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INFORMATION LETTER

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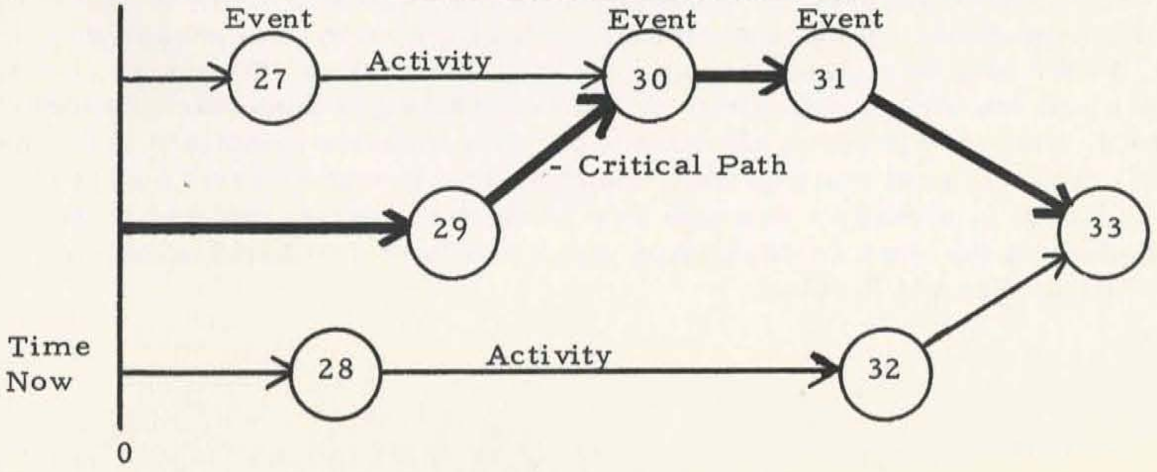
PERT - An Advance in Scheduling Technology

"The best laid plans of mice and men gang aft agley" perhaps describes the relationship between production scheduling and progress reporting better than any other phrase. A good production man knows that a perfect production plan cannot work unless coupled with a sensitive follow-up system to isolate potential trouble spots and indicate the need for corrective action. Problem is, this important principle of feedback frequently is not applied universally among all functions and when it is, the control and correction aspects may not be fully implemented.

Early in the Polaris missile program, project boss Admiral Raborn realized this when he was assigned the coordination responsibility for a most complex program: the design of a nuclear submarine along with the missile launching and guidance system. Instead of avoiding the seemingly insoluble problem of rigorous progress control, he appointed a task force which soon provided him with a set of graphically charted records and computer calculated time estimates for every milestone on the Polaris schedule, This maze of charts was called PERT, "governmentese" for Program Evaluation and Review Technique; their impact on Polaris is now history. The significance of PERT is measured by the fact that progress on an intricate weapons system covering large numbers of subcontractors could be controlled not only for physical but also intellectual activities. PERT, divested of its flossy nomenclature, is basically a scientific method of program evaluation, i.e., a continuous appraisal of performance in terms of plans and schedules as they are established to meet program objectives.

To begin the PERT analysis, a series of flow diagrams are drawn covering all phases of the program starting with the desired completion date and working back in time to "now".

Sample PERT Control Chart



Three factors are considered to have a major influence on progress: (1) resources, (2) technical performance specifications, and (3) time, of which only time is variable. Next, three elapsed time estimates are requested from every individual who will be responsible for contributing to some phase of the program: (1) most likely, (2) optimistic, and (3) pessimistic times. These are then reviewed for reasonableness and fed into a computer. Interpreted statements are printed out from the computer and screened by a technical direction team before presenting to management. A typical team is comprised of from two to twelve people including Quality Control, Production Control, Purchasing, Engineering, and specialists from other functional areas. Two possibilities are open to the manager: (1) make adjustments and trade-offs in schedules, resources, and specifications or (2) test the affects of different alternatives through simulation using additional PERT models. Approved decisions from either method are re-cycled by the computer and the whole process is repeated.

Out of all this, management is provided: a complete sequence and interrelationship for all events and activities in a program, a picture of the relative criticalness among different areas of effort, and their impact on end objectives, a statistical probability distribution which predicts the chances of meeting scheduled due dates, an integrated program summary on a continuous recycling basis, and alternative courses of action which are computed and analyzed before decisions are made. Production Control, constrained as it is by lead times, plant capacity, etc., can readily appreciate the importance of PERT as a complete planning and control technique with the obvious added advantage of measuring the time requirements for engineering and design work, and making it compatible in time to production requirements. For example, the cycle on a piece of test equipment includes among other things: design, quotation from vendors, contracting officer approval, and procurement. This is compared in PERT to the cycle of the part it will test: design, drafting, procurement, welding, etc. and a complete schedule sequenced for all events.

Early applications of this comprehensive scheduling evaluation technique have been to large-scale military and civilian engineering and construction projects. Light Military Electronics has introduced PERT to some of its work and found it cut one program's time from twenty-four to sixteen months; nine months were shaved from another. Missile and Space Vehicle has adopted this concept for NIMBUS, SKYBOLT and other current programs, and also in the formulation of proposals. Ordnance employs Pert to control cycle time in the design and manufacture of prototype radar antennae systems. Still in the embryonic stages of development, PERT may be expanded to include cost information, manpower skills, and other more precise standards. Critical Path scheduling techniques, as represented by PERT, also may produce significant benefits when its principles and concepts are applied to a typical multi-product short cycle General Electric business. As it stands today, it is already a valuable new production control tool and is designed to complement the work in simulation which has been developed in recent years by Production Control Service

Coming Meetings and Workshops

Systems Specialist Conference II The week of March 20 saw the kick-off of a new series of Systems Specialists Conferences designed to promote the exchange of current best practices among Materials Systems personnel in operating departments. As guests of the Armament and Control Section of the Light Military Electronics Department at Johnson City, New York, the first group of conferees established the format and plans for succeeding conferences. Upwards of sixty registrations were received for this inaugural meeting, indicating the strong desire among operating personnel for meetings of this type.

The need for the continuance of these conferences was unanimously agreed upon, as well as the desirability of a centralized catalog of all existing Materials systems within the General Electric Company. A design for such a catalog was discussed in some detail.

It was decided to hold each future conference at a different plant location with the participating departmental representative acting as a volunteer host and chairman for the meeting. In this manner, it was thought that a practical operational orientation would be brought to each meeting.

The next conference is scheduled to be held at the Range Department, Appliance Park, from June 12-24, at which time Feedback Systems will be one of the major topics under discussion.

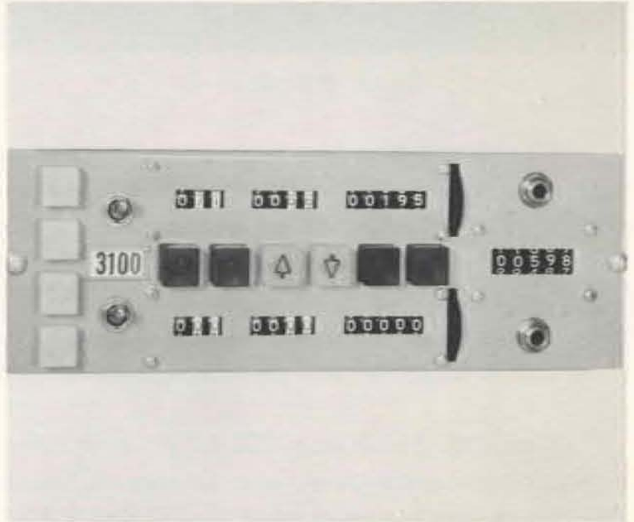
Inventory Management Practices Exchange Sharing the wealth of all the effective inventory control practices which are available within our large company is the aim of a new series of Inventory Management Practices Exchanges. Under the tutelage of an Advisory Council of eight representative Materials Managers, the Exchanges will be structured along product group lines. The first meeting, to be held June 26-28 at the Nassau Inn, Princeton, New Jersey, will be attended by Inventory Control personnel from the Industrial and Electric Utility groups. Personnel from the Consumer Products and Electronics groups will meet in the near future. The Exchange meetings will consist largely of selected presentations and roundtable discussions covering concepts and practices that have proven their effectiveness in controlling inventory in operating departments. Participants will arrive at the Exchanges fully briefed as to their content and are expected to contribute heavily to the discussion sessions and class exercises that follow.

Computer Department Announces GE 3100 and GE 3101 Data Collector Systems

The Computer Department recently announced the addition of two new products to its rapidly growing line of equipment designed to fill business' needs for integrated information processing systems. The GE 3100 and GE 3101 data collection and monitoring systems are communications networks linking factory and production control centers to provide management with the tools needed to exercise "on line" control of manufacturing operations. "Live" information representing the exact production status of each work station is automatically tallied and is instantly available for control of scheduling, dispatching, and inventory. The same data also may be used for payroll, cost, and wage rate purposes.

The GE 3100 system consists of just two basic units linked together by the necessary wiring and circuitry. They are: the Operator Control Station located at the work station and the Status Monitor located at the production control center.

Operator Control Station



Status Monitor

The Operator Control Station transmits signal impulses representing units of work to the production control center where they are recorded on digital counters and the operations monitor recorder. Piece counters such as limit switches, pressure switches, electric eyes, and flow gauges are mounted on tools and machines at the work stations to automatically record units produced.

The Status Monitor located in the production control center is connected directly to the Operator Control Stations. Status lights indicate set-up, running, and delay conditions of the work station. Separate counters tally set-up time, operating time, units produced, and delay time at the work station. Status Monitors are mounted in groups of twenty in cabinets at the production control center. Here in one place the status of each work station is instantly available for analysis and control.

The GE 3101 data collection and monitoring systems consist of a card reader sub-station and a data accumulator and output station linked by a pair of telephone wires.

Card Reader

Data Accumulator

The card reader accepts cards containing prepunched job and operator information plus dialed-in data from eleven multi-position selector switches which may cover variable items of information such as employees' number, pieces produced, and labor class code. The data accumulator located in the production control center compiles the data transmitted from a number of card reader sub-stations and transfers it to punched paper tape. Periodically, the tape is taken to data processing for analysis and preparation of reports.

The GE 3100 and GE 3101 systems are complementary and may be combined in varying configurations to serve the specific requirements of job and flow shops. The first major installation of the GE 3100 system will be at the Metallurgical Products Department in Detroit where 543 Operator Control Stations are to be installed in the Carbides Manufacturing Section. Delivery of component parts is scheduled to begin shortly with project completion in September, 1961. Other GE applications are currently under active consideration throughout the Company.

The new GE 3100 and GE 3101 systems provide production management with prompt and accurate feedback of current shop status, making "on line" production control a reality. For further information regarding these new products, contact the Computer Department, Phoenix, Arizona.

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PRO & CON features

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THE SIGNIFICANCE OF BUFFER STOCKS

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Buffer stocks have long been relegated to a secondary position in the analysis and management of inventories. Economic Order Quantities, ABC Analyses, Mechanized Stock Control and other approaches have successfully stolen the limelight. Part of this has been the result of a poor "press" since few have found it a glamorous enough subject to write about; but, more important, there has been a lack of basic communication ability since "buffer stock" apparently means something different to each person. It's called cushion stock, process stock, safety, backup, in-line, excess, protective, balancing, leveling, reserve, and so on. The use of these different words is really the clue to buffer stock's lack of appeal.

There are four major, different objectives that buffer or reserve stocks can serve whether we deal with raw material, in-process components or finished goods:

1) to prevent stock shortages caused by usage variation or lead time change

2) to permit use of economical lot sizes

3) to provide a variable cushion between two processes so that they may operate at different or variable rates or may have independent lot sizes

4) to permit more rapid response to changing product demand.

With this topic organization, buffer stock can now be subdivided, analyzed and new control techniques devised. In the balance of this paper then, there will be an operating definition given for each of these classes and an effort made to describe the manner in which an analytical solution can be reached for your particular problems. This is intended to be a survey of present knowledge and as such will require further reading or reference for detailed applications.

Insurance Stocks

The first objective, that of preventing stock shortages, has been much discussed in other papers; nevertheless it seems worthwhile reviewing some of the pertinent conclusions.

The size of the stock needed generally varies with the square root of both the rate of usage and the lead time. This problem has not been well studied yet in terms of stability of these two factors, but it is evident that, regardless of the magnitude, the buffer stock should also vary with the degree of uncertainty in the prediction of these elements. These factors can be analyzed so that the various materials and parts might be classified into:

- highly variable usage or lead time
- moderately variable usage or lead time
- minimal variation in usage and lead time

The results of this objective show up in the reorder point or frequency of order review. The measure of efficiency is the probability of being out of stock on one reorder cycle multiplied by the number of orders placed per year. This yields a stock-out per year ratio. It is therefore possible to select any desired degree of confidence and adjust the "safety" stock to compensate. This measurement shows the strong dependence that these stock levels have on frequency of reorder. With large order quantities, the frequency of being subjected to the likelihood of a stock-out is correspondingly reduced. Therefore, as a general rule the reorder point stock for "C" items should be proportionately smaller than for "A" items.

One item frequently overlooked is that there is a reasonable likelihood of obsolescence in holding high reserve stocks. This is dependent on the accuracy of future forecasts and ability to be forewarned of design changes.

Another potential source of "stockouts" is quality failure. To guard against needing 100 of a certain assembly and only having 95 in satisfactory condition, it is sometimes customary to start more of the assembly than is actually desired. This extra quantity is normally determined by examining historical experience and calculating the average failure rate for that class of parts. A technically sounder procedure would be as follows: Record the actual probabilities of having 1, 2, 3, etc. failures; approximate the cost involved in rectifying the shortage using overtime expense, added setup, longer inventory cycle, short-lot premium (if purchased), or whatever figure gives the lowest cost; next, compare the product of the "make good" cost and the frequency of spoiling 1 part with the cost of "running" 1 additional part times the frequency that the 1 part will not be needed (the probability of 0 failures). By performing this same computation for each possible number of failures the optimal protection level can be uniquely determined. It can be concluded that this type of buffer could be called "Insurance Stock" and is designed to achieve an implicit balance between inventory carrying cost and the cost of being out of stock considering the probability of each eventuality occurring. It is an insurance policy protecting against an out-of-stock condition.

Utilization Stocks

The second objective, the use of buffer stocks to permit the use of economical lot sizes, is normally not recognized as a true buffer stock problem. Rather it is treated as an independent computation related only to Inventory Carrying Costs versus paperwork, setup, and quantity discounts. But this is not the whole story. As mentioned under Insurance Stocks there is a strong correlation between frequency of order and size of buffer stock. It is also true that inventory tied up in large lots can be justified in terms of increased process utilization. Naturally, there is a reverse connotation: if completely flexible plants existed in which the order preparation and setup costs approximated zero (or were fixed regardless of product sequence or lot size) the economic lot size as presently computed would also reduce to zero. This would imply that the lot size could then be determined by external factors--stock availability, customer needs, transportation requirements, etc.

Therefore, it can be concluded that we are carrying "Utilization Stocks" to make up for our own or our vendors' lack of flexibility. We should carefully measure the price we are paying for our batch operation concept and make reasonable efforts to bring our preparation costs to a minimum.

Cushion Stocks

The third objective is to provide a variable cushion or "fluid clutch" between two processes so that they may operate at different or variable rates or may have independent lot sizes. This serves to "disengage" two successive operations, be they both shop processes, raw material and initial machining, or assembly and shipment.

This shows up just as strongly in the job shop as in the flow shop though in the job shop it is usually charged to transportation, waiting, or delay time. It seems appropriate that we examine this "cushion" stock in some detail to see how it functions, why it is needed and in what way it can be optimally determined.

Essentially, there are two major types of cushion stock: selective and in-sequence. The first is seen in virtually all job shops where, in effect, the parts are sorted or segregated by shop order and drawing number so that the next operation or process has full flexibility in selecting any one of the available jobs. The in-sequence buffer is usually observed where the parts or shop orders are locked in sequence on a conveyor line. The succeeding process may have flexibility in determining when it starts on the next part, but it must take the next one in-line; it cannot select what job it is to work on. There are, of course, all gradations and variations between these two extremes: side tracks, fixed dispatch rules, "kitties", etc. But we think of a cushion stock as providing some amount of process independence or of permitting a new degree of freedom. Since there are only two possible degrees of freedom: when a job is started and what job is started, we can compare these stocks in terms of their effect on these factors.

The "what" problem is being subjected to intensive study in the job shop through work in Production Control Service under Alan J. Rowe and independent explorations at UCLA in the Management Sciences Research Project. These are both efforts to quantify the relationships between various jobs and to uniquely determine an optimum selection rule. By testing or simulation with various rules it should be possible to determine the amount of "slack" time to be introduced in a parts schedule in order to permit achievement of the process objectives.

The "when" problem is sometimes solved by a fixed series of operation start and stop times. This is clearly seen in most "automated" lines and in many chemical or continuous processes. In other words every 20 seconds the line moves and the operator must work on the next selected product. This can also be seen in certain office systems where the scheduling is built on a fixed operation interval such as at Sears, Montgomery Wards, etc. If we have an in-sequence cushion stock with fixed start-stop times then the only purpose the stock serves is to prevent process shut-down in case of prior process failure.

It is axiomatic that once a cushion stock is depleted the only two ways by which it can be reestablished is through delay in the subsequent process or through excess speed in the prior process. This raises the issue as to whether the individual stations on an automated line should not have a "high-speed" mode in which they could operate for short intervals to establish optimal buffers. An interesting side light is that though this increased potential speed would not directly reduce the size of the cushion stock needed to cover process failures it would permit more frequent operation at maximum protection levels and hence might indirectly affect the stock position required.

The whole concept of cushion stocks is complicated by the use of multistage processes. We start with raw material cushion stocks to take care of inherent time variances through daily delivery schedules, truckload lots for transportation efficiency, efficient mill runs, etc. We can then have stocks at every intermediate stage of manufacturing and assembly, culminating in warehouse or shipping room stocks to recognize seasonal demand variation, distribution channel convenience, and customer order size. Of all the buffer stocks this is probably the most difficult to compute or analyze. There is some hope that through simulation testing some indication may be obtained of the proper magnitude and location of these cushion stocks. It also seems likely that further work in analyzing product and operation relationships may lead to logical computational procedures. Certainly, better information regarding machine breakdown, employee absenteeism, spoilage frequency, and operator effort will permit some intelligent mathematical determination of the risks involved.

The problem is also being approached from the other direction. To the extent that scheduling techniques can be improved and economical sorting and

selection devices designed it should become practical to increase effective machine output when needed so as to maintain a more balanced intermachine relationship. As we automate more of our manufacturing processes we find that the in-line or "product" layout permits significant reductions in the level of cushion stocks. Another program has to do with effective preventive maintenance programs allied with machine component standardization and unit replacement techniques. It's surely within the realm of possibility that we shall soon be able to set optimal lot sizes for each operation and use controlled cushion stocks to absorb the variable impact.

Cycle Reduction Stocks

The fourth and final objective for buffer stocks is to permit more rapid response to changing product demand. The extreme of this case is seen in objective (1) where a finished goods insurance stock may be maintained to lower the likelihood of running short. The purpose here though is more directly related to the reduction in response cycle by determining those stocks of raw materials, parts, and assemblies which will have the greatest impact on the delivery cycle.

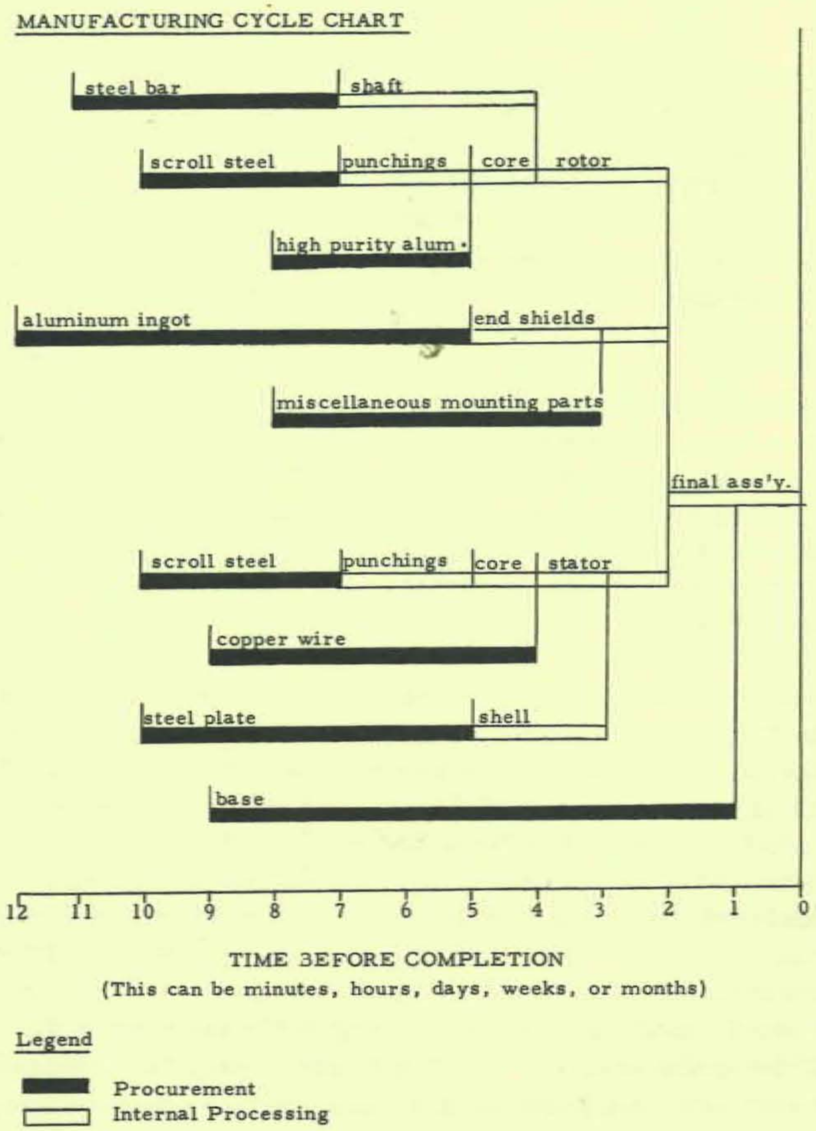
This problem arises primarily in a business where the final output product is not fully standardized and where customers can select from alternative features. It is illustrated by automobiles, fractional motors and electronic assemblies. Generally, it is characteristic of that class of products lying between "custom design" and standard off-the-shelf models. The customer usually will give the business to the company with the shortest delivery promise, other things being equal, so there's a real incentive to reduce the cycle to a minimum.

Now in talking about the delivery cycle we should include the total time it takes from the time the customer writes the order until he receives the desired product. This will consist of transmitting the order to the factory as well as transporting the material to the customer; although these two items fall outside the range of this discussion, it's worth noting that they are frequently overlooked in attempts to reduce cycles, and buffer stocks are created where they could be avoided.

The objective of a "cycle reduction" stock is the shortening of some of the elements in the total procurement-manufacturing program so that the net delivery time may be reduced. To do any type of effective planning of "cycle reduction" stocks it is necessary to have a good clear picture of the product structure and model to model relationships. Stocks do the greatest good where there is a maximum of standardization. It is also logical that the greater the number of models which use a particular component, the smaller the total insurance stock needs to be. For example, if our output is 1000 motors a week and only one diameter of bar stock is used for shafts we can very effectively plan our shaft stock needs and require very little insurance stock because the usage rate will be quite stable. This indicates that standardization and its recognition is implicit in a planned delivery cycle reduction program.

One other major point is the need for sound, unbiased forecasting of demand. Since, by definition, this type of stock is bought or manufactured in anticipation of actual orders all we have to go on is historical trends or experienced Marketing judgment.

Now let's put aside for the moment questions concerning the amount of detail and the time extent of these schedules and look instead at the single most important element in this portion of stock planning: the Manufacturing Cycle chart. The Manufacturing Cycle chart is a pictorial representation of the procurement, machining and assembly times involved in the processing of a Customer Order. The base is time before completion against which each material, part, and assembly is shown in terms of "goes-into" relationships. This is a time oriented picture of a product structure graph. Each individual line must begin at the junction of two or more parts or at the initial procurement of a "make from" material; the only alternative is to begin at a stock-pile, but since this is actually the problem we're trying to solve we'll assume that there is no stock of any sort yet. To illustrate some of these ideas let's review a sample product chart .



To analyze this chart we start at the left-hand side. If we're going to reduce the cycle by establishing proper stocks we've got to take some time off the longest cycle item. In this case aluminum ingot has to be ordered 12 time periods ahead of product completion. However, if we purchase aluminum ingot just 1 time period before the customer's order arrives we can reduce the cycle by 1 time period. This is really a "cycle reduction" stock since a commitment to a vendor is the equivalent of carrying extra inventory.

But to buy in advance of actual orders implies forecasting the demand. Here's where standardization comes in. If there is only 1 size and grade of aluminum ingot used in making all end shields and if all end shields use exactly the same amount of metal, then the only forecast necessary is by total volume. It is not necessary to get a 12 time period forecast if 1 time period in advance is adequate. Similarly it is not necessary to specify the forecast to an accuracy of 1/10 time period or even 5/10 time period--to the nearest 1 time period will be good enough. This has a very significant implication to market forecasting. It is only necessary to predict sales for: (1) the degree of variation needed to support "cycle reduction" stocks; (2) the time period in advance of order receipt for which stocks are prepared; and (3) the incremental time periods for which individual requirements will be ordered.

How far should we go in reducing the Manufacturing Cycle? Only as far as the customer will reward you adequately for your additional inventory costs and risks. Unfortunately this is most difficult to determine. The customer can reimburse you in two different ways: by giving you more business or by paying you a higher price per unit. Therefore, it is essential to obtain an evaluation of these two possibilities before embarking on extensive stocks of this type. Sometimes a trial program or discreet sales inquiries can give you a feel for the situation. On the other hand it's often a matter of having to match a competitor's delivery cycle and this, of course, gives you a concrete objective to shoot for.

Let's go back to the manufacturing cycle chart for a moment. Suppose we want to cut the cycle from 12 to just 6 time periods. This means preordering:

Aluminum ingot	6	time periods
Steel bar	5	" "
Scroll steel	4	" "
Steel plate	4	" "
Copper wire	3	" "
Base	3	" "
High purity aluminum	2	" "
Misc. mounting parts	2	" "
Punchings	1	" "
It also means prestarting shafts	1	" "

Now on some of these parts the number of variations might be quite large such as on bases or mounting parts. This is often especially true of manufactured parts. We have one additional tool to bring into the picture here and with it we can make a substantial dent in the problem. An ABC curve of individual part drawings by name showing yearly dollar usage will indicate clearly where the money should be placed. Instead of offering across-the-board a 6 time period cycle, we might offer this only on those models using a preponderance of "A" items and then fully support these models through preordering their parts. On models with mostly "B" items we might offer 9 time periods and on the others a 12 time period promise. A slightly different approach would be a volume of sales classification by model and arrange for cutting the cycle only on the high volume models.

This all leads to a very interesting rule: Never carry a cycle reduction stock of any item unless all longer cycle items are similarly covered.

For example, if we cannot preorder a certain base by 3 weeks it's wasteful from a cycle reduction standpoint to preorder or prestart the corresponding shafts or punchings. This one rule alone, carefully followed, could make a substantial impact on our inventory obligations.

This area of cycle reduction stocking has not in the past been carefully and separately analyzed, yet it is a problem close to the heart of management considerations: how can we most effectively service our product demand? Numerical analysis using the tools suggested will offer many opportunities for improved profit through logical planning.

Conclusions

With this summary of the impact and attack on buffer stocks it should be evident that there are now a variety of ways to improve and advance the hard core of our inventory control problems. The key apparently is to separate the inventory into its various segments according to the function which it serves. Only in that way can you uniquely determine the optimal inventory level for your business. The payoff is ready for those who can think through and analyze their need for buffer stocks.

PRO & CON features

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A SUMMARY OF THE PRODUCTION LEVELING PROBLEM

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Introduction

During the past three years, the problem of leveling production rates in the face of variable sales demand has received increasing attention from many organizations throughout the country. As a result of this concentration of effort both inside and outside General Electric, there has been substantial progress in describing the factors to be considered and also in defining the type of solution which should lead to best results. Initial work has also been done in evaluating particular production leveling programs in terms of an absolute attainable best program.

The purpose of this paper is to review the essence of this work on production leveling and point out the references which are particularly significant.

Cost Factors in Production Leveling

There are a large number of cost factors which enter into a decision on the best production rate. These costs can be organized in the following way:

(1) The cost of carrying inventory
(2) The cost of being out of inventory
(3) The cost of changing the production rate
(4) The unit cost under varying production levels

The cost of carrying inventory considers four factors; the first includes: space rented, heat, light, insurance, taxes on inventory value, depreciation of fixtures, handling costs, etc. These are described and analyzed in reference (1). The second kind of carrying cost relates to deterioration and obsolescence where, after a period of time, the product is worth less than the original value because of some change either in the usage rate or in the physical characteristics of the part itself. The third type of carrying cost is the required return on investment. This is the most complex factor in the analysis since it deals with the alternate investment opportunities for like risk. This is described in reference (2). The fourth factor is general business conditions which relates to the possibility of inflation - deflation effects on prices. The values for the cost of carrying inventory should often be 30-40% or even greater and has a major impact on the optimum inventory to carry.

The second major cost factor is the cost of being out of inventory; this is reflected in possible loss of business either temporarily or permanently or in the necessity for excess plant facilities in order to cope with high demand periods. The usual way of avoiding this inadequate inventory position is by carrying buffer or insurance stocks. This factor is most difficult to evaluate since it is a conditional problem and depends upon what your competition is doing. An implicit value can be obtained by computing the carrying costs for the insurance stock. This cost is discussed in references (3) and (4).

The third major cost is that of changing the production rate. This has been well analyzed in references (4) and (5). There seem to be three key elements. The first is the initial level from which the change is to be made, the second is the rate of change either up or down and the third is the magnitude of the total change.

Some of the factors to be considered when increasing the production output rate include employee training, additional services or staff activities, and extra shift costs. In decreasing the production level, the primary costs are those of higher unemployment insurance, "bumping" charges, excess staff and clerical expense, plant-community relations, and idle time costs. The unemployment insurance item is apt to be the largest single cost in decreasing production level, though occasionally cancellation charges on materials could be significant. On the upswing, the most important charges are normally the increases in unapplied direct labor because of higher training charges and the increased spoilage and rejections of bad parts.

Two interesting papers prepared on this same subject specifically describe how to compute these costs of changing production rate. (References 6 and 7)

The fourth area is that of the unit cost itself. This relates to the costs incurred in manufacturing a particular product at a certain factory operating level. The variation in value is primarily a matter of relative amortization of fixed expenses, though occasionally line balancing problems, material discounts or other special factors will have an effect. In computing unit cost, the one-time costs of changing the production rate should be omitted and only those costs of a continuing nature should be included. As a matter of fact, this is one area

that has not been carefully delineated in previous studies. There has been a tendency to lump all increased costs into the cost of changing of production level rather than separating them between one-time costs and continuing costs.

Determination of the Production Rate

Even with a careful effort to determine the various costs involved in changing or not changing a production program, this still only begins to solve the problem. Having the cost factors does not answer the question of how much should be produced next month, or what should the basic production program be. This section will attempt to answer this in some detail.

The production rate is a function of a variety of items. Included are: (1) estimates of sales, (2) accuracy of sales prediction both in total and by specific models, (3) seasonal or cyclical variation, (4) long-term trend effects, (5) previous months' production rates, (6) present inventory position, (7) desired inventory position, (8) facilities' investment for maximum production rate.

As you can see, there are a multitude of factors, some of which are of an inherently stochastic or variable nature. This adds a second degree of complication to our problem. If there were a completely fixed (deterministic) sales program, a specific best production schedule could be determined. It is possible that this type of thinking could be applied to a business such as Large Steam Turbine or Power Transformer where there is strong stability for a reasonable period of time and firm orders are often on the books out one or two years. But the bulk of General Electric's businesses are not of this type. We are dealing with inherently variable sales which varies both as to specific level and secondly, as to the natural variation about these levels. For analytical purposes, it may be desirable to separate these characteristics. Work described in reference (8) by Messrs. Mills and Singleton indicates that a best solution can be obtained where there are no trend effects or cyclic variations, by the application of a rule of the following type:

Production Rate for next period =
(A) x (last period's production) + (1-A) x (last period's sales)
Where A is a managerially determined constant equal to or greater than zero and less than or equal to one.

In this paper it is proven that this rule will meet or beat any other production rule postulated for any given objective in terms of production stability at the expense of inventory stability. Logically, it also shows that you can't realize lowest values for both objectives simultaneously. Similarly, in reference (9) it is shown that the only way a constant level of customer service can be realized is through permitting variation in the inventory level. If inventories have to be held fixed, then the customer service level will vary up and down.

The extensive work done at Carnegie Institute of Technology (see references 10, 11, and 12) comes up with a production rate formulation in terms of projected sales for the next number of periods and uses in the formulation specific values derived from cost analyses of the product line adjusted to reflect the particular trend and cyclical effect valid in that business. Other work in this same area has been performed at the Case Institute and by our own Hotpoint Division (reference 13). In the Hotpoint system, a restricted rate of decline and growth was introduced together with a balancing effect introduced by not fully correcting to the desired inventory level. This is done by weighting the answer in terms of the previous month's production rate.

The Evaluation of Production Programs

The most serious problem still facing us in any program is how sensitive it is to major changes up or down. It is evident from the material now available that most of the programs do reasonably well during periods of minor changes or minor adjustments. It is not nearly as evident that they will be successful in forewarning and compensating for major increases or decreases in sales level. As a matter of fact, many of them may be of the type which chase their own tail so that when business goes down badly they tend to discount this and maintain the production rate. Conversely, when business goes up strongly, they may think this is a somewhat temporary phenomenon and not make adequate compensation. Both of these results can be serious. Therefore, any use of production leveling equations must be carefully tempered by high level executive judgment on the apparent sales trends for the future. It should not be assumed nor be sold to management that this type of production leveling will in any way insure against a major catastrophe, but rather that other things being equal, this type of plan should result in minimum total cost for the actual sales level and therefore maximum profit.

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