5.11a and 5.11b which occurs in practice. Generally a small order remains in the buffer longer than the normal three days, but it is still delivered in less than the standard lead time (S. F. stock must be available to achieve this).

5.5 Transportation

Work is transported from the S. F. pad stores into the G.T.1 and G.T.2 basic shape buffers in cages by means of a fork-lift truck. This service is available throughout two shifts - therefore the physical size of the G.T.1 and 2 buffers must be able to accommodate at least one shift's work.

The S. F. pads are then unloaded onto the first machine in the cell and thereafter throughout the cell the work is transported in trays by means of gravity roller conveyors, see Fig. 5.12. Each machine within the cell is linked with roller conveyor and the machine operatives push the trays along the conveyor when they require more work. Thus, although the operatives are paid a small allowance for performing a service operation they are never held up waiting for work to be transported. The queueing time for transport within the cell can therefore be taken to be zero. This is a particularly important point and will be discussed further in Chapter 6.

At the end of the basic shape G.T. lines the work is offloaded from the trays on the conveyors back into cages ready for transfer into the features G.T. line section, the method of transportation being identical in the features section to that employed in the basic shape section.

FIG 5.12 G.T BASIC SHAPE LINES SHOWING TRAYS FOR TRANSPORTATION

CHAPTER 6

OBSERVATIONS FROM ANALYSING THE MDBL MANUFACTURING SYSTEM

6.1 Relationship between w.i.p., manufacturing lead time and output

w.i.p. = manufacturing lead time x output

Desired (or planned) output can be considered to be controlled by a combination of company policy and customer demand and can be expected to vary with time. The above relationship is only valid if consistent units are used throughout - e.g.

w.i.p. expressed in no. of linings = manufacturing lead time in days x output in no. of linings/day.

The manufacturing lead time (m) is composed of two main elements, one being the *machining (or processing) time (p) and the other being the queueing time (q).

Thus m = p + q.

Generally speaking, in a batch industry, $q \gg p$ and for a typical brake lining $\frac{p}{q} = \frac{1}{120}$.

The problem of optimising the w.i.p. level can thus be reduced to optimising the queueing time, since the machining time (or processing time) is relatively insignificant. Furthermore, significant reductions in p are usually not possible, since this invariably will have been the focus of attention by production

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* Examination time is included in machining or processing time.

engineers for many years in an attempt to reduce direct labour costs.

6.2 Analysis of Queueing Time (q) within the Manufacturing System

6.2.1 The queueing time (q) can be segregated into elements as indicated below.

$q = q_1 + q_2 + q_3 + q_4 + q_5$

where q_1 = time consumed during and awaiting planning

q_2 = " " " location in buffer

q_3 = " " " transportation

q_4 = " " awaiting examination

q_5 = " " during and awaiting machine repair

q_6 = " " " " " tooling repair

These factors will be discussed below, but it must be borne in mind that each of these may appertain to each section or production process, thus, where there are n production processes,

$$q_1 = (q_1)_1 + (q_1)_2 + (q_1)_3 + \dots (q_1)_n$$

Since there may be several production processes associated with one section and the section may be planned as a whole resulting in only one value of q_1 for the section, it follows that some of these sub-elements $(q_1)_2$ etc. may be zero. Similarly, any of the sub-elements of $q_2 \dots q_6$ may be zero.

6.2.2 q_1 = time consumed during and awaiting planning

Let $q_1 = q_{1a} + q_{1b} + q_{1c} + q_{1d}$* where ,
q_{1a} is the time necessary for the paperwork to flow through the system and for the programme to be prepared.

q_{1b} is the time consumed as a result of planning policy, e.g. by holding the order over a longer period it may be possible to group with a similar order and thus reduce machine set-up costs.

q_{1c} is the time consumed awaiting machine or tooling capacity.

q_{1d} is the time consumed awaiting other components (or constituents), mainly associated with an assembly process.

6.2.3 q_2 = time consumed during and awaiting location in buffer.

Having transported the work from one section to

* Each of the constituents q_{1a}, q_{1b}, q_{1c} and q_{1d} can be split into sub-elements as indicated in 6.2.1

another, it is frequently necessary to physically locate the work before the documentation proceeds for planning to the next stage.

6.2.4 q_3 = time consumed during and awaiting transportation.

When work moves from one work station to another, it may have to wait for a tranport service, e.g. fork lift truck, hand-operated truck etc. or alternatively the mode of transport may be automatic by means of conveyors or semi-automatic as in the case of the G.T. cells where the work is manually pushed along roller conveyors by the operator himself. This can be an important factor, particularly when work is transported from one section to another i.e. when a change in management responsibility occurs and also when the transport service function is operating on fewer hours than the machining units.

6.2.5 q_4 = time consumed awaiting examination

In some cases, this can be zero, if, for example, a patrol examination system is in operation when the work is examined while queueing for some facility other than specifically examination.

6.2.6 q_5 = time consumed during and awaiting machine repair.

This element of time is the total elapsed time from the moment the machine breaks down to the moment it is in production again.

6.2.7 q_6 = time consumed during and awaiting tooling repair.

The same comment applies here as above in 6.2.6. Clearly both q_5 and q_6 could be sub-divided into further categories, for example, transportation time, time awaiting repair and actual repair time.

6.2.8 Analysis of q in the general case.

For a batch manufacturing system having n distinct manufacturing operations, the queue time is the summation of all the elemental times as shown in the matrix in Table 6.1.

6.3 Development of a Methodology to Determine the Approximate Optimum W.I.P. Level

In this chapter, an attempt has been made to analyse the manufacturing lead time and determine

PRODUCTION PROCESSES	$q = q_1$	$+ \; q_2$	$+ \; q_3$	$+ \; q_4$	$+ \; q_5$	$+ \; q_6$	ANALYSIS OF q_1
1	$(q_1)_1$	$(q_2)_1$	$(q_3)_1$	$(q_4)_1$	$(q_5)_1$	(q_6)	$(q_{1a})_1 + (q_{1b})_1 + (q_{1c})_1 + (q_{1d})_1$
2	$(q_1)_2$	$(q_2)_2$	$(q_3)_2$	$(q_4)_2$	$(q_5)_2$	$(q_6)_2$	$(q_{1a})_2 + (q_{1b})_2 + (q_{1c})_2 + (q_{1d})_2$
3	$(q_1)_3$	$(q_2)_3$	$(q_3)_3$	$(q_4)_3$	$(q_5)_3$	$(q_6)_3$	$(q_{1a})_3 + (q_{1b})_3 + (q_{1c})_3 + (q_{1d})_3$
4	$(q_1)_4$	⋮	⋮	⋮	⋮	⋮	⋮ ⋮ ⋮ ⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮ ⋮ ⋮ ⋮
n	$(q_1)_n$	$(q_2)_n$	$(q_3)_n$	$(q_4)_n$	$(q_5)_n$	$(q_6)_n$	$(q_{1a})_n + (q_{1b})_n + (q_{1c})_n + (q_{1d})_n$

TABLE 6.1 ANALYSIS OF THE QUEUEING TIME (q) FOR THE GENERAL CASE OF A BATCH MANUFACTURING INDUSTRY WITH n PRODUCTION PROCESSES

its constituent elements. It is shown that even in a simple production system with only a few manufacturing stages, a large number of elements are involved and in order to determine the optimum w.i.p. level, i.e. that level yielding minimum total cost, one has to assign a *cost to the w.i.p. associated with each of the constituent elemental lead times. This in itself can be a difficult task. One can then build up a cost equation which theoretically can be minimised. This approach is considered impractical for the following reasons.

(1) A tremendous amount of data is required, some of which may already be on computer files, but much of it will not be available without much research.

(2) Information is dynamic and because of the large amount of data that has to be collected, by the time it has been collected, verified and analysed, there is a high risk of obsolescence.

It is therefore suggested that a method of approximation should be derived which is relatively easy to handle in a practical situation.

* 'cost' can be defined as an estimated value.

The matrix shown in Table 6.2 is the general matrix already developed, but applied to the MDBL manufacturing system. Times have been estimated for each element and approximated to the nearest time period of minutes, hours or days. For example, if a particular queueing period is of the order of a few minutes, this has been designated (M). If the queueing time is a few hours it was designated (H) and similarly if 24 hours or more, (D). Using this matrix, it is then relatively easy to pick out the important buffers which warrant more detailed analysis. The critical buffers are those with an elemental queueing period of D and these warrant close attention since they consume such a large proportion of the total queue time in comparison with those having elemental times of H or M. These buffers are the same ones that were chosen as being critical by intuition and subjected to close scrutiny in Chapters 4 and 5.

However, it must be borne in mind that the author was only able to determine the critical buffers by intuition, by virtue of the fact that he was intimately involved with the whole manufacturing unit (and had been for a few years).

QUEUEING TIME q

PRODUCTION PROCESS	q_1								
	(q_{1a}	+ q_{1b}	+ q_{1c}	+ q_{1d})	+ q_2	+ q_3	+ q_4	+ q_5	+ q_6
B_1 (Cont. Mix)	H	H	H	O	M	M	†O	M	M
B_2 (AM Banbury)	H	H	H	O	M	M	†O	*O	*O
B_3 (Rubber Banbury)	H	H	H	O	M	M	†O	*O	*O
B_4 (Roll Former)	M	H	H	O	M	M	†O	H	M
B_5 (Sheeting Calenders)	O	H	H	O	M	M	†O	*O	*O
B_6 (3 Bowl Calender)	O	H	H	O	M	M	†O	*O	*O
B_7 (Ply Calender)	O	H	H	O	M	M	†O	*O	*O
B_8 (L.T. Ovens)	O	D	H	O	M	M	M	*O	*O
B_9 (Guillotine)	O	H	H	O	M	M	†O	*O	*O
B_{10} (Rad. Roller)	O	H	H	O	M	M	†O	*O	*O
B_{11} (Bake)	H	D	D	O	H	H	M	*O	M
B_{12} (G.T. Basic Shape)	H	D	H	O	H	H	H	*M	H
B_{13} (G.T. Features)	H	D	H	O	H	H	H	*M	H

* operating in an environment of excess capacity

† continuous sampling or patrol viewing

M - minutes

H - hours

D - days

O - zero

TABLE 6.2 QUEUEING MATRIX APPLIED TO THE MDBL MANUFACTURING UNIT

QUEUEING TIME q

	q_1								
PRODUCTION PROCESS	$(q_{1a}$	$+ q_{1b}$	$+ q_{1c}$	$+ q_{1d})$	$+ q_2$	$+ q_3$	$+ q_4$	$+ q_5$	$+ q_6$
B_1 (Cont. Mix)	H	H	H	O	M	M	†O	M	M
B_2 (AM Banbury)	H	H	H	O	M	M	†O	*O	*O
B_3 (Rubber Banbury)	H	H	H	O	M	M	†O	*O	*O
B_4 (Roll Former)	M	H	H	O	M	M	†O	H	M
B_5 (Sheeting Calenders)	O	H	H	O	M	M	†O	*O	*O
B_6 (3 Bowl Calender)	O	H	H	O	M	M	†O	*O	*O
B_7 (Ply Calender)	O	H	H	O	M	M	†O	*O	*O
B_8 (L.T. Ovens)	O	D	H	O	M	M	M	*O	*O
B_9 (Guillotine)	O	H	H	O	M	M	†O	*O	*O
B_{10} (Rad. Roller)	O	H	H	O	M	M	†O	*O	*O
B_{11} (Bake)	H	D	D	O	H	H	M	*O	M
B_{12} (G.T. Basic Shape)	H	D	H	O	H	H	H	*M	H
B_{13} (G.T. Features)	H	D	H	O	H	H	H	*M	H

* operating in an environment of excess capacity

† continuous sampling or patrol viewing

M - minutes

H - hours

D - days

O - zero

TABLE 6.2 QUEUEING MATRIX APPLIED TO THE MDBL MANUFACTURING UNIT

This method of approximation is proposed to enable a manufacturing system to be analysed without such intimate knowledge.

Three time periods have been chosen which facilitate easy decision making. It is assumed that the w.i.p. investigator, having determined all the production processes, would interview the first line production managers to determine all the elemental queue times. He is far more likely to get a positive answer to the question, 'Is the elemental time period of the order of minutes, hours or days?', rather than to the question, 'How long is the elemental time period?'.

These three particular time periods lend themselves to the MDBL manufacturing unit, but it is conceivable in some industries that other time periods may be more applicable, e.g. hours, 1 day, 4 days. Clearly some thought must be applied in choosing these time periods, but it is suggested that the choice be limited to three, otherwise the decision-making becomes too difficult, particularly when many elemental times are involved.

6.4 Factors within the Manufacturing System which can affect w.i.p. Levels

By observing the mechanism of Stage 1 and Stage 2, the following factors have been found to affect w.i.p. levels.

6.4.1 The production planning and control system

The type of production planning and control system employed (including section scheduling) has been shown to be very important and generally speaking, the effectiveness of the system employed is proportional to the w.i.p. level. Thus one would associate a high w.i.p. level with a poor control system and similarly one would associate a low w.i.p. level with a good or efficient control system. As will be shown in Chapter 7, a good control system should not be confused with a complex or sophisticated system and vice versa.

6.4.2 Plant Layout

Plant layout is closely related to the production planning and control system (see Fig.1.3) in that poor plant layout, giving rise to irrational product flow can lead to an unnecessarily complicated production planning and control effort (in terms of cash), an irrational plant layout will require more w.i.p. than a rational plant layout.

6.4.3 Space Availability

Space availability has been shown to be a controlling factor in determining w.i.p. levels. Space can be in the form of physical ground space or in terms of number of containers. In other words, w.i.p. levels can be constrained not only by the amount of ground space available but also by the containers available. Thus both situations have been observed in the MDBL system where

(a) w.i.p. was controlled because of a lack of ground space, containers being available and

(b) w.i.p. was controlled because all containers available were in use, but ground space was available.

It is felt that there is a definite tendency for w.i.p. to expand to fill the space available, (the 'space' may be in the form of physical ground area or containers).

6.4.4 Interest Rates

W.i.p. has to be financed and the cost of this can be assumed to be equivalent to the current bank rate. This is a reasonable assumption since a reduction in w.i.p. usually results in a reduction in the size of bank overdraft and similarly an increase in w.i.p. may well have to be financed from an increased overdraft.

6.4.5 Cost of Machine Set-Ups

Machine set-ups are non-productive in themselves and are merely catalysts to allow production to commence. In Chapters 4 and 5 these have been shown to be a major factor, particularly in the group technology system where like products are grouped together in order to reduce machine set-up costs.

6.4.6 Product Variety

Product variety is closely allied to 6.4.5 in that this is the major cause of machine set-ups. Quoting from (1), 'Technology has itself produced a demand for greater variety. Engineers are constantly making very precise specifications to meet specific circumstances. Manufacturers have met this demand and so expanded their product range'. Product variety will always present problems in quantification since Production Engineers prefer minimum variety, while salesmen strive for maximum variety. This is a subject which warrants much more research, but within four manufacturing units at Ferodo, the author has shown that a relationship exists between product variety and the cost of planning and production control, see Fig. 6.1. Clearly product variety has a considerable influence on the optimum w.i.p. level and reducing variety to the limit of one material and one size of lining in the MDBL manufacturing unit, the optimum w.i.p. level would be dramatically reduced. However, it must be stated that product variety can usually be assumed to be a constant in any investigation to determine optimum operating levels because product variety is usually a question of sales policy, which is not easily or quickly altered.

6.4.7 Time Constraints

This factor may not be present in all industries, but is included since this was found to be a constraining factor in buffer size. A time constraint is usually imposed in order to achieve a certain standard of quality and as such it is

A 'Live' Specification is one that has been demanded within the last 2yrs.

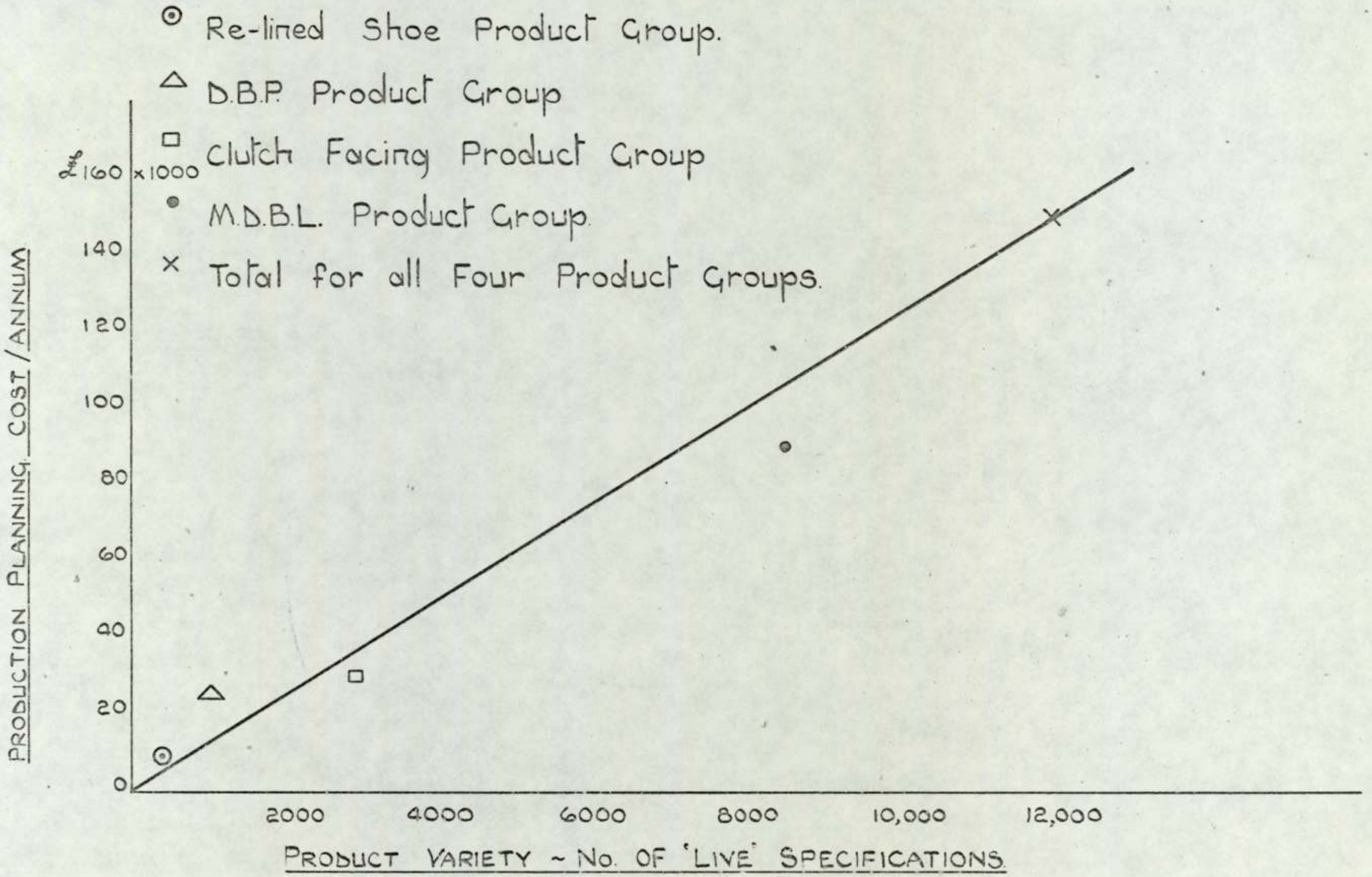

FIG. 6.1 GRAPH SHOWING RELATIONSHIP BETWEEN PRODUCT VARIETY & PLANNING COST

usually very difficult to quantify.

6.4.8 Transportation

Various types of transportation methods from buffer to buffer have been observed and discussed in Chapters 4 and 5. Buffers are sometimes allowed to accumulate awaiting transportation when production is operating on a three shift system, but the transportation system only operates on a one shift system. Generally speaking it is usually possible to quantify transportation.

6.4.9 Communications

Poor communications can prevent the system operating satisfactorily at its optimum w.i.p. level. For example, if it is necessary to operate a buffer stock at a relatively small level, this must be clearly explained to everybody concerned - i.e. management, clerical staff, unions and operatives. If the reasons why the buffer stock should be at a certain level are not clearly explained, then a credibility gap appears and frustration builds up, each faction blaming the other when the system fails to operate at the optimum level. Fig. 6.2 indicates the communication network

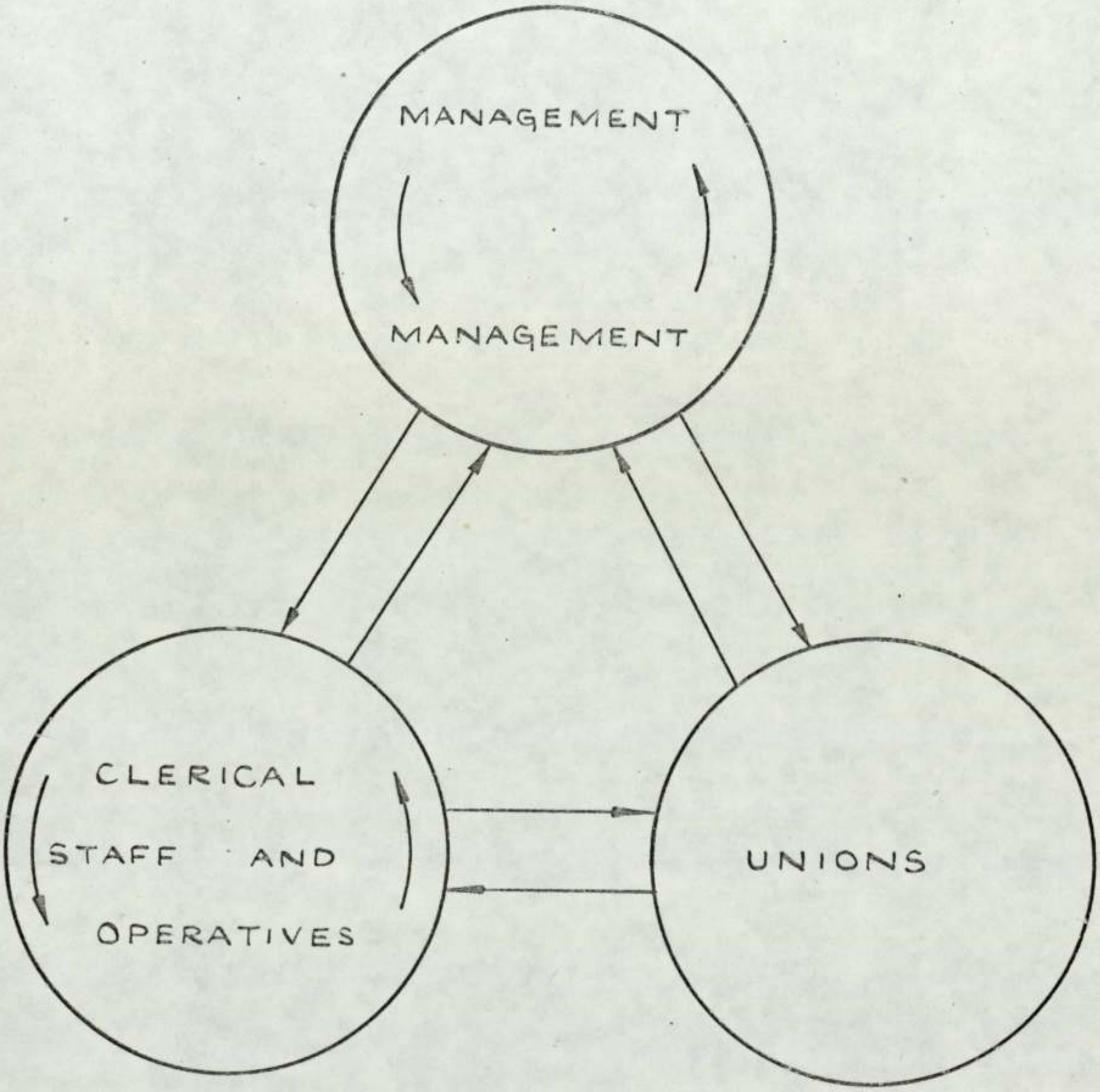

FIG. 6.2. COMMUNICATION NETWORK IN A MANUFACTURING SYSTEM.

associated with the manufacturing system, the personnel being split into three discrete factions. Poor communications are often prevalent within the management group and in the MDBL system this was particularly evident between the planning management (junior) and the production management, the two often working towards achieving opposing objectives. As an example of this, the planning management issues a production plan to the mixing and forming section, taking cognisance of constraints and requirements of the following section (H.T. Bake). The production management on the mixing and forming section complain that the plan is not ideally sequenced to minimise production costs on their section, this being because they have never had the total system explained to them. Consequently, they have little faith in the capabilities of the planning staff. Similarly, if a buffer stock is reduced to zero in a situation where the order books are full and the management is urging the operatives to produce more (via the * Joint Works Council), the operative feels distrustful of the management which must inevitably lead to reduced co-operation in the future.

* This body meets monthly and is chaired by the Company Chairman, the composition being approximately 50% management and 50% unions.

When the author was in the position of Planning Manager on the MDBL section, he attempted to overcome this to a certain extent by giving a lecture to the Joint Works Council on the overall planning of the MDBL system, stressing the relationship between the buffers and the reasons why these can be exhausted even though there are plenty of orders in the pipeline. He also introduced monthly meetings with the unions to discuss the workload situation, the state of the intermediate buffer levels and to explain any abnormalities. It is felt that this kind of communication helped greatly in being able to reduce the w.i.p. level significantly without any opposition.

6.4.10 Operator Performance

There are probably many factors which affect the performance of a machine operator as regards his rate of working and this has been the subject of much research already.

However, there was one aspect which the author felt should be investigated and could be relevant to the control of w.i.p. levels. It was felt that the size of the buffer stock could affect the operator's performance and that performance could reduce as the buffer stock approaches zero. It was decided to test this hypothesis by checking the performance of the key machine operators on the light feature G.T. lines - i.e. the small pollard machine operators. The day cards of 12 operators were analysed over a period of 26 weeks and the point hour performance calculated. This analysis was done without the knowledge of the operators, this being very important since prior knowledge is likely to influence the results. Fig. 6.3 shows the average weekly performance of the 12 operators and it would seem from this that there is a slight reduction in performance as the buffer stock approaches zero.

Individual performances were also plotted similarly and three of these are shown in Fig. 6.4. Operator A is an extremely steady worker and would appear not to be influenced by the size of the buffer awaiting machining. Operator B would seem to increase output considerably as the buffer size reduces and operator C would seem to be similarly affected though not to the same extent. The remaining operators' performances (not shown) did not indicate any particular trend, but were rather more erractic than operator A.

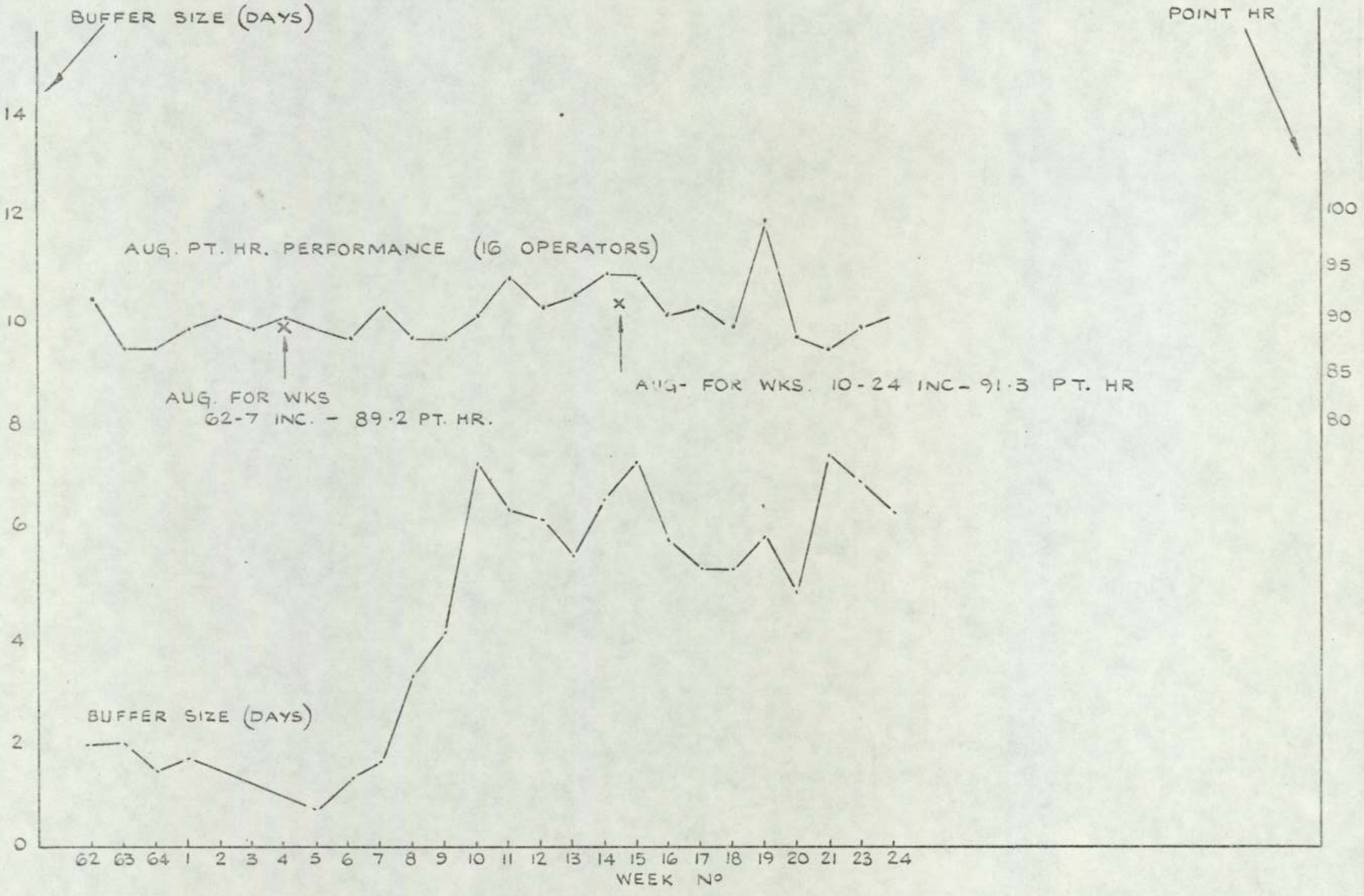

FIG 6.3 GRAPH SHOWING RELATIONSHIP BETWEEN BUFFER SIZE AND AVERAGE OPERATOR PERFORMANCE FOR LIGHT FEATURE KEY MACHINE (SMALL POLLARD)

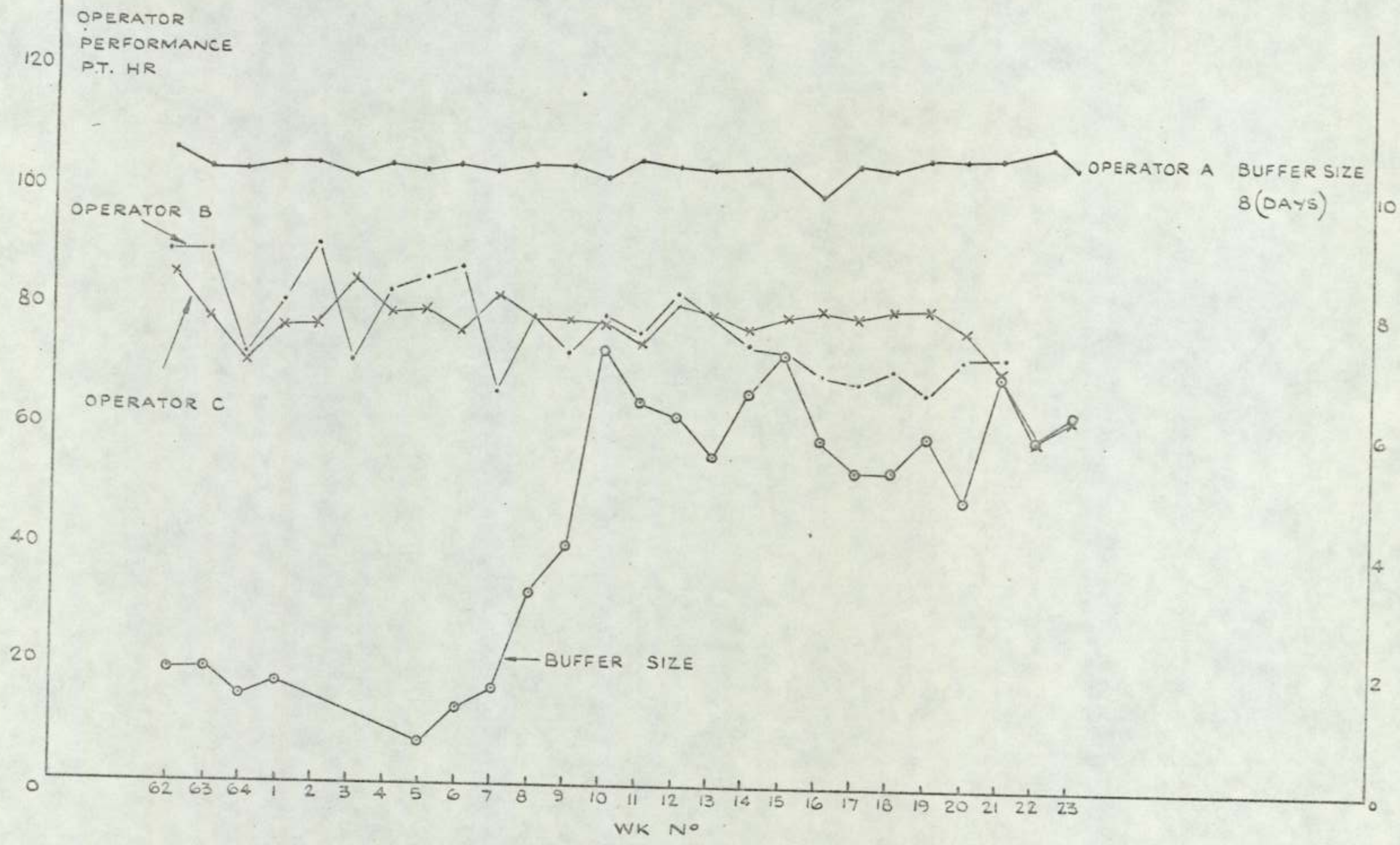

FIG. 6.4 GRAPH SHOWING RELATIONSHIP BETWEEN BUFFER SIZE AND OPERATOR PERFORMANCE FOR LIGHT FEATURE KEY MACHINE (SMALL POLLARD.)

Operators B and C would seem to be concerned that the buffer may be completely exhausted, the attitude being to earn as much as possible while work is available. The average trend as shown in Fig. 6.3 would seem to indicate that the general attitude is to slow down and make the work last longer as the buffer size approaches zero.

Clearly the investigation is inconclusive but the performance of operators B and C would suggest insecurity and a lack of confidence in the management's ability to sustain the flow of work. This insecurity would probably be solved by better communications as discussed in the previous section. Further work is required in this area to form any positive conclusions.

6.4.11 Machine Maintenance

The speed of machine maintenance (including associated tooling) was observed to be a factor which can affect the optimum w.i.p. level. One can have a situation where work is waiting in the buffer for either a machine to be repaired or for tooling to be repaired. The likelihood of this occurring can easily be determined statistically from historical data and the frequency of breakdown is a function of the degree of planned maintenance that is carried out (if any) and also of the number of standby machines or jigs that are available. In the moulded drum brake lining system the effect of breakdowns is minimised by duplicating critical plant and also on the G.T. sections by employing maintenance fitters on a three-shift basis who are seconded to the G.T. production managers. This was considered to be an essential part of the G.T. system and enables fitters to be re-directed at a moment's notice without time being lost due to communication problems, since they are administratively responsible to the production managers while being technically responsible to the Works Engineer. This arrangement enables 80% of repairs to be carried out locally and quickly while the remainder has to be carried out in the main engineering workshop and takes much longer. Thus in the MDBL system at Ferodo, a very good machine maintenance service is operational which results in little or no hold-ups in the buffers owing to machine breakdowns. However, it is true to say that if the maintenance effort was reduced, the optimum buffer size would be affected.

It is probably true to say that the maintenance service level in most companies is arrived at quite arbitrarily, depending on the strength and demands of the production managers, While it is relatively easy to determine the cost of a maintenance service, it is not easy to determine at what service level the system should operate. This is considered to be an important factor and should be the subject of further research.

6.4.12 Payment System

The payment system employed certainly affects the level of w.i.p. in a manufacturing system and this aspect is discussed in Chapter 7. However, whether the payment system affects the ideal (planned or optimum) w.i.p. level is debatable and should be the the subject of further research.

6.4.13 Importance of factors within the manufacturing system which affect the optimum w.i.p. level

The above factors have been considered subjectively and classified as being of primary or secondary importance, see Table 6.3, the criterion for importance being economics. This table should be of use to workers who are attempting to evaluate optimum w.i.p.

Factor	Usually Quantifiable	Quantifiable by Further Research	Degree of Importance
Production planning & control (6.4.1)		*	Primary
Plant layout (6.4.2)		*	Primary
Space (and containers) (6.4.3)	*		Primary
Interest Rates (6.4.4)	*		Secondary
Cost of machine set-ups (6.4.5)	*		Primary
Time Constraints (6.4.6)	*		Secondary
Product Variety (6.4.7)		*	Primary
Transport (6.4.8)	*		Secondary
Communication (6.4.9)		*	Primary
Operator performance (6.4.10)		*	Secondary
Machine maintenance (6.4.11)		*	Primary
Payment System (6.4.12)		*	Primary

TABLE 6.3 Importance of Factors which Affect the Optimum w.i.p. Level in a Batch Manufacturing System

levels and also as a guide for further research.

6.5 Summary of optimum w.i.p. level for the MDBL system as evaluated in Chapters 4 and 5

A summary of the recommended w.i.p level for car size products (PG10) in the MDBL system is shown in Table 6.4. The associated tolerance levels are given which are the allowable fluctuations to cope with day to day disturbances such as absentees and minor breakdowns. This level is compared with that existing prior to commencement of the investigation in Chapter 8.

CAR SIZES (PG 10) UNDRILLED

SECTION	RECOMMENDED W.I.P. LEVEL (DAYS)	RECOMMENDED TOLERANCE LEVELS (DAYS)
MIXING	2	± ½
H.T. BAKE BUFFER (B_{11})	5	± 1
H.T. BAKE OPERATION	½	± ½(HR)
G.T. 2 BUFFER	2½	+ 1½ − ½
G.T.2 PROD.	2	± ½
TOTAL	12	

CAR SIZES (PG 10) DRILLED

SECTION	RECOMMENDED W.I.P. LEVEL (DAYS)	RECOMMENDED TOLERANCE LEVELS (DAYS)
MIXING	2	± ½
H.T. BAKE BUFFER (B_{11})	5	± 1
H.T. BAKE OPERATION	½	± ½(HR)
G.T. 1 BUFFER	4	± 1
G.T. 1 OPERATION	2	± ½
G.T. FEATURES BUFFER	3	± 1
G.T. FEATURES OPERATION	3	± ½
TOTAL	19½	

TABLE 6.4 SUMMARY OF RECOMMENDED OPTIMUM W.I.P. LEVELS FOR CAR SIZE PRODUCTS (PG 10) IN THE MDBL SYSTEM

CHAPTER 7

Comparison of the Moulded Drum Brake Lining System with the Disc Brake Pad Manufacturing System

7.1 Why the D.B.P. Manufacturing System was chosen for Comparison

Certain data is available regarding the situation in the MDBL product group prior to the introduction of group technology, some of which is reported in (11). However, the author did not have the advantage of observing the system closely prior to G.T. It was therefore felt that some meaningful data could result by comparing the MDBL system with the DBP system with particular reference to w.i.p. levels, since both are operating in the same environment and both are essentially small batch industries. When comparing two systems it is particularly important that they should be in similar environments since such factors as method of payment and industrial relations (between Management and Unions) play a vital role and can render comparisons totally meaningless if the environments are different. An example of totally differing environments would be the manufacture of cars in Britain and Japan (or the U.S.S.R.). The outlook and motivating forces of the individuals in the two situations is so vastly different, that meaningful comparisons are extremely difficult.

Even if one could choose an industry operating in the same environment it would be extremely difficult to gain access to the required information and furthermore to be able to assess the accuracy of such information. This is because firstly, companies are extremely reluctant to divulge detailed information and secondly, particularly in large companies, the data has passed through so many operations and departments that the accuracy of the information is suspect. The author therefore chose the D.B.P. system for comparison purposes because information was freely available and also he was able to reject doubtful information. The latter point is particularly important in the days when computer tabulations are used more and more for data analysis. Many people tend to assume that the data on computer tabulations is always accurate. The adage, "garbage in means garbage out" in the context of computer information should be uppermost in any research worker's mind.

The computer is used to some extent for both the MDBL and DBP systems. Master data files are held in the computer containing such information as dimensions, jigs, work categories, reject rates, cost information etc. All this information is constantly being updated and time lags occur between the actual situation and the situation as indicated by the computer master files. In order to assess broadly the implications on data accuracy it is therefore essential to have a working knowledge of the data collection systems operational within the company. The author is very familiar with the data collection and processing systems operational at Ferodo and is confident that all the data used in this thesis is reliable. Conversely, if one accepts data from a company without knowledge of their data processing system, one cannot be completely confident that the information is reliable.

7.2 Brief Description of the D.B.P. Manufacturing System

7.2.1 Product Variety

The current number of *"live" specifications is approximately 1,000 and the batch size varies from 50 to 1,000, although the problem of "small" orders is far less than in the MDBL product group.

7.2.2 The D.B.P. Manufacturing System

There is a distinct similarity between the M.D.B.L. and D.B.P. factory layouts in that both can be split into four distinct sections as shown in Fig. 7.1. Metal plates are prepared in section 1 and in section 2 friction material is compacted onto the metal plate to form an uncured, relatively soft disc brake pad.

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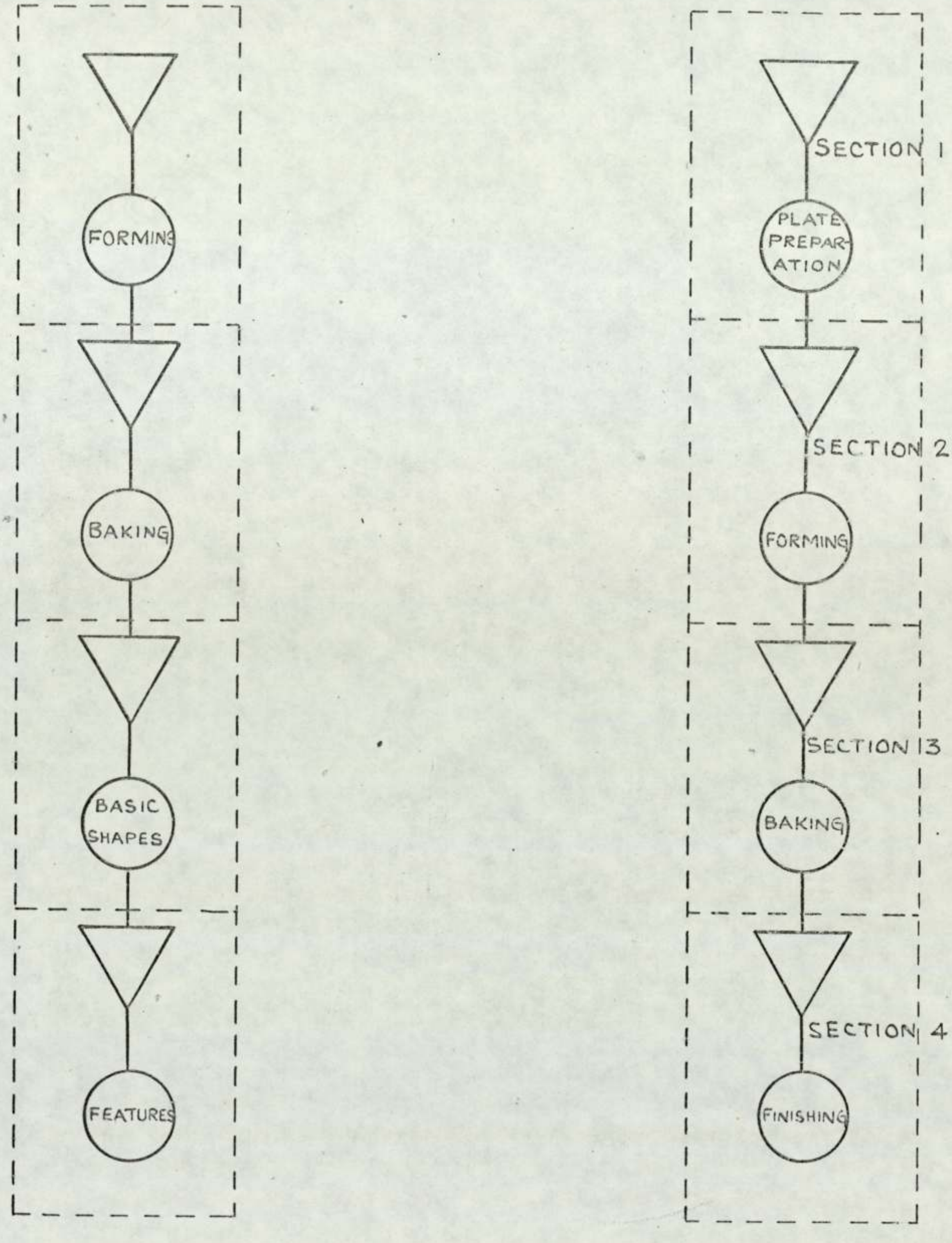
*"live" is defined as that which has been demanded within the last two years.



M.D.B.L.

D.B.P.

FIG. 7.1 DIAGRAMMATIC REPRESENTATION OF MDBL AND D.B.P. MANUFACTURING SYSTEMS.

In section 3, the pad is baked when it then becomes a hard, cured product, ready for machining into its final form in section 4.

The finishing section is by far the largest section and is perhaps too large to operate efficiently as one section. Consideration has been given to redesigning the section along group technology lines. This will probably be effected in the future, but because this product group has been under tremendous pressure to achieve maximum output over the last few years, it has not been possible to consider implementation. This section is very similar to the group technology cells in particular, since the input to the finishing section is a basic shape disc brake pad and the output is the finished product. On its way through the section it undergoes a series of machining operations such as grinding, routing, drilling, chamfering and branding.

Regarding w.i.p., the finishing section (section 4) causes the biggest problems since the other three sections are governed to a certain extent by time constraints in much the same way as stage 1 of the MDBL system. Section 4 is designed on a functional layout basis, the orders following a sometimes tortuous route dictated by the feature requirements. This leads to serious production control problems which will be discussed later in 7.4.

7.3 Comparison of w.i.p. levels in the M.D.B.L. and D.B.P. systems

Section 4 (finishing) of the D.B.P. system will be compared with G.T.1 and the light feature lines combined in the M.D.B.L. system. This is because section 4 is similar to the other two sections combined as regards number of machines, operatives and physical area occupied; the type of operation performed is also similar.

Because of the loose production control system, a physical check of w.i.p. is taken every week on the D.B.P. section, this being measured in terms of work queuing at each machine. Fig. 7.2 shows the variation of w.i.p. on section 4 over a six-week period. The buffer size has been expressed as -

$$\text{Buffer size} = \frac{\text{no. of pads awaiting processing}}{\text{average daily output}}$$

It should be noted that the average daily output is in many cases far less than the maximum possible, working on three shifts.

Sixteen operations are shown in Fig. 7.2, the very minor operations being excluded. A typical disc brake pad will require about 10 of the 16 operations.

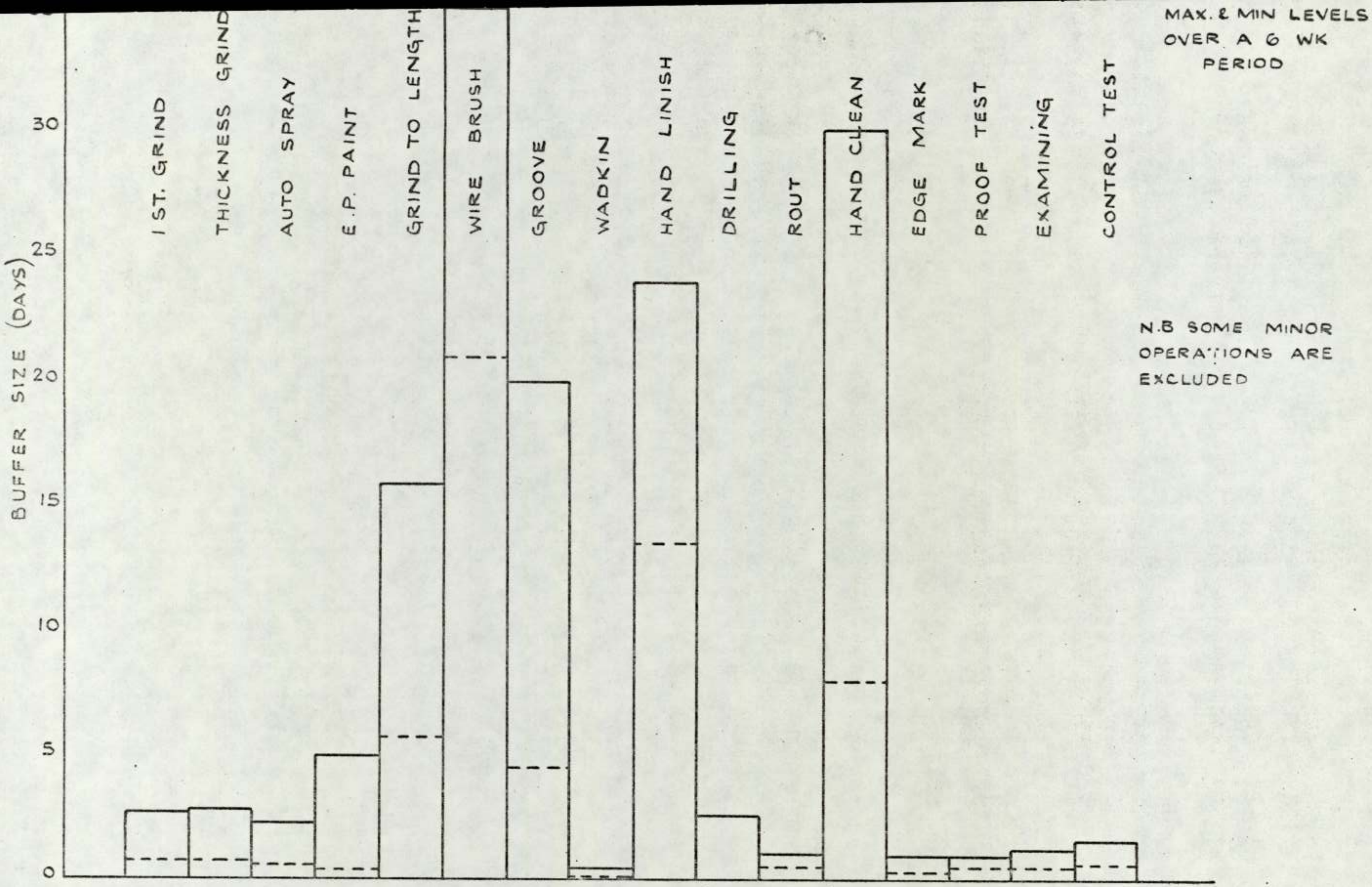


FIG. 7.2. BUFFER STOCK LEVELS - SECTION 4 (FINISHING) - D.B.P. PRODUCT GROUP.

Five out of the sixteen operations have a maximum buffer level of more than five days and each one of these is concerned with less than 50% of the section output in terms of volume. However, these levels are far too high and are the principle cause of lead time variation, see Fig. 7.3. It is interesting to note two points. The first is that all the factory operatives are members of the Transport and General Workers' Union and that the secretary of this Union works on the section where the five high buffer levels are. Secondly, there is an unwritten agreement (stated by the T & G Union) that no overtime should be worked on a machine where less than five days work exists. The latter could well have arisen from management attempting to work with very small buffer levels in the past, overtime being worked to effect this, resulting in the buffer stock being depleted to zero periodically and the operative suffering from a drop in wages. This is a considerable restriction and it is one that the management should attempt to remove. One could argue that the objective of any operative should be to reduce his buffer stock to zero and having achieved this, he should be paid an incentive. By adopting this approach, the system would tend to minimise lead time whereas the present one would seem to maximise it, the attitude of the operatives being the more w.i.p. there is, the healthier the work situation is. One immediate drawback to the scheme

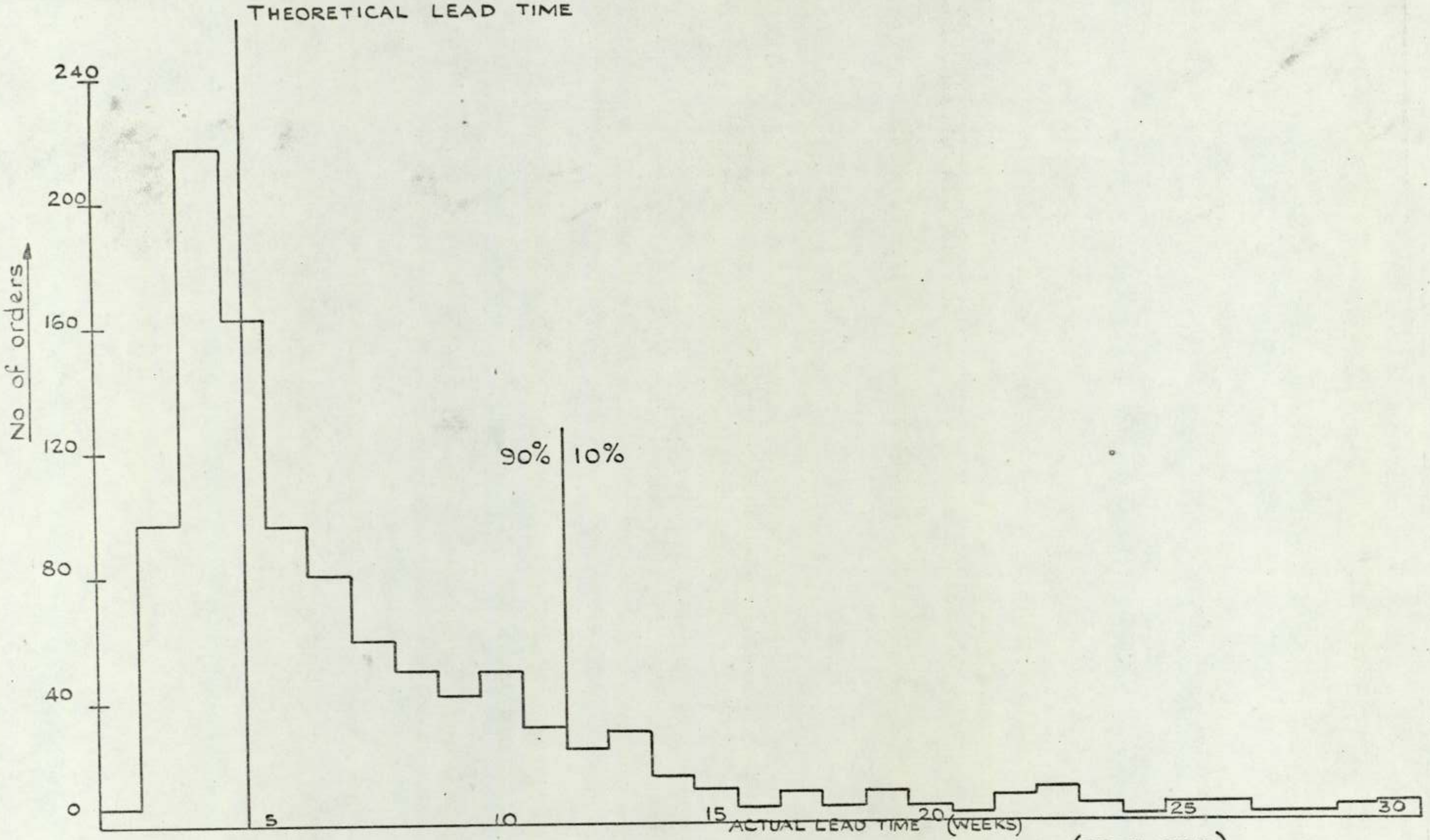


FIG 7·3 MANUFACTURING LEAD TIME ANALYSIS OF DISC BRAKE PADS (FEATURED.)

would be the dangers of "engineering" a stock out. It would be relatively easy for one section or one machinist to work slow, thus reducing the input to the following buffer. However, it is still felt that this is an important basic philosophy and should be incorporated into the payment system.

Fig. 7.4 shows a similar analysis of the G.T. lines, (G.T.1 and light feature G.T. line) but each cell is treated as a synthetic machine; that is as though the cell was one machine. In the G. T. system, the work is queued at the entrance to the cell and only a nominal amount of work queues in front of each machine, indeed the queue may well be zero. Thus, referring to Fig. 7.4, the total work within each cell is constant and amounts to a maximum of approximately three days (the actual value is a function of output) and cannot exceed this because of insufficient storage space on the conveyors. The buffer size immediately in front of any machine within the cells is only a matter of hours with a maximum of approximately 12 hours. The lead time is therefore much more stable in the M.D.B.L. sections than in section 4 of the D.B.P. system because in the former system there are effectively only 2 buffer levels to control whereas in the latter there are 16. This accounts for why a very simple production control system is effective on a relatively complex area (M.D.B.L.) and yet a very complex production control system was found to be ineffective on a relatively

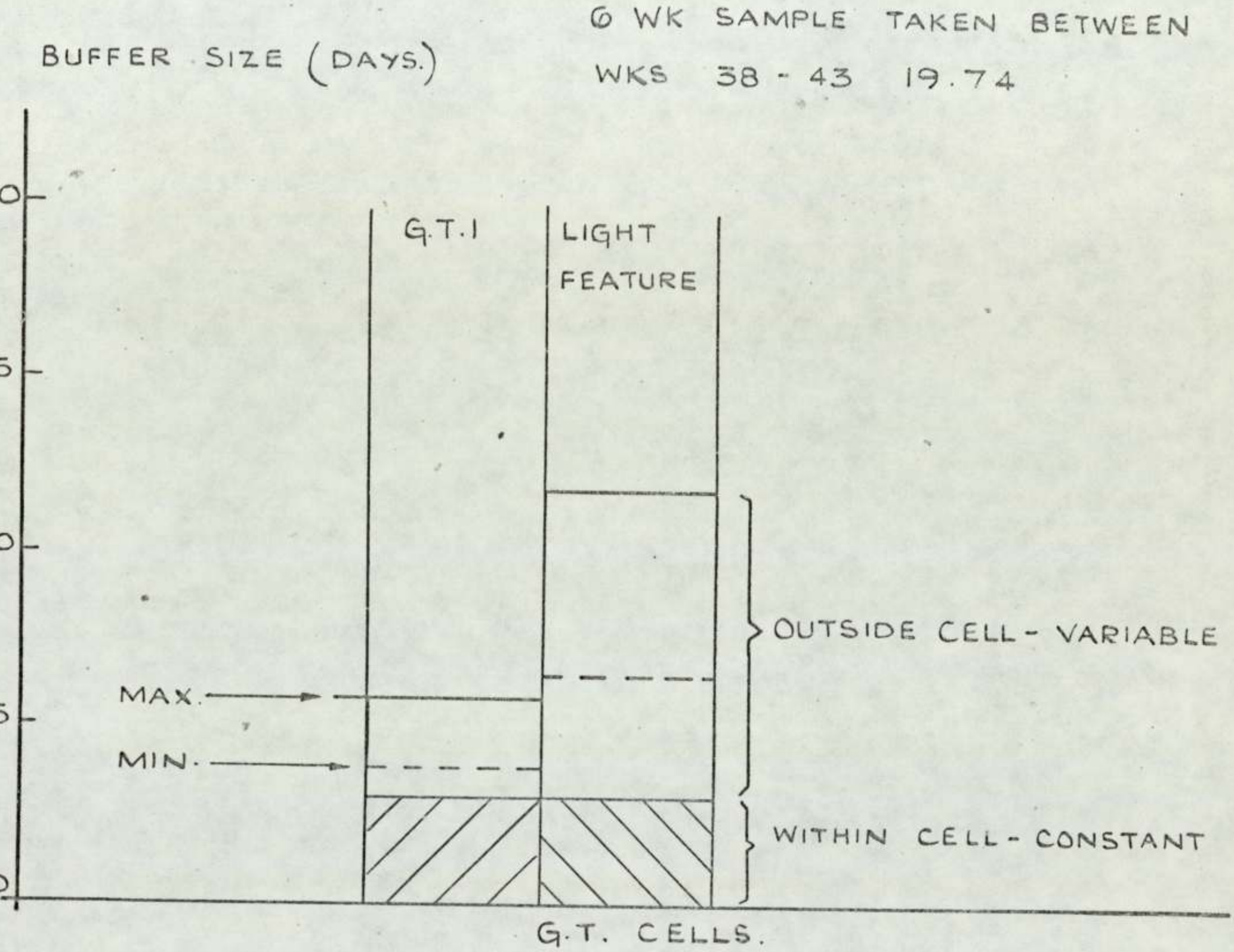


FIG. 7.4. BUFFER STOCK LEVELS - M.D.B.L. - G.T.1 AND LIGHT FEATURE CELLS

simple area (D.B.P.). In the D.B.P. system, it is necessary to have a buffer stock in front of each machine, whereas in the G.T. cell or synthetic machine, it does not matter if the buffer in front of a particular machine is exhausted, since the labour is flexible and the operative moves to another work station. Thus the basic difference between the two systems is that in the M.D.B.L. system, work flow is balanced by labour movement, whereas in the D.B.P. system, the work flow is balanced by holding excessive buffer stocks between each operation.

7.4. The D.B.P. Production Planning and Control System

Five years ago the D.B.P. production planning and control system was computerised, see (22), as an attempt to stabilise the varying lead times. The system is in two parts, the first gives a forward load statement for each machine, taking capacity into account and the second part gives a more detailed statement of individual orders to be made on each machine during the next production week.

Although this system produced valuable data, upon which sound decisions could be made, the basic objective of achieving stable lead times was not achieved, see fig. 7.3. It is felt that the main reason for failure was because the data associated with the existing system was computerised without examining the physical machine layout, product flow or sectionalisation. By computerising the system, more data was available in a short time, but it did not (and cannot) eliminate basic faults inherent in the system, for example, irrational product flow. In the development of a computerised production planning and control system it is vital that the whole system be re-examined and not just the data flow part of the system.

7.5 Observations on the Two Systems

7.5.1 General

The manufacture of disc brake pads is generally a much more simple problem than the manufacture of moulded drum brake linings. The product variety is far less - 1000 as compared with 8500 and the problems of 'small' orders are much less: indeed, on the DBP section, small orders are not considered to be problematical. Disc brake pads undergo fewer operations than moulded drum brake linings and the plant on the forming side is much simpler to plan in the DBP system. Thus, one would expect the DBP manufacturing system to operate far more smoothly than the MDBL system. This is not the case and the following are observed effects.

7.5.2 Plant Layout

The DBP factory area is always congested with w.i.p., whereas the MDBL factory area is usually free from congestion and work is stored in controlled areas. Figs. 7.5 and 7.6 show w.i.p. on the DBP and MDBL areas. Quoting Parker from (8), 'University and Industry Collaborate', he says when speaking of the G.T. cells, 'Earlier disorder contrasted with the new in-line arrangements, suggestive of cool rationality'.

The DBP system operates on a functional layout system and the MDBL system operates on a G.T. principle. Fig. 7.7, taken from (11), indicates the situation on the MDBL section when it operated on a functional layout principle prior to G.T. The situation then, is precisely the same as it is now on the DBP area, i.e. congestion due to high w.i.p. levels, unreliable delivery times, poor production control, resulting in the need to 'chase' urgent orders through the system. The symptoms associated with the MDBL system prior to G.T. and the advantages of introducing G.T. are summarised in (11). A reduction in manufacturing time and w.i.p. of the order of 8 : 1 was claimed and the stability of the manufacturing lead time greatly improved. Another major difference between the two systems, which is associated with plant layout, is the flexibility of labour in the G.T.

FIG. 7.5 D.B.P. FINISHING SECTION SHOWING W.I.P.

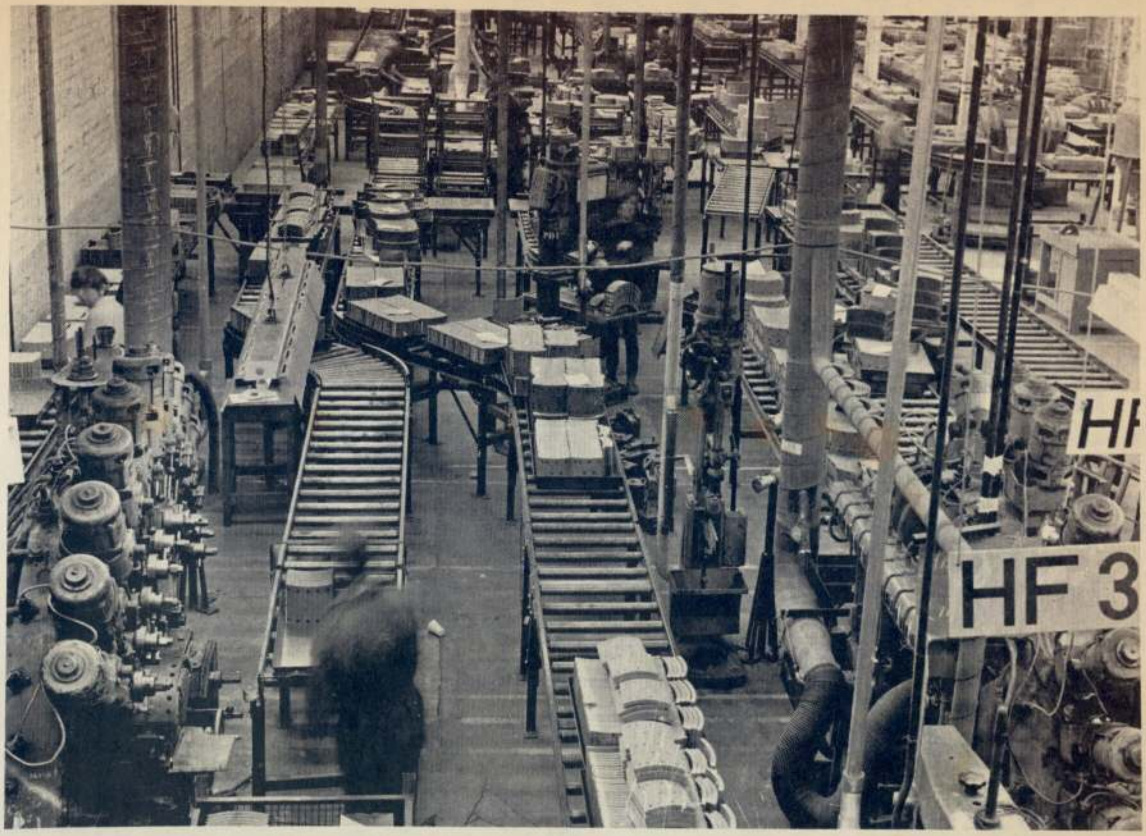


FIG 7.6 W.I.P. ON THE G.T LINES (M.D.BL ~ FEATURES SECTION)

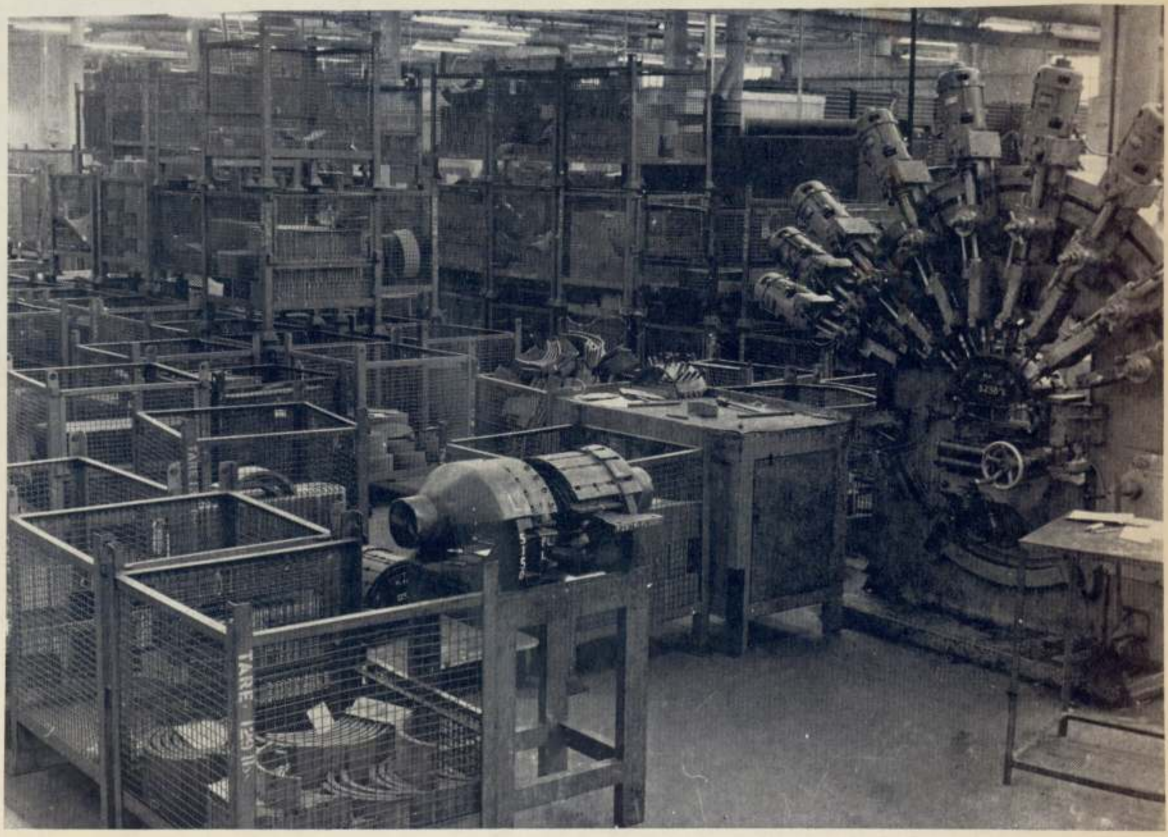


FIG 7.7 W.I.P ON THE MDBL DRILLING SECTION PRIOR TO THE INTRODUCTION OF G.T

system. However, labour flexibility alone is not sufficient: in the G.T. cells there are always more machines than men which means that labour flexibility is not only desirable, but is essential, this being the mechanism for reducing the w.i.p. to a minimum level.

7.5.3 Production Planning and Control

The introduction of G.T. on the MDBL product group has greatly simplified the problem of production planning and control and the author feels that this is probably the major advantage of G.T. The complicated computerised production planning and control system designed for the DBP system, while monitoring the confused state of affairs on the factory, has not helped to control or reduce the w.i.p. It is felt that in designing production planning and control systems, too much emphasis is laid on computerising complicated existing systems, or speeding the flow of paperwork.

In designing a production and planning control system, it is important to begin by analysing the work flow and plant layout before attempting to design the ensuing software. Thus, in the case of the DBP section, it is felt that a plant re-layout is necessary, probably along group technology lines in order to stabilise the lead time and reduce w.i.p.

7.5.4 Transportation System

Within the G.T. cells, the machines are interconnected by means of roller conveyors, the operatives pushing work along in trays as required. Between the cells, the work is moved by a forklift truck and is dependent upon the availability of an internal transport driver. The conveyors eliminate any waiting time associated with transporting the work from machine to machine.

On section 4 of the DBP product group, all work is transferred from machine to machine by a serviceman using a hand truck or a fork-lift truck. Inevitably, much time is consumed while the work is merely awaiting a transport service. It is interesting to note that the conveyors are not strictly part of the group technology philosophy, but are merely a convenient method of work transfer. Many people, even within Ferodo itself, think of G.T. as machines interconnected by conveyors, when in fact the conveyors are incidental.

CHAPTER 8

Discussion

8.1 Comparison of the recommended w.i.p. level with that prior to the investigation

Before the investigation into w.i.p. levels commenced, the MDBL system was operating at a level of 2.6 million products (PG 10 & 11). This was reduced to 1.5 million products at which point it was felt that this was probably too little for the system to function economically; this represented a reduction of 42.3%. Table 8.1 shows the % reduction of lead time when comparing the original level (2.6 million products) with the recommended level. This indicates that the original fears were well founded, that is, that when the system had been reduced to a w.i.p. level of 1.5 million products, it had passed through the optimum economic level. It should be borne in mind that the exercise was carried out over a period of three years, during which output levels for the work types under consideration varied considerably and it is for this reason that lead time has been used for comparison purposes, rather than product quantities.

8.2 Implementation

The findings were submitted to Ferodo management

PG 10 - UNDRILLED

SECTION	LEAD TIME (DAYS)		% REDUCTION
	PRIOR TO INVESTIGATION	RECOMMENDED LEVEL	
STAGE 1	10	7½	
G.T. 2	7	4½	
TOTAL	17	12	29.4

PG 10 - DRILLED

SECTION	LEAD TIME (DAYS)		% REDUCTION
	PRIOR TO INVESTIGATION	RECOMMENDED LEVEL	
STAGE 1	10	7½	
G.T. 1	7	6	
G.T. FEATURES	8	6	
TOTAL	25	19½	22.0

TABLE 8.1 LEAD TIMES - RECOMMENDED LEVELS AND LEVELS PRIOR TO INVESTIGATION

and implemented in stages throughout the three years, see appendix 4. There are two main comments to be made.

8.2.1 Education of middle management

Considerable effort was taken to educate planning and production supervision and the shop stewards involved. This is considered to be a vital ingredient in any successful implementation.

8.2.2 The author's personal involvement at Ferodo

It is considered that implementation was considerably eased because of the author's status within the company, the personal contacts that had been built up over several years and because he was recently the Production Planning Manager over the area considered.

8.3 Factors external to the manufacturing system which may affect w.i.p. levels

This thesis concentrates on factors within the manufacturing system mainly because in a practical situation, this is controlled by a Works or manufacturing director; finished stock and associated policies are usually controlled by the Sales Director and cannot be greatly influenced by the Production Director. It is thus reasonable to ignore such factors in deriving practical optimum operating w.i.p. levels. However, some factors are discussed here, but it is only intended to mention these briefly since they are often outside the realms of company control.

8.3.1 Competitors' Delivery Times

Companies can be forced to deviate from desired w.i.p. levels by the need to reduce lead times in order to become competitive and thus either remain in business or gain new business.

8.3.2 Finished Stock Policy

If it is policy to hold finished stocks in order to give an 'off the shelf' service, then the company is shielded to some extent from 8.3.1 since the finished stock acts as a buffer. However, it is true to say that the size of the finished stock has an effect on the optimum w.i.p. level in the manufacturing system, since an increase in manufacturing lead time will give rise to an increase in the size of the finished stocks (if customer service level is to be maintained).

8.3.3 Cash Flow Situation

A shortage of cash can impose constraints on w.i.p. levels in order to increase the cash flow situation. During the recent period of high inflation, the Ferodo Board issued an edict for all w.i.p. levels to be reduced by 10% without due cognisance to any deviation from the optimum operating level.

8.4 'The Optimum w.i.p. Level'

The Oxford Dictionary definition of 'optimum' is 'most favourable conditions' or 'best or most favourable'.

In this thesis, the optimum buffer stock level is that level which yields minimum variable cost and in this context, the total value of the cost at the minimum point is of secondary importance, since it is only the variable element that alters the size of the buffer: any variation in fixed cost merely alters the magnitude of the total cost, but does not alter the size of buffer at which the minimum point occurs.

The optimum w.i.p. level is thus a target level or ideal level which should be planned for, and in practice the actual level should oscillate between the associated tolerance levels.

CHAPTER 9

Conclusions

9.1 Factors which affect w.i.p. levels

The functioning of the buffer stock levels within the moulded drum brake lining system has been observed over a period of three and a half years with one objective being to determine the factors which determine an ideal (optimum or planned) w.i.p. level. These factors have been discussed throughout the thesis and a subjective assessment made as to which of these are the most important ones. These are listed below (see Table 6.3).

Production Planning and control
Plant layout
Space (& containers)
Interest Rates
Cost of machine set ups
Product variety
Communication
Payment system

The effect of some of these factors has not been determined and would require considerable research to establish the relationship, nevertheless, their involvement should be recognised. Other factors have been proposed as having a direct effect on optimum w.i.p. levels, but are either impossible to quantify (customer service) or outside the control of manufacturing management (finished stock levels and associated policy). Thus, in order to ensure a solution that can be applied to a practical situation, these effects have been ignored.

9.2 Approximate optimum w.i.p. level for the moulded drum brake lining manufacturing unit (PG 10 only)

By analysing the buffer stock levels within the moulded drum brake lining system in a discrete manner, an approximate optimum w.i.p. level has been determined (see 8.4) which has been accepted by Ferodo management and implemented. This approximation was arrived at by considering critical buffers only, that is, those consuming approximately 80% of the queueing time. These critical buffers were then considered in detail by quantifying the variable cost factors where possible.

The recommended approximate optimum level is 22% less (drilled types) than the operating level prior to the investigation and 29.4% less for undrilled types.

When the investigation commenced, an experiment was carried out by reducing the w.i.p. level from 2.6 million products to 1.5 million, or 42.3%. It was suspected at that time that the w.i.p. level was too low for the system to operate economically and this investigation has confirmed that the reduction had been too drastic and the system was in fact operating below the optimum point.

9.3 Methodology to determine approximation to optimum buffer stock levels

The more general problem of defining the optimum w.i.p. level in a given manufacturing system seems to be neglected. The literature survey did not reveal any information on how to arrive at a desirable w.i.p. level; indeed the references only discuss the problem of optimising discrete sections in isolation rather than considering the total system.

Since there are many factors which influence buffer stock levels, the evaluation of optimum w.i.p. levels in a manufacturing system is extremely complicated. Furthermore, in practice, such evaluation is rendered almost impossible because of the need to collate data which is often unobtainable, suspect in accuracy and outdated. Because of this, there is a need to devise a method of determining the approximate optimum w.i.p. level. It is felt that there is an urgent need for industrialists to be able to determine what order of magnitude the w.i.p. level should be so that costs are minimised. Such a methodology is proposed in this thesis and it is applicable to any batch manufacturing industry even though it has been developed on the basis of a batch manufacturing industry which partly operates on a group technology system. This approach is considered to be practical in that it highlights the important areas for in-depth study and indicates the areas that are of little importance. Furthermore it is based on analysis of an existing situation and not on a 'green field' situation. The methodology has been successfully applied on the MDBL section at Ferodo and it is considered to be a useful tool for industrial application.

9.4 Suggested further work

9.4.1 Psychological effect on operatives when the buffer stock is depleted.

When the buffer stock is depleted completely to zero and the operative is out of work, this probably encourages a feeling of no confidence in the management and breeds a feeling of job insecurity. The situation has certainly arisen within Ferodo where the management has stated through the Joint Works Council that the order book is full and plenty of work is available and yet certain operatives have been out of work due to an imbalance in the work in progress. Since the operative has neither an overall picture of the system nor perhaps the understanding of the problems facing management in providing a balanced system, he inevitably distrusts management information and feels that his job is insecure. It is felt that these aspects warrant further investigation.

9.4.2 Extension of Parkinson's Law

There is an extension of Parkinson's Law which warrants research. This is that the w.i.p. level of any manufacturing system is governed by the space available and that w.i.p. expands until the space is filled. When the space has been totally occupied, the management control system becomes operational and the flow of work is controlled by the space available. The space available may not only be ground space (or volume) but may be in the form of a finite number of containers, where containers are used to transport work between work stations. Thus, if the space available for buffer storage is not in balance with the number of containers, it is suggested that w.i.p. will expand until the smaller of the two constraints is absorbed..

9.4.3 Method of Work Transport

The method of transporting work from one work station to another can affect the w.i.p. level considerably. In this category, one must include not only the physical means of transfer, e.g. fork lift truck or roller conveyor, but also the total system, i.e. the frequency of servicing the buffer.

9.4.4 Effectiveness of the Production Planning and Control System

It is felt that the production planning and control system employed can affect the w.i.p. level significantly. It has been demonstrated in this thesis that by employing a very sophisticated system, this does not necessarily ensure tight control of w.i.p. nor does it eliminate the problem of high w.i.p. levels. In designing a production planning and control system, the total manufacturing sytem, including the physical plant layout and transportation system must be considered; this is necessary if control of w.i.p. is to be achieved and is a prerequisite to the optimisation of stock levels. In a batch manufacturing industry employing an effective production and planning control system, one would expect the degree of sophistication to vary with the degree of control. Where an ineffective control system is employed, this relationship is not so and one can have a situation where a sophisticated (and expensive) production planning and control system is employed but is accompanied by poor control often signified by high w.i.p. levels. This aspect is important in batch manufacturing industries and it should be investigated further.

9.4.5 Optimum Conveyor Lengths between Work Stations within the G.T. Lines

The amount of w.i.p. between work stations in the G.T. cells can be governed by the length of conveyor connecting the two work stations. Work should be carried out to determine the factors that determine the optimum length of these conveyors.

9.4.6 Payment System

The payment system employed can definitely affect w.i.p. levels as indicated in Chapter 7. However, it is uncertain as to what effect the payment system has on the optimum planned w.i.p. level and this aspect warrants further research.

9.4.7 Communications

This aspect was discussed in Chapter 6 and good communications are felt to be invaluable in both implementing any scheme and also being able to operate at the proposed economic levels. While it is probably impossible to quantify the effect of good communications, it may be possible by further research to lay down guidelines for successful implementation.

9.4.8 Plant Layout and Product Variety

These two factors should be considered together since they are virtually inseparable. The product variety of the business dictates to a very large extent, what type of layout should be employed, see Fig. 1.3. Further research is required to determine their effect on w.i.p. level.

Many of the above factors are interacting and it may not be possible to consider each one in isolation. All the above items with the exception of 9.4.5 appertain generally to any batch manufacturing industry. Item 9.4.5 relates to Ferodo in particular and G.T. cells in general.

APPENDIX 1

Definition of "key machine" as used in the context of a Group Technology Machine Cell

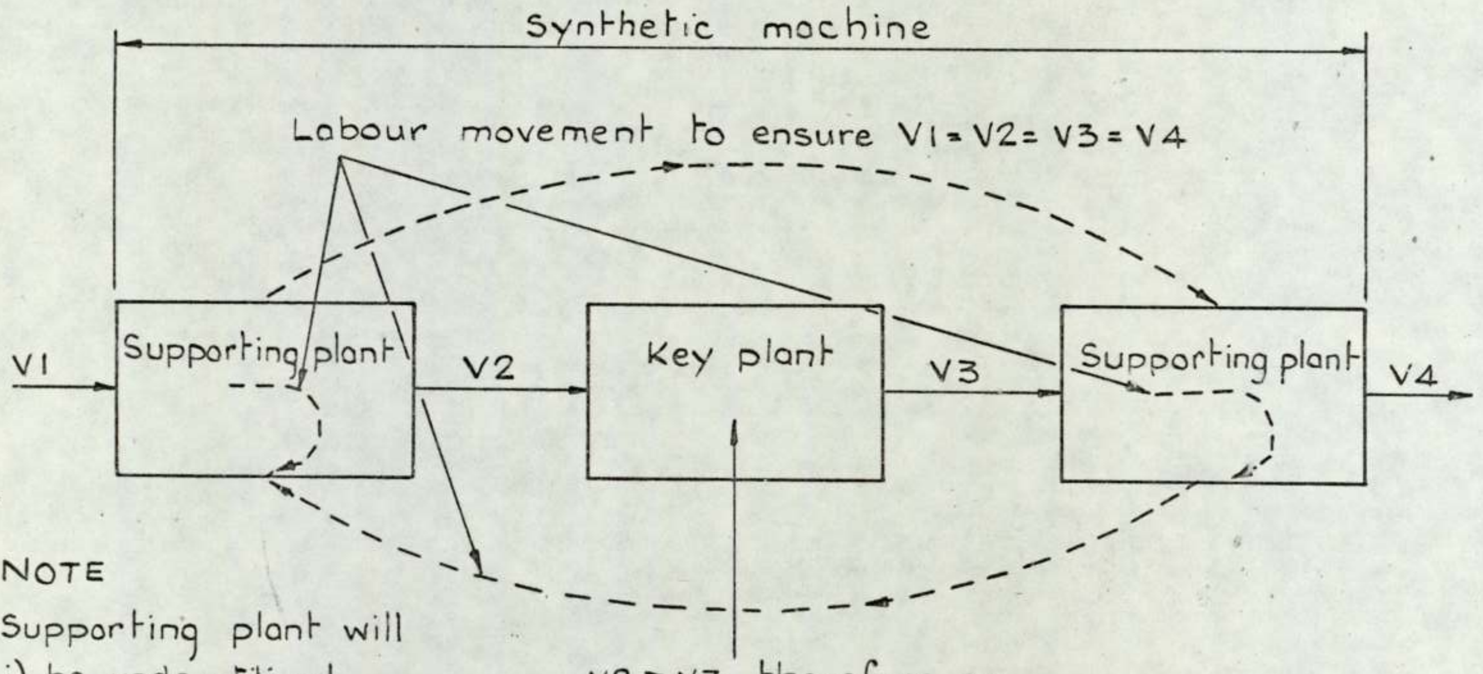
The term "key"machine or critical machine in a group technology cell is defined within Ferodo as the machine with the highest utilisation. The machine cells were designed to cater for a certain product range and to concentrate on maximum operator utilisation rather than maximum machine utilisation. However, in any cell it may be necessary to achieve maximum output or near maximum output to attain the desired output, bearing in mind that individual machine rates may not be balanced. The machine which has the highest utilisation is termed the "key" machine and this must be given particular attention when scheduling the work to the cell to ensure that it does not become a bottleneck and thus throttle the output. Fig. AP 1.1 is taken from (11) a paper on the Ferodo system and this indicates the role of the "key"machine.

The author feels that this definition is insufficient, since in a machine cell such as the G.T. cells at Ferodo, there are two distinct types of "key" machine, these will be termed key (volume) machine and key (set up) machine. For planning purposes it is necessary to recognise this differentiation since in the former case the output of the cell may well be governed by the output from the key (volume) machine and in the latter case it is necessary to minimise set ups by grouping onto this machine, since the set up time is a large proportion of the process cycle.

Fig. A.P. 1.2 shows the automotive size basic shape group technology cells at Ferodo. The two cells G.T. 1 and 2 are linked physically but are scheduled as individual units. Machine D is the key (volume) machine and the output from these machines is equal to the output of the cell. This is effected by adjusting the number of men and shifts so that the desired output is achieved. Machine D has a very small set up time and is relatively unimportant when scheduling the cell. However, regarding machine B, this is the key (set up) machine and has a relatively large set up time, the orders are therefore scheduled to minimise the set up time on this machine. The key (set up) machine can be defined as that machine having the highest % set up, where,

$$\%\ \text{set up} = \frac{\text{individual machine set up time/ planning cycle}}{\text{(Total cell machine set up time + total cell machining time)/planning cycle}}$$

It should be noted that the key (set up) machine is critical in terms of minimising operating costs and is non-critical regarding output. It is therefore possible for the key (set up) machine to be idle for some time, the operative moving to another work-station.



NOTE

Supporting plant will
i) be underutilised
ii) be worked by a flexible labour force to achieve maximum labour utilisation whilst ensuring $V1 \geqslant V2$

$V2 \geqslant V3$ therefore no labour movement and maximum utilisation of plant

FIG A.P. 1.1. OPERATIVE MANNING TO ACHIEVE HIGH UTILISATION OF KEY MACHINES.

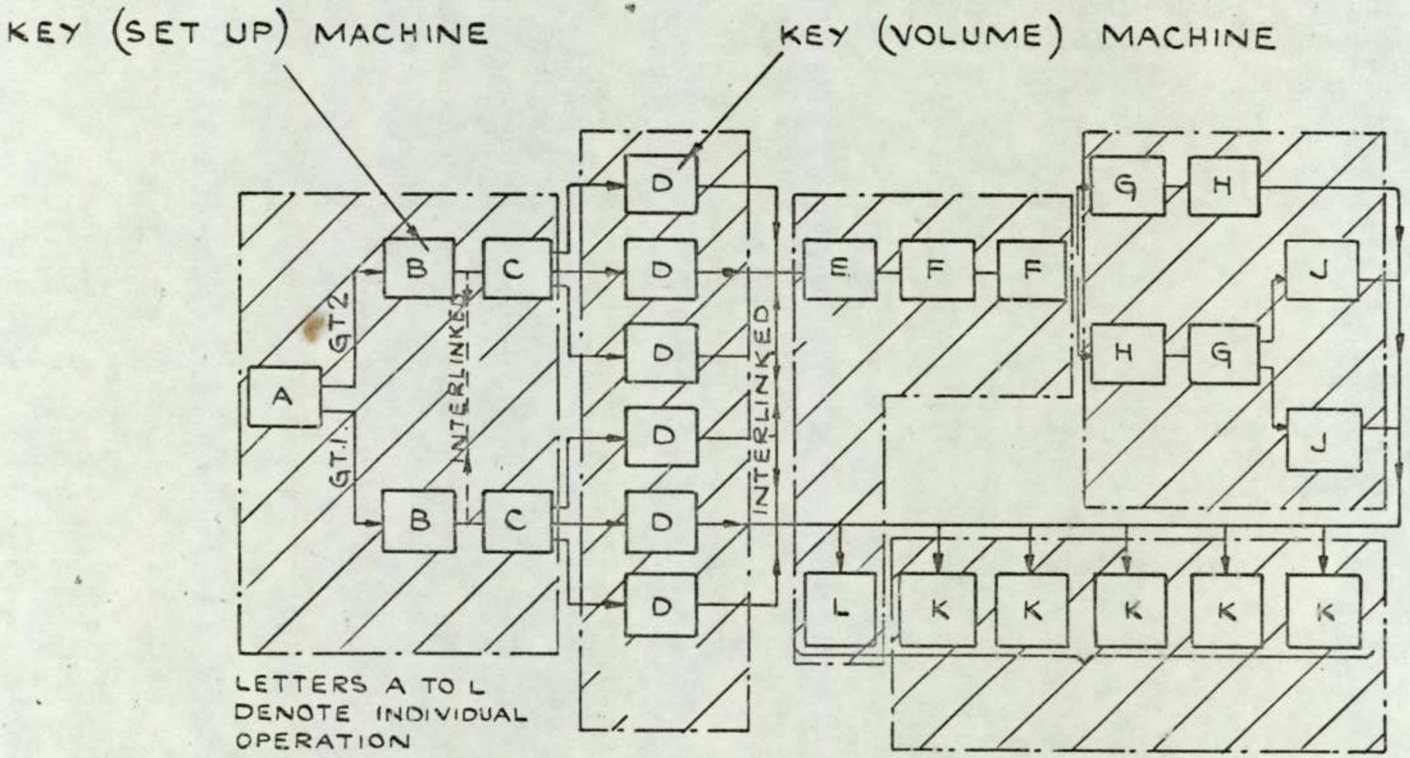


FIG. A.P. I. 2 G.T. BASIC SHAPE LINES.

APPENDIX 2

FERODO TECHNICAL DIVISION.
JES/DNR/TMG/DWL/RTW/L/F

Technical Memorandum 74-1168

19th December 1974

SCHEDULING OF THE CONTINUOUS MIXER/ROLL FORMER

Each time the continuous Mixer/Roll Former operate as one unit, the operation cards will have to be scheduled. It will be necessary to determine the sequence of the orders that will allow the continuous mixer to complete its mixing run uninterrupted. A method of scheduling has been devised.

PROCEDURE FOR SCHEDULING THE CONTINUOUS MIXER/ROLL FORMER

1. Group cards into thickness, within thickness group pad ref. numbers.

2. For each individual order, calculate the change in the level in the rollformer hopper when the order has been completed. This will be either +ve or -ve depending on the size and number of pads required.

   Taking the rollformed thickness and the width of the pad use graph 1 (Figure 1, to determine the material consumption. Then taking the pad length, determine the material usage ±lbs/min by the running time of the order. This will show whether the Rollformer hopper level has increased or decreased and by how many pounds.

   The hopper level will vary depending upon the rate of consumption i.e. if the output rate is greater than the feed rate the level will decrease and vice-versa.

3. At the start of the run the hopper level will normally be 1,000 lbs. The maximum level, after which material is diverted to the bin garage, is 1,200 lbs. The minimum level is 200 lbs. The scheduler would determine the point at which forming was commenced with 200 lbs or 1,000 lbs.

EXAMPLE

		*		*		*	
A	AM2	.420 thick	x	26.75 wide	x	14.00" long	x 64 pads
B	AM2	.448 thick	x	26.375wide	x	15.00" long	x 60 pads

NOTE Pads over 26" wide are made at 26"

*These are the dimensions as taken from the operation card and refer to the pad size.

A	From Graph 1 (Figure 1)	- at .420" thick and 26" wide, the hopper level is decreasing at 87 lbs/min.
	From Graph 2 (Figure 2)	- at 14" long and 64 off running time will be 6.25 x 0.64 = 4 mins.

hence when the order is complete the hopper level will have been depleted by 4 x 87 = 348 lbs.

B Similarly it can be calculated that the hopper level will decrease by 452 lbs.

The Continuous Mixer output is constant at 6,000 lbs/hr or 100 lbs/min. Graphs 1 and 2 have been calculated and drawn to this output rate. If it is altered, then Graph 1 will have to be redrawn.

At the start of a run, the hopper level could be 200 lbs or 1,000 lbs. Generally if there are predominantly +ve orders then the level of 200 lbs would be used, conversely if there are predominantly -ve orders then 1000 lbs would be used.

e.g. at start 1,000 lbs in hopper

order A 348 -
652 lbs this is the amount left in the hopper at the completion of order A.

Order B requires the rollformer to be set to different dimensions; this takes 2 mins. In 2 mins, the hopper level will rise by 100 lbs/min x 2 = 200 lbs.

hence 652 lbs
200 + (set up time)
852
Order B 452 -
400 lbs. This is the level of material in the hopper when order B is completed.

The next order could require a set up and it should be selected to increase the hopper level to enable other orders that would decrease the hopper level to be selected.

Consideration should be given to the fact that orders of similar thicknesses should be arranged consecutively. It is possible that with a concentration of large quantity, large pad orders, the Rollformer may have to wait for the hopper to fill to its maximum level before carrying on with the orders. The important point is, however, that the Continuous Mixer has not been stopped.

The procedure for scheduling has been studied and it is considered that since it was mainly a calculating problem then the arranging of the orders into a schedule could be performed by a machine. Such a machine is in use in the Technical Division; it is a Hewlett Packard Model No. 9820A. Simply it is a programmable calculator. A programme has been written and a few test runs on the operation cards for week 7/8 have been made. Each time the machine has given a sequence to make the orders in to ensure that the Continuous Mixer does not have to stop until the end of the mixing run. However, since only P.G.10 is on R/F then not all orders are included in the programme. The machine is expensive (several thousand pound) but it is considered that many other routine planning functions could be performed by this machine.

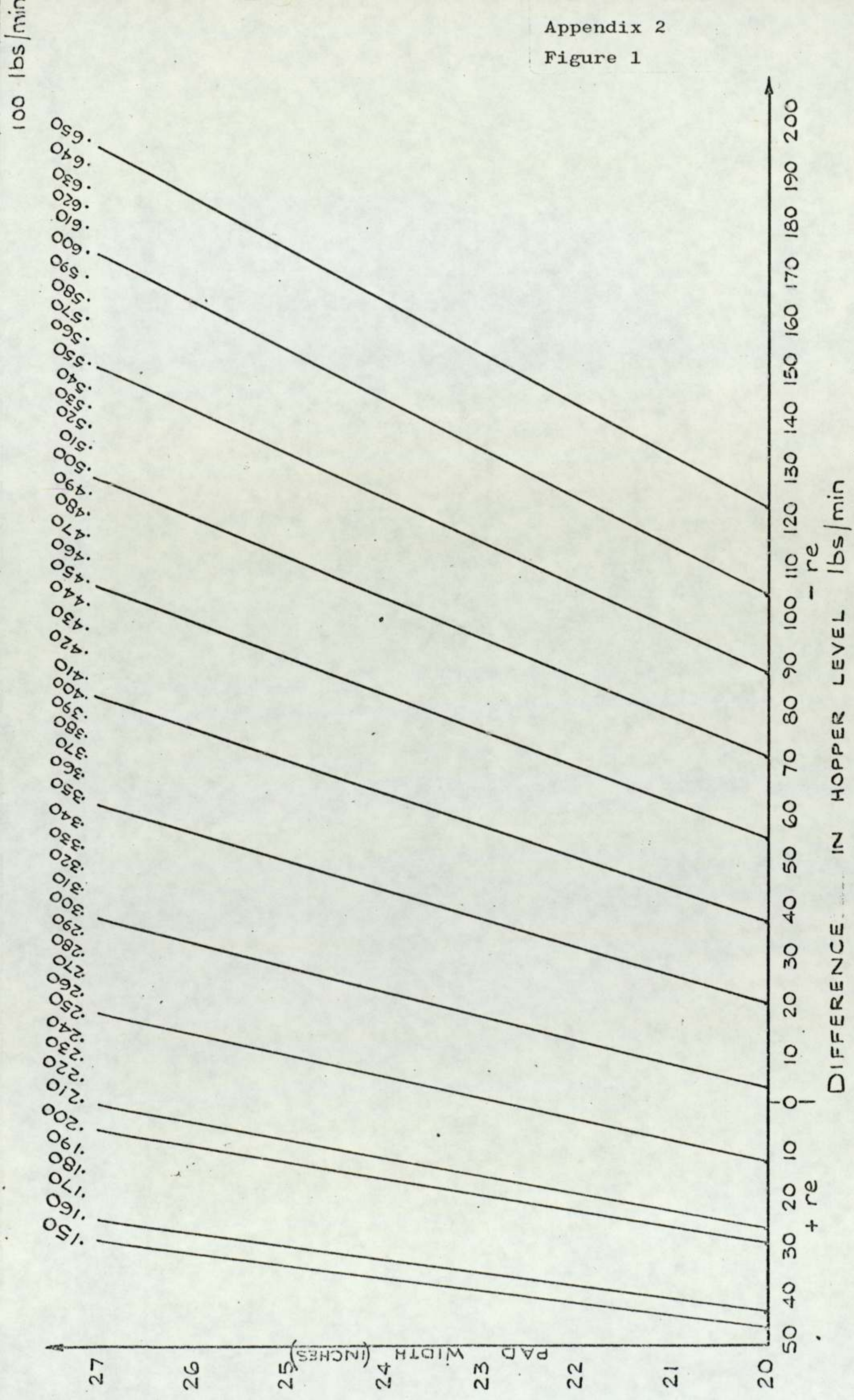
Continuous testing of the programme has been made and final programmes suitable for scheduling the R/F/C/M for all PG10 and PG11 work have been evolved. A sample print out is shown in Figure 3. Further confirmatory test of the programme is required.

R. T. WILSON

RTW/CF.6801

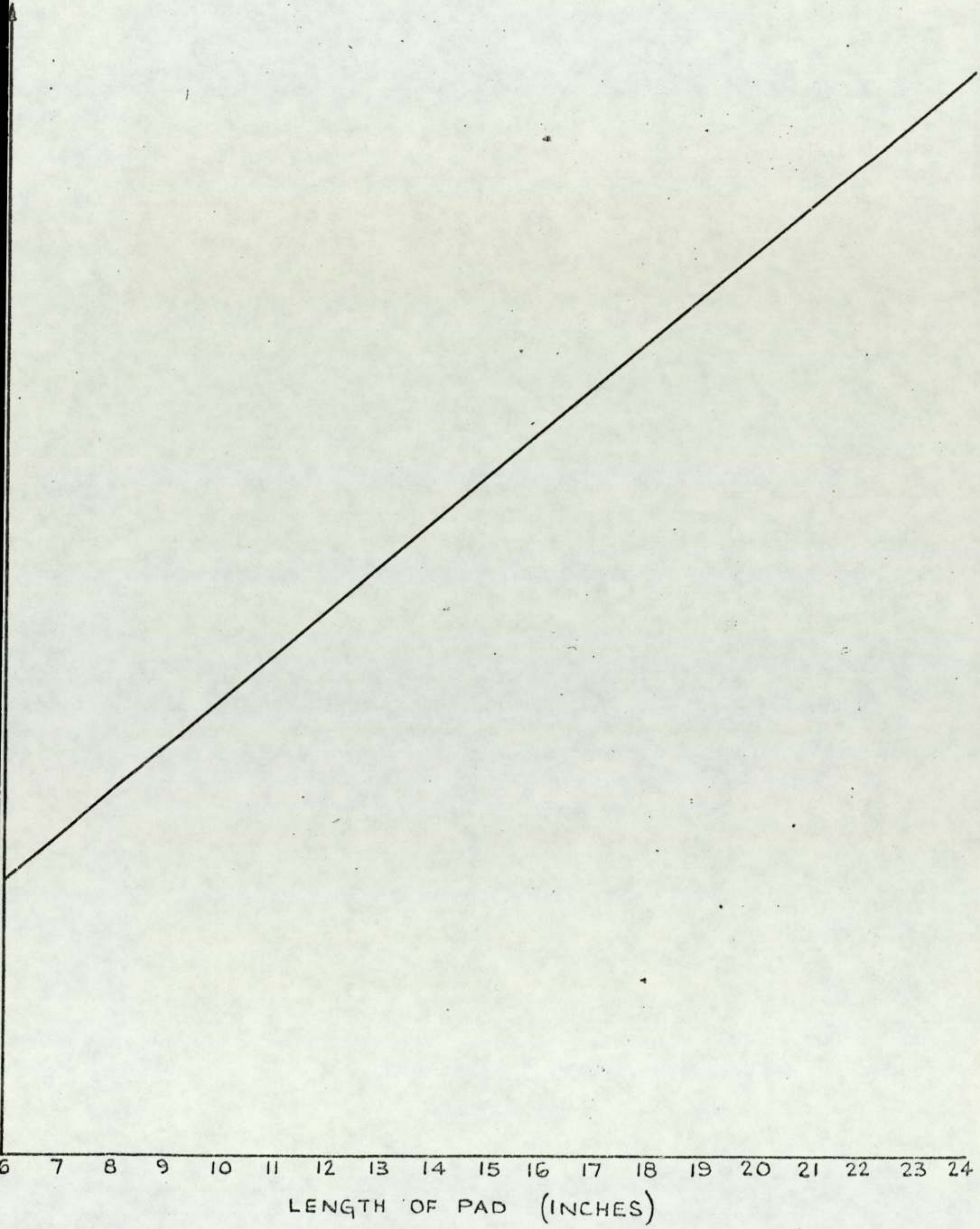
Appendix 2

Figure 1



Appendix 2

Figure 2



ppendix 2
igure 3

SAMPLE OF PRINT-OUT FROM HEWLETT PACKARD MACHINE

```
CARD NO                    CARD NO
     3009067.001                3017945.043
QUANTITY                   QUANTITY
              40                         60
LENGTH                     LENGTH
          13.875                     15.125
WIDTH                      WIDTH
          26.375                     21.875
THICKNESS                  THICKNESS
            .390                       .390
DELTA-W                    DELTA-W
          89.752                    126.330


CARD NO                    CARD NO
     3103728.037                3103819.105
QUANTITY                   QUANTITY
             144                         78
LENGTH                     LENGTH
          15.125                     12.375
WIDTH                      WIDTH
          26.750                     21.875
THICKNESS                  THICKNESS
            .390                       .400
DELTA-W                    DELTA-W
        -183.788                    113.654


CARD NO                    CARD NO
     3017945.042                3103819.106
QUANTITY                   QUANTITY
              60                         78
LENGTH                     LENGTH
          15.125                     12.375
WIDTH                      WIDTH
          21.875                     21.875
THICKNESS                  THICKNESS
            .390                       .400
DELTA-W                    DELTA-W
         126.330                    113.654
```

REF N° →

F PADS →

GTH OF PAD →

TH OF PAD →

MUM ROLL-
ED THICKNESS →

← OPERATION CARD SEQUENCE N°

← DIFFERENCE IN HOPPER LEVEL WHEN ORDER IS COMPLETED AND INCLUDES THE M/C SET UP ALLOWANCE

APPENDIX 3

Data and Calculation associated with Fig. 5.10

1. Line (a) - cost of set-ups

Basic rate of pay for the small Pollard (cc 2216 Job No. 2021) is £0.806/hour.

Bonus rate of pay is £0.57/hour.

During weeks 10 - 23, average set-up time = 31.9 hours/week working at a 91 point hour.

Cost of 1 hour at 91 point hour = $.806 + \frac{31}{60} \times .57$ = £1.10/hou

Cost of 31.9 hours = 31.9 x 1.10 = £35.00/week.

During weeks 10 - 23 the average % set-up = 8.8,

therefore the cost of 1% set-up = $\frac{35.0}{8.8}$ = £3.98.

Assuming a 47 week year, the annual cost of 1% set-up = 47 x £3.98 = £187.00/annum.

The following table can now be derived (in conjunction with Fig. 5.10).

Buffer Size (days)	% Set-Up	Annual Cost £
1.6	11.8	2210
6.2	8.8	1650

2. Line (b) - cost of overtime to compensate for loss of production due to increased set-ups.

Cost of overtime at 91 point hour is £1.71/hour.

The datum is taken to be when the buffer size is

6.2 days, i.e. an output of 225 000 is achieved within normal working hours. If the buffer size drops below 6.2 days, set-ups increase and output drops; therefore if output is to be maintained at 225 000 linings, overtime must be worked.

8.8% set-ups consumes 31.9 hours/week

∴ 1% set-ups consumes 3.63 hours/week

∴ to recover 1% set-ups it will cost 3.63 x £1.71

= £6.2/week = £292.00/year.

3. Line (c) - cost of interest on buffer stock

Material, labour and overhead costs for PG10 linings (average value) = 3.8p.

Interest rate = 13%/annum.

$$\text{Annual cost for a 5 day buffer} = \frac{£225\ 000 \times 13 \times 3.8}{100 \times 100}$$

$$= £1\ 110/\text{annum.}$$

4. Line (d) - cost of cages

Assume a cage contains 2000 linings - its life is 5 years and its cost in 1975 is £20.00.

$$\text{Cage cost} = \frac{2000}{5 \times 2000} = \text{p/lining/year}$$

$$\text{Cost of cages for a 5 day buffer} = \frac{£225\ 000}{5 \times 100} = £450.00\text{/year}$$

5. Cost of Insurance

Insurance cost is 5.5p/£100 value/year

* Value of 225 000 linings = 225 000 x 3.8 = £8550

$$\text{cost of insurance} = \frac{£85.5 \times 5.5}{100}/\text{year}$$

$$= £4.7/\text{year}.$$

This is considered to be insignificant compared with the other values calculated.

6. Notes on data used to determine Fig. 5.9 (used in deriving line (a) of Fig. 5.10)

All day-card entries were converted into standard hours where necessary and the % set-up calculated as follows.

$$\%\ \text{set-up} = \left(\frac{\text{set-up time}}{(\text{set-up time} + \text{machining time})}\right) \times 100\%$$

where machining time = normal hours + overtime hours - set-up time - cleaning and booking time - allowances - stop time - unmeasured time.

* Assuming 'value' = material, labour and overhead cost

To: RC/JES/SEA/TMG/JHFS
CB/JW

From: C. Beck To: Mr. T. M. Gibson May 15 1974

NOTES ON MEETING TO DISCUSS INVESTIGATION INTO THE LEVEL OF W. I. P. ASSOCIATED WITH THE MANUFACTURE OF M.D.B.L.

(Report No. 2)
May 14 1974

Actions based on the recommendations outlined in the report are as follows :

1. Recommendation 5.1. - 4 week programme period on Spooner No. 2 :

Agreed in principle. Will be implemented after Whitsun holiday.

J.E.S./T.M.G.

Proposed changes in buffers could have implications on layout and methods on Spooner No. 2 operatives. Any action taken must NOT invalidate incentive scheme.

J.E.S.

2. Recommendation 5.2. - Stock check and section records for baking drum tackle :

(a) Stock check - Some work would be carried out during the Whitsun holiday, probably on bands.

J.E.S.

Bulk of work would be planned for the summer holiday. The use of vacation students to be considered.

J.E.S./T.M.G.

(b) Records - Planning Manager (M.D.B.L.) to be responsible for refining records system and maintaining accurate tooling records.

Via J.E.S.

3. Recommendation 5.3. - Block 'C' baking drum and tackle store.:

Proposed that little used drums be stored in approximately half the area available in the 'Grey Room', Block 'C'. Some racking

Continued......

will probably be required. Mr. T. M. Gibson to arrange and discuss detail with Bake section managers.

This move is dependent upon removing chemicals from "Grey Room" which is an urgent action in its own right.

T.M.G.

4. Recommendation 5.4. - Introduce daily scheduling to Block "B" :

New Block "L" system has shown significant improvement over original system. Responsibility for scheduling clerk will be transferred from section managers to Planning Manager immediately.

J.E.S.

Then system to be extended to Block "B", and to be implemented with assistance from Systems department.

J.E.S.

Miscellaneous items and rebakes are to be included in the scheme.

5. Recommendation 5.5. - Resite mixing and forming section managers and clerks :

Objective agreed in principle. This will not be implemented, however, as the loss of communication that would occur in the R.M.M.R. group would not be compensated for by the gain for M.D.B.L., particularly as the stabilisation of the H.T. Bake section and the termination of development work on the roll former should improve work flow.

6. Recommendation 5.6. - Transfer of responsibility of scheduling clerk :

Agreed - action under 4 above (J.E.S.).

7. Recommendation 5.7. - Transfer autoguillotine to R.M.M.R. group :

Mr. J. L. Hallam is examining problem and will report.

Via S.E.A.

8. Recommendation 5.8. - Transfer bank of Stordy Ovens to M.D.B.L. group :

Current data on material flow through Stordy Ovens required to ascertain size of problem.

T.M.G.

9. Recommendation 5.9. - Education and training programme :

A programme will be drawn up for a seri.s of one week courses to start after the summer holiday.

Continued...

Persons involved are :

- 5 section managers
- 2 pool section managers
- 2 planners

J.E.S./T.M.G.

10. Review of actions : To be considered with report number 3 to be issued in June.

C Beck

C. Beck

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