An Investigation into some problems of Finished Vehicle Body Shell Production at Pressed Steel Fisher Ltd.

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SUMMARY

This thesis deals with some of the major problems involved in painting and trimming motor vehicles at a particular production unit of British Leyland.

These problems were identified as :-

(a) the procurement of sufficient quantities of component parts to fulfil a demand.

(b) the allocation of the available stock to meet some objective when the supply of parts is interrupted.

(c) the sequencing and control of the painting and assembly functions.

On the question of material procurement it was found that there was a remarkable lack of communication, on a sufficiently detailed level, between the sales organisation and the satellite production units. Vehicles were scheduled by the Sales Organisation for which there was insufficient stock and there were vehicles unscheduled, for which stock was available, and therefore could have been produced.

Two stages of a solution are suggested. Firstly to form a feed forward information loop in terms of a formal communication link between sales and the provisioning organisations in order that future demand patterns can be detected and material provisioned accordingly. The next stage is to use a linear programming model to test various purchasing and order scheduling strategies prior to fixing a firm demand.

The second problem area involved allocating the stock on hand, which due to extraneous factors may well not be of the

ideal level, to meet some management objective.

The problem was beyond manual solution and the technique of mathematical programming was used to determine optimum solutions. The problem was strictly an integer programming one but a technique was developed constraining a normal linear approach to give acceptable results without the unpredictability found with a pure integer technique. The solution produced an optimum build program and illustrated strategies which could lead to an improvement in the objective.

The third and final problem area investigated involved studying the reactions of the production system with the aid of a computerised simulation model. The model was found to be an accurate representation of the actual system and sensitivity testing indicated changes in strategy which would result in an improvement in production efficiency. These points were developed further and a strategy is submitted which will result in an improvement in the efficiency of the production system.

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LIST OF PHOTOGRAPHS

The majority of photographs were taken during a non-productive period.

LIST OF ILLUSTRATIONS

INTRODUCTION

The motor industry, for whom this research was undertaken, is one of the most important manufacturing industries in Britian. It is the largest private sector employer of labour (direct and indirect), the largest single exporter in the country and its wealth and prosperity are essential for the economy and well being of the whole nation.

Over the last two decades its history has been very troubled. Under the banner of rationalisation several famous companies, within the industry, have been forced to merge or have succumbed to American control. Some have just vanished into the pages of history.

The British car industry now consists of four main companies, Chrysler (U.K.), Ford of Britian, Vauxhall (a General Motors subsidiary) and British Leyland Motor Corporation (B.L.M.C.), the latter being the only wholly British-owned company. It is interesting and relevant to note that with the exception of Chrysler (U.K.), a recent American acquisition, British Leyland has an entirely different growth pattern to the American companies.

British Leyland has grown by taking over or merging with other British car manufacturers until at one time there were ten marques (Austin, Daimler, Jaguar, M.G., Morris, Riley, Rover, Triumph, Van den Plas, Wolsey), neglecting the commercial vehicle side of the business, all being manufactured under the B.L.M.C. flag. Fords and Vauxhall on the other hand have grown, principally, by expanding from within, with little diversification into other manufacturing fields.

This research was initiated at the request of the Pressed Steel Fisher division of the then British Motor Corporation (B.M.C.). The division had itself been formed from the Pressed Steel Co., and Fisher and Ludlow Ltd., formerly two independant sheet metalworking companies, to concentrate all of the body building facilities of B.M.C. in one group, with production units at Oxford (Cowley), Swindon, Birmingham (Castle Bromwich and Common Lane) and in South Wales (Llannelli).

The division was then absorbed into the British Leyland Motor Corporation when B.M.C. and Leyland were merged under the auspices of the Industrial Reorganisation Corporation. It remained virtually unaltered by the first phase of the British Leyland reorganisation, but under the second phase, which was announced in the summer of 1970 and is still to be completed it is now a part of the Austin and Morris Manufacturing Group, Body Division.

The main point is that the group structure always appeared to be very fluid and, before the last merger, very piecemeal, with various factions vying for leadership. This tended to aggrevate the divisions between the old companies and increased local loyalties which undoubtedly had an effect on morale and efficiency. This point will, however, be developed later.

The main activity of the group is the production of motor vehicles with various units, within the organisation, producing different parts of the vehicle to subsequently be brought together at an assembly location.

The production system for producing a finished vehicle can be broken down into several manufacturing stages. The first stage is considered as the production of the vehicle body shell from various assemblies of metal panels (it is then in what is known as the white metal condition). The second stage is the painting of the white metal body shell with primer and colour paint coats, and then the fitting of all the interior trim and parts. The final stage is the addition of the engine, transmission, suspension and wheels, the production of which is carried out parallel to the manufacture of the body shell.

This study was concerned with the problems involved in the second stage, namely painting and trimming the vehicle and was undertaken at the Castle Bromwich Factory. The trimming of the vehicle is also termed 'finishing' in that for the Castle Bromwich factory it is completed. This stage was considered the most complex of the three mentioned, for it was at this point that the vehicle assumed the major part of its unique identity and hence it was also the point at which the majority of the variations in the product were introduced. Each production line then assumes some of the complexity of a multi-product line with over four million possible different products on one line alone (exterior paint colours (7), drive system (2), type of gearbox fitting (2), interior trim colour (5), speedometer (2), windscreen (2), rear window (2), seat type (2), market requirements (8), type of heater (3), extras (5)).

At this stage the problems of provisioning material to be fitted on the assembly tracks, and the subsequent allocation to a demand becomes a major task. When the sequencing and control constraints are imposed on the system the problems intensify to a degree such that they can no longer be considered as isolated elements but must be examined as interacting factors within a total system. It is this total concept that this study sought to examine.

The three elements that constrain any production system are known as the 3 Ms, men, materials and machines. To these must be added the more abstract factor, the system.

Men in an assembly unit obviously contribute a major part towards the efficiency of the total system. There are many problems of morale, incentive and industrial relations concerning men who work on repetitive and somewhat boring tasks. In terms of a production constraint strikes, go-slows and working to rule hinders and may even completely halt the manufacturing process. The incentive system of piecework makes production planning difficult due to the open-ended nature of the work rate (although the take home pay at the end of any week is virtually unaltered). The introduction of daywork, now being painfully implemented, will do much to ease this problem.

Absenteeism and poor timekeeping delay the start of production at the beginning of a shift whilst either the men arrive or alternative labour is assigned new tasks. This, except in times of epidemics, tends to remain sensibly constant.

Within the area defined for this study however, the problems somewhat eased as the production is geared, principally, to mechanised conveyor systems and the variability due to the short term change in work rates is minimised. Industrial action in this environment is an even more powerful weapon than normal, with a few workers having the potential ability to halt the whole system.

It was impossible to justify budgeting, in production terms, for industrial action, except at a very low level, as it was unpredictable and frequently spread to other areas of the factory. This study did not, therefore, attempt to consider the labour constraint although it was recognised as an integral and important part.

Machines were mentioned as the pacesetters for the workrates in the system and as such any breakdown in a conveyor system could reduce the workrate to zero. Unlike the labour problem the stoppages on a machine or conveyor were predictable and were considered as a constraint.

The availability of material to assemble to a painted body shell was obviously a major constraint and with the large range of possible different products the task was particularly difficult. The value of the parts such as speedometers was very high and the throughput rates were also very large. Obsolescence, with new models and changes being constantly introduced, placed even more importance on low stock holdings and accurate control. Unlike the classical warehousing environment, all of the parts were interdependent as it was of little use having only 99% of the

It is true that industrial unrest has been a contributory factor towards a poor production record but an even greater burden must be placed on the inefficiencies within the organisation. As the pinicle of the production pyramid the painting and trimming activity assumes paramount importance as any inefficiency at this point can completely negate any gains made earlier in the system.

APPROACH

In any study the first task is to discover the way in which the system works, or is thought to work at the present time. In an investigation into an industrial environment this stage of the study assumes an additional importance as frequently deviations occur from the published procedure. Such deviations may hold the key to the solution of the problem as the changes are likely to have been introduced due to the shortcomings in the official procedure. Pounds, ref. 51, referring to a biological analogy of scheduling systems stated that "a new system will be like a mutation in an environment in which existing systems have evolved. It is highly unlikely that it will survive unless the environment changes".

A true comparison of improvement with a suggested system can only, therefore, be made with the actual environment and not the system that is presumed to be working.

The investigation, undertaken to determine the actual system, started by considering the appropriate routines and procedures covering material provisioning, allocation and scheduling of the production unit. The next step was to establish where senior management considered the problems existed.

A great deal of time and effort was then expended to discover the way in which the systems actually worked, noting where they deviated from the accepted path. A special note was made as to the method whereby the problems, identified by the managers, were overcome, if indeed they were solved or indeed existed. This meant, in the case of clerical operations, talking to section leaders and those directly involved on the shop floor, the foreman in charge. An attempt was made to isolate the main factors involved and also to note those which, the person making the decision felt, made a contribution to the judgement.

The effect of any inefficiency or shortcoming in the material provisioning, allocation and production scheduling systems is felt directly or indirectly on the shop floor. The findings of W. F. Pounds, ref. 50, that 'the job-shop scheduling problem is not recognised by most factory schedulers because for them, in most cases, no scheduling problem exists. That is there is no scheduling problem for them because the organisation which surrounds the schedulers reacts to protect them from strongly inter-dependent sequencing problems .... In fact, they are explicitly prevented from arising by stabilising decisions made in various parts of the plant organisation', were found to exist in the production unit studied. The foreman, on the shop floor, was isolated from the true problems of material provisioning, allocation and sequencing by a cocoon of backlogged orders, late deliveries and was protected from repercussions by performance monitoring which occurred only at a highly aggregated level. The aggregation of performance data inhibited the supervisors from implementing improvements as the precise gains could not be quantified and hence justified. The data tended to be used as a sheet anchor by supervisors, who were held responsible for drops in performance, as they could point to extraneous factors, for which they could not be held accountable, which may have influenced a fall in performance.

The problem of aggregation made the task of obtaining detailed objective information on the causes of performance losses impossible from the practical unit without the introduction of a complex and expensive monitoring systems. It was, therefore, only possible to study the total effects and to attempt to identify indicators to particular constraints on the system.

The only objective which economists feel is valid for a company is to maximise the return on investment and this is generally referred to as the corporate or global aim. This objective has, however, to cascade down through the levels of management until eventually it reaches the shop floor. At each level a different interpretation is put on the objective. For a single production unit the global or corporate objective may well be interpreted as maximise profit or minimise cost. On the shop floor, because they are denied cost information at a detailed level, the global objective is interpreted as maximise production. This was the only policy that realistically could be enforced, at the production unit studied, with only general directives on cost penalties as the costing information was totally inadequate.

When the criteria of maximum production was examined, for the activity of painting and trimming vehicles, it could be shown that production rarely exceeded 85% of potential capacity, ref. Appendix A. This figure is quoted against published manned capacity and not order demand or production demand from subsequent units, or programmed capacity. If the figure is quoted against order demand it would fluctuate wildly, as the number of orders received was a function of the amount of backlog. To quote against a demand made from a subsequent production unit would indicate a marginal improvement but this demand only imposes a real constraint when a major hold up occurs and the figure mentioned was derived from data accumulated during a period when the demand was sensibly steady. Programmed capacity was that which was laid by the Directors of the Company as a forward policy, covering three months and did not take the changes that occur between planning and production into account, e.g. local manning problems.

The absolute value of this performance figure was not a critical test until considered with several other indicators. The most important of these was the extent of backlogging which, at a peak, rose to three times the weakly production figure constrained only by the modifications to the order demand. It is important to note that this was not the collection of orders directly from customers which were held by the sales organisation, but the backlog held by a unit within the total production system.

The next important indicator of the conditions that existed was taken to be the number and extent of late deliveries. Over a two year period 40% of the orders were dispatched after the scheduled date and delays of six weeks were certainly not uncommon. Again care had to be taken in judging the bare numerical values as frequently interruptions in the supply of component parts, for assembly, influenced the system.

Another indicator which was used to judge sequencing efficiency was the amount of rescheduling of vehicles undertaken prior to the finishing tracks. Rescheduling was undertaken when it was discovered that insufficient component parts were available to complete the build of the originally scheduled vehicle. This involved searching the orders on hand for an alternative vehicle which required the same colour body shell and for which all of the component parts were available. This rose at one point to 45% of the total number of vehicles submitted with an average of approximately 20%. Precise figures are difficult to obtain as the rescheduling tended to be carried out very informally with little or no recording of the change.

A further indication of the problem existing was taken to be the number of vehicles which, after being submitted down the finishing tracks, have to have parts fitted as an additional operation, due to a stock shortage at the time of tracking. This figure reached 25% of total weakly production but tended to average approximately 10%. The total cost of these additional operations is impossible to define as conjestion caused can prevent the movement of completed vehicles, and if workers are removed from the finishing tracks to perform the work then the efficiency of those tracks will also be impaired.

The use of unofficial storage areas was also taken as indicative of possible inadequacies in the scheduling system or the resources available. Prior to the colour paint plant the use of such storage areas constituted 60% of the total. In some cases the use of such storage incurred not only the increased retrieval time but also additional cost due to damage caused under the poor storage conditions.

It must be stressed that the value of each indicator was not taken to be as important as the total picture, which pointed to constraints imposed on the system by inadequacies in

(a) Material provisioning

(b) Material allocation

(c) Sequencing and production control, and possibly

(d) The storage areas available.

It is also important to note that with the level of information and techniques available to supervisors at the time of this study, it was difficult to see a better alternative than the approach of backlogging, late deliveries, rescheduling, etc.

It could be easily seen that one of the major problems that imposed a constraint on the system, was the availability of sufficient material of the correct type to complete a vehicle. One of the first aims of the study was therefore set as the examination of the material provisioning system. If this could be developed to such a degree as to eliminate stock shortages then the remaining problems are simplified.

In a real world however, it is impossible, particularly with such fast stock turnover (once every two weeks), to guarantee this level of service. Many factors, some very unpredictable, will disturb the supply of component parts. Factors such as transport breakdowns, physical loss, human errors and strikes are common in the environment examined. There must exist, therefore, an alternative approach when the supply is interrupted, and in the case of material it is important to be able to provide details of the vehicles that could be built and if possible to optimise the use of the stock on hand to serve some objective. This was set as the second aim of the study.

If it is accepted that the first two aims can be satisfied then the total problem is reduced to solving the sequencing and control problems on the shop floor. The sequencing problem is particularly complex with variable routes, recycling and involved queueing disciplines, and with such a problem it may well have been optimistic to claim any absolute optimisation. Certainly the term optimal is one which has to be very carefully defined particularly in scheduling terms. The third aim was therefore determined as examining the sequencing system with a view to improvement. The final aim was set as presenting the three parts of the sectionalised problem as a total concept.

PART I

THE MATERIAL PROBLEM

Chapter I

MATERIAL PROVISIONING

The topic of stock control in general and inventory control in particular has attracted a great deal of interest from both academics and practitioners. Considerable interest was stimulated, from practitioners, after the 1921 depression in America, during which time several major companies suffered considerable inventory losses.

The reasons for holding an inventory are many and varied. Keynes, ref. 44, defines three motives for a company holding an inventory of cash, transaction, precaution and speculation. He defined the transaction motive as the cost of transferring rapidly from investments to cash, the precautionary as the need for protection against uncertainty and the speculative motive as the possibility of profit through changes in prices and interest rates.

In terms of component parts inventory, the transaction motive can be interpreted as the economy of placing large orders. This presumes that there is a fixed cost of procurement which does not change with the number ordered. Many research workers have developed this concept of economic order quantities, e.g. Davies, ref. 14 and Owen ref. 50. The speculative motive for a parts inventory can be considered as an investment of components against an expected rise in price, ref. Shaw 53. For example at the time of the Rhodesian declaraction of independence, several companies speculated an investment in parts containing a large amount of copper against the expected rise in price of the ore.

The precautionary motive can be considered as budgeting for a degree of uncertainty in the demand. One academic approach has been to determine the distribution of the instantaneous differences between supply and demand, and with such a distribution to determine the inventory necessary to give a known service level. A true justification of inventory for this motive is that parts can rarely be obtained immediately, if they could then although uncertainty exists there would be no need for an inventory. In some cases immediate delivery can be secured at a premium, however the argument that uncertainty in isolation is not a justification for an inventory is still valid.

In practice there are three methods of ordering material, although in theory there are four approaches that could be used. The variables are the quantity and the frequency of ordering (cycle) and often the choice is made not only in view of the economic order quantity, but also on the basis of simple convenience. The four methods are defined as

Variable order quantity/variable cycle
Variable order quantity /fixed cycle
Fixed order quantity/variable cycle

and a fourth which can only be used with a constant demand

Fixed order quantity/fixed cycle.

At the Pressed Steel Fisher plant at Castle Bromwich the procedure was to negotiate a price with a supplier for a particular part, on the basis of an estimated demand over a period of say one year. The items would then be called on a firm schedule covering one month, broken down into production weeks and indicating the expected trend in future weeks. This system was known as the blanket order approach, with the particular weekly demands being satisfied by calling for a supply on a variable quantity/fixed cycle basis. In academic terms it can be said that by this method the company was satisfying the transaction motive.

It was mentioned previously that the precautionary motive arises due to uncertainty and the infeasibility or cost of immediate deliveries. In dealing with the second factor it is important to determine the procurement time. In the blanket ordering environment the determination of such a figure is difficult and depends on several variables, viz.

(a) the amount required :-

if this is small in relation to the normal order quantity then the supplier may be able to provide the items immediately as part of the quantity scheduled for delivery in the following week. It should then be possible to make up the amount for the following week by increasing production, i.e. the response time is less than the available time.

(b) the amount of stock that the supplier was holding for economic production at the time of the demand.

(c) the notice that is given of an imminent stock out :-

this is a reflection on the stock recording undertaken but the time may be sufficient for the supplier to respond to the demand.

(d) the amount of pressure that the company is prepared and able to bring to bear on the supplier to modify his production plans.

The uncertainty factor arises with the prediction of future demand patterns. If a good estimate can be obtained, the uncertainty and hence the inventory can be reduced. The demand factor in itself is not always as straight-forward as it is sometimes presented. In a general sense it may well be that a customer will accept an alternative item or, without recriminations, be prepared to wait. In a store serving a production unit, a short term shortage may have little effect as, theoretically, there may be other products which can be produced, whilst the missing material is obtained, which have no detrimental effect on the production efficiency.

In the company studied the turnover of bought out parts was very high, the total value of stock being turned over in less than two weeks. The blanket order system allowed for a considerable amount of flexibility in terms of obtaining additional parts quickly and without additional cost from the supplier and the stock control exercised allowed imminent stock shortages to be noticed fairly quickly. In the assembly environment, if a shortage was discovered which implied that particular vehicles could not be built, alternatives were available which could be built. There was, however, one very important factor which complicated the situation to such a degree that it removed the problem from the work which has been undertaken in the area of inventory control.

The work done in inventory problems has concentrated on what is known as the warehousing environment whereby each demand made upon an item is independant of the other items available and the demand will be satisfied if that item along is held in stock. In a store serving an assembly production unit such as a vehicle assembly line, it is important not simply to have a 99% probability of a part being available, as it is impossible to complete a vehicle with only one part missing, e.g. the wheels, but essential to have all of the components available. It is not a simple case of determining the overall service required, and by using probability theory to arrive back at the necessary part service level, as the parts may be unique to only one vehicle, several, or common across the range of products.

This constraint returns the problem to the initial point where the prime forecast of demand assumes a critical importance. It is also relevant to state that a supplier can not be expected, nor do they, respond to every whim of a customer, and it is essential for the continuity of supply that a supplier is economically stable, which can rarely be the case if his production plans constantly have to be revised. An inefficiency at a supplier will inevitably impact upon his customers.

The first task in this area was set 'to examine the demand experienced at the production unit, to see if mathematical forecasting could be of assistance,' and the first element of this task was to examine the quality of the forecast obtained at the time.

The men responsible for performing the scheduling of the material from a supplier were given, monthly, a Vehicle Build Forecast (VBF) covering a three month period. This broke demand down into model (e.g. ADO 15), main derivative (e.g. Super de-luxe, Standard), engine size (850 cc. or 1000 cc.) and separated into the marque (Austin or Morris). The VBF also determines the export content, thereby giving the Directors who formulated the forecast the opportunity to regulate production in line with a corporate strategy. The forecast did not, however, give any details of the order mix within any particular group, e.g. the number of vehicles to be produced for the French market and the estimation of this was left to the scheduler.

Whilst the programme did indicate the total build within each group it did not show which of the production units, capable of the manufacture, would finally be allocated with the order.

In addition to this forecast the scheduler also received a firm order from the sales organisation, theoretically, ten days prior to the production date. The actual time fluctuated between ten days and three.

There existed at this stage a problem in transferring the vehicle demand down into a parts demand, i.e. a piece-parts explosion. Several workers, ref. 19 and 53 have treated the problem in matrix algebra terms. Giffler, ref. 23, also briefly discussed a linear programming approach omitting completely, however, any mention of the theoretical difficulties posed in the assembly situation. In the practical environment the problem of exploding and netting of parts requirements has been solved by sophisticated computerised systems such as the I.B.M. file organisation detailed in refs. 36 and 37.

Provided that there was no major change in the mix within a group the notice given by the Sales Organisation

ADO 15 TOTALS

Week No.	DENMARK	SWISS	GERMANY	CANADA	AUSTRIA	NORWAY	SWEDEN	FRANCE	MALTA	CAMEROUN	HOLLAND	LEBANON	AMERICA	ITALY	BMC	MAURITIUS	LIBEIA	HOME	TOTAL
45/46	156	90	64	5	13	15	-	-	-	-	-	-	-	-	-	-	-	199	542
47	99	50	5	12	25	40	25	465	-	-	-	-	-	-	-	-	-	-	721
48	480	75	25	87	-	42	1	-	3	3	25	1	76	-	-	-	-	181	999
49	190	108	-	77	-	-	-	67	-	-	-	-	1	70	1	2	2	305	823
50	129	91	-	42	15	10	-	110	-	-	-	-	-	-	-	-	-	464	861
TOTALS	1054	414	94	223	53	107	26	642	3	3	25	1	77	70	1	2	2	1149	3946

(at its theoretical value) was adequate. The problems arose when the change in mix was dramatic, as the system could not respond even with the flexibility mentioned earlier. Although it is difficult to examine lead times in a blanket ordering environment it was found that some items had procurement times of up to six weeks, particularly some of the electrical components (e.g. headlights).

A report, ref. 10, was produced by the material supplies department, detailing the cover required

1. 14 weeks minimum for Raw Material, and in some cases manufacture (vinyl cloth etc.)
2. Lucas require 14 weeks notice
3 Leathercloth 6 weeks
4. Lockheed 20 weeks

These periods were felt to be excessive and certainly included considerable safety margins.

When the past orders were examined it was found that the fluctuations were considerable, unpredictable and frequent. An example of the fluctuations is shown opposite and indicates a step input in the demand for French vehicles of 465. in week 47. Vehicles for the French market are particularly difficult to respond to as they require unique headlights, flashers, and transparent brake fluid reservoirs. This is by no means the only fluctuation occurring within the sample shown, for example the home market content and the total programme also vary. The VBF for this period showed a weekly demand for 1000 vehicles.

At this point the possibility of forecasting the future

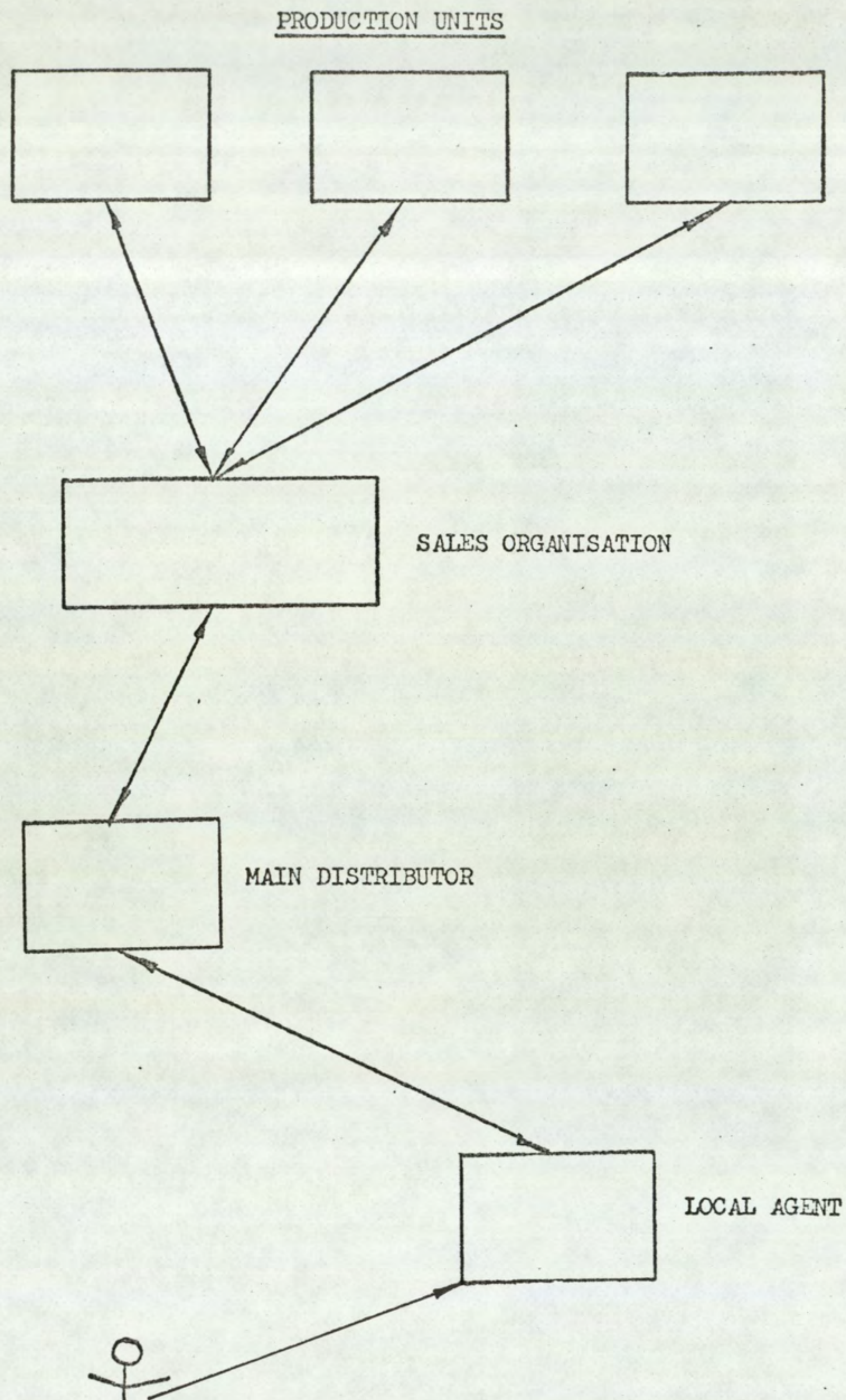

PRODUCTION UNITS
SALES ORGANISATION
MAIN DISTRIBUTOR
LOCAL AGENT
CUSTOMER

Fig. I

load at the production unit was abandoned as infeasible due to the near random nature of the data. An indication of the problem can be seen from the fact that when even a simple second degree exponential forecast was attempted on the total order size the tracking factor returned was 0.76 compared to the accepted normal value of 0.1, R.G. Brown ref. 7, recommended that of any value above 0.3 is returned then that approach is invalid.

The basic assumption was that the demand for vehicles comes from a natural market with customers placing their orders with a retailer, ref. fig. 1. If the demand can be satisfied at that point, and there was some evidence to suggest that a customer may willingly accept an alternative to his original demand, if it was available, then the retailer would simply replace his stock by ordering a further vehicle from the manufacturer. If the demand was not satisfied then the retailer would enquire if the main distributor was holding a suitable vehicle, if not he could then pass on to investigate if a vehicle was available in the factory stock. If at the end of the chase no suitable vehicle was found then the retailer must place an order on the manufacturer.

This type of market was undoubtedly seasonal, and in order to maintain production at sensibly an even level action has to be taken to smooth the effective demand. This was done by encouraging distributors to hold higher stocks of vehicles during a slack period and by accepting longer delivery dates in periods of heavy demand. Seasonal forecasting was certainly feasible, but as the data examined did not fluctuate only with the season, it had to be presumed that a further constraint was being imposed on the system.

The terms of reference then had to be expanded into examining the system of releasing orders from the sales organisation to the individual production units.

The Sales Organisation was based at the Austin Longbridge factory and controlled the whole marketing for the group which at the time of this investigation was B.M.C. This was a separate division to Pressed Steel Fisher for whom the research was undertaken.

It was felt at this stage that the orders were being released on the basis of production constraints, i.e. the sales organisation were waiting until orders for a batch of a particular type of vehicle were assembled before being released to the production units.

The Sales Organisation, of which there were three distinct parts, i.e. domestic, European exports (based on Lausanne), and other exports, was responsible for the firm allocation of an order to a production week, based on their judgement of the market conditions within the general constraints imposed by the VBF.

The system that existed at the time of this investigation was that when an export order was received it was firstly examined to see if it required any special priority. The order form had four copies, one for the Sales Organisation, one for Finance and two for the Computer Department (See Appendix A). One punched card was raised for every vehicle on the order form and described completely the vehicle requirements. These cards were then loaded to the computer and the file of outstanding export orders updated. (The Order Bank.) The card was then returned to the export sales department until the time arrived when it was necessary to firmly allocate the orders to a production week.

When this time arrived (15 days prior to production), the first task was to consult the VBF to determine the maximum number of vehicles to be produced in the appropriate week. It was then necessary to decide which of the production units will be allocated with the individual orders, and this was done by reference to the current arrears (outstanding orders) of each unit. It can be seen from this that the system had a response time of nearly four weeks before the new orders began to reflect the arrears position on the production unit.

The nett figures left are then given to the Sales Organisation for them to allocate to the domestic, European Export and Export sections. Both the export departments then select individual orders to be allocated up to the maximum amount. The appropriate punched cards were selected and forwarded to the Computer department, where they were merged with the domestic demand, and a firm production program produced. This program was then despatch to the production unit giving as stated previously a maximum of ten working days notice.

The criteria used for the selection of an order is based on several factors such as :-

Import Quotas, if a country operates an import quota restriction it may be necessary to complete the quota before the new quota year.

Credit Limitations, a particular distributor may have a credit limit which may not be exceeded.

Profitability of Market, due to different market conditions some are more profitable than others and will generally have priority.

Steady flow of vehicles to distributor. In order to maintain a reasonable service it is essential if possible, to give each distributor some of the vehicles on request.

Sales Policy. When a trade show occurs or new model is introduced it is important to establish stocks of vehicles prior to the opening or announcement.

At no stage did the Sales Organisation consider the question of whether the production unit had provisioned in line with their demand, indeed no information was given to them of the constraints, and they in their turn did not inform the production unit of their future intentions.

The gap was obvious. Information on the future intentions of the sales organisation not in terms of reasons but expressed in the mix of vehicles constituting a vehicle order, should be fed forward to the men responsible for provisioning each production unit. If any difficulties existed in provisioning to meet that demand, then the production unit should feed the information back to the sales organisation such that a more acceptable program may be negotiated. At no stage must it be considered that it is a question of the production unit telling the sales organisation which vehicles they can have, i.e. it must not be the tail wagging the dog.

The system should be formal and documented, in order that it is maintained as a record of the behaviour of the departments involved. Every department involved must accept a certain discipline in order that the maximum amount of benefit is derived.

During the study the Sales Organisation were constantly lamenting that they were unable to obtain from the production unit the vehicles which they felt they could sell, and they admitted that frequently there were other alternative orders still in the order bank which they would have been equally pleased to have received. It may well have been possible to produce these alternatives as they may not have required material in shortage.

The first need was therefore to feed information forward to the individual production units on the future demand. This can be best achieved by an examination of the order bank. In order to perform this in a meaning-full way several changes are needed.

The principal change necessary is that the Sales Organisation allocate a desired production week to each vehicle on an order at the time that the order is first received. This should be done on the same criteria used previously, taking the date required by the distributor if there are no other constraints. At this stage, the sales organisation should also indicate whether the vehicle production date is obligatory, i.e. it is essential that the vehicle is produced in that week to meet some objective of sales policy.

Once the decisions are reached then the information should be coded onto a punched card and the computerised order bank updated with the new orders. The punch card should be returned to the Sales Organisation.

The computer will, at the time that an order is required, perform a clerical sort on the order bank in the following manner.

1. Select a model (e.g. ADO 15).
2. Identify the maximum production possible for this model from the VBF.
3. Allocate the obligatory orders in the Order Bank to the stated week up to the maximum permitted, breaking any ties on a first come first served basis.
4. Add to each weekly order the non-obligatory orders up to the maximum permitted, breaking any ties on a first come first served basis. If this does not reach the maximum, then the date of manufacture of other non-obligatory vehicles should be advanced in order to top up the weekly programme. When making the selection an attempt should be made to consolidate batches of vehicle types for efficient production, e.g. if there is an order for a black vehicle in the obligatory section for a particular week then the program should give priority to other black vehicles in an attempt to build up acceptable colour batches.

The danger of such a system is obvious, i.e. if a non-standard colour is present then it may be reallocated back several times. In order to compensate for this it is suggested that a maximum of four

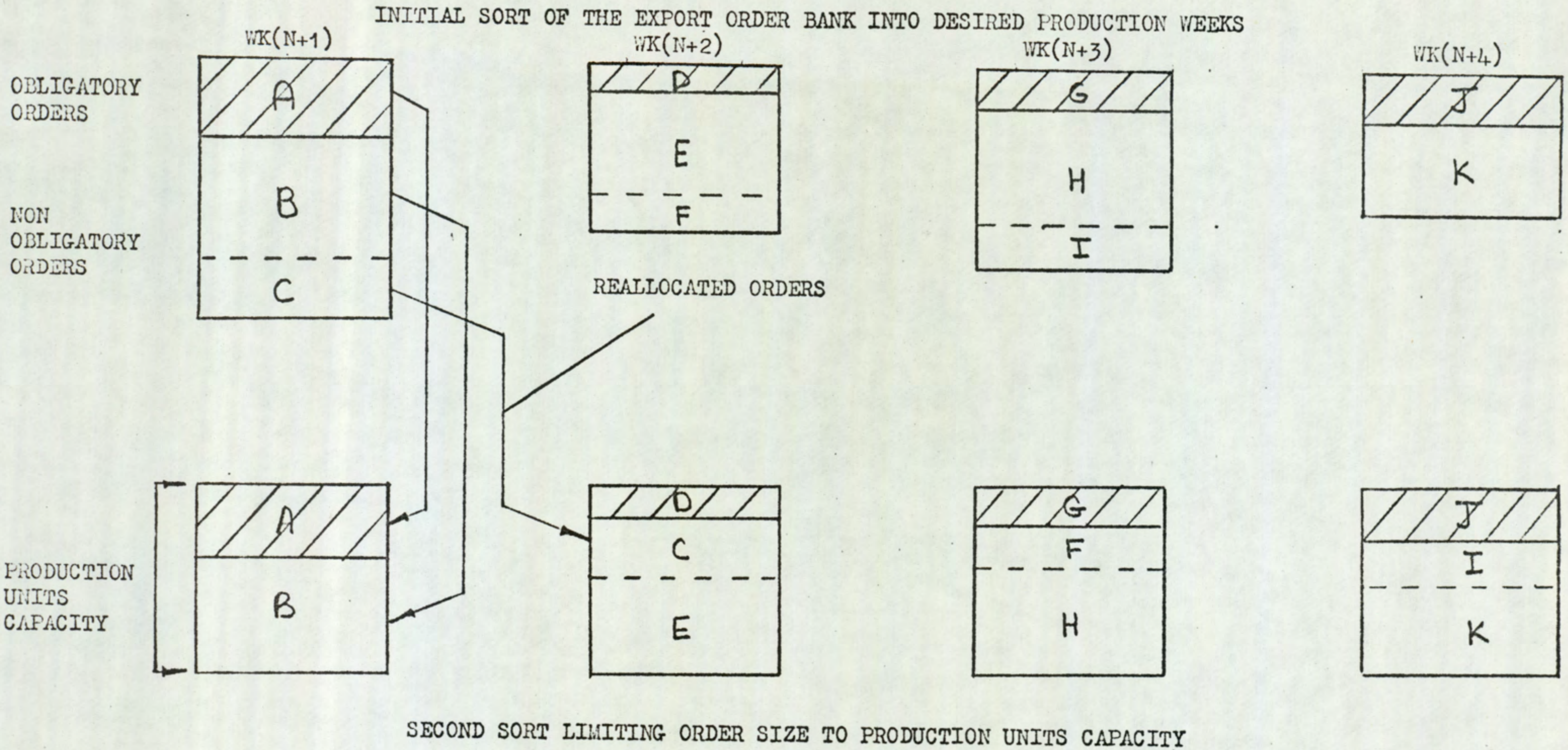

INITIAL SORT OF THE EXPORT ORDER BANK INTO DESIRED PRODUCTION WEEKS
WK(N+1)
WK(N+2)
WK(N+3)
WK(N+4)
OBLIGATORY ORDERS
NON OBLIGATORY ORDERS
A
B
C
D
E
F
G
H
I
J
K
REALLOCATED ORDERS
PRODUCTION UNITS CAPACITY
A
B
D
C
E
G
F
H
J
I
K
SECOND SORT LIMITING ORDER SIZE TO PRODUCTION UNITS CAPACITY

fig II

reallocations should be accepted after which the order should change its status and become obligatory.

The system is shown diagramatically in Fig. II.

At this point in time it must be stressed that the order is not a firm order but is an indication of future trends and it should be provided to the production units and to the Sales Organisation for reference.

When the time comes for a firm allocation, by the Sales Organisation, the prime reference must be the tabulation of the tentative production program for that week, for it is upon that basis that the production unit will have provisioned. Alteration at this stage must still be permitted however, as market conditions may well change, or the management alter their policy.

The method of alteration should be by selecting the relevant punched cards from the file of those orders to be added, deleted or changed. These should then be passed to the computer department for the firm production program to be produced. In this manner it is necessary to make a conscious effort to amend an original program.

The closer that the final allocation agrees with the initial one, the higher the probability that the production unit will be able to provision for the demand. An abuse of the facility to amend the program or to make a vehicle obligatory will result in poor stock control and a reduction in the likelihood of maximum production. It is suggested, therefore, that the number of obligatory orders and the extent of any late amendment should be recorded, and if either value rises above an acceptable amount a tabulation should be produced for senior management in order that the amounts can be justified or otherwise.

It was impossible to perform any further detailed analysis in this area as strictly it was outside the original terms of reference and the author was asked by senior management to discontinue his investigation in this area. The findings were, however, accepted as valid and a major investigation was initiated by the Austin Longbridge Division into the subject.

The main point is however that a formal feed forward information link must be established and maintained. The second point, that a feedback link should also be set up to transmit details of production constraints to the sales organisation, is dealt with in the next section.

Chapter II

MATERIAL ALLOCATION

In the previous chapter it was established that the prime task of a provisioning system is to obtain the best possible information concerning the future demand in order that the material can be procured at the correct time for production. In a practical world, however, it must be accepted that the supply may well be interrupted through many causes, strikes, breakdowns, unacceptable quality or simple human oversight. In this environment a system must be developed which will allow the production strategy to be modified in order to use the available parts to meet some management objective which may simply be 'maximise production'.

In a high volume assembly organisation such as the car industry, the shortage of component parts from either suppliers or from other sections of the organisation is a continual headache. The task of allocating the available stock to the orders on hand usually falls to the staff of the production control department. If there are only a few assemblies with a small number of parts then this task of allocation is not very arduous. An experienced production controller can quickly work out the total requirements, compare to the available stock and where there is a shortage, he can easily try out a few different allocations on paper, testing after each attempt to see if he has achieved his objective.

Consider a simple example involving three assemblies, A, B and C consisting of parts X, Y and Z as follows :

Assembly	A	B	C
	X	X	-
	Y	Y	Y
	Z	-	Z

If the situation arose whereby there were orders on hand for one of each assembly, all of equal urgency, and the stock available consisted of 3 Y's, 1 X and 1 Z, then with little effort the production controller could work out that for the maximum production he must make one of B and one of C. He could also work out that he needs a further supply of both X and Z, in order to manufacture the additional assembly A. The allocation must not be done sequentially, otherwise there is a possibility that the object, in this case maximisation of production, will not be realised. In the example given, if the stock had been allocated first to assembly A there would be insufficient left to build either B or C and the production would be limited to one assembly instead of the optimum two. In this particular case, when maximisation of production was taken to be the objective, each assembly contributed an equal amount to the objective. When profit maximisation is considered with a different contribution from each assembly towards the objective, then the argument against sequential allocation becomes even stronger.

In the practical situation the number of assemblies and parts was very large with 1,000,000 primary combinatinns of vehicles which could be built from over 800 major parts. Several factors decide on the format of the finished vehicle, the marque, the paint colour, the trim colour, the drive system, the country, the transmission type, the speedometer calibration, the options and extras. Each factor, once determined, required several parts to be fitted, e.g. if the car was to have been an Austin then this required an Austin grill, badge, steering boss, and rear motif. To perform any form of allocation, the production controller must have information on the stock position of each part within every package, as the minimum value determines the constraint. He must then attempt to match this to the orders on hand in such a way as to meet his objective. The problem is obviously impossible for manual solution and in practice the harsh constraints detailed had to be relaxed in order that the system would work. This was achieved by accepting the situation whereby the number of orders on hand was kept at a high level, in order that selection up to the capacity of the production lines could be obtained without a detailed search. A great deal of expediting was also carried out to obtain sufficient stock to keep the tracks moving. If stock was discovered to be in short supply when the vehicle arrived at the start of the finishing track, then it was either rescheduled to an alternative vehicle or the body shell was passed down the track to have any missing parts fitted as an addition operation after the main assembly line.

The backlogging of orders to obtain a large selection of vehicles, leads to considerable problems in terms of sequence to subsequent production units. A simple example can be seen when vehicles requiring different engines were presented to the same track. (ADO 15 850 cc. and 998 cc. versions). As the production unit under consideration did not fit engines then it was unaware of any sequence constraints on engine supply and hence as it had a large order bank available from which to select production then it selected to trim vehicles suitable only for the one engine version, creating havoc some 20/30 hours later when they arrived at the other production unit.

Clearly backlogging of orders can cause considerable delay in producing particular vehicles, delay which was in addition to that already imposed by the sales organisation, and to that which may have occurred in subsequent production operations. It must be made clear that with only a manual system, production control have no other alternative to this situation and can only hope to keep the problem within reasonable bounds by continual expediting.

The question of allocation, which is the key to the problem, can be recognised as requiring a resource allocation technique of the linear programming type. This can be expressed mathematically as

$$\text{Maximise/Minimise } C = \Sigma_{j=1}^{n}$$

subject to :-

$$\Sigma_{j=1}^{n} \; a_{ij}x_j \leq b_i \qquad i = 1, 2, \text{------} m.$$

$$x\,j \geq 0.$$

In the environment discussed a further constraint was imposed on the general l.p. problem, as in an assembly industry it was impossible to contribute towards the basic management objective by producing only part assemblies. This implies that any solution to the defined problem should be in integer values to be useful. Presented with a solution which suggested building 13.6 vehicles a production controller must either truncate to 13 or round off to 14. If many elements require modification then the total solution will be sub-optimal and rounding-off may well cause an infeasible solution. Idealistically the problem therefore needs to have the variables constrained to integer values and hence can be defined as an integer programming problem.

As Glover, ref. 25, mentioned "since its inception integer linear programming has paradoxically been a source of both promise and disappointment. Promise because there are manifold and compelling opportunities for its application, disappointment because it has made only the most dubious progress".

Hillier in October 1966, ref. 37, rather dishearteningly comments "it appears that an optimal algorithm (for IP) that is generally comparable in efficiency to the simplex method for larger problems may not be available in the foreseeable future."

Algorithms for solving integer programming problems, have been notoriously unpredictably slow in converging to optimal solutions when compared to the standard linear programming type, this has meant a restriction on the use of mathematical programming in assembly industries.

The first technique advanced by Gomory, ref. 27, was to develop further restrictions if, after solving by the standard linear programming algorithm, the solution still remained non-integer. Experience with this approach has generally found that the number of generated constraints can expand such that a solution will not be revealed within an acceptable time. Various techniques have been advanced to ease the problem such as Bender's, ref. 3, method of partitioning into two parts, one part containing variables constrained to integer values and one with pure linear variables. For example, if the orders coming to the assembly factory are in batches, ranging in size from one to one hundred, then it can be seen that to truncate a linear programming solution of 99.6 to 99 does not markedly affect the overall accuracy. Such a truncation in the region of 1-10, however, may well be unacceptable. One approach could therefore be to partition the problem into two parts restricting all variables bounded by an order constraint of less than, say 10, to an integer solution and solving the remaining orders by a standard linear programming technique. It could then be reasonably expected that the total computation time would be considerably reduced, although a penalty would have to be paid in terms of a slightly sub-optimal solution. The size of the reduction in computation time would depend on the accuracy required and the distribution of order sizes. It must also be seen that though the solution of the larger continuous variables may have an upper limit (number of orders on hand) of say 100 the solution value could range from 0 to this bound hence increasing the probable error. This could be eliminated by also specifying lower bounds but this will alter the structure of the problem such that the solution may be sub-optimal to an unacceptable degree.

Dantzig, ref. 11 developed very fast algorithms for solving the zero/one type of integer programming problem which answers the question "should we build this batch of assemblies or an alternative one" with no option other than yes or no hence this approach can only hope for reasonable accuracy in an assembly environment when the batch sizes are in the one or two range.

Separable variable programming, Hadley, ref. 30, can be used for dealing with non-linear constraints and can handle slightly concave sets which suggests that this approach may be used to solve special integer programming problems.

The main problem is that if the choice is between a large range of integer values the number of separable variables to constrain the problem increases the formulation and computation time. A further major problem exists in that it is possible with a concave set to obtain a local optimum which is considerably removed from the global optimum. This approach therefore can be disregarded for the problem in hand.

Some progress has also been made using direct search techniques which travel directly to a bound, testing the solution and then moving away, and returning to the bound of the convex set at a different point. The computational times recorded by Echols and Cooper, ref. 16, have shown considerable promise. The constants in the algorithms have a considerable influence on the efficiency of the technique and the feeling is that the determination of these for maximum efficiency is problem dependant.

In the problem considered the aim is to provide a production program which is known to be feasible and sufficient to cover a production period, which due to the large turnover and arrival rate of parts may be on a shift (8/10 hours) basis. This aim is constrained by availability of parts and orders. The error inherent in the truncation of a non-integer solution is, as mentioned previously, dependant on the distribution of order sizes and the solution size. The weekly order available for selection nominally for 1000 vehicles with approximately 30 different orders in terms of main derivatives. If it is assumed that the stock available is approximately 80% of total requirement then it could be reasonably expected that any solution will produce values averaging approximately 24. If these solutions were continuous and had to be truncated then assuming the average truncation to be 0.5 the total error would be approximately 2%. It must be realised that no absolute error estimation is possible in mathematical programming as it is problem dependant but this approach can be taken as a guide to the expected error.

A technique is, therefore, necessary which is both capable of fast computer execution times and yet keep any error due to non-integrality to a minimum and if possible zero. From the remarks made earlier pure integer programming seemed to hold little hope of fast execution and hence it was decided to return to the basic simplex linear programming technique and attempt to minimise any inherent errors.

If the normal simplex technique is considered then the transformation of the matrix from one feasible solution to a better solution proceeds by first selecting a pivotal element.

If the notation is adopted where

a is the constraint matrix

b is the limit vector

$\underline{b}$ is the row lower limit vector

$\overline{b}$ is the row upper limit vector

u is the bound vector

$\underline{u}$ is the variable lower bound vector

$\overline{u}$ is the variable upper bound vector

c is the row vector of objective function elements

m = number of rows

n = number of columns and

r, s denotes row numbers

j, k denotes column numbers,

e.g. a_{ij} is the element in the i^{th} row of the j^{th} column of the constraint matrix then the selection will proceed as follows.

PIVOT COLUMN

The pivot column is the column k for which a_{ok} = minimum a_{oj} for all j such that xj is not in the basis

PIVOT ROW

The pivot row is the row ℓ for which ϕ is a minimum when r = 1, 2, ------ , m.

The indication for the type of transformation to be performed on the matrix is determined by the lowest value returned from

(A) $u_k \qquad = \phi$

or (B) $\dfrac{b_r - \bar{u}_{jr}}{a_{rk}} \qquad = \phi$

or (C) $\dfrac{b_r}{a_{rk}} \qquad = \phi$

When this selection has been made then the set will be transformed in the following manner.

If the selection of ϕ has been determined by (A) then

$$b_r = b_r - a_{rk}\ u_k \quad \text{for } r = 0, 1, \text{------}, m.$$

and

$$a_{rk} = -a_{rk} \quad \text{for } r = 0, 1, \text{------}, m.$$

If ϕ is determined bv (B) then the negative simplex transformation applies

let $W_r = A_{rk}, 0 \leq r \leq m, r \neq s$

$W_s = 0$

$P = 1/a_{sk}$

$b_s = b_s - u_{j(s)}$ for $r = \ell$

$b_r = b_r - b_s W_r$ for $r = 0, 1,$ ------ , m.

$a_{sj} = a_{sk} \times P$ for $r \neq s$ and $r = s$

$a_{rj} = a_{rj} - a_{sj}\ W_r$ for all j and $r = 0, 1,$ ------, m; $r \neq s$

If ϕ is determined by (C) then the simplex transformation applies

$$b_s = b_s \times P \qquad \text{for } r = s$$

$$b_r = b_r - b_s W_r \qquad r = 0, 1, \text{------}, m; \; r \neq s$$

$$a_{sj} = a_{sj} \times P \qquad \text{for all } j$$

$$a_{rj} = a_{rj} - a_{sj} W_r \qquad \text{for all } j \text{ and } r = 0, 1, \text{------}, m; \; r \neq s$$

It can be seen that only the transformations resulting from (B) and (C) will cause a movement away from an integer solution, if b, a and u are all integers. This non-integrality can occur when P has a value other than unity. If a is now further restricted such that only values of 0 and 1 are present then P will maintain a unity value and hence only permit integral movement until such time as the transformation

$$a_{rj} = a_{rj} - a_{sj} W_r$$

occurs when $a_{rj} = 1$ and $a_{sj} = -1$, which in turn does not occur until either the same transformation has occurred with $a_{rj} = 0$ and $a_{sj} = 1$ or when transformation (A)takes place. This can then take the solution away from integer values when these transformations occur in the basis. The implication is however that if the problem can be structured into 0 and 1 elements of 'a' then the solution will tend to the integer solution if such a solution is also the optimum. There can be no guarantee attached to this approach but the important question is whether in a practical problem the number of non-integral values can be reduced such that the error in truncation is acceptable.

In order to test this the following practical, although greatly reduced problem was formulated :-

Motor vehicles are to be produced consisting of just a body with headlights and heaters. The vehicles can have three different trim colours but must have the same body shell, external colour and all other parts must be common. This condition is included to reduce the problem to a manageable size for experimentation. The choice of heaters is limited to :-

(a) NORMAL (N) (b) INDUCTION (I)

There are three types of headlight available :-

(a) L.H.DIP (L) (b) EUROPEAN (E) (c) FRENCH (F)

and the range of colours offered is :-

(a) RED(R) (b) WHITE (W) (c) BLUE (B)

The following constraints are imposed on the production of these vehicles :

(1) CAPACITY of the production unit.

(2) STOCK available.

(3) ORDERS on hand.

(4) PRIORITY of certain orders.

The company must have some objective in mind, and for the sake of simplicity the profit/vehicle was considered as equal and the maximisation of production taken as the criterion.

In practical terms there are generally two headlights fitted to each vehicle and the vehicle can only have two or none of any particular type fitted. The elements in matrix a are simply reduced to 0 or 1 by considering the two headlights as one part and dividing the stock figure by two. The trim sets can be treated in a similar manner, only now the minimum stock of any individual trim item is considered as the upper bound of the constraint.

The level of each constraint was varied in order to examine the integrality of the solutions at various severity levels. The values considered and results are tabulated in Appendix B but it will be useful at this point to consider a unique solution before discussing the general case.

The problem is now to build the maximum number of vehicles, given the following physical constraints

1. CAPACITY = 2000
2. STOCK (a) Heaters
   (1) NORMAL = 720
   (2) INDUCTION = 1200

   (b) Headlights
   (1) LHD = 760
   (2) EUR = 350
   (3) FRE = 200

   (c) Trim
   (1) RED = 620
   (2) WHITE = 556
   (3) BLUE = 578

3. ORDERS

Using the specified previously :

IFR 162 (52)*	IER = 206	ILR = 87
IFW 149	IEW = 107	ILW = 56
IFB 76 (25)*	IEB = 28	ILB = 195
NLR 106	NER = 63	NFR = 201 (76)*
NLW 212	NEW = 108	NFW = 71 (20)*
NLB 57	NEB = 96	NFB = 18

* Indicates the number of that order which must be completed if possible.

The problem (Model 1) was submitted to the standard linear programming 'packages' available on ICL 1905 (L.P. Mark 2), IBM 1440, IBM 360/40, 50 (M.P.S.). The solution from the IBM 1440 is shown opposite and the printouts from the other two are included in appendix B . It can be seen that the solution to the IBM 1440 is integer with a functional value of 1263. The printout implies that the optimum solution is to produce 106 NLR's, 212 NLW's, 57 NLB's, etc., and in this way the maximum number of vehicles will be manufactured with the available resources. The solution also indicates ways in which such a solution could be improved by a relaxation of certain constraints. This is shown by the REDUCED COST in the columns section and the SIMPLEX MULT. in the rows section. In practical terms this means that if the bound on the variable against which there is an indicator (NLR, NLW, NLB, ILR, ILW, ILB and EUROP, FRENC) is relaxed then a gain can be made in the optimal solution at the state rate. If single variable ranging is now undertaken on the solution (RANGEX) the extent of the gain can be examined. If the section concerning structural variables at bound is considered and in particular NLR then it can be seen that the variable has reached its upper bound of 106. If the INCR. ACT column is studied it can be seen that the indication is that a further forty seven vehicles can be produced if the upper bound (orders available) is relaxed from 106 to 153. In practice an enquiry could be made to the sales organisation as to whether they would be prepared to accept any additional vehicles of this type.

If the CONSTRAINT ROWS AT LIMIT section is now considered it can be seen that three items were out of stock (NORM, FRENC,

CONSTRAINT ROWS AT LIMIT

2	&NORM	U.L.	720.0000	720.0000	738.0000	.0000
				INFINITY-	642.0000	.0000
6	&FRENC	U.L.	200.0000	200.0000	283.0000	1.0000-
				INFINITY-	179.0000	1.0000
5	&EUROP	U.L.	350.0000	350.0000	455.0000	1.0000-
				INFINITY-	249.0000	1.0000

RANGEX ALLOC1

NAME	STATUS	ACT.LEVEL	ORIG.COST	UP.LIMIT LOW.LIMIT	INCR.ACT. DECR.ACT.	COST/UNIT COST/UNIT	LOW COST HIGH COST

STRUCTURAL VARIABLES AT BOUND

NAME	STATUS	ACT.LEVEL	ORIG.COST	UP.LIMIT / LOW.LIMIT	INCR.ACT. / DECR.ACT.	COST/UNIT / COST/UNIT	LOW COST / HIGH COST
NLR	U.B.	106.0000	1.0000	106.0000	153.0000	1.0000-	INFINITY
				.0000	88.0000	1.0000	.0000
NLW	U.B.	212.0000	1.0000	212.0000	259.0000	1.0000-	INFINITY
				.000	194.0000	1.0000	
NLB	U.B.	57.0000	1.0000	57.0000	104.0000	1.0000-	INFINITY
				.0000	39.0000	1.0000	.0000
NER	U.B.	63.0000	1.0000	63.0000	141.0000	.0000	INFINITY
				.0000	45.0000	.0000	1.0000
NEW	U.B.	108.0000	1.0000	108.0000	186.0000	.0000	INFINITY
				.0000	90.0000	.0000	1.0000
NFR	L.B.	76.0000	1.0000	201.0000	97.0000	.0000	1.0000
				76.0000	58.0000	.0000	INFINITY-
NFW	L.B.	20.0000	1.0000	71.0000	41.0000	.0000	1.0000
				20.0000	2.0000	.0000	INFINITY
NFB	L.B.	.0000	1.0000	18.0000	21.0000	.0000	1.0000
				.0000	18.0000-	.0000	INFINITY-
IFW	L.B.	.0000	1.0000	149.0000	21.0000	.0000	1.0000
				.0000	83.0000-	.0000	INFINITY-
IFB	L.B.	25.0000	1.0000	76.0000	46.0000	.0000	1.0000
				25.0000	58.0000-	.0000	INFINITY-
IFW	L.B.	.0000	1.0000	107.0000	101.0000	.0000	1.0000
				.0000	105.0000-	.0000	INFINITY-
IEB	L.B.	.0000	1.0000	28.0000	101.0000	.0000	1.0000
				.0000	105.0000-	.0000	INFINITY-
ILR	U.B.	87.0000	1.0000	87.0000	134.0000	1.0000-	INFINITY
				.0000	INFINITY-	1.0000	.0000
ILW	U.B.	56.0000	1.0000	56.0000	103.0000	1.0000-	INFINITY
				.0000	INFINITY-	1.0000	.0000
ILB	U.B.	195.0000	1.0000	195.0000	242.0000	1.0000-	INFINITY
				.0000	INFINITY-	1.0000	.0000

OUTPUT ALLOC123

OUTPUT COST 10**0 TOLERANCES 07 05 04 04

VARBLS	STATUS	NAME	ACTIVITY LEVEL	REDUCED COST
	U.B.	NLR	106.00	1.000
	U.B.	NLW	212.00	1.000
	U.B.	NLB	57.00	1.000
	U.B.	NER	63.00	
	U.B.	NEW	108.00	
		NEB	78.00	
	L.B.	NFR	76.00	
	L.B.	NFW	20.00	
	L.B.	NFB		
		IFR	79.00	
	L.B.	IFW		
	L.B.	IFB	25.00	
		IER	101.00	
	L.B.	IEW		
	L.B.	IER		
	U.B.	ILR	87.00	1.000
	U.B.	ILW	56.00	1.000
	U.B.	ILB	195.00	1.000

SLACKS	TYPE		NAME	ACTIVITY LEVEL	SIMPLEX MULT.
		OBJ	VALUE	1.263.00	
1	S		YIELD	737.00	
2	S		NORM		
3	S		INDUC	657.00	
4	S		LHDIP	47.00	
5	S		EUROP		1.000
6	S		FRENC		1.000
7	S		RED	108.00	
8	S		WHITE	160.00	
9	S		BLUE	223.00	

EUROP) although only two indicate that a further purchase of parts would be profitable (FRENC, EUROP). A further 83 vehicles could be built if the necessary FRENC parts were obtained and an additional 105 vehicles if EUROP parts were procured which indicates the degree of penalty on each part. The purchase of NORM parts would in itself free no more vehicles as all those held for a lack of that particular part are also held for other parts. The other two solutions to model 1 both returned optimal functional values of 1263 but offered different detailed solutions, ref. Appendix B.

It is important now to consider the question of integrality. In the solution shown all variables were integral but certainly as illustrated previously this will not always be the case hence it is necessary to explore the practical problem to examine if non-integrality is a problem and indeed if the structuring approach improves the likely error.

In order to perform this exploration the basic problem outlined above was used but with a very wide range of constraints and bound changes. The complete results and details of the models used are shown in Appendix B but can be summarised by stating that the overall error rate was found to be 0.053%,(a loss of 41 in a total of 76,551 vehicles in programs spanning weekly orders with an average order size of 26.9) in comparison with the expected 2%. It would therefore appear that structuring the problem into zero/one integers does tend towards integer solutions. In the case where a non-integer functional solution was found when this was constrained to be equal to the truncated value the structural variables returned to integer values. In the case where the functional was integer but the structural variables non-integer the solution was returned to integrality by constraining the functional to one less than the continuous solution. If such ploys are accepted then the error rate falls to 0.023%. The indication from the results of model 3 indicate that it may frequently be possible to seek an alternative integer solution at the optimum functional value, ref. Model 3 1 and 6.

In assisting the production controller to perform the allocation the implications are obvious. A saving will be realised in the effort involved in expediting, backlogs should be reduced, late deliveries can be minimised, priorities can be established for obtaining additional supplies, the optimum use can be made of the parts on hand, there should be a reduction in production loss due to rescheduling and running vehicles down the finishing tracks minus parts. To achieve this end the system requires

(a) an accurate and dynamic stock recording system

(b) a quick piece parts explosion

(c) a standard linear programming algorithm

Computerised packages are available for the last two items and the first has been implemented at the factory in question. The whole system must be computerised as it is only by this method that an answer can be provided in a short enough time to be useful. In a practical environment the time can be reduced by considering only those parts in short supply and the affected vehicles. This can be easily achieved after the piece part explosion section.

It is difficult to compare solution times for one computer and its software with those of another. As data input format and the facilities offered must influence the time. Generally the time taken on the IBM package was 0.6 min. to achieve an optimal solutinn and less than 0.01 secs. for each iteration when performing parametric programming. On the ICL 1905E the time on an equivalent program was estimated to be 0.4 min. to achieve optimality and again less than 0.01 secs. for each parametric iteration. The IBM package is however infinitely more sophisticated and worthy of the time penalty.

At this stage an attempt was made to put a small pilot scheme into operation at the factory. As there was no computerised piece parts explosion available the netting had to be performed manually which increased the total turnround time.

The allocation, however, was to be performed on an IBM 360/50 based at the Oxford, P.S.F. works with a Remote Job Entry link to an IBM 360/30 at the Castle Bromwich works. Due to a change in policy the computer link between the Oxford and Castle Bromwich works was postponed. This meant that the answer to the question of what to produce in a shift would arrive by post or at best telex three days later, hence the scheme had to be held until the necessary link is completed. The management have shown considerable enthusiasm in trying to implement as soon as it is feasible.

The implications of such a tool do not however stop at the shop floor level. With the model discussed it is possible to formulate the second stage of the solution to the material provisioning system and to use it as the vehicle of communication between the sales organisation and the production units. To such a model the production unit would supply information on projected stock levels of the component parts in a particular week on the basis of material ordered and available market intelligence. The sales organisation would then input data on their demand for the same week. Any conflict could then be resolved in the same manner as for the shop floor model, i.e. by relaxation of the bounds. It must be stated however that the production unit should do all that is possible to achieve the demand before any relaxation of the orders is considered.

It is suggested that this second stage should take place on a time scale shorter than the tentative demand obtained by examining the order bank and longer than the time when firm orders are issued to the production unit. In this manner the first objective would be to adequately provision the production unit to meet the demand from the sales organisation and secondly to flex the demand if this proves to be impossible, and finally to allocate the material as it arrives in order to optimise the management objective.

PART II

THE SEQUENCING AND CONTROL PROBLEM

Chapter III

THE SCHEDULING TASK

The scheduling of a production unit with a program of work to meet a stated objective, has for a long time attracted considerable interest not only from those involved, who frequently may not recognise the true extent of the problem, but also from those involved in academic research.

The first approach used by research workers has been to simplify the problem down into the main factors, in order that the total system could be more clearly understood. Unfortunately, at the moment it appears that the simplifying assumptions have frequently taken the problem so far away from the real system that the solution obtained, which is usually claimed to be optimal, is only valid for the derived problem and must be used with extreme care in the real-life situation.

On the shop floor, where the scheduler must come to terms with the problem, the approach appears to be to increase the amount of control as the problem increases in complexity. This can imply either additional staff (progress chasers), or a greater computerisation. With a large system the concept of global optimums for the manufacturing unit degenerate into local optimums when manual control is used. Each production controller will attempt to achieve the best performance in the section for which he is responsible. This may well incur a penalty as far as the total concept is concerned. Computerised schedulers to date, have relied heavily on sequential processing of the schedule, fitting work in where it will fit without regard to the optimal positions. If the complete schedule is not acceptable due to over utilisation of resources, etc., fresh scans are made to modify the position until an acceptable schedule is formed. Some computerised schedulers have been developed to a highly sophisticated degree, ref. 1 and 4, but most of the successful attempts have involved the process type of industry.

A considerable number of research workers have sought ways of obtaining optimal schedules, a concept which can so easily be all things to all men. The idea that it is possible at the beginning of a period to produce an optimal schedule, valid for that time, is in practice optimistic. Schedules depend for their efficiency on considerations of the available resources and objectives at that time. Although there must be a global objective which should remain stable, such as maximise profit, changes in the interpretation of this objective will inevitably occur as feedback controls such as cost analysis, or alterations in sales policy, influence the situation. The resources available at any one time will almost certainly alter from those used to determine any optimum schedule. In the face of uncertainty on the possible changes, it would seem reasonable to aim for a scheduling system which could investigate such variations.

Scheduling can be undertaken on both a macro or micro scale; the demarkation between the two is not firm, or of major importance, but generally it is considered that if the period under examination is less than one month it is likely to be micro and above, macro. A macro study would involve many aggregated factors in the determination of the schedule, e.g. Lippman, ref. 46 and Hansmann ref. 31 consider employment as one of the major elements with a fairly slow response time. Such studies seek to lay down the scheduling of work over long periods so that capital investment and recruitment can be assessed. Although such scheduling is essential, this study limits itself to the micro problem existing in the real system examined.

The micro approach can be further subdivided into deterministic and heuristic. Using a deterministic approach several authors claim optimal or near optimal solutions to the general scheduling problem, ref. Giffler 21 and Brookes 6. The favourite target for the academic attentions has been the job shop environment, which is considered as one of the most complex. In its simplest terms it consists of loading n jobs to m machines in such a way as to optimise some objective, e.g. minimise makespan, minimise late deliveries, maximise production, etc. and in theory there are $(n!)^m$ different sequences to be examined. In practice, however, the number of feasible schedules is considerably less, but still sufficient to present a formidable problem.

In deterministic terms this is a mathematical programming problem constrained to integer values, and many workers have formulated solutions on this basis, ref. Smith 54, Giffler 24, Wagner 59, Bowman 5, Story 57. The results so far have, however, been disappointing. Bowman reports that 'the computational effort involved makes the solution of such problems (scheduling/sequencing) uneconomical'. Story and Wagner add 'we have not yet found an integer programming method that can be relied upon to solve most machine sequencing problems rapidly'. All of the problem formulations have suffered from the same simplifying assumptions ref Wagner, 59.

1. No machine may process more than one operation at a time.
2. Once a job is started on a facility, it is processed to completion.
3. The job processing times, including set up time are known and are independent of sequence.
4. Transportation times between facilities are neglected.
5. Machines do not break down.
6. Once a job is started the order for the job cannot be cancelled.
7. The job route is given and no alternative routings are permitted.
8. Jobs do not re-cycle due to fabricatinn errors, engineering changes, etc.
9. Due date of each job, if known, is fixed and cannot be altered.
10. Available labour is stable and non-fluctuating.
11. In-process inventory is allowable.
12. Lot-splitting and phase overlapping is not permitted.

The first assumption may be considered reasonable although in practice it is common to group some jobs into batches incurring only one set up time. In a job shop however most of the work is allocated individually to the machine. The second assumption is fair in that removing a job before completion usually only occurs due to oversight of a higher priority job, or a change in the priority level. The third assumption is only realistic if the setting is not a separate or major operation. If for example the setting is skilled, then a fixed number of setters may well travel round from machine to machine and time awaiting a setter will be incurred if more jobs require setting than there are setters (i.e. no longer independent of sequence). The fourth assumption is reasonable.

Assumptions five, eight and ten all imply stable resources which rarely remain fixed, e.g. assumption five only details breakdowns but preventative maintenance can also effectively remove a resource. Recycling effectively enters new orders into the system absorbing, usually immediately, the desired resource. Assumptions six and nine are reasonable and have to be assumed in any situation.

The question of an alternative technology or operation by which the desired job can be manufactured, implicit in assumption 7, can be considered unbounded. There is usually however at least one alternative feasible method of production. Shaping and milling in a machine shop can in certain cases be used to produce the same cuts and a scheduler will certainly redirect such work to an idle machine if the preferred machine is overloaded.

Assumption eleven is valid as this occurs in practice. Assumption twelve, however, has only limited validity as the techniques mentioned are widely used to ease the schedulers task. Although few studies mention that all of the jobs are considered independant, i.e. each machined job can be despatched separately and does not have to wait for the completion of other parts, the assumption is implicit in the work undertaken. Orders are frequently placed on a job shop which require for their completion several parts (an assembly), each of which have different routes through the machining system.

Research work has also been undertaken, on the deterministic basis, in the flow shop environment both from the scheduling aspect refs. 38, 48, 29, and also in the line of balance area. The scheduling work has, however, had to draw on many of the simplifying assumptions made in the job shop formulation. The computational problems reported, using the branch and bound technique of Land and Doig (43), do appear to be considerably less than for the job shop.

In summarizing, however, the mathematical programming approach generally experiences computational difficulties in solving the derived problem, which in turn is not truly representative of the actual situation and as such for this study can be disregarded.

Many research workers have recognised this situation and have turned to the heuristic approach and in particular simulation, refs. 17, 18, 2, 52.

Eilon (18) considers that 'the vast complexities of job shop scheduling make this problem virtually impracticable for a theoretical treatment', and recommends simulation as a tool to be used in such cases. He then goes on, however, to formulate a problem with virtually the same assumptions made in the deterministic approach, although he does impose randomly input disturbances (urgent jobs). The arrival of jobs is considered a continuous process with known interarrival rate distributions, which are sampled and not presented as a step input as in the mathematical approach.

Eilon seeks to demonstrate the advantages of particular scheduling rules to the general problem, but as mentioned previously, it is only with extreme reservations that such results can be applied to the individual situations.

The technique does however lend itself to further development, until eventually a simulation model can be built which describes to an acceptable accuracy the manner in which real life situations operate. This may involve allowing alternative routing, job recycling following rejection distributions, etc., The results then can be used on the actual system with a reasonable amount of confidence.

Several workers, refs. 44, 55, 26, have taken this idea and used a dynamic simulation model as the heart of a scheduling system. The reports of particularly the Hughes Aircraft system have shown a considerable increase in efficiency. Steinhoff (55) claims that after 6 months of operation.

1. The percentage of orders completed by their scheduled due dates has increased by 10%.
2. The average order cycle time in the shop has been reduced by one week, effecting a significant reduction in work-in progress inventory and a simultaneous increase in machine and man power utilisation.

3. The co-ordination (expediting) effort in the shop has been reduced by 60%. The savings realised from the above more than offset the computer costs of simulation.

As the scheduling problem considered in this study is a very practical one with constraints removing it well away from any general scheduling problem, it was decided to examine the system with the aid of a simulation model.

From such an approach an optimal solution cannot be guarranteed and the only way that appeared open was to use some form of heuristic decision rules, attempting to maximise the sequencing efficiency. Modelling had the advantage that the relative gain to be made by the introduction of a set of decision rules could be measured prior to implementation in the actual system. Experimentation on the actual system would have been prohibitively expensive in terms of possible production loss, education, etc., and even then the results would have been unreliable as the environment would have changed from test to test.

The criteria that had to be laid down for such a model were that it firstly must be a true representation of the manner in which the main factors influenced the sequencing efficiency. A totally realistic model is impracticable and defeats one of the principal objectives of modelling, namely simplification. A compromise had to be sought at an acceptable accuracy level. Secondly the model had to built in such a way that modifications to both input and system logic were easy and inexpensive to implement.

This condition had to be imposed as the approach was heuristic, and as such required considerable experimentation. As the model had to be very dynamic in order to permit such change, a computerised simulation model was chosen as the means of evaluating alternative strategies and decision rules.

Chapter IV

SYSTEM DESCRIPTION

The boundaries of the problem were initially set to include only those functions which directly affected the production of painted and finished vehicles. It was found to be virtually impossible to stay within these boundaries and maintain the general validity of the work, avoiding the possibility of only solving a transient problem. Certainly in the area of material provisioning the boundary had to be expanded to cover the examination of future build programs.

In considering the sequencing and production control aspect of the problem the boundaries were slightly easier to define, and were generally taken as the examination of all the facilities between the completion of the assembled white metal body shell, to the despatch of the painted and trimmed shell in a condition to receive the engine, transmission etc.

Certain major simplifying assumptions had however to be made in order to isolate the sequencing and control problem. One of the principal factors in such a problem is the amount of interprocess storage available. The idealistic size of this store is determined not only on sequencing requirements, but also on what is, with British Leyland, termed 'natural storage' demands. This 'natural storage' is that which is required between two processes when,

(a) different start and finish times are worked on the two processes
(b) one process works two shifts (day/night) and the other works only one (e.g. day)

(c) different holidays are taken for each of the production stages.

The author found it difficult to consider (a) and (c) as 'natural', for they are not based on economic grounds but rather on the customs and practices that have grown up in individual factories. The management seem unable to solve this problem of offset working and accept the limitations imposed. The calculation of the size of this 'natural storage' is simple given the production rates and the offset time. This factor, therefore, was not considered as the elements will change rapidly leaving only transient solutions.

As discussed earlier, labour absenteeism and under manning were not considered, as these factors can fluctuate very quickly and to include them would add nothing to the validity of any sequencing rules which presume labour manning to be at the appropriate level. Start-up delays on the major plants were, however, included as they are fairly stable and do impede the production efficiency.

Material shortages,as discussed in earlier chapters, were a constraint on the system at the present, causing rescheduling and additional work to fit missing parts after the finishing tracks. This constraint exists directly because of

(a) the lack of information to production control concerning the stock levels;

(b) the absence of a sophisticated piece parts explosion technique applied to trim items with which to examine demand;

(c) the absence of any feasible attempt to optimise the use of the available stock,

and indirectly,

(d) inadequate provisioning.

This material constraint was not considered in the study of sequencing as the factors listed above can be, and should be, eliminated or minimised. It is technically and practically possible to give production control a program which is not subject to any material shortages, and which makes the best use of the available stock. (This system is outlined in chapter II) hence removing the constraint.

Before proceeding to a detailed description of the processes involved in the system, it is important to note that principles concerned were frequently not documented, and as a result some of the judgements at the decision points were very informal and left to the discretion of the man on the spot. This is common within the British Leyland organisation, as the informal philosophy of management, compared to the rigid formal approach used in companies such as Metal Box, etc., with well defined areas of responsibility and published terms of reference. It did however lead to different opinions on the precise factors and levels involved in the decisions, as several men were frequently concerned in the same decision.

The following description should be read together with the simplified schematic drawing fig. 4 included in pull out form at the end of this chapter.

The beginning of the system under study was considered to be after the white metal body assembly.

Body shells enter a storage area after passing off the white metal build lines, ref. photographs 2,3,4 and 5 and it is from this store that the vehicles are selected to be loaded to the first paint plant. This paint plant, known as the 'electrocoat' performed the priming function, first cleaning (mechanically and chemically) and then immersing the whole shell into a paint bath for the body to be 'plated' with a coat of primer paint, ref. photograph 6. The body is then sprayed with a sealing paint coat.

Selection of a body shell is made by reference to the 'track ratio'. This is the overall program load ratioed in terms of the individual body derivative, e.g. the program may be for 700 type A, 300 type B and 100 type C in which case the track ratio would be 7:3:1. The term 'track ratio' derived from the fact that the final trim or finishing tracks were single product lines, and as such had to produce in that ratio to complete the program.

The load would continue in this manner unless one of the following conditions existed,

(a) the electrocoat plant was full,

(b) there was a shortage of white metal bodies,

(c) there was a mechanical breakdown,

(d) there was no room to off load the plant (as the plant was, in simple terms, a chain conveyor once the off-load was prevented it also halted the on-load)

(e) there was a start-up delay.

The basic load ratio used to schedule the electrocoat was however, modified if, due to stoppages and changes in demand pattern, the system stock (defined as those body shells held between the load to the electrocoat and the finishing tracks) started to indicate an inbalance in the type of derivative held. This constituted the main feedback control to stabilise the system. A further feedback control loop monitored the ratio of saloon bodies within the system after the electrocoat and prior to the No. 1 colour paint plant, excluding the unofficial store, and had the effect of overriding the load ratio and forcing an alternative body to be loaded. It must be stressed that both of these feedback controls were informal and initiated at the discretion of the supervision.

The electrocoat paint plant had a capacity of 93 stations with a nominal cycle time of 2 minutes giving a total process time of 186 minutes. The off-load could only take place if :-

(a) there was no mechanical breakdown

(b) at least the process time has elapsed

(c) there was room to off-load

(d) there was a bogie available onto which the body shell could be placed.

Once off-loaded there were three areas into which sealer coated bodies could be sent. Two of the areas were unique to the main model derivative, namely saloon body shells had one fixed area and so did the commercial body shells, ref. photographs 7 and 8. The third area, which could accept either type of body shell, was completely unofficial but had become accepted as necessary storage and was located outside the production building, with bodies being distributed in the roadways.

The second feedback control, mentioned previously, could not prevent bodies already loaded from passing off the electrocoat, and into the main store causing possibly further instability in the system. The practice was therefore to transfer those body shells which would further upset the balance into the unofficial store and their return prevented until stability was restored. A body shell was only returned from the unofficial store when the electrocoat plant was not functioning. When such a return took place the body shell was introduced into one of the two unique areas, mentioned previously, according to the main derivative type, i.e. saloon or commercial.

In these areas the bodies were placed on a floor conveyor which propelled the body along whilst all of the primer paint drain holes, necessary to permit the escape of paint during the immersion process, were fitted with grommets and any defects in the paint coat were rectified. These two areas were referred to as the saloon and commercial plugging areas and had capacities of 16 and 19 respectively, ref. photographs 7 and 8.

At the end of each of these two sections were marshalling or assembly areas where the bodies were sorted into a loading sequence before being loaded onto the appropriate colour paint plant. In the case of saloons the area was capable of holding 10 body shells and for the commercial assembly area 6. The effective area for saloons, in practice, was not limited to the official area and in order to build batches up it was necessary to encroach into the main storage area prior to the trim tracks. The main store was capable of holding 44 body shells, but as the encroachment of sealer coated bodies could not be permitted to monopolise the area a level had to be set at which further encroachment was refused. This level proved difficult to determine as it depended very much on the supervisor. A series of observations revealed the level to be judged not by the number of sealer coated body shells in the store, but rather by the total activity level within the main store. The point at which encroachment was refused appeared to occur when the store already held 30 body shells, e.g. if there were no bodies held encroachment would be permitted up to a maximum of thirty whereas if 20 body shells were held in the main store then only 10 sealer coated body shells would be allowed to enter. Generally commercial body shells were not allowed to encroach into this same area.

For the saloon vehicles the load section, prior to the No. 1 paint plant, had an option of two areas from which to select a sealer coated body shell, either the principal assembly area or the main store into which sealer coated body shells had been moved. The body shell selection is made by attempting to find the correct derivative to match the desired sequence on the paint plant. This is the sequence which is laid down by production control and is in effect an authorisation to produce a certain number of a particular colour in a derivative type. The physical authorisation is in the form of an addressograph plate which is raised for a particular vehicle and which must be attached to the body shell headlight aperture before loading to the colour paint plant, reference to photograph 9. These plates are only released at the beginning of each work period, and if the desired sequence cannot be met then the option existed to change to the next demand on the schedule, provided that it had been authorised, i.e. within the scope of the available plates.

This implied a scan limit on the alternatives that could be selected from the total schedule. In this way the production control department attempted to limit production to those vehicles which they had examined.

An attempt was made, in selecting the schedule for the whole week, to form colour batches for the paint plant. This was achieved via what was termed, by the production controllers, vertical and horizontal scheduling. In simple terms a register is kept for each model produced and listed the models down each page in what at the beginning of the week was felt to be a desired sequence. This was the vertical scheduling, and for example the controller may have decided that for the ADO 15 the first twenty should all be white, followed by ten that should be black and so on until he exhausted the weekly program for that particular vehicle. The process would then be repeated for the other vehicle models.

The horizontal scheduling then takes place across each of the model registers to determine the sequence for a particular work period and considered the availability of material, colour batches and the track ratio. For example if all of the material is available the controller may have decided to load 21 white

ADO 15's followed by 9 white ADO 16's, followed by 3 Wolsey/Riley ADO 15's giving a colour batch of 33 and maintaining the track ratio of 7:3:1. A better schedule, in terms of more even supply if finished bodies would obviously be 1:3:7; 1:3:7; 1:3:7. The first problem encountered was the fact that as can be seen from table 1 the colours were not all common to each of the models produced, which resulted in a conflict between paint colour batch sizes and track ratios. The second, and major problem, was that all of the material was rarely available for every vehicle on the schedule, causing a further constraint. The conflicts were always resolved firstly to attempt to cater for the demands on stock, secondly to keep each of the finishing tracks supplied, and only when these could be satisfied was the colour batch considered. The examination of the material problem, as discussed in the chapter on material allocation, is infeasible manually, not only from the combinations aspect but also because account had to be taken of that stock that was required by body shells already in the system, but which had not, at that point, reached the assembly stage. In practice, due to the constraints, the vertical schedule was virtually abandoned within one shift from the start of the week, and the main scheduling effort was taken in the horizontal scheduling, with the registers just being used as lists of outstanding orders.

When, however, the shop floor were able to find a sealer coated saloon body shell of the correct model type to match an available addressograph plate, the body was loaded to the No. 1 paint plant, provided that :-

(a) that there were no sealer coated body shells being recycled round the No. 1 plant in which case the recycling body would take priority;

(b) that there was no breakdown;

(c) that there was room on the paint plant;

(d) that there was room to off-load (a conveyor dependant plant similar in concept to the electrocoat).

The body shell, once loaded, then proceeded round the No. 1 paint plant, propelled by an overhead conveyor, having several preparatory operations carried out before reaching the spraying point. The operations included rubbing and wiping down, applying underseal to the wheelarches, etc., filling in any creases at panel joints. At the spray section the body shell was introduced into a pressurised booth, ref. photograph 10, where various sprayers painted first the interior, inside the engine compartment, the boot, the underside of the wings, the door shuts and the sill before passing on to the next section, where the remaining outside panels, i.e. roof, doors, wing, etc., were painted. The body shell then passed on to a second group of sprayers who applied a further coat of paint, 'wet on wet'. The body was then stoved in a heated oven after which it was presented to the inspection station for examination, reference photograph 11.

The inspection task, which is detailed in a later chapter, was a visual examination of the body shell which was rotated in order to permit a close view of the roof and bonnet. Having formed a judgement on the condition of the body shell, the inspector filled in a report which was attached to the body.

The production supervision then decided if the faults noted by the inspector could be rectified after the finishing tracks (on loop line or lowbake), or whether they were serious enough to warrant processsing through the rectification plant (No. 2 paint plant). If acceptable the body shell would be moved into the main storage area prior to the tracks.

The No. 2 paint plant was a rectification unit and could undertake repairs to individual panels, in which case masking was needed, or on the complete body. The plant had a capacity of 34 stations and a nominal cycle time of 2.3 minutes. The body was taken through by a floor conveyor system and was inspected after being stoved. If unacceptable for trimming it was recycled, otherwise the body shell passed into the main storage area.

A commercial body shell proceeded through basically the same steps, but on a different production line. Firstly the drain holes were filled and any necessary rubbing down carried out. The bodies were then assembled into batches and loaded to the Lysaught colour paint plant provided that :-

(a) there was no recycled body shell awaiting load, in which case the recycling body has priority;

(b) there was no mechanical breakdown;

(c) there was sufficient room on the plant;

(d) there was room to off-load a body.

The Lysaught plant had 20 stations and a nominal cycle time of 4.8 minutes. Off-loading was permitted when :-

(a) the process time had expired;

(b) there were no breakdowns;

(c) there was room to offload.

The inspection task was performed in the same manner as for saloons, only the body shell was not rotated. If the body shell was considered as unacceptable for transfer to the finishing lines, it had to be recycled round the Lysaught, in which case it would queue in the rectification storage area. If acceptable, the commercial body shell would be hoisted up onto the gantry storage area for subsequent loading to the finishing track, or if that area was full it would queue in the temporary storage area between the Lysaught and the electrocoat paint plants. The commercial finishing track was laid out on a platform above the four saloon tracks. Only three saloon tracks are shown in figure 4 as one is a duplicate. Generally, a body shell would be loaded to its appropriate finishing track if,

(a) a suitable body shell (in terms of model derivative) was available.

(b) there was no mechanical breakdown.

(c) there was room on the finishing track to accept a body shell.

(d) the track was scheduled to be working. Some tracks only worked during the day shift.

(e) there was sufficient suitable material available to make tracking of the body shell feasible.

If the initial examination of the stock position had been done completely (which as stated previously is infeasible, manually) then the last constraint should not have occured. In practice, however, lack of suitable material occured frequently. This meant that either an alternative body shell would be loaded, or the body would be submitted having accepted that not all of the trim items could be fitted, (known as 'OK LESS') photograph ref. 17, in which case they would be added as an additional item after the trim track. Only approximately 10% of the total number of parts fitted were impossible to fit as additional operations, but as the practice incurred obvious problems (cost and conjestion) it was only used in times of extreme shortage or particularly poor scheduling. A third alternative existed, in that it was possible to reschedule the body shell, prior to loading to the finishing tracks, such that suitable material was available. For example an ADO 15 body shell could have been allocated as a French market vehicle, painted white, at the point when it was loaded to the No. 1 paint plant and given its appropriate addressograph tag. If when it reached the finishing tracks it was discovered that, say, the French headlights were not available, then the vehicle could be rescheduled to an order for a white, Swedish ADO 15 for which the parts were available. This would involve removing the addressograph tag, identifying an alternative order for which stock was available, and fixing a new tag to the body shell. If this rescheduling was performed quickly without a complete examination (again infeasible manually), it could lead to further problems at a later time causing still further rescheduling. The time to undertake this task depended on the availability of stock (severe shortage reduces the number of alternatives), the presence of a production controller, the number requiring scheduling (production was, as explained previously, in batches where possible) but in practice tended to be fairly short and random. If the rescheduling started to take a long time, the tracks would demand to run the vehicle 'OK LESS' in order to avoid stopping the finishing track.

Once loaded to the finishing track underfloor assembly work was carried out, fitting brake and suspension fluid pipes, mounting brackets, etc. All of this work was carried out over a pit in which the assembly fitters worked. The wiring harnesses, carpets, lights, facia panel, seats, roof lining, electrical equipment, windows, badges and grills etc., were then all fitted to take the body shell upto what was termed a trimmed condition. In fact the body shell still acked a power unit, transmission, suspension unit and wheels but as far as the Castle Bromwich works was concerned it should be a finished body shell, ready for despatch to Austin Longbridge.

At the end of each saloon finishing tracks the body was inspected for both trim and paint defects. The extent of any rectification work required determines the destination of the body shell. If a trim defect or missing part was reported, then the fault could have been rectified, before the body left the track, or it could have been done on the loop line or whilst awaiting transportation to the despatch bay, or in extreme cases in the despatch bay. If a paint defect was present then the body would be rectified on the end of the tracks if the defect occurs in such a position on the body that air drying spraying was acceptable, otherwise the repair would be undertaken on either the loop line or on the lowbake. Generally the defect could be rectified on the loop line provided that the defect had not exposed the base metal, in which case it was rectified on the lowbake. The decision on where to perform the rectification was left to the discretion of the production supervision.

The lowbake paint plant was one which could perform any type of paint rectification on a masked body, in the case of individual panels or on the whole body. The degree of masking (the covering of area which must be protected from the spray of paint) undertaken at this stage was significantly higher than that required when rectifying on the No. 2 paint plant as the trim items, fitted on the finishing track, require protection, e.g. door handles, windscreens, etc. The oven for storing the body, after spraying, was longer than that employed on the No. 2 plant and ran at a lower temperature to prevent the decomposition and premature failure of adhesives used in the soft trim, and indeed to stop the trim itself from burning.

The body shell was only off loaded from the trim track when

(a) there was no mechanical breakdown

(b) there was room to off load the body

otherwise a body would remain on the track, which was of the proximity conveyor type, i.e. queueing can be achieved.

It is important to note that the body shell had to pass through the area at the end of the tracks and if that was full this would prevent bodies, which could otherwise go straight into the despatch bay, from being off-loaded.

The loop rectification line undertook minor rectification work and additional painting which had to be done over parts fitted on the track. If the preparatory work, necessary to prepare a panel for a respray, i.e. rubbing down, exposed the base metal then the body would be left on the line to complete the circuit after which it would be transferred to the lowbake paint plant. Recycling round the loop line was not permitted but a body loaded to the lowbake remained there until it was in an acceptable condition for despatch.

When the body shell was judged to be acceptable from any of the different production points, i.e. directly off the tracks, off the loop line or off the lowbake plant, it was moved into an area to await transfer to the main despatch bay. Provided that there was room in the bay, the body shell was transferred as soon as the gang responsible for the work could move it.

The commercial body shell was finished on the elevated track, and if it was in an unacceptable condition after it had been completed the rectification work is carried out in a small area adjacent to the track. Acceptable bodies passed on to queue for the use of the crane, which when free lowered the body into the main despatch bay.

Once in the despatch bay body shells would wait for suitable transport to the next production unit.

The preliminary study of the system revealed the need for information on the following points

(a) the plant capacities and feasible speeds

(b) the incidence of breakdowns and the duration times for all of the mechanical system

(c) the system factors which contributed to the rejection and storage decisions

(d) the rejection levels and influencing factors

(e) the storage sizes and queue disciplines

It was therefore decided that, before proceeding to building the model, it was necessary to examine closely the whole question of paint rejection rates to include the all important inspection task.

SIMPLIFIED SCHEMATIC OF THE PRODUCTION SYSTEM

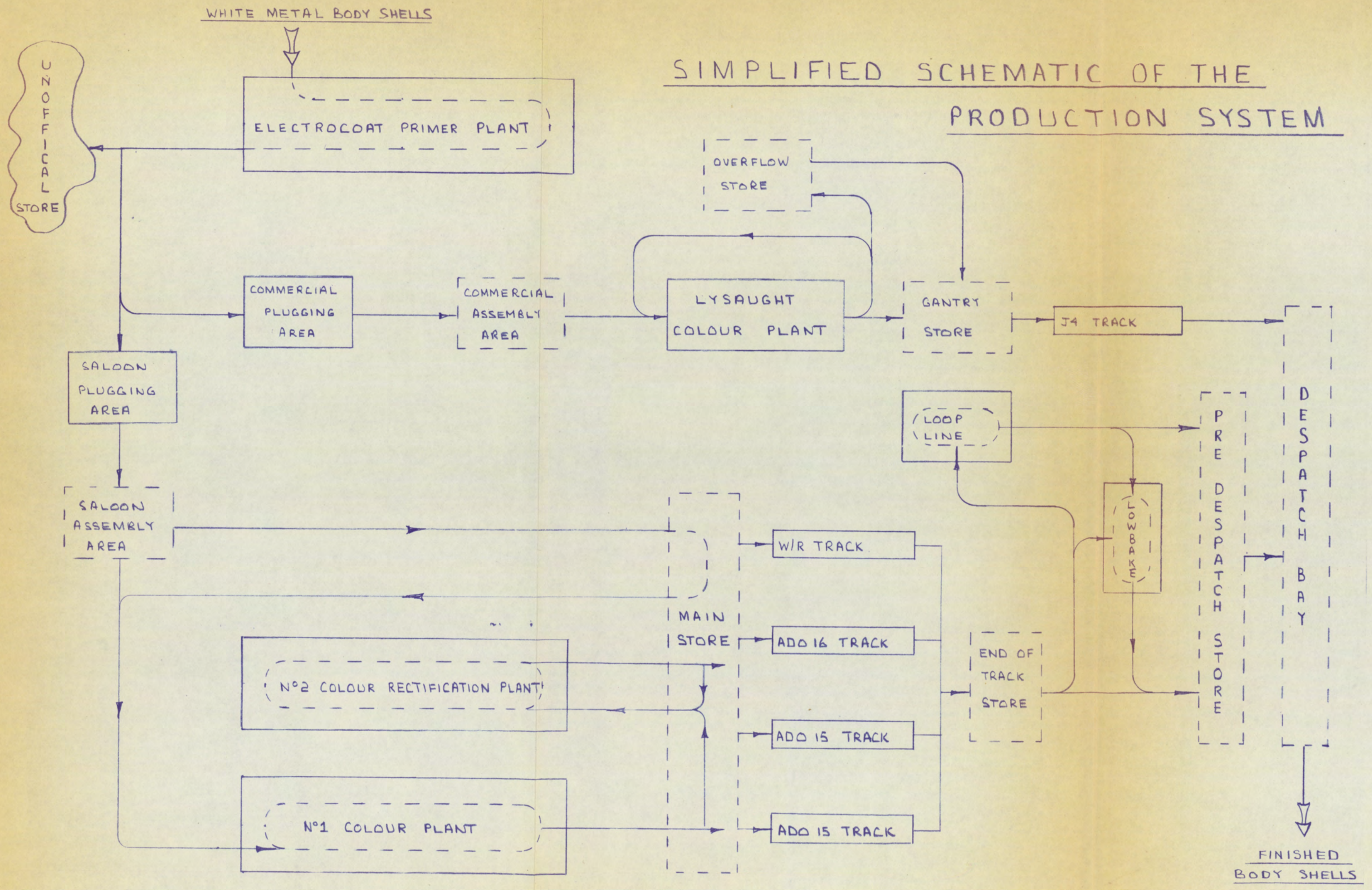


FIG IV

Chapter V

THE INSPECTION TASK

Before proceeding to a detailed analysis of the paint shop breakdown and rejection rates, it is important to consider some of the factors which react on the system.

The whole subject of paint inspection is one which arouses considerable interest and emotion within the motor industry. The decision as to whether or not a painted vehicle is in an acceptable condition is very subjective, and as a result any attempt at analysis, within a practical environment, is both difficult and provocative. If consideration is first given to the inspection task itself, then it clearly fits into the scanning class of inspection, as defined by Harris, ref. 32. There is general agreement between quality control staff and behavioural scientists that the task splits into four basic elements, ref. 34.

a) Interpretation of some acceptable standard by which to judge.
b) Comparison of the inspected item with either the absolute value or some picture the inspector may have in his mind.
c) The decision as to whether or not the item is sufficiently close to the standard that it can be accepted.
d) Action to discard or recycle the item and to record the findings.

The interpretation element was virtually ignored at the plant under study, with the only formal standard being one which is defined "off colour", i.e. the inspector was provided with a small sample plate, which he could compare with the painted vehicle, to judge the acceptability of the colour shade. The standards covering the remaining eighteen rejection conditions were left to the inspectors experience of an acceptable fault. Comparison and decision processes are carried out on the basis of these standards.

The mechanics of the actual task varies from inspector to inspector. One inspector would examine the front of the vehicle first, and then proceeding clockwise to inspect one side, then the rear, the remaining side, the roof and the floor in a similar manner. Another would inspect panel by panel, reporting on each after inspection. Harris, ref. 33, produced evidence to suggest that as product complexity increases, so the percentage of defects detected falls. In this context it would imply that by splitting the search area, the inspector reduced the complexity of the inspection and thereby increased the probability of fault detection. Other workers have confirmed this finding, ref. 47. It has also been found that as the defect rate increases, so the percentage of defects detected increases, ref. 33, p and it is said that the scanning inspection task is self exciting, i.e. if a fault is found, then it stimulates the inspector into looking for other faults. It has also been suggested by McKenzie (ref. 47), that after some time at a task, an inspector establishes rejection rate norms which he will subconsciously follow, i.e. he will expect to reject so many per hour. This is said to be particularly noticeable when the inspectors performance is judged on the rejection rate he records. As far as the author was able to ascertain, there was neither any formal or informal system of recording each inspectors rejection rate at this plant. The subject was only raised during informal discussions between production and inspection foremen, usually at times when there was a shortage of painted body shells. This particular pressure to which inspectors are subjected (production demand) is well known in industry. McKenzie considers the organisational pressure on inspectors to far outweigh the pressure of inter-personnel relationships. In the factories studied however, the inspection department in a particular area was not responsible to production supervision but were accountable to a quality control manager, who in turn was responsible to the managing director.

The decision on acceptability of an item is also subject to considerable variability, as Irving, 39, illustrated. He showed that in a visual inspection task little value could be placed on the decision of a single inspector, and he suggested that consistency would only be achieved by considering the judgements of several inspectors. In practical terms the policy of say triplicating the number of inspectors (Irving suggested a minimum of 6) is not economically viable and certainly larger gains could be expected by modifying other factors.

Vigilance of the inspector is another factor which is always considered to be a major influence in a visual inspection task. Several workers, Fraser, (ref. 21), and Jerrison, (ref. 40), have recorded a drop in detection rates after as short a period as 30 minutes. These minutes have however been on relatively simple inspection tasks, and results must be viewed with some reserve as to their practical validity. Jerrison (ref. 40) showed that when the complexity of the task was increased there was no vigilance decrement. At Pressed Steel Fisher the longest possible continuous work period was three hours, and the task of inspecting a complete body shell was considered complex compared to the simple can areas used in laboratory experiments, hence the vigilance decrement can be neglected.

It is also important to consider the people who carry out this task of inspection and their training. It is said that workers are transferred from other departments to inspection because they are no longer able to keep up with the piece work rate, either through ill health or age. This comment may however be a reflection of the sometimes antagonistic attitude that McKenzie referred to that exists between production and inspection. Generally people were selected by interview from other sections of the factory, e.g. welders, fitters, sprayers, track assembly workers, etc. It is however a fact that the average age of an inspector within the paint shop was 53.19 years compared to 46.17 years as the average age of piece workers. This difference is significant at the 1% level. There is also a considerable difference in the distribution of ages. (Graph Nos.1,2,Appendix C).

The training given to an inspector is informal and consists of in situ training by accompanying an experienced inspector for a period. The time of this period depends on two factors -

1. the ability of the trainee
2. the demand for inspectors.

In practice this period varied from one week to two months with no off line training undertaken.

In summary it was clear that the inspection department at Pressed Steel Fisher, Castle Bromwich, paint, trim and finish, had not established its true role in the manufacturing cycle. Instead of acting as a dynamic feedback to production, providing useful information which, in its analysis, can be both objective and constructive, it was assuming the role of a tiresome overseer, necessary only in response to the desire of senior management to maintain current quality. The maintenance of an acceptable quality level appeared to be the main goal and progress towards improvement is relegated to a negligible degree.

Chapter VI

REJECTION AND BREAKDOWN ANALYSIS

The need to examine the factors contributing to the rejection and breakdown rates has been established in a previous chapter and from the preceeding comments it can be seen that the whole question of inspection is very complex and a complete study constitutes a major piece of research work.

The constraints of time and industrial problems unfortunately limited this particular study to a more modest level and the following assumptions had to be made.

1. that any technical factors contributing to the rejection level, e.g. changes in paint viscosity, booth pressure drops, etc., remain uniformly distributed over all vehicles and were independant of load sequence.
2. that, in a like manner, inspector variability was independant of sequence. This assumption may be open to question for it was found that certain sequences tended to be run at particular times during the week and as such the recorded rejection rate may have been subject to a vigilance factor.

Considering Jerisons observations, however, and the low incidence of these fixed sequences (the highest occurance of a sequence repeat, at the same time for a period longer than one hour, was a case of four observations in twelve weeks), this error was considered to be negligible.

Both assumptions can only be valid if a large sample was taken and as a result a comprehensive data collection system had to be implemented to gather the relevant information over a long period. This period was chosen to be six months and when editing had been carried out on the data this covered 57,000 vehicle cycles. The error rate detected by editing amounted to only 8% of which it was possible to recreate 2%. The information validity was impossible to check completely but from a small sample the accuracy was found to be 92%.

Unfortunately, due to trade union opposition, the full data collection system could only be implemented on the No. 1, No. 2 and Lysaught paint plants (marked X on the simplified schematic of the production system) Fig. IV. A second data collection system had to be devised for collecting information and rejection rates off the finishing tracks, loop line and the low bake paint plant (marked Y on the schematic).

In the first system when a body shell was submitted for examination the inspector records

(a) the date
(b) the model
(c) the colour(s)
(d) the fault(s)
(e) the panel(s) involved
(f) where, in his opinion, the body shell could, technically, be rectified. The decision as to where the body shell was indeed rectified was the perogative of the production supervision.

The source document, of which a sample is included in

Appendix C, was ripped off a pad of serially numbered sheets. From this number it was possible to discover the sequence and as the senior digit indicated the paint plant involved it was also possible to record the plant where the body was sprayed. The data from the source documents was transferred to punched cards to be submitted to computer analysis.

A suite of computer programs (PL/1 and R.P.G.) were written to analyse the data. Briefly the first program reads the data in, checks validity and generally edits it before storing it on magnetic disc. The second program printed out the history of each vehicle as it went round the plant showing

(a) where it was first sprayed and the fault(s) and panel(s) involved, if any.

(b) where rectification (if necessary) actually took place and the fault(s) and panel(s) present afterwards, if any

(c) where rectification, in the inspectors opinion, was technically feasible

and so on until the vehicle was finally passed off as acceptable for submission to the trim tracks. A summary tabulation was also produced from this program, listing the average number of cycles for each model and colour combination.

The next program produced a tabulation detailing for each day the actual sequence in terms of model and colour and recording the colour batch size. The following two programs calculated firstly the probability of each type of fault at various factor levels, e.g. the probabaility of a dirt fault on an ADO 15 sprayed white on a Monday on the No. 1 paint plant for various colour batch sizes, and secondly using the same factors only replacing the type of fault, e.g. dirt, with the number of faults on a particular body shell.

Two further programs were added to the suite, the first combining the tasks of the last two programs but calculating for every occurrence, summerising at each factor change, and the second calculating the probability with the same factor except that the final factor was batch position rather than batch size.

Two criteria could have been used to judge whether or not a vehicle was in an unacceptable condition. It was first possible to simply follow the path of the vehicle, noting the rejection cycles or it was possible to accept the findings of the inspector. If the second criterion had been used then as the severity of the fault was not recorded there was a possibility of being misled by inspectors recording the faults which could be easily rectified at a later stage without recycling, (e.g. some dirt conditions can be polished out). If the first criteria had been followed there was also a danger of under-estimating when production, responding to expediency, decide to perform the rectification after the trimming operation.

In order to examine this further both criteria were used in the initial stages. Rejection was said to occur, on the basis of an inspectors report if either more than three panels had faults or the roof panel was involved. A roof, or turret panel as it is known, can be rectified after trimming but it is far easier to perform this on the first paint plants as the body can be rotated.

A simple correlation test was performed comparing the inspectors finding to actual rejection rates and R was found to be 0.84. This implied that in determining the system factors which influence paint rejection the inspectors report can be taken as an accurate reflection of the trends that actually occur. It was decided, therefore, to use the inspectors report in determining the important system factors influencing rejection and to use the actual rejection rates within the model as being more realistic absolute values.

There was considerable discussion on whether or not the data could be treated as continuous and not as enumerative quantities. The main argument centred round the robustness of the analysis of variance techniques compared to the Chi squared contingency table approach. The standard text leaves much to be desired in the treatment of multi-dimensional contingency tables usually dismissing it in the manner of Davies, ref. 13, who considered it a simple extension of two way tables. B. N. Lewis, ref. 44 did not, however, agree and devoted a long paper to the subject with the comment 'even the minimal extension (from tables of size 2 x 2 to those of size 2 x 2 x 2) pose entirely new conceptual problems.' Despite Davies somewhat presumptuous comments the general guide lines, for the analysis, were taken from his work on frequency data and contingency tables and in particular his statement ' it is perhaps rather surprising that the analysis of variance can be employed on data (discussing frequency data) which depart so violently from the Normal Distribution, but it is a fact that the methods remain very nearly correct provided we have suitably chosen our qualitative scale, i.e. provided that there is not a large excess of test pieces at either end of the scale'.

When discussing the contingency table approach W.G. Cochran, Ref. 8, suggests that the rule of 5 (expected value of 5 in any cell) is quite conservative and states that if we are prepared to accept an error of 20% in probabilities read from x^2 table (an error of up to 1% at the 5% level and up to 0.2% at the 1% level) we can let our smallest expected frequency fall to 2 if we have 6 degrees of freedom, 1 if there are 10 degrees of freedom and 0.5 if there are 25 all provided that there is only a single small frequency in the table.

The statistical approach used was, therefore, to examine the data for the batch size analysis by means of the Analysis of Variance technique as the number of elements in each cell is reasonably stable.

In order to maintain a reasonable sample size for the analysis the batch size was only considered up to a maximum size of five, the number of colours was kept to six, the number of models to two (ADO 15 and 16) which limited the sample size to 17,000. The standard transformation from the observed proportion p to the score x given by

$$x \text{ (radius)} = \text{arc } \sin\sqrt{p}$$

was used to give a nominally distributed variable with variance $\sigma^2 = 1/4N$, and x could be treated as the mean of a sample of n Normally distributed observations each having a standard deviation = 0.5 ref. 12.

For the analysis concerning Batch Position the number of observations in each cell was, understandably, biased to the lower end hence the multi-dimensional contingency test was used. The day of the week factor was not included in this analysis as it was found to be non-significant both by the general Analysis of Variance and detailed contingency tests.

The data for the ADO 15 and 16 vehicles for both No. 1 and No. 2 paint plants is included in Appendix C. The data for the J4 commercial vehicle on the Lysaught plant is not included as the overall reject rate was round to be only very small providing insufficient information for any statistical inference to be made.

The complete results for the statistical analysis is tabulated in Appendix C, but the main results may be summarised as

(a) the paint plant was a highly significant factor in influencing paint rejection (.001%)

(b) the model sprayed was significant (.005%)

(c) the colour that the vehicle was sprayed was highly significant (.001%)

(d) the day of the week that the vehicle was sprayed was non-significant

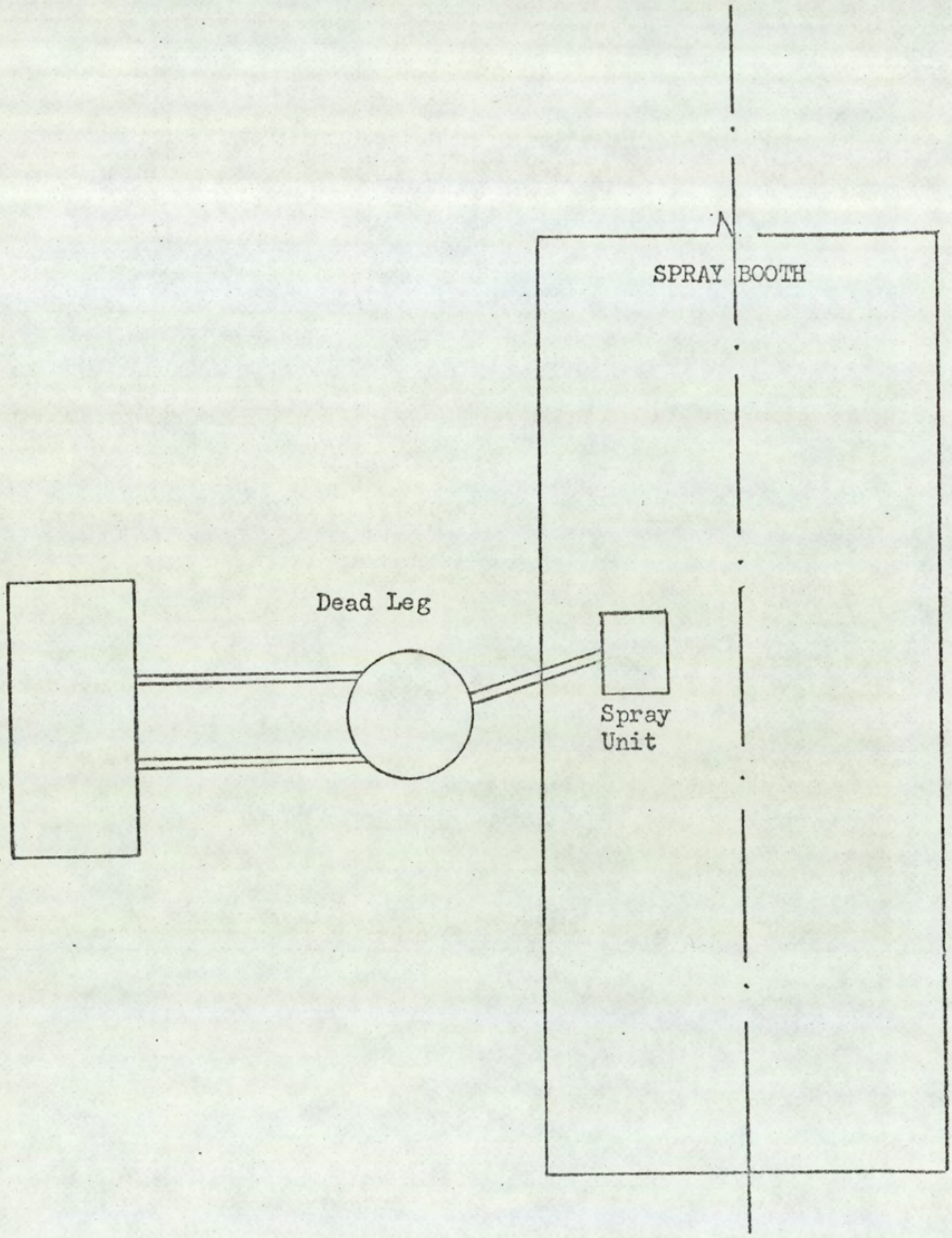
(e) a batch size of one was significant (.005%)

(f) for some types of fault the batch position was highly significant (.001%)

The fact that the paint plant was a highly significant factor was not surprising as the No. 1 paint plant was the main production unit and the No. 2 plant was a rectification plant hence the type of body submitted was basically different. A small study did however reveal a statistical significant difference (.001%) between rejected body shells rectified on the No. 2 and those recycled around the No. 1 plant. Again it could be argued that the type of rejected body submitted to each plant is basically different, the No. 1 dealing with complete rejects and the No. 2 with individual panel faults. It could further be shown that as the inspectors remained on the same plant, inspector variability would considerably influence the results but it could also be stated that the construction principles for the two plants was completely different. The No. 1 paint plant had an overhead conveyor whilst the No. 2 plant was operated by a floor conveyor. When the body shell was rotated, as it was on both plants, considerable vibration occured which could have caused dirt to fall from any conveyor. Dirt is the largest single type of fault recorded. The only way in which these questions could be resolved was to strip a rejected body shell completely down and thoroughly analyse the source of the dirt. This approach was discounted by the management as far too expensive on a sample large enough to be conclusive.

The factors contributing to this overall rejection rate were also examined in detail.

On the No. 1 paint plant when the dirt fault was analysed it was found that batch size was a significant factor (.001) and that in particular a body shell sprayed in a colour batch size of one was less likely to be rejected for a dirt fault than the larger batch sizes (significant at .005). It was also found that a vehicle body shell in batch position one was less likely to be rejected for a dirt fault (significant at .005).



RECIRCULATION SYSTEM

Fig. III

Two reasons were advanced as to why the first vehicle should be less likely to suffer a dirt fault. The first suggestion was that the dirt and dust collects, after rubbing down, in the rain channels around the roof and that the men tend to take more care tag-ragging (wiping with a sticky cloth) the dirt off on a colour change. It was difficult to completely discount this suggestion but during a series of observations it was noticed that the workers responsible for this work did not always look at the tag on each vehicle indicating the colour (ref. photograph 9), although a colour change was on some occasions shown with a piece of paper in the screen aperture. The supervision, as one would expect, maintained that every effort was made to remove all dirt, prior to spraying, on all vehicles.

The second suggestion was that the dirt within the paint was separating out when it lay for some time in the dead leg of the circulation system, i.e. from the pick-off point to the gun itself, ref. fig. III. This would mean that when the gun was reused the separated dirt was more easily trapped at the gun filter and there was sufficient paint in the dead leg to finish half of one body shell before paint drawn directly from the recirculation system was used, hence this could have influenced the rejection rate of the first vehicle within a colour batch. Again the only way to resolve the question was to have stripped several body shells down for analysis. As it was not the purpose of this research to discover the technical factors involved in paint rejection then this aspect had to be discontinued. The results were, however, given to the management and a small pilot scheme was devised with different filtration systems and controlled filter change times.

The examination of individual factors also showed that the probability of a body shell being rejected because it was not sprayed with its colour coat, i.e. in a sealer coated condition, falls off rapidly above a batch size of one. This was found to be consistent for all colours and both of the principal models, the rate of decrement depending on the number of the particular colour being sprayed. The explanation is fairly simple and straightforward and the decrement occured due to the limited number of colours available to the spray booth at any one time.

The system of delivering the paint to the booth was of the recirculation type with each sprayer picking up his supply by coupling his gun line to the pick-off point. The critical factor was that there were only seven lines to each sprayer implying that up to six colour changes could be accommodated without having to switch to a new colour, requiring the line to be washed out. If a large colour batch was loaded to the plant the sprayers were usually notified in order that the change could be completed before the body shells involved arrived. If they were not notified the change was still actioned in view of the large number of bodies involved, although the first one may well have been missed and gone through in just a sealer coated condition. If, however, a small colour batch had been submitted of a colour that was not available, and the sprayers had not been notified then they were frequently unwilling to change particularly if it meant rechanging shortly afterwards.

It was suggested to the management that it would be simpler to leave colour allocation to just prior to the colour spray booths ensuring close liaison and a quicker response time to any scheduling changes. Unfortunately although the management were firmly convinced of the benefits, the system was not implemented because of trade union difficulties.

The colour was found to be one of the major influencing factors in terms of rejection and it was common over all types of fault, both for batch position and for batch size. It was a highly significant factor on faults such as scars (code F) which occur prior to painting and in no way can logically be related to either the paint itself or the method by which it is applied. It must, therefore, be concluded that the manner in which it does influence the rejection is in the inspection task and it can be suggested that the brilliance of certain colours can blind the inspector as to small defects which he would otherwise record. It is not suggested that colour was the only factor as the percentage of pigmentation and base in the paint are variables or may well have influenced the results. It may well be that if this did prove to be the case then a slightly more expensive paint of a particular colour, with a changed mix may overall be far less expensive than the cheapest paint. As far as the author was able to discover no work had been undertaken in this field by either the paint manufacturers or the users. Unfortunately the necessary laboratory experimentation required to prove the point was outside the scope of this work.

As mentioned earlier trade union opposition prevented the data from being collected from the other inspection points, off the tracks, the loop line and the lowbake plant, in the format necessary for a detailed analysis. The only statistics which it was possible to gain from those areas were aggregated to a model level, i.e. an analysis on the basis of colour/batch size where painted and previous history was impossible. Results had to be gathered however, and these are presented in Appendix C. They are the actual rejection rates and not just based on the inspectors findings.

In all cases (except for the Lysaught plant for which there was insufficient data) the rejection rate was normally distributed about the mean ref. Appendix C.

For the purpose of the model it was also necessary to gather statistics on the stoppages involved in the various sections of the productinn system studied. The following factors were noted -

(a) the plant on which the stoppage occured

(b) the time in between stoppages

(c) the length of the stoppage

(d) the cause of the stoppage

These are presented in Appendix C. In the model the only interest, from these statistics lay with the non-system stoppages, e.g. breakdowns

white metal body shortage (a non-system stoppage within the paint and finish context)

shortages of bodies

The system causes, such as stoppages due to conjestion in an off-load area were not used in the subsequent simulation sampling but were valuable as check points for testing the validity of the models.

The data for both the interarrival rate and duration time of the stoppages conformed closely to a negative exponential for all of the four major paint plants and this distribution was used in the model for those plants and for the tracks where insufficient data was available for any other conclusion to be made.

PART III

THE TOTAL SYSTEM

Chapter VII

THE MODEL

The purpose of this chapter is to describe the way in which the logic of the computer program deals with the modelling of the real system. No attempt is made to explain the program, instruction by instruction, as it is fairly easy for anyone with a basic knowledge of the simulation language to follow the program through, given the tabulation, flowcharts and registers included in Appendix D, and with the philosophy of the model that will be detailed.

The basic philosophy adopted in writing the program for the model was to consider the whole system made up of a series of modules. Each module described a major section within the total system and generally the program modules were aligned with production facilities. Several other modules were written to handle the general housekeeping associated with a change in strategy. This approach meant that each module of the model could be written and tested separately. It also meant that where a production facility was represented by a program module, the initial phases of validation could be more easily undertaken without the complexity of the interactions occuring between modules. This was not a complete validation as that could only be undertaken when the modules were coupled together and the whole system examined. This is dealt with in chapter VIII.

The program for the model was written in the G.P.S.S. 360 (General Purpose Simulation System) language. This is a special purpose symbolic simulation language, written by IBM for physical system modelling, and, like nearly all of the American simulation languages, it is material based with the 'transaction' forming the base.

In this model the transaction was taken to be a vehicle body shell travelling through the system. Attached to this transaction were twelve parameters containing details of the physical characteristics of the shell, routing information, rejection rates and various indicators which changed as the sequence changed. These parameters were not pre-determined as the value entered depended entirely on the situation that existed within the model at the time the body shell encountered a decision point within the system.

The choice of the clock unit was between hours, minutes or some smaller unit of time. A longer period could not be considered as the model was intended to examine sequences on a detailed level.

After the main details had been gathered on the production system, it was decided that a clock unit of one hour was too insensitive to the changes that occured in practice. These changes were implemented as the body shells arrived at the various decision points in the production system. The arrival rates were obviously a function of the cycle times of the various units within the system, and although the major sequencing decisions were taken on an hourly basis, the cause of the change lay in the cumulative effect of small differences in cycle times between the units. For example the Electrocoat plant had a nominal cycle time of 2 minutes whilst the cycle time of the following colour plant (No. 1) was normally 2.307 minutes. As the program can only operate in integer clock units, and in order that the sensitivity of the cycle times could be examined, the clock unit was chosen as one tenth of a minute. This gave the cycle time of the saloon colour plant to be 23 one tenths of a minute.

The whole system was basically a series of sophisticated queues building up in between the production stages. The G.P.S.S. software was built up as a series of macro instructions that the user could utilise for the task of writing the program. One such set of macro instructions catered for queues by means of the 'QUEUE' and 'DEPART' instructions. Following the publication, by I.B.M., of some work done by Shell Canada, ref.[App.D], which indicated that these particular instructions were slow in execution, it seemed reasonable to use pseudo queues built up in term of user chains. This decision was later justified as it reduced the execution time of one of the early models, which used the pure queue, by 25% when the pseudo queues were introduced.

The first model that was 'built' did not attempt to perform the detailed sequencing, but was used to determine the main areas where the work had to be concentrated. Gradually the model was expanded and increased in complexity and validity. The philosophy presented is that of the final model.

The following sections should be read in conjunction with figure V provided in pull-out form at the end of this chapter.

THE ELECTROCOAT MODULE

Refs. Flowcharts 1 and 5.

The electrocoat plant was represented by a user chain (No. 1) with a capacity limited by the loading cycle of the plant (2 clock units). The transactions (vehicle body shells) were linked (loaded) to the chain from the supply of white metal body shells which, in turn, had come from the body shop.

A body shell was only loaded if :-

(a) there was space on the plant, i.e. the current contents of the chain were examined for less than or equal to 92.

(b) there was no stoppage, i.e. logic switch one was reset.

Stoppages occured following the interarrival rate and duration distributions discussed in chapter VI and were controlled by the Breakdown Module sampling on a Monte Carlo basis. A stoppage could be due to one of three occurances

(a) a lack of white metal body shells

(b) a lack of bogies on which to off-load the primed body shell

(c) a breakdown

When the body shell was successfully loaded, it was allocated with a model code which was entered into parameter one. This code was derived from the load ratio, e.g. if the production program called for vehicles 1, 2, 3 in the ratio X, Y, Z where Z is the lowest number then the load control would allocate the first Z bodies with code 3, the next Y with 2 etc.

If a body shell was to have been loaded which, due to an inbalance in the system stock, had been barred (feedback control No. 2) an alternative shell would be loaded after a delay of one cycle. This delay was introduced as usually the inbalance only occured when the system stock approach saturation and it was necessary, therefore, to reduce the nett feed rate off the primer plant.

Feedback control No. 2 is based on the number of saloon bodies existing in the system prior to No. 1 and after the electrocoat. In practice the inter-review time was virtually impossible to objectively quantify as at least three supervisors can influence the decision. Generally it was accepted that an initial inter-review time of one hour would be reasonable. The validity of this is examined in the validity and sensitivity tests.

A similar problem existed with feedback control No. 1, which monitored the load ratio based on the number of each derivative existing in the system, from the load to the Electrocoat until the start of the trim tracks. In a like manner the inter-review time was fixed initially at one hour offset to control 2 by 30 minutes. When the system stock reached saturation the inter-review time of control No. 1 was shortened to 30 minutes.

Once loaded onto the electrocoat plant the body shells had to remain there until at least the process time had expired, although it was possible for a body to remain on much longer due to stoppages. The queue discipline on the chain was maintained as a pure first in first out rule as in practice the bodies are held on a rigid chain conveyor. The attempt to load a body shell to the electrocoat plant was repeated every twenty clock units, i.e. based on the real cycle time of two minutes.

Attempts to unload the plant were repeated on the same cycle time, with a higher priority, but before a successful off-load could be executed a test was made to examine

(a) if the plant was working, i.e. no stoppages

(b) if the process time had expired

(c) if there was sufficient room to off load the body shell

When all three conditions were satisfied a body shell was released from the Electrocoat plant. The last of the tests performed was dependant on the type of body shell being unloaded as commercial shells had a different destination to saloons. As the conjestion factor was examined at the unload point there was no need to include this in the stoppage control, to have done so would not have been a true representation of the paint plants performance. The tests were performed by a boolean variable operating in the 'and' mode. From the results of the sample on the unofficial store the production supervision, in the model, were only allowed to move up to fifty bodies outside after which time, if there was no further official space left the plant would be forced to stop.

The Area Between Primer and Colour Paint Plants

Ref. flowchart 5.

It was stated in the previous section that there were two official areas into which bodies could be moved after being off-loaded from the Electrocoat primer plant. Both areas were identical in their purpose, the only difference being that one dealt with saloons whilst the other handled commercials. There were also differences in the physical sizes and processing times.

In the model an attempt was always made to off-load bodies, from the Electrocoat plant, into the official areas before trying to move them into the unofficial store outside. Body shells of a type which would disturb the balance beyond that permitted by feedback control No. 2 were also moved into the unofficial store. In practice bodies were, on occasions, moved outside when the balance was within the limits set and the official store was not full. This did not contribute greatly to the store (less than 5%) and as the practice was, strictly, not permitted, this was ignored in the model.

Bodies were returned from the unofficial to the official areas when the Electrocoat was unable to meet the demand, e.g. during a mechanical breakdown. In practice once committed to returning body shells from the unofficial store several were moved back, the exact number varying,but in the model this figure was fixed at a maximum of ten.

The number of ten was not always followed either in practice or in the model. In both cases the number moved was a function of the number moved in the previous sortie into the unofficial store. Too large an influx of body shells from outside overloaded the rectification area prior to No. 1, as the shell had to be cleaned after waiting in the open.

After the time to move these bodies had elapsed an attempt was then made to off-load further bodies from the Electrocoat, if this proved to be unsuccessful then further bodies were brought from outside. When all of the storage areas were full the attempts to unload were held for five minutes (50 clock units) before repeating the process.

Both the saloon and commercial plugging areas were organised on a F.I.F.O. basis as they were both governed by conveyor systems. After the grommets had been fitted and the body rectified, if necessary, the saloons attempted to move into the assembly area prior to the No. 1 colour paint plant. If that area was full then, provided that the main storage area held less than thirty body shells, the sealer coated body would be allowed to encroach into that store. If the primary assembly area was full and encroachment could not be permitted then the body shell had to wait in the plugging area. The option to encroach into the main store was not open to commercial vehicles, so if their primary area was full then the body had to wait in the plugging area.

The No. 1 Colour Paint Plant Module

Ref. Flowcharts 2 and 15.

The number one colour paint plant was represented, in the model, by user chain two with its capacity limited by the cycle and process times.

An attempt was made to load a body shell only if

(a) there was one available to load

(b) the plant was working

(c) there was space on the plant

If all of these conditions were met the queue of recycled sealer coated bodies, which had previously been loaded to No. 1, was examined. If a body shell was present it was immediately loaded as in practice the body would never have been removed from the conveyor. In the model a pseudo off-load was performed in order that Monte-Carlo sampling could be undertaken. This resulted in the body shell effectively disappearing from the statistics for the No. 1 plant for the time that it queued awaiting recycle. The queue was, however, only small and resulted in only a slight inaccuracy in the utilisation figures of the No. 1 paint plant (< 1%).

From the statistical analysis it was shown that the main factors influencing paint rejection were

(a) the paint colour

(b) the model

(c) the colour batch size

The effect of batch size was principally limited to a batch size of one. At the inspection station the transaction (body shell) was unlinked from the chain and the Monte Carlo sampling undertaken as follows. The body shell type was identified first and the function address set (1-3), the argument for the function was then set equal to the colour code, ref. to appendix C for the codes, and a mean rejection rate returned to the model. If the vehicle was submitted in a colour batch of one then this mean rate was modified according to function 11 which was model type dependant. The nett figure returned was then submitted to a normal distribution curve in line with the results found in the statistical analysis. In this manner the pattern of rejection rates was reproduced.

If a body shell was passed off it was immediately transferred into the main storage area (represented by S13) in the program, prior to the finishing tracks, and linked to chain 7. If rejected, the body shell would still proceed to the main store but it would have been linked to chain 6 for subsequent submission to the saloon rectification plant, No. 2. It is important to note that in absolute terms the actual reject rates were used and not the inspectors findings, for the reasons stated in chapter VI, and therefore it was possible to accept the reject rates without having to impose a further sample on the probability that the inspectors verdict would be followed.

An off-load from the No. 1 paint plant was only permitted when the plant was working, there was sufficient room in the main store to accept at least one body shell and the process time had elapsed.

The No. 2 Rectification Plant Module

Ref. Fig. V and Flowcharts 4.

This module was very similar to the one used for the No. 1 colour paint plant only the No. 2 was represented by user chain 3, with a capacity of 34 and an hourly maximum production rate of 25.8 bodies/hour. In practice this production rate was reduced as 2 detail spits were loaded every hour, (these spits were loaded with parts such as doors, bonnets, etc.) and the effective rate was therefore 23.8/hour.

Loading was permitted provided that there was room on the plant, and it was working. At the inspection station the Monte Carlo sampling varied from that used on the number one plant, as no weighting was used on the mean rejection rate for colour batches of one. This follows the results of the statistical analysis, which revealed no significant influence for batch size on the rejection rate for the No. 2 paint plant. The rejection rate was considered normally distributed as for No. 1 plant.

If a body shell was rejected at that point then it would have been relinked to chain 6, within the main store, to await recycling round No. 2, otherwise it would enter the main store and be linked to chain 7. An off-load was only actioned if the plant was working, there was room to offload and the process time had expired.

The Lysaught Commercial Vehicle Colour Paint Plant Module

Ref. Flowcharts 3 and 5.

The Lysaught plant was represented by user chain 4, and again operated in a similar manner to that used by the No. 1 paint plant module. The loading was constrained until there was a body available, the plant was working and there was space to accept a body shell.

Paint batches were built up in the same way as for the number one, although as this had no real effect the approach was not as rigorous as for the number one. The only real criterion used was to attempt to recombine rejected shells into the same colour batch for submission to the plant.

This practice is followed in the real system for simple convenience of spraying, thus reducing the number of colour changes.

At the inspection station the Monte Carlo sampling was taken as a uniform distribution about the mean. This was done as insufficient data was available to reach any positive distribution, and as the rejection level is very low compared to the No. 1 plant, hence any inaccuracy could be neglected. If rejected, the body shell was placed in the rejection store, chain 13, where the preparatory work was carried out prior to resubmission to the Lysaught plant.

The off-load from the plant was undertaken when the plant was working, the process time had expired, and there was room to store a body shell. The body shell, if passed, would move into the gantry store or if that was full into the overflow store, between the Electrocoat and Lysaught paint plants, for subsequent submission to the elevated finishing track.

The Finishing Track Module

Ref. Fig. V and Flowcharts 6 and 7.

All of the vehicle body shells acceptable for finish were held in individual stores, according to derivative, within user chain 7. Transactions (vehicle shells) were unlinked from this chain when (a) a demand for a particular vehicle was raised and it was available; (b) when the track was not held by a stoppage; (c) the track was due to be working, i.e. during the day shift on a 'days only' track; (d) the track was not full.

Each track had an individual capacity and cycle time. In practice there were two identical tracks for finishing type 1 saloons (ADO 15/20) and in the model these were combined into a single chain, with double the capacity and half the cycle time, in order to improve the computer efficiency of the model. The breakdown rate for the combined track was taken to be the addition of the two individual rates and this did cause a slight inaccuracy as it implies that both tracks halt at the same time, again however as the average rate was very small this factor was neglected.

The off-load of a body shell from the finishing track was only permitted

- (a) if there was room in the area immediately after the track (store 15)
- (b) if the process time had expired
- (c) if the track was due to be working
- (d) if the track was not stopped

Restriction (a) implies, as was indeed the case, that a large number of body shells unable to gain entry to either the loop rectification line or to the lowbake plant, or being rectified in situ, could block the way for good bodies, which could otherwise be moved to despatch. Once off-loaded Monte Carlo sampling was undertaken to determine whether it should be

(a) rectified in situ

(b) pass to the loop rectification line

(c) move to the lowbake paint plant

(d) move directly to the pre-despatch area

If decision (a) was operated then the body remained in the area following the tracks whilst the time for rectification passed. This was taken to be a mean of 25 minutes with a deviation of 10 minutes (uniform distribution). No detailed information was available on this value other than the opinions of the men and supervision involved. The decision to rectify in situ was changed to decision (b) if the area prior to the tracks was full.

If decision (b) was implemented then the body shell was moved to the loop line (store 16) incurring a transport time penalty, and then attempted to obtain the rectification service (facility 1). This could only be achieved if the facility was empty otherwise the body shell had to wait in store 15. Once service was gained then the body shell was held for rectification time and was then transported to the end of the line for inspection. At the inspection point the body could either be passed as acceptable for despatch, in which case it would queue awaiting transport to the despatch bay, or, it would be rejected and sent to the lowbake plant for rectification.

Each vehicle body that was passed entered into an individual store (S 25-27) within store 17 where it remained until it was transferred to the despatch bay (store 18).

The lowbake paint plant was represented by store 20 and followed a FIFO queue discipline to represent the conveyor constraint. A rejected body shell was loaded provided that the plant had sufficient room to accept the body and was working. The offload occured immediately the process time expired after which it was inspected for defects. If any were found then the transaction (vehicle body shell) was recycled to be presented to store 20 again. Otherwise the body moved into a queue to await transfer to the despatch bay.

Summarising, a body shell could enter these pre-despatch queues from

(a) directly off the finishing track

(b) off the lowbake

(c) the area immediately after the tracks where it had been rectified

(d) off the loopline

The body shells were then transferred round to the despatch bay by one group of men represented by facility 3, hence only one body could be moved at any one time. Once the transfer was actioned the body shell moved into a unique queue in the despatch area (S 28-30) all within store 18 where it queued awaiting the arrival of an appropriate lorry. As no demand pattern could be established for the finished vehicles it was settled at the mean supply rate with a standard deviation about this value. Once a vehicle was loaded to a lorry the transaction representing it was terminated as it was no longer of interest.

HOUSEKEEPING AND SUPPORT MODULES

1. BREAKDOWN MODULE Ref. Flowchart 8.

This controls the availability of the production plants by setting logic switches on when a breakdown or stoppage occurs. One cycling transaction was generated for each of the eight main units involved and carried information on the interarrival and duration times of each unit.

2. TRANSFER FROM FUNCTION TO MATRIX Ref. Flowchart 13.

This is a simple aid in the coding of data and transfers information from a function to a matrix. The coding to set up the initial matrix is both laborious and error prone whereas a free format function can be quickly written. An execution time penalty is however incurred.

3. STATISTICAL MODULE Ref. Flowchart

Due to the limitations of the output editor in the G.P.S.S. module certain values must be set up in savevalues before they can be referenced in any output editor. This module performed that task.

4. PERFORMANCE MODULE Ref. Flowchart 9.

This records, virtually in the manner of activity sampling, the number of units at various points in the production system and thereby enables bottlenecks or periods of under utilisation to be observed.

5. REORGANISATION MODULE (REORG) Ref. Flowchart 12.

The purpose of this module is to take an input order bank of vehicles and to break it down into a sequence for submission to the colour paint plants. The constraints used, and which can be varied, are

(a) the ratio of each derivative

(b) the maximum colour batch size

and when used with the SEQUENCE MODULE

(c) the colour sequence

The module attempts to maximise the colour batch size whilst maintaining the derivative ratio. The derivative ratio has the highest priority in breaking any conflicts.

6. THE SEQUENCE CONTROL Ref. Flowchart 11

This module permits the colour sequence to be varied by changing a basic order bank into the sequence defined by a further matrix. The order bank matrix (MH8) is changed colour by colour, i.e. column by column.

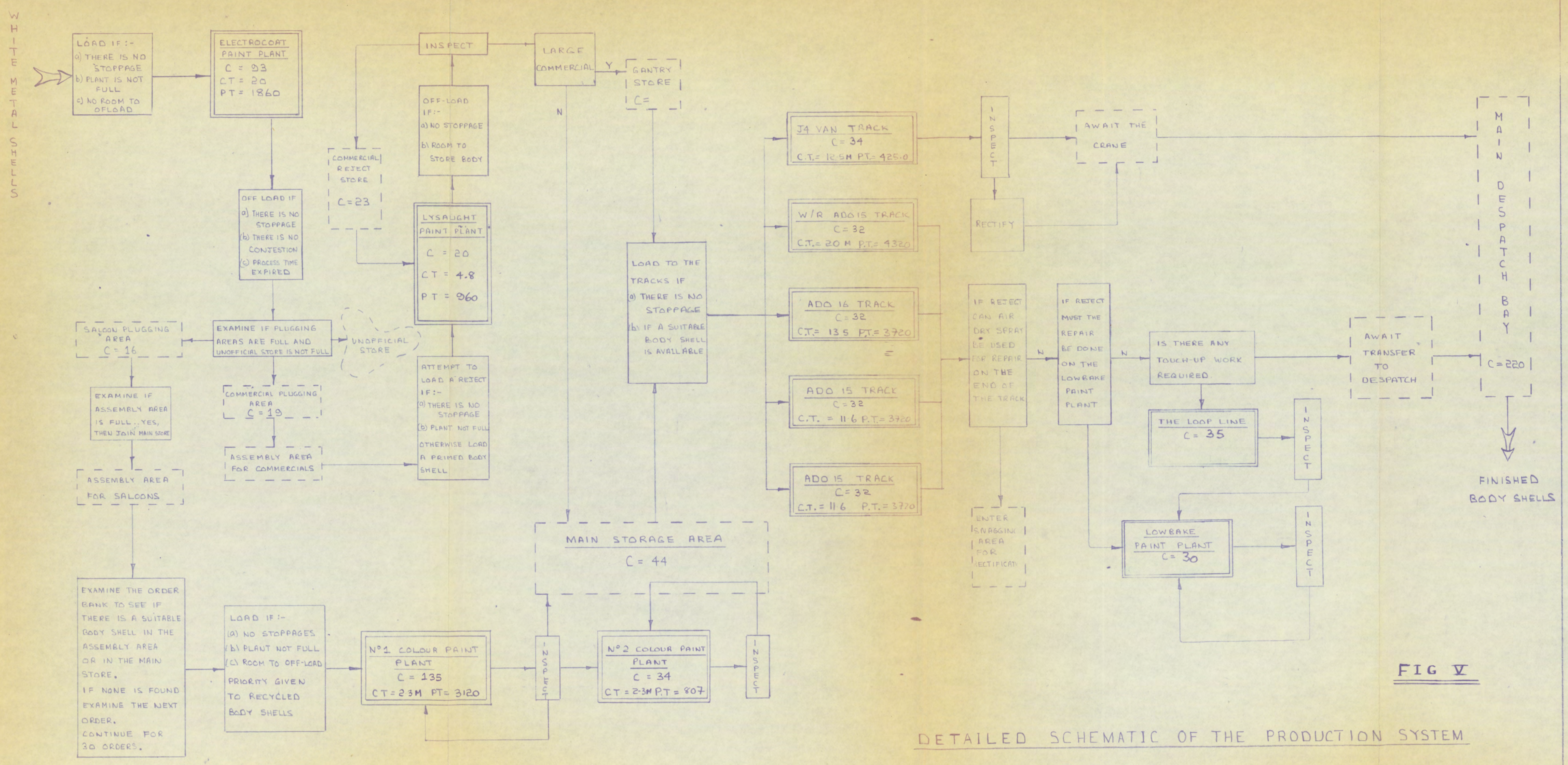


FIG V

DETAILED SCHEMATIC OF THE PRODUCTION SYSTEM

CHAPTER VIII

TESTING THE MODEL

VALIDITY

Validity of a model, which has been built to assist in the understanding of a real system, is the most important aspect of simulation. It is rare that a model can exactly reproduce a complex system for usually such a precise mirror of real life is expensive in terms of money and time. If simplification is accepted as a valid ploy in the search for a greater understanding of a system then a complex model will negate some of the advantages of simulation. A complex model implies, usually, that many variables are considered which may well mean that modifications to the input or logic are difficult to implement and as, by its nature, simulation requires a large number of trials this can further constrain the usefulness of the tool.

The important point is that the model reacts to the main factors with a tolerable degree of accuracy. Absolute results from a model are not always feasible and some must be used on a comparative basis, i.e. it may be possible to illustrate the improvement of one strategy compared to another whilst being unable to strictly define the absolute gain in the real world.

The first problem lies in deciding the main factors which must be introduced and discarding those which are considered to have a negligible effect. The researcher must at all times be preapred to modify or introduce new factors if the results do not conform to the tolerable accuracy.

Ideally, to examine the validity of the model the same criteria should be monitored in the model and in the real system for comparison. The tolerable accuracy level can only be established by examining the accuracy of the data recorded in the real system and the accuracy of the data input to the model. At this point it must be realised that a cost and time penalty must, usually, be paid for greater precision. Obviously there must be a threshold level below which the accuracy must not fall if the results are to be meaningful. This threshold limit is usually accepted to be $\pm$ 10% and this was taken as a suitable value for this study.

The tests of validity were based on the approach used by J. Forrester, ref. 20, in his book in Industrial Dynamics and consisted basically of examining the arrival rate patterns at the various stages in the production system. The absolute average values of the arrival rates were also compared but were expected to be on the threshold value of accuracy as the model only attempted to simulate the physical sequencing system. For the reasons discussed in previous chapters the model did not consider either a lack of men or materials as a system constraint, factors which did in the real system at the time of study, exert an influence on the system.

The labour problem is not one which can be truly solved by a sequencing system and falls into the area of industrial relations. The introduction of measured daywork will certainly eliminate some of the problems of piecework, which in this area of study were not particularly difficult as the work rate was sensibly governed by the conveyor speeds.

The main influence of the material problem was felt just prior to the finishing tracks and immediately afterwards in the area prior to and including despatch. When a stock shortage was noticed just prior to the tracks it frequently implied the rescheduling of painted body shells, as discussed in detail previously. The rescheduling activity frequently involved up to 45% of a shifts production but in terms of a system constraint on the finishing lines, only represented a small loss of efficiency as the finishing track supervision would demand that a body shell be loaded in order to keep the men working, accepting that missing parts would have to be fitted as an additional operation. This restricted the time delay due to rescheduling and in practical terms postponed the problem to satisfy an immediate demand.

The implication of this decision was that the body shells tracked to be run 'OK LESS' (a labelling system used to indicate that all the items were not fitted ref. photo 17) had to wait after the tracks until the missing items were obtained and fitted. This operation was carried out on the end of the tracks, in the storage area immediately after the tracks, on the loop line, in the queues prior to the despatch bay and even, in extreme cases, in the despatch bay itself. This situation caused sometimes severe congestion which could eventually halt the tracks completely.

In terms of monitoring the real system for comparison with the results from the model, which did not consider the material constraint, it was therefore to be expected that the utilisations for the areas after the finishing tracks would be lower for the model than the actual system. Indeed it can be seen that the problems for this section of the system are reduced and the critical area becomes that prior to the finishing tracks.

For monitoring purposes the following check points were established in both the model and the real system.

1. The saloon vehicle arrival rate off the electrocoat primer plant in bodies per hour.
2. The commercial vehicle arrival rate off the electrocoat primer plant in bodies per hour.
3. The saloon vehicle arrival rate off the colour paint plant in bodies per hour.
4. The saloon vehicle arrival rate off the No. 2 rectification paint plant in bodies per hour.
5. The commercial vehicle arrival rate off the Lysaught colour paint plant in bodies per hour.
6. The efficiencies of the trim tracks where efficiency = $\frac{\text{no. actual produced}}{\text{manned capacity}}$

Three further primary check points were also established as it became clear that the storage areas prior to the colour paint plants and immediately before the finishing tracks were important in terms of permissable sequence and hence efficiency. These were

1. The utilisation of the storage area prior to the No. 1 Colour paint plant. Utilisation = $\frac{\text{Average no. of bodies held}}{\text{Capacity}}$
2. The utilisation of the storage area prior to the Lysaught colour paint plant.
3. The utilisation of the storage area prior to the finishing tracks.

The method chosen to collect the data was to monitor the check points in the real system over several weeks, noting also the load sequences and the track ratios applicable at the time. A close examination was then undertaken to discover if any extraneous factors such as strikes or the production of prototypes occurred during the period until eventually one week was selected as being representative of the real system. The appropriate load program, track ratios, etc., were then submitted to the model for the results to be matched with the data from the check points. Breakdown and rejection rates were not included in the monitoring but were taken from the results of the statistical analysis discussed in a previous chapter.

The check points were monitored, in the real system by means of the source documents shown in Appendix E. The first document A, was filled in by the staff of the Production Control Department on an hourly basis, noting at each check point the number and type of body shell that passed.

The second document was filled in by the author on an activity sampling basis using the standard work study approach with the limit of accuracy set to ± 5%. The second set of check points had to be taken over two weeks to obtain sufficient readings. (400 with mean interarrival time of 10 mins. ± 5 mins.) The first set of data was gathered over one week. In the model the equivalent data was monitored over one simulated week.

The initial models proved to be inadequate and six major changes had to be implemented until the model gave acceptable results. The final model was described in chapter VII.

The complete results from the model are included in Appendix E but can be summarised as follows.

The arrival rates were generally 5-8% above the value experienced in practice but as the material constraint had been removed from the model this was to be expected. The pattern of the arrival rates were similar for the paint plants, with the deviation for the electrocoat plant being 9.320 for the actual system and 9.117 for the model. The corresponding figures for the No. 1 paint plant were 7.976 and 8.570. The pattern of the arrival rates for the finishing tracks was also very similar with the average values being within 8% of actual results. The deviations for the finishing tracks were as follows.

TRACK	ACTUAL SYSTEM	MODEL
ADO 15	2.750	2.984
ADO 16	1.347	1.269
W/R	1.023	1.093
J4	0.979	0.646

A further measure of the agreement between the arrival rate patterns can be taken by comparing the tables included in Appendix E and in particular the 'DEVIATION FROM THE MEAN'.

The utilisation of the storage areas tended to be higher prior to the tracks and considerably lower after the tracks and outside the 10% limit set initially. This apparent discrepancy can again be traced to the lack of any material constraint.

As each vehicle was considered completely trimmed on the finishing tracks then obviously there were no bodies awaiting for trim items to be fitted in the areas after the tracks. This in fact changed the pattern of bodies off the track as bodies were always able to be off-loaded which in practice was not always so.

The track efficiencies monitored in the model were found to be 6.9% above the values recorded in practice during the sample period. A slight inaccuracy was found in the results from the Wolseley/Riley track in that due to engine problems at the final assembly plant the production was reduced at the Castle Bromwich works. This factor was reflected by the model as the load sequence used was the one used in practice hence the efficiency figures returned for that track were comparable to the true results but not representative of the normal performance.

In summary the model was considered to be a valid representation of the actual system within ± 10% accuracy limits.

WARM-UP PERIOD

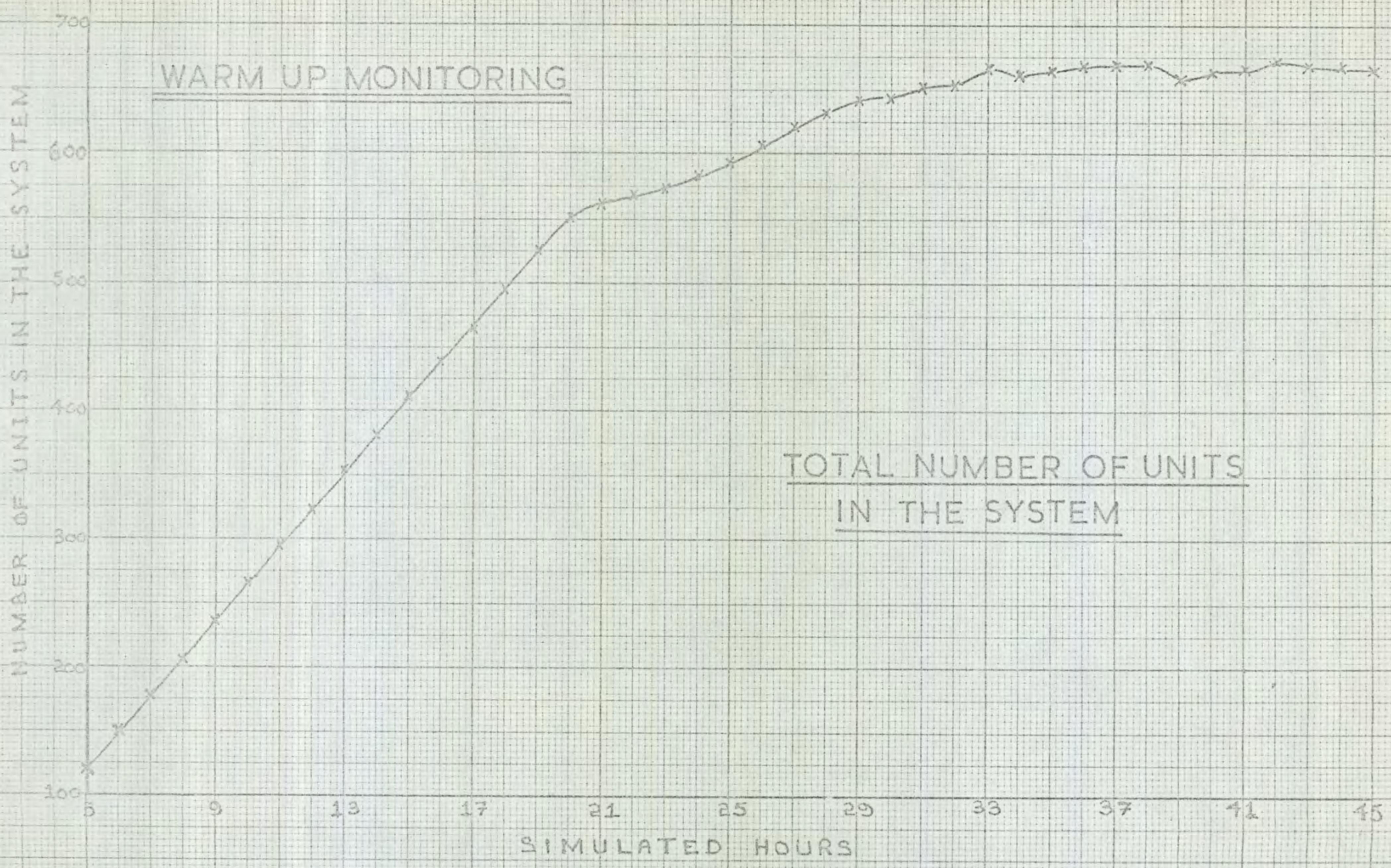
In order to test a strategy using a model it is important to get the model into a condition that resembles the practical state. Few profitable production systems are ever empty and most experience backlogging or pre-loading of orders. This implies that no practical system is ever in the cold state of having all machines idle at the beginning or end of a production period, e.g. a week or shift. They are usually in what is termed a warm condition.

Strategies can only be compared to each other in the light of their conformity to some objective, e.g. maximise profit. If a model is used which is not 'warmed' then it is very likely that some strategies may be more efficient in terms of a cold start and yet in practice, because of the continuous warm condition will not return the same results.

A simple press shop strategy planning model, built by the author for the sponsoring company, was particularly vulnerable to erroneous results when using a cold start. It was formulated on the basis of press lines (a series of logically connected presses) in which every machine had to be available before production could start. A cold start by definition made all of the machines available to the scheduler which if the sequence rule of, 'load the job with the greatest number of presses in a line first', was used improved performance resulted, whereas if the rule was changed to 'load the jobs with the smallest number of presses in a line first' it made only a marginal difference.

Run on or run out are terms which refer to the terminating conditions which exist in the model. Again for a true comparison of performance the model should also be stopped whilst it is in its 'warm condition'. To allow all of the jobs to be completed before any new ones enter into the system has virtually the same effect as a cold start in distorting the performance of a strategy.

A classical example of the misleading results that can be obtained from allowing the model to empty at the end of the run are those obtained from tests on job shops using a simple SI rule (shortest imminent time). This rule states, basically, that at each decision point prior to a machine the job that must be loaded is the one with the shortest imminent operation time. This implies that a good service will be obtained in terms of the number of jobs completed within a time period. The variance of due date lateness will, however, be high as the long jobs will be delayed a disproportionate time. If this simple rule is applied rigidly then it can be seen that if the model is allowed to run on until all of the jobs are completed, with no new orders entering into the system, then eventually a long job would be completed. In practice orders arrive continuously and there is a very real danger that a long job would never be started and almost certainly the variance of lateness would be considerably higher than that recorded by the model described. A rule such as the simple SI one is commercially unacceptable.



WARM UP MONITORING
TOTAL NUMBER OF UNITS IN THE SYSTEM
NUMBER OF UNITS IN THE SYSTEM
SIMULATED HOURS
700
600
500
400
300
200
100
5
9
13
17
21
25
29
33
37
41
45

In terms of the model constructed for this study the transient conditions existed for approximately 30 hours compared to the nominal run time, over which a strategy was examined, of 80 hours (one working week). To have omitted a warm-up would, therefore, have produced misleading results. If the transient condition had lasted for only a short time then it may have been possible to omit this stage.

The principle warm-up criterion used in this particular study was the overall stability of the modelled production system. This meant the examination of the total number of units in the system at any one point in time. Other criteria considered as indicative of the stability of the system were taken to be the utilisation curves of the individual units and storage areas within the total system. The graphs illustrating the detailed warm up patterns are included in Appendix E. A printout is also included showing the overall condition of the production unit at the end of the warm-up period. The cascading effect of bodies gradually filtering through to the final production stages can be clearly seen.

The decision as to when the warm-up period is sufficient is not critical provided that the period chosen is longer than the transient period. The transient period was judged to have expired after thirty five hours, i.e. at the point shown on the graph opposite. The model was at this point written onto magnetic tape so that all of the strategies under test could start from exactly the same 'warm' point when the tape is read in, at the start of a simulation run, and no further computer time is incurred in a warm up exercise.

SENSITIVITY

In discussing the problems of sensitivity analysis Demski, ref. 15, states that only certain ranging patterns can be considered and then that the application must be directed to the critical areas in the model. Taking his example of a model that contains 2000 data elements and sensitizing each single element and pair of elements this would require over 2 million different analyses. If the model is stochastic then further testing must be done in order to establish some confidence in the results.

There is, however, a considerable amount to be gained from an analysis which examines the changes which occur due to a set alteration in the data input. In a study such as the one undertaken for this research, sensitivity testing should reveal pointers to areas worthy of close examination for the formulation of appropriate decision rules. Obviously a complete search of all the feasible combinations is impracticable and it is necessary to restrict the analysis to those areas which promise the largest information yield.

In the model under consideration it was decided to limit sensitivity testing to perturbing each of the main variables individually and examining the result to determine possible profitable combinations for examination during the strategy analysis stage. It was further decided to repeat each test three times, altering the random number seed at each attempt, in order to minimise the effect of sampling.

Eight main variables were felt to have an effect on the system.

(a) The individual paint plant speeds

These were, generally, variable within an upper and lower bound for each of the five main plants.

(b) The individual finishing track speeds

These again were,within manning limits, variable with an upper and lower limit.

(c) The speeds of the auxiliary services.

(d) The paint rejection rate which was found to be dependant on

(i) the colour

(ii) the model

(iii) the batch size.

(e) The review times of the feedback controls.

(f) the size of the storage areas.

(g) The colour sequence.

(h) The feedback cycle time.

(i) The size of the order bank available for allocation prior to No. 1 paint plant.

Within these factors there were felt to be six elements which had an overriding effect and worthy of sensitivity analysis.

(a) The ratios between the service and demand of the three principal elements.

(i) the primer paint plant

(ii) the colour paint plant

(iii)the finishing tracks.

(b) The storage room prior to the No. 1 paint plant and the store size prior to the finishing tracks.

(c) The paint rejection level.

(d) The overall feedback cycle times.

(e) The span of allocation possible prior to the number one plant.

(f) The paint batch sizes.

The size of the perturbation was determined by considering the realistic bounds on the facilities and set at the maximum value, e.g. In the foreseeable future it is unlikely that the absolute rejection rate will be lowered or raised by more than 10%. It was also considered physically difficult to introduce more than an extra 50% increase on the storage areas prior to No. 1 paint plant and the finishing tracks.

The perturbation used were as follows :

(a) ±10% on the paint plants and ± 20% on the services after the finishing tracks. The speed of the tracks was kept constant.

(b) Store prior to No. 1 + 50%, reduction was not considered as the absolute value is fairly low. Store prior to the tracks ± 50%.

(c) The rejection level ± 10%.

(d) The feedback control ± 50%.

(e) Allocation span ± 50%.

(f) Paint batch sizes were set to intuitive maximum values and the reorganisation module determined the precise loading following the rules detailed in Chapter VII.

The results of each individual strategy are included in Appendix E, and are the <u>average</u> values from the three tests of each strategy. The results can be summarised as :

(a) An increase in the speed of the electrocoat primer plant by 10% increased the track efficiency by 2.4%. This was due to the fact that although the electrocoat rate was higher than the demand made on it the response to an inbalance in the ratio of derivatives was fairly slow. Increasing the speed of the primer plant improved this time and also gave the system a chance to build up larger stocks prior to the No. 1 paint plant, principally by encroachment into the main store. The storage utilisations for the two areas increased by 8.1% and 4.5%.

Decreasing the speed by 10%lowered the efficiency of the finishing tracks by 6.3%.

The reason for the fall is again the alteration in response time. The full effect of the decrease is not felt however as bodies from the unofficial store going to be reintroduced into the system buffering some of the loss although a time penalty has to be paid for their reintroduction. The 95% confidence limits on these results were $\pm$ 1.2% and 1.3% respectively.

The result of increasing the speed of the No. 1 paint plant by 10% was found to be a 5.4 $\pm$ 1.1% increasing in the track efficiency. The improvement is due to a reduction in the response time but the increase did impose a further constraint on the main store as it increased the peak demand on storage within the main store for body shells awaiting rectification on the No. 2 paint plant. A decrease inm speed resulted in a loss of 4.2 $\pm$ 1.3%. in track efficiency.

(b) Increasing the size of the store prior to the No. 1 paint by 50% to a value of 15 increased the track efficiency by an average of 9.1%. The reason for the increase is that a larger store increases the likelihood of being able to select the correct body shell for load to the No. 1 paint plant. It also tends to lower the encroachment by sealer coated bodies into the store prior to the tracks (the encroachment was lowered by 12.3%) increasing the storage available for holding body shells prior to the tracks and hence improving the selection at two points. The confidence limit (95%) was $\pm$ 1.8%.

Increasing the size of the store prior to the tracks by 50% increased the probability of a selection for submission to the finishing tracks. It also had the effect of releasing further space for the encroachment of sealer coated body shells prior to the No. 1 paint plant and hence improved the possibility of a successful selection at that point. The track efficiency rose by 8.6% $\pm$ 2.7%.

There is obviously an interdependance between the two storage areas as they overlap considerably in terms of their usage. A reduction of 50% to 22 bodies resulted in a 16.3% drop in the efficiency of the trim tracks. The cause of this large drop was traced to the encroachment level which for this test was set at 15 causing its utilisation to rise to 81.6% leaving on average only space for ten body shells some of which had to be taken up by body shells awaiting rectification on the No. 2 paint plant.

(c) Decreasing the paint rejection rate off the No. 1 paint plant by 10% had only a marginal effect on the track efficiency (2.3% $\pm$ 1.8%) but the utilisation of the rectification plant dropped by 16.9% indicating that a saving can be made in rectification costs. Increasing the paint rejection rate by the same amount decreased the track efficiency by (3.8% ± 2.1%) and increased the utilisation of the No. 2 plant by 12.7%.

(d) Increasing the time of the feedback control by 50% reduced the track efficiency by 6.6%. (± 2.1%) as it allowed a higher degree of inbalance to take place before corrective action was taken. A greater strain was placed on feedback control 2 which tried to stabilise some of the inbalance by placing further body shells in the unofficial store (the utilisation increased by 31%). A reduction (50%) in the feedback control cycle time increased the track efficiency by 1.2% (± 1%) suggesting that the time chosen of 600 clock units was valid.

(e) The allocation span was altered by ± 50%. Increasing the span raised the efficiency of the tracks by 9.7% (± 2.0%). The rise was predictable and resulted from the fact that more selections were available at the load to the No. 1 paint plant. It was argued at this point that increasing the span was not a valid ploy since to implement such a system would create considerable scheduling problems as production control would have lost the ability to determine production on a rational basis. This argument was accepted and no further work was done on increasing the allocation span. A decrease in the span by 50% led to an 18% (± 3.2%) reduction in the track efficiency and a 10.7% drop in the utilisation of the No. 1 paint plant. The utilisation of the area prior to No. 1 rose by 18.1% together with a 14.3% increase in the utilisation of the encroachment area in the main store.

(f) The introduction of rational batch sizes increased the efficiency of the tracks by 10.6% (± 2.1%) and lowered the utilisation of the No. 2 paint plant by 5.3% indicating a reduction in rectification costs.

The actual size of the batches was determined within the rules laid down for the reorganisation module. The maximum batch size permitted for each colour was however one of the input variables and this was varied until the highest value of track efficiency was found. The actual maximum colour batch sizes permitted for this result are shown in Appendix E.

The colour sequence for this test was determined firstly by submitting the colour with the lowest rejection rate followed by a batch with the highest rate and so on until all of the colours were exhausted. This sequence was changed by means of the sequence control module such that the colours were submitted in

(a) ascending rejection rate order
(b) descending rejection rate order
(c) two random sequences

All four sequences increased the efficiency of the finishing tracks ((a) 9.6 ± 1.9%; (b) 10.2 ± 2.6%; (c) 10.3 ± 2.3%) compared to the standard. This result indicated that the system was not very sensitive to a colour sequence provided that the track ratio was maintained. Three other factors were examined in the sensitivity analysis, namely the derivative ratio prior to the No. 1 paint plant, the despatch cycle time (mean time in which a lorry load left the despatch bay) and the loop cycle time. In all cases it was found that a perturbation of ± 10% had no effect whatsoever on track efficiency except that when the despatch cycle time was raised it did in fact halt the simulation model as the number of live transactions was exceeded. This indicated that such an effect would be cumulative and over several weeks the slower despatch rate would affect production as it would cause the despatch bay and preceeding areas to fill causing congestion.

The above results were used as the basis on which the strategy analysis was conducted.

Chapter IX

STRATEGY ANALYSIS

Strategy analysis was previously defined as an extension of sensitivity testing only considering all of the variables in combination to reach a solution. Such a solution may well not be an optimum solution, due to the heuristic nature of the approach, but a true optimum solution in scheduling terms is difficult to define and of somewhat doubtful value.

If the speeds of the various plants are considered it can be seen that the ratio of primer plant speed (electrocoat) to finishing track demand is 1.15 (30/hr : 25.89) requiring over 85% efficiency to supply a sufficient quantity of body shells to the area prior to the finishing tracks. If the ratio of colour plant speed to finishing track speed is now considered it can be seen to be 1.209 (26/hr : 21.51/hr.) for saloons and 2.85 (12.5/hr : 4.38/hr.) for commercial vehicles. It can be seen therefore that provided that sufficient primered body shells can be provided for the commercial paint plant then no problem should exist on the commercial vehicle side. The saloon colour plant requires 83% of the primer plant production, i.e. 25 body shells/hr. which in turn reduces the maximum possible ratio between colour plant and finishing tracks down to 1.162 (25/hr : 21.51/hr.)

In ideal conditions these ratios would be adequate but unfortunately breakdowns and stoppages do occur and for the production to continue storages must be placed between the two sets of dependant plants to buffer the effect. The average time of stoppage on the electrocoat was 21 mins. and if we wish to cater for 95% of the time the storage size must be sufficient to last for approximately one hour, i.e. 26 bodies. The unofficial store is adequate for this purpose but it is undesirable to use it due to the poor storage conditions. It was decided therefore to place this storage requirement directly prior to the No. 1 paint plant.

To this requirement must be added the storage needs for sequencing. One theoretical approach to the determination of such a store is as follows.

Let C = a period of time equal to the longest time that a facility will wish to draw one derivative from a store placed after another facility supplying all derivatives.

S = the storage size

P = production rate

Fi = fraction derivative

$$= \frac{\text{derivative total}}{\text{total production}}$$

now

Bodies of derivative painted during time C = bodies in store + bodies produced during painting

Production rate x fraction defective x time period = production rate x fraction derivative x time period x fraction derivative

If the production rates for the two facilities are identical then

$$PF_iC = S + PF_iCF_i$$

$$S = PC\ (F_i - F_i^{\ 2})$$

now for all derivatives F1, F2, F3 ---- n

$$S = PC\ (\Sigma^n_{\ 1}\ F_i - \Sigma^n_{\ 1}\ F_i^{\ 2})$$

and since $\Sigma^n_{\ 1}\ F_i = 1$

then

$$S = PC\ (1 - \Sigma^n_{\ 1}\ F_i^{\ 2})$$

The analysis is only a very simple attempt to quantify the size of store required and does not consider the primer plant, for example, supplying two paint plants whose total or individual production rates vary from the primer plant speed. The time period, C is difficult to determine as it is a function of the colours and their allocation to the various derivatives and the colour mix in a particular weekly order. If however it is considered that the maximum time period is 30 minutes and the derivatives are supplied in the ratio of 13 : 6 : 2 then if the supply rate is considered as 30/hr. and the demand at 25/hr. the storage requirements are 6.

Unfortunately this underestimates the store required by 50% as it does not take account of the fact that the lowest number within the ratio is 2, hence the true store required is 12. This gives the total storage requirement prior to the No. 1 paint plant as 38 bodies all of which must be directly accessable. In the store used there is only an immediate area capable of holding 10 body shells and unless encroachment is permitted up to the maximum of 30 then the desirable storage will not be obtained.

If the store before the tracks is now considered then the store size necessary to guard against breakdown is 18.5 + 21.3 mins, i.e. 15. The sequence required by the tracks is the opposite to the input side, i.e. 12 making a total of 27. The main store has the multiple role of not only holding bodies prior to the tracks and permitting sealer coated body shells to encroach but it also holds the rejected shells from both the No. 1 and No. 2 paint plants prior to their resubmission around No. 2 rectification plant.

If the No. 2 plant is the subject of a breakdown then body shells will begin to accumulate. To cover this eventuality a store must be provided capable of holding 22 body shells. No sequence store is required and the effect of runs of paint colours with a large reject rate is not considered to contribute to the storage demands.

If N = production rate off No. 1 paint plant

n = production rate off No. 2 paint plant

R = rejection rate off No. 1 paint plant

r = rejection rate off No. 2 paint plant.

then the number that will be moving into the store will be

$$NR + nr$$

which as $N = n$

$$= n(R + r)$$

and hence will only require additional storage when $R + r > 1$ which occurs for time periods of no longer than 15 mins.

In summary a very simple analysis reveals that the main store plus the store prior to the No. 1 paint plant must total 87 vehicles to maintain production at an even level. At the moment the store has a maximum capacity of 54 but in practice an unofficial store is used to supplement the storage needs.

It can clearly be seen from the sensitivity testing that the response of the model is to increase considerably the efficiency of the trim tracks if the storage facilities are increased. The sensitivity tests however only considered the effect of an increase in individual areas. The first strategy tested therefore took the two limiting conditions in the sensitivity tests, namely increasing the store prior to No. 1 and the main store by 50% up to a total of 81 vehicles. In order to minimise the sampling effect each strategy was tested five times with different random number seeds. The increased number of tests compared to the sensitivity tests is to give a greater reliability for the results.

The results of this strategy were to increase the track efficiency up to its maximum level namely 100%, an increase of 13% with no deviation as all tests yielded the same values. The storage size was then reduced by 10% to a total of 73. The results returned from the model gave an average track efficiency of 99.3% with a deviation of ± 0.65%. The reduction in storage size did not appear, at this level, to have any real influence and it must be noted that the value returned was 16% below the expected storage needs determined in the previous calculations.

One of the main variables in the calculations is the time period for which the paint plant wish to paint only one derivative whilst being supplied with three. The introduction of rational paint batch sizes but maintaining to a track ratio where possible had the twofold effect of reducing the time period C and improving the rejection rate off the No. 1 plant. In the sensitivity testing this ploy raised the track efficiency by 10.6%. It was therefore decided to attempt to use this approach with reduction in the storage requirements just determined of approximately 19%, i.e. a value of 59.

This lowered the track efficiency to 97% ± 1.9% and hence the storage area was increased to 65 with a resultant increase of 1.1%. The size of the store was progressively increased until a 100% efficiency could be guaranteed. This level of efficiency was found when the storage size was 69, a 26.1% reduction on the calculated value.

An attempt was then made to reduce the storage by decreasing the cycle time of the main feedback control to 30 minutes. In the sensitivity testing this reduction raised the standard efficiency by 1.2% but at the efficiency level obtained by the current strategy no benefit was detectable and it was found that the time could be increased up to 80 minutes before any loss in track efficiency was detected. The four colour sequences used in the sensitivity testing were examined together with a suggested sequence from the paint shop supervision and a reduction in the storage capacity was attempted.

The two random sequences did not permit any reduction in the storage area without a loss in track efficiency and the sequences using ascending and descending paint rejection rate required storage for an additional two body shells in order to maintain the track efficiency. The sequence determined by the paint shop supervision was able to maintain the track efficiency with a reduction of 1 body shell. This particular sequence did however cause some fluctuation in the work load on the rectification plant which was found to change in line with the fluctuations on the No. 1 paint plant hence maintaining a reasonable flow of body shells. The basic sequence of high rejection rate colour followed by low rejection rate colour kept the peak activity on the No. 2 plant 8% below that of the empirical sequence. As the storage reduction was only marginal the basic sequence was maintained as more suitable.

It was felt that a 10% reduction in the paint rejection rate is the maximum that can be realistically achieved in the near future and it was therefore decided to examine the storage requirements up to this figure. A reduction of 5% was found to require three body spaces fewer than the best strategy obtained. This effect was due to the reduction in the storage needs prior to the No. 2 paint plant to hold rejected shells awaiting rectification. A 10% reduction in the reject rate further reduced the store by two. Together with this benefit there is also a reduction in the rectification load of 15%, with a corresponding decrease in the rectification direct costs, i.e. material. A reduction in labour is also feasible.

An increase in the speed of the main plants namely the electrocoat and the No. 1 paint plant produced an increase in track efficiency compared to the standard results. If the storage sizes have been determined by maintaining maximum track efficiency and keeping the store requirement to a minimum then an increase in speed should result in the possibility of a further reduction in the store necessary.

The introduction of the increase speed on the electrocoat by 10% did not permit the store size to be reduced without a loss in track efficiency 0.7%. The same degree of increase on the No. 1 paint plant allowed the store prior to the finishing track to be reduced by only one with no effect on track efficiency. An increase in the peak load on the No. 2 paint rectification plant was noticed (5%) and was felt to be due to the increased maximum number of vehicles that it is possible to have rejected in any one period.

In summary it can be shown that it is possible to maintain the finishing track efficiency at 100% (considering that labour constraints are eliminated) in several ways but in terms of the minimum storage required the best strategy was found to be :

(a) use a colour sequence of a high rejection rate followed by a lower rejection rate.

(b) attempt to build up to maximum number of vehicles in a colour batch but only provided that the track ratio over one hour is maintained.

(c) increase the store prior to the No. 1 paint plant to 20.

(d) increase the store prior to the finishing tracks to 49.

(e) establish the feedback cycle time at 80 minutes.

and when a reduction in paint rejection rate of 10% is achieved then the storage requirements can be lowered for (d) by 5.

It must be stated that this storage requirement does not take account of offset working which must be added to the values given.

Chapter X

DISCUSSION

In the previous chapters an attempt was made to examine, somewhat in isolation, three major problem areas related to the painting and finishing of motor vehicles. It is now considered important to bring the work together to present it as a possible approach to a total problem.

Like any successful mutation the production unit adopted techniques and mannerisms which tended to protect it from the pressures and conflicts existing around it. Stripped of this protective cocoon the production unit would die unless it adopted new approaches which enable it to withstand the additional pressures. In the motor industry the pressures have been, principally, economic, which in turn depend on the basic law of supply and demand. Potential production capacity for the manufacture of motor vehicles has risen sharply in the last ten years with countries like Japan and Russia entering with great drive and enthusiasm. The potential market has also expanded but not at the same rate with the result that the pressures on manufacturers to produce more economically have increased.

The production unit examined protected itself from the difficulty of material provisioning and scheduling by back-logging orders which gave a large number of feasible orders and sequences for production. This solution resulted in an increase in the time that an order waited in the system before being processed. The method of selecting orders from future weeks, perhaps further retarding particular orders, was also considered a valid ploy to minimise some of the problems. Approaches such as these reduced the importance of good material provisioning techniques and rational sequencing, as the system had mutated to build in increased flexibility. This can only continue whilst the demand exceeds supply and now customers have become increasingly impatient at having to wait for a desired vehicle and intolerant of unpredictable delays.

Despite the protective system, the lack of the correct part to assemble to the body shell on the finishing tracks still remained a severe handicap imposing limitations on the feasible sequences that could be submitted, causing rescheduling at a late stage in production and frequently forcing incomplete vehicles to be produced. The system was prevented from completely eliminating the problem by further backlogging as the order cycle, determined by the management, imposed a ceiling of approximately three weeks production on the arrears.

The obvious solution to the problem is to provision the stores with sufficient material, at an economic level, to eliminate a shortage of parts. The prime task of any material provisioning system be it the simple warehousing case or the one, such as this, wherein all of the parts are inter-dependant, is to obtain the best possible information on future demand. In the environment studied this information was contained in the Vehicle Build Forecast and for the purpose of procuring components for subsequent assembly on the tracks was totally inadequate as it detailed neither the country, colour or production factory for any of the vehicles. It could only be used for the broader issues of production planning such as manning and aquisition of facilities.

The only way in which adequate information can be obtained, to the level required, is to base it on the latest market intelligence available. In terms of the organisation as it existed at the time of this study this information can be gleaned from the order bank of distributors orders, maintained by the Sales Organisation and covering at least six weeks production. If at any time the order bank falls to a low level then the prime input must be a projection of future demand based on the previous six weeks orders.

The suggested system which establishes a formal information link between the sales and material provisioning departments requires that the incoming orders are allocated with a desired production week. This allocation is the task of the sales department and should be done with reference to the market conditions. It is a tentative allocation but must be used with care as it will be the basis upon which the production units will provision. Once given a tentative allocation it is relatively simple to determine the weekly order pattern and this can then be passed to both the sales and production departments. In this way both parties will be working to the same rational base.

It is unfortunately inevitable that the market conditions upon which the initial allocation was made will change which, in turn will occasionally demand a change in the order pattern. This final allocation should be as close to the initial one as possible, otherwise if the ability to implement change is abused then the advantages of the system will be negated. If used carefully the system should result in a better service from the production unit to the sales department, which in turn should enable the sales department to realise more of the sales potential for particular vehicles. It should also result in lower stock holdings as the production units will only have to cater for a safety stock to cover unexpected market changes, and need not provision against a large unexpected demand from the sales department.

Once it is accepted that the prime need, in provisioning material, is a good assessment of the future demand patterns then it is possible to consider a rational stockholding policy. One of the factors that must also be considered in the determination of such a policy is the penalty to be paid for a stock shortage. If production can flex without any cost penalty then the stock service level can be reduced. In the situation studied all of the parts were inter-dependant and the possibility of alternative but equally acceptable build programs did exist. The problem of material allocation in times of stock shortage to meet the objective of, say maximise production, was extremely complex and well beyond any attempt at manual solution.

The suggested approach of using a linear programming algorithm with the matrix element all constrained to zero or one, to give an optimum allocation was found to give answers where the error resulting from non-integrality were well within an acceptable amount (less than .023%).

The constraint imposed on the system that the matrix elements should all be zero or one limits the technique to those assembly situations whereby if a part is fitted then the same number of parts are always fitted.

The fact that there may be 3 always fitted reduces to the zero one constraint by considering the part as a set and dividing the stock by the number off and truncating, e.g. (301/3) would be 100). The motor vehicle industry at the trim stage conforms 99% to this constraint. There are, certainly, cases where one particular vehicle required three of a part whilst another needs only two. In the main however, these parts contribute only 1% of total of which two thirds are very small items such as fastenings and grommets, etc., and the remainder are not major parts, e.g. interior door handles (2 off on 2 door 4 off on 4 door versions). The stock level of fastenings should never reach the stage whereby it is a limiting factor on production and the remainder of the 'special' parts can be incorporated without the error due to non-integrality rising above an acceptable value.

The technique is also limited to single level assemblies that is to say that the program expects all of the parts examined to be fitted directly to the main assembly. This is the situation that exists at the trim stage of production. For a multi level assembly problem, such as white metal body shell production, the technique can only be used level by level as some parts will be committed to intermediate assemblies, preventing them from being considered for any other major assemblies other than those at which the sub assembly fits.

To use the technique in the manner described would result in obtaining optimal solution applicable only to the one level which may be different if a large span was taken. The problem that exists in widening the span of the technique is the inability to consider the time delay implicit in the system, i.e. a body shell must be made well in advance of trimming in order that painting, etc., can take place. Expanded to cover the whole production of the body shell, the practical usefulness of the answer must be somewhat doubtful.

At the trim stage, however, the usefulness of the technique is beyond doubt. It will provide a means to optimise the use of the stock on hand to fulfil a stated management objective, within the constraints of orders on hand and capacity, and will also indicate the gains that can be made by obtaining either further supplies of particular components (detailing the precise gain that can be made and hence provinding an order in which to expedite the material) and show the possible increases that can be achieved by obtaining further orders.

It will also be possible to guarantee that all of the vehicles painted will have sufficient material available to them when they reach the finishing tracks. This should eliminate the need for drastic rescheduling prior to the finishing tracks and will reduce the number of painted body shells queueing before the tracks awaiting material. A further effect of such a system will be the opportunity for production control to establish more rational paint sequences as they will not have to respond to the same extent to material shortages. This should result in large paint batch sizes which should increase the efficiency of the paint plant by reducing the number of paint change-overs and also reduce the number of rejected body shells with a resultant cost saving.

Senior management have expressed keen interest in the technique and it is proposed that a scheme will be implemented at the Cowley complex of British Leyland to assist in the production of the ADO 14 (Austin Maxi) and ADO 28 (Morris Marina) vehicles. The likely savings of such a scheme are difficult to obtain but if implemented on a group basis it is considered that estimates of £500,000 per annum are not unrealistic.

The minimisation of the material problems has a major effect on the production efficiency but the sequencing problems still existed. The main approach taken in this study was to examine the advantages of different strategies testing each one in turn on a computerised simulation model. The heuristic method used cannot claim to find an 'optimum' solution to the problem posed and it is limited to stating the best strategy from those tested. This places the main responsibility on the researcher to examine all of the practical and profitable strategies.

The more deterministic techniques such as queueing theory and some of the scheduling algorithms that have been used can claim 'optimal' solutions. The problem is that the solution offered had to make so many assumptions in its formulation that the nett problem fails to resemble the original one that was posed. The main question is whether such assumptions in the environment studied would negate the validity of the assumption. The production unit examined used variable routing and complex queue disciplines which would render a strict deterministic approach impracticable.

The main problem that existed with the building of the simulation model was the lack of basic data on the performance of individual units, paint rejection rates, factors influencing the rejection and accurate, reliable cost information. Without accurate information no rational system can honestly claim any real gain over the current method. The large data collection necessary for a study in the unit examined is an overhead that would have to be paid regardless of the technique used. One of the major problems was that due to limited resources the data collection could not be continuous and hence by the time some of it was obtained and analysed it was not the latest information. Checking that it was still a realistic representation of the current performance consumed a considerable amount of time and limited the number of strategies that could be examined. Idealistically continuous monitoring is required on a formal basis.

The criterion used to examine the validity of the simulation model, namely matching the arrival rate patterns, within the production unit, obtained from the actual system with those gathered from the model, is the one that is generally used in simulation testing. In the model used, however, this was particularly difficult as one of the major constraints, i.e. the material problem, was considered eliminated.

The constraint imposed by a stock shortage was considered uniformly distributed across the whole span of production. The main problem in making this assumption occurs just prior to the trim track where, if a stock out is discovered, the vehicle is rescheduled. The rescheduling can cover a large number of vehicles but because the finish track demands a body shell within a short period to maintain production the time taken over rescheduling can be fairly small. The main influence of the material constraint was felt directly after the tracks where vehicles were held whilst the missing parts were fitted. This implied that the utilisation of the areas after the track would be significantly lower in the model than in practice and this was confirmed from the results, placing the major constraint in the system prior to the tracks.

Generally the measure taken of a strategies worth was considered as reflected in the efficiency of the trim tracks given a stable warm up condition to start. Idealistically the measure should have been cost in response to a global objective of maximising the return on investment. This approach at the time of the study was impractical as the costing system was totally inadequate.

The results from the model show, however, that considerable gains can be made in increasing the efficiency of the unit by

(1) controlling the colour paint load to the track ratio

(2) increasing the storage area prior to the colour paint plants

and (3) increasing the storage area prior to the finishing tracks

The influence of paint colour sequence was shown to have only a marginal influence on the system efficiency.

The main points to be made from the results of the model are that the lack of storage area in a form which allows access to all body shells, is a major factor in limiting the load sequence which in turn influences the rejection rate and hence reduces the effective feed into the area prior to the trim tracks. This impairs the efficiency of the trim tracks as they may be held awaiting a body shell.

A large store of painted shells prior to the finishing tracks would also solve the problem of the conflict between supply and demand but it is a general rule that the further back in production that the conflict can be buffered the more economic, as the item will increase in value as it travels through the system; increasing the value of work in progress. There must however be some storage between the colour plant and the tracks in order to combat the variability in supply, and the total aim must be to keep the overall storage at a minimum. The storage sizes which gave the best track efficiencies were 20 and 49 for the area prior to and after the colour plants respectively.

It was shown that if the load sequence deviated by more than 10% in any one hour then a drop in track efficiency resulted unless compensated by an increase in the storage size. Obviously the extent to which it is necessary to deviate from a pure track ratio in order to keep reasonable colour batches is a function of the weekly order mix, but as it was found that this did not have a major influence on the system then the track ratio should be maintained within ± 10% in any one hour.

The model took approximately 15 minutes C.P.U. time on an IBM 360/50 to simulate an 80 hour production week and executed in 140K partition. This implies that the cost of testing a strategy £15-20 prior to implementation is low compared to danger of uncertainty.

In summary the author has attempted to examine a large problem in sections but trying to keep within the total concept. The problems relating to material provisioning were felt to be best solved by the introduction of feed forward information loops. The material allocation can be solved by using the pure deterministic approach of mathematical programming and progress towards a solution of the sequencing problem was made with a heuristic approach.

CHAPTER XI

CONCLUSIONS

1. One of the major problems in attempting to introduce sophisticated management tools within British Leyland is the lack of basic data on costing and performance at a sufficiently low level to be meaningful. These basic data collection systems must be introduced and maintained.

2. The lack of communication, at a detailed level, between the Sales Organisation and the Production units contributed towards considerable production difficulties and a poor service to the sales organisation. The Vehicle Build Forcast was totally inadequate as a basis upon which to provision the production units to meet any subsequent demand.

3. A system based on the examination of the order bank of distributors orders could form the basis of local material provisioning provided that the Sales Organisation accept the need to allocate each order with a desired production week differentiating between obligatory and non-obligatory orders. The facility to respond to market changes is available but requires effort to implement. Having a good provisioning system does not eliminate the problems due to extraneous factors such as breakdowns, etc. interrupting the supply of parts.

4. In times of shortage the material allocation to optimise

a management objective is beyond manual solution.

5. It is possible to introduce a mathematical programming system based on pure linear programming but with the matrix elements contrained to 0 and 1 which will maintain the integrality, necessary for an assembly problem, to an acceptable degree of accuracy.

6. As the technique uses the simplex algorithm as its base then the time for the program to execute is more predictable and considerable faster than a pure integer programming approach.

7. Such a technique will provide
   (a) an optimal build program within the constraints of capacity, stock available, orders on hand and order priority.
   (b) the ability to examine the effect, in absolute terms, of obtaining further orders for vehicles, which can be built from the available stock, in addition to the optimum number obtained previously.
   (c) the ability to investigate the effect of obtaining more material to build additional vehicles.
   (d) the possibility of changing the objective, i.e. from maximise production to maximise profit, and the opportunity to make the objective non-linear (separable variable programming).

It has immediate practical application, to be implemented at British Leyland, Cowley, and promises considerable benefits. The technique is applicable to complex single level assembly situations where copmonents are fitted in sets or are not fitted depending on the identity of the assembly.

The elimination of the material constraint still left a sequencing problem which could not be solved by a pure mathematical approach as the assumptions that would have to be made would divorce the solution away from the real world.

9. The computerised simulation model built to describe the system was a valid representation.

10. The system was sensitive to :
    (a) a change in the size of the storage area prior to either the No. 1 colour paint plant or prior to the finishing tracks;
    (b) a change in the paint batch sizes and sequencing;
    (c) a change in the cycle time of the feedback control.

11. A financial basis would have been a more realistic yardstick by which to judge a strategy rather than the minimisation of facilities whilst maintaining the track efficiency at a maximum. Cost details were not available at a detailed level to make this practical.

12. Using the measure mentioned the best strategy was found to be obtained when the following factors were observed.

(a) the store prior to the No. 1 paint plant should be capable of holding 20 body shells all directly accessable.

(b) the store prior to the finishing tracks should be capable of holding 49 body shells all directly accessable.

(c) the paint sequence should be a high reject rate colour followed by a low reject rate colour.

(d) the paint colour batch size should be maximised but the track ratio within any hour must be held to ± 10% of its correct value.

(e) the feedback cycle time should be maintained at 80 minutes.

13. A computerised simulation model is a valuable aid in determining strategies which should result in some improvement if a management objective.

The approach is heuristic and solutions can rarely be claimed to be optimal but with a fast computer execution time such a model permits, at an economic level, sufficient experimentation to provide a solution which is acceptable. In production terms an optimal solution is of dubious value due to the fluid nature of the environment.

14. Computer simulation also permits the user to gain an intimate knowledge of the system and develops an almost intuitive feel for the reaction of the system to any change.

15. Computer simulation techniques and results can be readily understood by senior management and as such the difficulty in implementation is reduced. Mathematical programming is not accepted so readily.

PART IV

THE FUTURE

CHAPTER XII

FURTHER WORK

In an industrial research project which attempts to cover a large aspect of a companies business there is inevitably further work to be done to maintain the competitive position and certainly this research work fell well short of solving all of the problems in the area of painting and trimming vehicle body shells.

One of the main constraints on the work was found to be the consistent lack of reliable basic data upon which to build any firm base for a solution. Information is the key to running any large organisation successfully and certainly accurate costing data is essential. It is not, however, the only information that is required, data such as rejection rates at the production stages is necessary in order that a rational approach can be used to realise an improvement. Data is also necessary on the production facilities, recording not only the current production rates but also the limiting factors. The problem is that data collection systems that monitor performance and costing factors are expensive and difficult to justify in cold monetary terms before the data has been analysed. Accountants who readily accept the need for costing systems, which in themselves rarely give any direct benefit to the company, must also be prepared to accept that statistical data on production factors is necessary before permanent gains can be made. Within the British Leyland group the lack of base data presents one of the major problems. The company has recognised the fact, but the progress has been painfully slow.

In more specific terms the company has a considerable amount to do in order to bring together the Sales and Manufacturing areas of its business. The author has indicated one approach that can be used but the implementation stage still remains undone.

On the question of material allocation the solution offered will solve the single level paint and finish problem and as such has been enthusiastically received by the company. There still remains however the question of an optimum allocation of panels in the form of assemblies, sub-assemblies and single panels to manufacture a finished white metal body shell, i.e. a multiple-level assembly problem. Once the matrix algebra is determined whereby account can be taken of panels in any of the three conditions mentioned it will be possible to then consider the question of a global optimum build program spanning body assembly and paint and trim. There is however at this point a further problem introduced in terms of the time scale, i.e. the body must be built long before it is painted or trimmed. Such a global optimum could only be achieved with an overall up to date picture of the stock on hand and the orders in process which returns to the original point concerning data.

The sequencing and control problem is complex and virtually unique to every production unit. The conditions which surround the unit constantly change and an optimum sequence once week may well be the worst the following week. In such a case any scheduler must have either a very robust set of rules or be prepared to alter sequences in the light of changes. In a complex environment decision rules are unlikely to be able to consistently provide the correct answer and if the scheduler begins to change schedules without objective information on the consequences then it is well possible that such sequences may also be poor.

It may well be possible, however, to give the scheduler a means of testing strategies prior to implementation. One such means could be a computerised simulation model, similar to the one developed for this research, to which he could submit the current situation and his proposed strategy and receive a guide as to the effect, quickly and objectively. This could only be done on a practical scale if the production unit did not change rapidly with time and hence minimise the problem of maintaining the validity of the model. The author presented a paper on this aspect of modelling at the International Conference on Production Engineering Research, Birmingham 1970.

If such models were built to cover the main activities of the companies business then it would be possible for central management to examine the effects of changes in corporation manufacturing strategy prior to its implementation. Again, however, the validity of such models could only be maintained if they were provided with accurate data.

APPENDIX A

ANALYSIS OF PRODUCTION

ADO 15

WEEK NO.	DIRECTORS FORECAST	TRACK SPEEDS	SALES ORDERS	ARREARS	NUMBER PROD.	NUMBER DES.	OUTSTANDING ORDERS	EFFICIENCY *
15	350	350	350	0	58	59	350	16.6
16	350	350	700	291	146	137	991	41.7
17	350	350	300	854	286	252	1154	81.6
18	350	350	0	902	274	290	902	78.2
19	250	350	0	612	182	186	612	51.9
20	350	350	100	426	288	275	526	82.2
21	350	350	0	251	228	251	251	65.1
22	350	350	290	0	152	123	290	43.4
23	350	350	175	167	224	122	342	64.0
24	350	350	230	220	122	134	550	34.8
25	350	350	458	416	139	134	874	39.7
26	350	698	400	740	430	231	1140	61.5
27	1000	706	800	909	277	233	1709	39.2
28	1000	706	800	1476	594	423	2276	84.2
29	1000	752	802	1853	402	686	2655	53.5
30	1000	854	0	1969	568	686	1969	66.5
31	1000	854	200	1283	693	558	1483	81.2
32	1000	854	1594	925	721	772	2519	84.4
33	1000	854	1190	1747	841	924	2937	98.5
34	1000	952	996	2013	682	753	3009	71.6
35	1000	952	680	2246	790	827	2926	83.0
36	1000	952	972	2099	845	758	3071	88.8
37	1000	952	880	2313	927	995	3193	97.4
38	1000	952	490	2198	378	413	2688	49.7
39	1000	952	0	2275	829	742	2275	87.1
40	1000	952	1008	1533	906	938	2541	95.2
41	1000	952	997	1603	946	1002	2600	99.4
42	1000	952	1000	1598	704	677	2598	74.0
43	1000	952	1004	1921	938	937	2925	98.6
44	1000	952	1029	1988	838	818	3017	88.0
45	1000	952	241	2199	471	511	2400	49.5
46	1000	952	601	1929	799	758	2530	84.0
47	1000	952	721	1772	749	946	2493	78.7

* Efficiency = $\frac{\text{No. Produced}}{\text{Manned Capacity (Track Speed)}}$

3

Cars & Car Derivatives

F.1234

To: B.M.C. EXPORT SALES LIMITED.
A Subsidiary of the British Motor Corporation Ltd.
LONGBRIDGE, BIRMINGHAM, ENGLAND

B.M.C. Office use only

Type of Order

Nº 607210

1. *From:* **Distributor** ....
Address ....
2. **Please Supply:** (if confirmatory state whether phone, letter, cable) ....
3. **Model Description:** ....
Type (de luxe, etc.) ....
4. Total Quantity (in words)
5. Ex-Works Month required

Quantity	Body Colour	Trim Colour

Qty.	Clr.

PRODUCTION ALTERNATIVES

State Requirements

6. **Steering** ... Right; Left
7. **Lamps** ... LH Dip; RH Dip; French, U.S.A., European, Swedish, German
8. **Speedometer** Miles; Kilometres
9. **Radio** ... Less; With; State type
10. **Compression** High; Low; Diesel
11. **Heater** ... Less; With; Fresh air blower
12. **Gearchange** Centre floor; steering column; automatic; overdrive
13. **Trim** ... Leathercloth; Hide; Ambla
14. **Tyres** ... Standard; State alternative
15. **Front Seat** Standard; Bench type; LCV; Front passenger seat

COMPUTER

EXTRA EQUIPMENT

16. ....
17. ....
18. ....
19. ....
20. ....
21. ....
22. ....
23. ....
24. ....
25. ....
26. ....
27. ....

Shipment Terms ...

28. **Port of Discharge:** ....

Shipping Mark

Import Licence
Number:
Value:
Valid to:
Attach original or photostat

First Contractor ...

Total Contractors

Special Sales

Suppress

Battery Requirement (only code if non-standard for territory)

Date of Acknowledgement

29. **Special Instructions:** ....
....
30. Authorised Signature .... *Date* ....
31. **We hereby confirm this order**
(Confirming House use only)

Signed .... (Company Stamp) *Date* ....

APPENDIX B

SUMMARY OF MATHEMATICAL PROGRAMMING RESULTS

MODEL NO. 1

	TOTAL FUNCTIONAL VALUE	AVERAGE ORDER SIZE	TOTAL LOSS
RHS1	1263	84	-
RHS2	8480	24	-

MODEL NO. 2

RHS1-9 PRODUCT1-2	23467	80	13

MODEL NO. 3

RHS1	903	69	
RHS2	3811	54	3
RHS3	24634	36	25
RHS4	1151	14	

MODEL NO. 4

RHS2	12842	8	
GRAND TOTALS	76551		4.1

Average loss due to a non-integral solution $\frac{41}{76551} = .000535$

or .05%

If it is considered that integrality can be regained by a loss of 1 in the total function (see solutions for Model 3 marked 1-6) then the loss reduces to $\frac{18.}{76551}$ or .023%

Average Order Size = 26.9

SOLUTION TO MODEL 1, I.B.M. Mathematical Programming System 360/50

SOLUTION (OPTIMAL)

TIME = 0.47 MINS. ITERATION NUMBER = 14

...NAME...	...ACTIVITY...	DEFINED AS
FUNCTIONAL	1263.00000	PRODUCT
RESTRAINTS		RHS1
BOUNDS....		BOUND1
RANGES....		RANGE1

SECTION 1 - ROWS

NUMBER	...ROW..	AT	...ACTIVITY...	SLACK ACTIVITY	..LOWER LIMIT.	..UPPER LIMIT.	.DUAL ACTIVITY
1	CAPACITY	BS	1263.00000	737.00000	NONE	2000.00000	.
2	PRODUCT	BS	1263.00000	1263.00000-	NONE	NONE	1.00000
3	NORMAL	BS	648.00000	72.00000	NONE	720.00000	.
4	INDUCT	BS	615.00000	585.00000	NONE	1200.00000	.
5	LHD	BS	713.00000	47.00000	NONE	760.00000	.
6	EUROPE	UL	350.00000	.	NONE	350.00000	1.00000-
7	FRENCH	UL	200.00000	.	NONE	200.00000	1.00000-
8	WHITE	BS	395.00000	95.00000-	300.00000	556.00000	.
9	RED	BS	449.00000	149.00000-	300.00000	620.00000	.
10	BLUE	BS	419.00000	119.00000-	300.00000	578.00000	.

SECTION 2 - COLUMNS

	NUMBER	.COLUMN.	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT.	..UPPER LIMIT.	.REDUCED COST.
	11	IFR	BS	61.00000	1.00000	58.000000	162.00000	.
A	12	IFW	LL	.	1.00000	.	149.00000	.
A	13	IFB	LL	25.00000	1.00000	25.00000	76.00000	.
	14	IER	BS	56.00000	1.00000	.	206.00000	.
A	15	IEW	UL	107.00000	1.00000	.	107.00000	.
A	16	IEB	UL	28.00000	1.00000	.	28.00000	.
	17	ILR	UL	87.00000	1.00000	.	87.00000	1.00000
	18	ILW	UL	56.00000	1.00000	.	56.00000	1.00000
	19	ILB	UL	195.00000	1.00000	.	195.00000	1.00000
A	20	NFR	LL	76.00000	1.00000	76.00000	201.00000	.
A	21	NFW	LL	20.00000	1.00000	20.00000	71.00000	.
A	22	NFB	UL	18.00000	1.00000	.	18.00000	.
A	23	FER	UL	63.00000	1.00000	.	63.00000	.
A	24	NEW	LL	.	1.00000	.	108.00000	.
A	25	NEB	UL	96.00000	1.00000	.	96.00000	.
	26	NLR	UL	106.00000	1.00000	.	106.00000	1.00000
	27	NLW	UL	212.00000	1.00000	.	212.00000	1.00000
	28	NLB	UL	57.00000	1.00000	.	57.00000	1.00000

SOLUTION TO MODEL 1

ICL 1905 E   LINEAR PROGRAMMING MARK 2

PRIMAL   SOLUTION

VARIABLE	VALUE		COST		COST*VALUE
NLRORD	106.000000	-	1.000000	-	106.000000
NLWORD	212.000000	-	1.000000	-	212.000000
NLBORD	57.000000	-	1.000000	-	57.000000
NERORD	24.000000	-	1.000000	-	24.000000
NEWORD	108.000000	-	1.000000	-	108.000000
NEBORD	96.000000	-	1.000000	-	96.000000
NFRORD	79.000000	-	1.000000	-	79.000000
NFWORD	20.000000	-	1.000000	-	20.000000
NFBORD	18.000000	-	1.000000	-	18.000000
IFRORD	58.000000	-	1.000000	-	58.000000
IFBORD	25.000000	-	1.000000	-	25.000000
IERORD	122.000000	-	1.000000	-	122.000000
ILRORD	87.000000	-	1.000000	-	87.000000
ILWORD	56.000000	-	1.000000	-	56.000000
ILBORD	195.000000	-	1.000000	-	195.000000
			TOTAL COST	-	1263.000000

SLACK VARIABLES

NAME	VALUE
CAPACY*	737.000000
INDUCT*	657.000000
L HDIP*	47.000000
REDCOL*	144.000000
WHITEC*	160.000000
BLUECO*	187.000000
NERLIM*	39.000000
NFRLIM*	122.000000
NFWLIM*	51.000000
IFRLIM*	104.000000
IFWLIM*	149.000000
IFBLIM*	51.000000
IERLIM*	84.000000
IEWLIM*	107.000000
IEBLIM*	28.000000
NFRPRI-	3.000000

RESULTS FROM MATHEMATICAL PROGRAMMING MODELS

PACKAGE NAMES : LINEAR PROGRAMMING MK.2
360 MATHEMATICAL PROGRAMMING SYSTEM
LINEAR PROGRAMMING 1440

COMPUTERS : ICL 1905/IBM 360/50/IBM 1440

PROGRAM NAMES : ALLOC1, SMPSTEST, ALLOC1

MODEL NO. 1

OBJECTIVE NAME	RHS NAME	BOUND NAME	θ FUNCTIONAL	NO. OF VARIABLES IN SOLUTION	LOSS
* PRODUCT	RHS1	BOUND	- 1263	15	-
** "	RHS1	BOUND	- 1263	14	-
*** "	RHS1	BOUND	- 1263	16	-
	RHS2	BOUND 2	434	17	-
	"	"	433	17	-
	"	"	432	17	-
	"	"	430	17	-
	"	"	429	17	-
	"	"	428	17	-
	"	"	427	17	-
	"	"	426	17	-
	"	"	425	17	-
	"	"	424	17	-
	"	"	423	17	-
	"	"	422	17	-
	"	"	421	17	-
	"	"	420	17	-
	"	"	419	17	-
	"	"	418	17	-
	"	"	417	17	-
	"	"	416	17	-
	"	"	415	17	-
	"	"	414	17	-

* RUN ON ICL 1905

** RUN ON IBM 1440

*** RUN ON IBM 360/40 & 50

MODEL NO. 1

VARIABLE	CONSTRAINT TYPE	RIGHT HAND SIDES		
		RHS1	RHS2	CHNG1
PRODUC	O	-	-	-
CAPACY	L	2000	800	
NORMAL	L	720	260	-1
INDUCT	L	1200	310	-1
LHOIP	L	760	225	-1
EUROPE	L	350	187	-1
FRENCH	L	200	108	-1
RED	L	620	273	-1
WHITE	L	556	257	-1
BLUE	L	578	284	-1

VARIABLE	BOUND 1		BOUND 2		OBJECTIVE
	UPPER	LOWER	UPPER	LOWER	MAX. PRODUCTION
NLR	106		27		1
NLW	212		53		1
NLB	57		16		1
NER	63		17		1
NEW	108		28		1
NEB	96		23		1
NFR	201	76	50	19	1
NFW	71	20	15	5	1
NFB	18		5		1
ILR	87		22		1
ILW	56		12		1
ILB	195		47		1
IER	206		53		1
IEW	107		21		1
IEB	28		7		1
IFR	162	52	40	13	1
IFW	149		35		1
IFB	76	25	20	6	1

MODEL NO. 1

		N	N	N	N	N	N	N	N	N	I	I	I	I	I	I	I	I	I
		L	L	L	E	E	E	F	F	F	L	L	L	E	E	E	F	F	F
		R	W	B	R	W	B	R	W	B	R	W	B	R	W	B	R	W	B
PRODUCT	N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CAPACTY	L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NORMAL	L	1	1	1	1	1	1	1	1	1									
INDUCT	L										1	1	1	1	1	1	1	1	1
LHDIP	L	1	1	1							1	1	1						
EUROPE	L				1	1	1							1	1	1			
FRENCH	L							1	1	1							1	1	1
RED	L	1			1			1			1			1			1		
WHITE	L		1			1			1			1			1			1	
BLUE	L			1			1			1			1			1			1

RESULTS FROM MATHEMATICAL PROGRAMMING MODELS

PACKAGE NAME : Mathematical Programming System

COMPUTER : IBM 360/40

PROGRAM NAME : SMPS TEST

MODEL NO. 2

OBJECTIVE NAME	RHS NAME	BOUND NAME	FUNCTIONAL	NO. OF VARIABLES IN SOLUTION	LOSS†
PRODUCT 1	RHS 1	BOUND 1	15990**(973*)	15	-
PRODUCT 1	RHS 1	BOUND 2	19040 (1116)	13	-
PRODUCT 1	RHS 2	BOUND 2	21290 (1270)	15	-
PRODUCT 1	RHS 3	BOUND 2	22782 (1354)	16	-
PRODUCT 1	RHS 4	BOUND 2	16465 (957)	14	-
PRODUCT 1	RHS 5	BOUND 2	20659 (1193)	12	-
PRODUCT 1	RHS 6	BOUND 2	21485.67 (1312)	17	4
PRODUCT 1	RHS 7	BOUND 2	19020.5 (1145)	16	4
PRODUCT 1	RHS 8	BOUND 2	27245.0 (1582)	16	-
PRODUCT 1	RHS 9	BOUND 2	25821.0 (1710)	18	-
PRODUCT 2	RHS 1	BOUND 2	1116*	20	-
PRODUCT 2	RHS 2	BOUND 2	1270	19	-
PRODUCT 2	RHS 3	BOUND 2	1354	20	-
PRODUCT 2	RHS 4	BOUND 2	983	16	-
PRODUCT 2	RHS 5	BOUND 2	1193	15	-
PRODUCT 2	RHS 6	BOUND 2	1312	19	-
PRODUCT 2	RHS 7	BOUND 2	1170	16	4
PRODUCT 2	RHS 8	BOUND 2	1582	17	-
PRODUCT 2	RHS 9	BOUND 2	1825.5	20	1.5

TOTAL FUNCTIONAL (vehicles) = 23,467

TOTAL LOSS = 13

TOTAL NO. OF VARIABLES = 294

** Functional in terms of profit. * Functional in terms of production

† A loss is only occurred if the solution is non-integer.

MODEL NO. 2

VARIABLE	CONSTRAINT TYPE	RHS1	RHS2	RHS3	RHS4	RHS5	RHS6	RHS7	RHS8	RHS9
		RIGHT-HAND SIDES								
CAPACITY	L	2000	2200	2500	1500	1750	1549	1410	14651	5312
PRODUCT		-	-	-						
NORMAL	L	720	857	961	631	701	923	697	1046	1111
INDUCT	L	1200	1161	1235	942	987	842	803	1312	2403
LHD	L	760	829	991	627	721	639	527	978	987
EUROPE	L	350	463	516	421	569	257	243	589	2401
FRENCH	L	200	217	227	193	251	831	655	832	1632
WHITE	L	500	571	597	431	618	418	379	731	1321
RED	L	500	593	600	500	504	621	598	748	879
BLUE	L	500	637	621	403	531	273	193	516	342
AUTO	L	700	829	892	621	976	655	524	658	999
MANUAL	L	800	876	896	734	217	727	687	924	1365
BFSTL	L	618	717	731	518	618	681	572	834	867
BFTRA	L	389	398	426	217	259	353	321	543	1342
FLASO	L	227	426	513	193	783	251	205	612	643
FLASC	L	373	397	418	176	921	311	296	711	106
STRLK	L	127	179	209	276	101	103	97	402	59
LAMWS	L	163	167	187	198	157	126	124	243	69
BOOTM	L	567	596	599	273	432	493	361	586	1340
BOOTR	L	217	221	321	195	197	173	128	348	631

MODEL NO. 2

VARIABLE	BOUNDS BOUND 1 UPPER	LOWER	BOUND 2 UPPER	LOWER	OBJECTIVES PRODUCT 1 MAX. PROFIT	PRODUCT 2 MAX. PRODUCTION
IFR	162	58	162		12	1
IFW	149		149		11	1
IFB	76		76		14	1
IER	206		206		11	1
IEW	107		107		17	1
IEB	28		28		12	1
ILR	87		87		10	1
ILW	56		56		15	1
ILB	195		195		11	1
NFR	201	76	201		16	1
NFW	71		71		19	1
NFB	18		18		10	1
NER	63		63		14	1
NEW	108		108		16	1
NEB	96		96		13	1
NLR	106		106		21	1
NLW	212		212		16	1
NLB	57		57		18	1
NFRA	201		201		11	1
NFWA	71	20	71		13	1
NFBA	18		18		16	1
NERA	63		63		12	1
NEWA	108		108		1	1
NEBA	96		96		9	1
NIRA	106		106		8	1
NLWA	212		212		17	1
NLBA	57		57		14	1
IFRA	162		162		15	1
IFWA			265		19	1
IFBA	76	25	76		12	1
IERA	206		206		17	1
IEWA	107		107		16	1
IEBA	28		28		15	1
ILRA	87		87		10	1
ILWA	56		56		23	1
ILBA	195		195		15	1

MODEL NO. 2

		IFR	IFW	IFB	IER	IEW	IEB	ILR	ILW	ILB	NFR	NFW	NFB	NER	NEW	NEB	NLR	NLW	NLB	NFRA	NFWA	NFBA	NERA	NEWA	NEBA	NLRA	NLWA	NLBA	IFRA	IFWA	IFBA	IERA	IEWA	IEBA	ILRA	ILWA	ILBA	RHSL	RHSL
CAPACITY	L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	D	
PRODUCT	N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
NORMAL	L										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1										C	
INDUCT	L	1	1	1	1	1	1	1	1	1																			1	1	1	1	1	1	1	1	1	D	
LHD	L							1	1	1							1	1	1							1	1	1							1	1	1	C	
EUROPE	L				1	1	1							1	1	1							1	1	1							1	1	1				C	
FRENCH	L	1	1	1							1	1	1							1	1	1							1	1	1							C	
WHITE	L		1			1			1			1			1			1			1			1			1			1			1			1		C	
RED	L	1			1			1			1			1			1			1			1			1			1			1			1			C	
BLUE	L			1			1			1			1			1			1			1			1			1			1			1			1	C	
AUTO ·	L																			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	C	
MANUAL	L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1																			C	
BFSTL	L		1	1	1	1	1	1				1	1	1	1	1	1															1	1					C	
BFTRA	L	1									1							1	1	1	1	1	1	1					1							1	1	C	
FLASO	L						1							1	1										1					1				1				C	
FLASC	L	1						1	1	1								1	1							1	1	1							1	1	1	C	
STRLK	L				1								1									1	1						1									C	
LAMWS	L					1						1														1							1					C	
OOTM	L																																						
OOTR	L																																						

RESULTS FROM MATHEMATICAL PROGRAMMING MODELS

PACKAGE NAME : LINEAR PROGRAMMING MK.2

COMPUTER : ICL 1905

PROGRAM NAME : ALLOC1

MODEL NO. 3

OBJECTIVE NAME	RHS NAME	BOUND NAME	θ	FUNCTIONAL	NO. OF VARIABLES IN SOLUTION	LOSS
PRODUC	RHS3**	BOUND3	-	126	1	
"	"	"		209	2	
"	"	"		259	3	
"	"	"		306	4	
"	"	"		312	5	
"	"	"		327	6	
"	"	"		408	7	
"	"	"		435	8	
"	"	"		496	9	
"	"	"		499	10	
"	"	"		502	11	
"	"	"		519	12	
"	"	"		523	13	
"	"	"		543	13	
"	"	"		584	14	
"	"	"		586	15	
"	"	"		610	16	
"	"	"		616	17	
"	"	"		619	18	
"	"	"		623.5(1)N*	19	1
"	"	"		631.5(2)N	19	1
"	"	"		633 (3)N	20	3
"	"	"		637.5(4)N	20	2
"	"	"		639.5(5)N	21	2
"	"	"		642	22	
"	"	"		659	23	
"	"	"		383	10	
"	"	"		436	11	
"	"	"		477	12	
"	"	"		496	13	
"	"	"		560	14	
"	"	"		596	15	
"	"	"		609	15	2
"	"	"		633.5	16	2

*() indicates ref. number N = non integer I = integer a cross-reference from the non integer solution to its nearest integer eg.(1)N ref. (1)(I)

** This table indicates the path of the solution to its optimal value.

MODEL NO. 3

OBJECTIVE NAME	RHS NAME	BOUND NAME	θ	FUNCTIONAL		NO. OF VARIABLES IN SOLUTION	LOSS
PRODUC	RHS3	BOUND3	-	650.5		16	2
"	"			654.75		17	2
"	"			666.50		18	1
"	"			673		19	
"	"			674		20	
"	"			687		20	3
"	"			689		21	
"	"			690	6I	21	
"	"			690.5	6N	22	2
"	"		40	565.5		21	2
						677	
	RHS1	BOUND1		903		13	-
	RHS2	BOUND2		808	7N	14	3
				807	7I	14	-
			9	781		14	
			27	727		14	
			40	688		15	
						71	
	RHS4	BOUND4		188		14	
			1	185		13	
			5	173		12	
			6	170		13	
			9	161		12	
			13	149		11	
			21	125		10	
						85	
	RHSA			624		20	-
			7	623	1I	21	-
	RHSB			632		22	-
			4	631	2I	22	-
	RHSC			633	3I	22	-
	RHSD			638		23	-
			3	637	4I	23	-
	RHSE		1	639	5I	24	-
						177	

MODEL NO. 3

VARIABLE	BOUND1	BOUND2	BOUND3	BOUND4	OBJECTIVE PRODUCT
			BOUNDS (UPPER)		
IFR	149	136	118	46	1
IFW	76	49	37	53	1
IFB	206	201	163	94	1
IER	107	316	217	300	1
IEW	28	17	19	12	1
IEB	9	23	14	46	1
ILR	87	64	50	1	1
ILW	56	27	17	7	1
ILB	195	106	53	16	1
NFR	201	201	106	21	1
NFW	71	70	27	17	1
NFB	18	9	3	9	1
NER	63	56	51	26	1
NEW	108	93	17	13	1
NEB	96	48	6	17	1
NLR	106	27	18	11	1
NLW	212	31	23	3	1
NLB	57	56	15	17	1
NFRA	201	103	21	12	1
NFWA	71	78	86	14	1
NFBA	18	7	2	7	1
NERA	63	54	17	14	1
NEWA	108	96	81	8	1
NEBA	96	101	27	17	1
NLRA	106	164	103	27	1
NLWA	212	51	41	16	1
NLBA	57	103	63	46	1
IFRA	162	217	171	18	1
IFWA	265	73	21	1	1
IFBA	76	214	13	3	1
IERA	206	91	17	17	1
IEWA	107	23	12	2	1
IEBA	28	46	41	5	1
ILRA	87	53	16	16	1
ILWA	56	142	102	17	1
ILBA	195	0	0	0	1

MODEL NO. 3

VARIABLE	CONSTRAINT TYPE	RIGHT HAND SIDES				
		RHS1	RHS2	RHS3	RHS4	CHNGO1
CAPACY	L	1549	807	690	601	-
NORMAL	L	923	362	217	217	1
INDUCT	L	842	754	539	398	1
LHOIP	L	639	506	216	217	1
EUROPE	L	257	217	439	126	1
RED	L	621	439	218	69	1
WHITE	L	418	372	307	73	1
BLUE	L	273	269	251	46	1
AUTO	L	655	587	398	392	1
MANUAL	L	727	329	306	100	1
BFSTL	L	681	617	587	49	1
BFTRA	L	353	298	231	163	1
FLASO	L	251	213	183	173	1
FLASC	L	311	303	287	94	1
STRLK	L	103	93	83	27	1
LAMWS	L	126	98	76	63	1
BOOTM	L	493	378	291	117	1
BOOTR	L	173	161	137	142	1
FRENCH	L	162	197	126	97	1

RHS = RHS + θ x CHNGO1

MODEL NO. 3

	IFR	IFW	IFB	IER	IEW	IEB	ILR	ILW	ILB	NFR	NFW	NFB	NER	NEW	NEB	NLR	NLW	NLB	NFRA	NFWA	NFBA	NERA	NEWA	NEBA	NLRA	NLWA	NLBA	IFRA	IFWA	IFBA	IERA	IEWA	IEBA	ILRA	ILWA	ILBA
CAPACY	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NORMAL										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1									
INDUCT	1	1	1	1	1	1	1	1	1																			1	1	1	1	1	1	1	1	1
LHDIP							1	1	1							1	1	1							1	1	1							1	1	1
EUROPE				1	1	1							1	1	1							1	1	1							1	1	1			
RED	1			1			1			1			1			1			1			1			1			1			1			1		
WHITE		1			1			1			1			1			1			1			1			1			1			1			1	
BLUE			1			1			1			1			1			1			1			1			1			1			1			1
AUTO																			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MANUAL	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1																		
BFSTL		1	1	1	1	1	1				1	1	1	1	1	1															1					
BFTRA	1									1							1	1	1	1	1	1	1					1							1	1
FLASO						1							1	1										1					1			1	1			
FLASC	1							1	1	1							1	1							1	1	1							1	1	1
STRLK				1												1					1	1						1								
LAMWS					1										1										1							1				
BOOTH		1	1																					1			1	1			1					
BOOTR						1	1							1	1	1							1			1										
FRENCH	1	1	1							1	1	1							1	1	1							1	1	1						

RESULTS FROM MATHEMATICAL PROGRAMMING MODELS

PACKAGE NAME : Mathematical Programming System

COMPUTER : IBM 360/50

PROGRAM NAME : Explore

MODEL NO. 4

OBJECTIVE NAME	RHS NAME	BOUND NAME	θ	FUNCTIONAL	NO. OF VARIABLES IN SOLUTION	LOSS
PRODUCT	RHS 2-θ	BOND 2		303	36	
"	"	"	1	302	35	
"	"	"	2	301	"	
"	"	"	3	300	"	
"	"	"	4	299	"	
"	"	"	5	298	"	
"	"	"	6	297	"	
"	"	"	7	296	"	
"	"	"	8	295	"	
"	"	"	9	294	"	
"	"	"	10	293	"	
"	"	"	11	292	"	
"	"	"	12	291	"	
"	"	"	13	290	"	
"	"	"	14	289	"	
"	"	"	15	288	"	
"	"	"	16	287	"	
"	"	"	17	286	"	
"	"	"	18	285	"	
"	"	"	19	284	"	
"	"	"	20	283	"	
"	"	"	21	282	"	
"	"	"	22	281	"	
"	"	"	23	280	"	
"	"	"	24	279	"	

MODEL NO. 4

VARIABLE	CONSTRAINT TYPE	RIGHT HAND SIDE	CHANGE COL.
PRODUCT			
CAPACTY	L	800	-1
NORMAL	L	260	-1
INDUCT	L	310	-1
LHDIP	L	225	-1
EUROPE	L	187	-1
FRENCH	L	108	-1
RED	L	273	-1
WHITE	L	257	-1
BLUE	L	284	-1
BFSTL	L	193	-1
BFTRA	L	265	-1
LAMWS	L	143	-1
TUFWS	L	307	-1
FASHO	L	416	-1
FASHW	L	293	-1
BOOTMR	L	398	-1
BOOTMB	L	251	-1
STALK	L	85	-1
RECSTS	L	167	-1
FIXSTS	L	367	-1
RADIO	L	106	-1
KPH	L	213	-1
MPH	L	329	-1
LHS	L	361	-1
RHS	L	261	-1
MAN	L	196	0
AUTO	L	281	-1
AUSTIN	L	254	-1
MORRIS	L	275	-1

RHS = RHS + θ x Change Col.

OBJECTIVE NAME	RHS NAME	BOUND NAME	θ	FUNCTIONAL	NO. OF VARIABLES IN SOLUTION	LOSS
PRODUCT	RHS 2-θ	BOND 2				
"	"	"	25	278	"	
"	"	"	26	277	"	
"	"	"	27	276	"	
"	"	"	28	275	"	
"	"	"	29	274	"	
"	"	"	30	273	"	
"	"	"	31	272	"	
"	"	"	32	271	36	
"	"	"	33	270	36	
"	"	"	34	269	36	
"	"	"	35	268	36	
"	"	"	36	267	36	
"	"	"	37	266	35	
"	"	"	38	265	"	
"	"	"	34	264	"	
"	"	"	40	262	"	
"	"	"	41	260	"	
"	"	"	42	258	"	
"	"	"	43	256	"	
"	"	"	44	254	"	
"	"	"	45	252	"	
"	"	"	46	250	34	
"	"	"	47	248	"	
"	"	"	48	246	"	
"	"	"	49	244	"	
"	"	"	50	242	"	

MODEL NO. 4

VARIABLE	BOND 2 UPPER	BOND 2 LOWER	PRODUCT MAX. PRODUCTION
NLR	7		1
NLW	3		1
NLB	6		1
NER	7		1
NEW	8		1
NEB	3		1
NFR	9	3	1
NFW	5	1	1
NFB	5		1
ILR	2		1
ILW	2		1
ILB	7		1
IER	3		1
IEW	3		1
IEB	7		1
IFR	8	2	1
IFW	5		1
IFB	4	2	1
NLRA	17		1
NLWA	11		1
NLBA	16		1
NERA	17		1
NEWA	4	1	1
NEBA	13		1
NFRA	12	3	1
NFWA	14		1
NFBA	5		1
ILRA	16		1
ILWA	2		1
ILBA	17		1
IERA	13		1
IEWA	13		1
IEBA	17		1
IFRA	18	1	1
IFWA	13		1
IFBA	6	2	1

MODEL NO. 4

		NLR	NLW	NLB	NER	NEW	NEB	NFR	NFW	NFB	ILR	ILW	ILB	IER	IEW	IEB	IFR	IFW	IFB	NLRA	NLWA	NLBA	NERA	NEWA	NEBA	NFRA	NFWA	NFBA	ILRA	ILWA	ILBA	IERA	IEWA	IEBA	IFRA	IFWA	IFBA	RHS2	CHNG1
PRODUCT	N	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
CAPACTY	L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		C
NORMAL	L	1	1	1	1	1	1	1	1											1	1	1	1	1	1	1	1	1											C-1
INDUCT	L										1	1	1	1	1	1	1	1	1										1	1	1	1	1	1	1	1	1		C-1
LHDIP	L	1	1	1							1	1	1							1	1	1							1	1	1								C-1
EUROPE	L				1	1	1							1	1	1							1	1	1							1	1	1					C-1
FRENCH	L							1	1	1							1	1	1							1	1	1							1	1	1		C-1
RED	L	1			1			1			1			1			1			1			1			1			1			1			1				C-1
WHITE	L		1			1			1			1			1			1			1			1			1			1			1			1			C-
BLUE	L			1			1			1			1			1			1			1			1			1			1			1			1		C-1
VFSTL	L	1			1			1		1			1				1	1	1			1		1		1	1		1	1		1	1		1	1			C-
BFTRA	L			1		1	1		1		1	1		1	1	1				1	1		1		1			1			1			1			1		C-1
LAMWS	L		1					1			1					1	1	1						1						1				1					C-1
TUFWS	L	1		1	1	1	1		1	1		1	1	1	1				1	1	1	1	1		1	1	1	1	1		1	1	1		1	1	1		C-
FASHO	L	1	1	1	1					1	1			1	1	1				1		1		1	1		1			1		1	1	1					C-1
FASHW	L					1	1		1			1	1				1	1	1		1		1			1		1	1		1				1	1	1		C-1
BOOTMR	L	1		1		1			1		1		1		1,		1		1	1	1			1	1	1								1		1	1		C-1
BOOTMB	L		1		1		1	1		1		1		1		1		1				1	1				1	1	1	1	1	1	1		1				C-
STRLK	L			1							1						1								1						1					1			B-1
REOSTS	L		1			1	1		1	1										1							1	1						1					C-1
FIXSTS	L	1		1	1			1			1	1	1	1	1	1	1	1	1		1	1	1	1	1	1			1	1	1	1	1		1	1	1		C-1
RADIO	L			1					1	1			1			1					1					1			1		1			1	1				C-1
KPH	L		1								1				1	1				1					1				1				1				1		C-
MPH	L	1		1	1		1	1	1	1		1	1	1			1	1	1		1	1	1	1		1	1	1		1	1	1		1	1	1			C-1
LHS	L	1		1	1		1			1			1	1			1	1	1			1		1		1	1	1		1		1			1	1			C-1
RHS	L		1			1		1	1		1	1			1					1	1		1		1				1		1		1	1			1		C-1
MAN	L	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1																				C
AUTO	L																			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		C-1
AUSTIN	L	1	1		1				1		1	1	1	1			1			1		1		1	1	1		1	1					1	1	1	1		C-1
MORRIS	L			1		1	1	1		1					1	1		1	1				1				1			1	1	1							C-1

APPENDIX C

SUMMARIES OF PAINT REJECTION ANALYSIS

KEY

p	percentage defective	(analysis of variance test)
x	arc sin $\sqrt{p}$	(analysis of variance test)
e	expected value	(chi squared test)
NS	non significant	
*	significant 5%	
**	highly significant 1%	

CONDITION CODES

C	dirt fault
D	dry spray
F	scars
J	sealer coat
3	at least 3 panel faults
4	at least 4 panel faults

SUMMARY OF PAINT REJECTION ANALYSIS

OVERALL EXAMINATION

CRITERIA	TEST	BATCH SIZE	COLOUR	DAY	PLANT	MODEL	INTERACTION
		A	B	C	D	E	
C	x	**	**	NS	**	*	
	p	**	**	NS	**	**	
D	x	*	**	NS	**	*	
	p	**	**	NS	**	**	
F	x	NS	**	NS	**	NS	
	p	*	**	NS	**	*	
J	x	*	**	NS	*	NS	
	p	**	**	NS	**	*	
3	x	**	**	NS	**	**	
	p	**	**	NS	**	**	
4	x	**	**	NS	**	**	
	p	**	**	NS	**	**	

CRITERIA	TEST	BATCH POSITION	COLOUR	PLANT	MODEL	INTERACTION
		A	B	C	D	
C	e	**	**	**	*	
D	e	NS	**	**	*	
F	e	NS	**	*	NS	
J	e	NS	**	**	*	
3	e	*	**	*	**	
4	e	*	**	**	**	

SUMMARY OF PAINT REJECTION ANALYSIS

PLANT : NO. 1 COLOUR PAINT PLANT

MODEL : ADO 15

CRITERIA	TEST	BATCH SIZE	COLOUR	DAY	INTERACTION
		A	B	C	
C	x	**	**	NS	-
C	p	**	**	NS	-
D	x	**	**	NS	-
D	p	**	**	NS	-
F	x	NS	**	NS	BC*
F	p	*	**	NS	BC*
J	x	**	NS	NS	-
J	p	**	*	NS	-
3	x	*	**	NS	BC*
3	p	*	**	NS	BC*
4	x	**	**	NS	-
4	p	**	**	NS	-

CRITERIA	TEST	BATCH POSITION	COLOUR	INTERACTION
C	e	**	**	-
D	e	NS	**	-
F	e	NS	**	-
J	e	NS	**	-
3	e	NS	**	-
4	e	*	**	-

SUMMARY OF PAINT REJECTION ANALYSIS

PLANT : NO. 2 COLOUR RECTIFICATION PLANT

MODEL : ADO 15

CRITERIA	TEST	BATCH SIZE	COLOUR	DAY	INTERACTION
		A	B	C	
C	x	NS	**	NS	-
C	p	NS	**	NS	-
D	x	NS	**	NS	-
D	p	*	**	NS	-
F	x	NS	**	NS	-
F	p	*	**	NS	-
J	x	NS	NS	NS	-
J	p	NS	*	NS	-
3	x	NS	**	NS	BC*
3	p	NS	**	NS	-
4	x	NS	**	NS	AC*
4	p	*	**	NS	-

CRITERIA	TEST	BATCH POSITION	COLOUR	INTERACTION
		A	B	
C	e	NS	*	-
D	e	NS	*	-
F	e	NS	**	-
J	e	NS	NS	-
3	e	NS	*	-
4	e	NS	**	-

SUMMARY OF PAINT REJECTION ANALYSIS

PLANT : NO. 1 COLOUR PAINT PLANT

MODEL : ADO 16

CRITERIA	TEST	BATCH SIZE	COLOUR	DAY	INTERACTION
		A	B	C	
C	x	*	**	NS	-
C	p	**	**	NS	-
D	x	NS	*	NS	-
D	p	NS	*	NS	-
F	x	NS	*	NS	BC*
F	p	NS	**	NS	-
J	x	NS	*	NS	-
J	p	NS	*	NS	-
3	x	*	**	NS	BC*
3	p	*	**	NS	-
4	x	*	**	*	-
4	p	*	**	*	-

CRITERIA	TEST	BATCH POSITION	COLOUR	INTERACTION
		A	B	
C	e	*	*	-
D	e	NS	NS	-
F	e	NS	**	-
J	e	NS	*	-
3	e	*	*	-
4	e	**	**	-

SUMMARY OF PAINT REJECTION ANALYSIS

PLANT : NO. 2 COLOUR RECTIFICATION PLANT

MODEL : ADO 16

CRITERIA	TEST	BATCH SIZE	COLOUR	DAY	INTERACTION
		A	B	C	
C	x	*	**	NS	-
	p	*	**	NS	-
D	x	NS	*	NS	-
	p	NS	**	NS	-
F	x	NS	**	NS	-
	p	*	**	NS	-
J	x	NS	*	NS	-
	p	NS	*	NS	-
3	x	NS	**	NS	-
	p	NS	**	*	-
4	x	NS	**	NS	-
	p	NS	**	*	-

CRITERIA	TEST	BATCH POSITION	COLOUR	INTERACTION
C	e	NS	*	-
D	e	NS	*	-
F	e	NS	NS	-
J	e	NS	*	-
3	e	*	NS	-
4	e	*	**	-

REJECTION ANALYSIS

FACILITY REJECTED FROM	REJECTION RATE %	STANDARD DEVIATION %	REJECTED TO
ADO 15 TRACK	3.6	1.1	SNAGGING AREA
ADO 16 TRACK	4.8	1.6	SNAGGING AREA
W/R TRACK	2.4	0.9	SNAGGING AREA
J4 TRACK	3.2	1.2	SNAGGING AREA
ADO 15 TRACK	80.7	6.8	LOOP LINE
ADO 16 TRACK	73.8	5.7	LOOP LINE
W/R TRACK	78.5	9.3	LOOP LINE
ADO 15 TRACK	15.7	2.2	LOW BAKE
ADO 16 TRACK	21.4	3.8	LOW BAKE
W/R TRACK	19.1	2.9	LOW BAKE
LOOP LINE	0	0	LOOP LINE
LOOP LINE*	23.8	12.6	LOW BAKE
LOW BAKE*	14.9	5.2	LOW BAKE

A NORMAL DISTRIBUTION WAS FOUND TO ADEQUATELY DESCRIBE THE REJECTION DISTRIBUTIONS.

* THE DATA AVAILABLE AT THIS POINT WAS AGGREGATED SUCH THAT AN ANALYSIS ON A MODEL BASIS WAS IMPOSSIBLE.

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 3+

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	64	.671	41	.926	39	.742	64	.733
	2	70	.399	48	.770	44	.590	44	.817
	3	60	.399	33	.817	42	.570	66	.742
	4	48	.541	20	.850	20	.500	40	.825
	5	40	.650	25	1.000	15	.400	25	.680
TUESDAY	1	74	.553	103	.872	34	.881	52	.730
	2	106	.499	102	.901	52	.767	66	.636
	3	129	.472	105	.847	51	.803	75	.666
	4	104	.615	88	.851	48	.833	52	.634
	5	25	.560	80	.975	25	.800	40	.550
WEDNESDAY	1	50	.600	101	.880	49	.734	40	.900
	2	74	.472	96	.832	46	.651	40	.700
	3	84	.511	117	.828	72	.707	69	.811
	4	40	.550	96	.802	56	.589	56	.910
	5	35	.513	50	.840	30	.800	35	.799
THURSDAY	1	48	.728	79	.872	29	.688	54	.777
	2	76	.657	98	.846	46	.651	70	.728
	3	114	.675	81	.752	36	.721	54	.758
	4	92	.673	68	.911	28	.713	36	.693
	5	35	.628	50	.860	25	.640	25	.600
FRIDAY	1	36	.721	28	.821	14	.713	37	.675
	2	36	.721	28	.856	18	.943	36	.666
	3	60	.700	6	.666	21	.666	9	.555
	4	96	.624	12	.500	16	.750	44	.749
	5	35	.656	15	.933	5	.600	15	.733

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 3+

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	53	.791	29	.826				
	2	74	.782	36	.776				
	3	93	.752	36	.777				
	4	60	.782	40	.700				
	5	60	.816	15	.666				
TUESDAY	1	49	.836	38	.841				
	2	68	.823	50	.780				
	3	87	.815	48	.875				
	4	40	.950	48	.811				
	5	50	.840	50	.900				
WEDNESDAY	1	81	.740	27	.777				
	2	80	.874	38	.868				
	3	63	.745	39	.793				
	4	84	.749	16	.812				
	5	50	.760	30	.799				
THURSDAY	1	42	.785	30	.900				
	2	76	.775	26	.807				
	3	66	.772	33	.817				
	4	28	.784	64	.765				
	5	35	.799	30	.700				
FRIDAY	1	22	.590	7	1.000				
	2	28	.785	4	.750				
	3	18	.721	12	.999				
	4	4	1.000	16	.687				
	5	5	.800	5	.600				

PAINT REJECTION ANALYSIS

PAINT PLANT 1 MODEL ADO 15 CRITERION 4+

B.S. = batch size N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	64	.437	41	.634	39	.512	64	.546
	2	70	.228	48	.312	44	.204	44	.590
	3	60	.183	33	.454	42	.190	66	.424
	4	48	.250	20	.450	20	.250	40	.450
	5	40	.400	25	.520	15	.333	25	.440
TUESDAY	1	74	.297	103	.601	34	.676	52	.442
	2	106	.226	102	.627	52	.461	66	.333
	3	129	.255	105	.533	51	.549	75	.293
	4	104	.298	88	.488	48	.604	52	.365
	5	25	.160	80	.700	25	.640	40	.275
WEDNESDAY	1	50	.360	101	.623	49	.510	40	.575
	2	74	.189	96	.562	46	.369	40	.375
	3	84	.297	117	.478	72	.402	69	.565
	4	40	.350	96	.500	56	.357	56	.589
	5	35	.285	50	.640	30	.600	35	.457
THURSDAY	1	48	.520	79	.607	29	.551	54	.555
	2	76	.407	98	.581	46	.260	70	.414
	3	114	.456	81	.456	36	.444	54	.277
	4	92	.369	68	.529	28	.392	36	.388
	5	35	.457	50	.420	25	.280	25	.200
FRIDAY	1	36	.388	28	.607	14	.571	37	.486
	2	36	.444	28	.428	18	.555	36	.416
	3	60	.300	6	.666	21	.428	9	.222
	4	96	.302	12	.749	16	.625	44	.477
	5	35	.285	5	.600	5	0	15	.333

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 4+

B.S. = batch size . N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	53	.452	29	.620				
	2	74	.445	36	.388				
	3	93	.365	36	.444				
	4	60	.466	40	.300				
	5	60	.333	15	.533				
TUESDAY	1	49	.673	38	.578				
	2	68	.500	50	.460				
	3	87	.413	48	.500				
	4	40	.600	48	.541				
	5	50	.440	50	.380				
WEDNESDAY	1	81	.506	27	.518				
	2	80	.412	38	.447				
	3	63	.428	39	.435				
	4	84	.357	16	.250				
	5	50	.360	30	.366				
THURSDAY	1	42	.452	30	.533				
	2	76	.223	26	.346				
	3	66	.333	33	.333				
	4	28	.392	64	.484				
	5	35	.428	30	.433				
FRIDAY	1	22	.409	7	1.0000				
	2	28	.428	4	.500				
	3	18	.444	12	.583				
	4	4	1.000	16	.187				
	5	5	.400	5	.400				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 'C'

B.S. = batch size N = number in sample
p = fraction defective $x = \arcsin \sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	64	0.609	41	.731	39	.615	64	.453
	2	70	.685	48	.875	44	.727	44	.613
	3	60	.733	33	.909	42	.880	66	.803
	4	48	.750	20	.850	20	.700	40	.850
	5	40	.825	25	1.000	15	.866	25	.960
TUESDAY	1	74	.702	103	.747	34	.558	52	.634
	2	106	.783	102	.852	52	.711	66	.636
	3	129	.751	105	.866	51	.705	75	.946
	4	104	.875	88	.897	48	.625	52	.846
	5	25	.800	80	.925	25	.400	40	.925
WEDNESDAY	1	50	.680	101	.732	49	.551	40	.500
	2	74	.648	96	.885	46	,739	40	.825
	3	84	.714	117	.871	72	.847	69	.898
	4	40	.650	96	.895	56	.857	56	.750
	5	35	.971	50	.940	30	.833	35	.942
THURSDAY	1	48	.562	79	.835	29	.379	54	.555
	2	76	.855	98	.877	46	.760	70	.785
	3	114	.798	81	.913	36	.694	54	.945
	4	92	.836	68	.926	28	.821	36	.916
	5	35	.800	50	.940	25	1.000	25	.880
FRIDAY	1	36	.555	28	.857	14	.500	37	.594
	2	36	.555	28	.821	18	.500	36	.777
	3	60	.716	6	.833	21	.666	9	.777
	4	96	.718	12	.750	16	.812	44	.886
	5	35	.885	15	.800	5	1.000	15	.800

PAINT REJECTION ANALYSIS

Sheet 2 [illegible]

PAINT PLANT No. 1 MODEL ADO 15 CRITERION [illegible]

B.S. = batch size N = number in sample

p = fraction defective $x = \arc \sin \sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	53	.622	29	.551				
	2	74	.810	36	.861				
	3	93	.892	36	.888				
	4	60	.766	40	.850				
	5	60	.866	15	.933				
TUESDAY	1	49	.530	38	.684				
	2	68	.882	50	.760				
	3	87	.873	48	.854				
	4	40	1.000	48	.833				
	5	50	.960	50	.980				
WEDNESDAY	1	81	.728	27	.629				
	2	80	.937	38	.789				
	3	63	.857	39	.871				
	4	84	.976	16	.937				
	5	50	.980	30	.900				
THURSDAY	1	42	.833	30	.733				
	2	76	.868	26	.884				
	3	66	.924	33	.939				
	4	28	.964	64	.921				
	5	35	.828	30	1.000				
FRIDAY	1	22	.772	7	0				
	2	28	.892	4	1.000				
	3	18	.944	12	.750				
	4	4	1.000	16	1.000				
	5	5	1.000	5	.800				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 'D'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	64	.234	41	.0	39	.051	64	.218
	2	70	.214	48	.083	44	.090	44	.227
	3	60	.350	33	.030	42	.142	66	.363
	4	48	.645	20	.050	20	.350	40	.650
	5	40	.600	25	.120	15	.600	25	.240
TUESDAY	1	74	.216	103	.038	34	.147	52	.192
	2	106	.235	102	.058	52	.173	66	.333
	3	129	.294	105	.142	51	.254	75	.573
	4	104	.596	88	.113	48	.208	52	.538
	5	25	.400	80	.150	25	.160	40	.575
WEDNESDAY	1	50	.200	101	.069	49	.142	40	.225
	2	74	.310	96	.083	46	.065	40	.425
	3	84	.511	117	.111	72	.194	69	.492
	4	40	.425	96	.031	56	.071	56	.571
	5	35	.457	50	.080	30	.133	35	.771
THURSDAY	1	48	.270	79	.037	29	.172	54	.166
	2	76	.434	98	.051	46	.217	70	.342
	3	114	.482	81	.037	36	.222	54	.444
	4	92	.489	68	.161	28	.357	36	.277
	5	35	.400	50	.020	25	.560	25	.520
FRIDAY	1	36	.277	28	.035	14	.142	37	.405
	2	36	.416	28	.142	18	.277	36	.361
	3	60	.533	6	0	21	.619	9	.222
	4	96	.510	12	.333	16	.562	44	.545
	5	35	.628	15	0	5	.800	15	.333

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 'D'

B.S. = batch size
p = fraction defective

N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	53	.056	29	.103				
	2	74	.040	36	.083				
	3	93	.118	36	.222				
	4	60	.083	40	.325				
	5	60	.166	15	0				
TUESDAY	1	49	.040	38	.131				
	2	68	.147	50	.060				
	3	87	.160	48	.187				
	4	40	.300	48	.270				
	5	50	.222	50	.520				
WEDNESDAY	1	81	.074	27	.074				
	2	80	.112	38	.184				
	3	63	.063	39	.153				
	4	84	.273	16	.250				
	5	50	.180	30	.566				
THURSDAY	1	42	.095	30	.066				
	2	76	.065	26	.192				
	3	66	.121	33	.272				
	4	28	.071	64	.343				
	5	35	.342	30	.500				
FRIDAY	1	22	.045	7	0				
	2	28	0	4	.250				
	3	18	0	12	0				
	4	4	0	16	.187				
	5	5	0	5	0				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 'F'

B.S. = batch size N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	64	.187	41	.219	39	.076	64	.171
	2	70	.228	48	.375	44	.204	44	.318
	3	60	.250	33	.315	42	.428	66	.469
	4	48	.375	20	.600	20	.200	40	.300
	5	40	.425	25	.600	15	.400	25	.440
TUESDAY	1	74	.229	103	.213	34	.264	52	.230
	2	106	.235	102	.441	52	.442	66	.272
	3	129	.348	105	.476	51	.137	75	.373
	4	104	.403	88	.465	48	.250	52	.576
	5	25	.680	80	.612	25	0	40	.525
WEDNESDAY	1	50	.280	101	.247	49	.102	40	.275
	2	74	.202	96	.343	46	.086	40	.375
	3	84	.261	117	.478	72	.222	69	.536
	4	40	.100	96	.749	56	.500	56	.500
	5	35	.338	50	.600	30	.066	35	.742
THURSDAY	1	48	.208	79	.354	29	.068	54	.296
	2	76	.223	98	.336	46	.369	70	.242
	3	114	.412	81	.469	36	.361	54	.648
	4	92	.413	68	.485	28	.285	36	.694
	5	35	.514	50	.560	25	.560	25	.400
FRIDAY	1	36	.027	28	.321	14	.428	37	.135
	2	36	.138	28	.321	18	.166	36	.500
	3	60	.300	6	.333	21	.190	9	.444
	4	96	.322	12	0	16	.375	44	.522
	5	35	.628	15	.400	5	.600	15	.733

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 'F'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	53	.188	29	.068				
	2	74	.175	36	.305				
	3	93	.268	36	.444				
	4	60	.300	40	.200				
	5	60	.250	15	.266				
TUESDAY	1	49	.163	38	.315				
	2	68	.294	50	.300				
	3	87	.206	48	.583				
	4	40	.375	48	.541				
	5	50	.640	50	.360				
WEDNESDAY	1	81	.222	27	.148				
	2	80	.325	38	.315				
	3	63	.396	39	.333				
	4	84	.392	16	.312				
	5	50	.380	30	.500				
THURSDAY	1	42	.238	30	.133				
	2	76	.223	26	.076				
	3	66	.363	33	0				
	4	28	.607	64	0				
	5	35	.371	30	0				
FRIDAY	1	22	.045	7	.142				
	2	28	.214	4	0				
	3	18	.444	12	0				
	4	4	.500	16	0				
	5	5	.800	-	-				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 'J'

B.S. = batch size N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	64	.140	41	.170	39	.282	64	.312
	2	70	.071	48	0	44	.022	44	.090
	3	60	.100	33	.272	42	0	66	.151
	4	48	.083	20	.200	20	.200	40	.175
	5	40	.300	25	.480	15	.200	25	0
TUESDAY	1	74	.081	103	.194	34	.264	52	.192
	2	106	.113	102	.176	52	.134	66	.181
	3	129	.162	105	.085	51	.313	75	.106
	4	104	.067	88	.215	48	.166	52	.134
	5	25	.160	80	.125	25	.400	40	.175
WEDNESDAY	1	50	.200	101	.168	49	.224	40	.225
	2	74	.027	96	.093	46	.217	40	.075
	3	84	.095	117	.128	72	.166	69	.028
	4	40	.250	96	.187	56	.214	56	.214
	5	35	.171	50	0	30	.200	35	0
THURSDAY	1	48	.208	79	.126	29	.379	54	.222
	2	76	.026	98	.102	46	.152	70	.114
	3	114	.070	81	.098	36	.250	54	.018
	4	92	.054	68	.264	28	.250	36	.166
	5	35	.228	50	.160	25	.120	25	.160
FRIDAY	1	36	.222	28	.142	14	.214	37	.189
	2	36	.083	28	.071	18	.333	36	.138
	3	60	.050	6	0	21	.285	9	.333
	4	96	.156	16	0	16	.250	44	0
	5	35	0	15	.660	5	0	15	.333

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 CRITERION 'J'

B.S. = batch size N = number in sample
p = fraction defective $x = \arcsin \sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	53	.226	29	.275				
	2	74	.162	36	.222				
	3	93	.161	36	.083				
	4	60	.133	40	.300				
	5	60	.250	15	.333				
TUESDAY	1	49	.326	38	.236				
	2	68	.029	50	.220				
	3	87	.172	48	.145				
	4	40	.275	48	.375				
	5	50	.160	50	.180				
WEDNESDAY	1	81	.172	27	.222				
	2	80	.150	38	.105				
	3	63	.174	39	.256				
	4	84	.059	16	.187				
	5	50	.120	30	.333				
THURSDAY	1	42	.119	30	.233				
	2	76	.052	26	..153				
	3	66	.090	33	.212				
	4	28	0	64	.250				
	5	35	.542	30	.100				
FRIDAY	1	22	.181	7	.714				
	2	28	.142	4	0				
	3	18	.055	12	.333				
	4	4	0	16	0				
	5	5	0	5	0				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 3

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	119	.167	39	.460	65	.337	104	.210
	2	84	.094	18	.443	56	.213	48	.103
	3	45	.110	3	1.000	24	.166	27	.111
	4	68	.131	-	-	8	.375	32	.311
	5	35	.142	5	0	15	.133	-	-
TUESDAY	1	101	.158	130	.176	96	.301	93	.235
	2	74	.054	116	.154	40	.200	62	.145
	3	54	.092	66	.226	21	.237	24	.166
	4	12	.166	36	.054	12	.583	16	.374
	5	20	0	25	.160	5	0	15	.266
WEDNESDAY	1	86	.116	142	.203	61	.359	94	.169
	2	54	.055	112	.160	24	.125	52	.057
	3	36	0	90	.188	12	0	30	.232
	4	24	.124	36	.221	12	.583	16	.187
	5	10	0	30	.166	10	.500	-	-
THURSDAY	1	94	.095	131	.152	72	.263	89	.201
	2	64	.124	92	.118	32	.218	40	.175
	3	30	.033	72	.193	27	.074	21	.142
	4	28	.320	40	.100	8	.125	16	.124
	5	15	.066	10	.200	5	.400	10	.200
FRIDAY	1	53	.131	51	.136	30	.433	44	.181
	2	46	.064	24	0	6	.500	22	.271
	3	33	.120	12	.249	12	.333	18	.055
	4	28	.142	12	0	-	-	4	.250
	5	5	0	10	0	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 3

B.S. = batch size N = number in sample
p = fraction defective $x = \arcsin \sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	83	.276	66	.196				
	2	34	.323	36	.333				
	3	36	.360	18	.221				
	4	24	.249	12	.249				
	5	5	.200	10	.100				
TUESDAY	1	114	.218	69	.144				
	2	58	.119	58	.102				
	3	36	.277	18	.222				
	4	12	.166	12	.083				
	5	-	-	5	.200				
WEDNESDAY	1	126	.189	73	.163				
	2	80	.137	28	.214				
	3	33	.242	15	.133				
	4	16	.062	8	.250				
	5	10	0	10	.300				
THURSDAY	1	87	.274	72	.179				
	2	40	.075	22	.180				
	3	21	.142	18	.055				
	4	24	.291	12	.166				
	5	10	.500	5	0				
FRIDAY	1	50	.260	21	.285				
	2	10	.200	2	0				
	3	12	.166	-	-				
	4	4	0	-	-				
	5	5	0	-	-				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION '4'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	111	.075	39	.230	65	.230	104	.134
	2	84	.047	18	.277	56	.142	48	.062
	3	45	.066	3	.333	24	.083	27	.037
	4	68	.073	-	-	8	.250	32	.043
	5	35	.057	5	0	15	.133	-	-
TUESDAY	1	101	.059	130	.123	96	.239	93	.096
	2	74	0	116	.077	40	.100	62	.016
	3	54	.037	66	.136	21	.095	24	.041
	4	12	.083	36	.027	12	.500	16	.312
	5	20	0	25	0	5	0	15	.200
WEDNESDAY	1	86	.093	142	.112	61	.196	94	.074
	2	54	0	112	.080	24	.125	52	.038
	3	36	0	90	.055	12	0	30	.066
	4	24	.083	36	.166	12	.500	16	.062
	5	10	0	30	.066	10	.300	-	-
THURSDAY	1	94	.042	131	.038	72	.194	89	.134
	2	64	.046	92	.021	32	.125	40	.050
	3	30	.033	72	.055	27	.037	21	.095
	4	28	.178	40	.025	8	.125	16	.062
	5	15	0	10	.100	5	0	10	.200
FRIDAY	1	53	.094	51	.078	30	.300	44	.068
	2	46	.043	24	0	6	.333	22	.090
	3	33	.030	12	.166	12	.166	18	0
	4	28	.142	12	0	-	-	4	0
	5	5	0	10	0	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION '4'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	83	.204	66	.075				
	2	34	.147	36	.083				
	3	36	.222	18	.055				
	4	24	.083	12	.166				
	5	5	.200	10	.100				
TUESDAY	1	114	.166	69	.043				
	2	58	.051	58	.051				
	3	36	.250	18	0				
	4	12	.166	12	0				
	5	-	-	5	0				
WEDNESDAY	1	120	.158	73	.054				
	2	80	.087	28	0				
	3	33	.121	15	0				
	4	16	0	8	.125				
	5	10	0	10	.100				
THURSDAY	1	87	.137	72	.041				
	2	40	0	22	.090				
	3	21	.095	18	0				
	4	24	.208	12	0				
	5	10	.300	5	0				
FRIDAY	1	50	.160	21	.095				
	2	10	0	2	0				
	3	12	.166	-	-				
	4	4	0	-	-				
	5	5	0	-	-				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 'C'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	119	.369	39	.717	65	.353	104	.250
	2	84	.309	18	.666	56	.285	48	.395
	3	45	.422	3	1.000	24	.500	27	.333
	4	68	.426	-	-	8	.500	32	.437
	5	35	.400	5	0	15	.533	-	-
TUESDAY	1	101	.247	130	.576	96	.343	93	.354
	2	74	.270	116	.534	40	.350	62	.370
	3	54	.222	66	.590	21	.238	24	.375
	4	12	.166	36	.611	12	0	16	.750
	5	20	.250	25	.680	5	1.000	15	.533
WEDNESDAY	1	86	.337	142	.570	61	.262	94	.212
	2	54	.407	115	.544	24	.125	52	.365
	3	36	.277	90	.533	12	.083	30	.400
	4	24	.416	36	.888	12	.250	16	.750
	5	10	.400	30	.800	10	.300	-	-
THURSDAY	1	94	.329	131	.633	72	.277	89	.438
	2	64	.359	92	.608	32	.437	40	.650
	3	30	.266	72	.555	27	.333	21	.714
	4	28	.142	40	.625	8	.500	16	.062
	5	15	0	10	.900	5	.200	10	0
FRIDAY	1	53	.396	51	.607	30	.233	44	.545
	2	46	.239	24	.583	6	0	22	.772
	3	33	.393	12	.416	12	.333	18	.277
	4	28	.071	12	.500	-	-	4	1.000
	5	5	.400	10	.700	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 'C'

B.S. = batch size N = number in sample
p = fraction defective $x = \arcsin \sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	83	.409	66	.545				
	2	34	.600	36	.694				
	3	36	.472	18	.611				
	4	24	.666	12	.750				
	5	5	.200	10	1.000				
TUESDAY	1	114	.517	69	.492				
	2	58	.517	58	.500				
	3	36	.750	18	.166				
	4	12	.500	12	.166				
	5	-	-	5	0				
WEDNESDAY	1	126	.436	73	.616				
	2	80	.650	28	.428				
	3	33	.454	15	.666				
	4	16	.875	8	.500				
	5	10	.700	10	.500				
THURSDAY	1	87	.425	72	.541				
	2	40	.550	22	.590				
	3	21	.857	18	.722				
	4	24	.500	12	.833				
	5	10	1.000	5	0				
FRIDAY	1	50	.400	21	.571				
	2	10	.400	2	1.000				
	3	12	.750	-	-				
	4	4	0	-	-				
	5	5	.600	-	-				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 'D'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	119	.235	39	0	65	.030	104	.211
	2	84	.226	18	0	56	.035	48	.250
	3	45	.288	3	0	24	0	27	.185
	4	68	.147	-	-	8	0	32	.312
	5	35	.285	5	0	15	.400	-	-
TUESDAY	1	101	.198	130	.007	96	.031	93	.333
	2	74	.162	116	.025	40	.050	62	.274
	3	54	.185	66	0	21	.238	24	.500
	4	12	.166	36	.111	12	0	16	.187
	5	20	.150	25	.040	5	0	15	.800
WEDNESDAY	1	86	.197	142	.035	61	.114	94	.276
	2	54	.148	112	.035	24	0	52	.192
	3	36	.138	90	.022	12	0	30	.500
	4	24	.375	36	.027	12	0	16	.312
	5	10	0	30	.133	10	0	-	-
THURSDAY	1	94	.255	131	.015	72	.055	89	.224
	2	64	.156	92	0	32	.125	40	.225
	3	30	.166	72	.069	27	.074	21	.571
	4	28	.571	40	0	8	.125	16	.312
	5	15	.266	10	.600	5	0	10	.300
FRIDAY	1	53	.169	51	.058	30	.100	44	.227
	2	46	.260	24	0	6	0	22	.272
	3	33	.363	12	0	12	.083	18	.333
	4	28	.357	12	0	-	-	4	0
	5	5	0	10	0	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 'D'

B.S. = batch size N = number in sample
p = fraction defective $x = \text{arc sin} \sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	83	.060	66	.106				
	2	34	.088	36	.166				
	3	36	.166	18	.611				
	4	24	0	12	.333				
	5	5	0	10	0				
TUESDAY	1	114	.061	69	.086				
	2	58	.051	58	.241				
	3	36	.083	18	.166				
	4	12	0	12	.250				
	5	-	-	5	.800				
WEDNESDAY	1	126	.063	73	.123				
	2	80	.037	28	.250				
	3	33	.030	15	.333				
	4	16	.187	8	.500				
	5	10	0	10	.700				
THURSDAY	1	87	0	72	.208				
	2	40	.075	22	.500				
	3	21	0	18	.055				
	4	24	0	12	.333				
	5	10	0	5	.800				
FRIDAY	1	50	.080	21	.285				
	2	10	0	2	0				
	3	12	0	-	-				
	4	4	0	-	-				
	5	5	0	-	-				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 'F'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	119	.050	39	.025	65	.015	104	.192
	2	84	.059	18	.111	56	.017	48	.166
	3	45	.088	3	0	24	.041	27	.333
	4	68	.191	-	-	8	0	32	.125
	5	35	0	5	.600	15	.200	-	-
TUESDAY	1	101	.158	130	.115	96	.010	93	.107
	2	74	.094	116	.077	40	0	62	.112
	3	54	.074	66	.060	21	.095	24	0
	4	12	0	36	.333	12	0	16	.312
	5	20	0	25	.080	5	0	15	.133
WEDNESDAY	1	86	.081	142	.098	61	.049	94	.031
	2	54	0	112	.098	24	0	52	.038
	3	36	.055	90	.100	12	.166	30	.066
	4	24	0	36	.222	12	0	16	0
	5	10	0	30	.100	10	0	-	-
THURSDAY	1	94	.031	125	.045	72	.041	89	.056
	2	64	.062	92	.108	32	0	40	.175
	3	30	0	72	.180	27	0	21	.190
	4	28	.035	40	0	8	0	16	.250
	5	15	.266	10	.200	5	0	10	.200
FRIDAY	1	53	.018	51	.039	30	0	44	.045
	2	46	.065	24	.083	6	.166	22	0
	3	33	.060	12	.083	12	0	18	.111
	4	28	.142	12	0	-	-	4	0
	5	5	.800	10	.600	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15 CRITERION 'F'

B.S. = batch size N = number in sample
p = fraction defective $x = \arcsin\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	83	.048	66	.075				
	2	34	.176	36	.166				
	3	36	.027	18	0				
	4	24	.083	12	.166				
	5	5	0	10	.500				
TUESDAY	1	114	.052	69	.028				
	2	58	0	58	.017				
	3	36	.027	18	.166				
	4	12	0	12	.166				
	5	-	-	5	.400				
WEDNESDAY	1	126	.079	73	.068				
	2	80	.012	28	.071				
	3	33	.090	15	0				
	4	16	.062	8	0				
	5	10	.300	10	.500				
THURSDAY	1	87	.011	72	.055				
	2	40	.050	22	0				
	3	21	.095	18	.166				
	4	24	0	12	.250				
	5	10	0	5	.800				
FRIDAY	1	50	.040	21	.095				
	2	10	.100	2	0				
	3	12	.250	-	-				
	4	4	0	-	-				
	5	5	0	-	-				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 16 CRITERION 3

B.S. = batch size N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	120	.732	4	.750	51	.842	12	.749
	2	40	.725	4	.250	22	.908	22	.862
	3	30	.599	-	-	6	.666	-	-
	4	8	.125	4	.250	-	-	-	-
	5	5	.200	-	-	5	0	-	-
TUESDAY	1	79	.771	63	.952	58	.879	16	.625
	2	56	.749	30	.833	36	.804	8	.500
	3	15	.399	9	.555	3	1.000	-	-
	4	12	.749	12	.499	4	1.000	4	.750
	5	-	-	5	.200	5	1.000	5	0
WEDNESDAY	1	103	.766	69	.999	53	.848	27	.925
	2	58	.620	14	.571	14	.785	4.	.750
	3	30	.532	27	.814	12	.666	3	.666
	4	8	.125	12	.249	16	.374	8	.625
	5	10	.900	10	.300	5	1.000	-	-
THURSDAY	1	87	.654	68	.911	50	.900	41	.950
	2	36	.416	38	.815	14	.999	22	.908
	3	27	.444	15	.399	9	.777	3	1.000
	4	32	.406	-	-	-	-	-	-
	5	10	.600	10	.200	-	-	-	-
FRIDAY	1	65	.707	20	.850	8	.750	13	.922
	2	16	.624	10	.900	6	.833	2	1.000
	3	12	.582	-	-	-	-	-	-
	4	20	.350	8	.500	-	-	4	-
	5	-	-	5	1.000	-	-	5	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 16 CRITERION '4'

B.S. = batch size N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	120	.491	4	.500	51	.450	12	.583
	2	40	.600	4	.250	22	.590	22	.681
	3	30	.266	-	-	6	.500	-	-
	4	8	.125	4	.250			-	-
	5	5	.200	-	-	5	0	-	-
TUESDAY	1	79	.569	63	.746	58	.724	16	.375
	2	56	.464	30	.600	36	.527	8	.510
	3	15	.333	9	.333	3	1.000	-	-
	4	12	.583	12	.416	4	1.000	4	.500
	5	-	-	5	.200	5	1.000	5	0
WEDNESDAY	1	103	.543	69	.768	53	.622	27	.777
	2	58	.396	14	.500	14	.571	4	.500
	3	30	.466	27	.555	12	.666	3	.666
	4	8	.125	12	.166	16	.312	8	.625
	5	10	.800	10	.300	5	.800	-	-
THURSDAY	1	87	.436	68	.588	51	.666	41	.682
	2	36	.166	38	.605	14	.785	22	.545
	3	27	.296	15	.266	9	.777	3	1.000
	4	32	.375	-	-	-	-	-	-
	5	10	.600	10	0	-	-	-	-
FRIDAY	1	65	.492	20	.400	8	.375	13	.615
	2	16	.312	10	.900	6	.333	2	.500
	3	12	.416	-	-	-	-	-	-
	4	20	.200	8	.500	-	-	4	.250
	5	-	-	5	-	-	-	5	.600

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 16 CRITERION 'C'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	120	.591	4	.500	51	.549	12	.583
	2	40	.625	4	.250	22	.363	22	.636
	3	30	.366	-	-	6	.666	-	-
	4	8	.125	4	0	-	-	-	-
	5	5	0	-	-	5	.200	-	-
TUESDAY	1	79	.518	63	.523	58	.293	16	.562
	2	56	.714	30	.766	36	.472	8	.750
	3	15	.333	9	.222	3	0	-	-
	4	12	.666	12	.416	4	1.000	4	.500
	5	-	-	5	.200	5	.400	5	.200
WEDNESDAY	1	103	.621	69	.724	53	.528	27	.481
	2	58	.603	14	.500	14	.500	4	0
	3	30	.633	27	.740	12	.416	3	0
	4	8	.625	12	.250	16	.250	8	.625
	5	10	1.000	10	.200	5	1.000	-	-
THURSDAY	1	87	.586	68	.838	50	.440	41	.560
	2	36	.472	38	.710	14	.357	22	.681
	3	27	.296	15	.400	9	.444	3	1.000
	4	32	.375	-	-	-	-	-	-
	5	10	.500	10	.200	-	-	-	-
FRIDAY	1	65	.738	20	.750	8	.750	13	.538
	2	16	.750	10	.700	6	.833	2	.500
	3	12	.583	-	-	-	-	-	-
	4	20	.500	8	0.750	-	-	4	0
	5	-	-	5	1.000	-	-	5	.600

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 16 CRITERION 'D'

B.S. = batch size N = number in sample
p = fraction defective $x = \arc\sin \sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	120	.266	4	0	51	.156	12	.083
	2	40	.325	4	0	22	.227	22	.272
	3	30	.333	-	-	6	0	-	-
	4	8	0	4	0	-	-	-	-
	5	5	.200	-	-	5	0	-	-
TUESDAY	1	79	.189	63	.047	58	.137	16	.125
	2	56	.089	30	.066	36	.277	8	.125
	3	15	.066	9	0	3	.0	-	-
	4	12	.250	12	0	4	.750	4	.500
	5	-	-	5	0	5	0	5	0
WEDNESDAY	1	103	.155	69	.057	53	.113	27	.037
	2	58	.224	14	0	14	.357	4	0
	3	30	.300	27	.074	12	0	3	0
	4	8	.125	12	0	16	.250	8	.750
	5	10	.500	10	0	5	0	-	-
THURSDAY	1	87	.149	68	.029	51	.120	41	.219
	2	36	0	38	.157	14	0	22	.454
	3	27	.111	15	.000	9	.222	3	0
	4	32	.187	-	-	-	-	-	-
	5	10	.500	10	0	-	-	-	-
FRIDAY	1	65	.230	20	.350	8	0	13	.230
	2	16	.062	10	.200	6	.166	2	.500
	3	12	.500	-	-	-	-	-	-
	4	20	.350	8	.250	-	-	4	.500
	5	-	-	5	.800	-	-	5	1.000

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 16 CRITERION 'F'

B.S. = batch size N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	120	.241	4	.500	51	.254	12	.250
	2	40	.350	4	.250	22	.545	22	.090
	3	30	.300	-	-	6	0	-	-
	4	8	.125	4	0	-	-	-	-
	5	5	0	-	-	5	0	-	-
TUESDAY	1	79	.278	63	.206	58	.137	16	.187
	2	56	.446	30	.433	36	.333	8	.750
	3	15	0	9	.111	3	.666	-	-
	4	12	.333	12	.250	4	.750	4	.500
	5	-	-	5	0	5	.600	5	0
WEDNESDAY	1	103	.281	69	.405	53	.188	27	.259
	2	58	.379	14	.071	14	.142	4	0
	3	30	.500	27	.370	12	.583	3	.666
	4	8	.125	12	.083	16	.187	8	.250
	5	10	.700	10	0	5	.800	-	-
THURSDAY	1	87	.287	68	.411	50	.260	41	.414
	2	36	.222	38	.421	14	.214	22	.590
	3	27	.111	15	.333	9	.444	3	1.000
	4	32	.187	-	-	-	-	-	-
	5	10	.100	10	.100	-	-	-	-
FRIDAY	1	65	.523	20	.350	8	.375	13	.307
	2	16	.250	10	.500	6	.166	2	0
	3	12	.250	-	-	-	-	-	-
	4	20	.250	8	.250	-	-	4	.500
	5	-	-	5	.800	-	-	5	1.000

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 16 CRITERION J'

B.S. = batch size
p = fraction defective
N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	120	.066	4	.500	51	.215	12	.333
	2	40	.125	4	0	22	.181	22	.409
	3	30	.133	-	-	6	0	-	-
	4	8	0	4	.250	-	-	-	-
	5	5	0	-	-	5	0	-	-
TUESDAY	1	79	.113	63	.222	58	.189	16	.125
	2	56	.142	30	.133	36	.111	8	.250
	3	15	.133	9	.225	3	1.0000	-	-
	4	12	.5	12	.083	4	1.0000	4	0
	5	-	-	5	0	5	1.0000	5	0
WEDNESDAY	1	103	.203	69	.130	53	.169	27	.296
	2	58	.086	14	.285	14	.357	4	0
	3	30	.100	27	.111	12	.250	3	0
	4	8	0	12	0	16	0	8	0
	5	10	.300	10	.100	5	.200	-	-
THURSDAY	1	87	.137	68	.088	51	.285	41	.195
	2	36	.055	38	.105	14	0	22	.318
	3	27	.222	15	.133	9	0	3	.666
	4	32	.093	-	-	-	-	-	-
	5	10	.200	10	0	-	-	-	-
FRIDAY	1	65	.061	20	.050	8	0	13	.230
	2	16	.250	10	.200	6	.333	2	1.000
	3	12	.250	-	-	-	-	-	-
	4	20	0	8	0	-	-	4	0
	5	-	-	5	0	-	-	5	.400

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 16 CRITERION 3

B.S. = batch size N = number in sample

p = fraction defective $x = \arcsin\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	74	.067	17	.411	32	.218	12	.166
	2	52	.104	2	0	10	.416	14	.142
	3	21	.047	-	-	9	.222	6	.332
	4	28	.071	-	-	-	-	12	0
	5	15	.132	5	0	-	-	-	-
TUESDAY	1	55	.254	60	.266	55	.381	24	.041
	2	44	.180	50	.200	10	.400	2	.500
	3	27	0.	24	.166	15	.266	3	0
	4	12	.332	16	0	-	-	4	.250
	5	15	.066	10	0	-	-	-	-
WEDNESDAY	1	61	.229	33	.180	60	.349	17	.117
	2	44	.136	36	.110	22	.317	6	0
	3	36	.166	30	.100	4	.166	3	0
	4	20	.050	4	.250	-	-	-	-
	5	10	0	10	0	5	0	-	-
THURSDAY	1	57	.157	60	.216	51	.235	46	.107
	2	34	.175	26	.038	16	.249	10	.200
	3	9	.111	27	.111	24	.082	6	.332
	4	12	.083	12	0	4	.500	4	.250
	5	15	.066	5	.200	5	0	-	-
FRIDAY	1	36	.194	31	.225	20	.250	17	.235
	2	16	.187	28	.071	4	0	4	.250
	3	18	.166	12	.083	-	-	3	0
	4	28	.071	12	.083	4	0	-	-
	5	-	-	5	0	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No 2 MODEL ADO 16 CRITERION 4

B.S. = batch size N = number in sample
p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	74	.040	17	.294	32	.156	12	.083
	2	52	.038	2	0	10	.166	14	.071
	3	21	0	-	-	9	.111	6	.166
	4	28	0	-	-	-	-	12	0
	5	15	0.066	5	0	-	-	-	-
TUESDAY	1	55	0.127	60	.150	55	.200	24	.041
	2	44	0.090	50	.080	10	.400	2	..500
	3	27	0	24	.041	15	.266	3	0
	4	12	.166	16	0	-	-	4	.250
	5	15	.066	.10	0	-	-	-	-
WEDNESDAY	1	61	.098	33	.090	60	.116	17	0
	2	44	.068	36	.055	22	.136	6	0
	3	36	.111	30	0	4	.083	3	0
	4	20	0	4	0	-	-	-	-
	5	10	0	10	0	5	0	-	-
THURSDAY	1	57	.087	60	.150	51	.137	46	.021
	2	34	.058	26	.038	16	.062	10	.200
	3	9	.111	27	0	24	.041	6	.166
	4	12	0	12	0	4	.250	4	0
	5	15	0	5	0	5	0	-	-
FRIDAY	1	36	.083	31	.064	20	..200	17	0
	2	16	.062	28	0	4	0	4	0
	3	18	.0	12	0	-	-	3	0
	4	28	0	12	0	4	0	-	-
	5	-	-	5	0	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 16 CRITERION C

B.S. = batch size N = number in sample
p = fraction defective $x = \arcsin \sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	74	.283	17	.764	32	.500	12	.166
	2	52	.288	2	0	10	.083	14	.285
	3	21	.190	-	-	9	.222	6	0
	4	28	.178	-	-	-	-	12	0
	5	15	.200	5	0	-	-	-	-
TUESDAY	1	55	.309	60	.500	55	.236	24	.500
	2	44	.227	50	.400	10	0	2	0
	3	27	.074	24	.250	15	.266	3	0
	4	12	.250	16	.312	-	-	4	0
	5	15	.400	10	.200	-	-	-	-
WEDNESDAY	1	61	.229	33	.424	60	.383	17	.058
	2	44	.159	36	.194	22	.590	6	.166
	3	36	.250	30	.466	4	.416	3	0
	4	20	.400	4	.250	-	-	-	-
	5	10	.300	10	.300	5	0	-	-
THURSDAY	1	57	.210	60	.533	51	.215	46	.304
	2	34	.323	26	.500	16	.125	10	0
	3	9	.222	27	.222	24	.125	6	.500
	4	12	.166	12	.166	4	.500	4	0
	5	15	0	5	.400	5	0	-	-
FRIDAY	1	36	.222	31	.774	20	.350	17	.352
	2	16	.187	28	.607	4	.750	4	.500
	3	18	.388	12	.416	-	-	3	0
	4	28	.178	12	.166	4	1.000	-	-
	5	-	-	5	.200	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 16 CRITERION D

B.S. = batch size
p = fraction defective

N = number in sample
$x = \arcsin\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	74	.081	17	.235	32	.031	12	0
	2	52	.096	2	0	10	.083	14	.071
	3	21	.047	-	-	9	0	6	0
	4	28	.178	-	-	-	-	12	0
	5	15	.133	5	0	-	-	-	-
TUESDAY	1	55	.181	60	.100	55	.054	24	.041
	2	44	.136	50	.040	10	0	2	0
	3	27	.111	24	.041	15	0	3	0
	4	12	.416	16	0	-	-	4	0
	5	15	.133	10	0	-	-	-	-
WEDNESDAY	1	61	.147	33	0	60	.133	17	.294
	2	44	.136	36	.027	22	.090	6	0
	3	36	.111	30	0	4	.166	3	0
	4	20	.350	4	0	-	-	-	-
	5	10	0	10	0	5	.200	-	-
THURSDAY	1	57	.210	60	.050	51	.098	46	.173
	2	34	.294	26	0	16	.125	10	0
	3	9	0	27	0	24	0	6	.333
	4	12	.166	12	0	4	0	4	0
	5	15	0	5	1.000	5	0	-	-
FRIDAY	1	36	.194	31	.161	20	0	17	.117
	2	16	.125	28	.035	4	0	4	0
	3	18	.555	12	0	-	-	3	0
	4	28	.214	12	.333	4	0	-	-
	5	-	-	5	0	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 16 CRITERION F

B.S. = batch size
p = fraction defective

N = number in sample
x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
	B.S.	N	p	N	p	N	p	N	p
MONDAY	1	74	.081	17	.117	32	.031	12	.083
	2	52	.019	2	0	10	.083	14	.142
	3	21	0	-	-	9	.222	6	0
	4	28	.035	-	-	-	-	12	.333
	5	15	.200	5	0	-	-	-	-
TUESDAY	1	55	.018	60	.183	55	.036	24	.125
	2	44	.136	50	.060	10	.100	2	0
	3	27	.074	24	.166	15	.0	3	0
	4	12	0	16	.062	-	-	4	.750
	5	15	.400	10	0	-	-	-	-
WEDNESDAY	1	61	.065	33	.090	60	.083	17	.235
	2	44	.159	36	.083	22	0	6	0
	3	36	.138	30	.066	4	0	3	0
	4	20	0	4	0	-	-	-	-
	5	10	0	10	.200	5	0	-	-
THURSDAY	1	57	.087	60	.116	51	.117	46	.130
	2	34	0	26	0	16	0	10	.300
	3	9	0	27	.037	24	.125	6	.333
	4	12	0	12	.166	4	0	4	.250
	5	15	.133	5	0	5	0	-	-
FRIDAY	1	36	.055	31	0	20	.100	17	.117
	2	16	0	28	.107	4	0	4	0
	3	18	.222	12	.250	-	-	3	0
	4	28	.214	12	.250	4	0	-	-
	5	-	-	5	0	-	-	-	-

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15

B.P. = batch position C = criterion N = number in sample

p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
C	B.P.	N	p	N	p	N	p	N	p
'C'	1	808	.446	851	.597	440	.370	597	.429
	2	532	.453	477	.658	275	.425	349	.493
	3	374	.492	291	.687	173	.405	220	.527
	4	234	.444	192	.646	100	.470	131	.489
	5	152	.500	116	.672	57	.404	75	.533
'F'	1	808	.063	851	.088	440	.045	597	.082
	2	532	.077	477	.101	275	.069	349	.095
	3	374	.064	291	.079	173	.064	220	.091
	4	234	.068	192	.120	100	.030	131	.099
	5	152	.039	116	.121	57	.035	75	.120
'H'	1	808	.040	851	.022	440	.159	597	.017
	2	532	.058	477	.015	275	.175	349	.029
	3	374	.051	291	.017	173	.202	220	.023
	4	234	.060	192	.010	100	.210	131	0
	5	152	.053	116	0	57	.193	75	0
'J'	1	808	.001	851	0	440	.002	597	0
	2	532	0	477	0	275	0	349	0
	3	374	0	291	0	173	0	220	.005
	4	234	0	192	0	100	0	131	0
	5	152	.004	116	0	57	0	75	0
'D'	1	808	.119	851	.008	440	.045	597	.112
	2	532	.158	477	.002	275	.047	349	.129
	3	374	.150	291	.003	173	.023	220	.118
	4	234	.184	192	.010	100	.060	131	.115
	5	152	.118	116	0	57	.105	75	.107

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15

B.P. = batch position C = criterion N = number in sample

p = fraction defective $x = \arc\sin\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
C	B.P.	N	p	N	p	N	p	N	p
'C'	1	658	.544	367	.504				
	2	414	.604	233	.575				
	3	250	.576	159	.553				
	4	141	.610	102	.598				
	5	87	.598	56	.500				
F	1	658	.084	367	.074				
	2	414	.072	233	.090				
	3	250	.124	159	.069				
	4	141	.085	102	.059				
	5	87	.057	56	.089				
H	1	658	.084	367	.035				
	2	414	.072	233	.039				
	3	250	.124	159	.063				
	4	141	.085	102	.029				
	5	87	.057	56	.071				
J	1	658	0.003	367	0				
	2	414	0	233	0				
	3	250	0	159	0.006				
	4	141	0	102	0				
	5	87	0	56	0				
D	1	658	.017	367	.035				
	2	414	.024	233	.060				
	3	250	.040	159	.038				
	4	141	.014	102	.049				
	5	87	.023	56	.054				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15 Sheet 1 of 2

B.P. = batch position C = criterion N = number in sample

p = fraction defective $x = \arcsin \sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
C	B.P.	N	p	N	p	N	p	N	p
3+	1	808	.649	851	.874	440	.718	597	.742
	2	532	.615	477	.864	275	.731	349	.705
	3	374	.642	291	.859	173	.659	220	.768
	4	234	.637	192	.880	100	.750	131	.710
	5	152	.618	116	.897	57	.684	75	.640
4	1	808	.369	851	.575	440	.480	597	.466
	2	532	.336	477	.541	275	.385	349	.390
	3	374	.326	291	.543	173	.410	220	.414
	4	234	.342	192	.536	100	.370	131	.389
	5	152	.362	116	.603	57	.421	75	.347

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 15

B.P. = batch position C = criterion N = number in sample

p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
C	B.P.	N	p	N	p	N	p	N	p
3+	1	658	.778	367	.839				
	2	414	.831	233	.811				
	3	250	.768	159	.774				
	4	141	.780	102	.775				
	5	87	.816	56	.732				
4	1	658	.439	367	.493				
	2	414	.425	233	.425				
	3	250	.388	159	.409				
	4	141	.418	102	.431				
	5	87	.448	56	.446				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15

B.P. = batch position C = criterion N = number in sample

p = fraction defective $x = \arcsin \sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
C	B.P.	N	p	N	p	N	p	N	p
'I'	1	712	.029	809	.009	441	.077	605	.005
	2	264	.027	288	.003	127	.079	180	.017
	3	128	.023	125	.016	47	.085	77	.026
	4	74	.014	60	0	22	.091	35	0
	5	33	0	31	0	14	0	16	0
3+	1	712	.124	809	.204	441	.302	605	.183
	2	264	.133	288	.160	127	.244	180	.150
	3	128	.148	125	.152	47	.255	77	.221
	4	74	.162	60	.133	22	.455	35	.286
	5	33	.091	31	.032	14	.429	16	.188
'C'	1	712	.059	809	.180	441	.052	605	.068
	2	264	.038	288	.181	127	.055	180	.083
	3	128	.039	125	.152	47	.021	77	.078
	4	74	.041	60	.150	22	0	35	.114
	5	33	0	31	.097	14	.143	116	.063
'D'	1	712	.090	809	.007	441	.020	605	.114
	2	264	.087	288	.017	127	.008	180	.117
	3	128	.094	125	0	47	.021	77	.039
	4	74	.081	60	0	22	.045	35	.029
	5	33	.061	31	.032	14	.071	16	0
'F'	1	712	0.004	809	0.015	441	.005	605	.010
	2	264	0.004	288	0.010	127	0	180	.017
	3	128	0.008	125	0	47	0	77	.013
	4	74	0.014	60	0.033	22	.045	35	.059
	5	33	0.030	31	0	14	0	16	0

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 15

B.P. = batch position C = criterion N = number in sample

p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		ISLAND BLUE		ALMOND GREEN					
C	B.P.	N	p	N	p	N	p	N	p
'J'	1	648	.031	416	.012				
	2	187	.048	114	.009				
	3	76	.053	42	0				
	4	30	.200	18	0				
	5	11	0	8	0				
3+	1	648	.218	416	.204				
	2	187	.187	114	.123				
	3	76	.224	42	.119				
	4	30	.267	18	.111				
	5	11	.182	8	0				
'C'	1	648	.103	416	.154				
	2	187	.096	114	.149				
	3	76	.066	42	.119				
	4	30	.033	18	.056				
	5	11	.091	8	0				
'D'	1	648	.015	416	.079				
	2	187	.011	114	.053				
	3	76	.026	42	.048				
	4	30	0	18	.111				
	5	11	0	8	0				
"F"	1	648	.012	416	.007				
	2	187	.016	114	.035				
	3	76	.013	42	0				
	4	30	.067	18	0				
	5	11	0	8	0				

PAINT REJECTION ANALYSIS

PLANT : No. 2 MODEL : ADO 15 CRITERION :

B.P. = Batch Position N = No. in sample p = Fraction Defective

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
C	BP	N	p	N	p	N	p	N	p
4	1	712	.065	809	.098	441	.211	605	.094
	2	264	.045	288	.059	127	.150	180	.050
	3	128	.063	125	.096	47	.149	77	.078
	4	74	.095	60	.083	22	.364	35	.200
	5	33	.061	31	0	14	.357	16	.125

PAINT REJECTION ANALYSIS

PLANT : No. 2. MODEL : ADO 15 CRITERION

B.P. = Batch Position N = NO. in sample p = Fraction Defective

COLOUR		ISLAND BLUE		ALMOND GREEN					
C	BP	N	p	N	p	N	p	N	p
	1	648	.142	416	.063				
	2	187	.107	114	.026				
4	3	76	,158	42	.024				
	4	30	.133	18	.056				
	5	11	.091	8	0				

PAINT REJECTION ANALYSIS

PAINT PLANT No. 1 MODEL ADO 16 Sheet 1 of 1

B.P. = batch position C = criterion N = number in sample

p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		ISLAND BLUE		ALMOND GREEN	
	B.P.	N	p	N	p	N	p	N	p
3	1	605	.740	291	.935	282	.865	147	.871
	2	153	.758	81	.877	62	.887	38	.789
	3	57	.825	36	.944	16	.875	11	.909
	4	38	.842	11	1.000	7	1.000	6	.833
	5	23	.826	12	1.000	6	1.000	4	.750
C	1	605	.385	291	.471	282	.273	147	.340
	2	153	.464	81	.481	62	.274	38	.526
	3	57	.298	36	.389	16	.250	11	.182
	4	38	.263	11	.545	7	.286	6	.500
	5	33	.522	12	.583	6	.333	4	.250
D	1	605	.066	291	.031	282	.035	147	.061
	2	153	.085	81	.012	62	.032	38	.026
	3	57	.140	36	.056	16	0	11	.273
	4	38	.079	11	0	7	0	6	0
	5	33	.087	12	0	6	0	4	0
F	1	605	.099	291	.148	282	.067	147	.129
	2	153	.078	81	.173	62	.097	38	.132
	3	57	.158	36	.167	16	.125	11	.091
	4	38	.158	11	0	7	.143	6	.167
	5	33	.130	12	.250	6	.167	4	.250
J	1	605	.076	291	.010	282	.216	147	.007
	2	153	.078	81	0	62	.210	38	.026
	3	57	.018	36	.028	16	.313	11	.091
	4	38	.079	11	.091	7	.143	6	0
	5	38	.045	12	0	6	.167	4	0

PAINT REJECTION ANALYSIS

Sheet 1 of 1

PAINT PLANT No.1 MODEL ADO 16

B.P. = batch position C = criterion N = number in sample

p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
C	B.P.	N	p	N	p	N	p	N	p
	1	605	.524	291	.670	282	.613	147	.660
	2	153	.503	81	.642	62	.645	38	.500
'4'	3	57	.561	36	.611	16	.813	11	.545
	4	38	.632	11	.727	7	1.000	6	.667
	5	23	.609	12	.750	6	1.000	4	.750
'J'									

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 16 Sheet 1 of 1

B.P. = batch position C = criterion N = number in sample

p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
C	B.P.	N	p	N	p	N	p	N	p
C	1	412	.068	276	.207	266	.083	142	.099
	2	118	.085	82	.073	36	.111	26	.038
	3	51	.020	34	.147	19	.053	9	.111
	4	32	.031	11	0	5	0	4	0
	5	25	.080	8	.125	2	0	2	0
3+	1	412	.177	276	.214	266	.316	142	.141
	2	118	.212	82	.171	36	.333	26	.154
	3	51	.098	34	.235	19	.263	9	.444
	4	32	.094	11	0	5	0	-	0
	5	25	.240	8	.125	2	0	-	0
D	1	412	.080	276	.029	266	.026	142	.014
	2	118	.085	82	.012	36	.056	26	.077
	3	51	.020	34	.059	19	.053	9	0
	4	32	.094	11	0	5	.200	-	0
	5	25	.080	8	0	2	0	-	0
F	1	412	.012	276	.043	266	.026	142	.035
	2	118	.017	82	.037	36	0	26	0
	3	51	0	34	.088	19	0	9	.111
	4	32	0	11	0	5	0	-	0
	5	25	0	8	0	2	0	-	0
H	1	412	.049	276	.007	266	.068	140	.014
	2	118	0	82	0	36	.111	26	.038
	3	51	.039	34	0	19	.053	9	.111
	4	32	.063	11	0	5	.400	-	0
	5	25	0	8	0	2	0	-	0

PAINT REJECTION ANALYSIS

PAINT PLANT No. 2 MODEL ADO 16 Sheet 1 of 1

B.P. = batch position C = criterion N = number in sample

p = fraction defective x = arc sin $\sqrt{p}$

COLOUR		SNOWBERRY WHITE		TARTAN RED		SANDY BEIGE		EL PASO BEIGE	
C	B.P.	N	p	N	p	N	p	N	p
	1	412	.075	276	.109	266	.158	142	.049
	2	118	.093	82	.061	36	.194	26	.115
4	3	51	.059	34	.029	19	.263	9	.111
	4	32	.031	11	0	5	0	4	0
	5	25	.160	8	.125	2	0	2	0

BREAKDOWN & STOPPAGE ANALYSIS

A detailed analysis is included for the Electrocoat paint plant and the main results for the remaining plants.

ELECTROCOAT

There are two main types of stoppage. (All times in minutes)

(1) Scheduled	Day	Night
(a) Starting Delay	15	15
(b) Mid-Morning Break	15	15
(c) Lunch	30	30
(d) Mid-Afternoon Break	15	15
(e) Shut Down	15	15
	90	90

With a sample of 104 the starting delay was checked and found to average 13.28 mins. with little deviation.

(2) Non-Scheduled

(a) Conjestion

(b) Maintenance

(c) Labour

(d) Bay shortage

(e) Body shortage

(f) Others

A sample was taken over 101 shifts and the following results were found. (14th November - 7th February).

Cause	a	b	c	d	e	f
Average No. of occurances/ shift	.500	.404	.048	.404	.433	.076
Average duration of delay	23.6M	18.02	45.2	20.17	16.04	36.25
Standard deviation of delay	19.7	20.75	74.45	15.97	11.42	-
% of total by occurance	26.8	21.6	2.6	21.6	23.2	4.1
% of total by time	30.2	18.6	5.6	20.8	17.7	7.1

Overall results (1) Average No. of delays/shift = 1.86

(2) Average duration of delay - 20.97 mins.

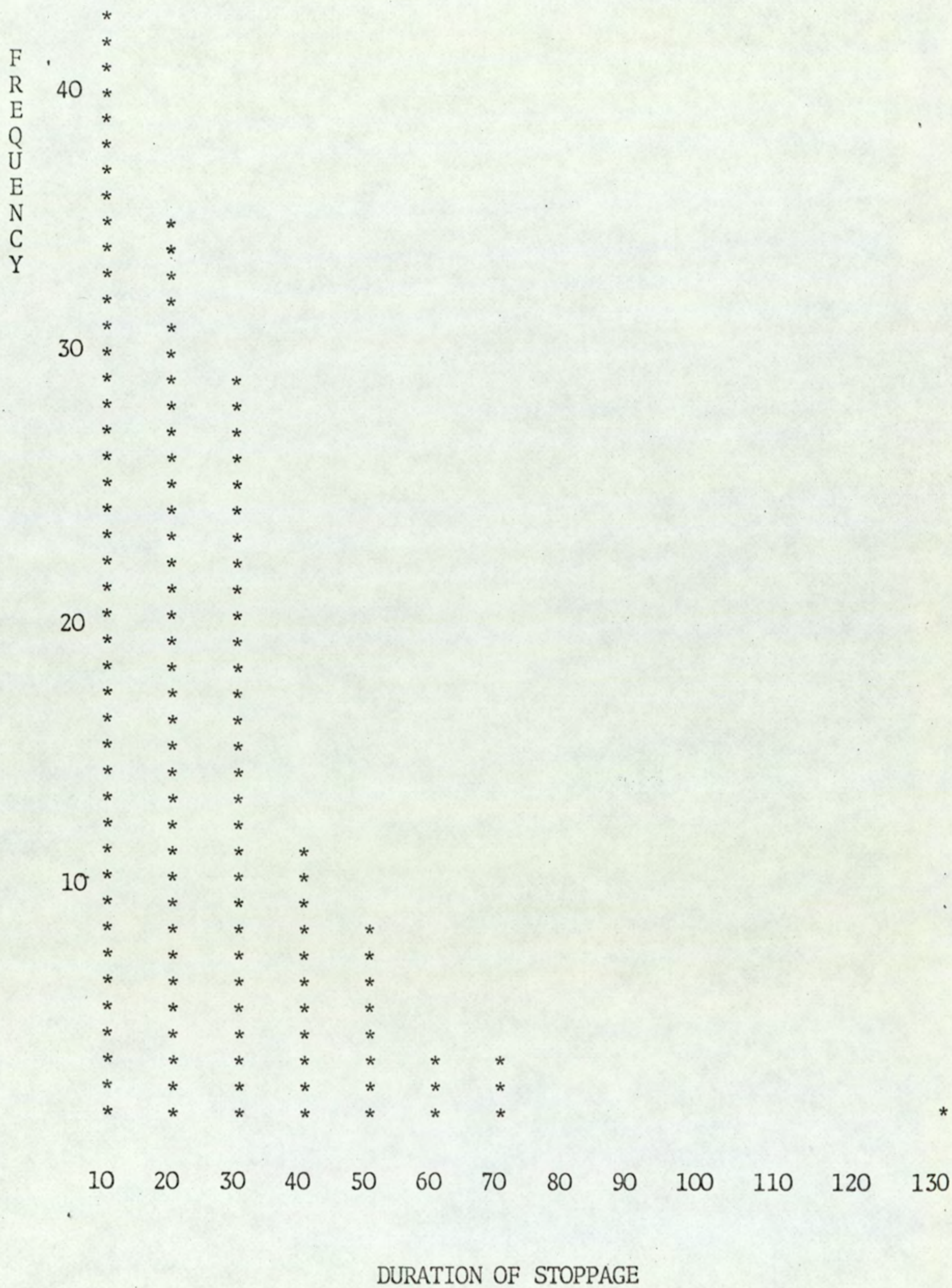
(3) Std. deviation of delay 39.38 mins.

(4) Delay/shift = 39.1 mins.

Sample size 101 shifts

194 unscheduled stoppages

DISTRIBUTION OF STOPPAGE DELAYS



BREAKDOWN & STOPPAGE ANALYSIS

FACILITY	AVERAGE DURATION OF STOPPAGE	AVERAGE TIME BETWEEN STOPPAGES
NO. 1 PAINT PLANT	18.5	100.3
No. 2 PAINT PLANT	25.4	270.0
LYSAUGHT PLANT	10.0	400.0
ADO 15 TRACK	14.6	476.1
ADO 16 TRACK	11.0	432.2
W/R TRACK	14.8	540.0
J4 TRACK	17.0	456.6
LOOP LINE	18.3	189.2
LOWBAKE	20.1	317.4

IN ALL CASES A NEGATIVE EXPONENTIAL CURVE WAS FOUND TO MATCH BOTH THE INTERARRIVAL AND DURATION TIMES OF THE STOPPAGES.

REJECTION ANALYSIS

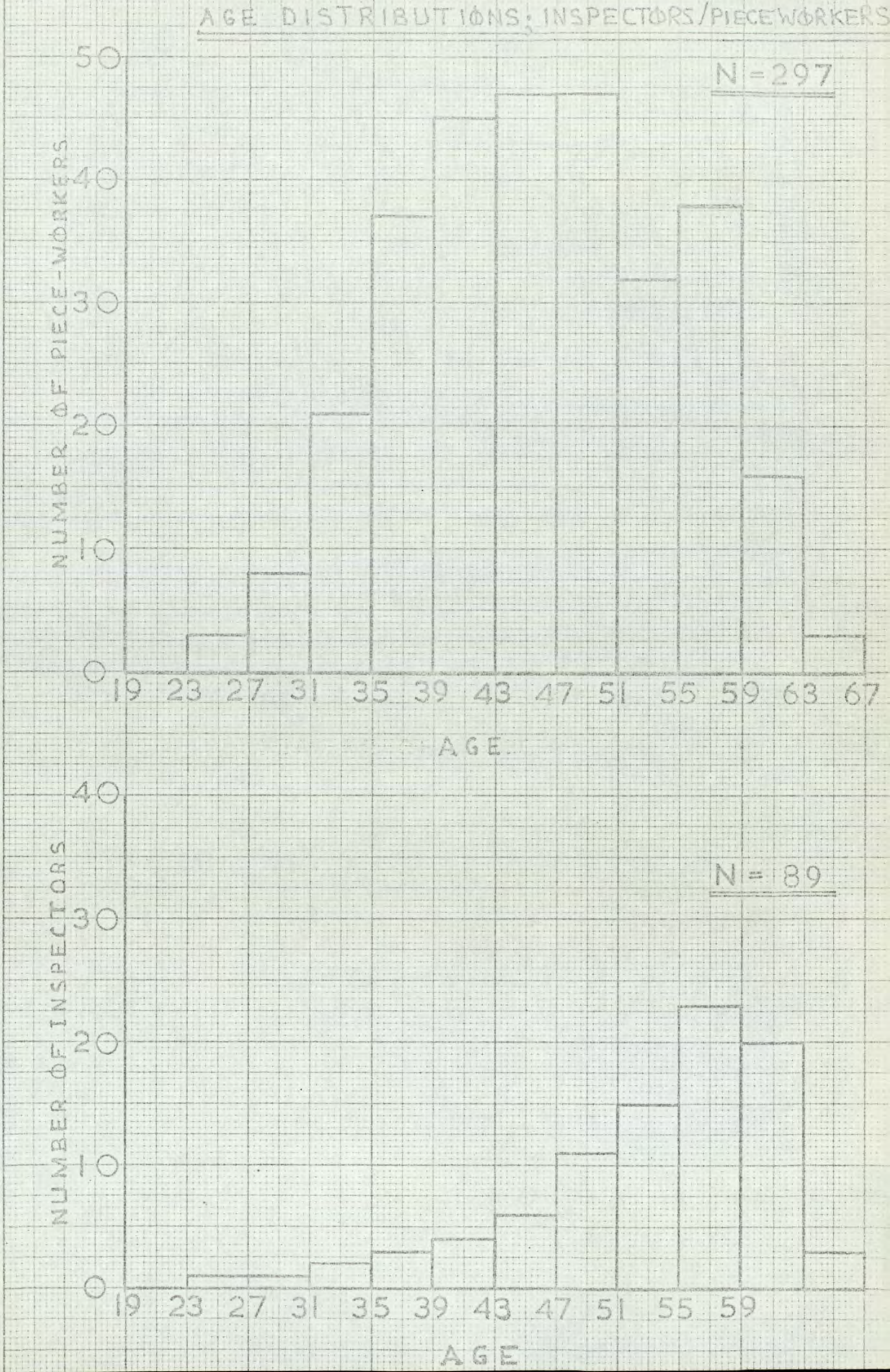
CORRELATION TEST

REJECTION RATES

ACTUAL	INSPECTORS REPORT
0.525	0.469
0.622	0.595
0.589	0.604
0.548	0.649
0.673	0.684
0.640	0.746
0.566	0.820
0.675	0.964
0.697	0.962
0.741	0.978
0.771	0.993

R = .810

95% confidence limits 0.408 to 0.949



AGE DISTRIBUTIONS: INSPECTORS/PIECEWORKERS
N = 297
NUMBER OF PIECE-WORKERS
50
40
30
20
10
0
19 23 27 31 35 39 43 47 51 55 59 63 67
AGE
N = 89
NUMBER OF INSPECTORS
40
30
20
10
0
19 23 27 31 35 39 43 47 51 55 59
AGE

Production Statistics			Shift:				Date:				Time:				To:			
Location	ADO 15 Saloon		ADO 15 Elf		ADO 15 Hornet		C/Man: 1100		Traveller 1100		C/Man: 1300		Traveller 1300		J4		TOTAL:	
	Hrly	Cum:	Hrly	Cum:	Hrly	Cum:	Hrly	Cum:	Hrly	Cum:	Hrly	Cum:	Hrly	Cum:	Hrly	Cum:	Hrly	Cum:
Electrocoat																		
Load to No.1 Plant.																		
Passed off Paint.																		
Load to Finish.Track																		
Passed off Finish.Track																		
Despatched																		
Finish Target																		

DATA COLLECTION FORM 'A'

(Filled in by Production Control)

DATA COLLECTION FORM 'B'

STORAGE UTILISATION   Sheet...... of......

STORAGE AREA.........................

Sample Number	Time	Number of Bodies	Sample Number	Time	Number of Bodies

TABLE 1 COLOUR CODES

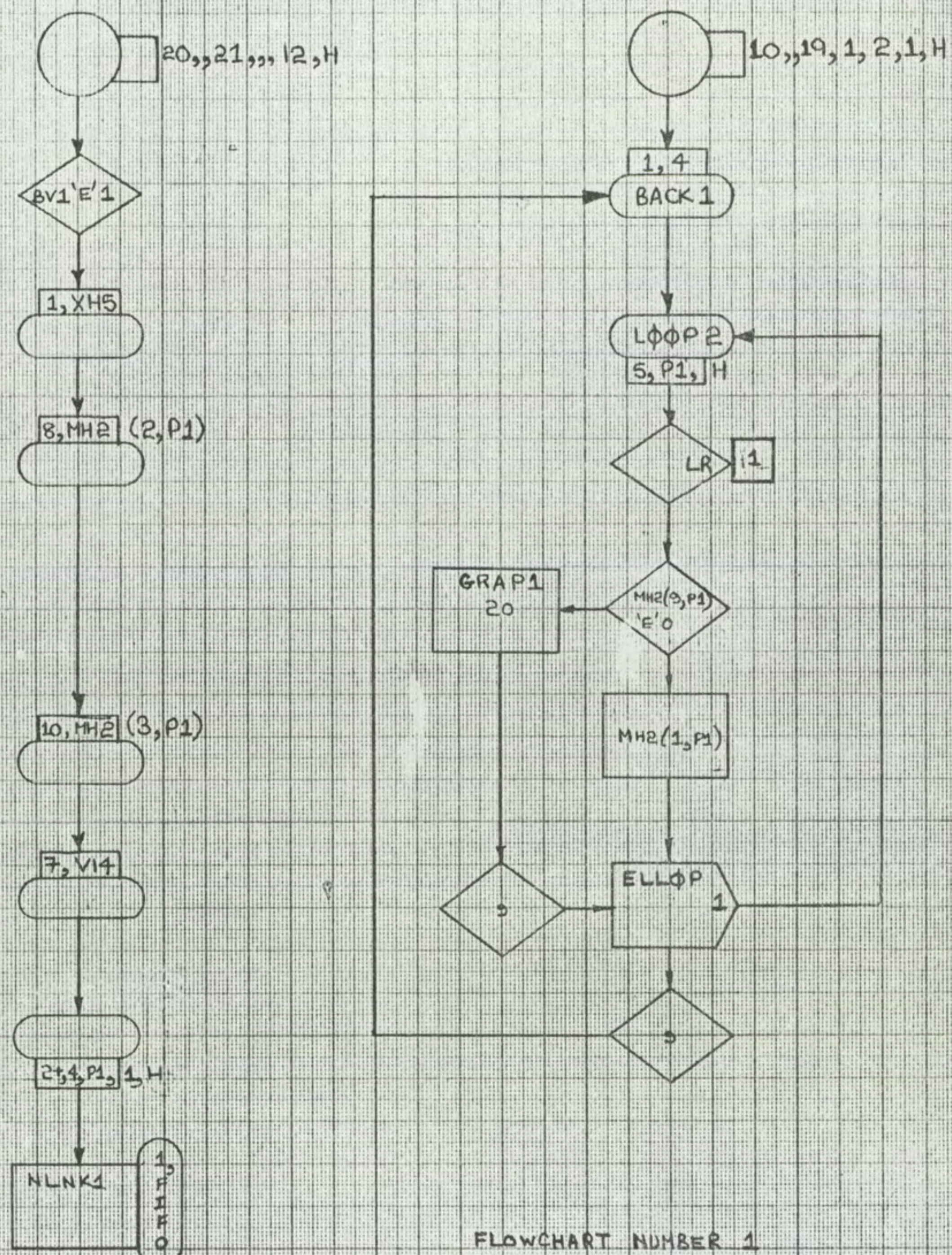
COLOUR	COMPUTER CODE	MODEL CODE	USED ON*
Snowberry White	GA	1	A,B,C,D
Tartan Red	GB	2	A,B
Sandy Beige	GC	3	A,B
Almond Green	GD	4	A
El Paso Beige	GE	5	A,B
Island Blue	GF	6	A
Glen Green	GG	7	C
Maroon 'B'	GH	8	C
Everglade Green	GJ	9	C
Cumulus Grey	GK	10	B,D
Spruce Green	GL	11	D
Trafalgar Blue	GM	12	B
Damask Red	GN	13	C
Yukon Grey	GO	14	C
Cumberland Green	GP	15	C
Persian Blue	GQ	16	D
Fawn Brown	GR	17	C
Birch Grey	GS	18	C
Pale Ivory	GT	19	C
Whitehall Beige	GU	20	C
Black	GV	21	A,B
Alaskan Blue	GW	22	B
Smoke Grey	GX	23	B
Connaught Green	GY	24	B
Maroon	GZ	25	A

TABLE 1 cont....

COLOUR	COMPUTER CODE	MODEL CODE	USED ON *
Beige Sealer	HA	26	D
Post Office Red	HB	27	D
Azure Blue	HC	28	D
Mid Bronze	HD	29	B,C
Met Police Blue	HE	30	D
Biscuit	HF	31	D
Signal Red	HG	32	D
Tweed Grey	HH	33	C
Baltic Blue	HJ	34	A,B
Carribean Turq.	HK	35	B
Royal Blue	HL	36	A
Bronze Green	HM	37	B
Lemon BS 355	HN	38	D
Police White	HP	39	D
Der Red	HR	40	D
Golden Yellow	HS	41	D
French Blue	HT	42 -	A,B
Whiter than White	HU	43	A,B,C
Glazier White	HV	44	A,B,C,D
Dark Blue	HW	45	A,B
Antelop	HX	46	A
Flame Red	HY	47	A
Bronze Yellow	HZ	48	A
Blue Royale	JA	49	A
Aqua	JB	50	B
Supreme White	JC	51	A,B
Fawn Brown	JD	52	D
Bermuda Blue	JE	53	

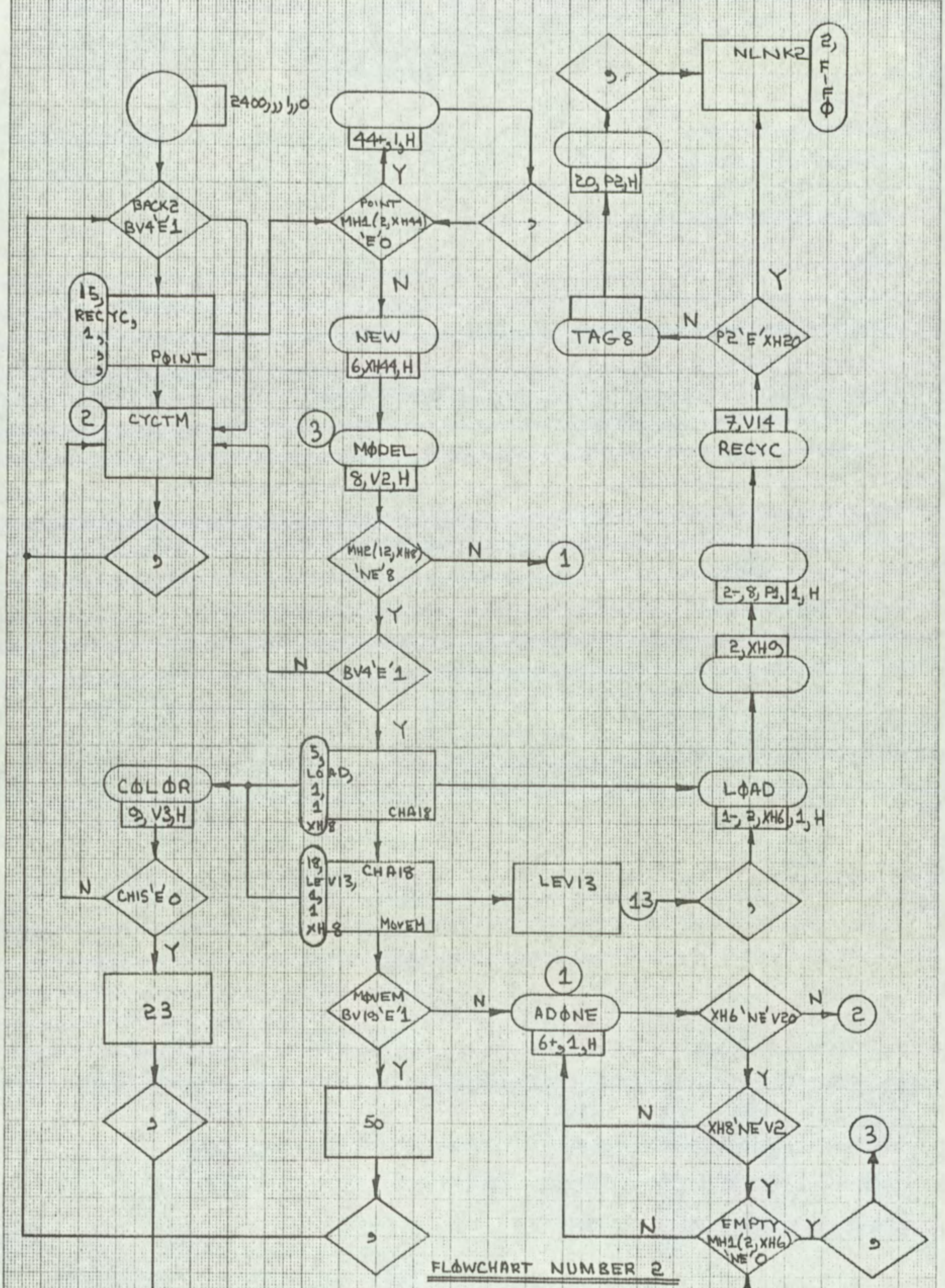
APPENDIX D

FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION	SHEET
PREPARED BY: M Bennett	DATE	PROGRAM No.	LOAD TO THE ELECTROCOAT PLANT	1 OF 1



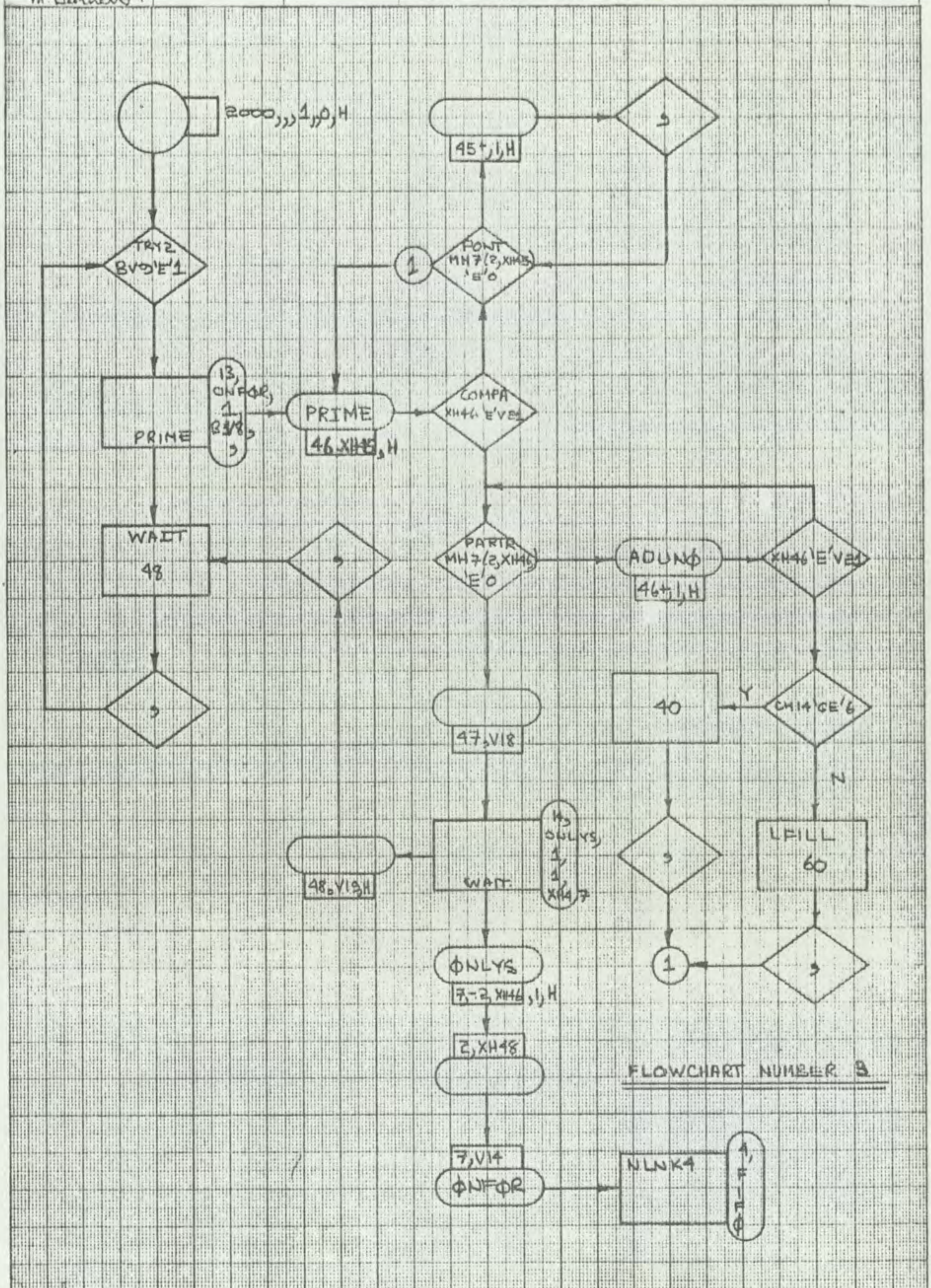
FLOWCHART NUMBER 1

FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION	SHEET
PREPARED BY M. Bennett	DATE	PROGRAM No.	LOAD TO THE No.1 COLOUR PLANT	1 OF 1



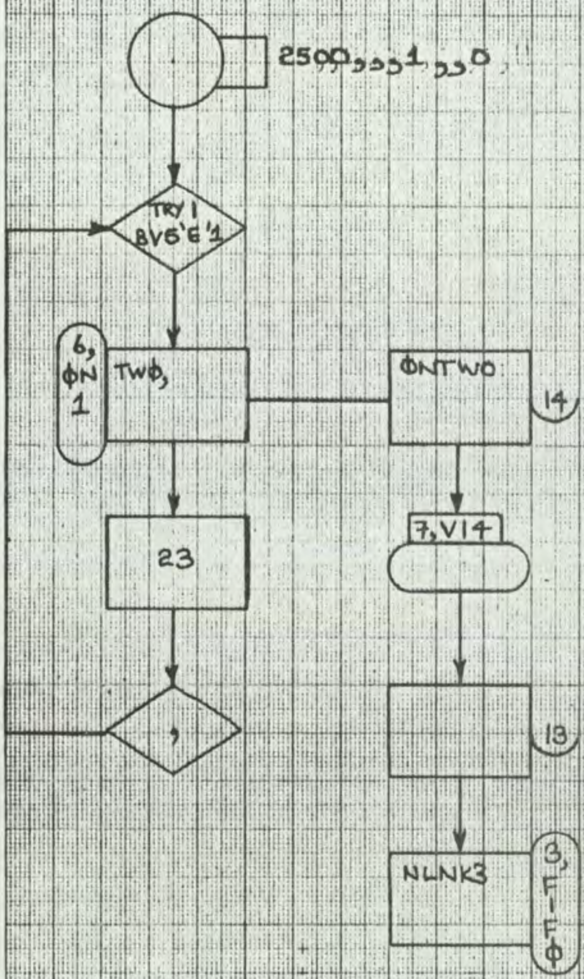
FLOWCHART NUMBER 2

FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION	SHEET
PREPARED BY: M. Burnett	DATE	PROGRAM No.	LOAD TO LYSAUGHT PLANT	1 of 1



FLOWCHART NUMBER 9

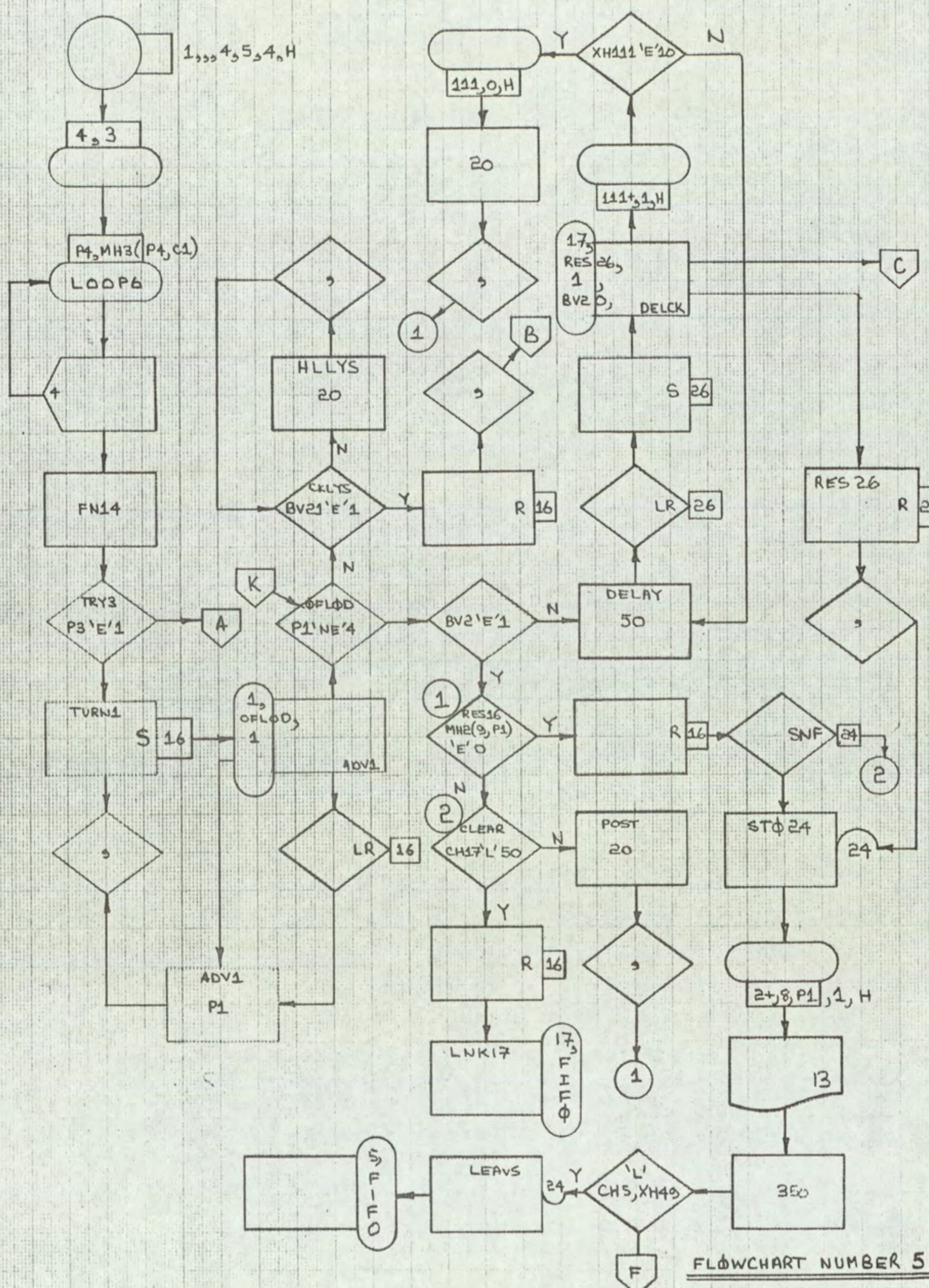
FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION:	SHEET
PREPARED BY M. Bennett.	DATE	PROGRAM No.	LOAD TO THE No 2 PAINT PLANT	1 OF 1



FLOWCHART NUMBER 4

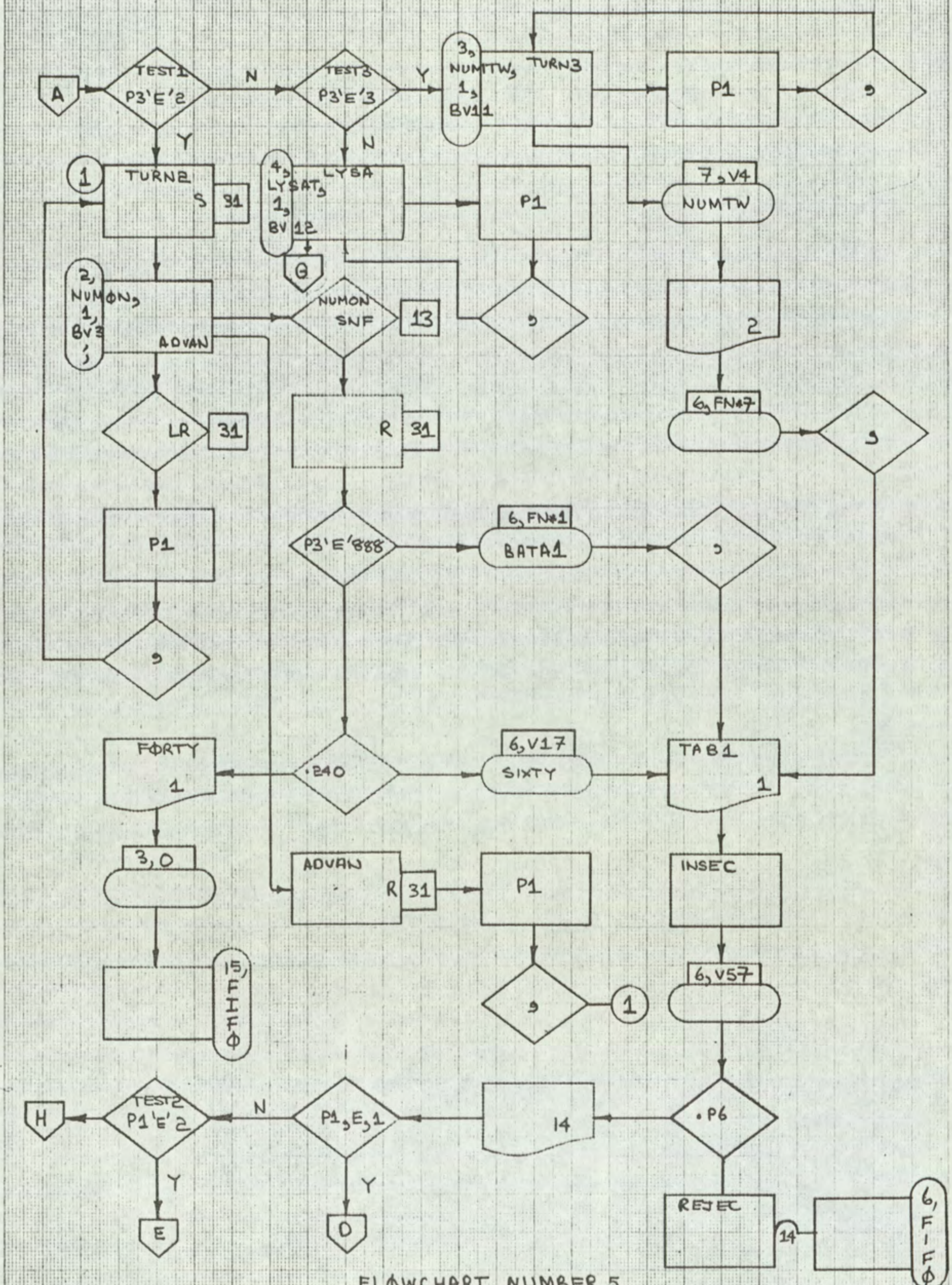
050882

FLOWCHARTING WORKSHEET	PROJECT No.	DESCRIPTION	SHEET
PREPARED BY: m Bennett / DATE	PROGRAM No.	OFF LOAD MODULE	1 OF 3



FLΦWCHART NUMBER 5

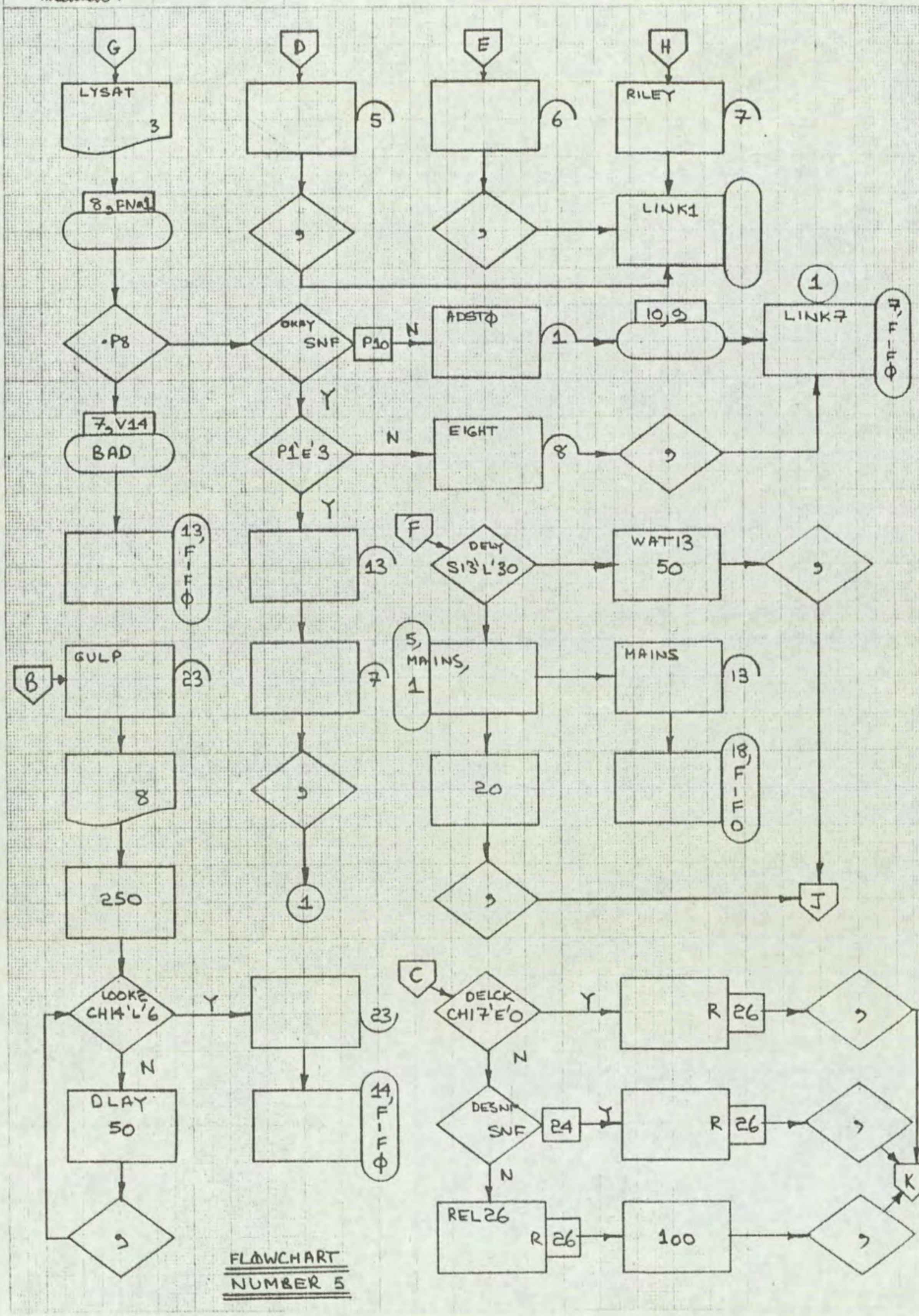
FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION:	SHEET
PREPARED BY m. Bennett.	DATE	PROGRAM No.	ΦFF LΦAD MΦDULE	2 of 3



FLΦWCHART NUMBER 5

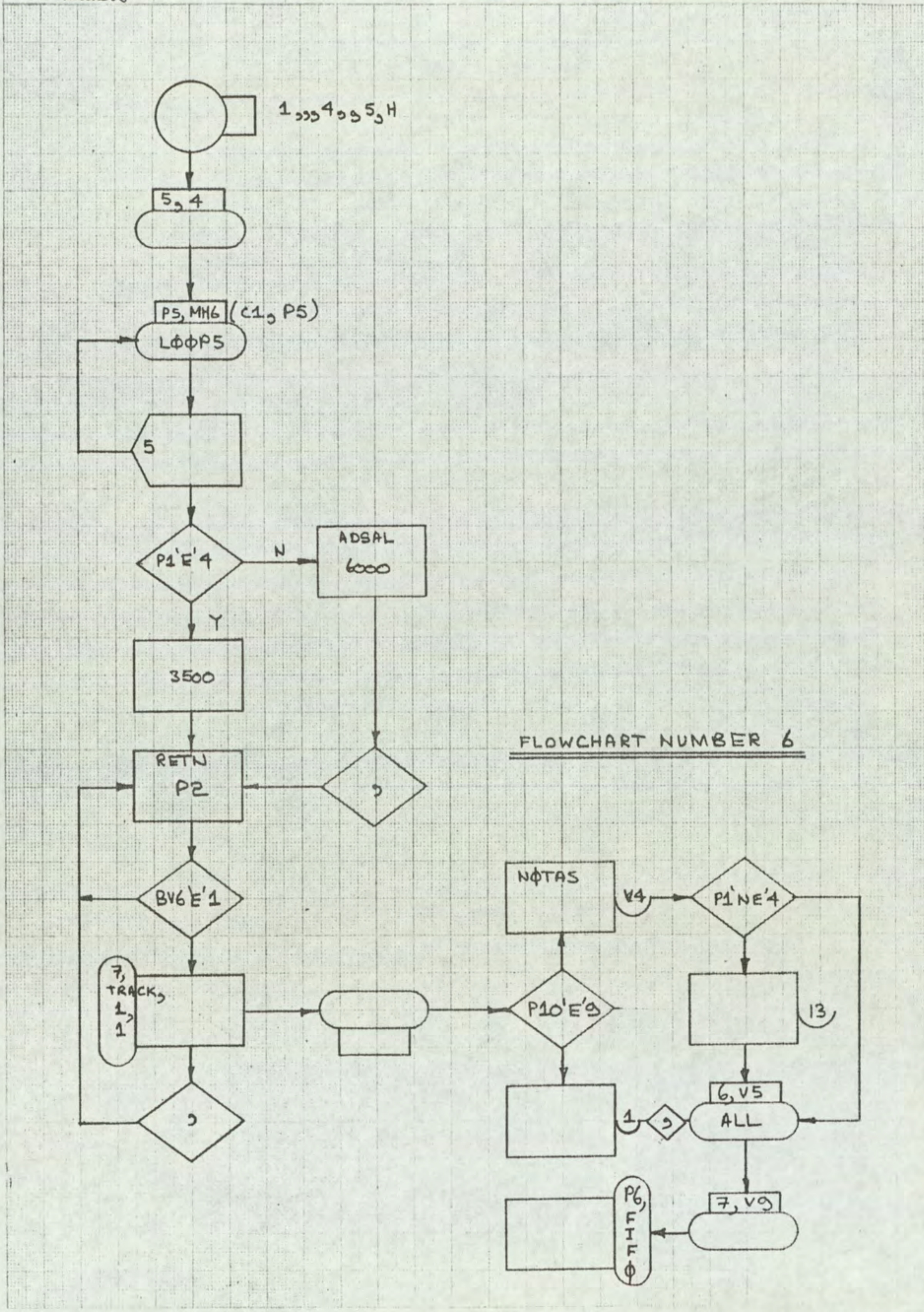
FLOWCHARTING WORKSHEET | PROJECT No | DESCRIPTION | SHEET

PREPARED BY M. Bennett | DATE | PROGRAM No | ØFF LØAD MØDULE | 3 of 3



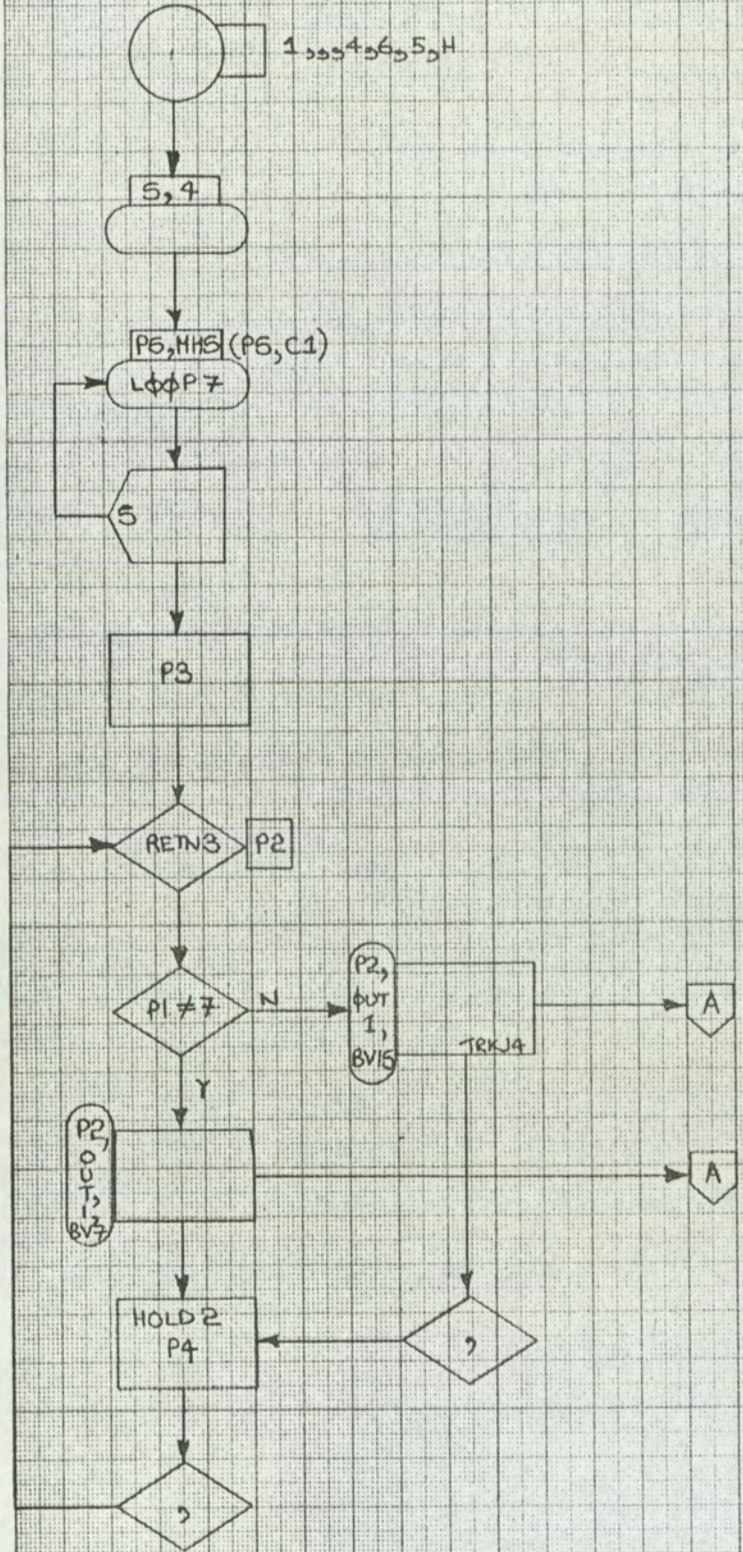
FLØWCHART NUMBER 5

FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION	SHEET
PREPARED BY M. Bennett.	DATE	PROGRAM No.	LØAD TØ THE TRACKS	1 OF 1



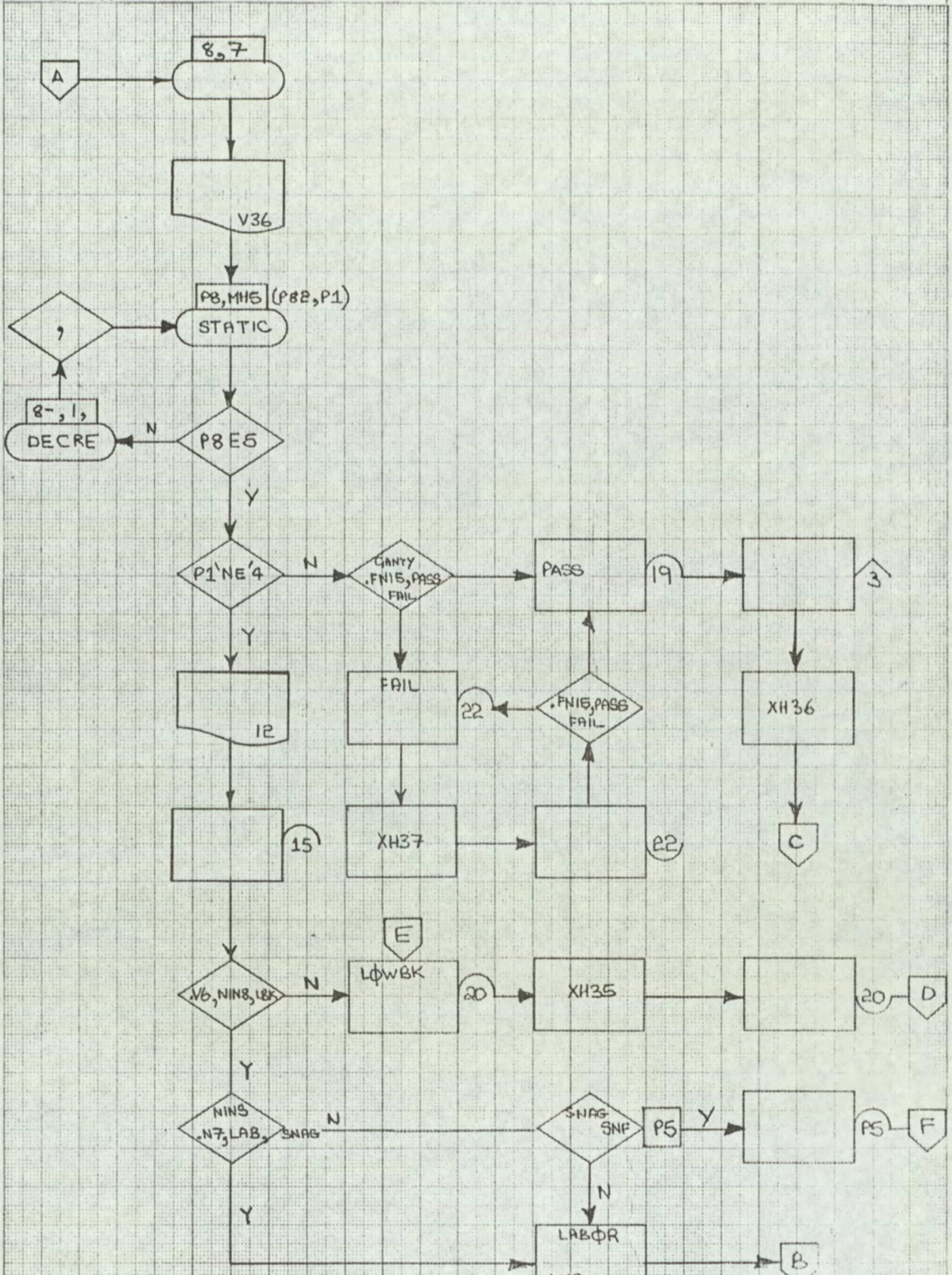
FLOWCHARTING WORKSHEET

PREPARED BY	DATE	PROJECT No. / PROGRAM No.	DESCRIPTION	SHEET
M. Bennett.			LØØP AND LØWBAKE	1 OF 3



FLØWCHART NUMBER 7

FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION	SHEET
PREPARED BY M. Bennett.	DATE	PROGRAM No.	LØØP AND LØWBAKE	2 OF 3



FLØWCHART NUMBER 7

FLOWCHARTING WORKSHEET

PROJECT No.

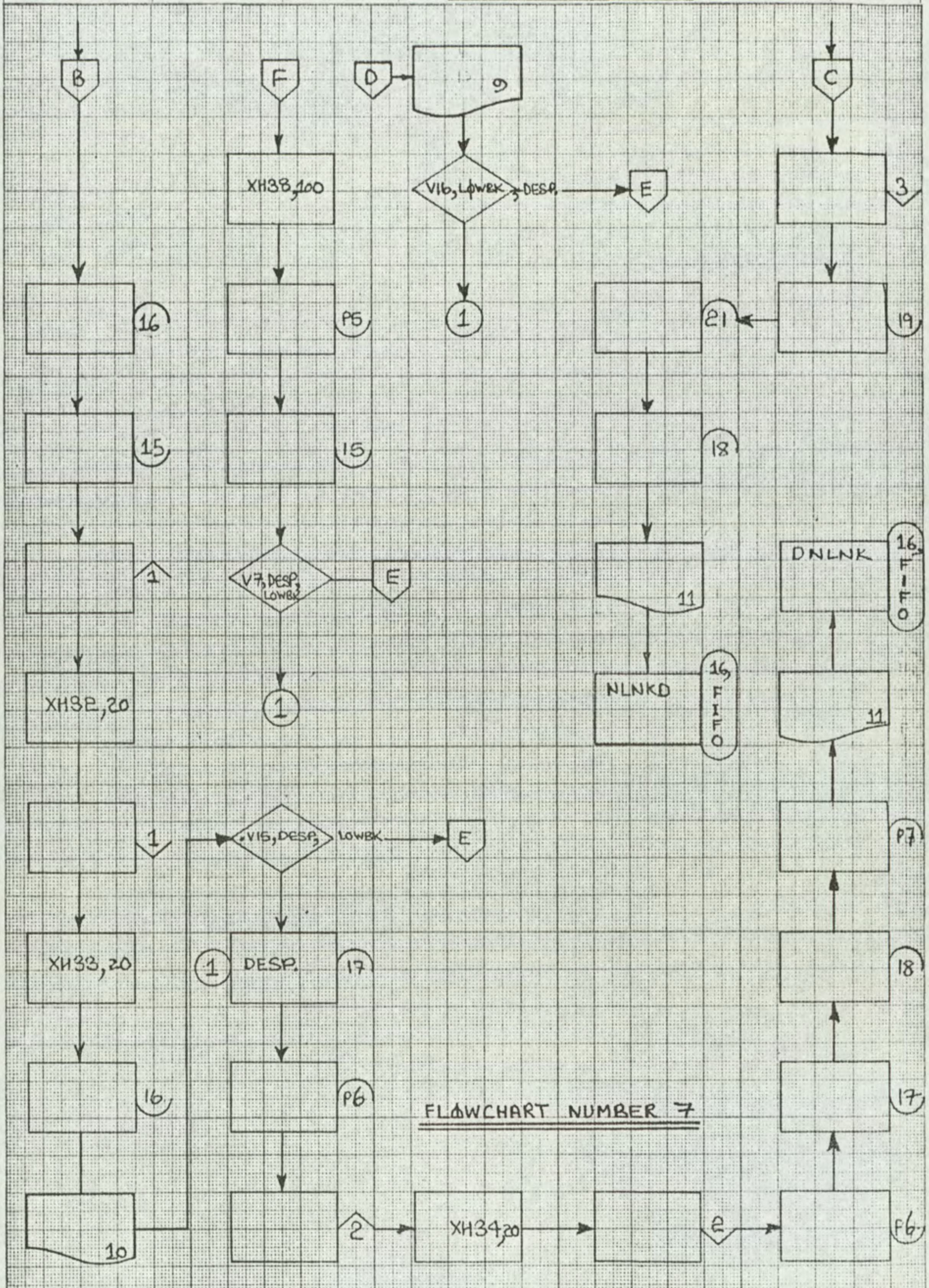
DESCRIPTION: LØØP AND LØWRAKE

SHEET 3 OF 3

PREPARED BY: M. Bennett

DATE

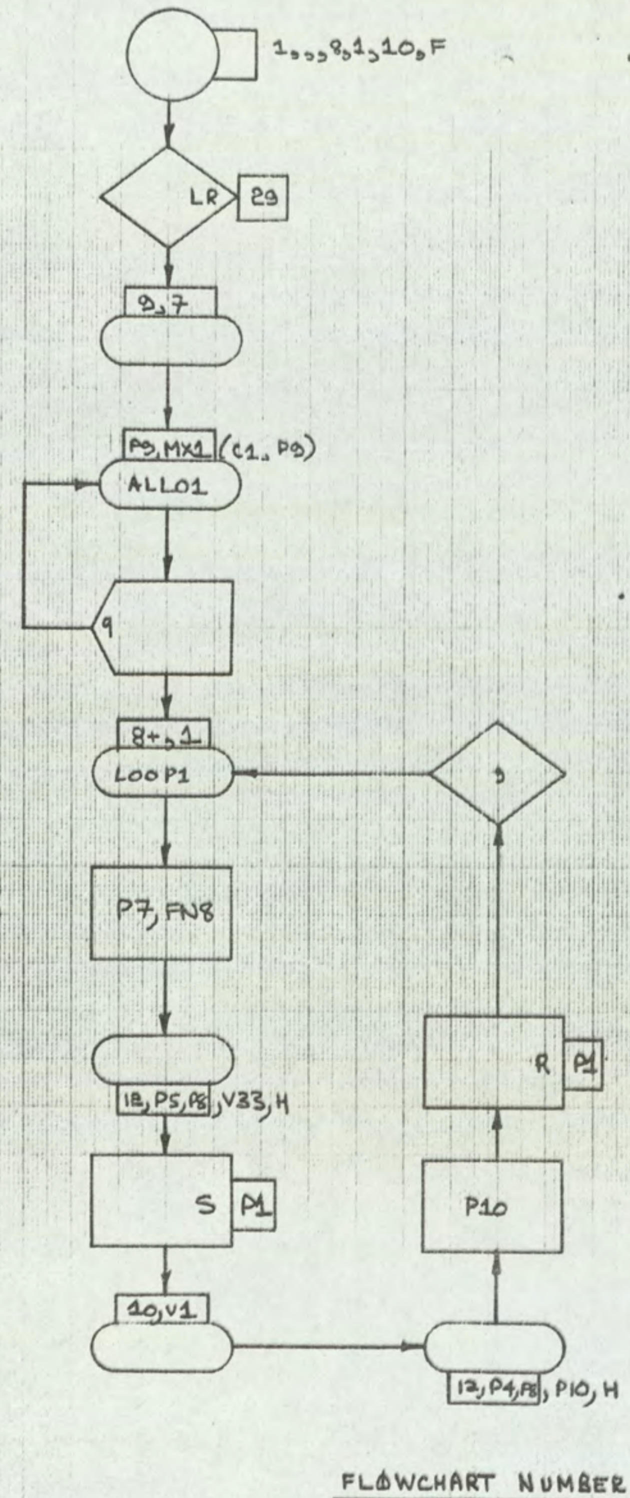
PROGRAM No.



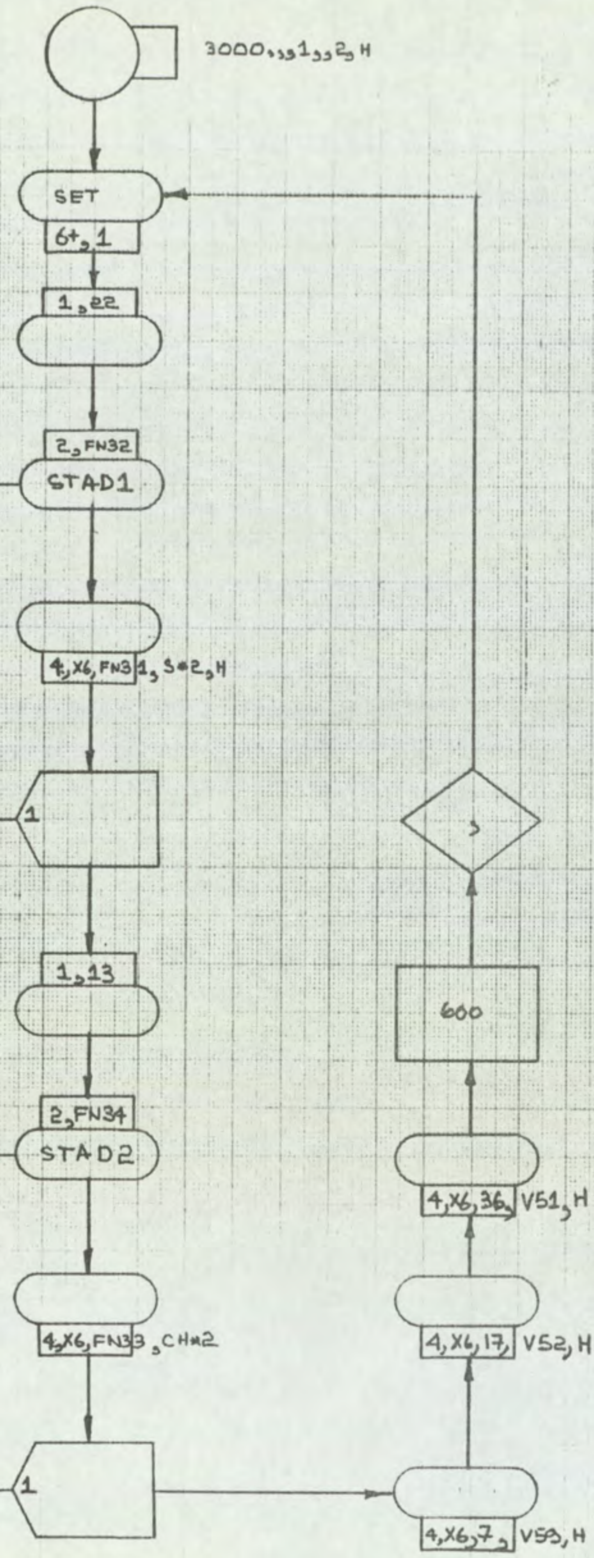
FLOWCHARTING WORKSHEET

PREPARED BY mBennett

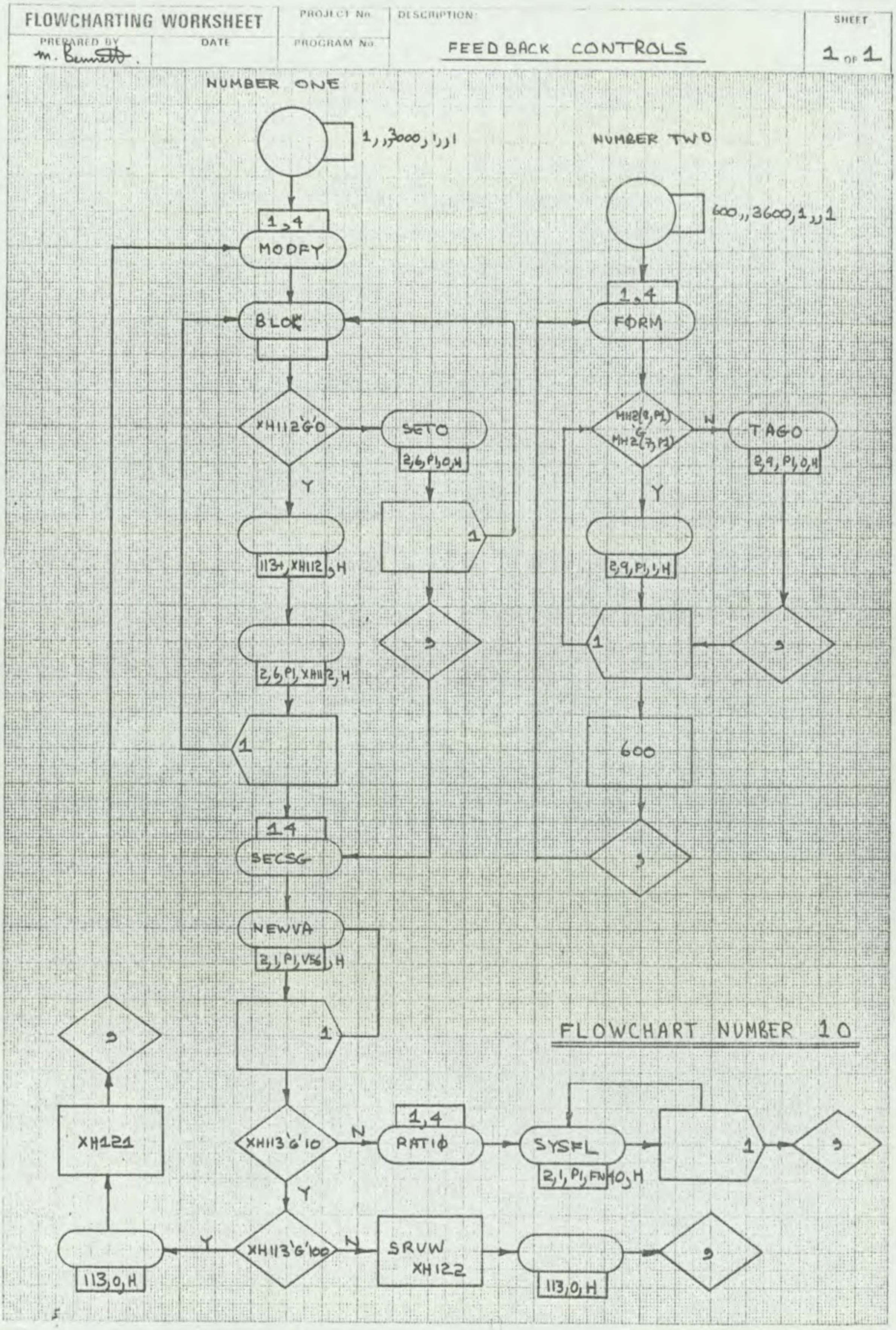
BREAKDOWN CONTROL



FLOWCHART NUMBER 8

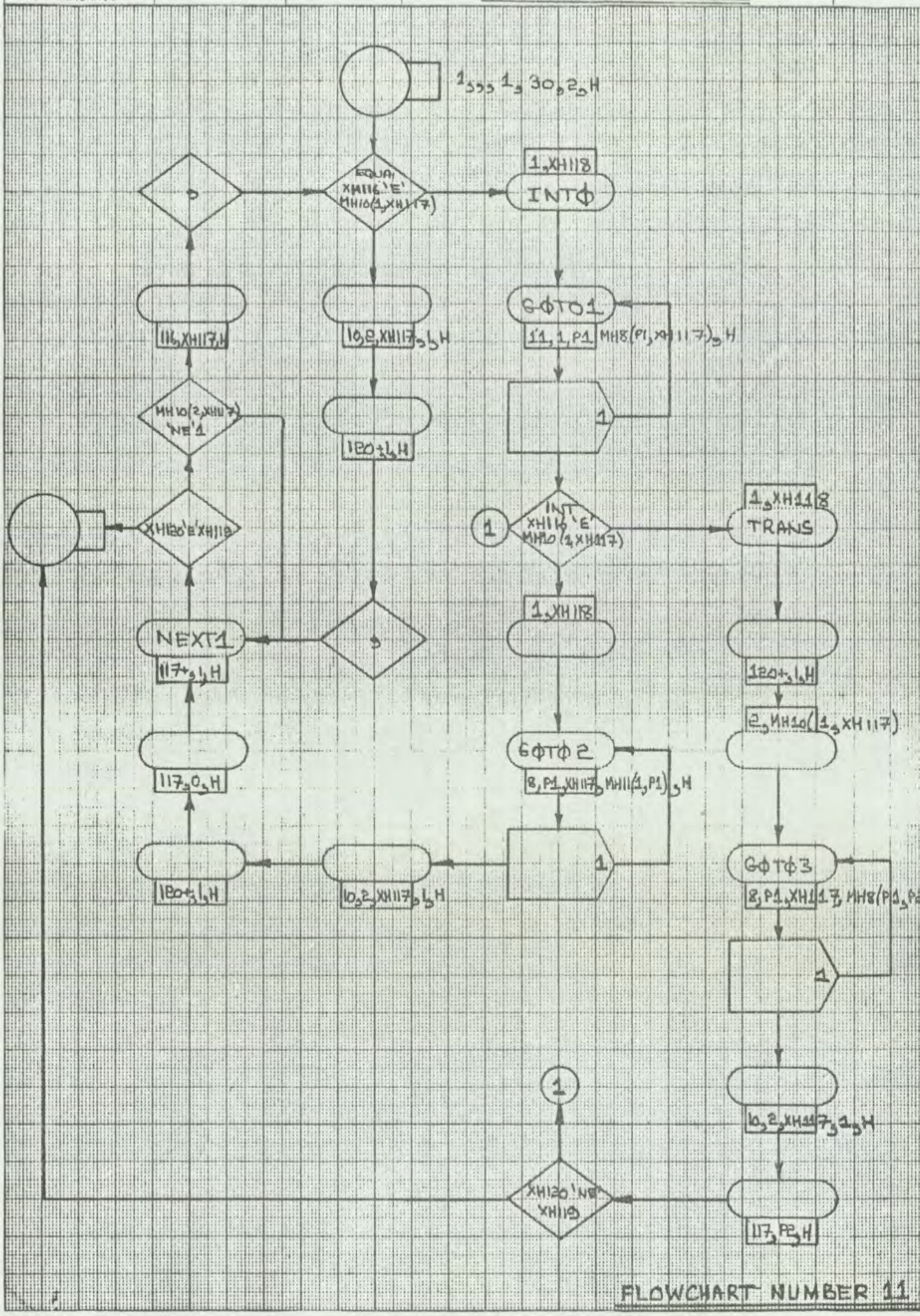


FLOWCHART NUMBER 9

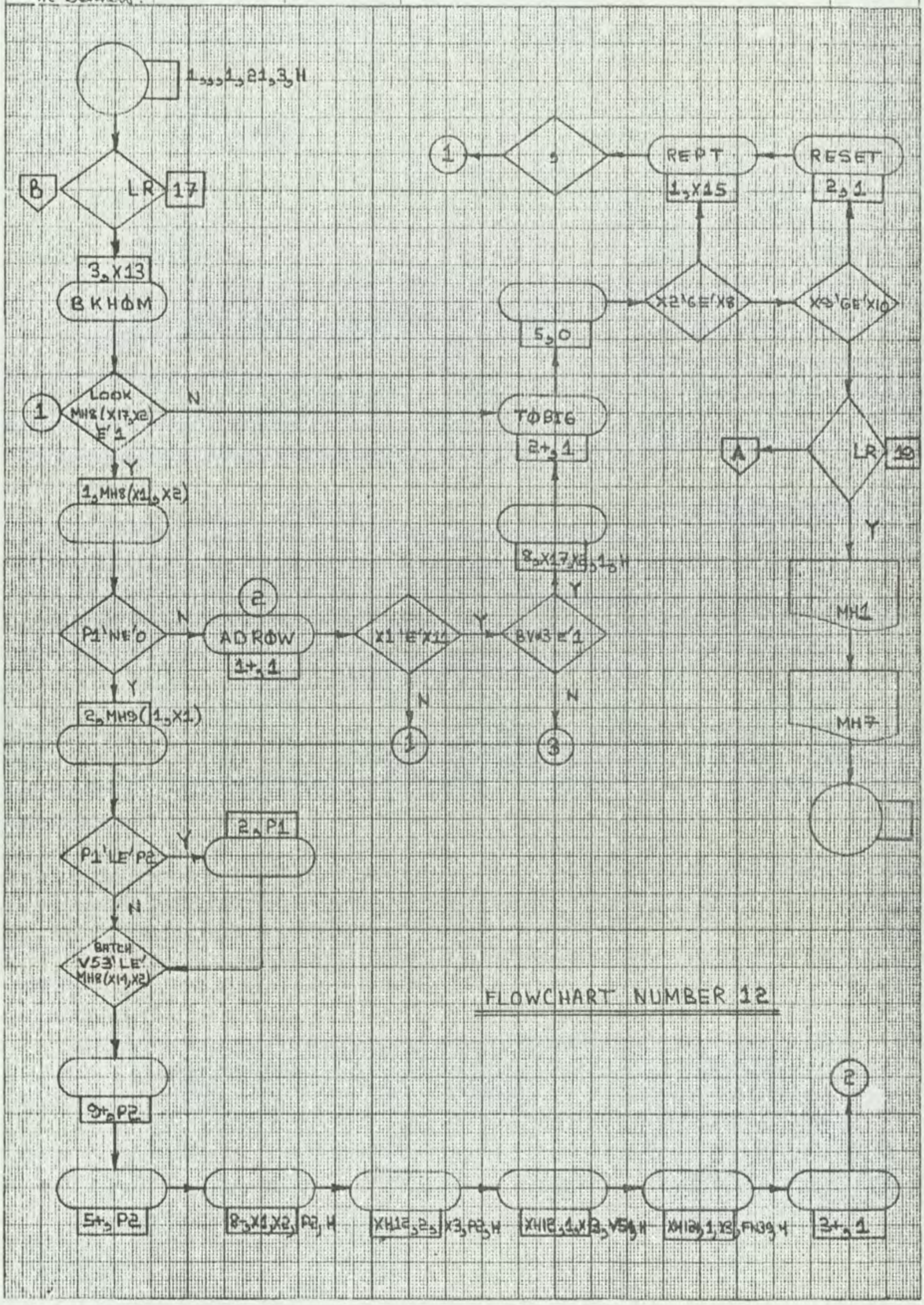


FLOWCHARTING WORKSHEET
PREPARED BY m. Bennett.
DATE
PROJECT No.
PROGRAM No.
DESCRIPTION:
FEEDBACK CONTROLS
SHEET 1 OF 1
NUMBER ONE
1,,3000,1,,1
1,4
MODFY
BLOK
XH112'G'0
SETO
2,6,P1,0,H
Y
113+,XH112,H
1
2,6,P1,XH112,H
1
14
SECSG
NEWVA
2,1,P1,V56,H
1
XH113'G'10
N
1,4
RATIO
SYSFL
2,1,P1,FN10,H
1
Y
XH113'G'100
Y
N
SRUW XH122
113,0,H
113,0,H
XH121
NUMBER TWO
600,,3600,1,,1
1,4
FORM
MH12(8,P1)'G'MH12(7,P1)
N
TAGO
2,9,P1,0,H
Y
2,9,P1,1,H
1
600
FLOWCHART NUMBER 10

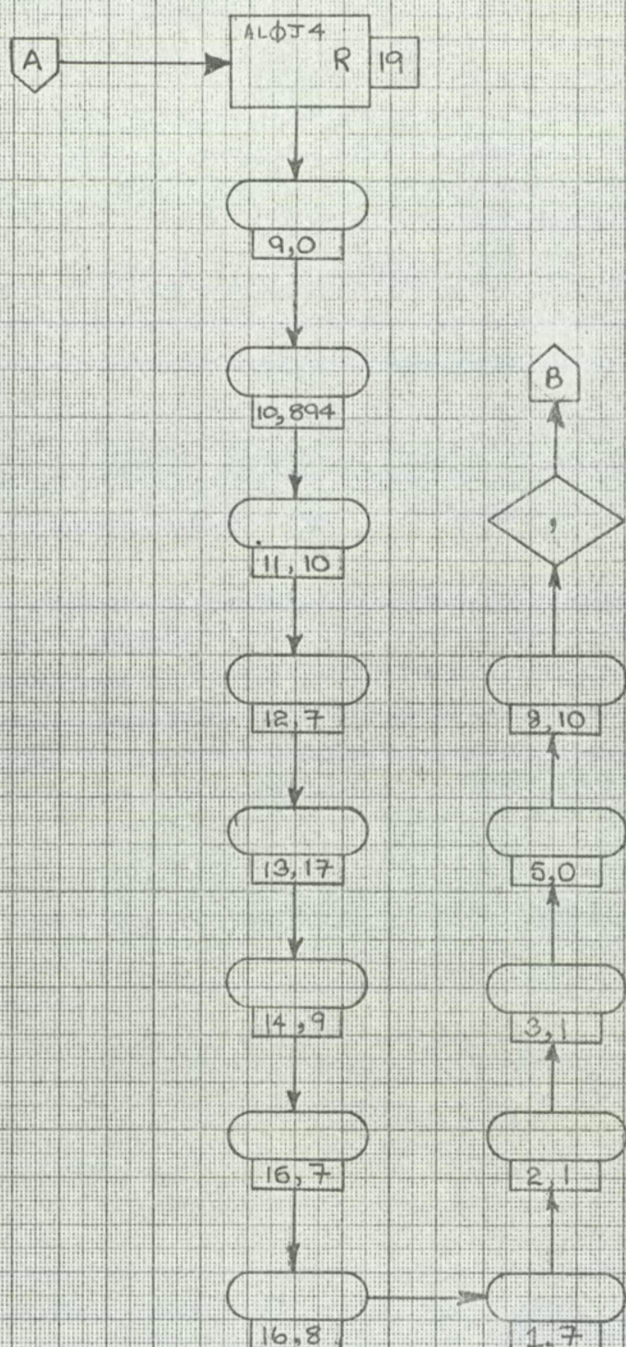
FLOWCHARTING WORKSHEET	PROJECT No.	DESCRIPTION:	SHEET
PREPARED BY: M. Bennett / DATE	PROGRAM No.	SEQUENCE CONTROL	1 OF 1



FLOWCHARTING WORKSHEET	PROJECT No.	DESCRIPTION	SHEET
PREPARED BY: M Bennett. DATE	PROGRAM No.	REORGANISATION CONTROL	1 of 2

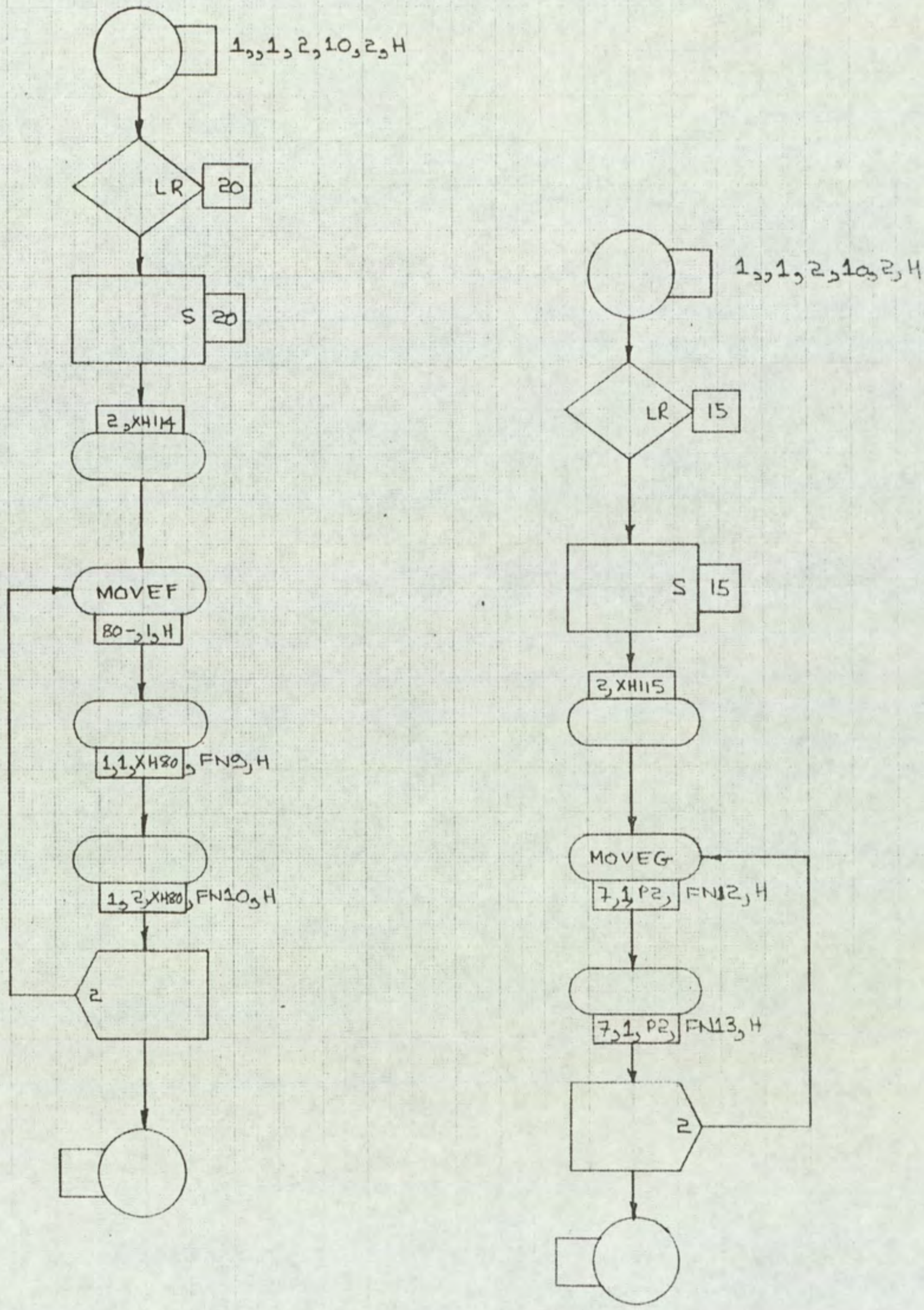


FLOWCHARTING WORKSHEET		PROJECT No.	DESCRIPTION	SHEET
PREPARED BY m Bennett	DATE	PROGRAM No.	REØRGANISATION CONTROL	2 OF 2



FLØWCHART NUMBER 12

FLOWCHARTING WORKSHEET	PROJECT No	DESCRIPTION	SHEET
PREPARED BY Bennett / DATE	PROGRAM No	TRANSFER CONTROL	1 of 1



FLOWCHART NUMBER 13

```
*
*
*
*                 LOAD TO THE ELECTROCOAT
*

                 GENERATE      20,,21,,,12,H
                 TEST E        BV1,1
                 ASSIGN        1,XH5
                 ASSIGN        8,MH2(2,P1)
                 ASSIGN        10,MH2(3,P1)
                 ASSIGN        7,V14
                 MSAVEVALUE    2+,4,P1,1,H
         NLNK1   LINK          1,FIFO
                 GENERATE      10,,19,1,2,1,H
         BACK1   ASSIGN        1,4
         LOOP2   SAVEVALUE     5,P1,H
                 GATE LR       1
                 TEST E        MH2(9,P1),0,GRAP1
                 ADVANCE       MH2(1,P1)
         ELLOP   LOOP          1,LOOP2
                 TRANSFER      ,BACK1
         GRAP1   ADVANCE       20
                 TRANSFER      ,ELLOP
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*
*                 LOAD TO THE NUMBER ONE PAINT PLANT
*

                GENERATE        2400,,,1,,0
        BACK2   TEST E          BV4,1,CYCTM
                UNLINK          15,RECYC,1,,,POINT
        CYCTM   ADVANCE         23
                TRANSFER        ,BACK2
        POINT   TEST E          MH1(2,XH44),0,NEW
                SAVEVALUE       44+,1,H
                TRANSFER        ,POINT
        NEW     SAVEVALUE       6,XH44,H
                SAVEVALUE       131,V2,H
        MODEL   SAVEVALUE       8,V2,H
                TEST NE         MH2(12,XH8),8,ADONE
                TEST E          BV4,1,CYCTM
                UNLINK          5,LOAD,1,1,XH8,CHA18
        COLOR   SAVEVALUE       9,V3,H
                TEST E          CH15,0,CYCTM
                ADVANCE         23
                TRANSFER        ,EMPTY
        CHA18   UNLINK          18,LEV13,1,1,XH8,MOVEM
                TRANSFER        ,COLOR
        MOVEM   TEST E          BV19,1,ADONE
                ADVANCE         50
                TRANSFER        ,BACK2
        LOAD    MSAVEVALUE      1-,2,XH6,1,H
                ASSIGN          2,XH9
                MSAVEVALUE      21,8,P1,1,H
        RECYC   ASSIGN          7,V14
                TEST E          P2,XH20,TAG8
        NLNK2   LINK            2,FIFO
        TAG8    ASSIGN          3,888
                SAVEVALUE       20,P2,H
                TRANSFER        ,NLNK2
        LEV13   LEAVE           13
                TRANSFER        ,LOAD
        ADONE   SAVEVALUE       6+,1,H
                TEST NE         XH6,V20,CYCTM
                TEST NE         XH8,V2, ADONE
        EMPTY   TEST NE         MH1(2,XH6),0,ADONE
                GATE LR         32,NEW
                TRANSFER        ,MODEL
        MAINS   ENTER           13
                LINK            18,FIFO
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*
*           LOAD TO LYSAUGHT PAINT PLANT
*

        GENERATE     2000,,,1,,0,H
TRY2    TEST E       BV9,1
        UNLINK       13,ONFOR,1,BV8,,PRIME
WAIT    ADVANCE      48
        TRANSFER     ,TRY2
PRIME   SAVEVALUE    46,XH45,H
COMPA   TEST E       XH46,V21,PARTR
PONT    TEST E       MH7(2,XH45),0,PRIME
        SAVEVALUE    45+,1,H
        TRANSFER     ,PONT
PARTR   TEST NE      MH7(2,XH46),0,ADUND
        SAVEVALUE    47,V18,H
        UNLINK       14,ONLYS,1,1,XH47,WAIT
        SAVEVALUE    48,V19,H
        TRANSFER     ,WAIT
ONLYS   MSAVEVALUE   7-,2,XH46,1,H
        ASSIGN       2,XH48
ONFOR   ASSIGN       7,V14
NLNK4   LINK         4,FIFO
ADUNO   SAVEVALUE    46+,1,H
        TEST E       XH46,V21,PARTR
        TEST GE      CH14,6,LFILL
        ADVANCE      40
        TRANSFER     ,PONT
LFILL   ADVANCE      60
        TRANSFER     ,PONT
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*
*                    LOAD TO THE NUMBER TWO PAINT PLANT
*

                GENERATE      2500,,,1,,0
        TRY1    TEST E        BV5,1
                UNLINK        6,ONTWO,1
                ADVANCE       23
                TRANSFER      ,TRY1
        ONTWO   LEAVE         14
                ASSIGN        7,V14
                LEAVE         13
        NLNK3   LINK          3,FIFO
        FIN14   TERMINATE


*
*
*       LOAD TO TRACKS
*

                GENERATE      1,,,4,,5,H
                ASSIGN        5,4
        LOOP5   ASSIGN        P5,MH6(C1,P5)
                LOOP          5,LOOP5
                TEST E        P1,4,ADSAL
                ADVANCE       3500
        RETN2   ADVANCE       P2
                TEST E        BV6,1,RETN2
             UNLINK           7,TRACK,1,1
                TRANSFER      ,RETN2
        TRACK   MSAVEVALUE    2-,4,P1,1,H
                TEST E        P10,9,NOTAS
                LEAVE         1
                TRANSFER      ,ALL
        ADSAL   ADVANCE       6000
                TRANSFER      ,RETN2
        NOTAS   LEAVE         V4
                TEST NE       P1,4,ALL
                LEAVE         13
        ALL     ASSIGN        6,V5
                ASSIGN        7,V9
        NLNKT   LINK          P6,FIFO
```

SIMULATION MODEL, PROGRAM LISTING

```
*              OFF LOAD CONTROL FOR THE PAINT PLANTS
*
               GENERATE        1,,,4,5,4,H
               ASSIGN          4,3
      LOOP6    ASSIGN          P4,MH3(P4,C1)
               LOOP            4,LOOP6
               ADVANCE         FN14
      TRY3     TEST E          P3,1,TEST1
      TURN1    LOGIC S         16
               UNLINK          1,OFLOD,1,,,ADV1
               GATE LR         16
      ADV1     ADVANCE         P1
               TRANSFER        ,TURN1
      OFLOD    TEST NE         P1,4,CKLYS
               TEST E          BV2,1,DELAY
      RES16    TEST E          MH2(9,P1),0,CLEAR
               LOGIC R         16
               GATE SNF        24,CLEAR
      STO24    ENTER           24
               MSAVEVALUE      2+,8,P1,1,H
               TABULATE        13
               ADVANCE         350
      LOOK3    TEST L          CH5,XH49,DELY
      LEAVS    LEAVE           24
               LINK            5,FIFO
      PR1      LOGIC S         32
               LINK            5,FIFO
      CKLYS    TEST E          BV21,1,HLLYS
               LOGIC R         16
               TRANSFER        ,GULP
      HLLYS    ADVANCE         20
               TRANSFER        ,CKLYS
      DELAY    ADVANCE         50
               GATE LR         26
               LOGIC S         26
               UNLINK          17,RES26,1,BV20,,DELCK
               SAVEVALUE       111+,1,H
               TEST E          XH111,5,DELAY
               SAVEVALUE       111,0,H
               ADVANCE         20
               TRANSFER        ,RES16
      RES26    LOGIC R         26
               TRANSFER        ,STO24
      DELCK    TEST E          CH17,0,DESNF
               LOGIC R         26
               TRANSFER        ,OFLOD
      DESNF    GATE SNF        24,REL26
               LOGIC R         26
               TRANSFER        ,OFLOD
      REL26    LOGIC R         26
               ADVANCE         100
               TRANSFER        ,OFLOD
      CLEAR    TEST L          CH17,50,POST
               LOGIC R         16
      LNK17    LINK            17,FIFO
      POST     ADVANCE         20
               UNLINK          17,STD24,1,BV20
               ADVANCE         10
               TRANSFER        ,CLEAR
      TEST1    TEST E          P3,2,TEST3
```

SIMULATION MODEL, PROGRAM LISTING

```
TURN2    LOGIC S      31
         UNLINK       2,NUMON,1,BV3,ADVAN
         GATE LR      31
         ADVANCE      P1
         TRANSFER     ,TURN2
NUMON    GATE SNF     13
         LOGIC R      31
         TEST E       P3,888,BATA1
         TRANSFER     .240,SIXTY,FORTY
FORTY    TABULATE     1
         ASSIGN       3,0
         LINK         15,FIFO
ADVAN    LOGIC R      31
         ADVANCE      P1
         TRANSFER     ,TURN2
SIXTY    ASSIGN       6,V17
TAB1     TABULATE     1
INSEC    ENTER        13
         ASSIGN       6,V57
         TRANSFER     .P6,STORE,REJEC
REJEC    ENTER        14
         LINK         6,FIFO
STORE    TABULATE     14
         TEST E       P1,1,TEST2
         ENTER        5
         TRANSFER     ,LINK1
TEST2    TEST E       P1,2,RILEY
         ENTER        6
         TRANSFER     ,LINK1
RILEY    ENTER        7
LINK1    LINK         7,FIFO
BATA1    ASSIGN       6,FN*1
         TRANSFER     ,TAB1
TEST3    TEST E       P3,3,LYSA
TURN3    UNLINK       4,NUMTW,1,BV11
         ADVANCE      P1
         TRANSFER     ,TURN3
LYSA     UNLINK       4,LYSAT,1,BV12
         ADVANCE      P1
         TRANSFER     ,LYSA
NUMTW    ASSIGN       7,V4
         TABULATE     2
         ASSIGN       6,FN*7
         TRANSFER,    INSEC
LYSAT    TABULATE     3
         ASSIGN       8,FN*1
         TRANSFER     .P8,OKAY,BAD
BAD      ASSIGN       7,V14
         LINK         13,FIFO
OKAY     GATE SNF     P10,ADSTO
         TEST E       P1,3,EIGHT
         ENTER        13
         ENTER        7
         TRANSFER     ,LINK7
EIGHT    ENTER        8
         TRANSFER     ,LINK7
ADSTO    ENTER        1
         ASSIGN       10,9
LINK7    LINK         7,FIFO
DELY     TEST L       S13,30,WAT14
```

```
         UNLINK       5,MAINS,1
         ADVANCE      20
         TRANSFER     ,LOOK3
WAT13    ADVANCE      50
         TRANSFER     ,LOOK3
GULP     ENTER        23
         TABULATE     8
      ADVANCE         250
LOOK2    TEST L       CH14,6,DLAY
         LEAVE        23
         LINK         14, FIFO
DLAY     ADVANCE      50
         TRANSFER     ,LOOK2
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*      OFF LOAD FROM THE TRACK
*

              GENERATE     1,,,4,6,5,H
              ASSIGN       5,4
LOOP7         ASSIGN       P5,MH5(P5,C1)
              LOOP         5,LOOP7
              ADVANCE      P3
RETN3         GATE LR      P2
              TEST NE      P1,7,TRKJ4
              UNLINK       P2,OUT,1,BV7
HOLD2         ADVANCE      P4
              TRANSFER     ,RETN3
TRKJ4         UNLINK       P2,OUT,1,BV15
              TRANSFER     ,HOLD2
OUT           ASSIGN       8,7
              TABULATE     V36
STATC         ASSIGN       P8,MH5(P8,P1)
              TEST E       P8,5,DECRE
              TEST NE      P1,4,GANTY
              TABULATE     12
              ENTER        15
              TRANSFER     .V6,NINS,LEA15
NINS          TRANSFER     .V7,LABOR,SNAG
LABOR         ADVANCE      XH31,15
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*       THE LOOP LINE
*

        NLOOP   ENTER      16
                LEAVE      15
                SEIZE      1
                ADVANCE    XH32,20
                RELEASE    1
                ADVANCE    XH33,20
                LEAVE      16
                TABULATE   10
                TRANSFER   .V15,DESP,LOWBK
        DESP    ENTER      17
                ENTER      P6
                SEIZE      2
                ADVANCE    XH34,20
                RELEASE    2
                LEAVE      P6
                LEAVE      17
                ENTER      18
                ENTER      P7
                TABULATE   11
        DNLNK   LINK       16,FIFO
        SNAG    GATE SNF   P5,LABOR
                ENTER      P5
                ADVANCE    XH38,100
                LEAVE      P5
                LEAVE      15
                TRANSFER   .V7,DESP,LOWBK
                TRANSFER   ,DESP
        DECRE   ASSIGN     8-,1
                TRANSFER   ,STATC
        GANTY   TRANSFER   .FN15,PASS,FAIL
        PASS    ENTER      19
                SEIZE      3
                ADVANCE    XH36
                RELEASE    3
                LEAVE      19
                ENTER      21
                ENTER      18
                TABULATE   11
        NLNKD   LINK       16,FIFO
        FAIL    ENTER      22
                ADVANCE    XH37
                LEAVE      22
                TRANSFER   .FN15,PASS,FAIL
        LEA15   LEAVE      15
        LOWBK   ENTER      20
                ADVANCE    XH35
                LEAVE      20
                TABULATE   9
                TRANSFER   .V16,DESP,LOWBK
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*       DESPATCH MODULE
*

        GENERATE      12000,,,1,,4
        ASSIGN        1,4
        ASSIGN        2,2
        ASSIGN        3,1
FORP3   ASSIGN        4,3
LORRY   UNLINK        16,CHOWS,P*4,1,P4
        LOOP          4,LORRY
        ADVANCE       300
        TRANSFER      ,FORP3
CHOWS   LEAVE         V35
        LEAVE         18
        TERMINATE
        GENERATE      12100,,,1,,4
CLANE   UNLINK        16,CHOWC,3,1,4
        ADVANCE       400,200
        TRANSFER      ,CLANE
CHOWC   LEAVE         21
        LEAVE         18
        TERMINATE

*
*
*
*
*
*
*       NIGHT SHIFT CONTROL
*

        GENERATE      1800,,,1,,0
SLND1   GATE LR       28,FINI4
        MSAVEVALUE    2,12,3,0,H
        ADVANCE       7800
        MSAVEVALUE    2,12,3,8,H
        ADVANCE       3000
        TRANSFER      ,SLND1
        GENERATE      100,,,1,,0
        GATE LR       28,FINI4
NIGHT   MSAVEVALUE    2,11,3,9,H
        ADVANCE       6000
        MSAVEVALUE    2,11,3,0,H
        ADVANCE       4800
        TRANSFER      ,NIGHT
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*     OVERALL FEEDBACK MODULE
*

              GENERATE        1,,3000,1,,1
      MODFY   ASSIGN          1,4
      BLOK    SAVEVALUE       112,V55,H
              TEST G          XH112,0,SETO
              SAVEVALUE       113+,XH112,H
              MSAVEVALUE      2,6,P1,XH112,H
              LOOP            1,BLOK
      SECSG   ASSIGN          1,4
      NEWVA   MSAVEVALUE      2,1,P1,V56,H
              LOOP            1,NEWVA
              TEST G          XH113,10,RATIO
              TEST G          XH113,100,SRVW
              SAVEVALUE       113,0,H
              ADVANCE         XH121
              TRANSFER        ,MODFY
      SETO    MSAVEVALUE      2,6,P1,0,H
              LOOP            1,BLOK
              TRANSFER        ,SECSG
      SRVW    ADVANCE         XH122
              SAVEVALUE       113,0,H
              TRANSFER        ,MODFY
      RATIO   ASSIGN          1,4
      SYSFL   MSAVEVALUE      2,1,P1,FN40,H
              LOOP            1,SYSFL
              TRANSFER        ,SRVW


*
*
*     LIMITED FEEDBACK MODULE
*

              GENERATE        600,,3600,1,,1
      FORM    ASSIGN          1,4
      FMAN    TEST G          MH2(8,P1),MH2(7,P1),TAGO
              MSAVEVALUE      2,9,P1,1,H
      LPCHK   LOOP            1,FMAN
              ADVANCE         600
              TRANSFER        ,FORM
      TAGO    MSAVEVALUE      2,9,P1,0,H
              TRANSFER        ,LPCHK
```

SIMULATION MODEL, PROGRAM LISTING

```
*       SEQUENCE CONTROL MODULE
*
*

                GENERATE        1,,,1,30,2,H
                GATE LR         30,FINI4
        EQUAL   TEST E          XH116,MH10(1,XH117),INTO
                MSAVEVALUE      10,2,XH117,1,H
                SAVEVALUE       120+,1,H
                TRANSFER        ,NEXT1
        INTO    ASSIGN          1,XH118
        GOTO1   MSAVEVALUE      11,1,P1,MH8(P1,XH117),H
                LOOP            1,GOTO1
        INT     TEST E          XH116,MH10(1,XH117),TRANS
                ASSIGN          1,XH118
        GOTO2   MSAVEVALUE      8,P1,XH117,MH11(1,P1),4
                LOOP            1,GOTO2
                MSAVEVALUE      10,2,XH117,1,H
                SAVEVALUE       120+,1,H
                SAVEVALUE       117,0,H
        NEXT1   SAVEVALUE       117+,1,H
                TEST NE         XH120,XH119,FINI4
                TEST NE         MH10(2,XH117),1,NEXT1
                SAVEVALUE       116,XH117,H
                TRANSFER        ,EQUAL
        TRANS   ASSIGN          1,XH118
                SAVEVALUE       120+,1,H
                ASSIGN          2,MH10(1,XH117)
        GOTO3   MSAVEVALUE      8,P1,XH117,MH8(P1,P2),H
                LOOP            1,GOTO3
                MSAVEVALUE      10,2,XH117,1,H
                SAVEVALUE       117,P2,H
                TEST NE         XH120,XH119,FINI4
                TRANSFER        ,INT

                GENERATE        30000,,,1,,0
                GATE LR         18,FINI4
        SAFE    TEST GE         XH6,500,EDGE
                SAVEVALUE       6,1,H
                SAVEVALUE       44,1,H
                SAVEVALUE       80,174,H
                ASSIGN          2,XH114
                TRANSFER        ,MOVEF
        EDGE    ADVANCE         600
                TRANSFER        ,SAFE
                START           1
                SAVE
                JOB
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*     REORGANISATION MODULE
*

               GENERATE        1,,,1,21,3,H
               GATE LR         17
      BKHOM    ASSIGN          3,X13
      LOOK     TEST NE         MH8(X17,X2),1,TOBIG
               ASSIGN          1,MH8(X1,X2)
               TEST NE         P1,0,ADROW
               ASSIGN          2,MH9(1,X1)
               TEST LE         P1,P2,BATCH
               ASSIGN          2,P1
      BATCH    TEST LE         V53,MH8(X14,X2),TOBIG
               SAVEVALUE       9+,P2
               SAVEVALUE       5+,P2
               MSAVEVALUE      8-,X1,X2,P2,H
               MSAVEVALUE      X12,2,X3,P2,H
               MSAVEVALUE      X12,1,X3,V54,H
               MSAVEVALUE      X12+,1,X3,FN39,H
               SAVEVALUE       3+,1
               TRANSFER        ,ADROW
      ADROW    SAVEVALUE       1+,1
               TEST E          X1,X11,LOOK
               TEST E          BV*3,1,REPT
               MSAVEVALUE      8,X17,X2,1,H
      TOBIG    SAVEVALUE       2+,1
               SAVEVALUE       5,0
               TEST GE         X2,X8,REPT
               TEST GE         X9,X10,RESET
               GATE LR         19,ALOJ4
               PRINT           1,1,MH
               PRINT           7,7,MH
               TERMINATE
      RESET    SAVEVALUE       2,1
      REPT     SAVEVALUE       1,X15
               TRANSFER        ,LOOK
      ALOJ4    LOGIC R         19
               SAVEVALUE       9,0
               SAVEVALUE       10,894
               SAVEVALUE       11,9
               SAVEVALUE       12,7
               SAVEVALUE       13,17
               SAVEVALUE       14,9
               SAVEVALUE       15,7
               SAVEVALUE       16,8
               SAVEVALUE       1,7
               SAVEVALUE       2,1
               SAVEVALUE       3,1
               SAVEVALUE       5,0
               SAVEVALUE       8,10
               TRANSFER        ,BKHOM
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*       PERFORMANCE RECORDER
*

                GENERATE        18000,,,1,,2,H
        SET     SAVEVALUE       6+,1
                ASSIGN          1,22
        STAD1   ASSIGN          2,FN32
                MSAVEVALUE      4,X6,FN31,S*2,H
                LOOP            1,STAD1
                ASSIGN          1,13
        STAD2   ASSIGN          2,FN34
                MSAVEVALUE      4,X6,FN33,CH*2,H
                LOOP            1,STAD2
                MSAVEVALUE      4,X6,7,V59,H
                MSAVEVALUE      4,X6,17,V52,H
                MSAVEVALUE      4,X6,36,V51,H
                ADVANCE         600
                TRANSFER        ,SET
```

```
*
*
*        OUTPUT EDITOR MODULE
*

                    GENERATE      X30,,X29,,,0
                    SAVEVALUE     41,V37,H
                    SAVEVALUE     2,V33,H
                    SAVEVALUE     7,V22,H
                    SAVEVALUE     16,V30,H
                    SAVEVALUE     17,V23,H
                    SAVEVALUE     18,V31,H
                    SAVEVALUE     19,V24,H
                    SAVEVALUE     26,V26,H
                    SAVEVALUE     27,V25,H
                    SAVEVALUE     29,V32,H
                    SAVEVALUE     30,V27,H
                    SAVEVALUE     40,V28,H
                    SAVEVALUE     42,V29,H
                    SAVEVALUE     51,V38,H
                    SAVEVALUE     67,V41,H
                    SAVEVALUE     68,V42,H
                    SAVEVALUE     69,V43,H
                    SAVEVALUE     70,V44,H
                    SAVEVALUE     71,V45,H
                    SAVEVALUE     72,V46,H
                    SAVEVALUE     73,V47,H
                    SAVEVALUE     74,V48,H
                    SAVEVALUE     75,V49,H
                    SAVEVALUE     76,V50,H
                    SAVEVALUE     78,V40,H
                    SAVEVALUE     100,V58,H
                    SAVEVALUE     102,N£NLNK1,H
                    SAVEVALUE     103,N£NLNK2,H
                    SAVEVALUE     104,N£NLNK3,H
                    SAVEVALUE     105,N£NLNK4,H
                    SAVEVALUE     106,N£NLNKT,H
                    SAVEVALUE     107,N£LOWBK,H
                    SAVEVALUE     108,V39,H
                    LOGIC R       17
                    LOGIC R       23
                    LOGIC R       15
                    LOGIC R       20
                    GATE LR       21,RESAT
                    TERMINATE     1
          RESAT     SAVEVALUE     4,C1
                    SAVEVALUE     4,V34,H
                    SAVEVALUE     52,CH5,H
                    SAVEVALUE     53,S24,H
                    SAVEVALUE     77,CH1,H
                    SAVEVALUE     79,CH14,H
                    SAVEVALUE     81,CH2,H
                    SAVEVALUE     82,CH3,H
                    SAVEVALUE     83,CH4,H
                    SAVEVALUE     84,CH13,H
                    SAVEVALUE     87,S13,H
                    SAVEVALUE     88,S1,H
                    SAVEVALUE     89,S8,H
                    SAVEVALUE     90,CH9,H
                    SAVEVALUE     91,CH10,H
                    SAVEVALUE     92,CH11,H
```

```
        SAVEVALUE    93,CH12,H
        SAVEVALUE    109,S23,H
        LOGIC R      21
FINI    TERMINATE    1
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*
*      TRANSFER FROM FUNCTION TO MATRIX
*
              GENERATE      1,,1,2,10,2,H
              GATE LR       20
              LOGIC S       20
              ASSIGN        2,XH114
       MOVEF  SAVEVALUE     80-,1,H
              MSAVEVALUE    1,1,XH80,FN9,H
              MSAVEVALUE    1,2,XH80,FN10,H
              LOOP          2,MOVEF
              TERMINATE
*
*
*



*      TRANSFER FROM FUNCTION TO MATRIX
*
              GENERATE      1,,1,2,10,2,H
              GATE LR       15
              LOGIC S       15
              ASSIGN        2,XH115
       MOVEG  MSAVEVALUE    7,2,P2,FN12,H
              MSAVEVALUE    7,2,P2,FN13,H
              LOOP          2,MOVEG
              TERMINATE
```

SIMULATION MODEL, PROGRAM LISTING

```
*
*
*
*       BREAKDOWN CONTROL FOR THE PAINT PLANTS AND THE TRIM TRACKS
*

                 GENERATE        1,,,8,1,10,F
                 ASSIGN          9,7
        ALLO1    ASSIGN          P9,MX1(C1,P9)
                 LOOP            9,ALLO1
        LOOP1    ASSIGN          8+,1
                 GATE LR         29,FIN14
                 ADVANCE         P7,FN8
                 MSAVEVALUE      FN16,P5,P8,V33,H
                 LOGIC S         P1
                 ASSIGN          10,V1
                 MSAVEVALUE      FN16,P4,P8,P10,H
                 ADVANCE         P10
                 LOGIC R         P1
                 TRANSFER        ,LOOP1

*
*
*
```

REGISTER OF VARIABLE STATEMENTS

REALLOCATED VALUE = 60

NUMBER	USE IN MODEL
1	P6 * FN8 Calculates the negative exponential delay used in the breakdown module.
2	MH1 (1, XH6) @ 10. Calculates the Model Code.
3	MH1 (1, XH6)/10 Calculates the Colour Code.
4	P1 + 4 Indexes P1 by 4
5	P1 + 8 Indexes P1 by 8.
6	FN19 + FN20 * FN21/100 Calculates the normal distribution for tracks to lowbake.
7	FN22 + FN23 * FN21/100 Calculates the normal distribution for snagging.
8	X2 * 10 Enters colour code to MH1.
9	(C1 + MH5 (3, P1) + X4)/10 Calculates the minimum off load time for finishing track.
10	(C1 + X4)/10-P7 Calculates the minimum off load time for paint plants.
11	P7 + 12 Index control.
12	X5 + P1 Row Pointer to MH8.
13	CC9 + CC10 + CC11 + CC12 Total contents of the finishing tracks.
14	(C1 + X4)/10 Calculates absolute time.
15	FN24 + FN25 * FN21/100 Calculates the Normal Distribution loop to lowbake.
16	FN26 + FN27 * FN21/100 Calculates the Normal Distribution lowbake to lowbake.
17	FN11 * FN*1 Loading factor for batches of 1.
18	MH7 (1, XH46) @ 10 Calculates the Model Code.

19 MH7 (1, XH46)/10
Calculates the Colour Code.

20 XH44 + 50
Determines the span of examination of MH1.

21 XH45 + 9
Determines the span of examination of MH7.

22 CA1 * 1000/XH54
Calculates utilisation of electrocoat paint plant.

23 CA2 * 1000/XH55
Calculates utilisation of No. 1 paint plant.

24 CA3 * 1000/XH56
Calculates utilisation of No. 2 rectification plant.

25 CA4 * 1000/XH57
Calculates utilisation of Lysaught paint plant.

26 CA9 * 1000/XH58
Calculates utilisation of Type A saloon finishing track.

27 CA10 * 1000/XH59
Calculates utilisation of Type B saloon finishing track.

28 CA11 * 1000/XH60
Calculates utilisation of Type C saloon finishing track.

29 CA12 * 1000/XH61
Calculates utilisation of large commercial finishing track.

30 (CA5 + SA24) * 1000/(XH62 + XH63)
Calculates utilisation of area prior to No. 1 paint plant.

31 (CA14 + SA23) * 1000/(XH49 + XH50)
Calculates utilisation of area prior to Lysaught paint plant.

32 CA6 * 1000/XH64
Calculates utilisation of reject area prior to No. 2.

33 C1/60
Calculates clock time in tenths of an hour.

34 X4/60
Calculates reset time in tenths of an hour.

35 P1 + 27.
Increment control on P1.

36 P1 + 3
Increment control on P1 references off-load rate tables.

37 CA13 * 1000/XH65
Calculates the utilisation of large commercial reject area.

38 CA5 * 1000/XH49
Calculates the utilisation of assembly area prior to No. 1.

39 N £ DNLNK + N £ NLNKD
Calculates number of bodies released for despatch.

40 CA14 * 1000/XH62
Calculates utilisation of assembly area prior to Lysaught.

41 (TB8 + TB13) * 10000/300
Calculates the efficiency of electrocoat.

42 TB1 * 10000/258
Calculates the efficiency of No. 1.

43 TB2 * 10000/238
Calculates the efficiency of No. 2.

44 TB3 * 10000/125
Calculates the efficiency of Lysaught.

45 TB 10 * 10000/75
Calculates the efficiency of loop line.

46 TB9 * 10000/200
Calculates efficiency of lowbake.

47 TB4 * 1000/125
Calculates efficiency of AD015 track.

48 TB5 * 10000/59
Calculates efficiency of AD016 track.

49 TB6 * 10000/38
Calculates efficiency of W/R track.

50 TB7 * 10000/44
Calculates efficiency of J4 track.

51 CH1 + CH2 + CH3 + CH4 + CH5 + CH14 + V52 + V59 + S1
+ S8 + S15 + S16 + V60
Total contents of major chains.

52 CH9 + CH10 + CH11 + CH12
Total contents of major store areas.

53 X5 + P2
Increment on X5 used in REORG.

54 MH8 (1, X2) * 10
Enters colour code into load matrix.

55 MH2 (5, P1) - MH2 (4, P1)
Calculates difference in actual and desired system stock.

56 MH2 (6, P1) * 300/XH113
Alters time control depending on system stock position.

57 P6 + P6 * FN21/300
Calculates a normal distribution.

58 CA17 * 1000/50
Calculates the utilisation of the unofficial storage area.

59 S5 + S6 + S7
Calculates contents of stores prior to tracks.

60 S17 + S18 + S19 + S20 + S23 + S24 + CH18 + CH6
Calculates contents of auxiliary areas.

REGISTER OF BOOLEAN VARIABLES

REALLOCATED VALUE = 26

NUMBER USE IN THE MODEL

1 LR1 * CH1 'L' 92 * (SNF24 * SNF23 + CH17 'L' 50).
Controls the load to the Electrocoat paint plant.

2 LR1 * 186 'LE' V10 * (SNF24 + CH17 'L' 50).
Controls the off-load from the Electrocoat for saloons.

3 312 'LE' V10 * LR2
Controls the off-load from No. 1 colour paint plant.

4 LR2 * CH2 'L' 135 * (CH5 'G' O + CH18 'G' O + CH15 'G' O) * LR31
Controls the load to the No. 1 colour paint plant.

5 LR3 * CH3 'L' 34
Controls the load to the No. 2 paint plant.

6 CH * 3 'L' P4 * LR * 3*MH2 (11, P1) 'NE' 9.
Controls the load to the finishing tracks.

7 P7 'LE' V14 * SNF15 * MH2 (11, P1) 'NE' 9.
Controls the off load from the finishing tracks.

8 V11 'LE' C1 * LR4
Controls the load to the Lysaught paint plant of rejects.

9 LR 4 * CH4 'L' 20 * (CH14 'G' O + CH13 'G' O)
Controls the load to the Lysaught paint plant.

10 MH8 (1, X2) 'E' O * MH8 (2, X2) 'E' O * MH8 (3, X 2) 'E' O
Tests that order bank for a particular colour is empty.

11 81 'LE' V10 * LR3 * SNF13
Controls the off load from the No. 2 paint plant.

12 96 'LE' V10 * LR4 * (SNF1 + SNF * 10)
Controls the off-load from the Lysaught paint plant.

14 P2 'NE' XH20
Tests for a colour change.

15 P7 'LE' V14 * SNF 19

16 MH8 (2, X2) 'E' O * MH8 (3, X2) 'E' O
Check on the state of the order bank.

17 MH8 (7, X2) 'E' 0 * MH8 (8, X2) 'E' 0

Check on the state of the order bank.

18 MH8 (4, X2) 'E' 0 * MH8 (2, X2) 'E' 0 * MH8 (3, x 2)'E' 0

Check on the state of the order bank.

19 CH5 'E' 0 * CH18 'E' 0

Test if a primed vehicle has arrived.

20 SNF 24 * MH2 (9, P1) 'NE' 1

Control on re-entry of vehicle from unofficial store.

21 LR1 * V10 'LE' V14 * SNF23

Controls commercial vehicle off load from Electrocoat.

REGISTER OF HALFWORD SAVEVALUES

REALLOCATED VALUE = 130.

NUMBER	USE IN THE MODEL	INITIAL VALUE
1	Used in the Output Editor to indicate run number.	Dependant on model.
2	Holds the simulated hours for which the model ran in one tenths of an hour for transfer to the Output Editor.	0
5	Contains the model code of the next body shell to be loaded to the electrocoat.	0
6	Used as a column pointer for selecting vehicles from matrix (H) 1. XH44 is kept as the overall pointer.	1
7	Holds the utilisation of the Electrocoat plant for transfer to the Output Editor.	0
8	This is used as a hold area for the model code in order that a match can be made between demand and supply on the No. 1. paint plant.	0
9	Used to transfer the colour code to the transaction being loaded once a match has been established. Load to No. 1.	0
16	Stores the utilisation of the No. 1 paint plant.	0
17	Stores the utilisation of the No. 1 paint plant.	0
18	Utilisation of the fixed area for primed commercials prior to the Lysaught paint plant.	0
19	Utilisation of the No. 2 rectification paint plant.	0
20	Holds the colour code of the last vehicle loaded to the No. 1 paint plant.	0
21	Holds the No. of the column from MH8 which is being held in MH11. Used in SEQUE.	0
22	Holds the pointer to MH8. Used in SEQUE.	0
23	Holds the No. of rows in MH8 that are to be transferred. Used in SEQUE.	Dependant on model.

24	Holds the No. of columns in MH8. Used in SEQUE.	Dependant on model.
25	Holds a counter. Used in SEQUE.	0
26	Utilisation of type A Finishing Track.	0
27	Utilisation of the Lysaught colour paint plant.	0
28	Carries the No. of terminations required for the warm up period. Not always used.	Dependant on model.
29	Utilisation of the area for rejects queueing prior to loading to No. 1 paint plant.	0
30	Utilisation of type B Finishing Track.	0
31	Time to transport one body from track to the loop line.	20
32	Process time on loop rectification line.	30
33	Time to transport from loop to pre-despatch queue.	30
34	Time to transport from pre-despatch to despatch.	50
35	Lowbake process time.	900
36	Time to transport large commercial to despatch.	90
37	Time to perform rectification on a large commercial.	160
38	Time to spray/rectify a body shell at the end of the finishing tracks.	250
39	Utilisation of the area used for large commercials prior to the finishing tracks.	0
40	Utilisation of Type C finishing track.	0
41	Utilisation of commercial rejection area.	0
42	Utilisation of the large commercial finishing track.	0
44	Overall column pointer for MH1.	1
45	Overall column pointer for MH7.	1
46	Column pointer for selecting from MH7.	0
47	Carrier for model code. Used during the loading of the Lysaught paint plant.	0
48	Carrier for colour code. Used during the loading of the Lysaught paint plant.	0
48	Carrier for colour code. Used during the loading of the Lysaught paint plant.	0

49	Capacity of saloon assembly area prior to No. 1.	10
50	Capacity of the saloon plugging/rectification area.	16
51	Utilisation of the assembly area prior to No. 1. paint plant.	0
52	Warm-up contents of saloon plugging area.	0
53	Warm-up contents of assembly area prior to No. 1.	0
54	Capacity of electrocoat paint plant.	93
55	Capacity of No. 1 paint plant.	135
56	Capacity of No. 2 paint plant.	34
57	Capacity of the Lysaught paint plant.	20
58	Capacity of Type A saloon finishing track.	64
59	Capacity of Type B saloon finishing track.	32
60	Capacity of Type C saloon finishing track.	32
61	Capacity of large commercial finishing track.	34
62	Capacity of assembly area prior to Lysaught.	6
63	Capacity of plugging/rectification area for commercials.	19
64	Capacity of area prior to the No. 2 rectification plant.	5
65	The capacity of the reject area for commercials.	23
66	The capacity of the electro/Lysaught store.	23
67	Efficiency of the Electrocoat paint plant.	0
68	Efficiency of No. 1 paint plant.	0
69	Efficiency of No. 2 paint plant.	0
70	Efficiency of Lysaught paint plant.	0
71	Efficiency of loop rectification line.	0
72	Efficiency of lowbake paint plant.	0
73	Efficiency of Type A Finishing Track.	0
74	Efficiency of Type B Finishing Track.	0
75	Efficiency of Type C Finishing Track.	0
76	Efficiency of large commercial Finishing Track.	0
77	Warm-up contents of the Electrocoat paint plant.	0
78	Utilisation of assembly area prior to Lysaught paint plant.	0

79	Warm-up contents of assembly area prior to Lysaught paint plant.	0
80	Pointer in function to Mil transfer.	Dependant on model
81	Warm-up contents No. 1 paint plant.	0
82	Warm-up contents No. 2 paint plant.	0
83	Warm-up contents Lysaught paint plant.	0
84	Warm-up contents of reject area for commercials.	0
85	Capacity of general store.	44
86	Capacity of gantry store.	20
87	Warm-up contents of general storage area.	0
88	Warm-up of Electro/Lysaught store.	0
89	Warm-up of gantry store.	0
90	Warm-up contents of Type A finishing track.	0
91	Warm-up contents of Type B finishing track.	0
92	Warm-up contents of Type C finishing track.	0
93	Warm-up contents of Type C finishing track.	0
94	Capacity of the snagging area after finishing tracks.	10
95	Capacity of area for queue of large commercials awaiting the crane.	3
96	Capacity of the loop rectification line.	35
97	Capacity of lowbake paint plant.	30
98	Capacity of despatch area.	220
99	Capacity of pre-despatch storage area.	30
100	Utilisation of the unofficial storage area.	0
102	Total No. loaded to electrocoat paint plant.	0
103	Total No. loaded to No. 1 paint plant.	0
104	Total No. loaded to No. 2 rectification plant.	0
105	Total No. loaded to Lysaught paint plant.	0
106	Total No. loaded to Finishing Tracks.	0
107	Total No. loaded to lowbake paint plant.	0
108	Total No. sent to despatch.	0

109	Warm-up contents of plugging area for commercials or; total system stock (only used for this purpose in warm-up tests).	0
110	Total system stock.	0
111	Counter controlling the re-entry of bodies from the unofficial store.	0
112	Temporary store for the difference between expected and actual number in the system stock. Overall feedback control.	0
113	Accumulator for difference e-a system stock.	0
114	No. of points to be transferred FN9-10 to MH1.	Dependant on model.
115	No. of points to be transferred FN12-13 to MH7.	Dependant on model.
116	Column control on MH10.	1
117	Column pointer for MH10.	1
118	Number of rows to be transferred.	Dependant on model.
119	Number of columns to be examined.	Dependant on model.
120	Count on number of columns examined.	0
121	Length of overall feedback review time.	Dependant on model.
122	Length of short feedback review time.	Dependant on model.

REGISTER OF STORAGES

REALLOCATED VALUE = 35

NUMBER	DESCRIPTION	CAPACITY
1	Represents the area for painted commercial body shells prior to the finishing tracks. Located between the electrocoat and the Lysaught.	23
5	Represents the area for painted type A saloons prior to the finishing tracks. (ADO15 or ADO20.)	44
6	The area for painted type C saloons prior to the finishing tracks. (ADO16.)	44
7	The area for painted type C saloons prior to the finishing tracks. (W/R, ADO15 VANS.)	44
8	The area for painted large commercials prior to the finishing tracks. (J4 VANS.)	30
13	Overall store of painted saloons and small commercials prior to the finishing tracks.	44
14	Store of bodies awaiting rectification on the No. 2 colour paint plant.	44
15	Rejection area at the end of the finishing tracks for Air Dry Spraying.	10
16	The loop touch-up and rectification line.	35
17	The overall area for saloon bodies awaiting transport to the despatch bay after being finished.	30
18	The overall area in the despatch bay for both saloons and commercials.	220
19	The area in which commercials queue for the crane.	3
20	The lowbake plant.	30
21	The area within store 18 which can be used for queueing large commercials.	200
22	The rectification area at the end of the finish tracks used for large commercials.	4
23	The area in which drain holes, in commercial shells, are filled.	19

NUMBER	DESCRIPTION	CAPACITY
24	The area in which drain holes in saloon shells, are filled.	16
25	The area in which type A saloons await transport to the despatch bay after being finished.	30
26	The area in which type B saloons await transport to the despatch bay after being finished.	30
27	The area in which type C saloons or small commercials wait before transfer to the despatch bay.	30
28	The area within the despatch which type A saloons can occupy.	200
29	The area within the despatch which type B saloons can occupy.	200
30	The area within the despatch which type C saloons or small commercials can occupy.	200

REGISTER OF FULLWORD SAVEVALUES

REALLOCATED VALUE = 30

NUMBER	USE IN THE MODEL	INITIAL VALUE
1	Row control MH8.	Dependant on model.
2	Column control MH8.	"
3	Column control MH1.	"
4	Holds the reset time.	"
5	Current batch size in REORG.	"
6	Row control on MH4.	"
7		"
8	Number of columns to be referenced in MH8 + 1.	"
9	Number transferred to date.	"
10	Number to be transferred.	"
11	Terminating row number.	"
12	Matrix number.	"
13	Number of Boolean variable to be referenced REORG.	"
14	Row reference for MH8 checking on batch size.	"
15	Overall row control MH8.	"
17	Address of tag row.	"

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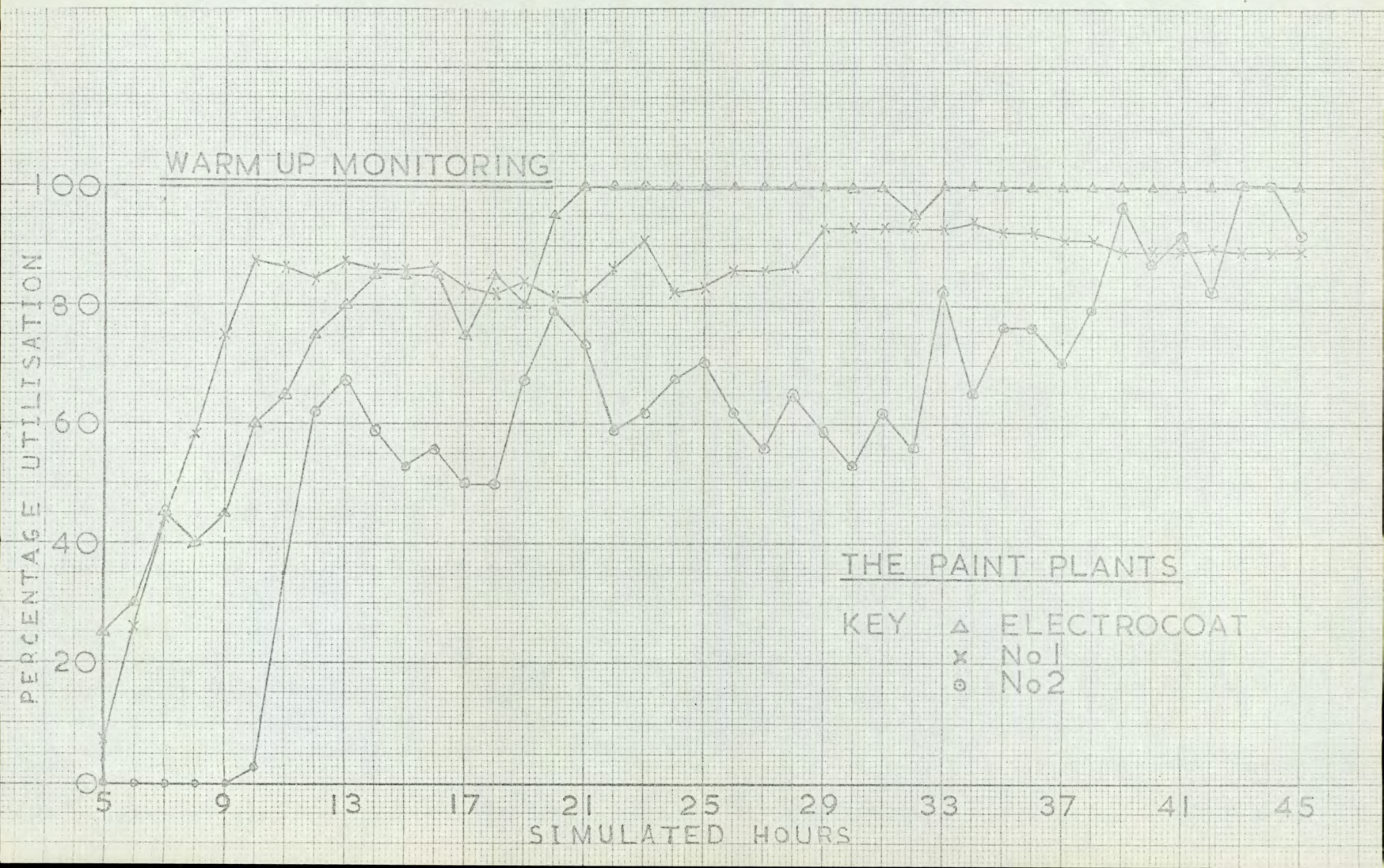
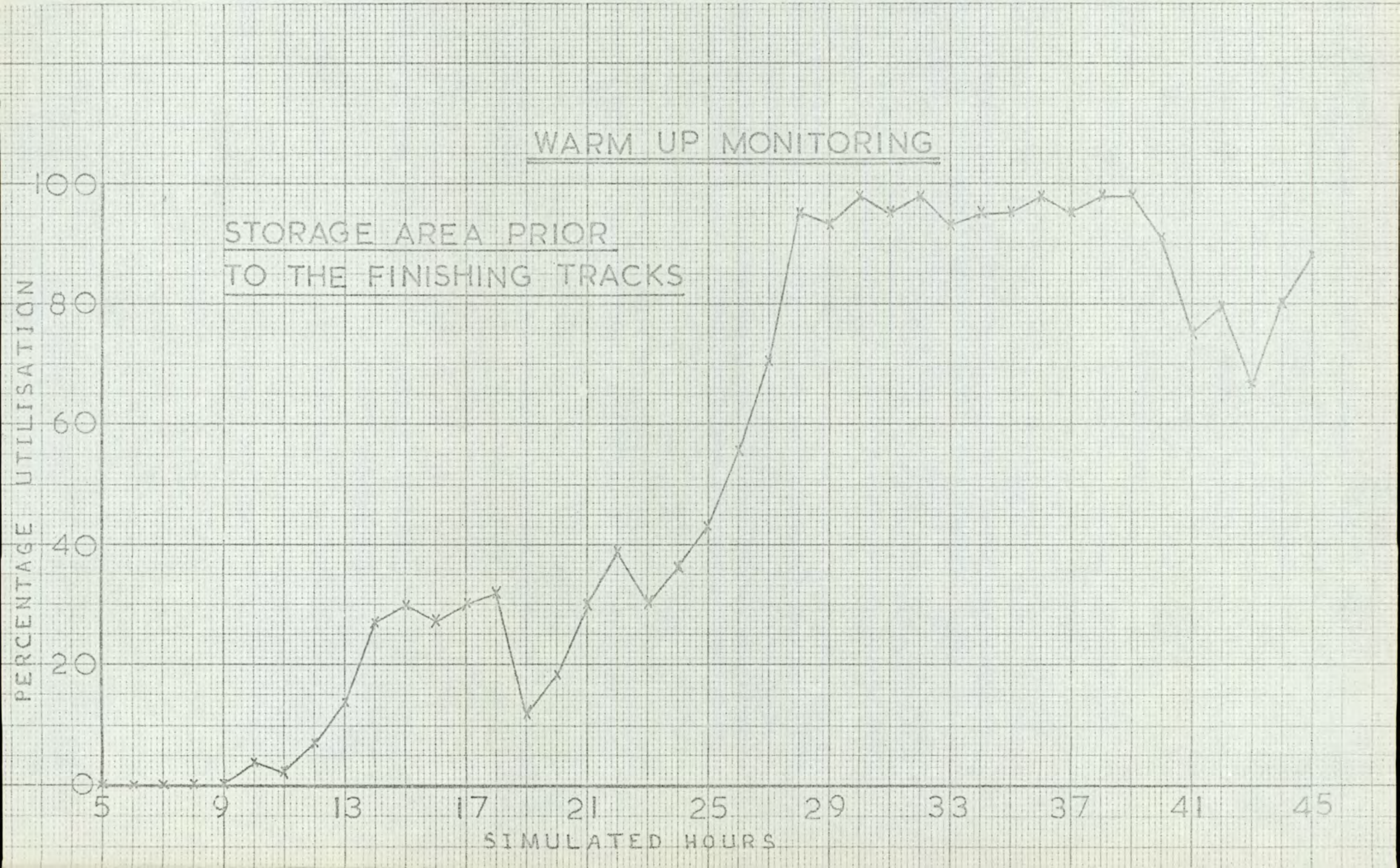
BLOCK NAME	TIME/EXECUTION & ASSEMBLY IN MILLISECONDS - IBM 360/40	NOTES
ADVANCE	4.8	
DEPART	27.0	
ENTER	2.4	
LEAVE	2.4	
PREEMPT	1.2	
QUEUE	27.0	
RELEASE	1.8	
RETURN	1.2	
SEIZE	1.8	
SELECT	12.0	
TABULATE	47.0	
ASSIGN	7.3	
LOOP	2.4	
MARK	0.6	
SAVEVALUE	2.4	
PRINT	893.0	1 line printed
TEST	6.6	
TRANSFER	2.4	
LOGIC	0.6	Too small to measure accurately
INDEX	0.6	Too small to measure accurately
PRIORITY	0.6	Too small to measure accurately
CHANGE	0.6	Too small to measure accurately

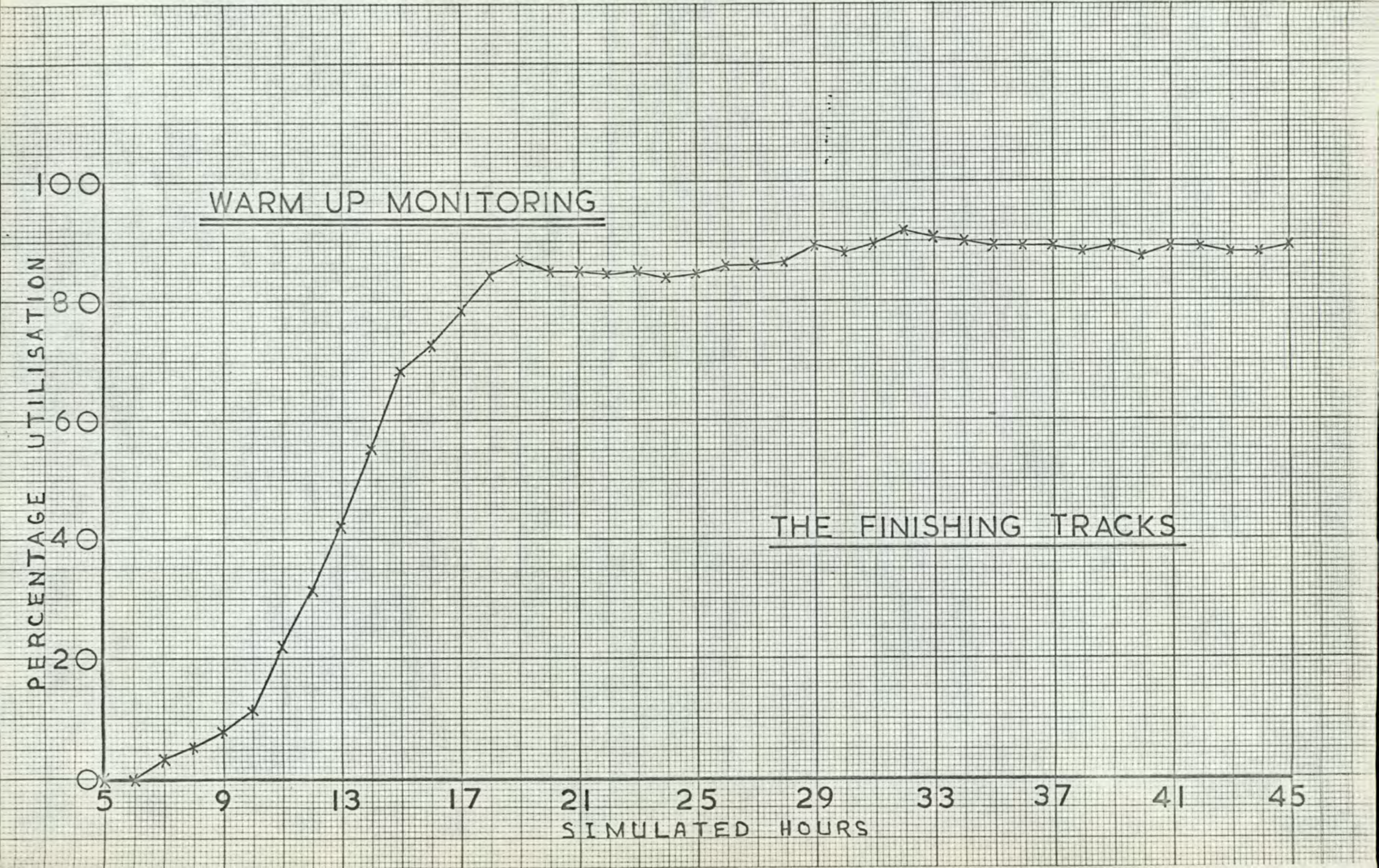
APPENDIX E

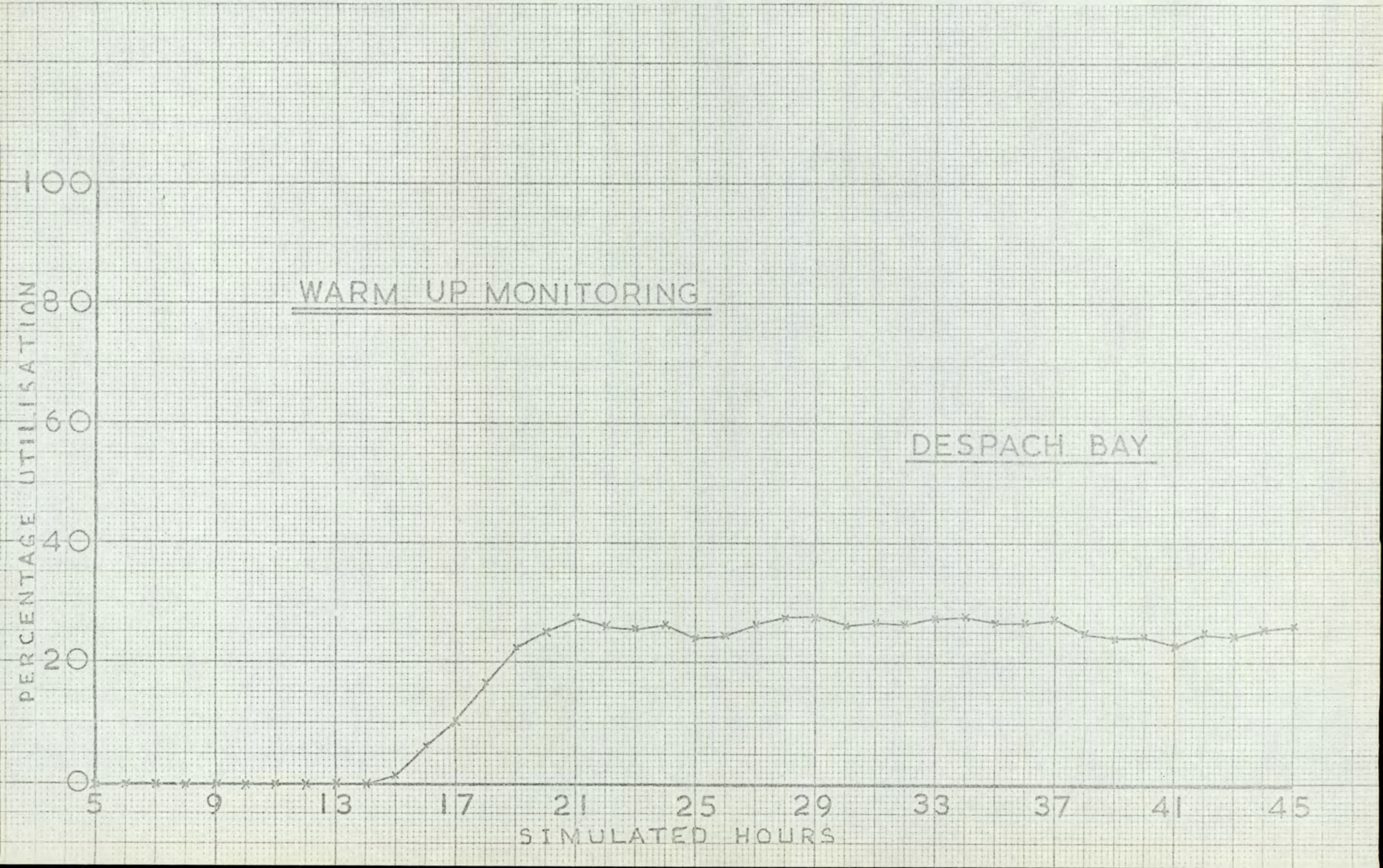


WARM UP MONITORING
PERCENTAGE UTILISATION
100
80
60
40
20
0
5
9
13
17
21
25
29
33
37
41
45
SIMULATED HOURS
THE PAINT PLANTS
KEY
ELECTROCOAT
No 1
No 2



WARM UP MONITORING
STORAGE AREA PRIOR
TO THE FINISHING TRACKS
PERCENTAGE UTILISATION
100
80
60
40
20
0
5
9
13
17
21
25
29
33
37
41
45
SIMULATED HOURS

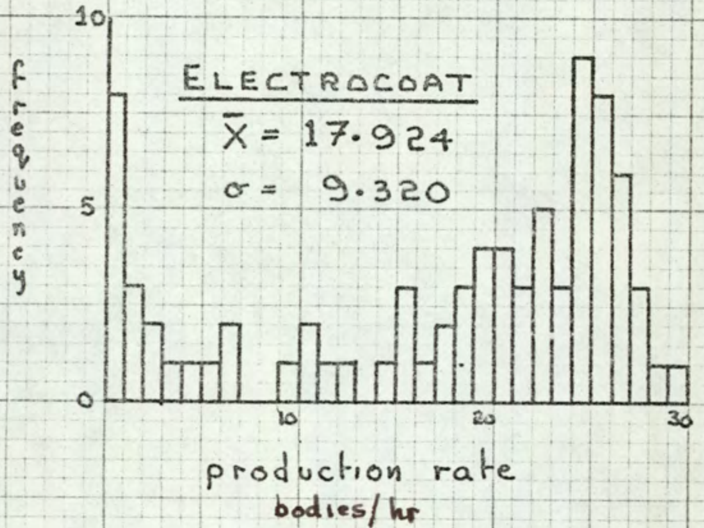

WARM UP MONITORING
THE FINISHING TRACKS
PERCENTAGE UTILISATION
0
20
40
60
80
100
5
9
13
17
21
25
29
33
37
41
45
SIMULATED HOURS

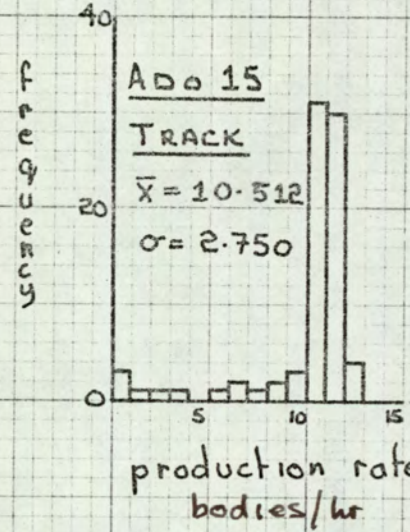


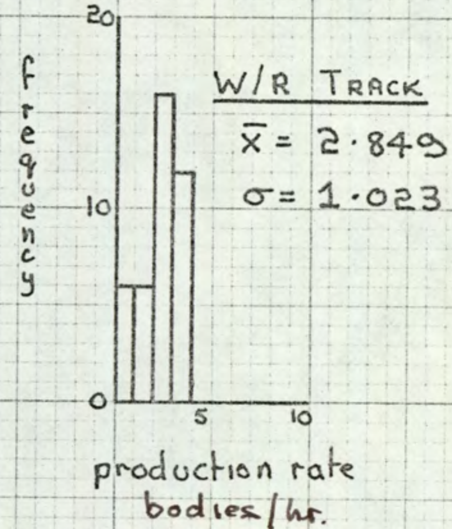
WARM UP MONITORING
DESPACH BAY
PERCENTAGE UTILISATION
100
80
60
40
20
0
5
9
13
17
21
25
29
33
37
41
45
SIMULATED HOURS

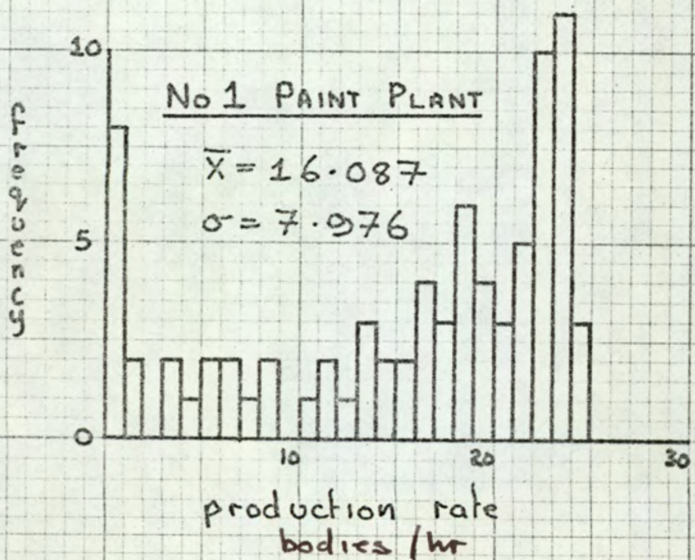
VALIDATION TESTS

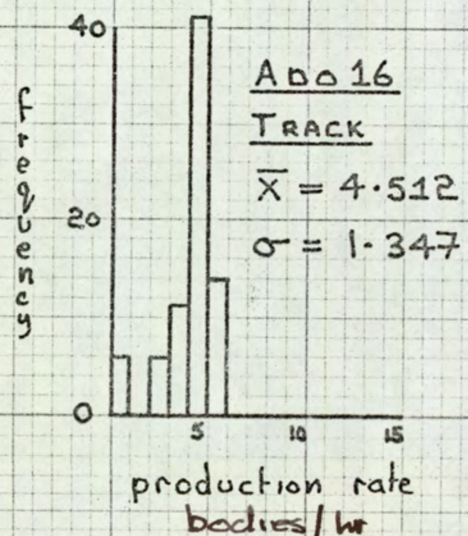
RESULTS FROM THE ACTUAL SYSTEM

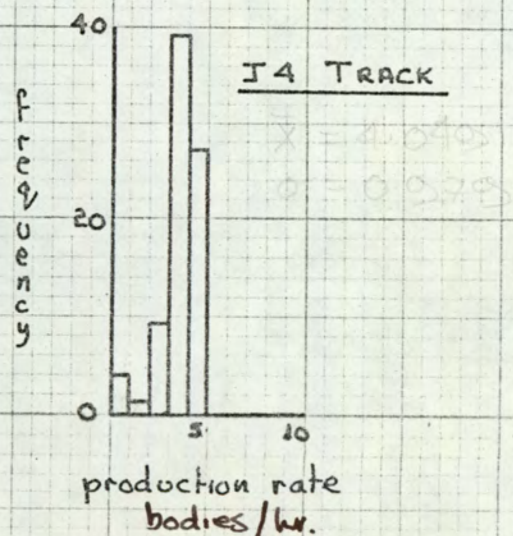






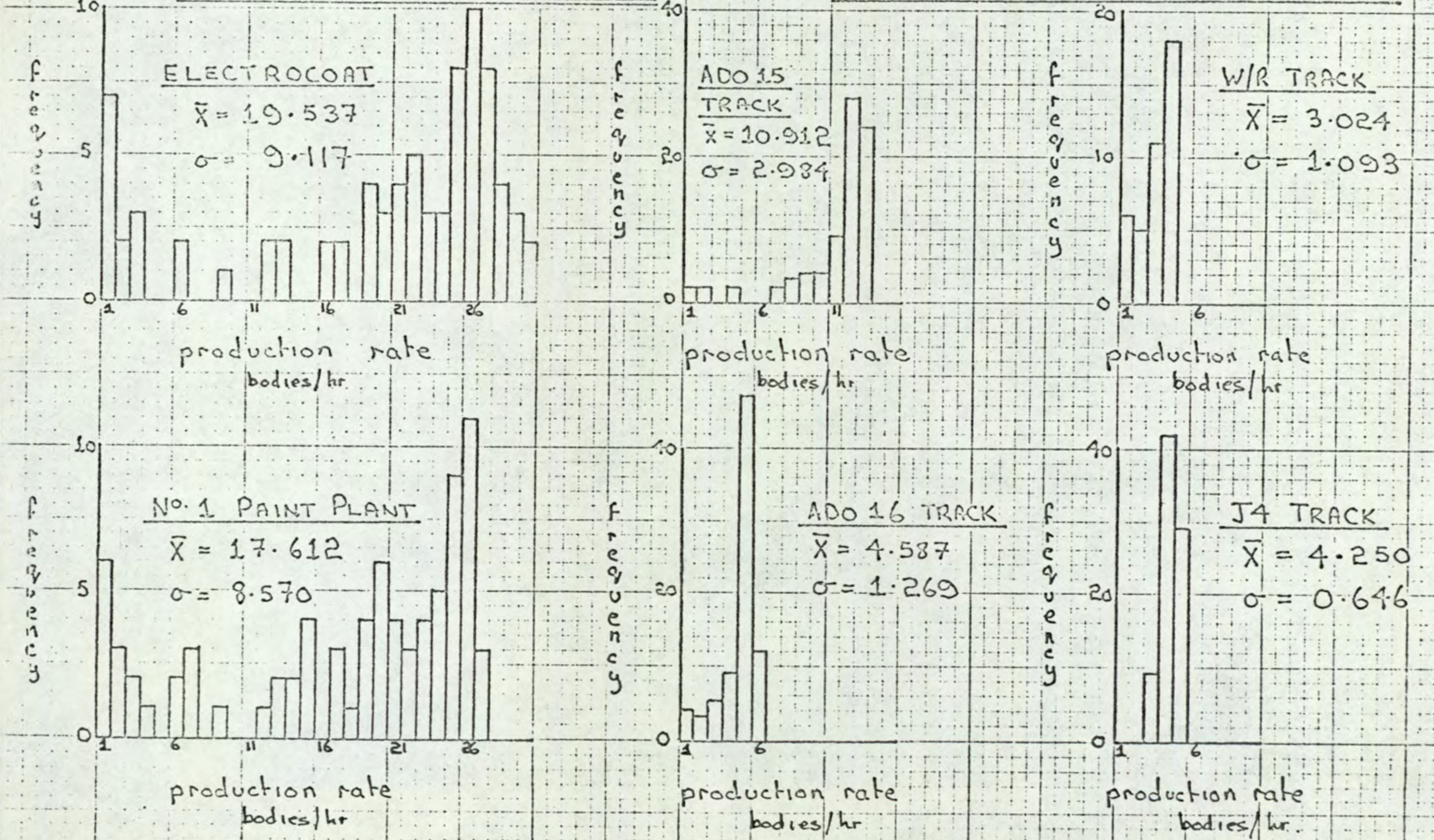






VALIDATION TESTS

Results from the model



RESULTS FROM THE ACTUAL SYSTEM

VALIDATION TESTS

ELECTROCOAT PAINT PLANT

ENTRIES IN TABLE	MEAN ARGUMENTS	STANDARD DEVIATION	SUM OF ARGUMENTS
80	17.924	9.320	1434.000

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	NON-WEIGHTED DEVIATION OF MEAN
1	8	9.99	9.9	90.0	.055	-1.815
2	3	3.74	13.7	86.2	.111	-1.708
3	2	2.49	16.2	83.7	.167	-1.601
4	1	1.24	17.4	82.5	.223	-1.494
5	1	1.24	18.7	81.2	.278	-1.386
6	1	1.24	19.9	80.0	.334	-1.279
7	2	2.49	22.4	77.5	.390	-1.172
8	0	.00	22.4	77.5	.446	-1.064
9	0	.00	22.4	77.5	.502	-.957
10	1	1.24	23.7	76.2	.557	-.850
11	2	2.49	26.2	73.7	.613	-.742
12	1	1.24	27.4	72.5	.669	-.635
13	1	1.24	28.7	71.2	.725	-.528
14	0	.00	28.7	71.2	.781	-.421
15	1	1.24	29.9	70.0	.836	-.313
16	3	3.74	33.7	66.2	.892	-.206
17	1	1.24	34.9	65.0	.948	-.099
18	2	2.49	37.4	62.5	1.004	.008
19	3	3.74	41.2	58.7	1.059	.115
20	4	4.99	46.2	53.7	1.115	.222
21	4	4.99	51.2	48.7	1.171	.329
22	3	3.74	54.9	45.0	1.227	.437
23	5	6.25	61.2	38.7	1.283	.544
24	3	3.74	64.9	35.0	1.338	.651
25	9	11.24	76.2	23.7	1.394	.759
26	8	9.99	86.2	13.7	1.450	.866
27	6	7.49	93.7	6.2	1.506	.973
28	3	3.74	97.4	2.5	1.562	1.080
29	1	1.24	98.7	1.2	1.617	1.188
OVERFLOW	1	1.24	100.0	.0		
AVERAGE VALUE OF OVERFLOW		30.00				

RESULTS FROM THE ACTUAL SYSTEM

VALIDATION TESTS

NO. 1 PAINT PLANT

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	NON-WEIGHTED
80	16.087	7.976	1287.000	

UPPER LIMIT	DESERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	8	9.99	9.9	90.0	.062	-1.891
2	2	2.49	12.4	87.5	.124	-1.766
3	0	.00	12.4	87.5	.186	-1.660
4	2	2.49	14.9	85.0	.248	-1.515
5	1	1.24	16.2	83.7	.310	-1.390
6	2	2.49	18.7	81.2	.372	-1.264
7	2	2.49	21.2	78.7	.435	-1.139
8	1	1.24	22.4	77.5	.497	-1.013
9	2	2.49	24.9	75.0	.559	-.888
10	0	.00	24.9	75.0	.621	-.763
11	1	1.24	26.2	73.7	.683	-.637
12	2	2.49	28.7	71.2	.745	-.512
13	1	1.24	29.9	70.0	.808	-.387
14	3	3.74	33.7	66.2	.870	-.261
15	2	2.49	36.2	63.7	.932	-.136
16	2	2.49	38.7	61.2	.994	-.010
17	4	4.99	43.7	56.2	1.056	.114
18	3	3.74	47.4	52.5	1.118	.239
19	6	7.49	54.9	45.0	1.181	.365
20	4	4.99	59.9	40.0	1.243	.490
21	3	3.74	63.7	36.2	1.305	.615
22	5	6.25	69.9	30.0	1.367	.741
23	10	12.50	82.4	17.5	1.429	.866
24	11	13.74	96.2	3.7	1.491	.991
25	3	3.74	100.0	.0	1.554	1.117

REMAINING FREQUENCIES ARE ALL ZERO

RESULTS FROM THE ACTUAL SYSTEM

VALIDATION TESTS

ADO 15 FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	10.512	2.750	841.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION OF MEAN
1	3	3.74	3.7	96.2	.095	-3.459
2	1	1.24	4.9	95.0	.190	-3.095
3	1	1.24	6.2	93.7	.285	-2.731
4	1	1.24	7.4	92.5	.380	-2.368
5	0	.00	7.4	92.5	.475	-2.004
6	1	1.24	8.7	91.2	.570	-1.640
7	2	2.49	11.2	88.7	.665	-1.277
8	1	1.24	12.4	87.5	.760	-.913
9	2	2.49	14.9	85.0	.856	-.549
10	3	3.74	18.7	81.2	.951	-.186
11	31	38.74	57.4	42.5	1.040	.177
12	30	37.50	94.9	5.0	1.141	.540
13	4	4.99	100.0	.0	1.236	.904

REMAINING FREQUENCIES ARE ALL ZERO

ADO 16 FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	NON-WEIGHTED
80	4.512	1.347	361.000	

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION OF MEAN
1	6	7.49	7.4	92.5	.221	-2.606
2	2	2.49	9.9	90.0	.443	-1.864
3	6	7.49	17.4	82.5	.664	-1.122
4	11	13.74	31.2	68.7	.886	-.380
5	41	51.24	82.4	17.5	1.108	.361
6	14	17.49	100.0	.0	1.329	1.103

REMAINING FREQUENCIES ARE ALL ZERO

RESULTS FROM THE ACTUAL SYSTEM

VALIDATION TESTS

J4 FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	4.049	.979	324.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION OF MEAN
1	4	4.99	4.9	95.0	.246	-3.113
2	1	1.24	6.2	93.7	.493	-2.092
3	9	11.24	17.4	82.5	.760	-1.071
4	39	48.74	66.2	33.7	.987	-.051
5	27	33.74	100.0	.0	1.234	.969

REMAINING FREQUENCIES ARE ALL ZERO

W/R FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
40	2.849	1.023	114.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION OF MEAN
1	6	14.99	14.9	85.0	.350	-1.807
2	6	14.99	29.9	70.0	.701	-.830
3	16	39.99	69.9	30.0	1.052	.146
4	12	29.99	100.0	.0	1.403	1.123

REMAINING FREQUENCIES ARE ALL ZERO

RESULTS FROM THE MODEL

VALIDATION TESTS

ELECTROCOAT PAINT PLANT

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	19.337	9.117	1563.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	7	8.74	8.7	91.2	.051	-2.033
2	2	2.49	11.2	88.7	.102	-1.923
3	3	3.74	14.9	85.0	.153	-1.813
4	0	.00	14.9	85.0	.204	-1.704
5	0	.00	14.9	85.0	.255	-1.594
6	2	2.49	17.4	82.5	.307	-1.484
7	0	.00	17.4	82.5	.358	-1.375
8	0	.00	17.4	82.5	.409	-1.265
9	1	1.24	18.7	81.2	.460	-1.155
10	0	.00	18.7	81.2	.511	-1.046
11	0	.00	18.7	81.2	.563	-.936
12	2	2.49	21.2	78.7	.614	-.826
13	2	2.49	23.7	76.2	.665	-.717
14	0	.00	23.7	76.2	.716	-.697
15	0	.00	23.7	76.2	.767	-.497
16	2	2.49	26.2	73.7	.818	-.388
17	2	2.49	28.7	71.2	.870	-.278
18	0	.00	28.7	71.2	.921	-.168
19	4	4.99	33.7	66.2	.972	-.058
20	3	3.74	37.4	62.5	1.023	.050
21	4	4.99	42.4	57.5	1.074	.160
22	5	6.25	48.7	51.2	1.126	.270
23	3	3.74	52.4	47.5	1.177	.379
24	3	3.74	56.2	43.7	1.228	.489
25	8	9.99	66.2	33.7	1.279	.599
26	10	12.50	78.7	21.2	1.330	.708
27	8	9.99	88.7	11.2	1.381	.818
28	4	4.99	93.7	6.2	1.433	.928
29	3	3.74	97.4	2.5	1.484	1.037
OVERFLOW	2	2.49	100.0	.0		
AVERAGE VALUE OF OVERFLOW		30.00				

RESULTS FROM THE MODEL

VALIDATION TESTS

NO. 1 PAINT PLANT

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	17.612	8.570	1409.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	6	7.49	7.4	92.5	.056	-1.938
2	3	3.74	11.2	88.7	.113	-1.821
3	2	2.49	13.7	86.2	.170	-1.705
4	1	1.24	14.9	85.0	.227	-1.588
5	0	.00	14.9	85.0	.283	-1.471
6	2	2.49	17.4	82.5	.340	-1.354
7	3	3.74	21.2	78.7	.397	-1.238
8	0	.00	21.2	78.7	.454	-1.121
9	1	1.24	22.4	77.5	.511	-1.004
10	0	.00	22.4	77.5	.567	.888
11	0	.00	22.4	77.5	.624	-.771
12	1	1.24	23.7	76.2	.681	-.654
13	2	2.49	26.2	73.7	.738	-.538
14	2	2.49	28.7	71.2	.794	-.421
15	4	4.99	33.7	66.2	.851	-.304
16	0	.00	33.7	66.2	.908	-.188
17	3	3.74	37.4	62.5	.965	-.071
18	1	1.24	38.7	61.2	1.022	.045
19	4	4.99	43.7	56.2	1.078	.161
20	6	7.49	51.2	48.7	1.135	.278
21	4	4.99	56.2	43.7	1.192	.395
22	3	3.74	59.9	40.0	1.249	.511
23	4	4.99	64.9	35.0	1.305	.628
24	5	6.25	71.2	28.7	1.362	.745
25	9	11.24	82.4	17.5	1.419	.861
26	11	13.74	96.2	3.7	1.476	.978
27	3	3.74	100.0	.0	1.533	1.095

REMAINING FREQUENCIES ARE ALL ZERO

RESULTS FROM THE MODEL

VALIDATION TESTS

ADO 15 FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	10.912	2.984	873.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	2	2.49	2.4	97.5	.091	-3.321
2	2	2.49	4.9	95.0	.183	-2.986
3	0	.00	4.9	95.0	.274	-2.651
4	2	2.49	7.4	92.5	.366	-2.316
5	0	.00	7.4	92.5	.458	-1.981
6	0	.00	7.4	90.0	.549	-1.646
7	2	2.49	9.9	86.2	.641	-1.310
8	3	3.74	13.7	81.2	.733	-.975
9	4	4.99	18.7	76.2	.824	-.640
10	4	4.99	23.7	65.0	.916	-.305
11	9	11.24	34.9	30.0	1.008	.029
12	28	34.99	69.9	.0	1.009	.364
13	24	25.99	100.0		1.191	.699

REMAINING FREQUENCIES ARE ALL ZERO

ADO 16 FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	4.587	1.269	367.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION OF MEAN
1	4	4.99	4.9	95.0	.217	-2.825
2	3	3.74	8.7	91.2	.435	-2.038
3	5	6.25	14.9	85.0	.653	-1.250
4	9	11.24	26.2	73.7	.871	-.462
5	47	58.74	84.9	15.0	1.089	.324
6	12	14.99	100.0			

REMAINING FREQUENCIES ARE ALL ZERO

RESULTS FROM THE MODEL

VALIDATION TESTS

J4 FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
80	4.250	.646	340.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION OF MEAN
1	0	.00	.0	100.0	.235	-5.029
2	0	.00	.0	100.0	.470	-3.481
3	9	11.24	11.2	86.7	.705	-1.934
4	42	52.49	63.7	36.2	.941	-.386
5	29	38.24	100.0	.0	1.176	1.160

REMAINING FREQUENCIES ARE ALL ZERO

W/R FINISHING TRACK

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	
40	3.024	1.093	121.000	NON-WEIGHTED

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION OF MEAN
1	6	14.99	14.9	85.0	.330	-1.851
2	5	12.50	27.4	72.5	.661	-.937
3	11	27.49	54.9	45.0	.991	-.022
4	18	44.99	100.0	.0	1.322	.891

REMAINING FREQUENCIES ARE ALL ZERO

STRATEGY ANALYSIS

STRATEGY ..Validity.Tests.:.Simulated.Results

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	92.3	65.1
NO. 1 PAINT PLANT	69.5	67.8
NO. 2 PAINT PLANT	50.1	42.6
LYSAUGHT PAINT PLANT	84.8	42.8
ADO 15 FINISHING TRACK	93.7	87.6
ADO 16 FINISHING TRACK	95.1	86.1
W/R FINISHING TRACK	90.8	80.6
J4 FINISHING TRACK	98.9	97.0
LOOP RECTIFICATION LINE	20.7	
LOW BAKE PAINT PLANT	51.3	
STORAGE PRIOR TO NO. 1 PAINT PLANT	78.1	
STORAGE PRIOR TO LYSAUGHT PLANT	68.6	
STORAGE PRIOR TO TRACKS	79.1	
STORAGE PRIOR TO DESPATCH BAY	5.3	
DESPATCH BAY	37.8	
OVERALL PAINT REJECTION RATE	.657	
AVERAGE TRACK EFFICIENCY		87.8

STRATEGY ANALYSIS

STRATEGY ....Validity Test. Actual results....

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 Clock Units
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	90.6	59.7
NO. 1 PAINT PLANT	67.9	61.8
NO. 2 PAINT PLANT	46.5	41.9
LYSAUGHT PAINT PLANT	81.9	39.8
ADO 15 FINISHING TRACK	87.9	84.3
ADO 16 FINISHING TRACK	86.5	85.8
W/R FINISHING TRACK	84.2	76.2
J4 FINISHING TRACK	98.5	92.4
LOOP RECTIFICATION LINE	19.5	
LOW BAKE PAINT PLANT	45.0	
STORAGE PRIOR TO NO. 1 PAINT PLANT	75.6	
STORAGE PRIOR TO LYSAUGHT PLANT	63.0	
STORAGE PRIOR TO TRACKS	70.9	
STORAGE PRIOR TO DESPATCH BAY	4.6	
DESPATCH BAY	35.4	
OVERALL PAINT REJECTION RATE	.603	
AVERAGE TRACK EFFICIENCY		85%

STRATEGY ANALYSIS

STRATEGY ..WARM-UP TEST..............................

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	80
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.S.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300
LOOP LINE CYCLE TIME	=	30

RESULTS :

FACILITY	UTILISATION %	EFFICIENCY %
ELECTROCOAT	92.8	76.6
NO. 1 PAINT PLANT	69.5	56.6
NO. 2 PAINT PLANT	44.3	38.3
LYSAUGHT PAINT PLANT	71.2	39.8
ADO 15 FINISHING TRACK	61.5	46.3
ADO 16 FINISHING TRACK	52.9	38.0
W/R FINISHING TRACK	49.7	32.6
J4 FINISHING TRACK	71.0	59.3
LOOP RECTIFICATION LINE	40.6	
LOW BAKE PAINT PLANT	18.8	
STORAGE PRIOR TO NO. 1 PAINT PLANT	44.2	
STORAGE PRIOR TO LYSAUGHT PLANT	44.7	
STORAGE PRIOR TO TRACKS	36.2	
STORAGE PRIOR TO DESPATCH BAY	13.3	
DESPATCH BAY	12.7	
OVERALL PAINT REJECTION RATE	.677	
AVERAGE TRACK EFFICIENCY		45%

STRATEGY ANALYSIS

STRATEGY .Increase speed of Electrocoat plant by 10%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	33/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	93.0	58.9
NO. 1 PAINT PLANT	73.2	68.2
NO. 2 PAINT PLANT	53.6	41.0
LYSAUGHT PAINT PLANT	90.1	43.3
ADO 15 FINISHING TRACK	94.0	89.6
ADO 16 FINISHING TRACK	96.3	88.0
W/R FINISHING TRACK	89.4	85.3
J4 FINISHING TRACK	98.5	97.7
LOOP RECTIFICATION LINE	22.8	
LOW BAKE PAINT PLANT	52.5	
STORAGE PRIOR TO NO. 1 PAINT PLANT	86.2	
STORAGE PRIOR TO LYSAUGHT PLANT	73.1	
STORAGE PRIOR TO TRACKS	70.0	
STORAGE PRIOR TO DESPATCH BAY	4.8	
DESPATCH BAY	39.4	
OVERALL PAINT REJECTION RATE	.631	
AVERAGE TRACK EFFICIENCY		90.2

STRATEGY ANALYSIS

STRATEGY ..Lower Electrocoat Speed by 10%..

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	29/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	91.6	70.1
NO. 1 PAINT PLANT	65.8	64.5
NO. 2 PAINT PLANT	42.1	37.6
LYSAUGHT PAINT PLANT	85.7	43.0
ADO 15 FINISHING TRACK	85.1	79.2
ADO 16 FINISHING TRACK	86.4	82.7
W/R FINISHING TRACK	81.8	70.7
J4 FINISHING TRACK	98.6	96.1
LOOP RECTIFICATION LINE	18.7	
LOW BAKE PAINT PLANT	46.7	
STORAGE PRIOR TO NO. 1 PAINT PLANT	71.2	
STORAGE PRIOR TO LYSAUGHT PLANT	63.3	
STORAGE PRIOR TO TRACKS	70.4	
STORAGE PRIOR TO DESPATCH BAY	5.2	
DESPATCH BAY	35.7	
OVERALL PAINT REJECTION RATE	.650	
AVERAGE TRACK EFFICIENCY		81.5

STRATEGY ANALYSIS

STRATEGY ... Increase speed of No. 1 plant by 10%.

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	28.6/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	93.2	69.3
NO. 1 PAINT PLANT	70.6	62.6
NO. 2 PAINT PLANT	53.8	45.4
LYSAUGHT PAINT PLANT	86.0	44.1
ADO 15 FINISHING TRACK	97.3	94.0
ADO 16 FINISHING TRACK	96.0	91.6
W/R FINISHING TRACK	91.7	87.4
J4 FINISHING TRACK	98.6	98.2
LOOP RECTIFICATION LINE	21.2	
LOW BAKE PAINT PLANT	52.8	
STORAGE PRIOR TO NO. 1 PAINT PLANT	87.6	
STORAGE PRIOR TO LYSAUGHT PLANT	74.3	
STORAGE PRIOR TO TRACKS	85.1	
STORAGE PRIOR TO DESPATCH BAY	6.3	
DESPATCH BAY	39.4	
OVERALL PAINT REJECTION RATE	.668	
AVERAGE TRACK EFFICIENCY		93.2

STRATEGY ANALYSIS

STRATEGY ....Decrease speed of No. 1 paint plant by 10%....

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	23.4/HR
FINISHING TRACK PRODUCTION RATE	=	25.9
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	93.8	63.8
NO. 1 PAINT PLANT	76.2	72.1
NO. 2 PAINT PLANT	50.2	41.8
LYSAUGHT PAINT PLANT	81.0	44.6
ADO 15 FINISHING TRACK	89.3	82.9
ADO 16 FINISHING TRACK	80.1	73.3
W/R FINISHING TRACK	87.4	84.6
J4 FINISHING TRACK	98.0	97.3
LOOP RECTIFICATION LINE	21.3	
LOW BAKE PAINT PLANT	48.9	
STORAGE PRIOR TO NO. 1 PAINT PLANT	86.3	
STORAGE PRIOR TO LYSAUGHT PLANT	67.4	
STORAGE PRIOR TO TRACKS	73.8	
STORAGE PRIOR TO DESPATCH BAY	5.1	
DESPATCH BAY	35.4	
OVERALL PAINT REJECTION RATE	.648	
AVERAGE TRACK EFFICIENCY		83.6%

STRATEGY ANALYSIS

STRATEGY ..Increase the size of the store prior to the No. 1 plant by 50%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	15
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	40:18:7
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	94.2	71.2
NO. 1 PAINT PLANT	78.8	73.7
NO. 2 PAINT PLANT	58.4	45.6
LYSAUGHT PAINT PLANT	86.0	44.2
ADO 15 FINISHING TRACK	98.2	97.8
ADO 16 FINISHING TRACK	97.8	97.0
W/R FINISHING TRACK	94.0	92.5
J4 FINISHING TRACK	98.7	98.3
LOOP RECTIFICATION LINE	21.7	
LOW BAKE PAINT PLANT	52.8	
STORAGE PRIOR TO NO. 1 PAINT PLANT	56.3	
STORAGE PRIOR TO LYSAUGHT PLANT	87.2	
STORAGE PRIOR TO TRACKS	81.5	
STORAGE PRIOR TO DESPATCH BAY	6.1	
DESPATCH BAY	42.8	
OVERALL PAINT REJECTION RATE	.644	
AVERAGE TRACK EFFICIENCY		96.9%

STRATEGY ANALYSIS

STRATEGY Increased store prior to the tracks by 50%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	66
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	93.8	70.1
NO. 1 PAINT PLANT	80.6	78.1
NO. 2 PAINT PLANT	65.1	50.3
LYSAUGHT PAINT PLANT	80.5	37.8
ADO 15 FINISHING TRACK	98.6	97.3
ADO 16 FINISHING TRACK	97.8	97.1
W/R FINISHING TRACK	94.0	92.5
J4 FINISHING TRACK	100.0	98.3
LOOP RECTIFICATION LINE	26.6	
LOW BAKE PAINT PLANT	58.4	
STORAGE PRIOR TO NO. 1 PAINT PLANT	80.5	
STORAGE PRIOR TO LYSAUGHT PLANT	88.7	
STORAGE PRIOR TO TRACKS	71.6	
STORAGE PRIOR TO DESPATCH BAY	5.9	
DESPATCH BAY	40.3	
OVERALL PAINT REJECTION RATE	624	
AVERAGE TRACK EFFICIENCY		96.4

STRATEGY ANALYSIS

STRATEGY ...Reduce the size of the store prior to the finishing tracks by 50%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	22
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	91.6	62.1
NO. 1 PAINT PLANT	80.6	59.8
NO. 2 PAINT PLANT	51.3	40.4
LYSAUGHT PAINT PLANT	78.6	43.1
ADO 15 FINISHING TRACK	82.8	72.0
ADO 16 FINISHING TRACK	76.2	73.4
W/R FINISHING TRACK	75.7	67.0
J4 FINISHING TRACK	98.0	97.2
LOOP RECTIFICATION LINE	18.7	
LOW BAKE PAINT PLANT	48.3	
STORAGE PRIOR TO NO. 1 PAINT PLANT	86.3	
STORAGE PRIOR TO LYSAUGHT PLANT	46.1	
STORAGE PRIOR TO TRACKS	91.6	
STORAGE PRIOR TO DESPATCH BAY	4.8	
DESPATCH BAY	38.1	
OVERALL PAINT REJECTION RATE	681	
AVERAGE TRACK EFFICIENCY		74.5

STRATEGY ANALYSIS

STRATEGY ..Increase the paint rejection rate by 10%.

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL + 10%
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	95	68.8
NO. 1 PAINT PLANT	76.2	71.3
NO. 2 PAINT PLANT	62.8	48.9
LYSAUGHT PAINT PLANT	89.8	43.0
ADO 15 FINISHING TRACK	87.4	82.8
ADO 16 FINISHING TRACK	89.2	82.5
W/R FINISHING TRACK	81.3	76.1
J4 FINISHING TRACK	98.0	96.0
LOOP RECTIFICATION LINE	21.3	
LOW BAKE PAINT PLANT	56.8	
STORAGE PRIOR TO NO. 1 PAINT PLANT	73.9	
STORAGE PRIOR TO LYSAUGHT PLANT	71.3	
STORAGE PRIOR TO TRACKS	72.8	
STORAGE PRIOR TO DESPATCH BAY	5.7	
DESPATCH BAY	40.6	
OVERALL PAINT REJECTION RATE	.698	
AVERAGE TRACK EFFICIENCY		84.0

STRATEGY ANALYSIS

STRATEGY ..Reduce the Paint Rejection rate by 10%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL - 10%
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	92.8	68.3
NO. 1 PAINT PLANT	71.2	69.8
NO. 2 PAINT PLANT	33.2	31.6
LYSAUGHT PAINT PLANT	83.9	41.8
ADO 15 FINISHING TRACK	92.8	91.0
ADO 16 FINISHING TRACK	86.3	83.9
W/R FINISHING TRACK	90.4	87.7
J4 FINISHING TRACK	98.0	97.1
LOOP RECTIFICATION LINE	18.6	
LOW BAKE PAINT PLANT	51.2	
STORAGE PRIOR TO NO. 1 PAINT PLANT	72.5	
STORAGE PRIOR TO LYSAUGHT PLANT	74.1	
STORAGE PRIOR TO TRACKS	75.4	
STORAGE PRIOR TO DESPATCH BAY	5.2	
DESPATCH BAY	39.3	
OVERALL PAINT REJECTION RATE	.596	
AVERAGE TRACK EFFICIENCY		90.1%

STRATEGY ANALYSIS

STRATEGY ..Increase the time of the feedback control by 50%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	900 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	95.0	63.8
NO. 1 PAINT PLANT	75.6	62.7
NO. 2 PAINT PLANT	46.3	39.8
LYSAUGHT PAINT PLANT	82.1	42.6
ADO 15 FINISHING TRACK	80.2	77.0
ADO 16 FINISHING TRACK	79.9	74.2
W/R FINISHING TRACK	87.1	86.0
J4 FINISHING TRACK	98.3	97.1
LOOP RECTIFICATION LINE	19.6	
LOW BAKE PAINT PLANT	50.4	
STORAGE PRIOR TO NO. 1 PAINT PLANT	96.8	
STORAGE PRIOR TO LYSAUGHT PLANT	63.8	
STORAGE PRIOR TO TRACKS	72.1	
STORAGE PRIOR TO DESPATCH BAY	4.9	
DESPATCH BAY	40.7	
OVERALL PAINT REJECTION RATE	.671	
AVERAGE TRACK EFFICIENCY		81.2

STRATEGY ANALYSIS

STRATEGY ...Reduce..the.feedback.control.cycle time by 50%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26.0/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	300 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	91.6	68.4
NO. 1 PAINT PLANT	70.8	68.2
NO. 2 PAINT PLANT	53.6	41.9
LYSAUGHT PAINT PLANT	90.6	43.6
ADO 15 FINISHING TRACK	93.1	89.1
ADO 16 FINISHING TRACK	90.6	87.2
W/R FINISHING TRACK	90.5	86.4
J4 FINISHING TRACK	97.0	96.0
LOOP RECTIFICATION LINE	21.7	
LOW BAKE PAINT PLANT	56.2	
STORAGE PRIOR TO NO. 1 PAINT PLANT	75.6	
STORAGE PRIOR TO LYSAUGHT PLANT	71.3	
STORAGE PRIOR TO TRACKS	80.6	
STORAGE PRIOR TO DESPATCH BAY	5.6	
DESPATCH BAY	38.3	
OVERALL PAINT REJECTION RATE	.649	
AVERAGE TRACK EFFICIENCY		89.0%

STRATEGY ANALYSIS

STRATEGY Increase the allocation span by 50%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	= 30/HR.
NO. 1 COLOUR PAINT PRODUCTION RATE	= 26/HR.
FINISHING TRACK PRODUCTION RATE	= 25.9/HR.
STORAGE SIZE PRIOR TO NO. 1 PLANT	= 10.
STORAGE SIZE PRIOR TO TRACKS	= 44.
LOAD SEQUENCE FOR NO. 1	= ACTUAL.
PAINT REJECTION LEVEL	= ACTUAL.
SPAN OF ALLOCATION TO LOAD NO.1	= ACTUAL + 50%
OVERALL FEEDBACK CYCLE TIME	= 600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	= 35:15:5
DESPATCH CYCLE TIME	= 300 C.U.
LOOP LINE CYCLE TIME	= 30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	94.6	70.8
NO. 1 PAINT PLANT	81.3	72.1
NO. 2 PAINT PLANT	59.8	49.6
LYSAUGHT PAINT PLANT	91.2	44.6
ADO 15 FINISHING TRACK	100.0	98.7
ADO 16 FINISHING TRACK	98.7	96.5
W/R FINISHING TRACK	96.1	95.5
J4 FINISHING TRACK	100.0	98.0
LOOP RECTIFICATION LINE	23.2	
LOW BAKE PAINT PLANT	54.8	
STORAGE PRIOR TO NO. 1 PAINT PLANT	62.7	
STORAGE PRIOR TO LYSAUGHT PLANT	70.1	
STORAGE PRIOR TO TRACKS	89.6	
STORAGE PRIOR TO DESPATCH BAY	6.8	
DESPATCH BAY	42.9	
OVERALL PAINT REJECTION RATE	.638	
AVERAGE TRACK EFFICIENCY		97.5%

STRATEGY ANALYSIS

STRATEGY . Decrease the allocation span by 50%

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	= 30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	= 26/HR
FINISHING TRACK PRODUCTION RATE	= 25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	= 10
STORAGE SIZE PRIOR TO TRACKS	= 44
LOAD SEQUENCE FOR NO. 1	= ACTUAL
PAINT REJECTION LEVEL	= ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	= ACTUAL - 50%
OVERALL FEEDBACK CYCLE TIME	= 600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	= 35:15:5
DESPATCH CYCLE TIME	= 300 C.U.
LOOP LINE CYCLE TIME	= 30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	90.8	60.2
NO. 1 PAINT PLANT	57.2	51.3
NO. 2 PAINT PLANT	36.8	35.1
LYSAUGHT PAINT PLANT	80.7	41.3
ADO 15 FINISHING TRACK	72.2	69.0
ADO 16 FINISHING TRACK	70.9	62.6
W/R FINISHING TRACK	68.3	55.8
J4 FINISHING TRACK	98.6	95.6
LOOP RECTIFICATION LINE	19.2	
LOW BAKE PAINT PLANT	47.3	
STORAGE PRIOR TO NO. 1 PAINT PLANT	96.2	
STORAGE PRIOR TO LYSAUGHT PLANT	41.2	
STORAGE PRIOR TO TRACKS	60.4	
STORAGE PRIOR TO DESPATCH BAY	5.0	
DESPATCH BAY	32.4	
OVERALL PAINT REJECTION RATE	.637	
AVERAGE TRACK EFFICIENCY		69.8

STRATEGY ANALYSIS

STRATEGY Introduce a controlled batch sequence

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	CONTROLLED
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	94.9	71.2
NO. 1 PAINT PLANT	74.3	69.8
NO. 2 PAINT PLANT	44.8	34.2
LYSAUGHT PAINT PLANT	82.9	43.6
ADO 15 FINISHING TRACK	100	99.4
ADO 16 FINISHING TRACK	98.7	96.2
W/R FINISHING TRACK	100	99.2
J4 FINISHING TRACK	99.2	98.1
LOOP RECTIFICATION LINE	24.8	
LOW BAKE PAINT PLANT	62.1	
STORAGE PRIOR TO NO. 1 PAINT PLANT	59.8	
STORAGE PRIOR TO LYSAUGHT PLANT	84.6	
STORAGE PRIOR TO TRACKS	92.1	
STORAGE PRIOR TO DESPATCH BAY	7.2	
DESPATCH BAY	46.0	
OVERALL PAINT REJECTION RATE	.651	
AVERAGE TRACK EFFICIENCY		98.4

STRATEGY ANALYSIS

STRATEGY ..Sequence Test (a) Ascending reject rate order

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	CONTROLLED
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	95.0	70.4
NO. 1 PAINT PLANT	70.9	69.2
NO. 2 PAINT PLANT	54.6	45.9
LYSAUGHT PAINT PLANT	86.3	44.1
ADO 15 FINISHING TRACK	99.6	98.0
ADO 16 FINISHING TRACK	97.0	96.3
W/R FINISHING TRACK	97.1	95.5
J4 FINISHING TRACK	98.2	98.1
LOOP RECTIFICATION LINE	23.7	
LOW BAKE PAINT PLANT	56.4	
STORAGE PRIOR TO NO. 1 PAINT PLANT	64.2	
STORAGE PRIOR TO LYSAUGHT PLANT	82.9	
STORAGE PRIOR TO TRACKS	89.4	
STORAGE PRIOR TO DESPATCH BAY	6.0	
DESPATCH BAY	41.9	
OVERALL PAINT REJECTION RATE	.648	
AVERAGE TRACK EFFICIENCY		97.4

STRATEGY ANALYSIS

STRATEGY . Sequence Test (b). Descending reject rate order

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	44
LOAD SEQUENCE FOR NO. 1	=	CONTROLLED
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	94.3	69.8
NO. 1 PAINT PLANT	68.9	69.6
NO. 2 PAINT PLANT	56.2	47.0
LYSAUGHT PAINT PLANT	84.9	43.4
ADO 15 FINISHING TRACK	99.0	98.3
ADO 16 FINISHING TRACK	97.6	96.5
W/R FINISHING TRACK	97.3	96.2
J4 FINISHING TRACK	99.1	98.1
LOOP RECTIFICATION LINE	24.1	
LOW BAKE PAINT PLANT	57.2	
STORAGE PRIOR TO NO. 1 PAINT PLANT	69.5	
STORAGE PRIOR TO LYSAUGHT PLANT	80.6	
STORAGE PRIOR TO TRACKS	88.8	
STORAGE PRIOR TO DESPATCH BAY	5.4	
DESPATCH BAY	40.7	
OVERALL PAINT REJECTION RATE	.662	
AVERAGE TRACK EFFICIENCY		98.0

STRATEGY ANALYSIS

STRATEGY ..Sequence test (c) Mean of the two random sequences

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	10
STORAGE SIZE PRIOR TO TRACKS	=	40
LOAD SEQUENCE FOR NO. 1	=	CONTROLLED
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	95.6	70.4
NO. 1 PAINT PLANT	71.0	68.4
NO. 2 PAINT PLANT	51.2	48.1
LYSAUGHT PAINT PLANT	85.6	42.9
ADO 15 FINISHING TRACK	99.2	98.3
ADO 16 FINISHING TRACK	97.2	97.1
W/R FINISHING TRACK	97.0	96.0
J4 FINISHING TRACK	99.2	98.3
LOOP RECTIFICATION LINE	21.8	
LOW BAKE PAINT PLANT	52.7	
STORAGE PRIOR TO NO. 1 PAINT PLANT	68.6	
STORAGE PRIOR TO LYSAUGHT PLANT	81.3	
STORAGE PRIOR TO TRACKS	90.1	
STORAGE PRIOR TO DESPATCH BAY	6.1	
DESPATCH BAY	40.3	
OVERALL PAINT REJECTION RATE	.659	
AVERAGE TRACK EFFICIENCY		98.1

STRATEGY ANALYSIS

STRATEGY .... Increase store prior to No. 1 up to 12 and up to 61 prior to finishing tracks.

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	12
STORAGE SIZE PRIOR TO TRACKS	=	61
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600.C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300.C.U.
LOOP LINE CYCLE TIME	=	30.C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	93.7	73.2
NO. 1 PAINT PLANT	80.1	76.2
NO. 2 PAINT PLANT	63.5	50.2
LYSAUGHT PAINT PLANT	86.0	43.9
ADO 15 FINISHING TRACK	99.8	99.2
ADO 16 FINISHING TRACK	100.0	99.0
W/R FINISHING TRACK	99.8	99.5
J4 FINISHING TRACK	100.0	100.0
LOOP RECTIFICATION LINE	27.3	
LOW BAKE PAINT PLANT	57.9	
STORAGE PRIOR TO NO. 1 PAINT PLANT	81.7	
STORAGE PRIOR TO LYSAUGHT PLANT	82.4	
STORAGE PRIOR TO TRACKS	82.1	
STORAGE PRIOR TO DESPATCH BAY	5.9	
DESPATCH BAY	42.4	
OVERALL PAINT REJECTION RATE	.655	
AVERAGE TRACK EFFICIENCY		99.3

STRATEGY ANALYSIS

STRATEGY Increase store prior to No. 1 to 11; store prior to tracks to 48 controlled batching.

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	11
STORAGE SIZE PRIOR TO TRACKS	=	48
LOAD SEQUENCE FOR NO. 1	=	CONTROLLED
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U.
LOOP LINE CYCLE TIME	=	30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	93.2	72.6
NO. 1 PAINT PLANT	82.4	80.1
NO. 2 PAINT PLANT	65.2	52.7
LYSAUGHT PAINT PLANT	86.4	43.1
ADO 15 FINISHING TRACK	97.0	96.2
ADO 16 FINISHING TRACK	95.9	95.9
W/R FINISHING TRACK	97.4	96.5
J4 FINISHING TRACK	99.6	98.7
LOOP RECTIFICATION LINE	27.6	
LOW BAKE PAINT PLANT	59.2	
STORAGE PRIOR TO NO. 1 PAINT PLANT	91.6	
STORAGE PRIOR TO LYSAUGHT PLANT	90.1	
STORAGE PRIOR TO TRACKS	93.2	
STORAGE PRIOR TO DESPATCH BAY	6.8	
DESPATCH BAY	44.7	
OVERALL PAINT REJECTION RATE	.671	
AVERAGE TRACK EFFICIENCY		97

STRATEGY ANALYSIS

STRATEGY ..Increase store prior to No. 1 & main store up to 81

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	=	30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	=	26/HR
FINISHING TRACK PRODUCTION RATE	=	25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	=	15
STORAGE SIZE PRIOR TO TRACKS	=	66
LOAD SEQUENCE FOR NO. 1	=	ACTUAL
PAINT REJECTION LEVEL	=	ACTUAL
SPAN OF ALLOCATION TO LOAD NO.1	=	ACTUAL
OVERALL FEEDBACK CYCLE TIME	=	600 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	=	35:15:5
DESPATCH CYCLE TIME	=	300 C.U
LOOP LINE CYCLE TIME	=	30 C.U

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	94.8	74.1
NO. 1 PAINT PLANT	80.8	79.6
NO. 2 PAINT PLANT	65.3	51.8
LYSAUGHT PAINT PLANT	85.7	44.7
ADO 15 FINISHING TRACK	100.0	100.0
ADO 16 FINISHING TRACK	100.0	100.0
W/R FINISHING TRACK	100.0	100.0
J4 FINISHING TRACK	100.0	100.0
LOOP RECTIFICATION LINE	29.8	
LOW BAKE PAINT PLANT	60.3	
STORAGE PRIOR TO NO. 1 PAINT PLANT	86.2	
STORAGE PRIOR TO LYSAUGHT PLANT	89.3	
STORAGE PRIOR TO TRACKS	86.4	
STORAGE PRIOR TO DESPATCH BAY	7.2	
DESPATCH BAY	43.2	
OVERALL PAINT REJECTION RATE	.649	
AVERAGE TRACK EFFICIENCY		100

STRATEGY ANALYSIS

STRATEGY ....The final strategy....

PREVAILING CONDITIONS :

ELECTROCOAT PRODUCTION RATE	= 30/HR
NO. 1 COLOUR PAINT PRODUCTION RATE	= 26/HR
FINISHING TRACK PRODUCTION RATE	= 25.9/HR
STORAGE SIZE PRIOR TO NO. 1 PLANT	= 20
STORAGE SIZE PRIOR TO TRACKS	= 49
LOAD SEQUENCE FOR NO. 1	= CONTROLLED
PAINT REJECTION LEVEL	= ACTUAL
SPAN OF ALLOCATION TO LOAD NO. 1	= ACTUAL
OVERALL FEEDBACK CYCLE TIME	= 800 C.U.
DERIVATIVE RATIO PERMITTED PRIOR TO NO. 1	= 35:15:5
DESPATCH CYCLE TIME	= 300 C.U.
LOOP LINE CYCLE TIME	= 30 C.U.

RESULTS :

FACILITY	UTILISATION	EFFICIENCY
ELECTROCOAT	95.1	75.3
NO. 1 PAINT PLANT	80.7	79.9
NO. 2 PAINT PLANT	67.4	50.3
LYSAUGHT PAINT PLANT	84.3	43.8
ADO 15 FINISHING TRACK	100	100
ADO 16 FINISHING TRACK	100	100
W/R FINISHING TRACK	100	100
J4 FINISHING TRACK	100	100
LOOP RECTIFICATION LINE	23.9	
LOW BAKE PAINT PLANT	59.8	
STORAGE PRIOR TO NO. 1 PAINT PLANT	82.5	
STORAGE PRIOR TO LYSAUGHT PLANT	81.6	
STORAGE PRIOR TO TRACKS	82.1	
STORAGE PRIOR TO DESPATCH BAY	5.9	
DESPATCH BAY	44.6	
OVERALL PAINT REJECTION RATE	.656	
AVERAGE TRACK EFFICIENCY		100

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