



COLLEGE OF AERONAUTICS

(Proposed Cranfield Institute of Technology)

DEPARTMENT OF PRODUCTION ENGINEERING

AUTOMATIC ASSEMBLY DESIGN PROJECT 1968/9

REPORT OF ECONOMIC PLANNING COMMITTEE

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SUMMARY

Investigations into automatic assembly systems have been carried out. The conclusions show the major features to be considered by a company operating the machine to assemble the contact block with regard to machine output and financial aspects.

The machine system has been shown to be economically viable for use under suitable conditions, but the contact block is considered to be unsuitable for automatic assembly.

Data for machine specification, reliability and maintenance has been provided.

ACKNOWLEDGEMENTS

The Committee would like to thank Dr. Redford of Salford University for allowing the use of their computer system for buffer stock calculations.

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1. INTRODUCTION

This report is one of a series which give full details of the design project 1968/9. A Management Report (ref. 1) is available which summarises the work done and the conclusions reached during the course of the project.

The purpose of the Economic Planning Committee from the time of its formation has been to add to the design project the facility for advisory and directive services. To expand fully the terms of reference; the work of Operations Research, Production Planning and Finance Services are covered on a broad basis.

The first part of the work consisted mainly of the items contained in the section entitled the feasibility of automatic assembly devices of the report. The intention throughout this work was to advise the design committees on the magnitude of the major problems to be encountered whilst avoiding investigations which could be undertaken by these committees. Since the design concept was only in embryo, very little factual data could be used to facilitate this task. For the above reason, the results produced by the Economic Planning Committee tended to be of an exemplary nature, using hypothetical figures to prove basic principles without necessarily referring to the machine. By this means, allowance could be made for the versatility required in the machine. The whole of this work was to be of advisory standard and to aid committees having problems not readily soluble within their terms of reference. The design stage was seen by this committee to be comprised of two major items.

The first one was to assess buffer stock requirements and reliability for the machine configuration employed. This was the main contribution in assessing the machine performance to achieve optimum conditions and overcome poor quality parts. The role of the reliability study was not so much to predict the absolute reliability of the final configuration as to guide and check design efforts in relation to original design goals. The computations were complex but the benefit to be obtained made them quite justifiable.

The other item was to advise on and forecast the state of the machine financially. It was felt that the value of this exercise lay in the constant reminder of the fact that the smallest capital expenditure should be the target, consistent with a realistic machine specification. The presentations of this work to the Board served to illustrate the viability of a complex versatile machine and indicate the target price range. A further important requirement at this time was to collect cost and reliability data; this was accomplished by distributing special forms for completion by each committee.

The final stage of the work was also of two main categories. Firstly, the data that had emerged in the latter weeks of the design programme was used to finalise quantitatively machine cost and performance matters.

The second category was a financial investigation of market potential and the justification for capital expenditure for the machine and contact block.

For these studies use was made of information from the results of the Technical Survey supplemented by information from a mail survey made, which was concerned with the economics and finance of assembly industries.

2. THE FEASIBILITY OF AUTOMATIC ASSEMBLY DEVICES

2.1 Cycle times

The first task of the Economic Planning Committee was to provide a working estimate of cycle time targets for one, two and three shift working to meet the output requirement. The calculation was made in order to unify the thinking of the group for a target cycle time maximum.

The figures for the initial calculations were:-

- 1) A five day working week.
- 2) An eight hour shift per day.
- 3) Forty-five working weeks per year. This is made up from fifty-two weeks minus three weeks for holidays and maintenance and four weeks estimated to stop the machine for tooling and machine changes.
- 4) One and one quarter million units annual output of acceptable assemblies.
- 5) 70% machine utilization. This figure was arrived at by reference to assembly machine users and, bearing in mind that a high utilization factor is required from the machine design.

$$\begin{aligned} \text{Cycle time} &= \frac{5 \times 8 \times 45 \times 3600 \times 0.7}{1.25 \times 10} \\ &= 3.6 \text{ seconds.} \end{aligned}$$

It can be seen that for two 8 hour shifts the cycle time would be 7.2 seconds and for three 8 hour shifts 10.8 seconds cycle time is available.

This was not proposed as an absolute value but only as a starting point to which updated matter could be added. In fact, no allowance is made for off standard conditions such as machine breakdown or breakdown of parts supply which would have to be accommodated in overtime working under this system. The practical limitation on the cycle time is the physical performance of the machine. This largely affects the number of shifts operated for optimum efficiency which is again limited by the company policy on working hours. No definite decision on the overall solution can be expected without a detailed schedule of machine design data.

2.2 Loading time interval

The estimate of time between parts feeding operations was necessary to establish a system for materials handling, component supply and machine operator requirements. Before any design data or experience could be drawn upon, a large number of assumptions was necessary to achieve a quantitative estimate of the time interval. These factors involved are listed since it shows fully the matters concerned with this work.

- 1) Physical maximum capacity of hoppers.
- 2) Component quality.
- 3) Availability of labour to feed hoppers.
- 4) Time required to feed a load to a hopper.
- 5) Provision of hopper capacity to last between shifts where applicable.
- 6) Packaging and availability of parts at workplace.
- 7) Availability and need for mechanization of equipment to handle parts containers.
- 8) Sizes of stillages, magazines and pre-packed items where applicable.
- 9) Any inspection of parts that may be necessary in or before the feed device.
- 10) The amount of time that the machine can work without the need for attention to allow parts feeding to be undertaken by an operator.



The final factor raises the question of personnel to attend to the machine. The type of person to do this kind of work would not require a high degree of skill but a suitable degree of intelligence. This presupposes planned maintenance and major breakdowns would be serviced by skilled specialists from the maintenance department. Utilizing a system of this type, the extent to which the personnel, who will be referred to as machine attendants, can load the hoppers is governed by the time spent in correcting short duration faults.

Another matter which requires an establishment of principle is the time taken to load a hopper. Obviously, a great variation between different components can be expected in terms of packaging methods, which will affect the feeding to the hoppers. Those components which are heavy may require mechanical handling for large bulk whereas small items, such as nuts and bolts, may be easily handled, many thousands at a time.

Assumptions have been made that a company embarking upon a high capital expenditure would put some effort into arranging for optimization of materials handling methods and parts packaging. Also, the machine attendants would be given pay that would be an incentive to intelligent personnel. This is clearly profitable when considering that lost time is worth about £15 per hour (section 4.1.2) on eight hours per day of working time.

The final breakdown of the operations of feeding parts appears reasonably represented by the following.

1) Observe the need for refilling - collect handling equipment, (if required)	2 min.
2) Load and manoeuvre handling equipment - or collect container of parts	1 min.
3) Remove equipment, check or create parts inflow	4 min.
4) Move to next position	1 min.
	<hr/>
	TOTAL: 8 mins.
	<hr/> <hr/>

It can be seen that some operations can be much longer or shorter, but this will serve as an average for the type of parts in the switch assembly. Due allowance must be made for checking stations which do not need attention and generally organizing parts storage. This would add to the original time about 5 minutes per part. Since about 15 different types of components are to be fed the approximate time per loading of all parts would be:-

$$13 \text{ minutes} \times 15 = 3 \text{ hours } 15 \text{ minutes.}$$

It must be noted that some components would need more loads in a period than others. This would only be clear after work study of the operation when running.

At this stage the minimum desired machine utilization must be used for quantitative results. The 70% figure is used as in Section 2.1. The 30% of unprofitable machine time should be roughly equivalent to fault correction time of the machine attendants.

The analysis of the data to this point gives best conditions for an average of six loadings per 8 hour shift for each component.

Total of (3.25 x 6) hours	=	19.5 hours
Plus fault correction	=	2.5 hours
		<hr/>
		22.0 hours
		<hr/>

This suggests three machine attendants per eight hour shift with the other two hours being personal allowance. This requires a loading time interval of 1.33 hours. If about 1.5 hours is used as a target figure, allowance is made for shift change over conditions.

This is not considered to be an absolute answer but gives an estimate to work to. The actual answer will only materialize in practice when running the machine.

2.3 Comparative merits of indexing and free transfer systems

This Section deals with the major concept of configuration and transfer between subsequent operations. Both systems utilize motion of in-process assemblies between fixed position heads and movement of heads over stationary parts is not considered.

Before comparison of the two systems, it is necessary to define them. An indexing system is taken to be such that a fixed number of assemblies are mounted equidistant on a rigid base under a similar number of workheads. Each increment of motion will thus move all assemblies simultaneously and any stoppages at any particular workhead will cause all work to cease. A free transfer system employs workheads operating independently. This system implies that a float or buffer stock of parts may be held between workheads which overcomes any short periods of zero output at any particular head.

Consideration of indexing mechanisms will be discussed to some extent in Section 2.4 where the effect of parts quality has a great effect on efficiency. From the information already discussed and, in the opinion of assembly machine users, it is apparent that parts quality is the major cause of machine breakdown so free transfer methods are reviewed to observe its performance in this respect.

A simplified analysis has been made by Boothroyd and Redford (ref. 7). Many assumptions are necessary for this calculation and other items of information must be established to make quantitative assessment possible. These are discussed since they clarify the problems involved.

- 1) A buffer stock of optimum length will reduce the downtime of the machine and hence raise its efficiency.
- 2) Parts quality faults only are allowed for by the buffer stock since only short fault correction time can be accommodated by a buffer stock of practical length.
- 3) A fault correction time of 30 seconds is used, which allows for short term stoppages of the type which are corrected simply, eg. removing a jammed part. This time is an average as used by a large company of assembly machine users for this type of fault correction.
- 4) Breakdowns are assumed to occur at random on all heads and no two heads are inoperative at the same time. This is most likely if a planned maintenance schedule is in operation and all workheads have been proved, so that no workhead is inherently more liable to breakdown than another.
- 5) The cycle time at each workhead is the same. This may not be true in practice but if each workhead is controlled by its adjacent buffer stock positions the overall effect is the same.
- 6) A uniform value of quality of parts is used throughout. This figure would be that determined in Section 2.4.

It must be emphasized that the reliability of the machine is not allowed for in this analysis.

It is shown in Section 3.1.1 that a graph of the form of Figure 1 will be produced which shows highly significant increase in efficiency for increase in buffer stock size.

From this information free transfer systems appear to offer the solution to the problem of defective parts and would be recommended for multi-station machines.

2.4 Parts quality

The quality of parts used by an automatic assembly machine is highly critical for a high overall efficiency to be maintained. This is due to the fact that in manual assembly, operators act as inspection devices which quickly compensate for bad parts in many ways.

The definition of a bad part can be a quantitative or qualitative assessment but here a bad part is taken to be that which will not assemble with its mating component to produce a satisfactory assembly.

The parts quality has the greatest effects on the reliability of feeding equipment and the operation of the workheads.

An example of the resulting machine efficiency is shown by considering an indexing machine feeding 30 components per assembly.

With 1% bad parts per cycle the average output is:-

$$(0.99)^{30} = 0.74 \text{ good assemblies} \\ \text{ie. } 26\% \text{ bad assemblies}$$

With 0.1% bad parts per cycle the average output is:-

$$(0.999)^{30} = 0.92 \text{ good assemblies} \\ \text{ie. } 8\% \text{ bad assemblies}$$

In terms of overall machine efficiency:-

For 1% bad parts:-

$$\text{Downtime} = \frac{26\% \times 60 \text{ secs/min}}{3.6 \text{ secs(cycle time)}} \quad \times \text{ time lost}$$

This time lost is estimated as being the loss of one assembly, which is worth the cycle time plus an estimate of 1 second for indexing without productive work. The resultant downtime is 20.5 secs., which means 65.9% of the time good assemblies are being produced.

For 0.1% bad parts an efficiency of 89.5% is found similarly.

When considering a free transfer machine the situation is different in that the size of the buffer stock can be utilized to offset the overall machine downtime. The calculation is more complex for the free transfer system than that of the indexing type, as referred to by Section 2.3.

The effect of improving quality is to shorten the buffer stock and reduce the amount of time spent by machine attendants in correcting faults.

At this point an improvement in quality appears to be the answer to the problem. Two methods of achieving this improvement suggest themselves. The first is inspection devices for components. These have relevance where a particular feature of a component must be within small tolerances in low quality parts. The cost of such devices and the addition of complexity into the machine system are major disadvantages which may be minimized only if the

inspection can be easily incorporated into the feeding system. A further problem is brought about by doing this when feed rates are slowed by this extra inconvenience. The other point which is against these devices is the doubt as to the feasibility of automatically selecting good components since the attributes of a "good" component are rarely possible to define. Many automatic assembly machine users advocate a reasonable quality part and no inspection devices used for these reasons.

The second method of achieving the high quality is by specification of the quality level to the manufacturer. The major consideration must be cost. It is sufficient to say here that the cost increase is generally very rapid. To illustrate this point a tabulation is made of "typical" figures as expressed by one large company using assembly machines on small assemblies.

<u>Defective Rate</u>	<u>Percentage Cost Increase</u>
Standard supply 1%	Zero
0.5%	50%
0.1%	150%

Referring to the standard supply of parts for the contact block, which is at 1% defective rate, it is reasonable to suppose that this quality level cannot be economically improved. This is particularly applicable to this product since the materials to labour cost ratio is very high.

It follows that exceptions could be feasible if this state is reversed where materials are a comparatively minor cost.

2.5 Discussion of reliability factors

The reliability of the machine is taken to be dependent solely on the breakdown of the machine itself or of the tooling. Reliability must therefore be combined with effects of bad parts to estimate total output.

This subject is one which is generally approached empirically and is difficult to assess without specific design data or, in some cases, the test data from the operating equipment.

Figure 2 shows this inter-relationship. It can be seen that reliability study is a developing process, and quantification is only possible in well advanced stages of design.

To assess the implications on reliability, of operating a multi-station automatic assembly machine, only broad generalizations may be made. In principle it can be seen that prime items are that all designs must be simple and use the least number of

dependent parts. This extends to the configuration where the number of stations should be reduced when consistent with allowing simplicity in the remaining stations. One way of doing this is to create as many sub-assemblies as is feasible, which would feed a main assembly line through large in-process storage units. By this means lesser dependence of some heads on others may be made. This has other repercussions in floor space and cost of equipment which would have to be justified. Any complications or restrictions in parts feeding or assembly should be avoided and, where necessary, some types of assembly not undertaken at all, if the expected output is very low compared with the rest of the machine. Simplifications can be approached by either redesign of parts to overcome particular problems or to use manual assistance at some stage. Once again justification for either alternative would need detailed assessment before acceptance.

In general, the reliability of a proven machine is very high compared with the effect of bad parts on efficiency. For this reason it is to some extent discounted by some machine users. With a high output machine, such as that for the contact block two factors are still of the greatest importance.

- 1) Output must be sufficient to meet market requirements.
- 2) For every 1% drop of reliability 12,500 units are lost which represents about £500 to £600 profits loss.

2.6 Calculations for reliability and maintainability

2.6.1 Reliability

An automatic assembly machine is made up of a number of standard sub-systems and some sub-systems of original design. Actual reliability and maintainability values may be obtained from the acceptance tests of the standard sub-systems and prototype testing of the other systems separately. Each sub-system should be tested for as long as possible in periods of 8 hours. This would simulate working conditions and should also take into consideration any differences in reliabilities at switching on and off. The observations noted should include:-

- 1) Number of 8 hour periods each system was tested, T.
- 2) Total number of failures observed, N.
- 3) N should be sub-divided into n' and n'' where n' is the number of failures which take more than 60 seconds to repair and n'' the number of failures taking less than 60 seconds to repair.
- 4) The repair times for each failure. This should not include any logistic or administrative time losses but should be the actual shop repair time.

Each sub-system can be conveniently divided into 3 parts:-

- a) Controls, C.
- b) Operation, O.
- c) Parts feeding, F.

This will allow similar groups in all the sub-systems to be considered together, so that if N' tests are carried out on each of ll sub-systems of this machine and, say, four of these sub-systems use pick and place feeding devices the effective number of test samples for this unit will be 4N' from which a better estimate of its characteristics may be obtained.

The data obtained for any one sub-system will be tabulated as follows below. The tabulation shows that each part may be tested separately if this is convenient. In this case the equivalent number of whole sub-system tests are considered. This is the smallest value of T.

<u>Sub-system</u>	<u>Description</u>		
<u>Part</u>	<u>Total number of times tested</u>	<u>Total failures</u>	<u>Failures in last T* tests</u>
C	T_1	n_1'	f_1
O	T_2	n_2'	f_2
F	T_3	n_3'	f_3

$T^* =$ smallest of T_1, T_2, T_3 .

Using the values of T^*, f_1, f_2, f_3 , (ref. 4) and graph in fig. 3 the reliability of the sub-system may be read off directly.

2.6.2 Maintainability

$$M(t_i) = \frac{\sum_{j=1}^i n}{N + 1}$$

where $n_j =$ number of times the time t_j was observed for a repair time

$N =$ total number of failures

Experimental data on maintenance and repair obtained from a large number of diverse equipments indicate that these times follow a log-normal distribution (ref. 2). Tabulate the data as follows:-

Observed data	$M(t) = \prod_{j=1}^i n_j$	$(\log_{10} t_i)$	$(\log_{10} t_i)^2$	$\frac{x_i - \hat{\xi}}{t}$	$\log M(t)$
Time to repair	No. of obsvns.	x_i	x_i^2		
t_i	n				
t_1	n_1				
t_2	n_2	$\frac{n_1}{N+1}$			
		$\frac{n_1+n_2}{N+1}$			

$$\log \text{ mean } \hat{\xi} = \frac{\sum n_i x_i}{\sum n_i}$$

$$\hat{\tau} = \sqrt{\frac{\sum n_i \sum n_i x_i^2 - (\sum n_i x_i)^2}{\sum n_i (\sum n_i - 1)}} \quad \text{at 95\% confidence limits}$$

Upper and lower limites of mean repair time is given by
 antilog $\left(\hat{\xi} \pm 1.96 \frac{\hat{\tau}}{\sqrt{N}} \right)$

By plotting $M(t)$ vs. \log active repair times (t_i) the graph in fig. 4 is obtained. From this graph it will be possible to obtain the maintainability for any repair time considered. eg. M_1 and M_2 give the probability of completing repair in 8 or 16 hours.

2.7 Scrap

A serious aspect of high output automatic machines is the problem of scrap. The decision to re-use or scrap parts is dependent mainly on the materials to assembly cost ratio. To fully assess this situation a detailed cost analysis must be made, as will be mentioned later.

The first decisions to be taken must be based on data relating to the conditions under which scrap parts are taken from the machine. If partly assembled components are rejected at the station of rejection the strip-down or repair of these parts can be operated as a batch operation for each station. This may produce undesirable effects in loss of time and efficiency, or complexity of the machine. To overcome this situation reject assemblies may be transferred without subsequent assembly work after rejection. In this case a variety of part assemblies will be produced in reject containers so that strip-down or repair operations will not be the same for each reject.

In general, the costing process on which an analysis may be based is comparative costs of materials against the cost of breaking the part assembly into parts for re-use, or repairing and finishing the part assembly. The alternative to repairing and finishing the part assembly requires a manual operation, which will be far slower than automatic assembly and involve an analysis of faults before completing the work. With a high output machine the quantity of scrap that this could produce would be equivalent to a large scale operation. For this reason it is not considered as a viable proposition to include this situation in the analysis.

It can be seen that detailed information relating to work standards, costs and profits is necessary to make an analysis which applies wholly to the situation. This information is not available for the manufacture of the contact block. Using the best estimates possible under the circumstances an assessment for the contact block is provided in Appendix 10.1.

The results of Appendix 10.1 show that the cost of scrapping rejects is prohibitive owing to high material costs. By comparison the strip-down of part assemblies is very economical. The difference in costs is sufficiently distinct to ensure that the principle involved will be true for considerable change in the figures used. These figures will vary little or not at all in some cases with the introduction of the details required, so conclusions on basic facts can be made. The cost of strip-down and return of parts for rebuild is about 12% of scrapping the parts. Other matters would have to be taken into account such as:

- 1) The possibility of the parts that caused the scrap being returned to the machine and any inspection operations to eliminate this situation, would need to be costed.
- 2) The space and labour involved in strip-down operations would have to be weighted in importance according to the manufacturing system in which it is installed. This should be considered carefully since from the figures presented in Appendix 10.1 it can be seen that for every one percent of output that is scrapped, 3.5 operators are fully occupied with scrap strip-down.

3. MACHINE SPECIFICATION AND PERFORMANCE

3.1 Design Features

This section is concerned with those factors which can be physically varied to produce the required annual output from the machine. The main factors under review are the range of optimum conditions, for buffer stock size in a free transfer system and cycle times.

3.1.1 Buffer stock size

The size of the buffer stock is a vital factor in the ultimate economic running of the machine, as mentioned in section 2.3.

There are two effects on the overall output of acceptable assemblies. The first is that, in general, it can be seen that the longer the distance between stations the more part assemblies that are potentially available to maintain the overall output of the system. Secondly, parts quality is involved in that the more defects per unit volume of any part, the more likely it is that a stoppage will occur. Once again, a large number of part assemblies in the buffer stock appears to be the answer. It is appropriate to mention, at this point, that parts quality should not be such as to include too many defectives since this will mean more manual fault correction by machine attendants.

Conflicting with these requirements is the consideration of floor space required and materials that are necessary to expand buffer stock size. These items need very little explanation in terms of cost. Floor space may be available in some organizations although, in many places, it is at a premium and, whichever is the case, the costs must vary with the area occupied. The conveyor materials cost between stations will, possibly, be small for reasonable increase in length but other costs, such as extra platens and more powerful or robust driving equipment, could be larger in some cases.

These factors add to the complexity of decisions on buffer stock size. These are in addition to the list in section 2.4. The need to optimize the size of buffer stock is therefore of major importance.

To produce accurate results is, obviously, difficult in a calculation with the type and magnitude of the variables involved. A system for evaluation of buffer stock size is being developed at the University of Salford by a student as the subject of his Ph.D. research (ref. 8).

This system uses an analogue simulation of the assembly process on a digital computer to optimise the variables. The use of this system was made available for the machine designed for the switch assembly.

There are two ways of considering optimisation of buffer stock size. One is to vary the output to suit the best machine performance in terms of cycle times and efficiency. The other is to work to a fixed annual output quantity and alter cycle time and efficiency to suit. The former is convenient and could be applicable where a number of machines will be used as required. The latter is, in many cases, more realistic since production is generally geared to predictions of market demand.

The variables must be fixed over the range to be encountered and, in some cases, fixed at an agreed value. The parts quality is, perhaps, one of the more difficult factors to stipulate. The current rate of defects in the parts of the contact block is one in every 100, which is a figure that would be difficult to improve owing to the high costs which would be involved. This is discussed fully in section 2.4. Mainly for this reason and the fact that one defect per hundred is a reasonable figure for most manufactured goods, this was adopted.

The annual output was fixed at the figure of one and one quarter million so that cycle time and efficiency were dependent on it.

The cycle time was taken as being 4 seconds, since this was the predicted time that was most agreeable to all design committees. Machine stations are only significant in these calculations if parts are fed, which applies to 8 stations.

The final major factor affecting the calculation is the configuration of the assembly system in terms of the dependence of the final station on the first station. In fact, the configuration presented by the Assembly Process Committee is a "closed loop" having the situation of dependence stated. To overcome the extra buffer size required to deal with this situation it is necessary to have a manual feed of empty platens to the first station in the event of breakdown at the last head. Since an "open loop" system is so easily produced, it is assumed as operational for the machine.

The computed result gave information which was translated in the form of the trace of buffer stock versus machine efficiency shown in fig. 1. The percentage improvement per unit increase of buffer stock is seen to diminish rapidly beyond 7 units. This would suggest that the efficiency loss for parts alone would be satisfactory with a maximum of 7 units.

By use of information from section 4.1 the plot of cost of floor space has been superimposed on fig. 1. This is scaled appropriately from the other trace on the figure which now represents the cost of efficiency drop against buffer stock size. The net effect is to show the relationship of decreasing the cost of efficiency losses and increasing floor space cost. The conflict point is reached at slightly less than 3 units of buffer stock. For reasons of accessibility a buffer stock of less than 5 units could not be utilized at most stations to allow a practical configuration. The results of moving the stations closer together than the Assembly Process Committee recommends is shown in sections 3.2 and 5.0.

3.1.2 Optimisation of cycle times

The cycle time of the machine is a factor in the system design which will ultimately govern the effectiveness of the machine in fulfilling its purpose.

The first practical limitation is that of the maximum speed of operation of the component parts of the slowest workhead and the associated ancillaries. This is the deciding factor when the machine is running, but it is profitable to examine the effect of any variability that the machine might possess.

Ideally, the cycle time should be of such a length that one and one quarter million acceptable assemblies are produced each year and sufficient time is available for stoppages due to bad parts, machine breakdown and maintenance, machine changes for variations in assembly and factory holidays. Off standard conditions such as strikes or lack of parts for assembly would be made up as overtime work.

The cycle time will be considered in two stages to facilitate calculation. The first and largest loss of production time is due to breakdowns caused by parts and the effect it has on cycle time. The results of this will be used for the effect of machine breakdown, due to its inherent reliability, to be added for the overall optimisation.

Since a fixed output per year is the given condition, the approach must be to assess the cycle time and efficiency necessary to achieve the target output.

It is possible to calculate the efficiency required for each cycle time by re-arrangement of the equation used in section 2.1. The result is:

$$\text{Efficiency} = \frac{\text{Cycle time} \times \text{No. of assemblies p.a.}}{\text{No. of seconds available p.a.}}$$

With the exception of the number of working hours per day and the machine efficiency the original assumptions stand.

By plotting graphically, efficiency required against cycle time, different lines for different numbers of working hours per day produce the result shown in fig. 5. The efficiency required from the machine has been set at a range between 60% and 80%. Below 60% the utilization of the machine is uneconomic and above 80% very high parts quality and machine reliability are necessary, which produces another uneconomic situation.

The range of cycle times has been set between 3 and 6 seconds. This was ascertained by reference to the practical limitations that have been imposed in the machine design work. It can be seen from the graph that a 16 hour working period per day does not allow suitable working efficiency. Both 8 hour and 12 hour working periods are feasible. It will be noticed that a zone between 4.1 and 4.6 seconds presents a problem.

Since parts quality effects have been investigated the additional effects on cycle time of machine reliability can be discussed. For this analysis the maintainability is assumed to be 100% for 24 hours. This means that if a chance machine failure occurs, then it is certain this can be remedied by the same time during the following shift. A failure will, therefore, mean the complete loss of one whole working day whether it is 8 hours, 12 hours or 16 hours.

Figures 6, 7 and 8 show the relationship between module reliability and cycle time for various shift times worked, with and without manual standby.

Given any two of the following parameters, it is thus possible to determine the other two, by reference to fig. 14 as necessary, to be able to meet the design production rate and specifications.

- a) Overall reliability (with or without manual standby)
- b) Module reliability
- c) Cycle time
- d) Number of shifts worked per day.

For the purpose of plotting the graphs in figs. 6, 7 and 8 the initial information was taken from fig. 5. It can be seen in fig. 6 that an 8 hour working day will not allow a cycle time of more than 4.3 seconds, to meet the output requirement. Practical limits are set as being a module reliability range of 92-98% and a cycle time minimum of 4 seconds. It can be concluded that for 8 hours per day only a 4 second cycle time is suitable. For 12 hours per day, cycle times of between 4 and 5.8 seconds are suitable and for 16 hours per day, cycle times of 5.3 to 7.8 seconds are suitable. The effect of manual standby to permit versatility in cycle time and, in some cases, to allow the production requirement to be met is most pronounced in figs. 7 and 8.

3.2 Reliability of proposed design

Assuming an exponential reliability function for the automatic assembly machine, a mathematical reliability model has been derived which incorporates the possibility of having standby operators who will carry on manually the functions of any modules in case of failure. Using empirical relationships the approximate expected reliability has been predicted.

Methods of using acceptance and prototype tests to obtain more accurate reliability and maintainability values were given in section 2.6. Relationships between system reliability (with and without standby), module reliability, number of shifts per day and cycle times are given in graphical form.

3.2.1 System reliability model

The automatic assembly machine is divided into functional sub-systems. It is assumed that the entire machine and those sub-systems follow an exponential distribution in their failure rates. The relevant characteristics of this distribution are shown in figs. 9, 10 and 11. The important point to make is that the hazard rate is constant, ie. the probability of random or chance failure is independent of time. This is only possible if a planned maintenance system is operated, so that components are replaced before reaching their wear out stage of life ie. they are operated only in the life span $T_B - T_W$ in fig. 12.

The reliability model is shown in fig. 13. The boxes marked 'operator' indicate the positions where a manual operator may be considered. This does not mean that there will be (n-1) operators. The number of operators to be required will be discussed later. The automatic sub-system together with its operator thus forms a parallel redundancy, ie. an operator is always on standby so that the moment the head fails to operate he steps in and carries on with that particular operation. The time to failure density of the exponential distribution is

$$f(t) = \lambda e^{-\lambda t}$$

where λ is the constant failure (hazard) rate, or

$$f(t) = \frac{1}{\Theta} e^{-t/\Theta}$$

where Θ is the mean life and is equal to $\frac{1}{\lambda}$. The reliability

equation for an element with an exponential density function is

$$p(t) = \int_t^{\infty} e^{-\lambda t} dt = e^{-\lambda t}. \quad \text{If two elements in parallel have}$$

constant failure rates, λ_a and λ_b , then

$$\begin{aligned} R(t) &= 1 - q_a(t)q_b(t) = 1 - (1 - e^{-\lambda_a t})(1 - e^{-\lambda_b t}) \\ &= e^{-\lambda_a t} + e^{-\lambda_b t} - e^{-(\lambda_a + \lambda_b)t} \end{aligned}$$

$$s = \frac{1}{\lambda_a} + \frac{1}{\lambda_b} - \frac{1}{\lambda_a + \lambda_b}$$

Two factors will have to be allowed for:

- 1) Operator speed will be less than machine speed, say, $x_j\%$ of machine speed. This factor x_j will indicate the average speed for the period under consideration and will include tea and rest breaks etc.
- 2) The operator himself will have a reliability figure. This will vary for different operations. Let this be y_j . (ref. 5).

Since the number of completed operators by any head say A_j can be given by, $A_j \propto R_j$ and also $A_j \propto \rho_j$ where ρ_j is the efficiency of that head, the efficiency of the human operator can be combined with his reliability to give an effective reliability value. i.e.

$$R_{(op)_j} = (x_j \cdot R_j) y_j \quad \dots \dots \dots (3.1)$$

or if q_j is defined as the unreliability such that $q_j + R_j = 1$

$$q_{(op)_j} = 1 - (x_j \cdot R_j) y_j \quad \dots \dots \dots (3.2)$$

The reliability of a parallel redundant system with one redundancy is given by

$$R = 1 - q_1 q_2 \quad \dots \dots \dots (3.3)$$

For the j th. head this becomes

$$\bar{R}_j = 1 - q_j (1 - (x_j \cdot R_j) y_j) \quad \dots \dots \dots (3.4)$$

where \bar{R}_j is the effective reliability of the module j .

The various modules and the conveyor will then form a series system so that failure of any module or conveyor means failure of the system. The overall reliability of the system is then given by:

$$R_{\text{system}} = R_1 \prod_{j=2}^n (\bar{R}_j) \quad \dots \dots \dots (3.5)$$

It is desirable to design for highest reliability and if it is assumed that all the modules have this high reliability i.e. $R_1 = \bar{R}_2 = \bar{R}_3 = \bar{R}_n = \bar{R}$ then,

$$R_{\text{system}} = \bar{R}^n \quad \dots \dots \dots (3.6)$$

Graph 1 in fig. 14 shows the effects of module reliability on the overall system reliability. Graph II shows the system reliability when a standby operator is available to take over by manually performing the operations of any module that has failed. For computational purposes, the operator has been assumed to be able to work at half the speed of the machine. ie. putting $x_j = 0.5$ in equation (3.4) and his reliability $y_j = 0.998$ (ref. 2).

In both cases it is assumed that the number of modules including conveyor is $n = 11$. Since an operator cannot act for the conveyor, in obtaining the system reliability with operator standby, equation (3.6) is modified to

$$R_{\text{system}} = R_1(\bar{R}_j)^{(n-1)} \dots \dots \dots (3.7)$$

where R_1 = reliability of the conveyor and \bar{R}_j is the module reliability as given by equation (3.4).

3.2.2 Approximation to system reliability

Mutsenek and Lobnoz (ref. 6) estimate the average fault free operation of a five-stage automatic assembly machine to be 5 minutes and claim the reliability of automatic assembly machines to be generally lower. The coefficient of utilization which they define as

$$ut = \frac{T_e}{T_a} \quad \text{where } T_e = \text{actual operating time}$$

$$T_a = \text{possible operating time.}$$

is given as 0.8 to 0.9.

Van Alven (ref. 2) has collected data for various complex equipments which include electrical, mechanical and hydraulic components and has shown the relationship between system complexity and reliability. The relevant portion of this graph is shown in fig. 15. The system complexity is defined in units of Active Element Groups (AEG) which for purposes of this automatic assembly machine can be defined as a distinct part or group of elements in a sub-system, the failure of which will cause a failure of that particular sub-system. The configuration proposed has approximately 200 such groups. From fig. 15 the mean system life is seen to be 90 - 200 hours or about 2 to 5 weeks.

Employing these units (AEG) again, another reliability prediction may be obtained using the AGREE (ref. 2) method. This assumes an exponential distribution of failure rate and approximates to a first order expansion of the exponential.

The reliability of the j th assembly is given by

$$R_j = \frac{1 - 1 - (\bar{R})^{n_j/N}}{E_j}$$

where R_j = reliability of j th sub-system.

\bar{R} = overall system reliability (required).

n_j = number of AEG in the j th sub-assembly.

N = total number of AEG in the system.

E_j = importance factor of the j th sub-system.

3.2.3 System effectiveness

System effectiveness is here defined as the percentage time the automatic assembly machine is operating successfully to its design standards.

$$E_{\text{system}} = \frac{T_e}{T_e + T_d} \quad \dots \dots \dots (5.1)$$

where T_e = operating time

T_d = downtime.

The downtime T_d in the context of this analysis will be only the time taken to repair chance failures. It is assumed that scheduled maintenance will be carried out outside the normal shift hours. These failures will be due to

- a) Assembly component or parts quality, and
- b) Inherent design weaknesses, sudden overstressing or other similar unpredictable causes in the automatic assembly machine modules.

Failures due to parts quality are normally of short duration and can be rectified in an average of under 30 seconds (ref. 7). The downtime due to these can be minimised by selecting a suitable buffer stock in a free transfer system and, in this case the buffer stock has been computed to reduce downtime to 23% at 99.0% good parts quality level, as mentioned in section 3.1.1.

Assuming the assembly machine can work on a cycle time of four seconds and using a 40 hour week, and a 49 week year the downtime due to chance failures has to be limited to T_d to meet the design requirement of 1.25 million assemblies per year.

$$\bar{T}_d = 1 - \left(\frac{40 \times 49 \times 60 \times 60}{1.25 \times 10^6} \times .77 \right)^{-1} \times 4 \quad \dots \quad (5.2)$$

$$= 1 - 0.90 = 0.10$$

<u>Cycle Time</u>	<u>Machine Downtime Allowable</u>
3.5 secs.	21%
4.0 secs.	10%
4.45 secs.	0

Once a cycle time has been achieved say, 5 seconds, then the maximum allowable downtime will be fixed for this example to 13.5%. The probability of achieving this may be defined as

$$P_{(T_d)} = \bar{R} \cdot M \quad \dots \quad (5.3)$$

where \bar{R} = overall system reliability

M = maintainability of the system.

The maintainability of the system is the probability that when a maintenance action is initiated under stated conditions, a failed system will be restored to operable condition within a specified downtime.

3.2.4 Economic number of standby operators

Let N = expected number of stations breaking down simultaneously.

P_N = probability of N stations failing simultaneously.

n = number of standby operators.

Without any provision for standby operators, one or more stations failing will result in the entire assembly machine being non-productive after a short period of time, dependent on buffer stock size.

$$\text{Loss} = L_1 + L_2 \quad \dots \quad (1)$$

where L_1 = expected loss of profit by not manufacturing for period T.

L_2 = expected loss based on floor space overhead for period T.

Reliability has been defined as the probability of any module not breaking down for the duration of the shift and, in case of failure, the total time lost in repair to be one entire shift.

Hence if period T is assumed to be one year

$$L_1 = \left(\frac{1.25 \times 10^6}{49 \times 5} \right) \rho \cdot P_{N.250} \dots \dots \dots (2)$$

where $\left(\frac{1.25 \times 10^6}{49 \times 5} \right)$ = number of contact blocks produced per shift.

ρ = profit per contact block

$P_{N.250}$ = expected number of shifts lost due to module failures.

$$L_2 = \left(\frac{M.A}{49 \times 5} \right) (P_{N.250}) \dots \dots \dots (3)$$

where M = annual overheads/sq.ft. of floor space.

A = area of floor space required by machine.

$$\text{Loss} = \left[\left(\frac{1.25 \times 10^6}{49 \times 5} \right) \rho + \left(\frac{M.A}{49 \times 5} \right) \right] P_{N.250} \dots \dots \dots (4)$$

If n standby operators are employed;
Assuming manual operation of any station is at half the speed of mechanical operation,

$$\text{Loss} = \frac{(L_1 + L_2)}{2} + 2nC \dots \dots \dots (5)$$

where C = annual wages of operator and the factor 2 is to allow for factory overheads on the operator.

Hence expected savings by employing standby operators

$$\begin{aligned}
 &= (L_1 + L_2) - \left[\frac{(L_1 + L_2)}{2} + 2nC \right] \\
 &= \left[\left(\frac{1.25 \times 10^6}{49 \times 5} \right) P + \left(\frac{M.A}{49 \times 5} \right) \right] \frac{P_N \cdot 250}{2} - 2nC \\
 &\dots \dots \dots (6)
 \end{aligned}$$

Details for the case of the contact block are:

- 1) Profit per contact block = 4/- (20P) or £0.2
- 2) Overheads per square foot of floor space = £40 p.a.
- 3) Area required by machine = 500 sq.ft.
- 4) Number of stations = 11.
- 5) Wages per operator = £20 per week.

$$\begin{aligned}
 \text{Substitute in (6), expected savings} &= 175,000 P_N - 2080n \\
 &= 1000(175P_N - 2.08n)
 \end{aligned}$$

$$P_N = \sum_{x=N}^{11} \binom{11}{N} (P)^N (1 - P)^{11-N}$$

where P = probability of one module breaking down.

The following table gives the probability of n modules breaking down simultaneously for various values of module reliability.

No. of modules breaking down simult. = n.	Module Reliability	99	98	97	96	95
	%	—	—	—	—	—
0		1.00000	1.00000	1.00000	1.00000	1.00000
1		.10466	.19927	.28470	.36176	.43120
2		.00518	.01951	.04135	.06923	.10189
3		.00016	.00117	.00372	.00829	.01524
4		.00000	.00005	.00023	.00067	.00155
5			.00000	.00001	.00004	.00011
6				.00000	.00000	.00001
7						.00000
8						

If the final reliability of each module is 98% then the expected savings are:

<u>Number of operators</u>	<u>Expected Savings £</u>
1	32,920
2	34,340
3	32,260
4	30,180

To maximise savings then 2 standby operators must be employed.

3.2.5 Maintenance of the automatic assembly system

Two types of maintenance have to be allowed for:

- 1) Planned maintenance which will ensure that the machine will be operating in the constant failure rate region of its components' lives as shown in fig. 12.
- 2) Emergency maintenance to cater for chance breakdowns.

An initial maintenance program based on design features is given in fig. 16. Allowing for designer enthusiasm and unforeseen circumstances such a program can only be expected to cover about 15% of the total maintenance work that will have to be carried out. (ref. 9). As experience is gained, the proportion of total maintenance work that can be planned will rise to 75 - 80% (ref. 9).

In the course of building up the planned maintenance program from that given in fig. 16, it is possible to go through stages of under-maintenance and, at some stage, over-maintain the machine. This can happen when the expenditure on planned maintenance exceeds the benefits.

To provide a measure of the effectiveness of a planned maintenance program during the various stages of its evolution, Clarke (ref. 10) has proposed an effectiveness factor E, where

$$E = \frac{1}{C + K + W}$$

C = annual cost of maintenance divided by replacement value of plant maintained.

K = total downtime divided by number of production hours.

W = proportion of product wasted, divided by total output.

A graph of E v. time is given in fig. 17. The value of E should be calculated at intervals of, say, 3 months. The moment that the graph shows a negative slope the program should be carefully reappraised.

From fig. 18, it is seen that an average of 53 man hours of work annually at planned maintenance is predicted. Assuming this to represent 15% of the actual time that will be spent in maintenance work, it is seen to be well within the capacity of one skilled mechanic.

To justify the employment of one skilled fitter, his duties should also include emergency breakdowns. The probability of a breakdown due to chance failure is (from section 3.2.4) 0.19927. Under the original assumption that chance failures may take up to one whole day to repair, under the worst possible conditions this fitter will be working 400 hours a year on chance breakdowns. Allowing 200% logistic and administrative delays, this will amount to 60% of his total time.

On these assumptions one skilled mechanic will still be able to cope with the maintenance (both planned and unplanned) of this machine.

One anomaly arises in the working conditions of a maintenance crew which is that the more efficient they are, the less work they do. O'Callaghan (ref. 11) has devised a bonus scheme based on two factors for maintenance work which can be successfully used here.

a) Hour factor, $H = \frac{\text{standard maintenance hours}}{\text{actual working hours of dept.}}$

b) Machine non-available bonus factor,

$$N = \frac{\text{standard weighted machine non-available hours}}{\text{actual weighted machine non-available hours.}}$$

Thus more bonus is earned by keeping down actual hours spent in maintenance and machine available time.

One important record that has to be kept in all maintenance programs is a unit history card. The format is shown in fig. 19. Over a period of time, not only will this give a record of the suitability of that unit in this machine but, also, shows at what stage of life the unit should be replaced. General practice is to assume a component reaches its wear-out period of life (see fig. 12) when its breakdown rate doubles that in its constant hazard rate phase of life.

At this stage it will be difficult to predict the cost of a maintenance program. Operator costs will amount to about £2000 annually (this includes wages plus 100% overheads). It has been found (ref. 10) that most well-run maintenance programs cost 5 - 8% of the plant replacement value. At an estimated cost of £29,000 for the machine this amounts to about £1,500. Hence a total of about £3,500 will go annually into maintenance. This is equal to the loss in profits caused by a 7% drop in reliability per year (see section 2.5).

4. THE FINANCIAL ASPECTS OF THE ASSEMBLY SYSTEM

4.1 Justification for purchase

This section will detail the cost of the machine, its financial comparison with manual assembly and its overall profitability and value to an industrial concern.

It is intended that the approach of the analysis will be applicable to a wide range of possible users. Since specific information relating to the manufacturer of the contact block is not available in some cases, only some of the work is directly applicable to this company.

4.1.1 Machine tool costs

The cost of the machine has been undertaken in two parts; the basic machine, which can be adapted to assemble a variety of products that fall within the specification, and the tooling required to assemble these products. The basic machine consists mainly of the conveyor assembly, platens, pick and place heads and the control system. The pick and place heads have been included in the basic machine costs because the claws are the only part to be changed for different components. Only six pick and place heads have been allowed for in the costs, as that is the number required for assembling the contact block. The tooling and any sub-assembly spurs will be mostly special purpose, and therefore costed separately. The sub-assembly and assembly machine would not be subject to proving costs as it would be built by an outside manufacturer.

The machine cost

	£	s	d
The basic machine	4762	5	0
Total cost of tooling	3622	11	9
	<hr/>		
Development costs @ 100% of materials cost	8384	16	9
Labour, overheads, profit @ 100% of mats. cost	8484	16	9
Sub-assembly machine	3850	0	0
	<hr/>		
	29004	10	3

Total cost of machine for assembly of the contact blocks is:-

£29,004 10s. 3d.

Retail cost of £29,000 is assumed.

For further breakdown of costs see Appendix 10.3.

4.1.2 Comparison with manual assembly

When justifying capital expenditure manual labour costs are a major part of the cost saving programme. This is shown by appendix 10.2 to be true at present and will be increasingly so as labour costs continue to rise. Many beneficial factors arise from replacing the manual work with a machine operation, which are difficult to assess as cost savings. These include removal of labour relations problems and the fact that an assembly can only be automatically produced if the component parts are good. The result is better assemblies and more customer satisfaction from the product, by delivery on time and effective functioning. For the purpose of this study, only capital expenditure, floor space, labour and materials will be considered since the methods of quantifying them are acceptable.

In general, there are two ways of assessing the manual assembly method. One is to provide cost estimates for the method of assembly used in current production if the scheme exists. The other is to estimate for a system of manual work which is the "ideal" system, assuming that this is not the one already in operation. The comparison of either or both with any scheme for automatic assembly should be the basis for decisions by management. The comparison of the ideal system with an automatic machine must be the test case.

The cost of production will be given by:-

Materials + Labour and Labour Overheads + Factory Overheads
(inc. Floor Space and Administration) + Depreciation or write-off
costs of equipment.

It is clear that no savings can be made on the materials in a well-designed product since the best and easiest for automatic assembly is also the most suitable for manual assembly. It is acknowledged that depreciation will be greater for expensive automatic plant than for hand tools or mechanized operation. Factory overheads taken as a rate for area can be reduced only by the actual space taken up by the machine itself. According to good layout principles it will be recognised that stock, gangways and general accessibility require a large part of the floor space provision. For manual or automatic systems these factors show little variation, which means that, at best, only small savings can be expected for this item. It follows that the major item for cost saving is labour.

Unless a company policy dictates terms such as space allowed or available, the simple test recommended when considering suitability of automatic assembly is the ratio of labour cost to total cost of production. It is unlikely that a cost saving will be realised, of a size that will involve great profit, unless labour costs are a reasonable proportion of production cost.

For the contact block the following facts are set down on which to base a comparative assessment.

Two systems will be compared:-

- A) A system which is predominantly manual with mechanical aids. The estimate set by the manufacturer of the contact block is for equipment costing £9,000 which is used by 14 operators. One person is added to replenish parts containers. This person will be referred to as the line loader.

The justification for the line loader is as follows:-
About 15 different parts will need distribution to appropriate positions twice per day. Fifteen minutes are allowed for each part, so that the total time is

$15 \times 15 \times 2 = 450$ minutes per day. As this is seven and a half hours one operator is necessary.

- B) An automatic assembly system using a small amount of manual labour in the form of 3 machine attendants and 4 assembly operators. The retail cost of the system is £29,000.

For both systems the floor space and power required will be similar since inclusions of equipments and ancillaries have common features. The fixed quantities are:-

a)	Approximate materials price	4/- (20 P) per assy.
b)	Manual assembly labour	8/- (40 P) per hr.
c)	Machine attendants labour	10/- (50 P) per hr.
d)	Line loaders labour	8/- (40 P) per hr.
e)	Using 8 hours working time per day	
	Working hours per year	1,920 hours
f)	Overheads on operators	100% of pay rate
g)	Depreciation Period (App. 10.2)	4 years

System A production cost is

Materials . . . 1.25 m x £4/20	£250,000
Labour with Overheads . . .	
15 x £8/20 x 2 x 1920	£ 23,050
Depreciation . . . $\frac{£9,000}{4}$	£ 2,250
	<hr/>
Total	£275,300

System B production cost is

Materials . . . 1.25 m x £4/20	£250,000
Labour with Overheads . . .	
(3 x £10/20 + 4 x £8/20) x 2 x 1920	£ 11,900
Depreciation . . . <u>£29,000</u>	<u>£ 7,250</u>
Total	<u>£269,150</u>

The difference of £6,150 shows the result of automating assembling of a product with a low labour to materials cost ratio.

4.1.3 Profits

The representation of profits is made by two methods. These are graphical and discounted cash flow techniques.

Figure 20 shows a breakeven chart in the traditional manner using straight line plots. So far comparison of methods of assembly have only shown an ideal manual system compared with the machine designed by this project. The actual system of assembly which it replaces is currently operating at 20% of the new output required. Magnification of the current assembly method has been included in fig. 20 since this is the true state of the improvement being made. This is based upon the fact that a company will want to assess machine profitability against existing methods.

For the calculation of the figures on the graph for the current production system the following estimates are used:-

- 1) By allowing for redesigned components and minimising stock requirements 22 operators, 2 line loaders and 1,000 square feet of working space would be required.
- 2) An overall figure of £40 per square foot per year is provided for the Fixed Overhead Rate.

Fixed Overheads are 1,000 x 40 = £40,000

Labour and Labour Overheads =
22 x £8/20 x 1,920 = £33,800

From fig. 20 it can be seen that the increase in profits is £41,900 per annum. When considering the idealised mechanised manual method of assembly it was found that this profit would be £6,150 p.a. less (section 4.1.2) but this is offset by a cost of £11,500 p.a. in machine maintenance and efficiency loss in the automatic system. The nett effect is that the mechanized manual assembly method provides greater profit.

4.1.4 Capital expenditure appraisal

For outright purchase of the machine from a manufacturer a Discounted Cash Flow appraisal is carried out according to the Nett Present Value method mentioned in Appendix 10.5. Annual profits are considered steady at £41,900 as in section 4.13.

The whole scheme is analysed, including the Badalex Sub-Assembly machine, using the retail price of £29,000 and a write down period of 4 years. A longer period may be possible as in section 4.1.6. Profitability is checked assuming that the company requires a minimum of 10% profit and prefers to exceed 20% profit before acceptance of a project appropriation.

From Table 1 below it can be seen that the machine is altogether acceptable for the profit rate required.

<u>Received After</u>	<u>10% Discount Factor</u>	<u>Nett Present Value</u>	<u>20% Discount Factor</u>	<u>N.P.V.</u>
1 year	0.95	£39,800	0.907	£38,000
2 years	0.864	£36,200	0.756	£31,700
3 years	0.785	£31,650	0.630	£26,400
4 years	0.714	£29,900	0.525	£22,000
	Total =	<u>£137,550</u>	Total =	<u>£118,100</u>

If the machine can be obtained through a machine manufacturer on lease the effects on savings compared with outright purchase are shown by the following assessment. Reference can be made to Appendix 10.5 for details of investment grants and Capital Allowances. The conditions applied are those of section 4.2.2 on leasing.

Cost of machine	=	£14,287	without tooling and sub-assembly machine
Investment Grant	=	20%	
Annual Allowance	=	15%	
Length of lease	=	5 years	
Corporation Tax	=	42.5%	
Value of Machine at end of lease	=	<u>£6,090</u>	(from fig. 21)

Present Value method

Tax allowances on the purchase of a new machine.

	£
Cost of Basic Machine	14,287
Investment Grant	<u>2,857</u>
	11,430
Annual Allowance for year 1	<u>1,715</u>
	9,715
Annual Allowance for year 2	<u>1,458</u>
	8,257
Annual Allowance for year 3	<u>1,239</u>
	7,018
Annual Allowance for year 4	<u>1,053</u>
	5,965
Annual Allowance for year 5	<u>894</u>
	5,071
Value of Machine at end of lease	<u>6,090</u>
Balancing Charge	<u>(1,029)</u>

Rent for year 1	=	30%	of Machine Cost	=	£5,287
Rent for year 2	=	25%	of Machine Cost	=	£3,572
Rent for year 3	=	20%	of Machine Cost	=	£2,857
Rent for year 4	=	15%	of Machine Cost	=	£2,144
Rent for year 5	=	10%	of Machine Cost	=	£1,429

Rental paid on a quarterly basis.

	£	£	£	£	£	£	£
	Savings by Paying Inslmnts.	Tax on Savings	Capital Allowance	Tax saved by C.A.	Cash Flow	Discount Factor 10%	Present Value
1	4,287		1,715		4,287	0.95	4,070
2	3,572	1,821	1,458	729	2,480	0.864	2,100
3	2,857	1,517	1,239	619	1,959	0.785	1,537
4	2,144	1,213	1,053	526	1,457	0.714	1,040
5	1,429	912	894	448	965	0.649	626
6		607	-1,029	380	- 227	0.590	- 134
7				-437	- 437	0.536	- 234

Present Vslue of all net Cash flow in = £9,005

TABLE II

Net investment amount

Cost of new basic machine	=	£ 14,287
Investment grant (discounted at 10% over 1 year)	=	(2,712)
Value of machine at end of lease (discounted over 6 years)	=	<u>(3,590)</u>
Net Investment	=	<u>7,985</u>

The assumptions made in the calculation are that the company is considering leasing as a comparative method of acquiring the machine.

Discounted cash flow

Year	Cash Flow from Table II £	Discount Factor (@ 20%)	Present Value £	Discount Factor (@ 22%)	Present Value £
1	4,287	0.907	3,890	0.899	3,855
2	2,480	0.756	1,875	0.737	1,827
3	1,959	0.630	1,234	0.604	1,182
4	1,457	0.525	764	0.495	720
5	965	0.438	423	0.406	392
6	- 227	0.365	- 83	0.333	- 76
7	- 437	0.304	- 147	0.273	- 132
Present Values of all Net Cash Flows in			<u>7,956</u>		<u>7,768</u>

TABLE III

Net Investment = £7,985

The present value and discounted cash flow methods are used for comparing an outright purchase with leasing of the basic machine. These are shown for a 5 year period to be compatible with lease plans. The present value method shows that if the cash flows command a 10% rate of interest, their present value (£9,005) is greater than the net investment (£7,985) and therefore, it is

beneficial to lease rather than purchase. Discounted Cash Flow method shows that, in these terms of present values, the cash flows in would have to command a 23% rate of interest before an outright purchase would be an advantage.

4.1.5 Depreciation

Depreciation of an asset is a function of time which depends upon wear and tear, inadequacy, obsolescence, and superfluity and plays an important part in the costing of an asset. The period in which capital is recovered for the replacement of an asset is a combined financial and company policy decision, taking into account the period in which allowances from the Inland Revenue act. There are several methods of calculating replacement provision, of which straight line and reducing balance are the most commonly used. In the straight line method, replacement provision is divided equally over a predetermined number of years, and is an advantage when the life of the asset is known eg. special purpose machinery. The reducing balance method uses a fixed percentage to reduce the balance values. The advantages are that a new machine has low maintenance costs thus giving a high rate of replacement provision in the early years, and that the replacement provision will never be zero.

In the case of a versatile, automatic assembly machine both methods can be used, and as the machine for assembling the contact block is divided into two groups, both methods can be used. The basic machine has been designed to assemble a wide variety of products, making obsolescence the prime cause of depreciation, as most of the parts can be replaced cheaply and quickly. The life of the machine cannot be accurately estimated, due to its versatility, and, therefore, the reducing balance method is better for calculating replacement provision. Figure 21 shows replacement provision represented as a percentage of initial costs, plotted against time at a fixed rate of $12\frac{1}{2}\%$. This shows that after 15 years the value of the machine has dropped by 86.5%. Replacement provision for the tooling, most of which will be special, can be calculated using the straight line method, as the approximate length of economic production can be predicted by sales forecasts. Figure 22 shows replacement provision using the straight line method, cost being represented as a percentage of initial cost.

4.1.6 Effect of machine versatility for use with different products

A major asset of this machine system is the versatility in its ability to assemble different products within a set size range. Over a number of years parts will require replacement and these are assumed to be a part of the planned maintenance cost. The only cost incurred, in change of the build ability of the machine, will be tooling costs and the manual labour to re-arrange and change parts. For minor changes, the machine designed can assemble many varieties of one assembly type as demonstrated by the contact block.

This function of the system must be taken into account when justifying the capital expenditure. The basic system will last indefinitely, within the limitations of obsolescence, with a continuous maintenance and replacement cost only. For the sake of practicability a fixed pay-back period must be established to write the capital expenditure out of the books. The attitude of industry as reflected by Appendix 10.2 shows that an awakening to the need for new accounting systems to deal with this situation is already apparent.

In the case of rental schemes to supply machines on a modular basis these facts are particularly relevant. The company supplying such a machine would take back redundant modules and supply new ones when a product change was made. This would be beneficial for all parties since a small rental could be charged and only maintenance is required before supply of the module to another customer.

To demonstrate the possibilities, a numerical representation is made by the following:-

Assuming the costs of the machine and tooling to be typical and that a Special Purpose machine can be 20% cheaper by avoiding the use of standard modules in every workstation. This allows for the worst situation, since once development of standard modules is complete, financial advantage must result. A five year product life is used.

<u>5 year periods</u>	<u>Versatile Machine</u>	<u>Special Purpose Machine</u>
<u>Product 1</u>		
Basic	£14,286	£20,100
Tooling	£10,866	
<u>Product 2</u>		
Basic		£20,100
Tooling	£10,866	
<u>Product 3</u>		
Basic		£20,100
Tooling	£10,866	
	<u>£46,884</u>	<u>£60,300</u>
Total Cost		

These figures will, of course, alter with different conditions but the principle remains true. Other costs such as power, maintenance and floor space are similar for both types of machine.

4.2 Methods of marketing

4.2.1 Outright purchase

When purchasing a machine, a decision has to be taken on the method to be employed to raise the necessary capital if it is not readily available from retained profits. If an outright cash purchase is anticipated capital can be raised by issuing debenture stocks, where capital is borrowed at a fixed rate, or from a bank loan where capital is loaned at varying rates due to fluctuations.

An alternative to an outright sale, as discussed in section 4.1.4, is to use credit facilities, which allow for machinery to be purchased or leased when capital is not available from other sources.

Whichever method is employed, a decision has to be taken as to which gives best savings in capital expenditure, and this can be undertaken using discounted cash flow techniques where the interest on "cash flow in" determines the best course to take.

4.2.2 Credit Facilities

Credit facilities can be sub-divided into two groups, leasing and hire purchase. The basic difference lies with the owner at the end of the credit term. When a machine is leased or purchased on credit, an agreement is drawn up which sets out the conditions of hire once the hirer has shown credit-worthiness. This agreement is basically the same for both types of credit, and its main contents are given in Appendix 10.4. The agreement has an advantage to the hirer, as it provides an extra guarantee. The disadvantages are that it is a legal bond which must be adhered to and that a constant outlay is required to meet instalments.

Leasing

Leasing is an advantage where the normal production rate is low and sales forecasts indicate that a production rate for one particular item will increase over a period of years. The disadvantage of leasing is that the machine will always remain the property of the lessor. When leasing a versatile automatic assembly machine, only the basic machine would come under the agreement, as most of the tooling required is specialised and it cannot be put to further use after the termination of the agreement.

Hire Purchase

The advantage of hire purchase is that it provides a source of capital when it is not available from elsewhere. It has an advantage over leasing in that the machine will be the property of the hirer at the end of the credit term. There are two types of hire purchase agreements available; the flat rate system where a deposit is paid,

and the outstanding balance is paid in equal sums over the period of the agreement; and reducing balance method where premiums paid reduce over the term. The reducing balance method is an advantage when the agreement is over a long term.

5. CONCLUSIONS

The conclusions that can be usefully drawn from sections 1. to 4. are listed below:

1. Before undertaking a system of automatic assembly, parts quality and the factors which create problems during assembly should be analysed and defined. A value analysis of the assembly in question helps towards this objective.
2. In general, free transfer systems of parts motivation between workstations results in a higher output of assemblies in any given period.
3. Scrap assemblies are a major problem and a preferable alternative to re-work on rejects is to discard the part assembly. Generally, this will only be economic when labour savings of the machine are high and the cost of the materials are low.
4. Minimum buffer stock size for specific conditions are -
3 units for maximum benefit with smallest floor space possible.
7 units for maximum useful increase of benefit per increment of buffer stock.
10 units to allow access for a standby operator when necessary. This is a provision which must result in the highest possible overall machine reliability. (ref. sections 3.1.2 and 3.2.4).
13 units to provide the maximum efficiency for the given configuration. In this case, the machine will be non-productive for 23% of the time.
5. Optimum cycle time for the required output is:-
4 seconds when working 8 hours per day.
4 to 5.8 seconds when working 12 hours per day.
5.3 to 7.8 seconds when working 16 hours per day.
The actual limits dictated by the design will thus determine the number of working hours per day.
6. The reliability figure can be achieved when the machine system is tested using the methods shown.
7. Reliability of various designs can be raised by simplification of the equipment and reduction of the number of items which rely on some interdependence. This is most easily facilitated through means such as buffer stocks and in-process floats.

8. The optimum number of standby operators is 2. When the machine has been proved the machine attendants will possibly be able to perform this task. The final assessment of this factor can only be made when the machine is in use. For this assessment reference may be made to procedures indicated by sections 2.6 and 3.2.4.
9. A system of Planned Maintenance is considered to be essential. The initial program of work is provided.
10. The additional cost of operating the maintenance system after it has been optimised will be about £3,500 per year. This figure is likely to be slightly reduced for the ideal mechanised manual assembly.
11. The problems involved in labour relations to employ manual assembly operators, machine attendants and maintenance staff for the work to be encountered would require a labour agreement in the initial stages.
12. The automatic machine system is shown to be much better than the existing system of assembly on a cost basis by giving £41,900 extra profit per year. When considering the idealised mechanised manual method of assembly it was found that this profit would be £6,150 p.a. less, but this is offset by a cost of £11,500 p.a. in machine maintenance and efficiency loss in the automatic system. The nett effect is that the mechanised manual assembly provides greater profit. These figures emphasize the unsuitability of the contact block in a project based on cost savings alone.
13. The contact block has a very high materials to labour ratio which makes it best suited to mechanised manual assembly. By use of mechanised manual assembly the high cost of 23% loss of efficiency and the cost of maintenance is reduced.
14. The automatic assembly system designed is worthwhile in cases where low materials to labour cost ratio is evident, or the scheme is part of a large automatic system. The large cost savings to be gained from automation of a suitable assembly process are demonstrated by Appendix 10.6. It must also be added that manual labour is increasing in cost consistently and labour relations incur problems that cannot be easily costed.
15. The cost of the machine at £29,000 is well within the figure of £35,000 that industry in general expect to pay (ref. Appendix 10.2).

16. The Capital Expenditure is acceptable for improvement to the existing system, when checked by D.C.F. methods.
17. Purchase of the machine by paying the instalments of a credit scheme is shown to be better than outright purchase, if such facilities are available.
18. Depreciation of the machine is best systematized to reducing balance for basic parts and straight line reduction for tooling. This allows for re-use of the basic parts of a versatile system, when a product is discontinued or changed.
19. A developed modular system would be a viable proposition for a machine tools manufacturer.

6. SUGGESTIONS FOR EXTENSIVES TO THE WORK

The following subjects could be researched further.

1. A complete survey of the factors limiting cycle times in practice.
2. General systems for establishing numbers of machine attendants required.
3. Investigations into the features or qualities of parts and tooling which cause stoppages.
4. Further studies on reliability and associated problems.
5. When a completely modular machine system is available, a 'modular' purchase justification plan could be formulated.
6. Comprehensive integrated analysis of buffer stock requirements would be useful.
7. Establishment of systems for appraisal of capital expenditure on versatile machines.
8. Suitability classifications of assemblies for automation.

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9. FIGURES

- 1 Buffer Stock Effects
- 2 Inter-Relationship between reliability and Engineering Design
- 3 System Reliability for Observed Failure Combinations
- 4 Maintainability of System
- 5 Effect of Defect Parts on Cycle Time
- 6 Relationship between Module Reliability and Cycle Time for an 8 hour day
- 7 Relationship between Module Reliability and Cycle time for a 12 hour day
- 8 Relationship between Module Reliability and Cycle Time for a 16 hour day
- 9 General Form of a Density Function
- 10 The Exponential Reliability Function
- 11 The Exponential Hazard Rate
- 12 Assumed Failure Pattern
- 13 Diagram of Mathematical Model of Assembly Machine
- 14 Comparison of Overall Reliabilities with and without Standby Provision
- 15 Effects of System Complexity on System Reliability
- 16 Annual Maintenance Program
- 17 Graph of Planned Maintenance Effectiveness v Time
- 18 Design Maintenance and Life of Components
- 19 Unit History Record Card
- 20 Breakeven Chart
- 21 Depreciation-Reducing Balance
- 22 Depreciation-Straight Line

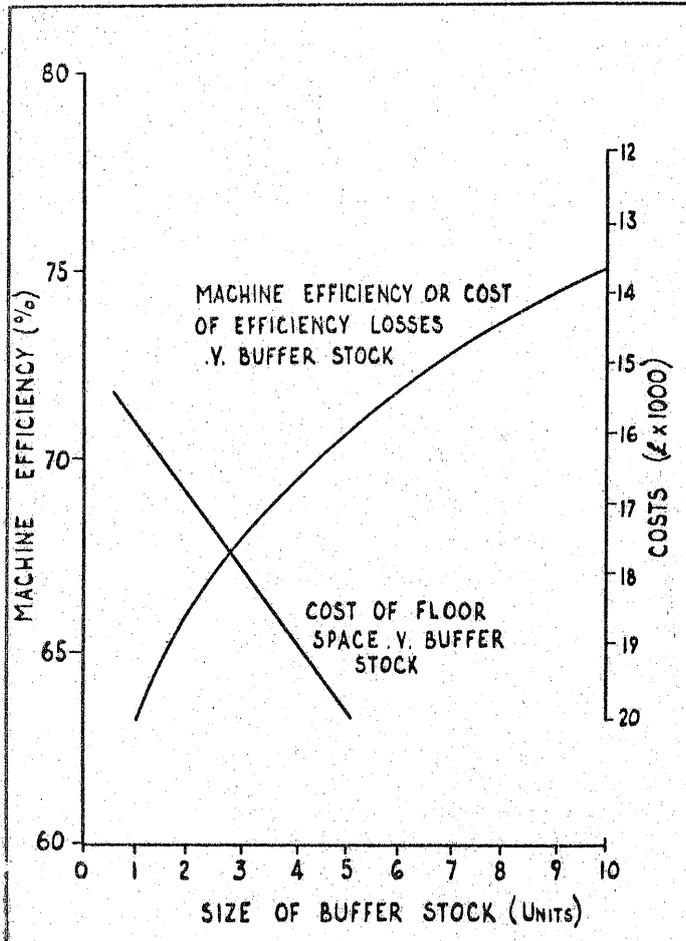


Fig. 1

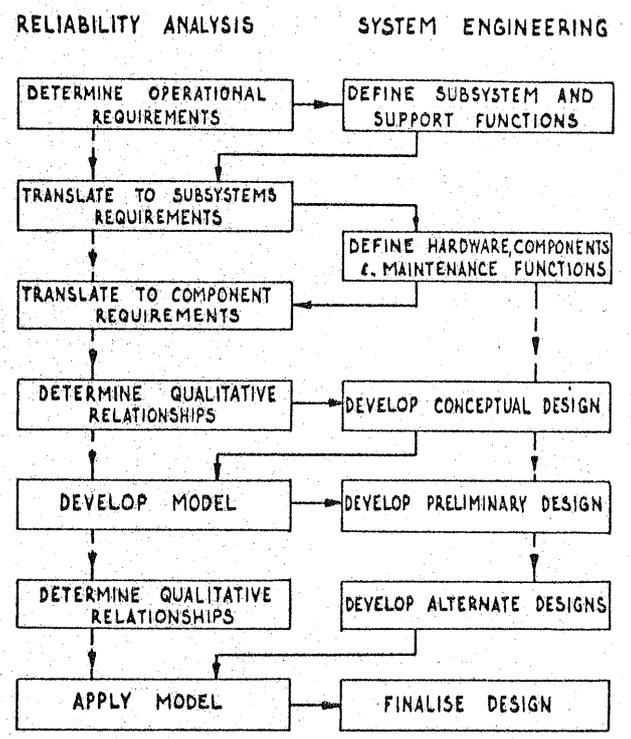


Fig. 2

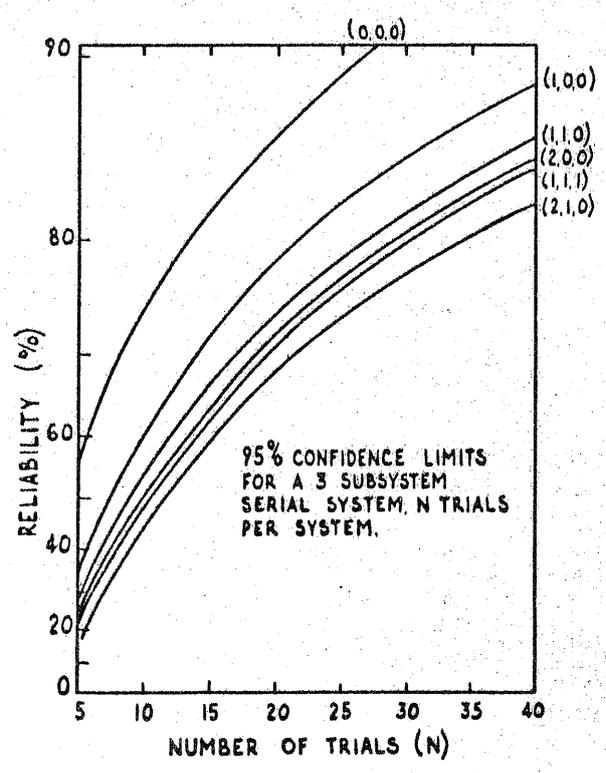


Fig. 3

Fig. 1 BUFFER STOCK EFFECTS.

Fig. 2 INTER-RELATIONSHIPS BETWEEN RELIABILITY & ENGINEERING DESIGN.

Fig. 3 SYSTEM RELIABILITY FOR OBSERVED FAILURE COMBINATIONS.

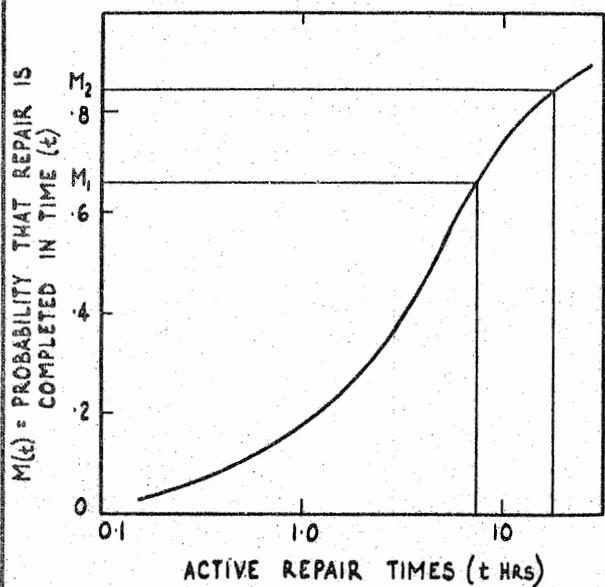


Fig. 4

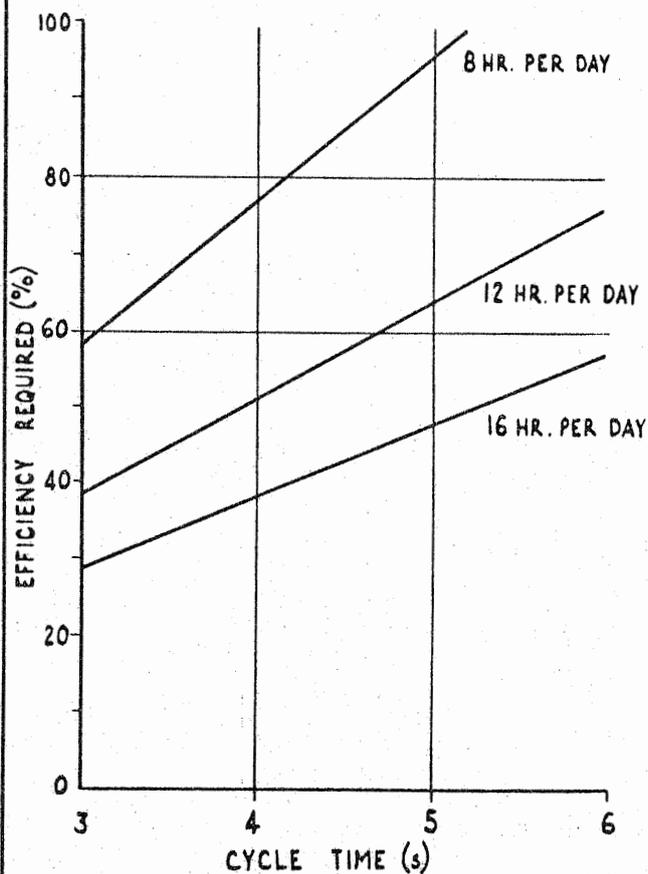


Fig. 5

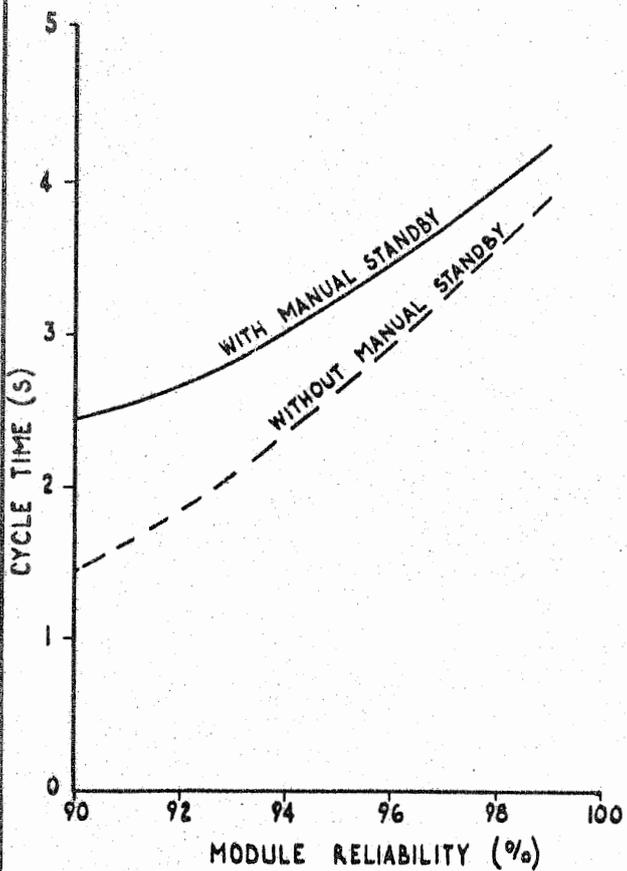


Fig. 6

Fig. 4 MAINTAINABILITY OF SYSTEM

Fig. 5 EFFECT OF DEFECT PARTS ON CYCLE TIME

Fig. 6 RELATIONSHIP BETWEEN MODULE RELIABILITY & CYCLE TIME FOR AN 8 HOUR DAY.

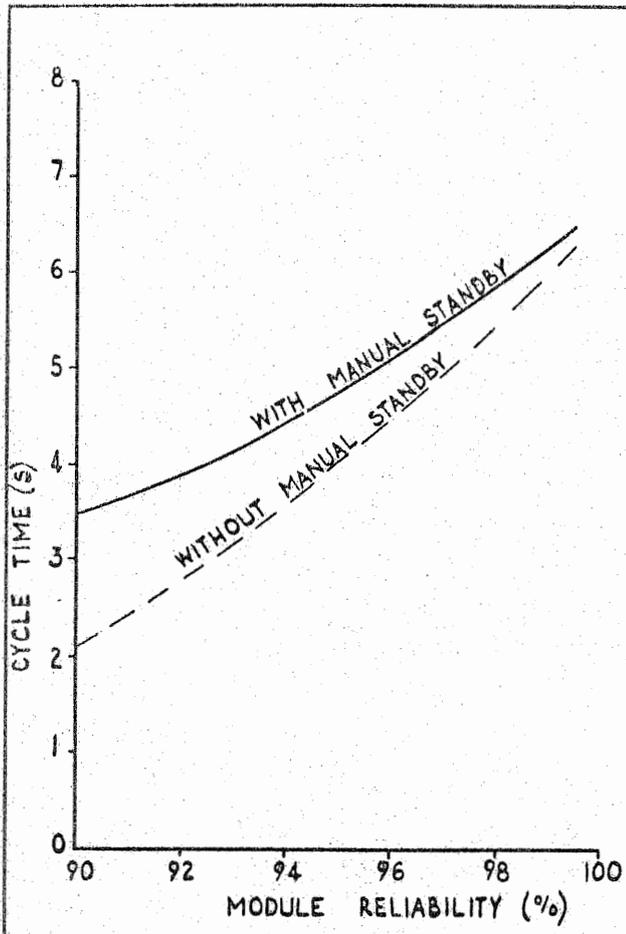


Fig. 7

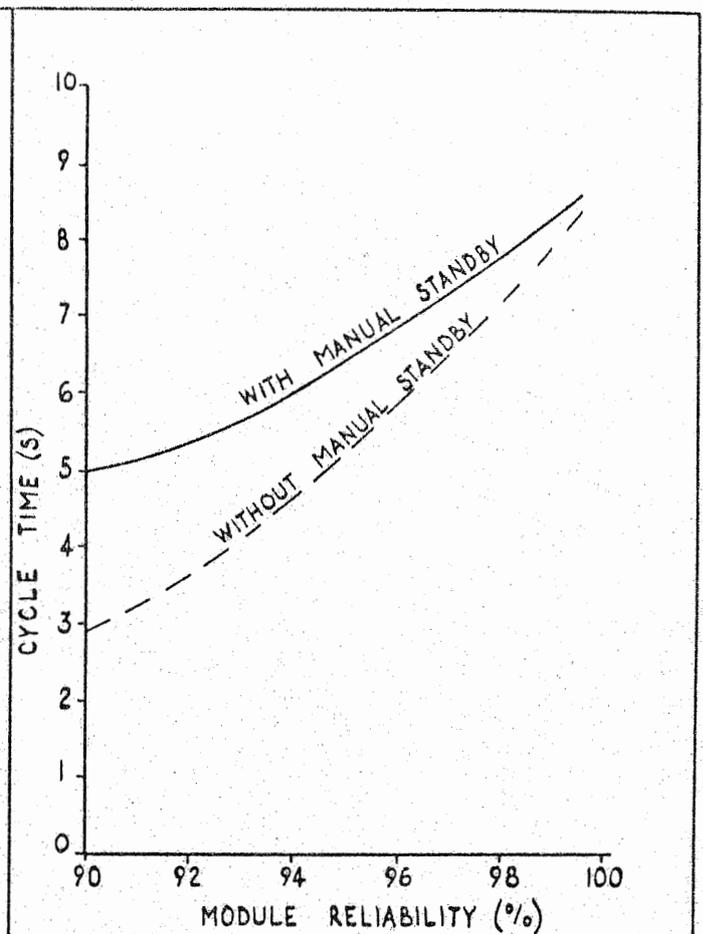


Fig. 8

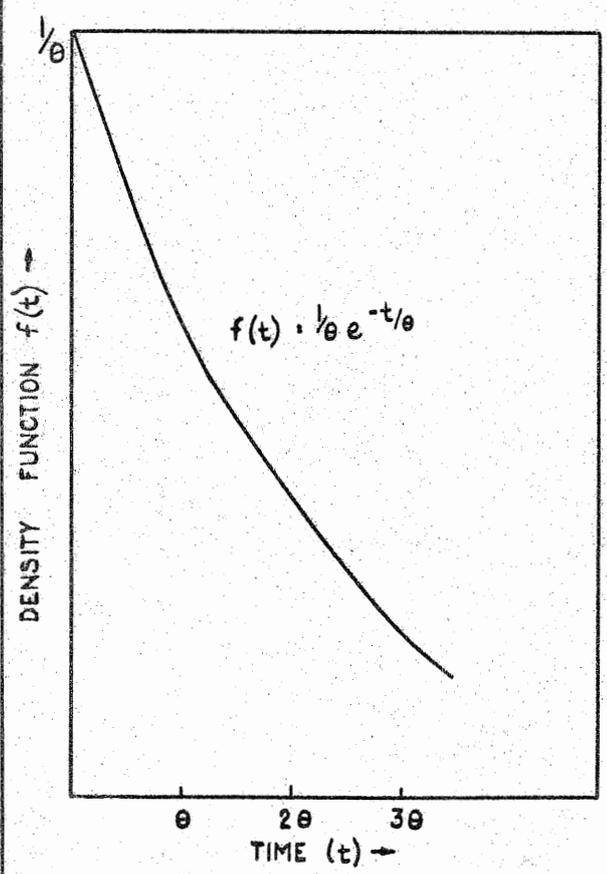


Fig. 9

Fig. 7 RELATIONSHIP BETWEEN MODULE RELIABILITY & CYCLE TIME FOR A 12 HOUR DAY.

Fig. 8 RELATIONSHIP BETWEEN MODULE RELIABILITY & CYCLE TIME FOR A 16 HOUR DAY.

Fig. 9 GENERAL FORM OF A DENSITY FUNCTION

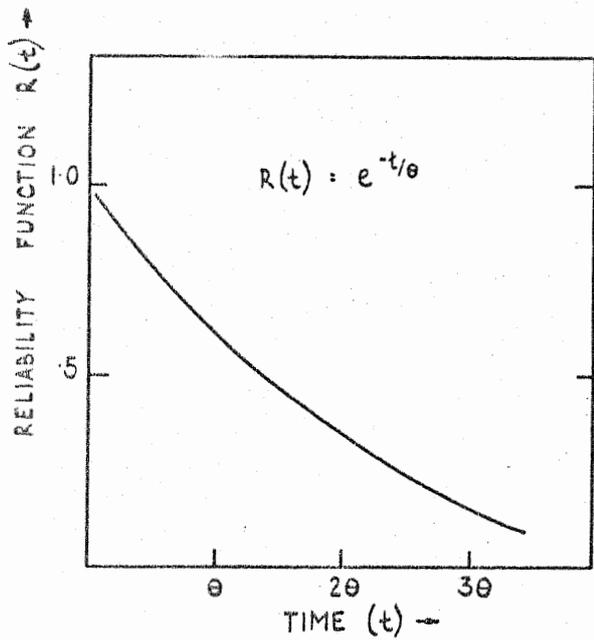


Fig. 10

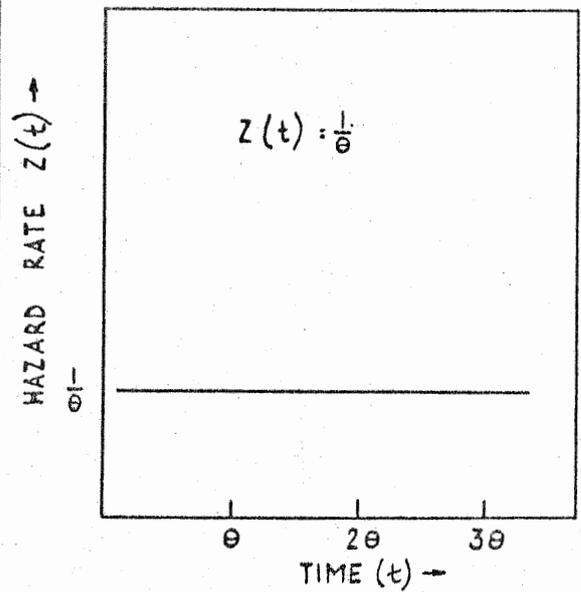


Fig. 11

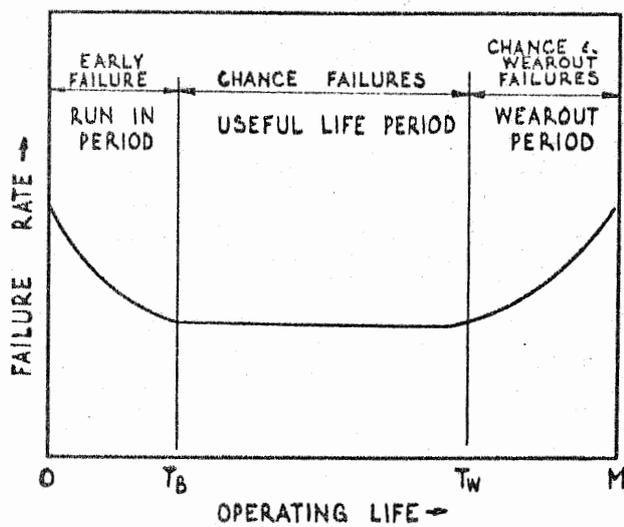


Fig. 12

Fig. 10 THE EXPONENTIAL RELIABILITY FUNCTION.

Fig. 11 THE EXPONENTIAL HAZARD RATE.

Fig. 12 ASSUMED FAILURE PATTERN

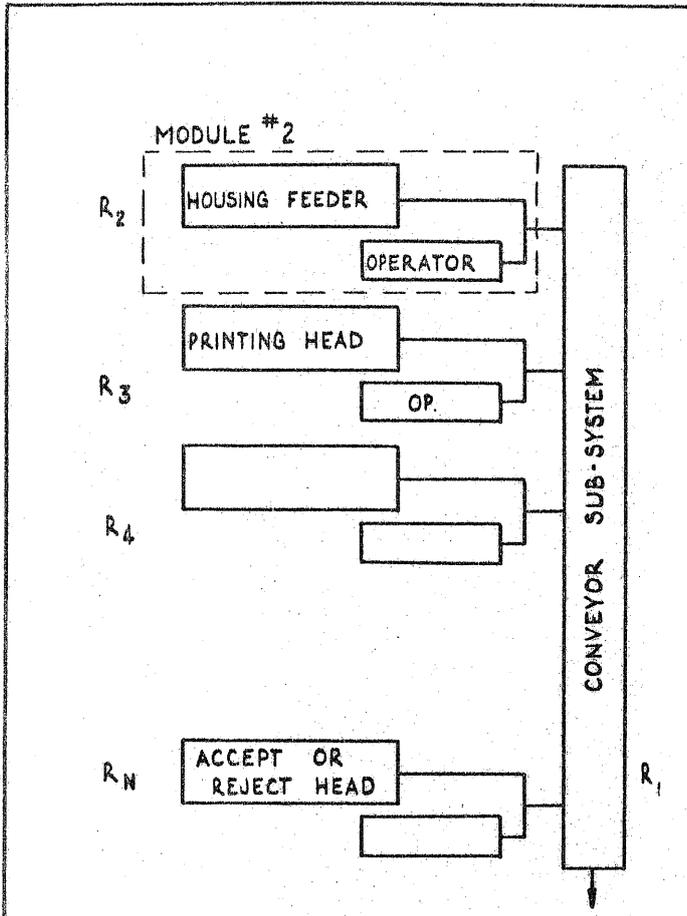


Fig. 13

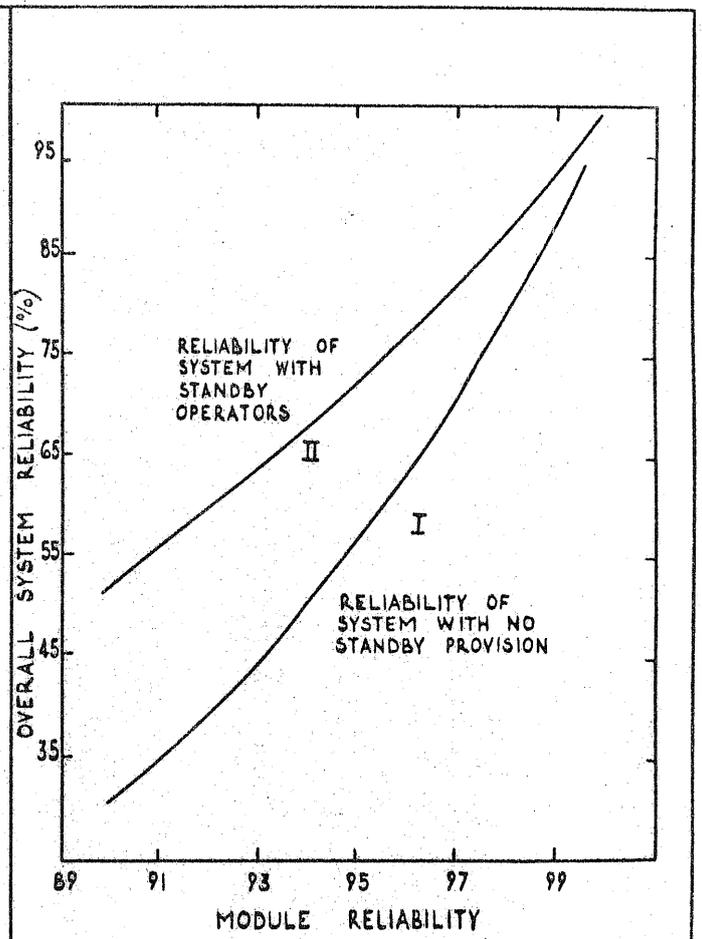


Fig. 14

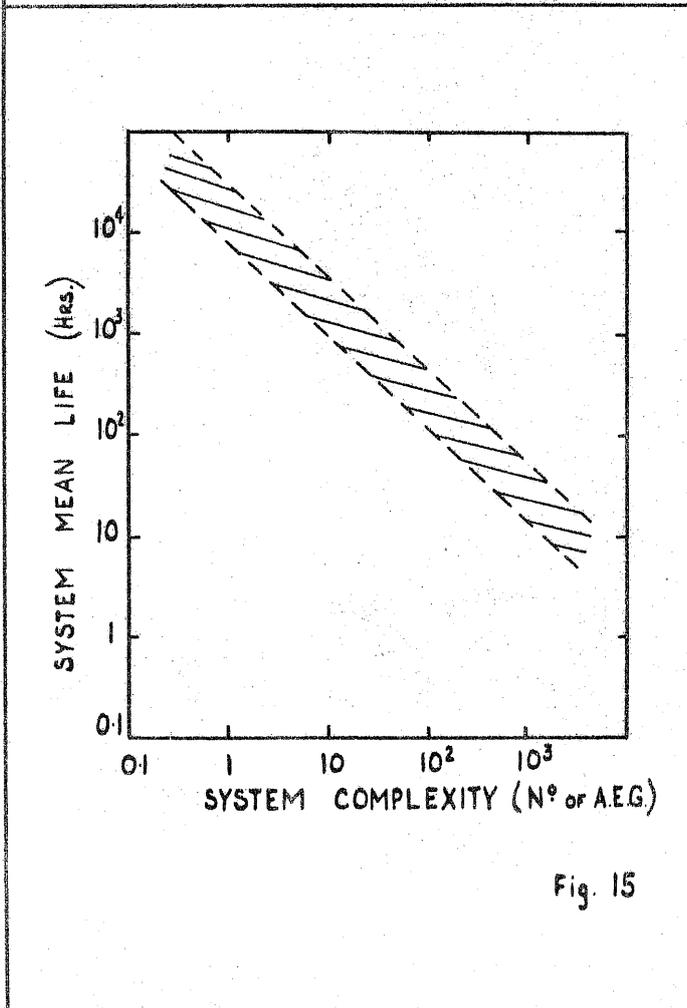
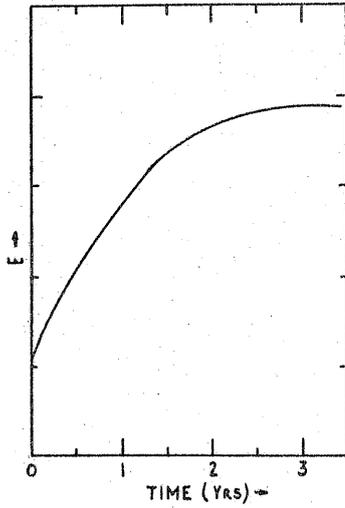


Fig. 15

- Fig. 13 DIAGRAM OF MATHEMATICAL MODEL OF ASSEMBLY MACHINE
- Fig. 14 COMPARISON OF OVERALL RELIABILITIES WITH AND WITHOUT STANDBY PROVISION
- Fig. 15 EFFECTS OF SYSTEM COMPLEXITY ON SYSTEM RELIABILITY.



GRAPH OF PLANNED MAINTENANCE EFFECTIVENESS .V.TIME

Fig. 17

UNIT HISTORY RECORD CARD*				
UNIT NAME:				
DATE	PART	DEFECT	CAUSE	ACTION

UNIT HISTORY RECORD CARD

Fig. 19

PART N°	PART NAME	MAINTENANCE	DAILY	WEEKLY	MONTHLY	ANNUALLY	EST. MAN. HOURS	EST. LIFE (Yrs)
	TRANSFER SYSTEM							
1	PLATEN	REPLACE WHEN WORN						2
2	FIXTURE	REPLACE WHEN WORN						2
3	LIFTING MECH FOR PLATEN	REPLACE JACKS						2
4	CONVEYOR LINKS	CHECK TENSION		o			5	
5	BONDED MAT- TO SLATS	REPLACE				Δ	8	
6	WORKHEADS	OILING CLEANING SLIDEWAYS			o		1.5	
7	CONVEYOR DRIVE MOTOR	REPLACE					8	3
8	BELTS ON REDUCTION BOX POWER SUPPLIES	REPLACE			o		1	0.5
9	FILTERS CONTROL	REPLACE			Δ		0.5	
10	CONTROL PANEL	CHECK & REPLACE LIGHTS			Δ		0.5	
11	HEAD CONTROLS	CHECK FLUIDIC SENSORS			Δ		3	
12	PRINTED CIRCUIT BOARDS	REPLACE					0.5	2
13	SOLENOID VALVES & SWITCHES WORKHEAD FOR FIXED CONTACTS	REPLACE				□	2	1
14	VIBRATORY BOWLS	CHECK & CLEAN		o			0.2	3
		REPLACE				□	20	3
15	ESCAPEMENT MECH.	CHECK & CLEAN			Δ		0.5	
16	PNEUMATIC CYLINDERS WORKHEAD FOR HOUSING	RENEW SEALS & PARTS				□	0.5	2
17	VIBRATORY BOWLS	CHECK & CLEAN			Δ		2	3
		REPLACE				□	20	3
18	ESCAPEMENT MECH.	CHECK & CLEAN		Δ			0.5	
19	PNEUMATIC CYLINDERS MANUFACTURING HEAD FOR INSULATION PLATES	RENEW SEALS & PARTS				□	0.5	2
20	MECHANISMS	CHECK		o			0.5	
21	PNEUMATIC CYLINDERS FIXING SCREW W/HEAD	RENEW SEALS & PARTS				□	0.5	2
22	REJECTING MECH.	CHECK		o			0.5	
23	PNEUMATIC CYLINDERS PICK & PLACE UNIT	RENEW SEALS				□	0.5	2
24	LINEAR BALL RACES	REPLACE ON FAILURE				□	4	5
25	PNEUMATIC CYLINDERS	RENEW ON FAILURE				□	1	5
26	BELT & DRIVE ASSEMBLES	REPLACE					1	2
27	ELEVATOR BRUSHES	REPLACE					3	0.25
28	ESCAPEMENTS	REPLACE					4	2

SYMBOLS FOR TYPE OF MAINTENANCE
 o RUNNING MAINTENANCE
 Δ SHUTDOWN MAINTENANCE
 □ BREAKDOWN MAINTENANCE

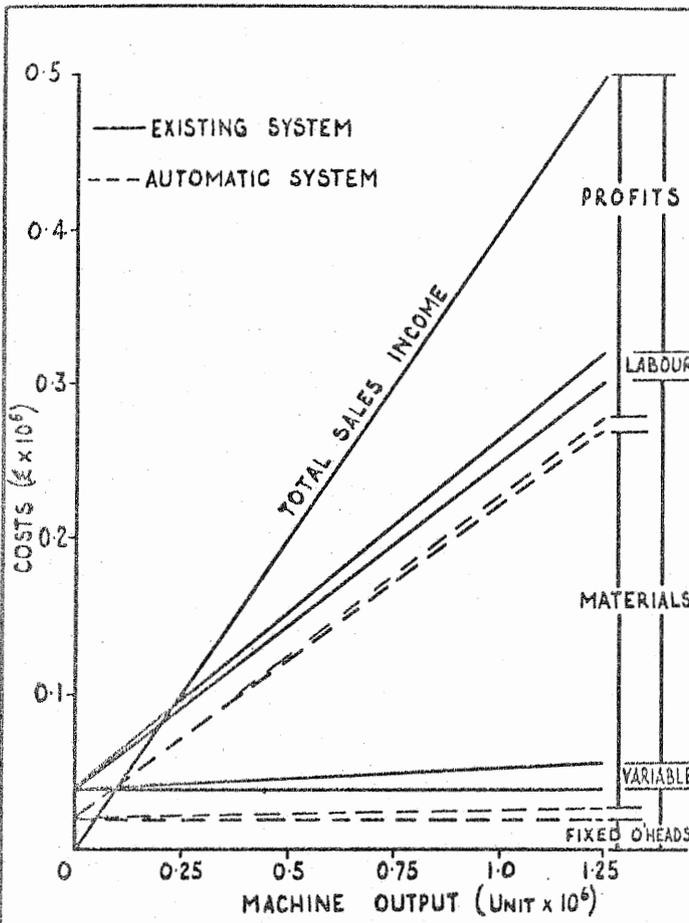


Fig. 20

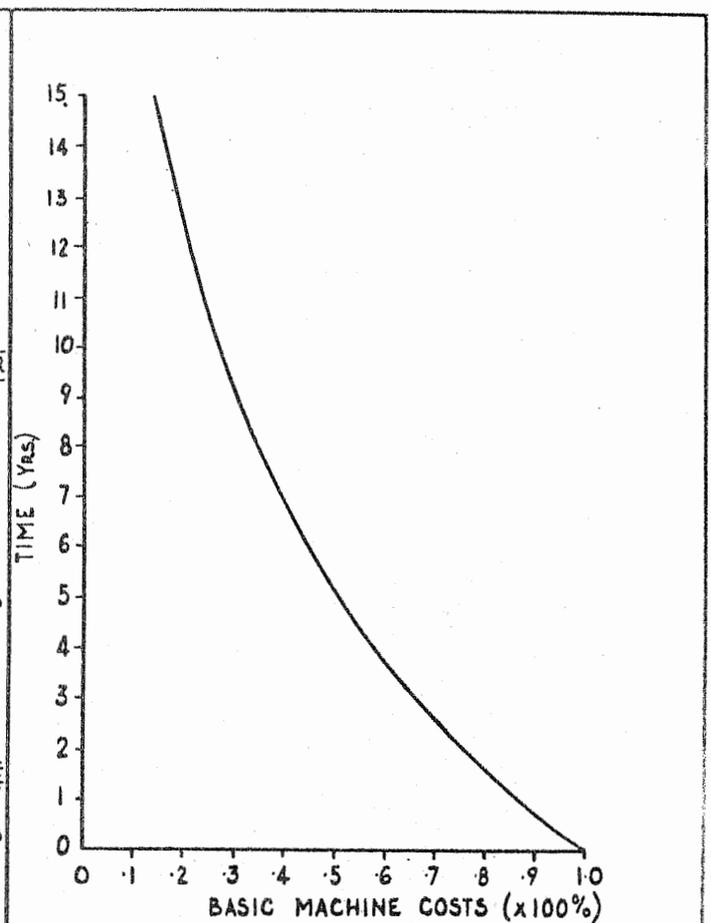


Fig. 21

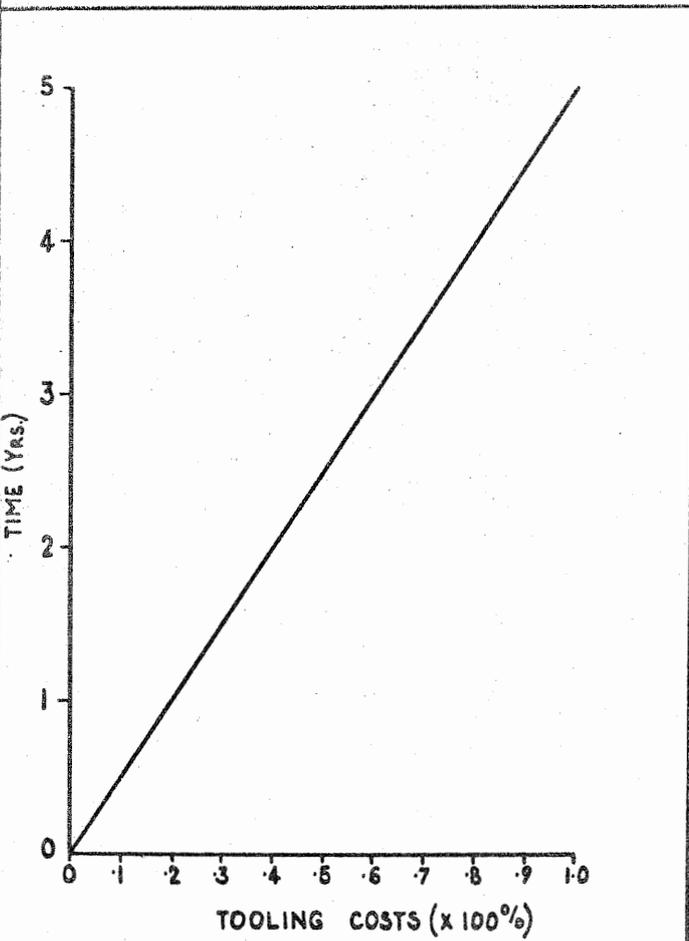
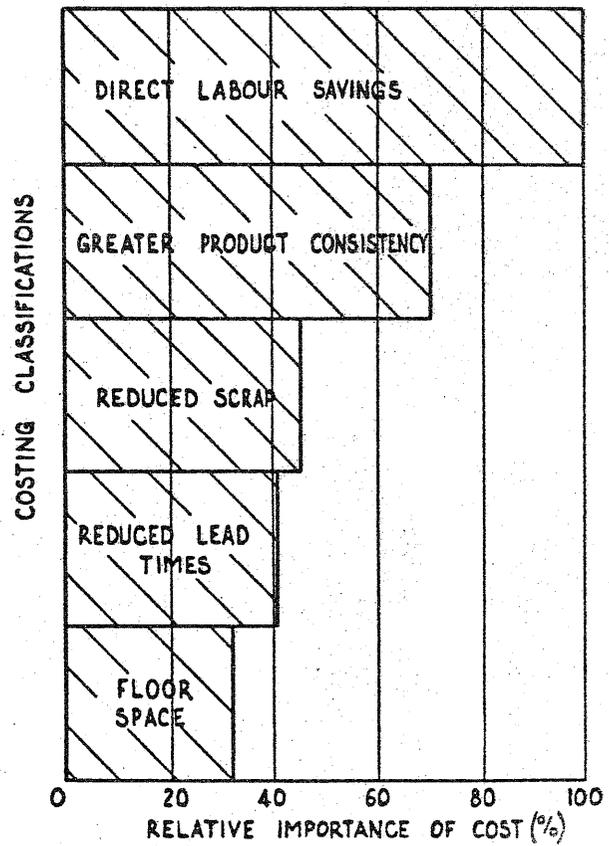
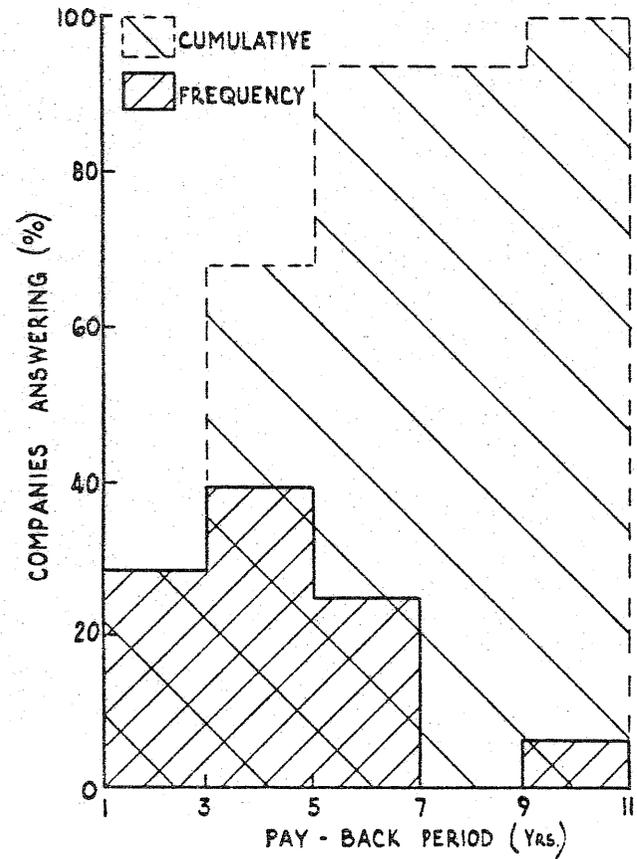


Fig. 22

- Fig. 20 BREAKEVEN CHART
- Fig. 21 DEPRECIATION - REDUCING BALANCE
- Fig. 22 DEPRECIATION - STRAIGHT LINE



RELATIVE COST SAVINGS IN INDUSTRY Fig. 23



PAY-BACK PERIODS ALLOWED Fig. 24

10. APPENDICES

<u>ITEM</u>	<u>CONTENTS</u>	<u>PAGE</u>
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10.2	Mail Survey of economic factors	46
10.3	Breakdown of machine costs	50
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10.6	Justification for the sub-assembly machine	54

APPENDIX 10.1

Costs of Scrap Assemblies

Two possibilities are apparent:-

- 1) To scrap all reject assemblies at any stage of the process.
- 2) To provide a repair station (or stations, according to reject rate) which would comprise an operator at a specially designed workstation. The workstation would be set out with the most effective workplace layout and purpose-built equipment for four simultaneous slotted pan head screw removals, two simultaneous rivet removals and two simultaneous fixing screw removals. Appropriate containers would be used for return of serviceable parts.

The costs involved are the cost of the parts in the assembly in the first case and the cost of an operator, stock handler, and the necessary equipment, including any inspection equipment required for stripped parts. Other costs have been ruled out as negligible.

Cost of item for 1

Only complete assembly costs are available so this will be used and different stages of process considered as dropping proportionally to zero. The cost varies between types of switch, but for this study the majority unit cost of 4/- (20P) will be used. Considering unit quantity of 5,000 -

$$\frac{4}{20} \times 5,000 = \underline{\underline{\pounds 1,000}}$$

Cost of item for 2

The cost of labour per assembly to reduce to parts is as follows -

From timed simulation of breaking down the assembly the strip-down time is 40 seconds.

$$\text{This is } \frac{40}{3,600} \times 5,000 = 55.5 \text{ hours}$$

With due allowances for operator efficiency this is equivalent to 8 days work.

Cost at 10/- (50 P) per hour plus 100% overheads

$$\frac{20}{20} \times 55.5 \text{ hours} = \underline{\underline{\pounds 55.5}}$$

Including Factory overheads at £40 per square foot per year and allowing 40 square feet for one operator

$$\frac{8}{240} \times 40 \times 40 = £53.3$$

Estimate Stock handlers work in moving full containers and replacing with empty ones as half an hour of work.

$$\text{Cost} = \frac{(8 + 12)}{20} \times 0.5 = £0.5$$

An inspection on the machine may be in operation. This will not be costed here but equipment required is estimated broadly as -

- a) One multi-spindle screwdriver
- b) One multi-spindle drill
- c) One hand press
- d) One special bench for the stripping operation.

An estimate is used as this will be a small proportion of the cost.

The cost of the above equipment would be £500 capital payment with a two year pay-back. If we use 240 working days per year for a batch of 5,000 switches -

$$\frac{8}{240 \times 2} \times 500 = £8.3$$

Therefore the total cost is £117.6

Recommendation

It is recommended that a strip-down station or stations be used with the machine. To invalidate this conclusion, the calculations would need to be in error to an unrealistic extent. Partial strip-down should vary with the same proportional characteristic to be compatible with item one. The difference in cost of items 1 and 2 is sufficiently great to absorb even high costs of auxiliary inspection equipment and the operation thereof, for the repair function.

APPENDIX 10.2

Mail Survey of Economic Factors

Contents

10.2.1	The Survey, its scope and significance
10.2.2	Justification for assembly machine
10.2.3	Costs of machines
10.2.4	Performance of assembly machines
10.2.5	Questionnaire
10.2.6	Discussion and conclusions
10.2.7	Acknowledgements.

10.2.1 The survey, its scope and significance

During the course of investigations in the Economic Planning Committee certain areas of information required from industry were apparent. The opportunity to include data in this report arose during the closing stages of this project. Advantage was taken of the availability of names and addresses from eighty named persons who had completed the Technical Survey. The information required was concerned with individual company policy so the questionnaire was tailored to preserve the anonymity of the participants. The questionnaire is shown in part 10.2.5 of the appendix.

The questions were worded in general terms to enable ease of answering by an informed party. Specific conclusions were drawn from the results since a broad spectrum of industrial attitudes were determined. This cautious policy was well received as can be seen by the 76% response within several weeks.

10.2.2 Justification for Assembly Machine

As shown by fig. 23 the major considerations when investing capital on automatic assembly plant are ;

- 1) Direct labour savings which show that industry consider that this is a major proportion of their product cost. This indicates that the products selected for automatic assembly should contain a high ratio of labour to materials cost. This would be expected although other factors can show benefits as discussed later.
- 2) Greater Product Consistency was the second consideration as it had the desirable effect of reducing non-productive personnel. The additional commercial advantage of promoting supplier, customer good-will and reducing service repairs and replacements is a further aid to profitability although difficult to assess.

The importance that industry attaches to this item is, perhaps, surprising. It is also encouraging since it is obvious that industry requires the consistency that automatic assembly should produce.

- 3) Reduced Scrap Assemblies were considered an important cost saving by 46% of industry. This indicated that scrap produced by manual assembly was not a major concern. The theory that "manual assembly" operates practically as "selective assembly" is borne out by the response to this question.
- 4) Reduced Lead Times gave a similar result to the previous one at 41%. It is reasonable that some industries do not require short lead times to effect cost savings. The fact that this proportion do require short lead times shows that the market is right for the introduction of versatile machines, which could be readily changed to produce a different assembly.
- 5) Reduced Floor Space was of the least interest, which indicates that this consideration is not expected to give a high cost saving yield. A possible reason for this is that the stock of parts on the production floor is a large part of the space requirement and is the same for manual and automatic assembly. Another reason is that, in many cases, floor space is not at a premium and is not used to capacity.

From question 4 the capital investment pay back period proved to be an average of 3.75 years, drawn from a range of one to ten years. Figure 24 shows frequency and cumulative distribution histograms which indicate that the average is representative of the range. The ten year pay back period does not appear to be consistent with the majority of industry.

Question 5 allowed further conclusions on pay back periods to be drawn. It was noted that 63% of industry were prepared to consider longer pay back periods for large capital expenditure on versatile re-toolable machines. The increasing awareness of industry to accept this type of machine is apparent.

10.2.3 Costs of Machines

An average of the replies to question 3 showed that industry would expect an automatic assembly machine to cost £1,460 per component in the assembly. Only 31% of the replies claimed sufficient experience to answer this question, which shows the current state of knowledge generally available. The number of replies received are considered to be sufficiently authoritative to warrant their use. The complexity of the assembly is the major reason for any variation between the replies. This emphasises the need for value analysis on component parts to be orientated towards automatic assembly.

10.2.4 Performance of Assembly Machines

The answers to question 2 covered many problems but, throughout, a consistency in type is noticeable. The type of problem which was mentioned with the greatest frequency was that of handling, feeding and placing the components due to the geometry and quality of the parts. This is due to the fact that industry is familiar with the problems of feeding devices and accurate placement of an infinite variety of shapes.

Another major consideration was the ability to meet a scheduled output volume reliably. This, rather than being an effect on assembly machine cycle time, is the effect cycle time should have on the machine design. Clearly, a versatile machine must possess versatility in cycle time. For complete control of cycle time and overall production output other factors such as standby provision, multiple assembly stations and in-process float of assemblies would appear to be an advantage.

10.2.5 Questionnaire

The following questions were posed by the questionnaire:-

- 1) If an automatic assembly machine is to be introduced into your company tick the 3 most important considerations taken into account when assessing expected cost savings.
 - a) Direct Labour Savings
 - b) Reduced Scrap Assemblies
 - c) Greater Product Consistency
 - d) Reduced Lead Times
 - e) Reduction in Floor Space.
- 2) What factors would you consider would influence an assembly machine cycle time.
- 3) What has been found to be the cost per component of existing automatic assembly machines (ie. Machine which cost £2,000 and assembles 4 components = £500 per component).
- 4) If an automatic assembly machine was purchased, over what period would your company expect capital expenditure to be repaid.
- 5) If a versatile re-toolable machine was purchased would your company allow a longer capital write off period.

10.2.6 Discussion and conclusions

The validity of the replies has been established by their consistency. The limited circulation to those using or interested in automatic

assembly ensured that all questions were answered sensibly or reasons given for inability to answer certain parts.

The attitude of industry as reflected by the level of management that answered the questionnaire showed increasing awareness of the need for versatile assembly techniques. Also, it was encouraging to note that company policy was sufficiently flexible to increase the period for return of capital.

As indicated from item 3, the cost of machine to assemble 24 components required for the contact block would be expected to cost in the region of £35,000. This is retail price including design, materials, labour, development, overheads and profit margin.

10.2.7 Acknowledgements

The Economic Planning Committee wish to thank the companies who participated in the survey. Also, the helpful suggestions of Mr. R. I. Paterson, Managing Director of Aylesbury Automation, in the formation of the questionnaire were much appreciated.

Further acknowledgements are given to Mr. K. Stout, who owing to his interests from other work in the project, joined with the Economic Planning Committee for the purpose of the survey.

APPENDIX 10.3

Breakdown of Machine Costs

Basic Machine

<u>Parts</u>	<u>Cost</u>			<u>Quantity</u>
	£	s	d	
Module	60	0	0	per 6 ft.
Drive Pulleys	23	3	2	4 off
Spiral Elevators	105	0	0	3 off
Benches and Chairs	36	0	0	3 off
Platen	3	6	8	per platen
Platen Control	57	0	0	per platen
Pick and Place Head	180	0	0	per head
Pick and Place Control	85	0	0	per head
Conveyor	3	2	6	per ft.
Conveyor Drive	40	0	0	1 off
Power Supplies and Controls	31	10	0	
Control Cabinet	68	0	0	
Equipment for Air Supply	65	0	0	
Buffer and Station Stop Mechanism	27	0	0	per workhead
Fast Input Mechanism (if required)	40	0	0	per workhead
Platen Jack and Input Mechanism	33	9	0	per workhead

Overall Cost of Basic Machine Required to Build Contact Blocks

Number of Stations	=	10	
Cost per workhead	=	£277 - 4 - 6	
Pick and Place Head	=	£265 each - 6 off	
Overall Cost	=	£4,362 5s. 0d + £400 for fast input	
	=	<u>£4,762 5s. 0d.</u>	

Sub-Assembly Spur

Badalex Indexing Machine with three parts positioners £3,850 0s. 0d.

Overall Cost of Tooling Required for Assembly of Contact Block

	£	s.	d
1	167	14	9
2	170	0	0
3	141	0	0
4	606	10	0
5	109	17	0
6	326	0	0
7	519	5	0
8	562	10	0
9	562	10	0
10	32	5	0
11	325	0	0
<hr/>			
<u>Total Costs</u>	=	3,522	11 9
<hr/> <hr/>			

APPENDIX 10.4

Contents of a Credit Agreement

The following list gives the main clauses of a credit agreement. Other clauses may be added, but these depend upon the article for which credit is given and whether it is a leasing or hire purchase agreement.

- 1) Name of Hirer
- 2) The commencing and termination dates of the agreement.
- 3) The installments - the amount, deposits (if any), period between payments and whether payments are made in advance or arrears.
- 4) The right of inspection by the owner.
- 5) The type of insurance required by the owners.
- 6) The address at which the machine is to be used, and regulations covering movements and sub-letting of the machine.
- 7) Clauses covering defaults made by the hirer. This enables the owner to reclaim property when the hirer fails to keep up with payments or commits a breach of the agreement.
- 8) Conditions of the surrender of the agreement.
- 9) Delivery and Installation charges (if any).
- 10) This clause names the party responsible for carrying out necessary maintenance.
- 11) Payments to be made by the owner and the hirer. ie. stamp duty and training of hirer's employees.
- 12) Name of the owner.

APPENDIX 10.5

Discounted Cash Flow Techniques

When purchasing a machine, a decision on the method of investing capital has to be taken. This can be undertaken by using discounted cash flow techniques. The bibliography includes reference literature.

The time element in this method is important because the interest gained on savings in capital expenditure can exhibit financial rewards when compared with present day values. There are two methods used; the present value method where the cash flow in is discounted at a predetermined rate of interest to coincide with present day values and, also, discounted cash flow where the interest rate on cash flow in is calculated to make the present value of cash flow in equal to the net investment. Whichever method is used, the cash flow in is calculated, taking into account the annual allowance, corporation tax and investment grants. The use of the discount factor enables payments or receipts made in future years to be converted into their present values. Although discounted cash flow techniques provide a numerical analysis on which a decision can be taken, other factors such as company policy, economic climate and risk must be considered. When these techniques have been used adjustments should be made to the original figures when the actual flow of cash is known.

Investment Grant

New machinery, used in a productive process of manufacturing industries, is entitled to an investment grant payable by the Board of Trade. This grant, which is not taxable, is paid at the standard rate of 20% in non-development areas and 40% in development areas.

Capital Allowances

Cash flow in is basically made up of net profit and depreciation and before corporation tax is deducted at the standard rate of 42.5% an allowance is given by the Inland Revenue on the depreciation. This is known as capital allowance and is a function of initial cost, estimated life and scrap value. The minimum rate of capital allowance, which is paid annually, is 15%; the actual rate being finally determined by negotiation with the Inland Revenue. The allowance for the first year is a percentage of the total cost less any cash grants and, for the following years is a writing-down allowance. When the asset, which has received a capital allowance, is disposed of a balancing allowance or charge arises depending upon whether the capital received for the asset is respectively less or greater than the paper value.

APPENDIX 10.6

Justification for the Sub-Assembly Machine

The N/O plunger assembly was considered as a feasible proposition for automatic assembly devices. Since this is a sub-assembly and not part of the main configuration, the Assembly Analysis Committee proposed that either manual assembly or automatic assembly, by a machine of proprietary manufacture, would be utilized.

To make the decision on a cost basis, on the same terms as other costing work, the Economic Planning Committee put forward the following cost analysis.

Justifications for figures used are made in section 4.1.2 and Appendix 10.2.

The values of the basic variables are given as:

- 1) An 8 hour working period per day.
- 2) 240 working days per year.
- 3) Machine Attendant with overheads at £1 per hour.
- 4) Cost of Manual Assembly Operators is £0.8 per hour.
- 5) Floor Space cost of £40 per square foot per annum.
- 6) Pay back period of 4 years (ref. Appendix 10.2)

The total costs were taken from calculations of the following items:

- 1) Depreciation of machine = $\frac{\text{Cost of machine}}{\text{Pay-back period}}$
- 2) Cost of floor space = floor space used x £40.
- 3) Cost of machine attendants (where required) = number of working hours per year x number of operators x cost per operator.
- 4) Cost of manual assembly operators (where required) = number of operators x cost per operator x number of working hours per year.

	<u>Badalex Automatic Machines</u>		<u>Manual</u>
	<u>In Line</u>	<u>Rotary</u>	<u>Assembly</u>
Cost of Equipment	£4,100	£3,700	£200
Floor Space used	30 sq.ft.	20 sq.ft.	45 sq.ft.
Proportion of Machine Attendants or Line Loaders Required.	0.75	0.75	0.25
Number of Manual Assembly Operators	-	-	3
	£p.a.	£p.a.	£p.a.
Cost of Depreciation	1,025	925	50
Cost of Floor Space	1,200	800	1,800
Cost of Attendants	1,440	1,440	384
Cost of Manual Assembly Operators	-	-	6,410
	-----	-----	-----
Totals:	<u>3,665</u>	<u>3,165</u>	<u>8,644</u>

Clearly, the Rotary Automatic Assembly machine is the most economical financially.