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Production planning and inventory control in job order manufacturing

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THESIS

Production Planning and Inventory Control in Job Order Manufacturing

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This thesis was prepared under my supervision, and approval is hereby indicated.

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I

INTRODUCTION

A review of past and current business literature reveals that in recent years many new terms have become part and parcel of management terminology - terms that were rarely, if at all, used a decade or two ago. Words such as operations research, linear and non-linear programming, optimization, statistical decision-making, game theory, to mention a few, tend to become more and more frequently used. The outstanding common feature of all these terms is that they concern themselves with attempts to enlarge the tool-kit available to management for the solution of complex business problems.

The concepts that these new terms stand for - and their practical applications - have entered the business world via the military.[1] As with many new things, they first tend to become available only to the few - in this case, the giants of the business world. It seems logical that it would be the larger firms that would pioneer these newer applications, for the following reasons:

1. The larger the company, the more complex does the nature of its problems tend to become. As a result, problem-solving becomes more difficult.
2. As size increases, so do also the consequences of poor decision-making. More critical decision-making carries

with it a need for better problem-solving techniques.

3. With few exceptions, the larger companies have had to rely upon themselves for research and development. Considering the new applications to belong to these categories - at least in spirit - it would seem natural that the large companies would be the ones to pioneer them.
4. Large company size, and the financial resources that go along with it, make specialization desirable and feasible. This enhances the large company's ability to acquire the skills necessary for inventiveness and creativity in a highly specialized and complicated line of work.

The literature that deals with these newer concepts and their applications, and particularly that of value to the practicing executive, concerns itself essentially with the mathematical treatment of complex problems. Much of this literature is therefore beyond the comprehension of the non-technical business executive. This is particularly the case in the small or medium-sized company where lack of exposure to the philosophies involved has put the executive at a relative disadvantage. The lack of available skills within the organization, as they pertain to the subject matter, also poses a serious handicap to the proper interpretation of this literature. This makes answers to the following type of questions hard to find: How can one determine whether these new approaches can be beneficially applied in a company of this size and with these particular problems? How can these theoretical treatments or practical applications be translated into workable solutions to this company's problems? Does this company possess the skills necessary to make useful applications of these techniques? And, how does one go about implementing a program of this nature? In addition to this, most published applications of these techniques advocate or strongly imply the use of electronic data processing equipment. For the above reasons, the problem of evaluation, and even that of getting started, tend to take on overwhelming proportions.

A company which lacks the ability to find answers to the previous questions may find its growth potential seriously impeded due to:

1. Loss of competitive position relative to companies which benefit from these approaches in terms of improved decision-making and better quality solutions, and whose skill in application grows with experience.
2. Little or no opportunity to create a more modern and progressive management team such as would result from exposure through day-to-day contacts with co-workers possessing these skills.
3. A continuous absence of policies in areas where sound and clear-cut policies are highly desirable, if not imperative.

Against this background, it seems that we are here dealing with a topic of considerable importance to management in general, and to management of the small and medium-sized companies in particular. The purpose of this paper therefore appears to be a worth-while one - to demonstrate to management of the small or medium-sized company that there is little mysticism connected with these newer management concepts and approaches; that with the application of fortitude, common sense, and only an elementary knowledge of mathematical and statistical techniques, workable solutions to many complex management problems can be found.

In order to demonstrate this, the writer has selected an application made by the Huyck Felt Company, a medium-sized company manufacturing a specialized industrial textile product. This company made its first application of an operations research technique in 1958. As a case study centered around this application, it should show that even in a relatively small company, one can go a long way toward sophisticated management without a formal operations research team, and without availability of electronic data processing equipment.

The paper will deal with the application itself, how it got started, what were the factors that contributed to its success, and the direct and indirect benefits accrued to the company.

The application to be dealt with has to do with production planning and inventory control. The product is papermaker's felt, a highly engineered textile product, manufactured to customer specifications. As a carrier of the paper stock through the papermaking machine, it plays an important part in the manufacture of paper. Its construction governs the life of the felt itself, the attainable speed of the paper machine, and the quality and appearance of the finished paper. Each paper machine utilizes several of these felts, each felt position requiring felts of different construction and dimensions. Due to different manufacturing techniques, similar machines in different paper companies will require different felts. For all practical purposes, there are as many different felts required as there are felt positions available in the paper industry. In addition to this, the paper companies prefer to order felts from several sources of supply, and design changes are frequent for competitive reasons. Felt manufacturing therefore becomes job order manufacturing at its extreme, with a high degree of product diversification and very few repeats. As price differences between felt companies are small, they compete basically on felt performance and delivery service. Competition on felt performance requires frequent design changes and this is in conflict with maintenance of a competitive delivery service.

As the paper companies do not stock their felts, and since design changes and uncertainty of repeat orders make it undesirable for the felt maker to stock them, little or no finished goods inventory exists. In order to shorten lead time in manufacturing, great emphasis must be placed on control of parts inventories, in this case inventories of yarn. By weaving, yarns become assembled into the grey felt which in turn has to go through several finishing operations before it becomes shippable. The industry, the company, the product and its processes will be covered in adequate detail in the thesis proper.

Since the nature of the business requires great emphasis on planning of yarn production and control of yarn inventories, it is intended that this area should become the focal point of the paper. Prior to application of new control techniques, this area posed a major problem to the company because of inventory size, poor inventory balance and obsolescence. A contributing factor to these problems was erratic demand for yarns, not only due to customer ordering practices, but also due to frequent changes within and expansion of the number of yarns used.

Part of the solution to these problems had to be sought in the classical "when" and "how much" of production planning and inventory control. More specifically, the questions foremost in the production planner's mind are:

WHEN shall I reorder the next batch or lot? And, HOW MUCH should I reorder when I do? Every decision to manufacture involves the finding of answers to these two questions; the quality of these decisions is no better than the quality of the answers found.

The thesis will show how the economic lot size theory was applied to determine the "when" and "how much". Also discussed will be the analysis that had to precede this application for the purpose of determining which yarns were controllable through these means. This lead to a sub-division of yarns into three groups depending on activity rate, with the economic lot size system applicable to the group with the highest activity rate. The conventional application which consists of a balancing of inventory carrying charges and ordering costs did not meet the bill; for delivery reasons, a third factor - the application of a predetermined stock-out risk - had to be superimposed. The paper will discuss the mathematical treatment involved and also the construction of the tools necessary to make maintenance of the system possible with the skills available in the planning department.

The yarn groups with the lower activity rates had to be controlled by more arbitrary means. These groups contained the slow or non-moving inventory items, many of which had a tendency to be forgotten in stock. Theoretically, these inventories should be small. However, due to design changes in the felt after the yarn had been made, and due to demotion of a yarn from a group with a high activity rate to one with a lower rate - carrying existing inventory with it, there was a tendency for these yarns to pile up in stock. A new procedure was set up to identify these yarns and to bring them to the attention of the design department so as to maximize their chances for incorporation in felt designs. After the yarns had been subject to a screening procedure for a predetermined length of time, any unused portions of the residual lots would be disposed of. This disposition point was determined by the use of probability mathematics so as to minimize the losses to the company.

Traditionally, sharing of information between companies in the felt industry has been kept to a minimum. Due to this practice, a company policy has been established which precludes the publication of what by the company's definition is classified information. For this reason, certain information pertaining to manufacturing costs, production volume, product and processes cannot be divulged. As one is here more concerned with principles, and less with exact magnitudes, the writer feels that this factor detracts little, if anything, from the value of the paper.

II

PAPERMAKER'S FELT - A LITTLE-KNOWN PRODUCT

The company we are concerned with is a textile manufacturer, manufacturing woven products. Its main products are papermaker's felts - woven felts for use in the manufacture of all kinds of paper. Papermaker's felts may not be generally known and will therefore stand some explanation.

According to Chinese records,[2] Tsai Lunn first made paper by boiling and then stamping with water in a mortar, fibers of hemp rags, ropes or fishing nets. The beaten pulp was then spread out on a piece of loosely woven fabric through which the water was permitted to drain off. This left on the fabric a wet web of fibres which could be peeled off and dried in the air. These records describe, not only the use of the papermaker's felt of some 1900 years ago, but also a method of manufacturing which were to continue, with only few improvements, through the 18th century. Throughout this period, paper was made by hand, and a woven fabric was a necessary tool of the papermaker.

It was in the early 19th century that the paper-making machine, as we know it today, was introduced and papermaker's felt was from the beginning an essential part of the operation. When paper-making went modern - with the introduction of the wood-pulp process in the late 1860's and early 70's - new demands were made on papermaker's felts.

Since that time, the feltmaking industry has steadily kept pace - by persistently exploring the factors controlling water removal, durability, and paper quality - and by continuously striving to translate its findings into better paper, greater production and lower costs.

The white paper, in its early stages, in the paper-mill,has been likened in appearance to milk. The "milk", so called, after reaching the paper-making machine, flows onto a broad wire screen, which runs in the form of an endless belt. Here a large part of the water content passes away through the wire meshes, leaving behind the white of the "milk" which is paper. At the end of its travel along the wire screen, the wet paper is still not strong enough to support its own weight. The fragile sheet is picked up and carried along by a series of two or more woolen belts. These are the papermaker's felts.

A papermaker's felt, unlike "true" felt, is a woven fabric, designed to act at the same time as a filter and as a carrier of the paper from one portion of the paper-machine to another. In its design, every effort is made to produce a fabric that will be very strong and yet porous, so that the water may pass through readily.

The fabric is composed of a warp yarn, running lengthwise and giving it the longitudinal strength necessary to turn the movable parts of the paper machine such as felt rolls, cylinder moulds, auxiliary press rolls, etc. The filling or weft is yarn woven into the felt crossways, and adds much to the strength of the fabric, although its chief function is to form a cushion agains which the paper may be pressed while passing between the press rolls.

The average piece of woolen cloth is finished 54" wide, whereas papermaker's felts are as wide as 340" and as long as 300 feet. These broad felts are designed to run on some grades of paper, at speeds of 3000 feet or more per minute, producing a sheet of paper, in some instances as much as 20 feet wide. This corresponds to a rate of approximately a mile of paper every two minutes. With such production speeds, the woven felt must be well near perfect, both in its design and construction. It should also be realized that scarcely two kinds of paper can be made to good advantage on the same design of felt; that lack of standardization in sizes of papermachines requires a wide range of felt sizes - all of which tend to tremendously increase the problems of the felt manufacturer. In addition, a difference in paper mill practice, a change from one type of roller cover to another, and an addition of a new paper machine accessory, may all call for a different design felt - even on the same kind of paper machine, making the same kind of paper.

The general term "paper" includes, to give a few types, news, writing, book, wrapping, roofing and general printing, as well as a large paper field known as "board". Board embraces cartons, wall boards, ticket stock, etc. It will be seen that this broad range of papers, with its varying demands upon the felt manufacturer, not only calls for a highly specialized and diversified knowledge of textile design and manufacturing, but also poses several problems from a production management point of view.

III

THE INDUSTRY AND THE COMPANY

Although a branch of the textile industry, the felt making industry suffers few of the ailments generally associated with the "normal" textile industry. The "feast and famine" conditions for which the textile industry is so well known - indicating a strong sensitivity to fluctuations in the economy as a whole - are virtually non-existent in the felt making industry. Generally, the textile industry is operating in markets where there is stiff competition, directly and indirectly, for the consumer dollar, and where the pressures of foreign competition cause small profit margins and profit squeezes. In addition, the textile market has been invaded by many new products - viz. paper and plastics - which partly or completely have replaced a number of the conventional textile products.

Servicing the paper industry, the papermaker's felt industry suffers few, if any, of these disadvantages. Due to the tailor-made nature of the papermaker's felt and the close cooperation required between the feltmaker and the papermaker, the problems of foreign competition - at least on the domestic market - is negligible. To date, no substitute has been found for the conventional papermaker's felt, nor is there evidence of any forthcoming revolution in this field.

Population growth, raised standards of living, creation of new demands for paper through education of the consumer, and the development of new paper products, have made the paper industry one of the fastest-growing industries in the world. One would expect, therefore, that the papermaker's felt industry would grow at a corresponding rate. This, however, is not the case. Despite its close tie-in with the paper industry, the papermaker's felt industry is not a growth industry; at best, it can be described as a stable one. During the last 40 years, paper production has increased by 425 per cent, whereas, during the same period, production of papermaker's felt has increased by only 100 per cent[3]. This corresponds to a 60 per cent reduction in pounds of felt used per ton of paper. This remarkable situation is the fruit of a continuous effort on the part of the feltmakers to improve the quality of their product and to increase its life on the papermaking machine. It has happened despite more stringent requirements with regard to the quality of paper, calling for replacement of a felt at an earlier stage of wear than would otherwise be the case, and despite a considerable increase in speeds of the papermaking machines, tending to increase this wear.

In this country, there are eleven companies engaged in the manufacture of felts for the paper industry. For the great majority of these companies, felt manufacturing is their main line of business. There are some instances where feltmaking is a sideline only.

Competition in the industry is concentrated on quality, and on technical and delivery service. The implications of this will be treated in some detail in Section IV. Price is a less important factor from a competitive point of view and tends to become of still lesser importance as paper production per pound of felt increases.

Entry into the industry is extremely difficult. In many respects, manufacture of papermaker's felt is the craft it used to be almost a century ago. This, and the relatively small size of the industry, are factors which make the craft skills required for certain manufacturing operations almost impossible to find in today's labor markets. Long training periods are required for developing new labor. Small size also affects the supply of the highly specialized engineering knowledge required for felt design and manufacturing. Weight and bulkiness of the product at the later stages of the manufacturing cycle call for machinery of mammoth size as compared to other branches of the textile industry. The capital investment in machinery which under normal circumstances would be large, is further increased by the fact that this machinery must be custom made. Small industry size makes the industry relatively unattractive to textile machinery manufacturers and precludes mass production of this machinery. Furthermore, the paper manufacturer, to a large extent, purchases felts on the basis of the confidence he has in the felt manufacturer. Although this consideration is probably always valid in the purchasing of industrial supplies, it appears to be of greater importance when it comes to papermaker's felts than is normally the case. Since the economic consequences of a poorly performing felt on a paper machine are significant, the papermaker would be very reluctant to turn to new and untested sources for the supply of his felts.

The 1960 sales volume of papermaker's felts made in the United States amounted to about 55 million dollars. Of this, the Huyck Felt Company made about 25 per cent, making it one of the largest manufacturers of papermaker's felt in the world[4]. It is a two-plant company with its main plant located in Rensselaer, New York. The other plant is located in Aliceville, Alabama. The company has about 1100 employees, with production capacity of the two plants divided about sixty-forty in favor of the Northern plant.

The felt company, which is the original company of the recently created Huyck Corporation, has been in business making papermaker's felts since 1870. Its plant in Rensselaer is a 3-story building, constructed in 1904, and suffering from the type of inefficient layout, which from today's management point of view was built into a plant of that vintage. The Alabama plant, on the other hand, was constructed in 1956, and has a modern one-floor, straight-line layout.

It would seem that a relatively small company which has been in existence this long, in a field where it largely has had to rely upon itself for technological developments, would tend to stagnate and get "bogged" down with traditions. That this is not so, is illustrated by the following statement from Fortune Magazine:[5]

> In an age of the corporate behemoth it is fashionable to lament the passing of the small company. The obsequies seem a bit premature because in any single year some 400,000 new companies, mostly small, come into being as others pass from the stage. Moreover, there are certain small companies that show a remarkable adaptability and staying power. Take in this connection the Huyck Corporation. For ninety years it has operated with a firm grip on a congenial industry in a market so little known that it appears to be a backwater of the American economy. But it is amply demonstrating how a small company may keep abreast of the tide of industrial development; and it is now in the middle of an interesting effort to change from a small company with a limited product to a larger company with a big future.

The implications of the industry and company makeup - from a production management point of view - will be dealt with in Section IV. Prior to this, and particularly for the benefit of the reader who is uninformed about textile operations, it seems desirable to treat, at least sketchily, the technical processes involved in the manufacture of papermaker's felts. These processes are basically the same as those employed in the production of other woven fabrics. But there are some differences, the most significant of which are due to[6]:

1. Large dimensions of felts
2. The fact that each felt is processed as a separate entity
3. The degree of precision required in the manufacture of felts
4. The endless construction of felts, requiring devices in the finishing process which are unusual in other branches of the textile industry.

The large dimensions of felts - the largest of which are about 300 feet long and 340 inches wide, weighing about 2500 lbs. - call for special machines which will completely dwarf all normal textile machines employed for the same processes.

For the purpose of this paper, it seems most logical to divide the manufacturing processes into three groups, as follows:

A. Yarn Manufacturing - the conversion of fibres from their natural state into continuous, even, twisted strands called yarn. The major operations are sorting, scouring, preparing, carding, spinning and rewinding.

B. Fabricating - the conversion of yarns into woven fabrics which are endless and ready for subsequent finishing operations. This conversion operation is completed by a series of processes. For felts woven flat in the loom, these include warp dressing, weaving, burling, joining and hooking. However, felts which are woven endless require only warp dressing, weaving and burling operations to obtain the desired product for the finishing department.

C. Finishing is a series of conversion operations which transforms the woven grease felt into the finished felt which must satisfy the specifications of the customer. There are four basic processes: fulling, washing and treating, gigging and drying.

As dictated by the scope of this paper, more emphasis will be placed on the yarn manufacturing processes than on those employed in the fabricating and finishing operations.

A. YARN MANUFACTURING

1. Sorting

From the vast assortment of wool available on the wool market, the types and grades of wool required for each variety of felt must be selected. Each fleece contains wool of various grades, each suitable for a particular purpose. The separation of these several grades of wool contained in a single fleece is called sorting. The operation is performed by hand.

2. Grease Blending

Blends of various grades of wool are made to obtain certain yarn characteristics. These blends are carefully selected to obtain the desired characteristics of the yarn going into a specific felt. The wool components going into each blend are placed in successive layers to insure good blending. The entire blend is made up of a number of these repeating layers. The grease blends are cut vertically and fed into the next operation.

3. Scouring

Before the stock is scoured, it must be opened up, as the greasy wool is still in clump form as received from sorting. The wool pulled from the grease blend is fed into a wool opening machine. This machine opens the stock and ejects it into the scouring train on the floor below. Scouring is a continuous operation used to remove the dirt, oil, grease, suint, salts, vegetable matter, etc. present in the wool. A detergent is used as the cleansing agent in the scouring solution. The wool is cleaned as it passes through successive stages of emersion and squeezing actions, followed by a final rinsing in warm water and a squeezing out of the excess moisture. The stock is then thoroughly dried, opened, and dusted before proceeding to the preparing operation.

4. Preparing

Preparing involves the mixing, oiling or lubrication, and opening of the stock into a homogeneous mass. This operation is performed on a machine called a mixing picker. Some of the blends which are made "in the grease", are scoured and run directly through the mixing picker from which they are blown into bins ready for the next operation - carding. Other blends made "in the grease" are modified at this point by addition of waste and/or synthetic fibres. The synthetic fibres most commonly used are nylon and dacron. If the original blend is to be modified, the wool received from scouring are stored in bins and are fed into the mixing picker along with predetermined additions of the other components.

5. Carding

Carding is the operation that converts the mass of blended fibres into even strands suitable for spinning into yarns. In addition, the carding machine is designed to complete the blending on a fibre to fibre basis and produce roving (i.e. untwisted strands of fibres) free of vegetable matter and neps (i.e. small lumps of intertangled fibres). It accomplishes these objectives in a continuous manner. The picked stock is fed by hand from bins of varying capacities into the feed end of the card, passes over and through series of rollers covered with card wire which is pointed and bent in specific directions. The stock emerges from the carding machine proper in the form of a web of predetermined density. This web enters a "condenser" where it is split up into strips. These strips or "roving", so called, are wound onto spools, 30 strips to a spool, which are transported by means of overhead rails to the spinning department.

6. Spinning

Spinning is a continuous process of drafting, twisting and winding the strands of roving delivered from the card, converting them into yarn. The style of yarn produced is determined by the blend, the thickness of the roving delivered from the card, and the degree of draft and turns of twist applied by the spinning frame. One spinning frame holds five card spools at one time. As each card spool holds 30 strands of roving, this means that 150 strands of roving can simultaneously be converted into 150 strands of yarn, all with the same draft and turns of twist. One spindle is required for each strand, each spindle holding a bobbin (a wooden core onto which the yarn is wound). One doffing cycle - the time required to fill up one set of 150 bobbins and removing them from the spinning frame - follows the other, making the process for all practical purposes a continuous one. After removal from the frame, the full bobbins are placed in baskets, ready for the next operation.

7. Rewinding

After the single yarns have been spun, they must still undergo further processing before they are suitable for use by the fabricating department. There are two distinct operations which the yarn may be required to undergo, viz. twisting and winding.

a. Twisting

Twisting consists of plying together two or more yarns to obtain a stronger, heavier yarn construction. A twisting frame is similar in construction to a spinning frame, except that spinning bobbins take the place of the card spools, and there is no drafting. Two or more spinning bobbins are required for each twisting frame spindle; the exact number depends on the ply required. All yarns do not have to be plied as single yarns suffice in some felts.

b. Winding

In this process, warp yarns are transferred from spinning or twister bobbins to intermediate spools preparatory to the warping process. Filling yarns are transferred to bobbins or cops - long, thin yarn packages to be used in the loom shuttles for weaving. Since all yarns must be used in either warp or filling of the felt, at least one of these operations is mandatory.

B. FABRICATING

1. Warp Dressing

In this process, a stated number of yarn threads are transferred from warp spools, first to large reels and from there to a warp beam. The loaded warp beam is taken to its designated loom preparatory to the weaving process.

2. Weaving

The beam carrying the warp yarn is placed in the back of the loom. Each yarn strand is threaded by hand through the eye of a wire heddle in a harness frame. There are several harness frames in the loom, and each strand of yarn is threaded through the heddles of these harnesses in a predetermined order. By alternate raising and lowering of these harness frames, the desired weave or design of woven fabric is obtained. A pattern "chain" with rollers, definitely arranged, controls the rise and fall of the harness frames.

This operation may be likened to a piano player roll with its series of perforations. So long as the same chain is used, the loom will play the same "tune", that is, produce the same weave.

The soft filling threads are carried back and forth across the loom and interlace the warp threads by means of a shuttle. After each interlacing of the filling yarn, the harnesses change their relative position causing the filling yarn to be firmly interlocked between the warp threads.

Felts are either woven endless, in belt form, or woven in long pieces and the ends joined together later by hand-weaving, to produce the belt form.

In the case of endless felts, the fabric is woven in the form of a flat tube, the diameter of the tube determining the length of the felt. Being woven in tube form, it is possible to cut off felts of any width, the length, as said before, being fixed.

Many lengths, types, and weaves of felts do not lend themselves to endless weaving. Here, the fabric is woven to the required length, with the warp threads extending from each end as fringes. These fringes are then woven together by hand, completing the belt form.

3. Burling

When the woven fabric comes off the loom it does not look like a felt at all, but like a piece of burlap. In the burling department, each felt is inspected to make sure that not even the slightest imperfection is overlooked. The fabric is drawn over a perch roll while the inspector looks through it to the light. This way, any variation in weaving can be readily detected. When found, it is immediately corrected.

4. Joining and Hooking

This process is the weaving together by hand of the fringe ends of the woven flat felt to form an endless belt. The corresponding yarn ends are alternately drawn up into the fabric for a given length, following the same pattern of interlacing as that accomplished in the loom. Hooking consists of looping the last few inches of each end back into the felt, thereby fixing each end and preventing the join from slipping open.

C. FINISHING

1. Fulling

The shrinking or fulling property of wool is a matter of common knowledge. On this peculiarity of the wool depends very largely the industry's ability to make papermaker's felts. When the felt is woven, it is not only longer, but much wider than the finished size. In the heavy fulling mills, with the application of soap, moisture and frictional heat, the shrinking or fulling process takes place until the felt is shrunk to almost finished size for the particular paper machine for which it is made. The fulling process gives the felt not only thickness, but much greater strength and resistance to abrasion and to the other forces that act upon it on the paper machine.

2. Washing and Treating

Washing involves the removal from the felt of all oil and grease stains which it has picked up during processing, and of the soap used in fulling. Treating may be required after washing and involves chemical modification of the properties of the felt to meet certain requirements with respect to dimensional stability and wear resistance as may be specified by the customer.

3. Gigging

This process is done by means of a vegetable burr called a teasel. By means of these teasels, set at an angle and riding free in position, the fibres are gently combed out to the surface of the felt, forming the kind of soft nap or cushion which is so necessary for the manufacture of all kinds of print and writing paper and for many grades of coarser paper.

4. Drying

The felts are dried by means of a steam heated cylinder. During the drying process, the felt passes over and around the driven steam heated cylinder and a carrier roller. The carrier roller which is movable on tracks, is positioned so that the felt is drawn out to a specified length and tension. This is the length and tension used on the paper machine.

Subsequent to drying, every felt is inspected for any imperfections that may have developed during the finishing process. The felts are then hung in a conditioning room overnight to provide the opportunity to partially relax as well as regain proper moisture condition. After weighing, the felts are packed and stored for shipment.

IV

PRODUCTION PLANNING AND INVENTORY CONTROL AS DETERMINED BY CUSTOMER ORDERING PRACTICES, THE PRODUCT AND THE MANUFACTURING PROCESSES

A. CUSTOMER ORDERING PRACTICES

Company records indicate that in this country there are about 800 paper mills, 1500 paper machines and 3800 felt positions. Competition in the felt industry centers around the objective of getting at as many of these felt positions as possible.

As downtime on a paper machine is an expensive proposition, it is a matter of great importance to the paper manufacturer to have his machine positions covered with felts at all times. Since the felt manufacturer is as vulnerable as any other manufacturer to strikes, acts of God and other situations which would necessitate curtailment of production and deliveries, the paper manufacturer naturally attempts to protect himself by relying on more than one source of supply for felts. Although he, at a given time, may give preference to one supplier, there is always at least one other supplier who is familiar with the papermaker's requirements for each of his felt positions and who stands ready to satisfy these requirements on short notice. In addition, and in order to make it possible for such alternate suppliers to keep their knowledge of the papermaker's requirements up-to-date, the papermaker will frequently switch an odd order from his main source of supply to such an alternate supplier. If on such occasions the felt delivered from an alternate source were to prove itself superior to that normally obtained from the main source, the papermaker would likely change his preference from one supplier to another. Due to this situation, the felt manufacturer is continuously exposed to the risk of losing felt positions. His best means of minimizing this risk is by prompt delivery of high quality felts. One significant feature of this situation, of course, is the lack of assurance he has for repeat orders for felts for a given felt position. The situation is also one, among several others, which is responsible for the high frequency of design changes in the feltmaking industry.

The number of felts required for each felt position during a given period of time depends on the features of the particular position and on the quality of the felts clothing it. The life expectancy of felts may vary from one to forty days depending on these factors. Due to the fact that the longer the life of a felt, the more attractive does it become to the paper manufacturer, it follows that as soon as one feltmaker develops a felt with a record life on a given felt position, competition must follow suit and improve its designs if it wants to compete for that particular position. A situation is created which tends to increase the flux in the product-mix as far as the individual felt manufacturer is concerned.

A second factor which taxes the design effort on the part of the felt manufacturer is the changing technology within the paper industry. New paper machines may call for felts of radical design, and, as pointed out in Section II, only a minor change within an existing paper machine may require a redesign of the felts that clothe that machine.

Thirdly, design changes are required by changes in the quality of paper produced. Many new paper products have been developed in recent years, a number of which are gaining in popularity in the consumer market. A typical example of such products are tissue papers for towels and napkins.

Lastly, design changes stem from the felt manufacturer's desire to increase his know-how and the incorporation of this increased know-how into new designs. So far, it has not been possible to reproduce paper mill conditions on a laboratory scale. As a result, experimental felts are designed which then become tested in the field. These experimental felts are of conventional dimensions and must be manufactured on the same machinery as regular production felts.

The paper manufacturer is reluctant to inventory felts. There are several reasons for this of which at least three seem outstanding. These are:

a. To keep inventory costs down

b. Due to competition on felt life and quality, he hopes to benefit to the greatest possible extent from the new felt designs continuously developed by the felt manufacturers

c. Traditionally, the felt industry has competed on delivery service. For this reason, the papermaker knows that the felt industry is ready and able to supply felts on short notice.

Orders for felts are of four main types. These are, in order of frequency:

1. For a promised delivery date
2. Make and hold. The felt manufacturer is to make the felt and hold it until the papermaker notifies that he wants to take delivery
3. On a rush basis
4. Standing order. The feltmaker is to deliver one or more felts at predetermined points of time, say, four felts every three months. This arrangement would remain in effect until the customer notifies to the contrary.

Orders of type 1, 2 and 3 may be for one or more felts; type 4, of course, will always be for more than one felt.

Due to the previously described inventory policy in the paper industry, small unit orders would be an expected result.

Approximately 65 per cent of all orders are for one or two felts, and approximately 95 per cent of the orders are for four felts or less. This is with the exception of standing orders which are open-ended, but includes the standing order felts which are required for delivery at a given point of time.

It should be noted that standing orders are frequently changed or cancelled and that it is therefore risky to release these orders for manufacturing too far ahead of delivery time. Some freedom exists, however, for releasing these and make-and-hold orders at a time when they can be combined and manufactured with other orders, where it appears economical to do so. In such cases, decisions involve the weighing of risk of design change and order cancellation against the reduction in production cost possible.

The above considerations add up to a situation which also precludes inventorying of felts by the felt manufacturer. These considerations also provide the reasons why manufacturing of papermaker's felts is job order manufacturing at its extreme. To summarize these reasons:

1. Large variety of felts due to large number of felt positions in the paper industry, each position requiring its own special design of felt
2. This basic variety, in effect, is still further increased due to design changes for quality

improvement and life expectancy reasons

3. Small unit orders
4. Paper industry ordering practices which, in addition to item 3 above, precludes inventorying of felts by the felt manufacturer due to lack of assurance for repeat orders
5. Short delivery times on the vast majority of orders reducing the opportunity for combining the manufacture of a given order with other orders for similar felts.

Traditionally, management in the felt industry has had to cope with the problems inherent in job order manufacturing. Lack of stability in the product-mix has always been a predominant factor. In the case of the Huyck Felt Company, the extent of these traditional problems has been further increased by recent policy decisions which call for increased emphasis to be placed on the research, development and design functions. Increased activity in these areas has resulted in further loss of stability in the product-mix.

B. PRODUCTION PLANNING PRACTICES IN YARN MAKING AND WEAVING

The production planning department of the company must perform its function within the framework of the above-mentioned product and marketing limitations and with those additional restrictions as are imposed by manufacturing methods and facilities. A detailed treatment of the overall planning function is not considered essential for the purpose of this paper; some of the broader aspects, however, should be mentioned so as to provide the reader with the perspective necessary for an understanding of situations to be described.

Figure I represents a simplified organization chart of the company and illustrates the position of the planning department in the overall picture. Organization of the functions within the department is depicted in Figure II. Of primary concern here are the yarn production planning and inventory control position, and the weaving production planning and delivery promises position.

Weaving is the key scheduling department and all deliveries are promised on the basis of the weave schedule with allowances added according to time requirements for subsequent processing. These subsequent processes have ample capacity and where machine operations are involved, the machines can, with few exceptions, be automatically loaded.

The weave schedule itself hinges on two major factors:

1. Loom availability, and
2. Yarn availability

1. Loom availability, in turn, depends on
    a. The weave width of the felt. Looms come in different widths and each loom will accept any felt narrower than its width. The wider the loom,

FIG. I

HUYCK FELT COMPANY– SIMPLIFIED ORGANIZATION CHART

EMPHASIZING FACTORY ORGANIZATION

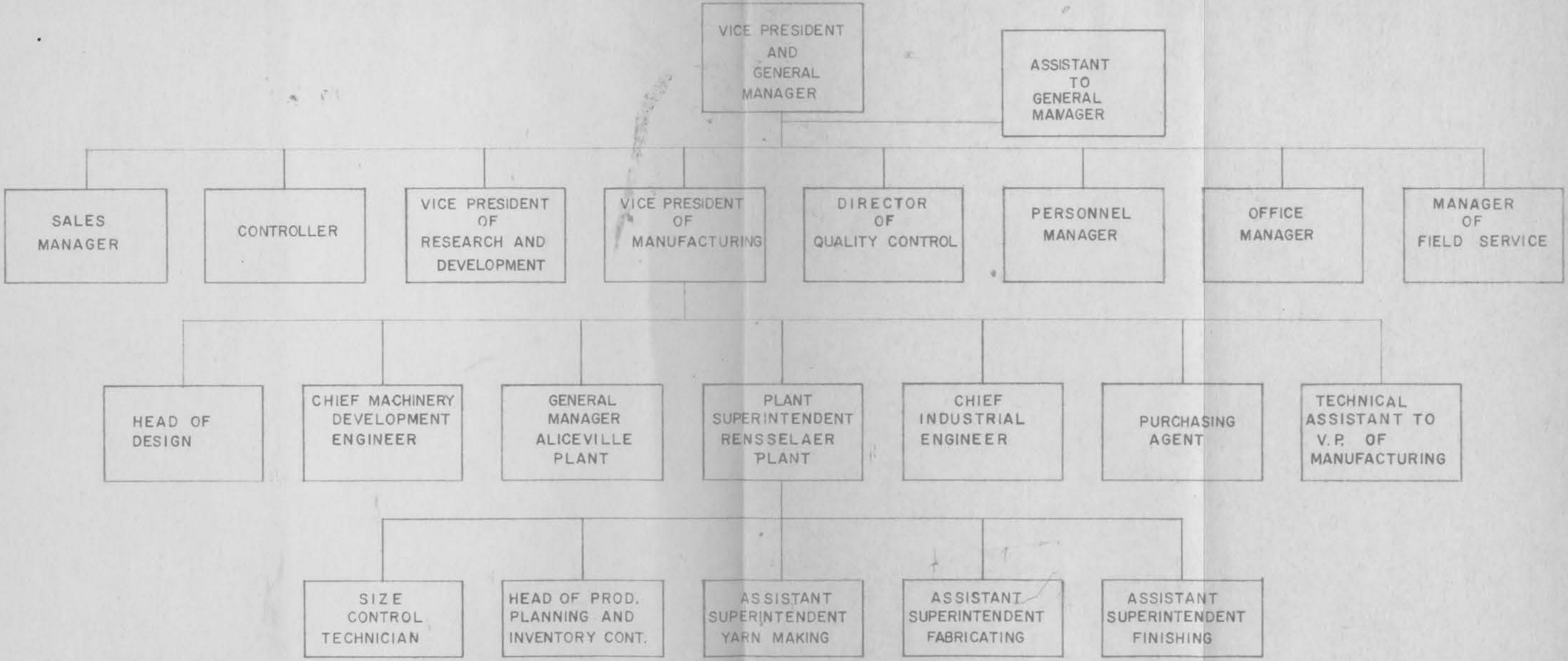
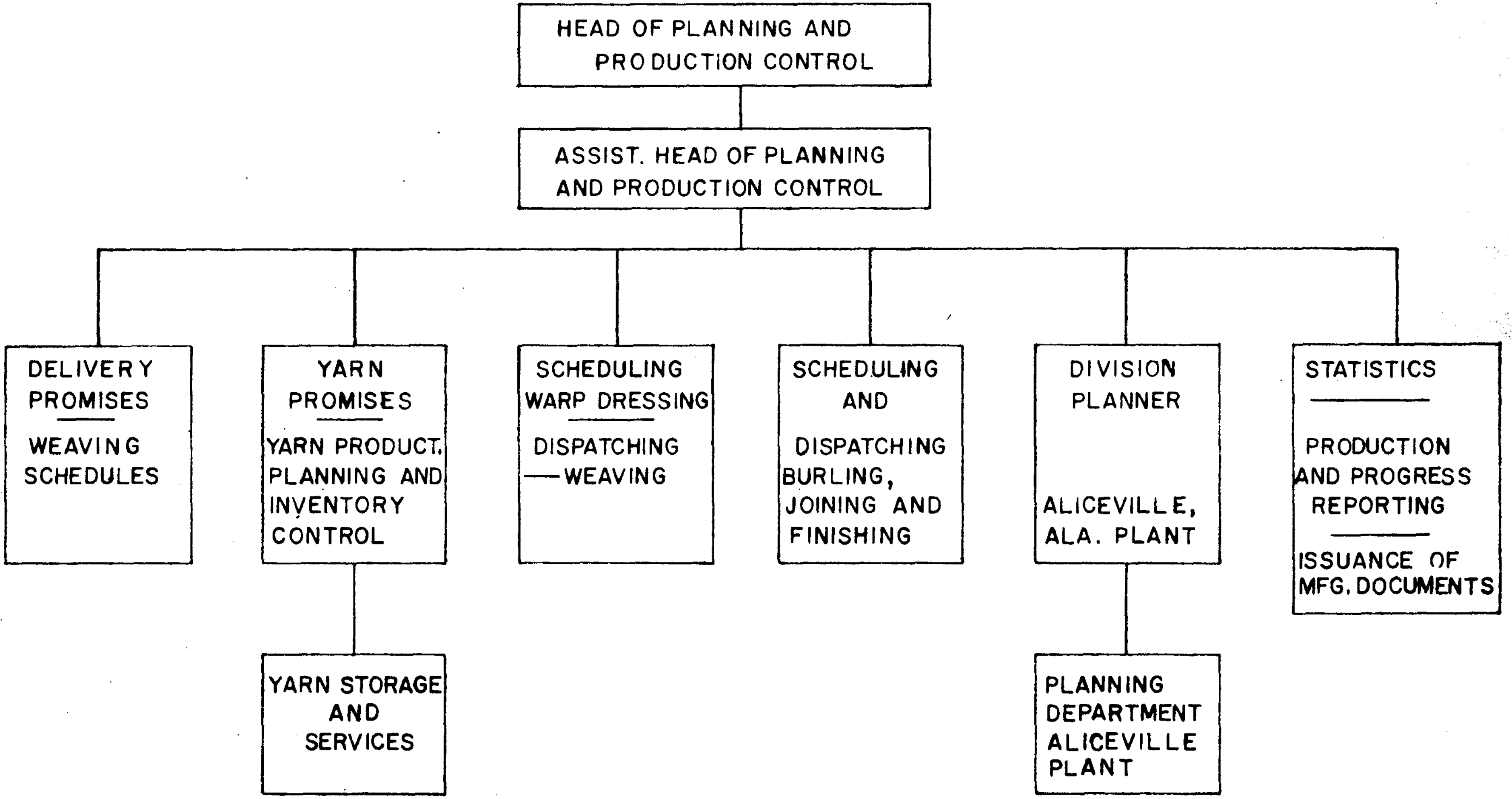


FIG II

PLANNING DEPARTMENT

ORGANIZATION CHART OF INTERNAL FUNCTIONS



however, the slower it runs; it is therefore poor economy to schedule a narrow felt in a wide loom A reasonably firm policy exists which specifies the range of felt widths to be woven in a given loom.

Due to fluctuations in the product-mix - as measured by the felt width - the work-load on the different width looms will vary from period to period. Furthermore, due to differences in loom construction, certain looms can only accept specific types of design. The workload on these looms becomes affected by product-mix fluctuations as measured by type of felt design.

b. The length of warps. Economy in weaving is accomplished by combining as many felts as possible in sequence on the same warp. This practice reduces the number of setups required on the looms. Since each warp must be prepared individually and the ends of the warp yarn must be drawn through the loom harnesses one by one, this setup cost is considerable and will vary in proportion to the width of the felt. For this reason, many orders which are of relatively low priority from a delivery point of view are processed with orders of higher priority. The longer the warp, the longer is the time it will spend in the loom. If the loom has been committed in this manner, high priority orders subsequently received may be affected. Despite this situation, due to the duration of each occurrence of loom setup - in some instances as long as 36 hours - an overall gain in capacity and reduction in lead time should result from the practice of combining felts on a warp.

2. As a felt is composed of two yarns - warp and filling - it can be fitted into the weave schedule no earlier than the time at which both components will become available to the loom. If both are available in stock, yarn availability poses no restriction. If, on the other hand, one or both are unavailable in stock, the felt can not be fitted into the schedule until such time that both components are available. In such cases, total manufacturing lead time for a felt is increased by the time it takes to procure the missing yarn or yarns.

   In order to maximize opportunities for combining felts on a warp, it is required that both warp and filling yarns are available for all felts to go on a given warp. Since the warp is dressed prior to weaving, and warp dressing fixes the length of the warp, warp yarns will be required ahead of the filling yarns. If the yarns are not available at the right time, it becomes necessary to stop combination of felts on a warp short of what available orders would otherwise permit.

Action with regard to promises, yarn and weave schedules, and yarn inventories has to be a result of orders received. The following is an outline of the portion of the order entry procedure which has as its objective to facilitate the taking of appropriate action by the planning department:

1. An order received by the sales department is entered on a standard order blank. Orders are then broken down by delivery priority and released according to the sequence dictated by these priorities.
2. From the sales department, the released order goes to the design department where the appropriate felt specification card for the customer, location, machine and machine position in question is matched with the order.
3. The order and felt specification card are passed along to the design engineer in charge of the account. He checks his files containing field reports from the company's field service engineers and statements of policy relative to a specific design or customer. From here on, the exact procedure to be followed in the design department will depend on whether a design change is called for. In either case, the end result of the efforts in this department is the delivery to the planning department of the order and felt specification card - the latter in its original or updated form, as the case may be.

4. In the planning department, the order and felt specification card are received at the yarn control desk. Depending on the situation encountered, one of three courses of action is taken:
    a. If a yarn is available in stock
        (i) the yarn requirement as indicated by the felt specification card is posted to the requirement column of the inventory control card for that particular yarn, and
        (ii) a yarn availability form indicating when the yarn is available for weaving is completed.
    b. If the yarn is not available in stock, but has been ordered from yarn making,
        (i) the yarn manufacturing schedule is checked,
        (ii) the yarn availability form is completed as in a. (ii) above, and
        (iii) the quantity required is posted to the requirement column of the inventory control card.
    c. If the yarn is not available in stock and has not been ordered
        (i) a yarn order form is prepared,
        (ii) the yarn manufacturing schedule is checked and the order fitted in,
        (iii) the yarn availability form is completed, and
        (iv) the yarn requirement is posted.

5. The order, felt specification card, and the two yarn availability forms - one for warp, one for filling - are passed along to the felt promise desk where the delivery promise is determined from the weave schedule and the yarn availability forms. Delivery date, warp number and loom number are entered on the order and it is passed on to order entry along with the felt specification card.
6. In order entry, a felt number is assigned and the necessary manufacturing, accounting and shipping documents are completed and submitted to the respective parties.

It should be noted that yarn production planning and control is decentralized in the sense that yarn production authorization forms originate at the yarn control desk and are handled independent of felt manufacturing documents.

C. SPECIFIC PRODUCTION PLANNING AND INVENTORY CONTROL PROBLEMS IN YARN MAKING

As noted, the total lead time for a felt is extremely sensitive to the control of yarn inventories. Not only does yarn availability to a large extent determine promise dates for felts, but lack of ability to meet these dates may result in loss of capacity in weaving due to waiting time for filling yarn after the warp has been set up in the loom and, in the case of warp yarn, due to reduced opportunity to combine felts on the same warp.

The effect of yarn control on felt lead time is determined by the relative proportion of the following three types of occurrences at the point when an order is received:

1. The yarn is available in stock
2. The yarn is not available but is ordered
3. The yarn is not available and is not ordered

From a felt delivery point of view, an ideal situation would exist if all yarns were available in stock. This, of course, would be a practical impossibility - not only due to excessive inventory carrying and obsolescence costs - but also due to creation of new yarns which clearly can not be inventoried prior to their creation. At the other extreme, the least favorable situation from a delivery point of view would be to have no yarn available or ordered. In addition to the direct effect of this on the weave schedule, setups in yarn making would be frequent and capacity losses would further compound the delivery problem.

It is evident from the foregoing that the regulation and control of the occurrences of each of the three types of situations mentioned must have a significant effect on felt deliveries and operational costs in yarn making. It is because of this significance that this area has been selected as the focal point of this paper.

Traditionally, yarn requirements have been directly tied in with felt requirements. Orders for a yarn were placed on the basis of orders for felts calling for that yarn. At some point, however, the yarn planner must have realized that he could make his job a lot easier by having the yarn in stock prior to the receipt of an order against it. Through evaluation and judgment, reviewing past consumption and taking into account whatever he knew about the future, he would place orders for yarn to cover estimated requirements for a certain period ahead. Unfortunately, the evaluation procedure preceding his decisions had never been formalized and frequently ended up as pure judgment propositions amounting to attempts to "outquess the market". As an example, if requirements for a particular yarn for a preceding three month period had been substantial and increasing, the planner would assume that a trend had been established. He would therefore order a substantial amount of that yarn to cover himself for the future. In the feltmaking industry where total annual sales volume remains fairly constant and where it is not seasonal, it should be recognized that orders could come in cycles by chance alone. Therefore, a substantial consumption during a given period is very likely to be offset by a receding demand for the subsequent period. Exactly this is what frequently took place.

To operate in the manner described would have been less problematic during a period when the product-mix was reasonably stable. Due to increased emphasis on design and also to the split in production between the Rensselaer and Aliceville plants, after the latter was built, this type of operation created some serious problems both to the planner and to the company. In addition to excessive inventories, yarn obsolescence became a painful phenomenon. The longer a yarn stays in stock, the greater become the chances that its consumption will be affected by design changes, thus rendering the yarn obsolete or semi-obsolete.

A contributing factor to these problems is the nature of the yarn as a product to be manufactured and the manufacturing processes required for producing it. The first step in the manufacturing cycle is the sorting and "sandwiching" of the basic fibre components into a so-called "grease blend". Depending on the desired properties of the yarn, a number of grease blends are created. Some of these are subject to modification in preparing by addition of waste and/or synthetic fibres.

From the grease blend stage, a "fanning" effect takes place. Each grease blend becomes the source material for several yarns. A particular grease blend can give rise to a multitude of single yarns by variation in thickness and degree of twist. A single yarn can be used as is or it can, in turn, give rise to a multitude of additional yarns by plying with one or more strands of the same or other yarns. For each of these combinations, different levels of twist may be specified. In addition, for each yarn created there are two types of end packages possible, one for warp, one for filling, and many yarns are used for both purposes.

Differentiation between yarns from a given blend starts in spinning. In other words, processing through all operations preceding spinning is identical for all yarns stemming from a given blend. Processing through scouring and preparing takes place in sequence, that is, the blends go directly from scouring into the preparing machines. From preparing, the opened stock is blown through pipes to bins in the card room. The cards are fed by hand from these bins. Due to limited bin capacity, the longest temporary storage of a blend in a card bin amounts to about 24 hours. The bins - two to a card - traditionally have a storage capacity of about 2000 lbs. each.

After carding, the card spools are sent to the appropriate spinning frames in the spinning department. Here again, some temporary storage exists but normally the spools are loaded onto the spinning frames within an hour after they have left the card room. Reasonably good balance between operations exists, with some tendency for the spinning frames to outproduce the cards.

From spinning, the yarn is brought to the rewinding department. If a yarn is to be twisted, it goes to a twisting frame first and then to the appropriate machine for rewinding into warp or filling. For yarns not requiring twisting, the twisting frame is by-passed. After rewinding, the yarn is put in storage.

According to past practice, yarn orders placed would call for processing of a batch all the way from the grease blend. The quantities ordered did normally coincide with the capacity of a bin in the card room, or they were a multiple of this capacity. This, at some time, was considered the most economical way of doing things - presumably due to the smaller problems created for the yarn planner. Provided a batch had not progressed through a manufacturing process which had committed the form of the yarn, subsequent orders for yarns from the same blend were filled by "robbing" the original order. Should processing of the original order have progressed beyond the point of commitment, new orders for yarns from the same blend had to be processed from scratch, perhaps the following day. These additional orders would frequently apply to the more marginal yarns for which only small quantities were required. These were the yarns that normally were made to specific felt requirements. The frequency with which felt orders calling for these yarns were received determined how often these yarns were to be processed, except for cases where other orders could be "robbed". Subject to the unpredictability of customer orders, these marginal yarns at times had to be processed in small quantities from scouring and on several times a week.

Due to the scheduling problems inherent in the above situation and to pressure applied to the yarn planner by supervision for longer runs, the planner gradually became more venturesome. With the idea of keeping the number of setups in manufacturing down, he started to order larger quantities of the marginal yarns. The erratic and largely unpredictable demand for these yarns resulted in a gradual inventory build-up. Since a large number of the yarns would never be required again, a significant inventory obsolescence problem was created.

The problems discussed above eventually grew to the point where top management became concerned and requested the industrial engineering department to provide the necessary solutions. Before we proceed to discuss how these problems were solved, a somewhat detailed treatment of economic lot size theory is deemed necessary. This will be given in the next section.

V

ECONOMIC LOT SIZE THEORY

A. DEFINITIONS

As suggested in the introduction, the economic lot size is one of many concepts belonging to a group of techniques and concepts called operations research. There is no finity to the number of these techniques and concepts; continued growth of scientific and technical skill and know-how on the part of workers in the field can in years to come be expected to enlarge further the membership of the operations research family of techniques and concepts.

No formal definition exists for what operations research stands for. This is probably due to the fact that operations research is in its early growth. For lack of such definition, it would seem desirable to demonstrate, by doing, what an operations research technique entails. In this manner, it is hoped that a concept is created in the mind of the reader which can act as a substitute for such a definition. One of the purposes of this paper is to attempt to do so. In order not to keep the reader completely in the dark, the following "usual" definition of operations research is given at this point[7]: "Operations research is an aid for the executive in making his decisions by providing him with the needed quantitative information based on the scientific method of analysis".

The above definition would apply equally well to the economic lot size technique. Being too general, however, it is of little value from a practical point of view. The definition of the economic lot given by Franklin G. Moore[8] is an improvement: "The economic lot is the quantity of any item which should be made at one time to realize the lowest possible unit cost. It can be used as the reorder quantity for any item which is regularly carried in stock or for which there is a continuing demand". This definition strongly implies that in order to determine quantitatively what the economic lot is, one has to define the items of cost that go into the unit cost. It also implies that for practical purposes, it is necessary to reduce the statement to mathematical terms.

The economic lot size concept is perhaps best clarified by the following illustration: Assume on one hand that small quantities of an item are ordered frequently. As a result, inventories are kept down and inventory carrying costs are low. However, frequent order processing and machinery setups will cause the costs for those items to be high. On the other hand, if we are to assume that large quantities of the item are ordered infrequently, inventories will go up and so will inventory carrying costs. Order processing and machinery setups will be down and the costs associated with these items will be low. It is evident that some order quantity can be stipulated which will minimize the total of the costs mentioned. If these were all the costs pertinent to the problem and they were accurately determined, we would in fact have stipulated the most economical, or optimum, order quantity. It will be shown later that there are normally several other costs involved and that to obtain an estimate of all these costs is a problem in itself.

B. HISTORY

According to John F. Newberry,[9] economic lot size theory is a fixed quantity inventory policy and is one of several policies designed for control of inventories. Other such policies are: fixed cycle policy, fixed cycle-quantity policy, and variable input and output systems, to mention a few. In a fixed quantity policy, the inventory is examined continuously. An order for a fixed quantity is placed when the stock level declines to a reorder point, regardless of the time between orders.

Newberry traces the history of such quantified inventory control policies back to 1912 when George Babcock attempted to determine lot sizes on a mathematical basis. In 1915, F. W. Harris of the Western Electric Company developed a formula which is almost identical to the present accepted economic lot size formula. This formula found wide acceptance at the Hawthorne plant of Western Electric where, according to

Moore,[10] a whole department at one time was engaged in computation of order quantities by the use of a specially designed slide rule. Application of the system later fell into disuse at Western Electric. As suggested by Moore, this was due - at least in part - to excessive clerical requirements. Newberry, on the other hand, brings out the fact that controversies arose between accountants and engineers over methods of determining costs and suggests that this may have been an underlying reason for the discontinuation.

In 1918, E. W. Taft modified Harris's formula to take into account the overlap between the manufacturing period and the sales period as would be the case when some items are diverted directly to the user without entering inventory. F. H. Thompson of the Dennison Manufacturing Company, in 1923, developed an additional factor for inclusion into the formula. This factor took into account storage on a bulk basis rather than on value.

Newberry proceeds in his discussion to state that no new developments with regard to economic lot sizes took place between 1923 and 1931. In 1931, what according to Newberry was the most significant contribution to economic lot size theory took place when Fairfield E. Raymond published his work on "Quantity and Economy in Manufacture". In his work Raymond considered such factors as:

1. An economic range for lot sizes with little

effect on unit cost to give executives a freedom of choice between lot sizes within this range,

2, An allowance for spoilage and scrap,

3. Influence of seasonal demand, and

4. A quantitative determination of obsolescence cost.

Later in the thirties Erich Schneider[11] attempted to minimize the combined cost of production for situations were a) the sales forecast is given as a function of time, b) the initial inventory is given, c) certain capacity restrictions exist, and d) inventory carrying charges and production costs are known.

Since then, it appears that no major developments took place until 1951. Moore states in 1951[12] that at some time, vis. the late 20's and early 30's, there was considerable interest in economic lot sizes. By 1931, about 250 different formulas had been developed to take account of the many different situations that could take place in practice. It would appear, according to Moore, that since the unit cost is very little affected by a 25 per cent increase or decrease in the lot size from the optimum, satisfactory answers can be obtained by the use of the basic economic lot size formula in preference to the more complicated ones.

Moore indicates that in 1951, little, if any computation of economic lot sizes took place. He suggests that the reason for this, at least in part, was the high cost of computation. Another reason suggested by him was the difficulty in obtaining reasonably accurate costs and to predict future requirements and the possibility for obsolescence.

Prior to 1951, all work with economic lot sizes had been of a fixed deterministic nature. With the rise of operations research after World War II, several students entered the field who were well equipped with the mathematical and statistical tools necessary to cope with the factors of uncertainty that frequently exist in business situations. Although the result of this work in many instances was to make the application more complicated, the new approaches tended to provide more realistic answers than had previously been the case. The arrival of electronic computers made possible computations involving more complicated mathematical treatments in less time than previously was required for the basic economic lot size formula. It is possible that increased acceptance of the economic lot size theory in the 50's was also a result of a change in the general climate making management more receptive to the idea that decision-making with mathematical support was superior to decision-making based on judgment alone. An account of developments in the 50's is given by Newberry.[13] The contributions during that period -

and since for that matter - have been so large, and the contributors so many, that it would be too much to attempt to give a fair treatment in this paper. Mention should be made of the fact that a lot of the work done was directed toward determination of buffer, or safety, stock requirements under a variable demand condition. Some of the details of this determination will be discussed later in this paper.

Where do we stand today? A survey made in 1961[14] indicates that we still have a long way to go in the application of more exacting inventory control techniques. According to this survey of 387 manufacturing plants in this country, less than one third employ economic order quantities. In 33 per cent of the plants, reorder quantities are based on review or opinion, and this is the "method" used more than any other single method. The survey suggests that the relatively limited use of more sophisticated systems is primarily due to lack of management interest and support. An interesting observation made is that the use of computers for inventory control purposes had increased by over 80 per cent since 1958. Still, less than 10 per cent of the companies use computers for controlling production orders and schedules.

C. THE MATHEMATICS OF ECONOMIC LOT SIZES

It is beyond the scope of this paper to treat in detail all the mathematical formulas that over time have been developed as expressions for the economic lot size. However, some of the basic mathematical considerations will be given at this point; it will later be necessary to get involved with some of the more advanced aspects.

The following will show the development of the basic economic lot size formula. This is the formula on which all other lot size formulas are based; essentially these other formulas are merely variations of the basic formula, taking into account various other factors of cost.

If Q=ordering quantity,

D=annual demand for an item, and

P=setup or ordering costs per order,

then $\frac{D}{Q}$ = number of orders per year, and

$\frac{D}{Q} \times P$ = annual ordering costs.

If I = percentage inventory carrying charges, and

C = unit cost,

since $\frac{Q}{2}$ = average inventory,

then $\frac{Q}{2} \times C \times I$ = annual inventory carrying charges.

Annual total cost of ordering and carrying of inventory is at a minimum for the ordering quantity which will make annual ordering costs equal to annual inventory carrying charges, i.e. when

$$\frac{D}{Q} \times P = \frac{Q}{2} \times C \times I$$

Solving this equation for Q, we get the expression

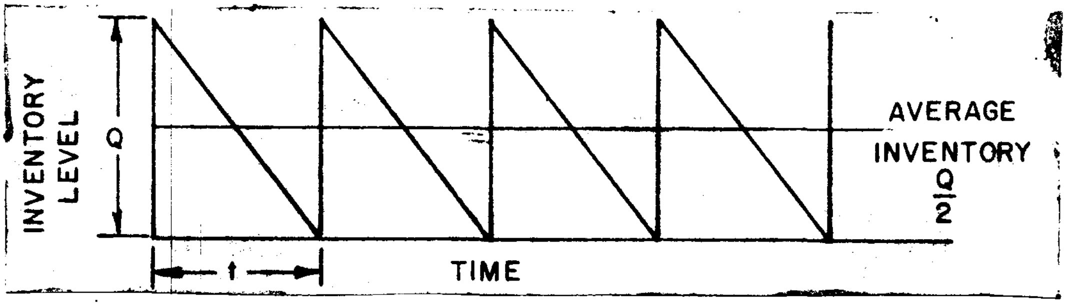
$$Q = \sqrt{\frac{2 \times P \times D}{C \times I}},$$

where Q becomes the economic lot size.

In its simplest form, inventory behavior would follow the characteristic saw-tooth pattern illustrated in Figure III.[15]

Fig. III

Pattern of Inventory Balance under Uniform Demand



As new orders are placed, each for a quantity Q, an inventory peak is reached when supply arrives. During a period t, under constant consumption, the inventory will gradually recede to zero, at which point a new supply is obtained. The average inventory during period t, and all other like periods with like behavior, equals half the ordering quantity, or $\frac{Q}{2}$.

In actual practice, one will normally encounter fluctuations in demand, both between periods and within each period. The lines representing the decline in inventory could therefore hardly be expected to be as uniform in slope and as straight as those pictured in Figure III. Replenishment of stock would not always be as instantaneous as that illustrated. In the case of a manufacturing operation, for example, there would be a gradual build-up of inventory at a rate corresponding to the production rate of the operation. The effect of such a situation would be to tilt the line representing stock replenishment in Figure III to the right.

It is also possible to find the economic lot size graphically by a plot of ordering costs and inventory carrying charges for different lot sizes. An example of this is given in Figure IV. From this graph, the following conclusions can be drawn:

1. There is a range of lot sizes over which the effect on total cost is small. Order quantities of 1510 lbs. and 2710 lbs. will only increase yarn cost per lb. by one tenth of one cent over what it is for the optimum order quantity of 2060 lbs.
2. By manufacturing in reorder quantities close to the low or the high extreme of the economic range, average inventories may be kept lower or higher than the optimum, as determined by the need to minimize risk of obsolescence or maximize delivery service, respectively. This can be accomplished with only a nominal increase in unit cost.

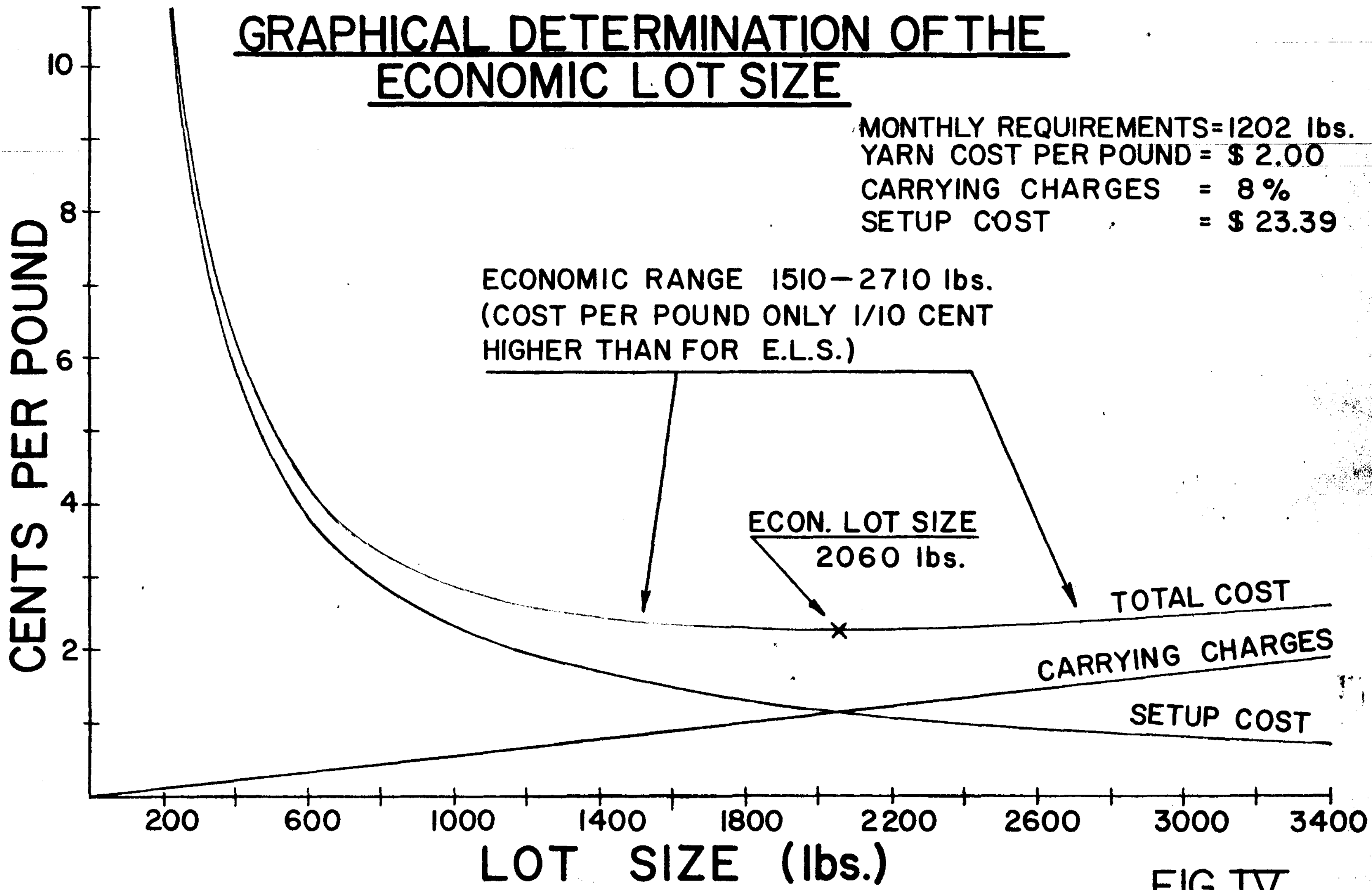

GRAPHICAL DETERMINATION OF THE ECONOMIC LOT SIZE
MONTHLY REQUIREMENTS = 1202 lbs.
YARN COST PER POUND = $ 2.00
CARRYING CHARGES = 8 %
SETUP COST = $ 23.39
ECONOMIC RANGE 1510—2710 lbs.
(COST PER POUND ONLY 1/10 CENT HIGHER THAN FOR E.L.S.)
ECON. LOT SIZE 2060 lbs.
TOTAL COST
CARRYING CHARGES
SETUP COST
CENTS PER POUND
10
8
6
4
2
200
600
1000
1400
1800
2200
2600
3000
3400
LOT SIZE (lbs.)

FIG. IV

3. For the same deviation from the optimum, the cost consequences of a lot size which is too small are greater than for a lot size which is too large. A lot size of 1510 lbs. which is 550 lbs. lower than the optimum carries with it the same unit cost as a lot size of 2710 lbs. which is 650 lbs. higher than the optimum; therefore, a lot size which is 650 lbs. too small would be more costly per unit than a lot size which is 650 lbs. too large. The significance of this is that costs are more sensitive to scheduling errors on the low side of the optimum than to errors on the high side, obsolescence and delivery service disregarded.
4. High setup costs relative to inventory carrying charges tend to shift the economic lot size to the right, indicating that longer runs would be more economical; if inventory carrying charges are high relative to setup costs, shorter runs are more economical.

It should be noted that the above treatment applies to situations under certainty, that is, situations where future demands are actually known or can be accurately determined. In practice, this good fortune rarely exists. Despite this weakness, the formula is still useful for many situations. Where the simplified approach becomes grossly inaccurate, or where it is unworkable for other reasons, other considerations must be superimposed.

The most common type of deviation from the ideal situation to which the basic economic lot size formula truly applies, and the one which creates the most serious problems in the operation of a system based on this formula, is the result of uncertainty with respect to future demand. Other types of deviations that frequently play an important part are due to seasonality of demand and an arrival rate of inventory items which is not instantaneous. The effect of the two latter types of deviations is negligible in the particular situation at hand; seasonality is virtually non-existent and the arrival rates of the inventory item are high relative to its inventory depletion rates. Both phenomena have therefore been ignored in the application to be made and will not be further discussed.

Uncertainty of future demand, on the other hand, is a far more significant factor as far as our particular problem is concerned and will therefore require treatment in some detail.

In a system under constant demand, a replacement order would have to be issued at a point of time selected so that the items in inventory would equal the known demand during the replacement lead time. With this condition satisfied, the inventory level would hit zero just as replenishment arrives. Where the demand is fluctuating according to a random pattern, the replacement order is issued at a point of time selected so as to make the items in inventory equal to a forecast demand during the replacement lead time. Depending on the reliability of this forecast, one of the following three situations may arise:

a. If the forecast was correct, the inventory level will equal zero as replenishment arrives
b. If the forecast was too high, an inventory balance greater than zero, and equal to the error in the forecast, will be on hand when replenishment arrives
c. If the forecast was too low, the inventory will be depleted at a time prior to arrival of the replenishment items. The length of this stock-out period, so called, is proportional to the error of the forecast.

From a delivery service point of view, situations a. and b. above create no problems. Situation c. entails a stock-out and will result in curtailment of deliveries for the duration of the stock-out period.

To overcome the problems which conceivably may result from a stock-out situation, a safety stock can be provided to give protection against sales or demand uncertainty. In cases where actual demand exceeds forecast demand, the excess demand can then be covered by drawing upon the safety stock, to the extent that it is available. The degree of protection offered appears to be proportional to the magnitude of the safety stock.

Basically, the larger the safety stock, the greater becomes the degree of protection offered against stock-outs. Since large errors in the forecast tend to occur less frequently than small errors, each additional unit of safety stock will buy a smaller protection than the previous unit. For this reason, the total benefit derived from an increase in safety stock will proceed at a decreasing rate as each unit is added, whereas inventory carrying charges will increase at a constant rate. The first problem facing us with regard to safety stocks is to find an answer to the following question: How much inventory for safety stock purposes can be economically justified?

The mathematical determination of safety stock will be dealt with in Section VI. At this point we will only consider some of the factors which enter into this determination.

Since a safety stock acts so as to diminish the shock of unexpectedly high levels of demand, it is often denoted a "buffer" stock. As this stock is a result of fluctuations in demand, it is not possible to keep both the order size and the time between placing orders fixed. One or both have to yield. The most common way to approach reordering problems is to keep the order quantity constant and to let the frequency of ordering take up the fluctuations in consumption.[16]

The following are the characteristics of a fixed quantity inventory policy under uncertainty of demand:

1. The time an order is placed is allowed to vary with fluctuations in usage
2. An order for a fixed quantity is placed whenever the amount on hand is sufficient to meet a reasonable maximum demand over the course of the replenishment lead time.

Fig. V

Pattern of Inventory Balance with Safety Stock

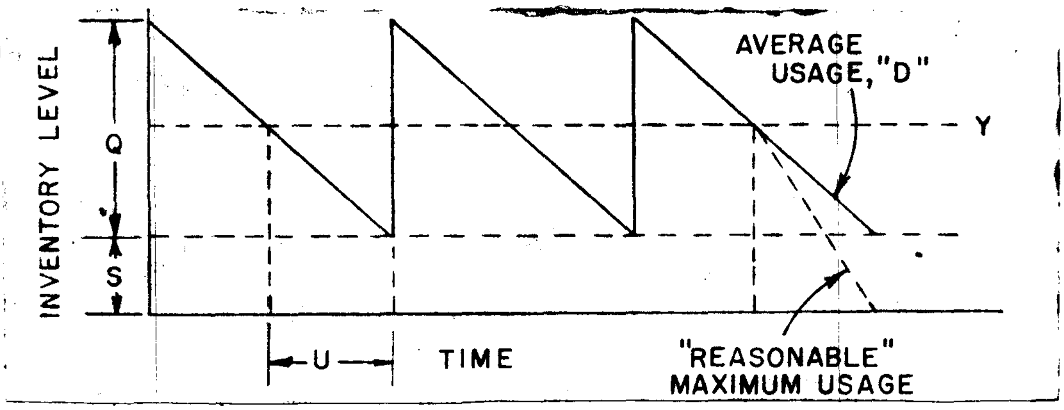


Figure V illustrates inventory behavior with safety stock. The total system can be described in terms of

1. the lead time, U,
2. the order size, Q,
3. the safety stock, S, and
4. the expected demand rate, D.

If demand is uniform at rate D, the inventory level behaves according to the solid line in Figure V. The average inventory level equals the safety stock, S, plus half the order quantity, Q, i.e.

$$I = S + \frac{Q}{2}$$

The reorder point, Y, is the inventory balance at which a new order is placed. The reorder point is reached when the inventory balance equals the expected demand during the lead time plus the safety stock:

$$Y = D + S$$

A treatment of the reorder point would be incomplete unless one were to define the inventory level against which it is to be evaluated. According to John F. Magee,[17] the reorder point must be based on both the amount on hand and on order. Magee explains this as follows:

> If the lead time is three months, for example, and the amount purchased at each order is a one-month supply, this does not mean that it is necessary to place a new order when the amount on hand drops to a maximum three months' usage. Since an order will be placed, on the average, once a month, there will almost certainly be some orders outstanding all the time, which on being filled, will help replenish the inventory on hand.

The inventory on hand and currently on order is the maximum amount available for use during the span between reorder and arrival of the reordered quantity. The minimum on hand is reached at the end of the lead time period. This minimum inventory will depend on the demand during the lead time period. If the actual demand exceeds the forecast demand for the lead time period by more than the safety stock, a stock-out will take place. In order to determine the safety stock, one must therefore know the distribution of the differences between forecast and actual demand. This distribution will show the frequency with which these differences will exceed a certain magnitude. By stipulating the frequency with which stock-outs would be permitted to take place, it becomes possible to compute the magnitude of the excess over the forecast, or the magnitude of the safety stock, which would limit the frequency of stock-outs to that stipulated.

It is evident that the permissible frequency of stock-outs is synonymous with the frequency of service failures or delays to customers one is willing to permit. The proposition essentially becomes one of weighing the cost of service failures against the cost of carrying sufficient inventory to prevent them.

To arrive at an objective estimate of the cost of a service failure is an almost impossible task. As noted earlier, each additional unit of safety stock placed in inventory adds a smaller increment of protection than its precessor. Since inventory carrying charges per unit are constant, one has here a diminishing return proposition where at some point the cost of buying extra protection becomes greater than the value of protection obtained. To illustrate the principle, let us assume that a $200,000 inventory investment is required for 100 per cent stock-out protection whereas for a 95 per cent protection the investment required is only $150,000. A reduction in protection level from 100 to 95 per cent results in an inventory reduction of $50,000. If inventory carrying charges were 30 per cent, inventory costs are reduced by $15,000 annually.

This illustrates that there may be a considerable cost associated with a service policy. Despite the impossibility of determining the dollar value of a service failure in the short and in the long run, a decision with regard to such a policy must at some point be made - formally or informally - even if it has to be based on judgment alone. Knowing what the inventory cost consequences are will no doubt assist in making such a decision.

D. THE NATURE OF COSTS

One of the basic requirements for a mathematical approach to the solution of production problems is that all costs must be described quantitatively in comparable units, including intangible costs and those not regularly defined by financial and cost accounting systems.[18] In the early days of quantitative inventory control, the common viewpoint appeared to be that if costs could not be accurately determined, gross errors would be introduced into the answers. However, since the costs associated with production in most instances are expressed as a U-shaped curve (Fig. IV, p. 66), the sensitivity to inaccuracies in cost estimates is small. This does not mean that carelessness in determining costs is condoned, but rather that cost data which would otherwise have to be rejected can be successfully incorporated into equations which will still give acceptable answers. The benefit accrued from this realization is that it prompts attempts to express numerically many values which may always have been present in management's thinking, but which have been unclear and poorly defined. By including all these values into one formula, one ensures that they become consistently considered in application and never overlooked. It is significant also that although true costs can probably never be determined, the mathematical approach will nevertheless provide optimum answers for whatever cost values are assigned. It would appear therefore that this approach would be superior to one which relies purely on experience or informed guesses. In one specific case,[19] an analysis of errors incurred by an overestimation of a specific cost value by 100 per cent and an underestimation by 50 per cent indicated that the decisions were affected so as to yield costs only 11 per cent higher than those obtained using correct estimates.

In practice, it is doubtful that one would go to the extent of determining every cost that has a bearing on a problem, for the following reasons: Firstly, the nature of all costs can not always be determined; secondly, even if the nature of a cost is known, where it is recognized that its effect on the final outcome is insignificant, one may decide to ignore it; thirdly, by considering only significant costs, it is possible to keep the solution simple enough to make it suitable for practical application.

In this section we will consider broadly some of the specific costs that enter into a quantitative inventory policy formulation; application of these costs will be discussed in Section VI.

A common feature of costs considered for a quantitative formulation of a production problem is that they shall represent only those out-of-pocket expenditures or foregone opportunities for profit whose magnitude is affected by the schedule or plan.[20] One significant aspect of this is that since accounting costs frequently contain allocated overhead costs, they should be viewed critically before they are applied as are.

There are a number of ways of classifying costs. For the sake of simplicity, the following classification will be employed:

1. Setup Costs

   These are essentially the costs incurred in getting a new order started and completed.

a. Machine Change-Over Costs. These are costs associated with changes in machine drives, tools and settings. In some instances, major changes to a machine are required before a job is started and after it has been completed.

b. Scrap and Spoilage Costs. Frequently further adjustments have to be made to a machine after the operation has started and production up to the point of adjustment must be rejected. In some operations, there is a scrap factor built into the machine dimensions as would be the case where, in starting and completing a job, the material has to extend beyond the area of the machine where processing takes place.

c. Clerical Costs. These are the costs associated with the issuance of an order and the recording and reporting of its completion. Cost of clerical time for completing forms and for scheduling, and the cost of the forms themselves are involved.

2. Inventory Costs

Typical of these costs is that they are expressed as a percentage of the unit cost of each inventoried item. One breakdown offered[21] for inventory carrying charges is:

a. Possession Costs

b. Value Losses

c. Return on Investment

d. Effect of General Business Conditions

It is essential that only those costs are considered which are chargeable to inventory and which will vary with the inventory level. Most of these costs are extremely sensitive to specific company conditions.

a. Possession Costs

(i) Space. One of three conditions may exist: If space freed up by reducing inventories will not be utilized, the cost of space chargeable to inventory becomes zero; if space freed up by reducing inventory will be utilized for increasing output, the cost chargeable to inventory becomes the cost of providing equivalent floor space equal to the area occupied; if reduction of inventory will avoid new construction for expansion of output, the cost chargeable to inventory is equivalent to the cost of additional space equal to the area occupied plus the cost of utilities for the new space.

(ii) Equipment. If an inventory reduction will permit sale of part of the equipment used in the storage areas, cost chargeable to inventory would be equal to the return earned on the resale value of the equipment.

(iii) Insurance and Taxes. There are two types of insurance and taxes, one based on floor space occupied, the other on inventory value. Insurance and taxes based on floor space are unaffected by an inventory reduction as they must be paid whether the space is occupied or not. Additional floor space for inventory purposes will require additional insurance and taxes chargeable to inventory, only if the additional space is created by new construction. Insurance and taxes based on inventory value are chargeable to inventory in proportion to this value.

(iv) Cost of Taking Physical Inventory. This cost is determined by the number of man-hours required to take physical inventory and the frequency with which it is done; the cost is proportional to the inventory level.

b. Value Losses

(i) Obsolescence. If proper records are kept, losses can be expressed as a percentage of inventory value.

(ii) Deterioration, Loss and Damage. This item is usually insignificant except when dealing with perishables. It is handled similarly to obsolescence.

c. Return on Investment

The cost chargeable to inventory depends on an imputed interest rate placed against a dollar of invested cash. The choice of the imputed interest rate would hinge largely on the financial policies of the company and would have to be determined from an investigation of these policies and the over-all return on investment.

d. General Business Conditions

Under extreme conditions one would want to consider such factors as the effect of cost reduction due to increased productivity in producing the inventoried items, and inflationary and deflationary effects.

3. Sales Costs.

These are the costs associated with the maintenance of a reasonable delivery service. This factor has been considered earlier in this section and will be further considered in Section VI.

VI

APPLICATION OF THE ECONOMIC LOT SIZE THEORY

A. ANALYSIS OF THE PRODUCT MIX

It is suspected that two major top management decisions made in recent years had affected yarn inventories considerably. These were:

1. Expansion into new facilities in the South,
2. Adoption of a policy toward increased diversification of design.

It is not possible to express the effect of these two decisions quantitatively. However, a preliminary analysis of inventories and consumptions for regular yarns (as contrasted with purchased yarns and experimental yarns) for both plants reveals that

1. The number of yarns in inventory on April 1st, 1958 was approximately 10 per cent larger than on December 1st, 1956
2. The number of yarns consumed in any quantity during March 1958 was approximately 35 per cent larger than during November 1956
3. Of all yarns inventoried, only about 55 per cent were consumed in any quantity during March 1958, whereas the corresponding figure for November 1956 was about 71 per cent. For the Rensselaer plant

alone, only about 51 per cent of the inventoried yarns were consumed during March 1958 versus about 70 per cent during November 1956

Speculation around these observations leads to the following conclusions:

1. Since several yarns were used in both plants, each of these yarns requires two inventory positions instead of the previous one
2. During the period considered, there had been a considerable increase in inventoried items, whereas the number of yarns consumed per month had increased significantly less. This situation appears to be the result of two possible causes:
    a. Due to a larger number of design changes, residues were left behind in inventories for a considerable length of time, and
    b. Due to an increase in the number of designs, a large number of yarns had been created which were used only infrequently and would remain in inventory during extended intervals of time between two points of usage.
3. Since yarn consumption as a whole had remained fairly constant during the period considered, each individual yarn had carried a smaller share of total requirements. An attempt, therefore, to make

batches of yarn equal in size to those made at a time when total requirements were shared by a smaller number of yarns must lead to yarns remaining in inventory for longer periods of time, resulting in an increase in inventories proportional to this time.

4. It was also found that there was a distinct correlation between the number of yarns and the number of pounds in inventory, a fact which tends to support the above conclusions.

Since inventory reduction is one of the benefits generally derived from standardization of product design, it is to be expected that the adoption of a policy toward diversification of design will have the reverse effect. It is deemed that this factor,together with expansion into new facilities, were both responsible for considerable changes in the economics of production. Due to a certain rigidity in the production planning system - batch sizes geared to bin sizes, lack of intermediate storage facilities in yarnmaking - the forces set up by these changes created pressures which tended to seek themselves an outlet in higher inventories.

It is further concluded that these conditions call for improved methods of inventory control, and that the necessity for action in this area must be considered an added cost of the major policy decisions made. Since production planning and inventory control go hand in hand, it is expected that the best results will come from action in both these areas. For practical reasons, it seems that any such action must be required to establish new and more meaningful policies within the frame work of existing production methods or be based on changes which can be put into effect relatively fast and simply, and the results of which are predictable.

At the outset, one must determine whether yarns exist with sufficient regularity of demand to be scheduled according to the economic lot size principle. If these yarns do exist, in sufficient quantity to justify the trouble, a system for their management can be designed at a later point. As a next step, therefore,the yarn mix must be analyzed in terms of regularity of demand. For this purpose, it is necessary first to establish certain criteria for this regularity so as to make possible a suitable breakdown of yarns into different classes or groups. The following preliminary classification of yarns is suitable for this purpose:

Group A - yarns which have consumption recorded against them for at least five of the six months preceding evaluation

Group B - yarns which have consumption recorded against them for at least two but not more than four of the six months preceding evaluation

Group C - yarns which have consumption recorded against them for one or less of the six months preceding evaluation.

With criteria established for classifying all yarns according to the above categories and with suitable decision rules for reordering of yarns for each category, it is believed that much can be accomplished toward a solution to at least some of the major problems. Some of the benefits to be derived from classifying yarns are visualized as follows:

1. Since each yarn must be classified, the consumption pattern for each yarn must be analyzed for this purpose. By stipulating that the status of each yarn must be reevaluated monthly, the person responsible will have forced upon him a thorough knowledge of changes in consumption patterns
2. In addition to reclassification resulting from a periodic review, yarns may be reclassified in the interim period as information affecting the status of the yarns is received by the planning department
3. Since the major decision with regard to each yarn is made at the point of reclassification, any decision with regard to the specific quantity to order will have to be consistent with the policy for the specific yarn group to which the yarn belongs. More automatic decision-making will therefore result, and less guess-work will be involved.

After the necessary criteria have been established, yarn consumption records must be examined. This examination reveals that during a six month period, 200 different yarns were consumed. Translating these yarns back to the single spun yarns from which they originate, it is found that only 135 such yarns were consumed, illustrating a considerable "fanning" effect after spinning. Table I has been developed on the basis of an assumption that all A yarns - that is, yarns consumed for at least five of the preceding six months - are suitable for production in economic lots, and that all other yarns are not. The following conclusions can be drawn from Table I:

a. In the order of 90 per cent of the yarn production can be handled in economic lots.

b. By combining demands for yarns of different end uses but stemming from the same single spun yarn, a larger percentage of the production can be handled in economic lots through spinning as compared to what is possible following old practice where each yarn, at the point of end use, is treated as an individual item and produced to order all the way from the grease blend. This combination of demands will also result in a reduction in small items not suitable for economic lot size production from 97 to 61. In many instances, the demand for an individual yarn is too

TABLE I

Breakdown of Yarns and Production Volume According to Suitability for Economic Lot Size Production

(Based on period July 1st - December 31st, 1957)

Suitability for Economic Lot Size Production	Production Schedule Based on			
	Spun Yarn Styles		Final Yarn Styles	
	No. of Styles	% of Prod'tn.	No. of Styles	% of Prod'tn.
Suitable	94	91	139	87
Unsuitable	61	9	97	13
Total	155	100	236	100

irregular to warrant production in economic lots; by combination, fluctuations tend to cancel out and make economic lot size production through spinning feasible.

c. Longer production runs for a smaller number of yarns will result from production according to combined demands through spinning.

On the basis of the foregoing, it appears that the company can benefit from production of A yarns with a) one end use only, in economic lots from scouring through rewinding, and b) those with more than one end use, in economic lots from scouring through spinning, and from spinning through the balance of operations according to requirements for the different end uses. In order to accomplish this, it is necessary to institute a new yarn storage position after spinning where the multiple end use yarns can be stored on spinning bobbins instead of processing them immediately through the next operations and further committing them to a new ply or package. The benefits expected from this method of operation are as follows:

1. Reduced risk of obsolescence, or at least the temporary obsolescence caused by having, for instance, a 3-ply yarn in stock when requirements at a given time is for a 2-ply yarn of the same components, or on filling bobbins when a like warp yarn is required.

2. Since one considers the aggregate demand for each single yarn, rather than the individual demand for each end use yarn, a larger demand for each single yarn will in effect have been created. As a result, the economic lot size must increase. However, this increase is smaller than the increase in demand thus created, and yarn inventory will therefore be kept at a lower level. The reasoning behind this is best clarified by an example: The economic lot size formula (p.64) shows that the economic reorder quantity will increase in proportion to the square root of the demand. If two yarns, each of monthly consumption 1000 lbs. are considered, and the separately computed economic reorder quantities are 800 lbs. each, then the average inventory for each yarn will be 400 lbs. and for both yarns 800 lbs. On the other hand, by using the combined demand approach, monthly consumption now becomes 2000 lbs. and the computed reorder quantity 1130 lbs. Average inventory based on the aggregate demand will therefore become 665 lbs., a 17 per cent reduction from the previous inventory level.
3. For a given total inventory, the average lead time for yarns will decrease. Since more yarns will be available on spinning bobbins, and less yarn committed to a certain ply or package, there will be less need to wait for a yarn to be processed all the way through from scouring.

4. Since fewer orders are to be scheduled through spinning and a more balanced inventory will result, a reduction in rush orders through yarn making can be expected.

B. DEVELOPMENT OF THE ECONOMIC LOT SIZE SYSTEM

The preliminary survey suggests that about 90 per cent of the production volume of yarns can be manufactured to stock in economic reorder quantities, and also that several other beneficial procedure changes can be made without too much difficulty. As a result, one can proceed to the next step which involves the design of a new ordering system. This makes possible a determination of economic lot sizes, and inventory and setup costs to be expected, and provides an idea of the general applicability of the system. The following steps will be employed in the development of this design:

1. Estimation of setup costs and inventory carrying charges
2. Determination of safety stocks based on demand forecasts
3. Computation of decision magnitudes - reorder quantities, reorder points and average inventories
4. Classification of yarns according to consumption patterns and prescription of decision rules for yarns not covered by the economic lot size system.

If time and waste standards are available in the industrial engineering department, as they were in this case, it is a relatively simple matter to determine setup costs for each yarn on each machine. As real costs - in contrast to accounting costs - are required, the setups must be analyzed for expenditures of direct and indirect labor, amounts of waste generated, and the amount of variable overhead involved. Credit must be given for production, if any, during the setup period and for the salvage value of waste resulting from the setup. The final setup cost arrived at for each machine will therefore represent a fair estimate of all variable costs involved. Planning costs can be determined from time studies and from the cost of forms required for the scheduling of each order.

A sample work sheet for determination of setup costs per order is shown in Figure VI. For each yarn considered for production in economic lots, the setup costs for the operations through which the yarn is routed are entered in the appropriate columns. For a yarn with one end use only, total setup cost is arrived at by adding together the costs of all setups involved from scouring through rewinding. For a multiple end use yarn, to be stored after spinning, the total setup cost represents the setup costs involved through spinning. If any of the derivative yarns are to be carried through rewinding in economic lots, total setup cost for the rewinding operations

FIG. VI

WORK SHEET FOR DETERMINATION OF SETUP COSTS

YARN	OPERATION NO.							TOTAL SETUP	INV. CH'GS	A
	1	2	3	4	5	6	22			
YARN "X"	$1.18	$4.03	$2.36	$9.81	—	$2.7	1.38	$22.38	$.39	57.4
" "Y"										
" "Z"										
ETC.										

can be calculated similarly.

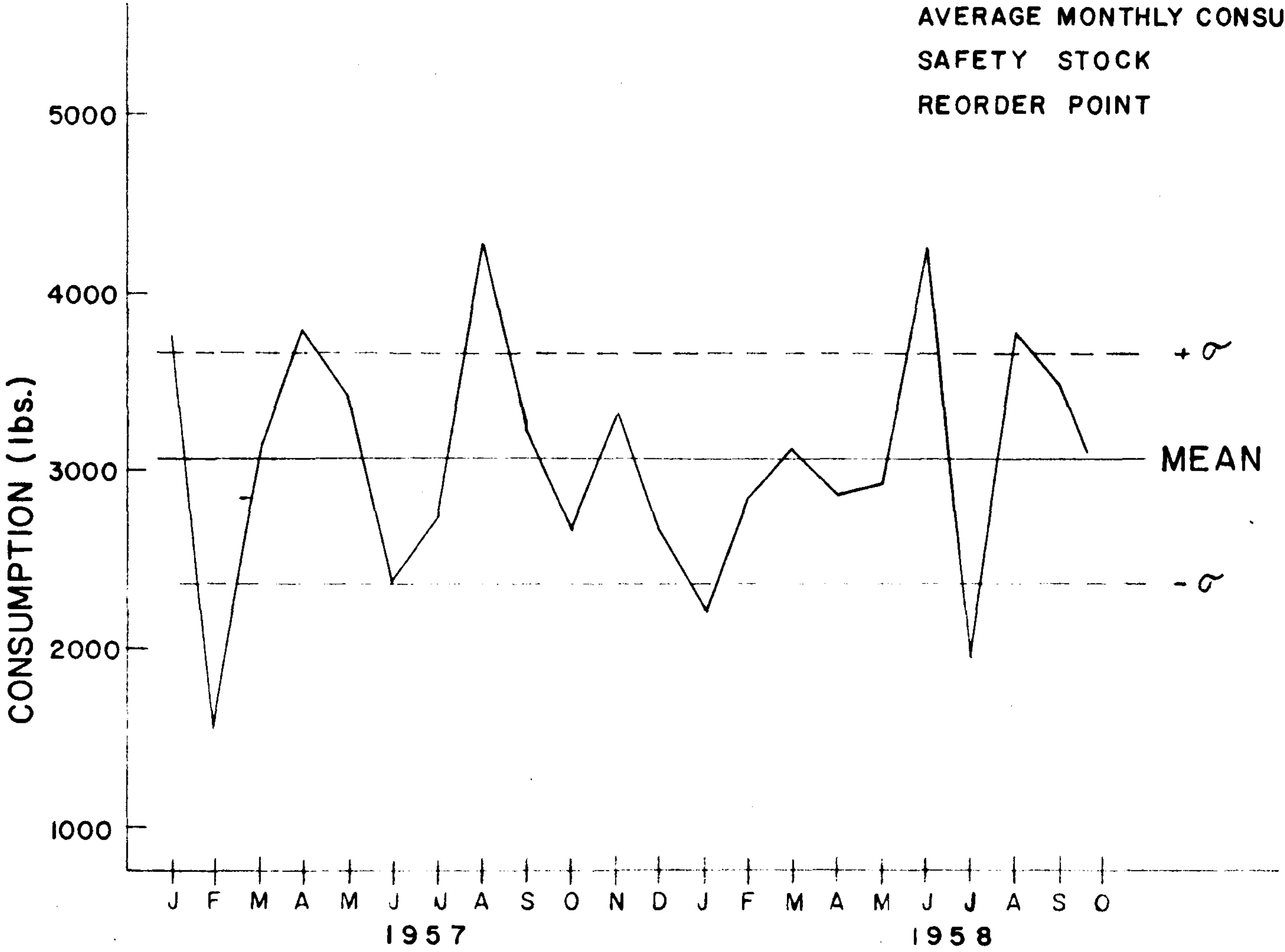
Inventory carrying charges can be determined following the procedure outlined in Section V (p.77). All items of cost must be examined, and all variable costs chargeable to inventory identified and lumped together. In this case, the total of all these carrying charges expressed as a percentage of total cost of all items in inventory amounts to 21 per cent.

Figure VI illustrates the determination of setup costs and inventory carrying charges for yarn X. Total setup cost arrived at for this yarn is $22.28. Inventory carrying charges of $.39 represent 21 per cent of the cost of that yarn. Value A is the ratio of setup costs to inventory carrying charges; the significance of this ratio will be explained later in this section.

The monthly consumption of each A yarn must next be plotted. Figure VII represents such a plot for yarn X. Since the company sales forecast does not go further than to a breakdown of sales by major felt classes, it provides little information of value for inventory control of specific yarns. For this reason, the average monthly consumption of each yarn provides the best available forecast of what future consumption will be, unless there in a specific case is positive information to the contrary. It must be recognized, however, that by using past history as a forecast for the future, an error will

YARN "X"

REORDER QUANTITY	2,400 lbs.
AVERAGE MONTHLY CONSUMPTION	3,056 lbs.
SAFETY STOCK	1,221 lbs.
REORDER POINT	4,277 lbs.



YARN CONSUMPTION GRAPH

FIG. VII

be incurred and that this error bears some proportionate relationship to the variability of the consumption during the plotted period.

According to the definition for a reorder system (p.71), the reorder point equals the average demand during the lead time plus the safety stock. If the system has no provision for a safety stock, the reorder point becomes equal to the average demand during the lead time period. An analysis of weekly machine load reports for one whole year indicates that the average lead time in yarn making was 4.1 weeks, or for all practical purposes, one month. Without provision for safety stock, therefore, a reorder point equal to one month average consumption will be required. On the assumption that yarn consumption is a random variable, this consumption will be greater than the average consumption about 50 per cent of the time. Under these conditions, there is a 50 per cent risk for a stock-out during every month following a drop in inventory to the reorder point level.

With provisions for safety stock, the reorder point is increased by an amount equal to the safety stock. On reaching the reorder point, the inventory level will be higher than the average monthly consumption by an amount equal to this safety stock. The risk of a stock-out is therefore reduced, or, expressing it differently, the degree of protection offered is increased.

It is evident that a 100 per cent protection against a stock-out requires a larger safety stock and a higher reorder point than for, say, an 80 per cent protection. Once a method has been arrived at for computing safety stocks for various stock-out protection levels, it is a relatively simple matter to determine the effect of different protection levels on total inventory. On the basis of an inventory comparison, not shown here, a stock-out protection of 95 per cent was agreed upon by management as the best compromise between delivery service and inventory carrying costs. This corresponds to a stock-out risk of 5 per cent. This means that the safety stock established to protect against run-out prior to the end of a month will, in fact, be permitted to run out 5 per cent of the time, or once in 20 months. However, if an emergency is taken - by overtime as an example - this percentage can be held to a lower figure.

With a safety stock established for a 5 per cent stock-out risk, the inventory will be exposed to this risk whenever the reorder point is reached. It follows, therefore, that the overall risk of stock-out is determined not only by the magnitude of the safety stock, but also by the frequency with which the reorder point is reached. This frequency, in turn, is directly determined by the magnitude of the reorder quantity. If the reorder quantity equals one month average supply, the reorder point will be reached on an average once a month or 12 times a year. One can expect a stock-out 5 per cent of these times or .6 times a year. If, on the other hand, a larger reorder quantity is used, equivalent to, say, 3 months average supply, the reorder frequency will drop to an average of 4 times a year and the stock-out exposures will be reduced to one third of what a reorder quantity of one month average supply will call for. As the stipulated number of stock-outs permitted in a year, .6, represents the product of the reorder frequency and the stock-out risk per exposure, 12 x .05, it is seen that a reduction in reorder frequency will permit an increase in the stock-out risk per exposure. This increase in permissible stock-out risk per exposure is determined by dividing the reorder frequency into the number of stock-outs permitted in a year. In the case of 4 reorders per year, the permissible stock-out risk per exposure becomes $\frac{.6}{4}$, equals .15 or 15 per cent. This means that with an average of 4 reorders per year, one can increase the risk per exposure from 5 to 15 per cent and still operate within the boundary of the permitted .6 stock-outs per year. Since the stock-out risk per exposure varies inversely with the size of the safety stock, an increase in permissible stock-out risk per exposure makes possible a reduction in the safety stock required for a specified amount of overall protection.

By the same token, a reduction in reorder quantity below a one month supply will result in an increase in reorder frequency and in the number of exposures to stock-outs per year. As a result, a retention of the permissible number of stock-outs per year can only be accomplished by a reduction in the stock-out risk per exposure. As an example, for a reorder quantity equal to a half month average supply, an average of 24 reorders a year will be required. In this case, the permissible stock-out risk per exposure must be reduced to $\frac{.6}{24}$, equals .025 or 2.5 per cent. This reduction in permissible stock-out risk calls for a larger safety stock than what is required for a reorder quantity equal to a one month average supply.

The plot of the monthly yarn consumption illustrated in Figure VII suggests that this consumption is a random variable. This being the case, it is possible to select from a statistical table for the area under one tail of the normal curve,[22] the number of standard deviations on either side of the mean outside which there will be a given probability for an occurrence to take place. It is found from this table that there is a 5 per cent probability for an occurrence to take place outside + 1.64 standard deviations from the mean. Translating this to the situation at hand, this means that there is a 5 per cent probability that the monthly consumption will exceed a quantity equal to the sum of the monthly average consumption and 1.64 standard deviations. It follows therefore that by establishing a reorder point equal to the average monthly consumption plus a safety stock of 1.64 standard deviations, there will on an average be a 5 per cent risk for a stock-out during the period between the placing of an order and the arrival of the new supply.

For the yarn illustrated in Figure VII, the standard deviation computes to 690 lbs. and the average monthly consumption to 3,056 lbs. In order to arrive at the economic lot size, the safety stock, the reorder point and the average inventory for this yarn, the following steps must be employed:

1. Select arbitrarily a reorder quantity for the yarn
2. Record the annual consumption of the yarn
3. Determine the annual number of setups required by dividing the annual consumption by the selected reorder quantity
4. Multiply the annual number of setups by the setup cost per occurrence. This yields the expected annual ordering cost.
5. Divide the estimated reorder quantity by 2 to arrive at the average inventory of active stock
6. Multiply the average inventory by inventory carrying charges per pound of yarn. This yields the annual inventory carrying charge for active stock
7. Determine the permitted risk by dividing the number of permitted stock-outs, i.e. .6, by the number of setups per year for the assumed order quantity.

8. From a statistical table for the area under one tail of the normal curve, read off the number of standard deviations required for a probability equal to the permitted risk arrived at in step 7 above
9. Multiply the computed standard deviation of the yarn consumption by the number of standard deviations required for the specified protection. The answer to this represents the safety stock required for an overall 5 per cent risk of stock-out
10. Multiply the safety stock by the inventory carrying charges per pound to obtain annual inventory carrying charges for the safety stock
11. Total the reordering cost, inventory carrying charges for active stock and inventory carrying charges for safety stock
12. Repeat the above process for several assumed reorder quantities and select the reorder quantity which yields the lowest total cost. This represents the most economic reorder quantity.

An illustration of the above procedure for yarn X is given in Figure VIII. In this example, the lowest total cost is for assumed reorder quantities of 2400 and 2600 lbs. 2400 lbs. can therefore be selected as the reorder quantity. The reorder quantities for all A yarns must be computed

FIG. VIII

WORK SHEET FOR COMPUTATION OF THE ECONOMIC LOT SIZE

YARN "X" { SETUP COST: $ 22.00
CARRYING CHARGES PER UNIT $ .39

REORDER QUANTITY (lbs.)	ANUAL USAGE (lbs.)	NUMBER OF SETUPS	ANNUAL ORDERING COSTS	AVERAGE ACTIVE STOCK (lbs.)	ANNUAL CARRYING CHARGES	PERMITTED RUNOUTS	PERMITTED RISK	PROTECTION LIMIT	STANDARD DEVIATION (lbs.)	SAFETY STOCK (lbs.)	ANNUAL CARRYING CHARGES	TOTAL COST
2200	36,672	16.67	$367	1100	$429	.6	.0362	1.80	690	1241	$485	$1281
2400	"	15.28	336	1200	468	"	.0393	1.77	"	1221	476	1280
2600	"	14.10	310	1300	507	"	.0426	1.72	"	1187	463	1280
2800	"	13.10	288	1400	546	"	.0458	1.69	"	1166	455	1289

similarly, and by an arbitrary decision, they can all be rounded off to the nearest 100 lbs. For each item, reorder points and average inventories are computed as follows:

Reorder Point = Average Monthly Consumption + Safety Stock

In the example cited,

Reorder Point = 3,056 lbs. + 1,221 lbs. = 4,277 lbs.

Average Inventory = Safety Stock + $\frac{1}{2}$ Reorder Quantity

For yarn X,

Average Inventory = 1,221 lbs. + 1,200 lbs. = 2,421 lbs.

For A yarns with multiple end uses, the reorder quantities, reorder points and average inventories must be computed through spinning. From spinning on, these yarns must be handled according to their consumption patterns. If a yarn is regularly used, as defined for an A yarn, that derivative will still be considered an A yarn and carried through rewinding in economic lot size quantities. A reorder point and an estimate of average inventory for final yarn storage have to be computed for such a yarn. Derivatives which according to their consumption patterns fall into the B and C categories, must be handled through rewinding according to the decision rules to be established for these categories.

With the proposed reordering costs and inventory carrying charges known for each A yarn, simple addition gives the total annual cost expected from operation on the proposed system. From inventory records, the average inventory of each A yarn for the preceding year can be determined. From the yarn orders for the same period, setups for the same yarns can be tabulated and costed out. By addition of inventory carrying charges and setup costs, an estimate of total cost of operation on the existing system is obtained.

In the case at hand, a comparison of the two sets of figures indicates that a savings of about $20,000 a year can be expected from operation on the proposed system. As no capital investment is anticipated as a result of a change to the proposed system, and since the problems of operation on the existing system appear to be on the increase rather than on the decrease, it is considered that this is a very desirable solution, and that the savings for a future period will be larger than those computed. Several intangible savings are also associated with the proposal; the delivery service aspect, in particular, seems very attractive.

Prior to implementation, it is still necessary to further define the decision rules for classifying yarns according to consumption patterns and to provide rules for reordering yarns not handled by the economic lot size system. The following rules and definitions are provided, encompassing all yarns and all foreseeable situations:

Group A - yarns which have consumption recorded against them for at least five of the six months preceding an evaluation. These yarns are carried through spinning in economic lots and stored on spinning bobbins, *or* they are carried through spinning and rewinding in economic lots and stored on the final package, as warp or filling.

Group B - yarns which have consumption recorded against them for at least two but not more than four of the six months preceding an evaluation. These yarns are carried through spinning and rewinding in quantities equal to requirements on the books, or in 500 lb. lots, whichever is the larger.

Group C - yarns which have consumption recorded against them for not more than one of the six months preceding an evaluation. These yarns are to be carried through spinning and rewinding in quantities equal to requirements on the books when an order is placed.

Group AA - yarns which are derived from A yarns stored on spinning bobbins and which have been consumed for at least five of the six months preceding an evaluation. These yarns are carried through rewinding in economic lots and stored as warp or filling.

Group AB - yarns which are derived from A yarns stored on spinning bobbins and which have been consumed for at least two but not more than four of the six months preceding an evaluation. These yarns are carried through rewinding in quantities equal to requirements on the books, or in 500 lb. lots, whichever is the larger.

Group AC - yarns which are derived from A yarns stored on spinning bobbins and which have been consumed for not more than one of the six months preceding an evaluation. These yarns are carried through rewinding in quantities equal to requirements on the books at the time when an order is placed.

C. MAKING THE SYSTEM OPERATIVE

Before the system can be put to practical use, further action is still required with regard to:

1. Establishment of procedures for the operation of the

the system, and

2. Facilitation of the computations required for determining reorder quantities and safety stocks.

1. Establishment of Procedures for the Operation of the System

   a. In order to keep the grouping of yarns up-to-date, yarns must be reevaluated monthly for changes in their consumption patterns and reclassified where changes indicate that this should be done.

   b. Yarn consumption graphs for A yarns (see Fig. VII) must be maintained and checked on a monthly basis to determine whether reorder quantities should be recomputed. If encountered, any one of the following conditions indicates a statistical change in the average or the standard deviation of the consumption and requires recomputation of reordering data:[23]

      (i) When consumption has remained on the same side of the average consumption line for five or more consecutive months

      (ii) When consumption for two or more consecutive months has occurred outside + 1 standard deviation or - 1 standard deviation from the mean

      (iii) When, in any set of three consecutive points, any two lie outside + 2 standard deviations or - 2 standard deviations, the third occurring anywhere else.

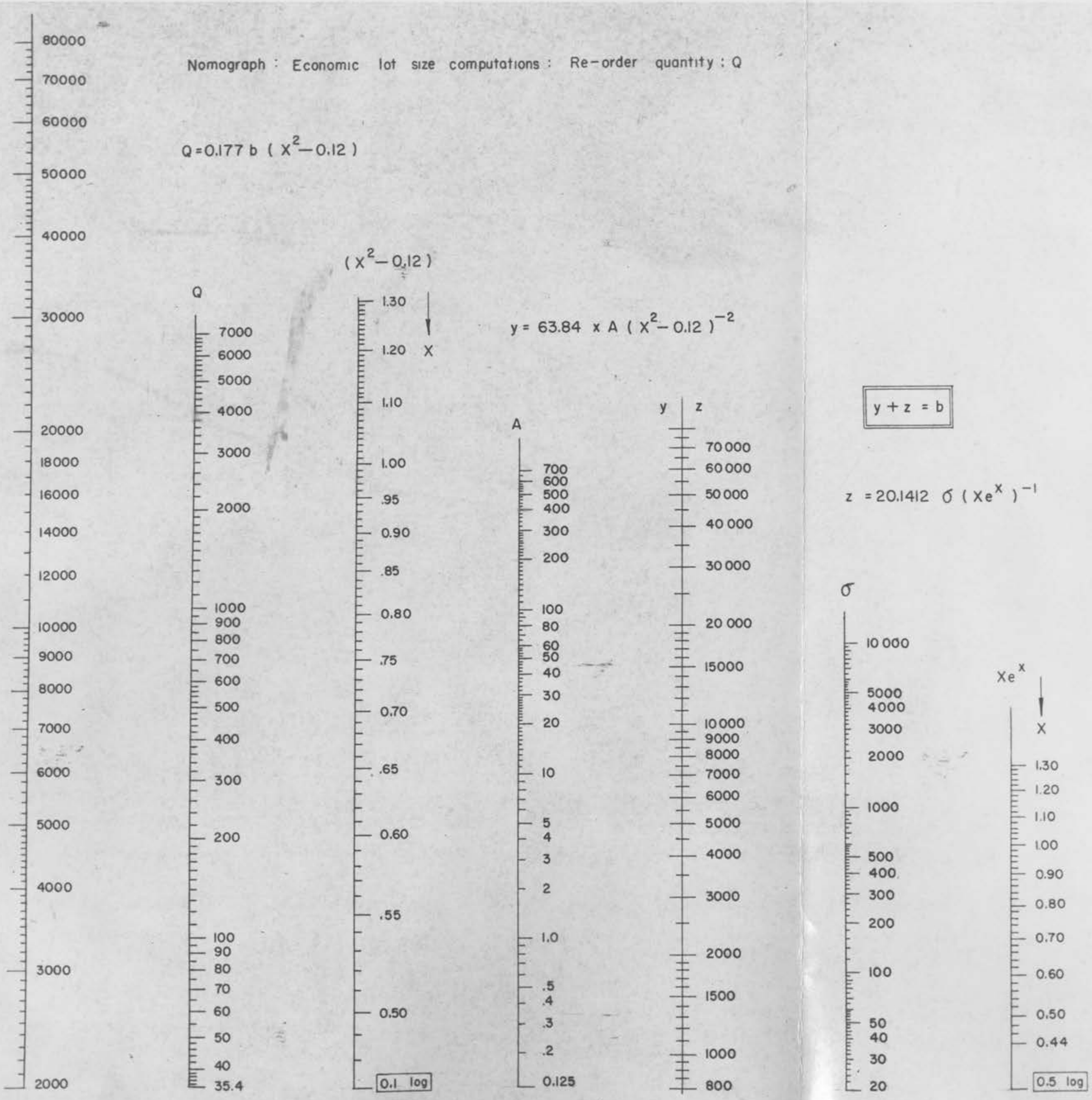
c. Updating of reordering data for changes in costs is required whenever a change in the ratio of setup costs to inventory carrying charges (value A, Fig. VI) exceeds ± 10 per cent. This ratio is to be reevaluted annually for the effect of changes in labor and material costs, and in the interim period for the effect of changes in methods and in routing of yarns.

2. <u>Computation of Reordering Data</u>

The computation of reordering data - reorder point, safety stock and reorder quantity - as described above, will require in excess of one half hour per occurrence. Although it is not anticipated that maintenance of the system on this basis will require in excess of 25 recomputations a month, it is still deemed desirable to simplify the computational procedure for the purposes of

a. Reducing the chance of erros, and
b. Making the computations possible for the caliber of personnel expected to perform them.

In order to simplify the determination of the reorder quantity, the nomograph illustrated in Figure IX has been constructed. Table II has been



Nomograph : Economic lot size computations : Re-order quantity : Q

$Q = 0.177\, b\, (X^2 - 0.12)$

$y = 63.84 \times A\, (X^2 - 0.12)^{-2}$

$\boxed{y + z = b}$

$z = 20.1412\, \sigma\, (Xe^X)^{-1}$

TABLE II

Table for Conversion from Value for X in Nomograph to Number of Standard Deviations of Safety Stock Required (N)

X	N	X	N	X	N
0.44	2.296	0.76	1.667	1.08	1.211
0.45	2.273	0.77	1.651	1.09	1.199
0.46	2.251	0.78	1.634	1.10	1.187
0.47	2.228	0.79	1.618	1.11	1.175
0.48	2.206	0.80	1.602	1.12	1.163
0.49	2.184	0.81	1.586	1.13	1.152
0.50	2.162	0.82	1.570	1.14	1.140
0.51	2.141	0.83	1.555	1.15	1.129
0.52	2.119	0.84	1.539	1.16	1.116
0.53	2.098	0.85	1.524	1.17	1.106
0.54	2.078	0.86	1.509	1.18	1.095
0.55	2.057	0.87	1.494	1.19	1.085
0.56	2.036	0.88	1.479	1.20	1.074
0.57	2.016	0.89	1.464	1.21	1.063
0.58	1.996	0.90	1.449	1.22	1.052
0.59	1.976	0.91	1.435	1.23	1.042
0.60	1.957	0.92	1.421	1.24	1.032
0.61	1.937	0.93	1.407	1.25	1.021
0.62	1.918	0.94	1.393	1.26	1.011
0.63	1.899	0.95	1.379	1.27	1.001
0.64	1.880	0.96	1.365	1.28	0.991
0.65	1.861	0.97	1.351	1.29	0.981
0.66	1.843	0.98	1.338	1.30	0.972
0.67	1.824	0.99	1.325		
0.68	1.806	1.00	1.311		
0.69	1.788	1.01	1.298		
0.70	1.770	1.02	1.286		
0.71	1.753	1.03	1.273		
0.72	1.735	1.04	1.260		
0.73	1.718	1.05	1.248		
0.74	1.701	1.06	1.235		
0.75	1.684	1.07	1.223		

developed for the determination of the safety stock required for a specified degree of run-out protection. Being somewhat complicated in nature, the mathematics involved in the design of these computational tools is considered beyond the scope of this paper. Their application, however, will be discussed next.

In the nomograph,

Q = reorder quantity

b = annual consumption

A = ratio of setup costs to inventory carrying charges

σ = standard deviation of monthly consumption.

The following are the steps necessary for determination of the reorder quantity, Q:

<u>Step 1.</u> Run a ruler through the applicable A value on the A scale and direct it to the Y scale at a value approximately 2/3 the annual consumption. The ruler will cross through a value for X on the left-hand X scale. Record the Y and the X values observed.

<u>Step 2.</u> Shift the ruler so that it crosses through the computed value for the standard deviation on the σ scale and the previously recorded value for X on the X scale to the far right. The ruler now runs

through a value for Z on the Z scale. Record this Z value.

<u>Step 3.</u> If Y + Z equals the annual consumption, then the correct value for X has been found. If Y + Z does not equal the annual consumption, a different value for Y must be selected and the process repeated until a value for X has been found which will make Y + Z equal to the annual consumption.

<u>Step 4.</u> When the correct X has been determined, place the ruler on this value on the left-hand X scale and let it run through the value for the annual consumption on the b scale. The ruler now crosses the Q scale at the economic reorder quantity, Q.

From Table II obtain the value for N which corresponds to the value for X determined in step 3 above. Multiply the standard deviation of the monthly consumption by this N value to obtain the safety stock required.

For yarn X, the long method of computation illustrated in Figure VIII gave as answers a reorder quantity of 2,400 lbs. and a safety stock of 1,221 lbs. It seems worth while at this point to verify these answers by the use of the nomograph and at the same time obtain a demonstration of its application. It should be noted that since the nomograph illustrated has been considerably scaled down from actual size, the reader may have some problems placing a ruler accurately on the scales.

For yarn X,

$A = 57.4$

$\sigma = 690$ lbs.

$b = 36,672$ lbs.

Step 1. Run ruler through 57.4 on the A scale and 25,000 on the Y scale. An X value of .705 is obtained from the left-hand X scale.

Step 2. Run ruler through 690 on the σ scale and .705 on the right-hand X scale. The ruler crosses the Z scale at 9,500 lbs.

Step 3. Add values for Y and Z:

25,000 lbs. + 9,500 lbs. = 34,500 lbs.

This answer does not check with the required b value of 36,672 lbs. Repeat step 1 selecting a value for Y equal to 27,000 lbs. The corresponding value for X is .700. A repeat of step 2 using an X value of .700 yields Z equal to 9,700 lbs. Add the values found for Y and Z:

27,000 lbs. + 9,700 lbs. = 36,700 lbs.

The answer is approximately equal to the required b value of 36,672 lbs.

Step 4. Run ruler through .700 on the left-hand X scale and 36,700 on the b scale. Ruler crosses the Q scale at 2,400 lbs. which is the economic reorder quantity.

For computation of the safety stock, turn to Table II where we find that for an X equal to .700, N equals 1.770. The required safety stock therefore becomes 1.770 x 690 lbs. = 1,221 lbs.

As demonstrated, the long and the short method of computation give identical answers for the reorder quantity and safety stock.

VII

DISPOSITION OF OBSOLETE YARNS

A. THE OBSOLESCENCE PROBLEM

After the economic lot size system had been implemented, the following problem became apparent: As a result of instability in the yarn mix stemming in turn from design changes and changes in customer ordering trends, demotions and promotions of yarn from one yarn group to another took place from time to time. In the case of a demotion of an A yarn to a B or a C yarn, or a B yarn to a C yarn, existing inventories were carried with it into the new yarn group. Since a demotion is the result of a decrease in requirements for a yarn, this inventory was slow in turning over. In many instances, consumption of such yarns faded out altogether, leaving the yarns in inventory for indefinite periods of time. Odd quantities of yarns found their way into these "dead" inventories for other reasons such as over-scheduling, off-standard quality and changes in design specifications after the yarn was made.

Lacking an orderly procedure for disposing of obsolete and semi-obsolete items, inventories of these items grew and tied up equipment - spools, bobbins and baskets - to a point where production problems were created. There were reasons to believe that many of these yarns could have been used at an earlier point of their inventory life, had they been subject to continuous effort for that purpose by the design department. All such action, however, was sporadic in nature and frequently deferred to the point where it was considered to dispose of the yarn to free up equipment. It was evident that here was an area where procedures were lacking. In March of 1960, the industrial engineering department was requested to establish the procedure necessary to at least alleviate a situation which at that time had become rather serious.

As a first step toward a solution to this problem, a framework of purposes which the new procedures are to serve must be established. More specifically, the procedures for disposition of obsolete and semi-obsolete yarns are required to:

1. Provide opportunity for these yarns to be used by bringing them to the attention of the design department. This "after-the-fact" action should not be a substitute for action which makes possible usage of existing inventories of yarns prior to design changes. It is recognized, however, that even under the most ideal conditions, some yarns will from time to time become inactive.
2. Provide a mathematically determined disposition point which will minimize the losses incurred by obsolescence of these yarns. This disposition point must consider the decreasing

probability for using these yarns as time lapses and the inventory carrying charges incurred by continuing to hold the yarns in stock.

3. Enable decision-making with regard to disposition of these yarns to be delegated to a lower level in the organization. A pre-established policy for disposition of these yarns eliminates the need for continuous devotion of executive time to these decisions.
4. Eliminate the need for supervision to search for old lots of yarn to dispose of to free up equipment. In the past, when permission to dispose of a yarn could not be obtained, equipment shortages frequently necessitated production of under-sized yarn lots and even curtailing of production. Additional equipment is not expected to correct this situation; as long as a decision to dispose of a yarn is hard to obtain, as under the old system, this additional equipment will be applied to store still more of the inactive yarns.

A direct result to be expected from the systematic screening implied in 1. above is to use up more of the inactive yarns and therefore reduce the amount of yarns to be disposed of. It should offer a reasonable assurance that at the disposition point, almost all opportunities for using these yarns have been exhausted. In the past, only opportunities at the time of disposition were examined.

B. DEVELOPMENT OF NEW CONTROL PROCEDURES

In order to focus attention on obsolete and semi-obsolete yarns, it is first necessary to provide a definition of what these yarns are. The following definition serves this purpose: An obsolete or semi-obsolete yarn is a yarn that has not been used for four or more months. Yarns falling into this category must be flagged in some manner by the planning department. This can be accomplished by placing an orange tag on the yarn baskets, spools and boxes concerned. The tagging date becomes the point of reference and the problem one of determining the number of months from this date action to dispose of a yarn should be delayed. This number of months must be determined so as to minimize the losses to the company. The postulates for this determination are:

1. The longer the yarn is held in inventory, the greater are the opportunities for using it, that is, the savings by using the yarn will increase. These savings stem from the fact that if the yarn is disposed of and is later needed, the cost incurred will be equal to the replacement cost of the yarn. By keeping the yarn in inventory, this replacement cost is saved. This saving is offset by the fact that
2. The longer the yarn is held in inventory, the greater is the return on investment forfeited. This is the return earned on the salvage value

of the yarn after it has been disposed of. This money is lost for the duration of the life of the yarn in inventory.

If S_n = savings from holding the yarn in inventory for n months, and

R_n = loss of return on salvage value by holding the yarn in inventory for n months,

we will be maximizing the savings (or minimizing the losses) when $S_n - R_n$ = Maximum.

In order to determine the month from tagging date when disposing of the yarn will maximize savings, it is necessary first to determine the probability for usage at various points of time after the yarn has been tagged. This probability can be determined as follows:

If the design department were to screen all tagged yarn for usage, it becomes possible to develop an "aging curve" which reflects the ability of the design department to use up these yarns after tagging date. Let us assume that an analysis of the usage from 25,000 lbs. of tagged stock indicates the following consumption:

Month from Tagging Date	Lbs. Used	Probability
1st	10,000	.400
2nd	5,000	.200
3rd	2,500	.100
4th	1,200	.048
5th	300	.012
6th	100	.004
7th	0	0
8th	40	.0016
9th	40	.0016

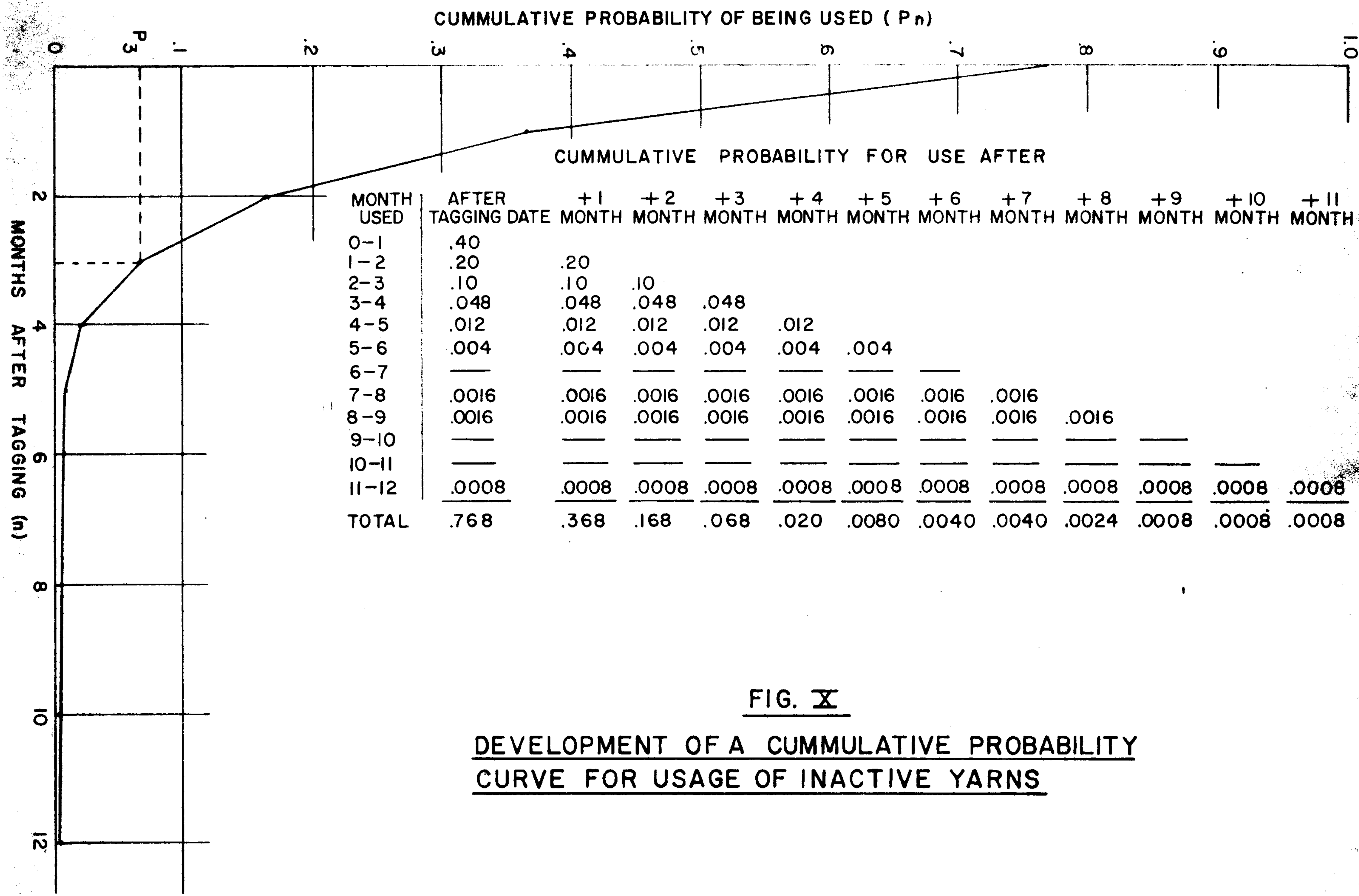
10th	0	0
11th	0	0
12th	20	.0008
	19,200	.7680

It can be seen that 5,800 lbs. were never used and may be considered real obsolete. This represents .232 or 23.2 per cent. The probabilities for being used by month can now be translated into a cummulative probability curve as illustrated by the graph in Figure X. One can see from the graph that for each month there is a certain cummulative probability for yarns being used which is found by going vertically up to the curve from a given month and then horizontally across to the probability ordinate. For example, after 3 months there is a probability of .068 or 6.8 per cent for using the yarn.

The mathematical treatment required for development of formulas for savings in replacement cost from holding yarn, S_n, loss of return on salvage value, R_n, and the disposition point, n, is slightly beyond the scope of this paper. It has therefore been included in the Appendix. From the formulas developed, using the probability curve established in Figure X and the following costs:

1. Replacement cost per lb. of yarn = \$1.60
2. Salvage value per lb. of yarn = \$.55
3. Expected annual return on investment = 30%,

we find that the most economical disposition point is five months from date of tagging. Depending on the probability



CUMMULATIVE PROBABILITY FOR USE AFTER

MONTH USED	AFTER TAGGING DATE	+1 MONTH	+2 MONTH	+3 MONTH	+4 MONTH	+5 MONTH	+6 MONTH	+7 MONTH	+8 MONTH	+9 MONTH	+10 MONTH	+11 MONTH
0-1	.40											
1-2	.20	.20										
2-3	.10	.10	.10									
3-4	.048	.048	.048	.048								
4-5	.012	.012	.012	.012	.012							
5-6	.004	.004	.004	.004	.004	.004						
6-7	—	—	—	—	—	—	—					
7-8	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016				
8-9	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016			
9-10	—	—	—	—	—	—	—	—	—	—		
10-11	—	—	—	—	—	—	—	—	—	—	—	
11-12	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008
TOTAL	.768	.368	.168	.068	.020	.0080	.0040	.0040	.0024	.0008	.0008	.0008

FIG. X

DEVELOPMENT OF A CUMMULATIVE PROBABILITY CURVE FOR USAGE OF INACTIVE YARNS curve determined by sampling from actual yarn lists depicting real usage, and by the use of more accurate costs, one can expect to find a different disposition point.

C. OPERATION OF THE CONTROL SYSTEM

The yarn storage department indicates on the white production tag used to identify stock items, the dates when an item is used. This is necessary in order to keep track of when an item was last used. An orange tag developed for this purpose is to be used for identification of all items which have remained in inventory for four months without usage. The orange tag indicates a) date tagged and pounds in inventory, and b) inventory activity following tagging. The planning department notifies yarn storage as to what items shall have an orange tag. This information is taken from the inventory records in the planning department and includes yarns brought to this department's attention by yarn storage as not having been used for four months based on the date on the white tag. Information recorded on orange tags is forwarded monthly by yarn storage to the planning department on a Slow Moving Lot Sheet. A sample of this form is shown in Figure XI.

During the implementation period, the planning department issues three copies of the Slow Moving Lot Sheet - one copy for the industrial engineering department, one copy

Fig. XI - SLOW MOVING LOT SHEET

ITEM	TOTAL LBS. IN INVENTORY	YARN LOT NO.	LAST MADE	LAST USED	DATE TAGGED	GR. WT. & OUTSTANDING CHARACTERISTICS	REMARKS

for the design department, and one copy to be filed in the planning department. The industrial engineering copy is to be used for statistical analysis. After the mathematical disposition point has been established based on a new probability curve depicting the actual usage rate of the tagged yarns, this copy should be dropped. The design department copy is used for yarn screening. Any accomplishments with regard to using up yarns during a given month will be reflected in the next Slow Moving Lot Sheet and will during the transition period be picked up by industrial engineering by comparing each current report with the previous month's report.

On the basis of the new probability curve developed by industrial engineering after a suitable sampling period, a new disposition point measured from the tagging date can be computed. At that point, adoption of the following decision-rule is recommended: The disposition point is to be measured from tagging date, or from the point of last usage, whichever is the latest. To illustrate: With a disposition point of 7 months, a yarn which has not been used since tagging will be disposed of 7 months after tagging. On the other hand, if part of the yarn is used, say, during the third month after tagging, the disposition point of 7 months will be measured from the end of the third month. Further usage of the yarn shifts the disposition point further into the future, and only yarns with 7 months of non-use will be disposed of. Although not mathematically correct, this procedure recognizes that a yarn that has been used during some portion of the screening period has a better chance to be used again, as compared to a yarn with no use at all.

Each month, a final yarn disposition list is prepared by the planning department from the Slow Moving Lot Sheets and presented to the design department for final screening. Only yarns for which there is positive proof of forthcoming usage are crossed off the list before it is returned to planning where action is taken to dispose of the yarns remaining on the list. Positive proof requires that there is an order on the books calling for the yarn or to which the yarn can be applied.

VIII

CONCLUSIONS

A common feature of the two projects discussed in this paper is that in both cases a mathematical approach was used to arrive at solutions to the original problems. As has been shown, the mathematics employed is of a relatively elementary nature. It appears therefore that the major skill requirements for this type of work is an ability to translate observed phenomena into a mathematical language of some sort. Although the ability to do so is important, it alone is of little value when it comes to providing workable solutions.

It is basic that no solution is really workable until it has been sold to whoever is in a position to accept or reject the recommendations made. However, a recommendation will rarely be accepted on the basis of mathematical and logical truths alone. What, then, are the other factor or factors which determine the saleability of a project? This is a broad question and not an easy one to answer.

In every organization, there are conditions that act as obstacles to change. These obstacles will vary between organizations. This, perhaps, is one of the reasons why some programs fail in some organizations while they succeed in others. On the theory that the best a single person spearheading a program can accomplish, is to influence the organization, and not change it, it appears that acceptance and success of a project will hinge on the ability to tailor the solution to the specific conditions in existence at a given time. There is little question that such action on the part of a project engineer, or his equivalent, involves a restriction of his freedom to provide what one may call "ideal" solutions and therefore reduces to some extent the yield obtainable from a project. The question, however, frequently resolves itself into a choice between an "ideal" solution with maximum yield which will not be accepted, and a solution short of "ideal" with some sacrifice in yield, which will be more readily acceptable.

It appears therefore that there is in each situation a set of factors which will affect the saleability of a proposal. The writer prefers to call these factors "strategic considerations". In addition to the mathematical or logical validity of a solution, its saleability will hinge on how well these strategic considerations have been incorporated into the project.

Let us consider here the strategic considerations which played a part in the solution of the problems discussed in this paper. It seems clear that a contributing factor to success was that there, in both cases, was a commonly recognized need for a solution. This in itself was helpful, but it is felt that it was a change from a chronic to an acute problem which really precipitated action and created a basic receptivity to new methods. Offsetting this advantage was the fact that this was the first time an approach of this nature had been employed in the company, and it was feared that the idea of having mathematically developed decision rules supersede judgment based on years of experience, would be objectionable, at least to some people. It was suspected that due to inexperience with mathematical and statistical decision rules there would be a lack of confidence in the answers provided.

Success of any mission has to be measured against the objective it sets out to accomplish. We are here dealing with two objectives, one for each project. The economic lot size project set out to minimize the total cost of setups and carrying of inventories, compatible with a satisfactory delivery service. The obsolete yarn project had as its objective to provide an orderly procedure for disposition of inactive yarn.

It was recognized at a relatively early stage of the economic lot size project that the economic lot size system itself could only provide the minimum cost for the conditions under which it had to operate. The savings would therefore be limited to the excess of the cost of operating on the old system over this minimum. It appeared that still larger savings could be expected from changes in the conditions which established this minimum. It was evident that the way to accomplish this would be to channel a greater percentage of the production volume from the B and C yarn groups into the A group. Only a reduction in the number of yarns available for incorporation into felt designs would accomplish this objective. How to go about this was in itself a major problem.

The situation at the time was one where there was a common realization on the part of all parties involved that the company was using too many different yarns. However, this was an agreement on generalities, and it was of little value as long as a decision to abolish a certain yarn required agreement on specifics. Although everybody agreed that there were too many yarns, nobody agreed on which were the ones too many. This had been a problem of long standing and several attempts to solve it had headed for failure. In the meantime, the selection of yarns continued to grow.

It was evident also that the policy for disposition of obsolete yarns would do little more than reduce losses which resulted from wasteful practices. Following the earlier argument, further reduction of these losses would have to stem from changes in the underlying conditions.

The strategy applied in both cases constituted a direct attack on two problem areas where solutions were both needed and sought by top management. Both solutions satisfied the original objectives very well. To go beyond these original objectives - to modify the underlying conditions which established the minimum cost level - would require an indirect attack. This was an area where a solution was needed but not sought by top management. By merging the two projects, it became possible to accomplish the more far-reaching objective.

The best that the obsolete yarn project could accomplish within the framework of its original objective was to reduce the need for condemning yarn to waste. Even under the most favorable conditions, it appeared that considerable quantities of yarn would still have to be disposed of in this manner. However, by specifying that a yarn which had been condemned to waste for reasons of inactivity could never again be ordered unless there was a clear-cut technological need for it, more and more of these marginal yarns started to fade out of the picture. As a result, the designers had available to them a decreasing choice of yarns from which to specify for new designs. A larger percentage of the production volume was therefore channeled into the A yarn group. Since more of the orders would also hit the B yarns, many of these became eligible for promotion into the A group. It is estimated that the value of this alone, from a monetary point of view, is greater than that obtained from the two original projects within the framework of their original objectives.

The paper also illustrates how systems of the type described make possible an extention of the mind of their designer to the person who is charged with the responsibility for their day-to-day operation. The yarn controller's position is a semi-clerical one and he is hardly expected to have the knowledge or time required to design the type of systems illustrated. The approach therefore makes it possible for someone in a clerical position to utilize in his daily work, the thinking of a person completely divorced from him and who most certainly would demand a considerably higher salary.

Perhaps the most important benefit obtained from the work done on these projects was an educational one. A familiarity with mathematical and statistical concepts - as provided by involvement in the two projects - has made management more alert to problems for which they so far had believed that no reasonable solutions were available. As a result, several problem areas have since been attacked along similar lines, with considerable success.

APPENDIX

DEVELOPMENT OF FORMULA FOR DISPOSITION OF OBSOLETE YARNS

If Delay Disposition	Cost of Yarn Used During Each Month
1st month	$(P_0 - P_1)$ Cy
2nd "	$(P_1 - P_2)$ Cy
3rd "	$(P_2 - P_3)$ Cy
4th "	$(P_3 - P_4)$ Cy
5th "	$(P_4 - P_5)$ Cy
6th "	$(P_5 - P_6)$ Cy
7th "	$(P_6 - P_7)$ Cy
8th "	$(P_7 - P_8)$ Cy

Cy = replacement cost per lb. of yarn used.

P_0, P_1, P_2, P_3 --- P_n = probability for usage after 0, 1, 2, 3 --- n months from tagging date.

Total value of yarn used after 8 months equals:

$$(P_0 - P_1)\ \text{Cy} + (P_1 - P_2)\ \text{Cy} + \text{---} + (P_7 - P_8)\ \text{Cy} =$$

$$(P_0 - \cancel{P_1} + \cancel{P_1} - \cancel{P_2} + \text{----------} + \cancel{P_7} - P_8)\ \text{Cy} =$$

$$(P_0 - P_8)\ \text{Cy},$$

and after n months, savings in terms of value of yarn used by delaying disposition action becomes

$$S = (P_0 - P_n)\ \text{Cy}$$

On the other side of the ledger we have:

If Delay Disposition	Return on Investment Forfeited during Each Month
1st month	$\left[(1 - P_0) + \frac{P_0 + P_1}{2}\right] C_s I$
2nd "	$\left[(1 - P_0) + \frac{P_1 + P_2}{2}\right] C_s I$
3rd "	$\left[(1 - P_0) + \frac{P_2 + P_3}{2}\right] C_s I$
4th "	$\vert$
5th "	$\vert$
6th "	$\vert$
7th "	$\vert$
8th "	$\left[(1 - P_0) + \frac{P_7 + P_8}{2}\right] C_s I$

C_s = Salvage value per lb. of yarn

I = Expected monthly return on investment

P_0, P_1, P_2, P_3 --- P_n = probability for usage after 0, 1, 2, 3 --- n months from tagging date.

Adding up, total return on investment forfeited after 8 months:

$$= \left[8\ (1 - P_0) + \frac{1}{2}\ (P_0 + P_8) + \sum_{i=1}^{7} P_i\right] C_s I$$

and after n months, return on investment forfeited by delaying disposition action becomes

$$R_n = \left[n\ (1 - P_0) + \frac{1}{2}\ (P_0 + P_n) + \sum_{i=1}^{n-1} P_i\right] C_s I$$

To find n, find set of p and n which will maximize our savings, i.e. make -

$$S_n - R_n = \text{Max.}$$

Substituting for S_n and R_n

$$(P_0 - P_n)\ Cy - \left[n\ (1 - P_0) + \frac{1}{2}\ (P_0 + P_n) + \sum_{i=1}^{n-1} P_i\right] C_sI = \text{Max.}$$

Rearranging -

$$P_0\ (Cy - \frac{1}{2}\ C_sI) - P_n\ (Cy + \frac{1}{2}\ C_sI) - n\ (1 - P_0)\ C_sI - \sum_{i=1}^{n-1} P_iC_sI = \text{Max.}$$

Substituting -

P_0 = .768
C_s = \$.55
I = 30% (2.5% monthly)
Cy = \$1.60

$$.768\ (1.60 - .0069) - P_n\ (1.60 + .0069) - .232n\ .01375 - .01375 \sum_{i=1}^{n-1} P_i = \text{Max.}$$

$$1.2334 - 1.6069\ P_n - .00319\ n - .01375 \sum_{i=1}^{n-1} P_i = \text{Max.}$$

$$1.2334 - \left[1.6069\ P_n + .00319\ n + .01375 \sum_{i=1}^{n-1} P_i\right] = \text{Max.}$$

This is maximum, when -

$$1.6069\ P_n + .00319\ n + .01375 \sum_{i=1}^{n-1} P_i = \text{Min.}$$

One can now determine the value of n which will minimize the expression. (For each value of n read corresponding P_n from graph).

n	P_n	$\sum_{i=1}^{n-1} P_i$	$1.6069\, P_n + .00319\, n + .01375 \sum_{i=1}^{n-1} P_i$
4	.020	.605	.05320
5	.008	.625	.03739
6	.006	.633	.03748
7	.005	.639	.03914
8	.004	.644	---

Minimum is for disposition point - i.e., for yarn costs and probabilities used, 5 months from tagging date.

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