

THE DYNAMICS OF PRODUCTION AND DISTRIBUTION
IN THE RAYON AND ACETATE SECTOR OF THE TEXTILE INDUSTRY

by

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Thesis

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Professor L. F. Hamilton
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Professor Hamilton:

In accordance with the requirements for graduation, I herewith submit a thesis entitled "The Dynamics of Production and Distribution in the Rayon and Acetate Sector of the Textile Industry."

I would like to express my sincere appreciation to my thesis supervisor, Professor Jay W. Forrester, who suggested this thesis topic and guided me in its development. In addition, I wish to acknowledge the generous assistance of many of the members of the Industrial Dynamics Group at the School of Industrial Management.

Sincerely yours,

Howard S. Krasnow.

ABSTRACT

Title of Thesis: The Dynamics of Production and Distribution in the Rayon and Acetate Sector of the Textile Industry

Name of Author: Howard Spencer Krasnow

Submitted to the School of Industrial Management in partial fulfillment of the requirements for the Degree of Master of Science.

The objective of this thesis is to identify and describe elements of behavior which may be expected to influence the dynamic performance of the textile industry. The production and distribution of rayon and acetate provides a relatively independent framework upon which the discussion is built. The structure of this sector is first developed in terms of distribution of product through the various stages from fiber production to retail sales. It is then further explored in terms of information flow through the system, with particular emphasis upon the ordering and pricing policies employed at each level. The activities of retailers, wholesalers, apparel manufacturers, converters, weaving mills and fiber producers are all described in an attempt to develop a plausible and realistic image as a foundation for a simulation model.

The model concentrates upon complementary flows of orders and goods. Both flows are interrupted at numerous stages to create backlogs and delayed orders-in-process, as well as inventories. The flow of orders is initiated by independent consumer demand which indirectly actuates the movement of goods throughout the system. The impact of fiber prices on rayon and acetate distribution is also considered in the model, both with respect to competition from cotton and to the role of price expectations in determining inventory policy at the converting level. In conclusion, it is pointed out that the model might be effectively utilized as a research tool for developing a more complete, representative model of the Textile Industry.

Thesis Supervisor: Jay W. Forrester

Professor of Industrial Management.

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INTRODUCTION

The manufacture and distribution of textile products constitutes one of the basic industrial activities in the United States, encompassing more than 50 diverse industries and trades. In 1954, more than three million people were directly employed by the industry, producing a gross annual product of 18.5 billion dollars.¹ Most of this output consisted of products for direct consumption; apparel, household furnishings, and piece goods accounting for 78% of all fiber marketed.²

Despite the vital nature of much of its product, the textile industry has never been especially noted for stability. Three distinct types of fluctuation have been observed in output at various stages of production. First, there is a pronounced tendency toward seasonal fluctuation resulting from the nature of the product (e.g., lightweight summer suits, heavy winter coats) and from the promotional

¹Estimated from several publications of the U.S. Bureau of the Census, primarily Census of Business: 1954, Vol. 2, Retail Sales-Area Statistics and Census of Manufactures: 1954, Vol. 2, Industry Statistics, Part I (General Summary and Major Groups 20-28).

²"Textile Inter-Fiber Competition," Textile Organon, Vol. 28, No. 11, October, 1957, Supplement.

policies of the retailing level (e.g., the Christmas season). Second, the consumption of textile fibers reveals a surprisingly consistent fluctuation with a period of about two years. This fluctuation has been so regular that it has been named "the textile cycle" by Stanley B. Hunt, Director of Textile Economics Bureau, Inc.³ Hunt believes that the textile cycle is closely correlated with a fluctuation in total inventory within the production-distribution system, which tends to vary between four and eight months' supply with a period of fluctuation of about two years. Finally, there is the long-term fluctuation of textile fiber consumption in consonance with the swings of the business cycle.⁴

There are, no doubt, many ways in which a study of the dynamic behavior of the textile industry could be undertaken. The direction taken by this thesis is suggested by Hiram S. Davis in conclusions drawn from a study of inventory policies in the textile industry. He states that, in the dynamics of cyclical behavior:

it is the operations of buyers which play the dominant role. By concentrating in a few weeks time buying that might otherwise be done over months, purchasers of textile products tend to create a boom; the slump inevitably follows; buyers have no need for additional goods until they have disposed of prior purchases. It

³As quoted by Jesse W. Markham in Competition in the Rayon Industry (Cambridge: Harvard University Press, 1952), p. 112.

⁴Ibid., p. 126.

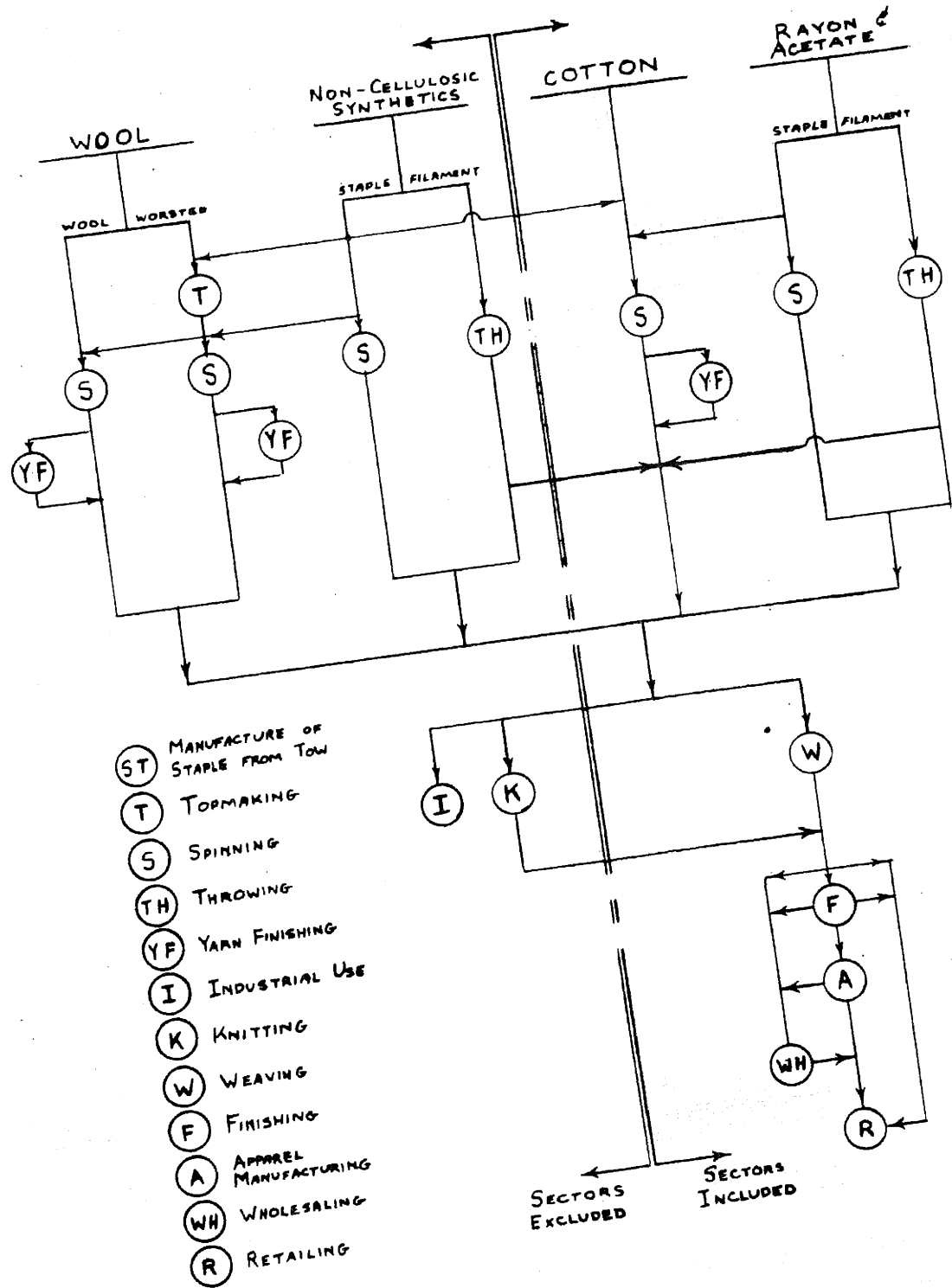
seems to follow, therefore, that one can hardly hope to understand fluctuations in the textile business or take steps to minimize them without first discovering why buyers of textiles operate as they do, and what circumstances make such operations possible.⁵

(Emphasis mine). The objective of this study, therefore, is to set forth as complete and accurate a description as possible of the characteristics of behavior which might determine the dynamic performance of the textile industry. Such a description is an essential prerequisite for an understanding of the fluctuations which have long plagued the industry.

The apparently limited goal of description is, unfortunately, monumental in scope when applied to the vast textile industry. The first requirement is to select a sector sufficiently limited in size to permit investigation, yet reasonably isolated so that much of its dynamic behavior may be generated from within. Figure 1 presents a simplified picture of process flow for the most important sectors of the textile industry and identifies the vertical sector that has been selected for study. Rayon and acetate compete primarily with cotton, so that the product of other fibers may be disregarded. Furthermore, the functioning of the woven fabrics sector, which is of major importance in terms of volume, is largely independent of conditions within the industrial or knit goods sectors.

⁵Hiram S. Davis, Inventory Trends in Textile Production and Distribution, No. 7 of Inventory Policies in the Textile Industries; (Washington, D.C.: The Textile Foundation, 1941), p.51.

FIGURE 1
TEXTILE INDUSTRY
PROCESS FLOW CHART



The difficulties of field investigation and model formulation impose one additional restriction upon the stated objective. A realistic representation, rather than an attempt at a complete description of the rayon and acetate sector, has been sought. An example should help to clarify the distinction: a complete description of ordering policies employed by the weaving mills would require, at the very least, detailed study of a large and representative sample of the several hundred mills operating in the rayon and acetate sector; instead, a few mills have been selected at random and their policies are used as the basis for a description.⁶ There is no intention to imply that the resulting descriptions are truly representative or typical of all behavior within the industry. It is sufficient that they be plausible, reflecting behavioral characteristics that can and do exist, even if the degree of generality which can be attributed to the description is uncertain. Every effort has been taken to achieve maximum generality within these limitations, of course, and there is reason to believe that much of the material presented is quite representative.

Two modes of description, verbal and mathematical, are employed, with quite distinctive goals. The verbal

⁶The firms that have cooperated in this study, at all levels, have requested anonymity; hence no credits are offered despite the considerable assistance that has been obtained.

description seeks to convey as full and rounded a picture as possible of the complex patterns of operation throughout the system of production and distribution. Needless to say, considerable abstraction, omission, and generalization has been necessary despite the desire for completeness. This verbal picture is useful primarily as a foundation upon which to build the mathematical model. It is the model which holds the key to the utility of accurate description.

The beauty of a model, as opposed to a verbal representation, is that it can be manipulated. Extensive experimentation with the simulated system is feasible, and provides a means of gaining insight into the dynamic performance of the real system. The validity of any experimental results relies heavily upon the accuracy with which the model describes the system. The latter chapters are concerned with the construction of the model, whose completeness and accuracy may readily be compared with the earlier description of the industry.

In describing a distribution system, it is useful to focus upon the flows of product and information. Product flow is the purpose for which the distribution system exists, but it is dependent upon, and controlled by, an opposing flow of information. The major aspect of information flow which will be considered concerns the transmission of demand, originated by the consumer and generated throughout the system in the form of orders. Price is an example

of another element of information which is transmitted, often imperfectly, through the system.

Chapter II describes the main characteristics of product flow for cotton, rayon and acetate fibers used in woven products. It is interesting to observe the specialized distribution techniques which have arisen around the complex technology of textile manufacturing. Chapter III explores the behavior of firms at each production and distribution stage in transmitting essential information. This behavior centers primarily upon ordering policies and secondarily upon pricing policies at each stage. The production of rayon and acetate fiber is omitted from these chapters and discussed separately in Chapter IV. The problems of the fiber producer differ considerably from those of firms at other levels of the textile industry, and the availability of extensive data has made possible a somewhat more complete discussion of this interesting sector.

The remainder of the thesis is devoted to construction and evaluation of a simulation model based upon the foregoing description. Chapter V describes some of the key features of a simulation model, and identifies the major aspects that have been incorporated into the model. The potential for incorporating additional features into such a model is pointed out, as well as the extensive simplifications that have been made. Chapter VI presents the model,

with particular emphasis upon the retail level as a prototype for several other stages. Finally, the potential uses to which the model can be put in its present form, its limitations, and the possibilities of improvement are discussed in the last chapter.

CHAPTER II

THE TEXTILE INDUSTRY -- PRODUCT FLOW

The textile industry has developed some specialized techniques to facilitate the distribution of product through the varied processing stages to the ultimate consumer. The actual system of distribution may be attributed in part to "trade practice," but there is little doubt that very basic and necessary functions are performed. The most outstanding of these are product differentiation and dispersion.

If the textile industry were viewed as a simple "black box," the input would be seen to consist of a small variety of fibrous materials: silk, wool, cotton, and man-made cellulosic and non-cellulosic fibers. The output is an astonishing variety of highly differentiated products: women's sheer negligees and heavy arctic parkas, curtains and carpets, sewing thread, tarpaulins, and countless other items demanded by a modern society. These items are mostly sold to individual consumers by a far-flung network of retail outlets, hence it is apparent that a tremendous task of dispersal has been accomplished.

Some insight into the manner by which this dispersion

is achieved is given in Table 1, which lists the size and number of establishments at each level of the distribution system.

TABLE 1

SIZE AND NUMBER OF ESTABLISHMENTS AT VARIOUS STAGES IN THE PRODUCTION AND DISTRIBUTION OF TEXTILE PRODUCTS¹
1954

Industry	Total No. Establishments	Establishments Employing 100 or more Persons
Synthetic Fiber Producers	46	40
Yarn Mills [spinning & throwing, cotton & synthetic]	591	304
Broad Woven Fabric Mills (cotton & synthetic)	899	606
Finishing Plants	725	188
Independent Converters	527	n.a.
Apparel Manufacturers (all fabrics)	31,372	2,589
Merchant Wholesalers	6,940	n.a.
Merchandising Agents	975	n.a.
Retail Outlets	173,111	n.a.

Notes:

¹Sources: a) Census of Manufactures: 1954, Vol. 2, Major Groups 22B, 23, 28B.

b) Census of Business: 1954, Vol. 2, table 1A; and Vol. 4, table 1A.

n.a. = not available

The range is from 46 synthetic fiber producing establishments,

most of which are large plants employing hundreds of people, to 173,111 retail outlets. This chapter will briefly examine some of the techniques employed at each level for achieving such extensive product differentiation and dispersion.

The flow of product through the textile production and distribution system is shown schematically in Figure 2 for cotton, rayon and acetate woven goods. This flow is accomplished through five principal markets:¹

1. raw natural fiber, man-made staple and continuous filament yarn
2. spun yarn
3. gray goods
4. finished fabric
5. finished textile products

Each of these marketing stages is represented on the flow chart by a horizontal line. Various degrees of integration are indicated by more than one operation's being performed within a single band; for example, spinning and weaving are both performed by the "weaving mill." A flow line passing through a band with no operations shown means that the given marketing stage has been omitted, as when fiber is sold directly to the weaving mill.

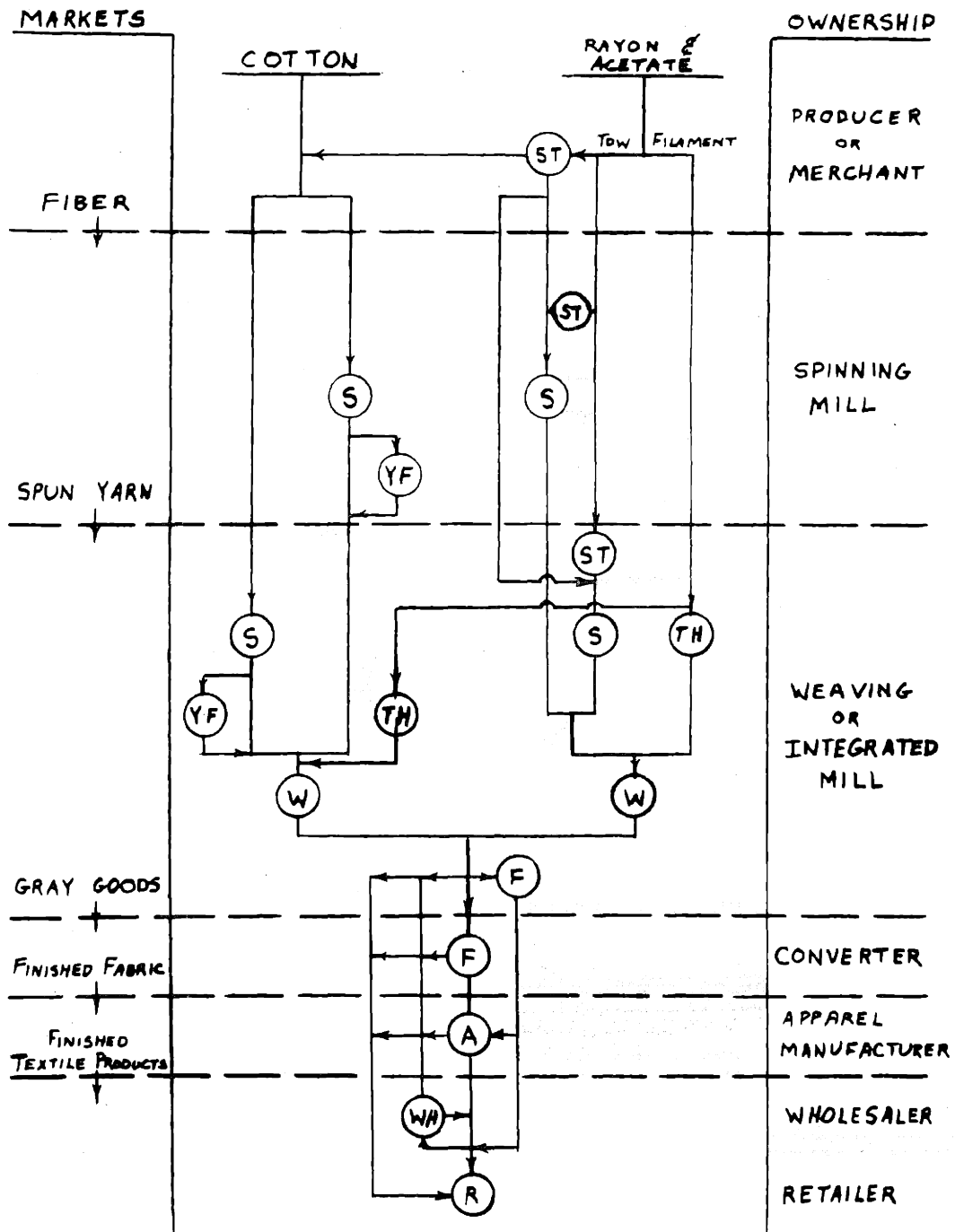
FIBER MARKET

For natural fibers, the first market shown is

¹The term "market" is used here in its broadest sense to describe the general process of transferring ownership and translating goods in space and time.

FIGURE 2 PRODUCTION & DISTRIBUTION FLOW CHART

FOR COTTON, RAYON, & ACETATE WOVEN GOODS



SEE FIGURE 1 FOR IDENTIFICATION OF PROCESSES

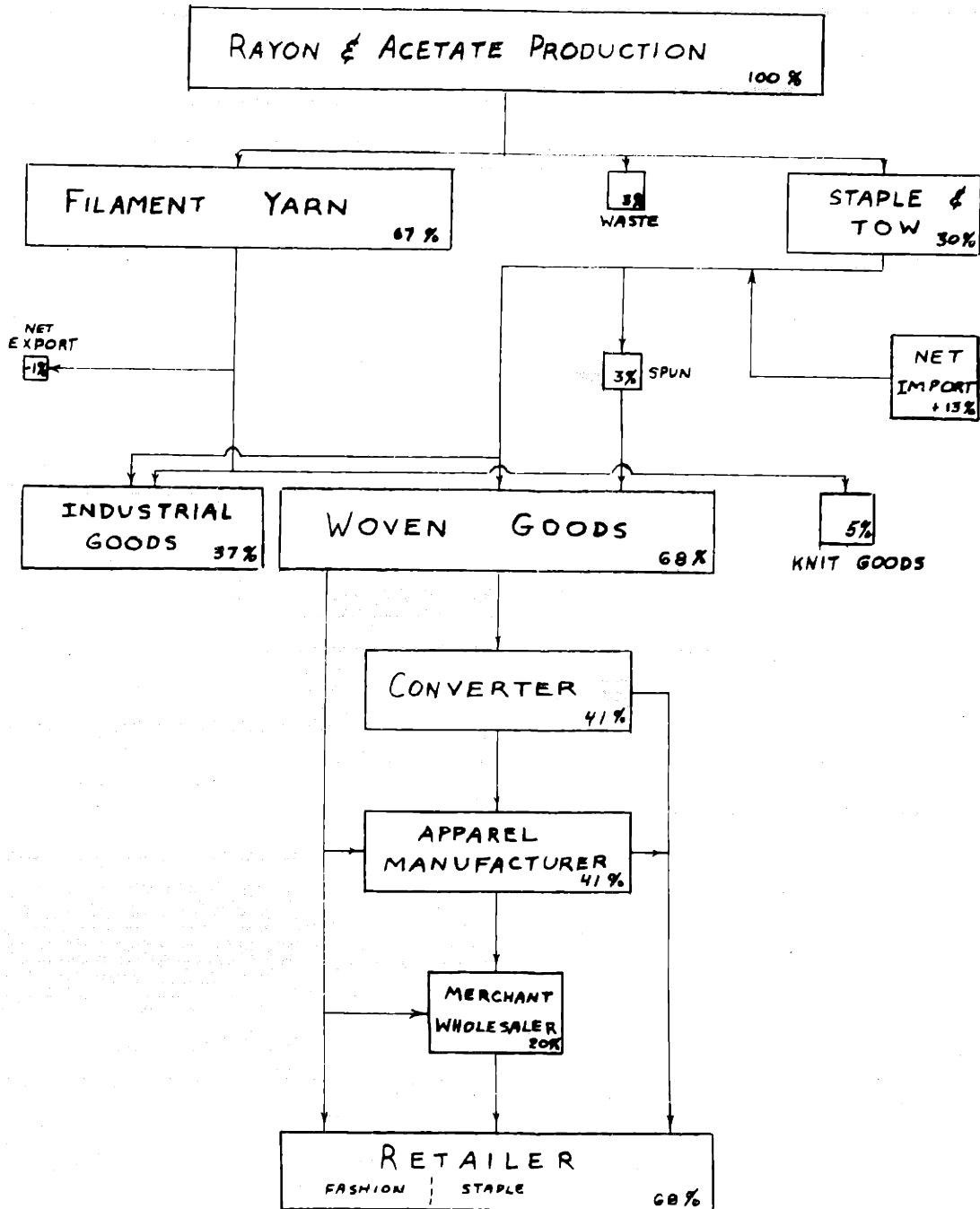
actually preceded by a vast network of markets which collect, grade, and store the basic commodity. These markets are of little interest for the present study except to the extent that they establish natural fiber prices which do have an impact on the demand for synthetic fibers. It is sufficient to note that the primary natural fiber markets are competitive, subject to the limitations of government supports and tariffs (since the natural fiber markets are world wide). They serve to bring together large numbers of small sellers, who sell to a far smaller group of fiber merchants, the merchants in turn selling to the mills, as shown in the first stage of the flow chart.

The starting point in the flow chart represents the various fibers immediately prior to transfer of ownership to the mill. In the case of natural fibers, this transfer is a relatively complex process as discussed above. The synthetic fibers, however, are almost entirely transferred by direct sale from the producer to the mill. Prices are set by the producer, subject only imperfectly to the pressure of market forces.² The relative importance of subsequent levels in the distribution of rayon and acetate products is shown in figure 3.

Man-made fibers are sold in three forms: staple, tow, and filament yarn. Staple and tow are essentially the

²See Chapter IV.

FIGURE 3
PROPORTIONATE DISTRIBUTION
OF RAYON & ACETATE
PRODUCTION



SOURCE: VARIOUS, SOME ESTIMATED. MOSTLY CENSUS DATA AND TEXTILE ORGANON.

same product, since tow is used only to be cut into staple. When tow is sold as staple, the producer performs the cutting steps, packaging the staple in bales in much the manner of raw cotton fibers. When it is sold as tow, the cutting step is transferred to the mill, thereby eliminating the need for baling. Although data are not readily available, it is believed that an increasing percentage of fiber to be used in staple form is sold as tow. At the spinning mill where it is used, staple can be spun directly into yarn, blended first with other natural or synthetic fibers and then spun, or dyed prior to spinning.

Continuous filament yarn is sold directly to the weaving mill in two classes of packages. The yarn may be wound on small spools (cones, cheeses, etc.), or on large section beams. In the latter case, the producer is essentially taking over one stage in the preparation of warp for the weaving mill. Since section beams must be wound to specifications to suit a particular fabric warp, they are not stocked, but are only made to order. This is in contrast to other continuous filament yarn packages and to staple, both of which are normally sold from stock. Section beams account for roughly one-quarter of all continuous filament yarn sales.

YARN MARKET

Spun yarn is traded in the yarn market for sale to weaving mills. However, a long-term trend toward

integration in the spinning and weaving industries has greatly reduced the importance of yarn trading. In 1954, less than 20% of cotton yarn was produced for sale. Stated differently, of the total installed loom capacity for broad woven (cotton, rayon) goods, over 82% was in mills equipped for spinning and weaving. Nevertheless, the yarn market is sufficiently widespread to establish representative prices. Yarn is sold both through merchants who buy and sell, and directly from the mill to the customer.

A significant volume of yarn is finished prior to further processing. Virtually all of this work is handled by commission finishers, whether or not the yarn is to be sold. Many of the man-made fibers are available in colored filaments, however, and these are rarely finished in the yarn.

All yarn requires additional processing before it is ready to be placed on the looms at the weaving mill. However, once the mill acquires ownership of the yarn, the throwing operation is the only one that is sometimes performed outside the mill. Commission throwsters receive about half of the continuous filament yarn requiring throwing after it leaves the fiber producer.

GRAY GOODS MARKET

The total output of woven goods can be classified into those that require further finishing before consumption,

and those that do not. The latter group consists of some goods made from dyed or colored yarns, although many of such goods still require finishing to achieve the desired luster, texture, etc. The former group is referred to as gray (or greige) goods. It has been estimated that in the late 1930's less than one-quarter of the cotton goods woven were yarn dyed, about one-quarter were never finished (going mostly for industrial uses), and more than half were produced in the gray.³ For the man-made fibers, neglecting industrial uses, 89% of total output consists of gray goods.⁴

Some gray goods are finished at the mill, carrying the integration process one step forward from the weaving operation. However, only 104 of the total of 899 weaving mills in the United States,⁵ with little more than 15% of installed weaving capacity, are equipped to do any finishing, and these operate mostly on cotton goods.

The absence of more extensive integration of weaving and finishing is partially due to the unique requirements of the distribution system. Finishing is the first production stage at which a great diversity of product is achieved.

³Reavis Cox, The Marketing of Textiles (Washington: The Textile Foundation, 1938), p.117. These percentages are probably not very different today, with a lower percentage going for industrial uses (due to the effect of rayon competition), and a higher percentage for yarn dyed goods.

⁴Census of Manufactures: 1954, Vol. 2, p22B-19.

⁵Ibid., p. 22B-32, Table 9D; for mills weaving cotton rayon and acetate fabrics.

Whereas weaving tends to be a high production, standard, and relatively efficient operation, finishing is concerned with creating a large variety of low-volume items for sale to a widespread trade. These finished fabric characteristics demand a marketing technique quite different from that used in selling gray goods, with the result that the mills prefer to leave the job to a specialist--the converter.

The converter is the man who bridges the gap between the few suppliers of gray goods and the many purchasers of finished fabrics. He buys goods "in the gray" from the mill and decides in detail how those goods shall be finished. Much of his decision concerning quality and quantity is based upon an intimate knowledge of the finished fabric market, and the converter must be alert to shifts and trends in that market. He performs no processing himself, but arranges for finishing, which he pays for on a commission basis. Although the converter may own considerable inventory at any one time, both finished and "in the gray," physical storage is normally handled by the mill or the finishing plant (frequently at a price).

A distinction should be made between integrated mill operation and integrated corporate operation. The previous discussions of integration referred to the mill level. An example might be the manufacture of cotton bed sheets or towels, where the fabric is successively woven, finished,

sewed, and shipped ready for consumption. However, for most woven production, including virtually all acetate and rayon output, the converting function cannot be eliminated so easily. Corporate integration merely brings the converter under the control of the mill, with no essential change in his operations save that he now obtains gray goods from a single source. In 1954, of the total fabrics that were finished, almost 35% were handled by corporate converters.⁶

FINISHED FABRIC MARKET

The converter (independent and corporate controlled) and the mill both operate on the supply side of this market, the mill selling through branch offices. Sales are made to the "cutting trade,"⁷ to wholesale houses, and direct to retail outlets. An interesting feature of this market is its extreme geographic concentration, with about 90% of the converters and mill offices located in New York City, which is the center of the apparel manufacturing industries.

Dispersal is one of the essential functions of the finished fabric market. The 587 independent converters and

⁶Estimated from Census data for cotton, rayon, and acetate.

⁷The term "apparel manufacturing" will be used to denote the many activities concerned with processing of finished fabrics into end products. This includes the work of jobbers, who handle a substantial part of the total volume. The jobber purchases finished fabric, performs product styling, and arranges for production with contract manufacturers who operate on a commission basis. With respect to marketing functions the jobber is indistinguishable from the apparel manufacturer.

899 mills (not all of which maintain sales offices)⁸ distribute their goods to most of the 31,372 apparel manufacturers, plus many wholesale and retail outlets. Neglecting industrial fabrics, about 60% of all cotton, rayon, and acetate fabrics pass through the hands of the cutter, with the remainder going direct to wholesale, retail, export (no more than 5%), and "institutional" consumers.⁹

The large number and generally small size of apparel manufacturing units is mostly due to the varied nature of textile end products. Manufacturing establishments tend to become specialists in very narrow, particularized areas, such as children's dresses, men's hosiery, etc., with too little in common between areas to encourage horizontal integration. Marketing specialization is perhaps as significant a factor as specialization of manufacturing techniques. Intimate knowledge of customers and sources of supply in one line may be of little value to another manufacturer with a different, even though related, line of work.

It should be obvious by now that there is no such thing as a "finished fabric" market in the sense that one

⁸The 1954 Census of Business lists only 86 sales offices and branches for cotton, rayon and acetate broad woven fabric sales.

⁹"Textile Inter-Fiber Competition," Textile Organon, Vol. 28, No. 11, Supplement, October, 1957.

speaks of a fiber market or gray goods market. These latter are characterized by relatively standard products, the output of one firm being more or less equivalent to that of any other. (In recent years even gray goods have been subjected to increasing product diversification, hence some of these statements are applicable to the gray goods market as well as to the finished fabric market). On the other hand, finished fabrics from different converters possess very few characteristics in common. Trading frequently consists of a limited number of buyers with specific requirements seeking out the few sources willing and able to satisfy those requirements.

It may be helpful to classify finished fabrics on the basis of fashion sensitivity, since this feature has considerable influence on the marketing techniques employed. At one end of the spectrum are staple fabrics--standards with a variety of possible end-uses not influenced by fashion. Bleached white cotton fabric for use in men's shirts might be an example of such a fabric. Staple items of this nature are produced and sold in much the same manner as gray goods. Production requirements can be established fairly far in advance and stabilized so as to assure most efficient operation. The primary risk associated with inventory accumulation is the possibility of future declines in raw material price.

High fashion fabrics represent the other extreme in

finished fabrics marketing. Although only a relatively small percentage of total volume falls within this category, the psychology of fashion marketing has a widespread impact on the industry. The epitome of fashion is "controlled individuality." That is, one seeks to be well dressed by wearing apparel which is uniquely styled¹⁰ within the limits of fashion. (A very few consumers move outside these limits in efforts to be fashion leaders.) It follows that a market which demands individually styled items will not support mass production. The producer of high fashion items faces an even greater problem than this, however. The very nature of high fashion merchandise requires frequent changes in the fashion limits. The style that is fashionable today soon becomes so popular that it loses the quality of uniqueness; the fashion shifts and the style is dead, almost overnight.

The converter of fashion fabrics must remain extremely flexible, designing styles based upon the latest fashion trend, rapidly exploiting those that prove successful, and keeping closely in touch with consumer demand, to be able to cease production as soon as an item goes out of fashion. This sector of the industry operates as a matter

¹⁰A fine distinction between "style" and "fashion" is worth noting. The unique characteristics of any item which differentiate it from its class constitutes "style." Those styles which are currently popular with the consuming public form the range of "fashion."

of course on a feast or famine basis: if a style is successful, demand is heavy almost regardless of price; but when a style fails, the value of inventory can be restored (partially) only by refinishing.

The mechanism which the converter of fashion fabrics uses to meet the unusual demands of his market is "sample selling." Having designed a new line of styles for the forthcoming season, he presents these styles to the market. His customers (mostly apparel manufacturers, since retail sales of piece goods tend to be less sensitive to fashion) select those styles which they prefer, ordering small quantities from which they in turn will prepare a sample line. The converter integrates this light advance season ordering in terms of probable fashion movements and initiates limited production in anticipation of the season.

As one might expect, the largest volume of finished fabrics fall somewhere in between the two extremes of staple and high fashion. These goods are characterized by varying degrees of stability and predictability of demand as well as by responsiveness to changes in fashion. The nature of the mix between these elements for any single product is a major determinant of the marketing technique employed.

FINISHED TEXTILE PRODUCTS MARKET

Most of what has been said in the preceding section applies with equal or greater force to this "market."

Apparel manufacturers sell directly to retail (especially in the case of fashion merchandise where speed is so essential), and through wholesalers. Converters and mill sales offices also sell consumer piece goods through these channels. The total number of retail and wholesale establishments exceeds 180,000 so once again the dispersal function is important, especially since these outlets are widely distributed geographically.

Merchant wholesalers are instrumental in achieving the necessary wide dispersal of goods. They buy in relatively large quantities, assembling a balanced product line from many sources. Sales are mostly in small lots to the small and medium-sized retailers who comprise the bulk of the total number of retail establishments. Roughly 30% of all consumer textile products are distributed through the wholesale channel.¹¹ An additional 35 to 40% of the total volume is handled by merchandising agents, representing either buyers or sellers or operating for their own account, who arrange for the transfer of goods without physically handling the merchandise. Agents facilitate the process of bringing together many buyers and sellers, and also provide a key link in the flow of information from consumer to producer.

The remaining 30 to 35% represent direct sales to

¹¹Estimated from Census data on sales, assuming 30 to 40% average retail mark-up.

retail, most of which go to large department stores, chains, and mail-order houses. The sales volume of these retail units is sufficiently large to justify direct sales, although many lines are also handled by agents.

The flow chart (Figure 2) has been simplified at this level by distinguishing only between sales direct to retail and sales through merchant wholesalers. It is assumed that the merchandising agent, who does not participate in the product flow at all, does not introduce a significant stage into the information flow and so may be entirely disregarded.

CHAPTER III

THE TEXTILE INDUSTRY--INFORMATION FLOW

There is one element of information which is regularly and formally transmitted from one end of the distribution system to the other, and that is demand. Demand is characterized by a firm commitment to buy, and hence is a necessary prerequisite to all other activities. Demand on the retailer, from the consumer, leads eventually to ordering from the retailer to his supplier, who in turn interprets this ordering as "demand." The process is repeated at each level, and if it were simply a matter of relaying demand from one level to another, there would be little worth studying in this phenomenon. However, in a very real sense all factors entering into the decision to order at any level, from the consumer to the fiber producer, can be said to have entered into or at least influenced the information flow. This includes anything from the long-range weather forecast to the current price of cotton in the raw fiber market. Costs, inventory levels, and expected delivery times are some of the items that are typically considered.

This chapter will be concerned primarily with exploring the nature and characteristics of such factors at each level. The center of focus will be the ordering and pricing policies of the individual firm. Although this is not necessarily identical to aggregate behavior of the industry, it is sufficiently indicative to serve as the foundation for the development of the industry model in Chapters V and VI.

THE RETAIL LEVEL

Retailers will deny the possibility of making any concise, yet valid, statements concerning their response to consumer demand. A vice-president of one of the larger Boston department stores stated emphatically that it is impossible to discern any over-all pattern with respect to ordering or inventory policies within the textile products lines. The extreme product diversity experienced by the retailer appears to be the motivation for such opinions from men with extensive merchandising experience. For it is true that, in the day to day operation of a store, each product must be evaluated individually with respect to sales performance, sales potential, availability of supply, inventory objective, and so on. But there remains an underlying framework of policy upon which most individual decisions are based, even when the policy is not explicitly defined, and it is this framework which we seek.

Ordering Policy.--The retailer's problem is simple: to stock whatever items the customer will want, in the quantities and at the time that he will want them. All he need do is accurately forecast these requirements, order early enough to assure delivery at the desired time, and sit back and listen to the cash registers clang. But how does one achieve an accurate forecast, not merely in total, but for each and every product line and, in the case of fashion merchandise, for each style within the product line? The risks associated with miscalculation are considerable. If too much is ordered relative to demand (or, what amounts to the same thing, if the wrong items are ordered), excess inventories will result which can only be cleared out at reduced profits, or even at a loss. Yet if too little is ordered, potential sales will be lost due to shortages, poor selection, etc.

The starting point for most forecasts is the season. Almost all textile products are subject to seasonal fluctuations in demand, some for obvious reasons and some merely as the result of tradition or long promotional efforts. January and August "white" sales, which stimulate an otherwise stable demand for many household items, are an example of the latter. The ordering pattern for a couple of "typical" product lines will help to illustrate various factors which influence ordering over a complete season. The operation of a large department store will be in mind,

although smaller retailers tend to follow a similar pattern, with the following distinctions:

1. Less formality. The small retailer is more apt to make subjective or intuitive judgments of the factors explicitly considered by a large department store.
2. Shorter lead times, especially when dealing with a merchant wholesaler.

Consider first an item with some fashion sensitivity, such as low priced women's house-dresses for winter wear. The season runs from September through Christmas, with sales normally peaking sometime in November. About May or June preceding the season, a sales forecast is made for each month during the season. This forecast is very heavily based upon sales performance of the product line for the fall season the preceding year. Of particular interest is the relative sales performance of the various style classifications within the house-dress line. Did the season finish strong or weak? (In other words, how were sales relative to the long-term seasonal expectations?) The preliminary forecast is further modified (but only slightly) by expectations concerning business conditions, and by the performance of related lines during the current spring and summer season. The sales forecast serves as the basis for a stock forecast, which indicates the maximum permissible stock levels for each month needed to achieve the desired turnover rate. Turnover, representing the ratio of total sales to average inventory for the season, is widely used

as a yardstick of performance in the retail trade. Industry and store standards for each product line are carefully adhered to as a check on excessive ordering. It is probable that "target" turnover is adjusted somewhat as sales vary, but the extent of such adjustment is difficult to determine. Ostensibly, all inventory planning revolves about a fixed turnover ratio for the product line.

During June, the dress manufacturers "open" their fall line and a small percentage, perhaps up to 25%, of expected sales for the season will be ordered. The exact percentage committed and the timing of the order are also influenced by expectations for the coming season. The product line assembled by this advance ordering is intentionally "broad and thin," that is, as large a variety as possible of individual items are acquired, with only a small order for each. As soon as the merchandise is received and placed on the floor, which would normally be late in August or early in September, sales of each style are closely monitored. Only the best selling items ("best" can mean a mere handful of sales during the first week or two) are reordered, with total ordering controlled by the forecast stock levels.

As the season progresses, sales are compared with last season, both on a current basis and cumulatively. This comparison provides a check on the original forecast, which is revised accordingly. Hence, sales running ahead of

expectations serve to raise the forecast, which in turn lifts the ceiling on ordering previously imposed by the prescribed turnover rate. In practice, buyers develop a keen feel for evaluating sales performance, and therefore couple their reordering more closely to current sales than might otherwise be expected. As one buyer said, "I don't worry about open-to-buy.¹ Anything I like, I get--so long as it sells, nobody ever complains."

Reorder quantities are almost entirely a function of the time required to get delivery. In the case of women's house dresses, manufacturer's stocks are usually low, but the manufacturing cycle is short, so that several reorders per season are practical. Unfortunately, the best items tend to be good in all stores and the resulting heavy ordering on the manufacturer slows delivery when it is wanted most. For some product lines the manufacturing cycle is so long that most, if not all, of a season's requirements must be ordered in advance of the season.

The ordering for men's shirts, a staple item, provides a second example of retail ordering practice. The difference between ordering for this product line and for a fashion item is evident from the far more relaxed atmosphere in the men's furnishings department. Sales are

¹The specific mechanism of control indicates to the buyer (and his superiors) the exact amount which he can commit during any period. This amount is termed "open-to-buy."

monitored much less closely, primarily by means of periodic inventory counts. The sales forecast and seasonal turnover ratio establish prescribed inventory levels throughout the season, as previously described. However, the sales forecast is merely a direct extension of the previous year's sales, and little effort is made to revise it during the season. Ordering is done periodically to restore inventory to the prescribed level, and delivery times are short and dependable, with shipments mostly from integrated mill stocks.

Pricing Policy.--Most textile products, particularly apparel, are purchased for sale in a particular price class. If the manufacturer's price is too high to place an item in the \$9.95 class, it must either be sold, for instance, at \$14.50 or not at all. One objective of any department is to maintain a prescribed percentage mark-up which is established very much like the prescribed turnover rate, i.e., on the basis of past performance, industry standards, management judgment, etc.² In addition, provision is made for getting rid of surplus inventory by means of markdowns, although a ceiling is usually placed on the percentage of total volume which may be achieved by markdown sales.

²Retail margins, defined as mark-up+sales price, ranged from 20 to 43% on a wide variety of textile products, averaging about 36% in 1942. Source: L.D. Howell, Marketing and Manufacturing Margins for Textiles (Technical Bulletin No. 891; Washington, D.C.: U.S. Dept. of Agriculture, March, 1945), p. 135.

Markdown policy varies with both the fashion sensitivity and seasonality of the product. At one extreme would be women's dresses which are reduced almost as soon as sales begin to lag behind expectations. Items less fashion sensitive would be "closed out" at or near the end of the season, while staple items might merely be placed on "sale" for a short period, relying mainly on reduced ordering to eventually bring inventories back into line.

WHOLESALE LEVEL

Merchant wholesalers parallel the operations of the large retail outlets to an appreciable extent. There tends to be a greater emphasis on staple items as opposed to highly styled items, which reduces some of the worst re-ordering problems. In addition, the wholesaler normally specializes in a relatively narrow line of products, thereby easing the problems associated with an extremely diversified group of products.

APPAREL MANUFACTURING LEVEL

The cutting trades, as manufacturers rather than distributors, face a somewhat more complex situation than the retail and wholesale trade. Demand is experienced in the form of requisitions³ received from those two levels.

³The following terminology shall henceforth be used, although the distinction is entirely arbitrary and is not based on trade practice:

- a) "requisition" is an order being received at a particular level,
- b) "order," or purchase order is the order being placed on the next level.

The complexity arises from the fact that the apparel manufacturer maintains not one, but three inventories: fabric, in-process, and finished goods. The response to new requisitions (during a season) takes place in three stages. Initially, orders are filled out of finished stock, much as the retailer sells from inventory. These sales provide the stimulus for production orders designed to satisfy unfilled requisitions or establish a desired finished stock level or both. The production orders, in turn, draw material out of fabric stocks (raw material), which will then be replenished to meet anticipated future orders or to satisfy remaining unfilled requisitions.

Ordering Policy.--The decision process for these three stages are normally merged into one by the small manufacturer, whereas larger establishments are more likely to segregate the individual decisions. In either case, fashion sensitivity of the product line is again a factor (as it is at the retail level). The seasonal ordering pattern for a fairly broad class of styled products is presented below. It is not suggested that this behavior is representative of all the apparel manufacturing industries, although some of the characteristics discussed are undoubtedly common to many sectors. The major area of difference is probably in the manufacture of staple goods for which new lines are not developed each season and for which larger finished inventories are normally maintained.

The manufacture of children's summer dresses will be used as typical of this class of product. Far ahead of the retail season, and several months ahead of the manufacturing season, the manufacturer orders sample quantities of a variety of styles from those being offered by the converter. For children's dresses, this might occur in August or September of the year preceding the retail season. The size of this initial purchase is relatively insensitive to expectations concerning the forthcoming season, although if expectations are high the manufacturer might decide to offer a somewhat wider selection of styles than otherwise, and ordering would be increased accordingly. From the samples selected the manufacturer creates his "line" for the season and, either through showings or by sending out salesmen, presents this line to the retail and wholesale trade. Advance orders from these trades begin to come in about the middle of November and, within the following month, the manufacturer must decide what to expect of the season and which styles to pursue. His forecast will be based mostly on a close comparison of this year's requisitions with those received the previous year, extrapolating from this an estimate for the forthcoming season. The manufacturer's forecast consists of two simple elements; he asks:

1. Is this going to be a "good" season or a "bad" season for the industry (that is, my particular sector)?

2. Is my line "good" or "bad" relative to competition?
Information from the grapevine, comments from customers and

competitors, and long experience from past years (i.e., long-run expectations) all enter into the evaluation.

Having arrived at a suitable, even if not explicit forecast, the manufacturer must now compromise between conflicting objectives. He would like to order sufficient fabric to cover his expected requirements for the season, but cannot afford the risk of having a particular style "go dead," in which case he would suffer a heavy loss on the fabric. Yet if his order is inadequate, it will take him too long to get delivery on a reorder, unless the converter still has the fabric in stock. His decision, therefore, must weigh the probabilities of the converter's stock running out (which are high for "fashion" fabrics and low for more standard items) against the risk of over-ordering. Except in the case of very highly styled fabrics, this compromise will result in an order for substantially less than the season's expectations would support.

Upon receipt of the fabrics ordered, production is immediately commenced against the ever-growing backlog of orders. Since the fabrics that were ordered, even under the most pessimistic outlook, normally exceed the requisitions accumulated ahead of the manufacturing season, the manufacturer faces another decision. What quantity should be placed into production and how much should be held as fabric against future orders? The problem is common to many producing sectors of the textile industry. On the one hand

is the desire for efficient operations characterized by stable production. Furthermore, the strong seasonal demand pattern requires some production in advance of orders if the peak demand is to be satisfied. On the other hand, whatever the risk of holding excess fabric inventories, the risks associated with excess finished goods inventories are much greater, reflecting both the increased factor costs entering into the finished product and the increased styling risk. The decision made will relate closely to revised forecasts for the season and will key to the particular stage of the season. For example, in January when production is first starting, the establishment of a small inventory in anticipation of future requisitions entails far less risk than it might in May or June, when the season is almost over.

The retail season (for children's summer dresses) commences in April and continues through July. Hence, all requisitions received from retailers prior to April are in advance of the retail season and probably constitute less than half of the total orders for the season. Reorders are placed by the retail level starting in April, providing the acid test for the previous planning by the manufacturer. If that planning has been well done, finished inventories will provide a useful cushion against the sudden influx of orders. At the same time, production can be adjusted to meet the new demand, drawing upon available fabric supplies.

The first phase of reordering will be especially instrumental in the formulation of additional fabric requirements for the remainder of the season. Orders for fabric at this stage will be calculated to very nearly satisfy the remaining requirements expected for the season. As the season draws to a close, fabric is placed into production only to satisfy unfilled requisitions. If the fabric is not available in stock, it is ordered from the converter against the specific requisition. In other words, no commitments are undertaken which are not supported by requisitions from retail.

Pricing Policy.--Pricing does not differ markedly from that at the retail level. The price tag on an item determines its competition, so that goods are manufactured with the intention of fitting into a specific price class. Quality can readily be adjusted to assure that the goods within a price class will yield a profit. Raw material (fabric) costs accounted for about half of the net selling price of women's cotton, rayon, and wool dresses during the period 1940-1942.⁴ Direct labor accounted for another 25%, so it is apparent that the substitution of cheaper fabrics, or the use of "accelerated" manufacturing techniques can sharply alter the profit picture with no change in price. Of course, competition is largely within price class, based upon quality, so that there are significant

⁴Howell, p.123.

sanctions against excessive "quality cutting."

The apparel manufacturer, like the retailer is apt to approach the close of a season with excessive finished inventory in some styles. These can be moved, but only by substantial markdowns. However, the manufacturer also faces the problem of surplus fabric inventory. This can be saved for next year, if the fabric is reasonably standard; returned to the converter (who will refinish it, e.g., dye it black) at a loss; or sold for whatever price it can bring.

CONVERTER

It has already been noted that the converter is the first operator to impart extensive diversification to the textile product. It is not surprising, therefore, to find that the behavioral characteristics on the demand side resemble those of the retail, wholesale, and manufacturing levels. Demand is seasonal and it is frequently style-conscious.

The fact that the converter does not directly perform the finishing function is of little consequence for the flow of information. The commission finisher is entirely passive, his only influence on the decision process being his available capacity. The converter, therefore, faces problems which very closely parallel those of the apparel manufacturer.

There are two points at which the behavior of the two levels diverge, however. The first is in the process of ordering goods from raw materials inventory (gray goods) into production. The production cycle for finishing is usually much longer than the apparel manufacturing cycle, hence the converter must rely far more heavily on having his goods available, in finished form, to satisfy demand when it arises. Early season forecasting therefore assumes an even greater importance for the converter than for the manufacturer.

A second difference occurs with respect to the supply of raw materials. The lead time for obtaining gray goods from the mill is very long, necessitating substantial commitments well in advance of demand. These commitments will be based largely on seasonal expectations as determined from long-run performance, and particularly from the performance of the previous season. Although the risk associated with stocking gray goods is less than that for the more highly differentiated finished fabrics, it is nevertheless substantial. The increasing importance in recent years of styling "in the gray" is a partial source of this risk. In addition, there is the danger of book loss from price changes. The price of the raw fiber represents a major part of the cost of gray goods,⁵ hence fluctuations in

⁵Raw fiber costs accounted for 40 to 60% of the mill price for cotton and rayon broad-woven gray goods in the period before World War II. Source: Howell, pp. 56 and 84.

fabric prices tend to be reflected by similar fluctuations in the price of gray goods. The converter, by assuming responsibility for large stocks of gray goods, runs a risk of considerable loss if prices should suddenly decline. Gray goods ordering will therefore be conditioned by expectations about future price changes.⁶ It will also tend to be conditioned by shifts in the relative price of competing fabrics. A sudden decline in the price of cotton relative to rayon, when passed on by the mill, will provide a strong incentive for the converter to shift some of his fabrics from rayon to cotton, to the extent that such a shift is otherwise feasible.

Still another determinant of converters' ordering for gray inventories is the need for adequate financing. Many converters are small operators who must borrow heavily to finance their inventories (which represent the bulk of their assets at any one time). In a tight money market, such as existed in 1957, many converters will be forced to keep inventories to a bare minimum, regardless of other considerations.

THE WEAVING MILL

The mill has some problems in common with the apparel

⁶The mills, in turn, attempt to protect themselves from price increases by charging higher prices for future delivery than for spot delivery, when stocks are available. This, of course, has the adverse effect on the mills of discouraging advance ordering.

manufacturer and converter, since it is a producing level handling raw, in-process, and finished inventory. However, the characteristics of the product, and the technology of the process give rise to an appreciably different response to the flow of requisitions arriving from below.

Ordering Policy.--It is possible for the mill to produce fabric for sale from finished stock, or to produce only against a backlog of requisitions. Of the two approaches, production-to-order is the prevailing practice in a large sector of the industry. Production of rayon and acetate for stock is reported by Dash⁷ to have been confined to the weaving of novelty fabrics, i.e., highly styled fabrics. In recent years there has also been some tendency to carry inventories on exceptionally standard items. Such fabrics constitute a small percentage of the total output and will not be discussed in detail.

The practice of weaving-to-order is contingent upon the willingness of converters and others to place their orders far in advance. Fluctuations in the requisitioning rate are absorbed (ideally) by changes in the level of backlogged requisitions, rather than by changes in the rate of output. However, in practice frequent changes in production schedules would be necessary. This comes into

⁷G. Allen Dash, Jr., Inventory Management in Rayon Weaving (No. 4 of Inventory Policies in the Textile Industries; Washington, D.C.: The Textile Foundation, 1941), p. 12.

direct opposition with the frequently cited policy of stabilizing production.

The high investment in equipment, and the costliness of frequent loom change-overs from one fabric to another, makes it desirable for mill management to alter production only slowly in response to shifting demand. At times when a severe decline in demand occurs, this tendency will lead to accumulation of finished inventories, despite the usual policy. The desire for maintaining production is so strong that it can even lead to cut-rate selling of production in excess of orders, mostly by the small mills.

A common procedure is to prepare a production schedule for the next three or four months to meet the present order backlog. In the face of declining orders, production schedules would be extended on the best items, perhaps with a gradual reduction in the number of looms committed. The less standard items would be curtailed shortly after the last orders were filled.

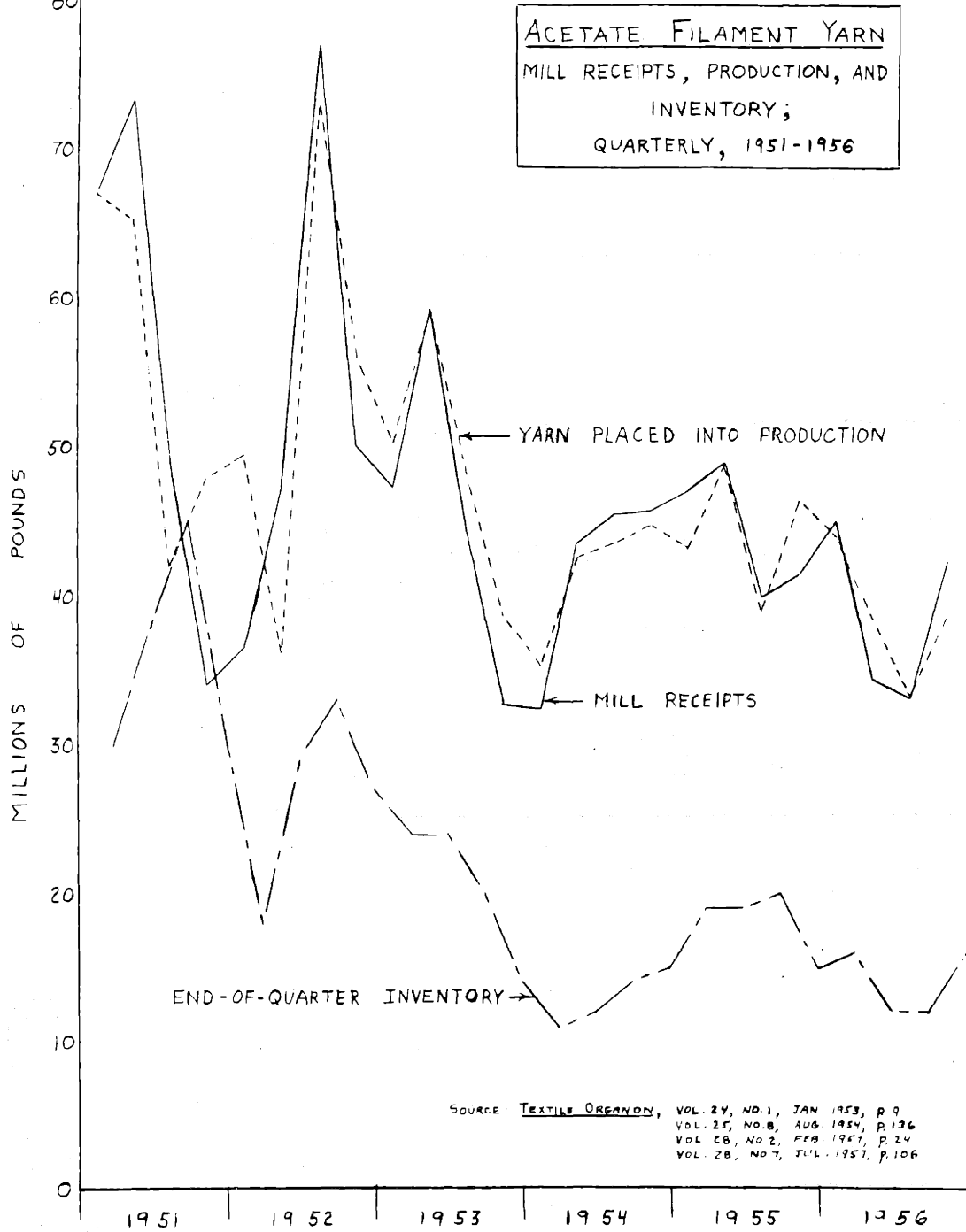
The ordering of raw material (yarn) depends upon whether filament or staple yarn is required, and upon the use to which it will be put. Orders of filament yarn for warp are normally obtained on section beams which come in lengths of up to 90 thousand feet. Since deliveries of section beams are fairly slow (two to four weeks), they are commonly ordered to cover an entire requisition, or the

production of a month or more. Filament yarn for use in filling is available from the producer on very short notice. It is therefore ordered at convenient intervals of two to four weeks to cover the requirements of the next period. Price is a secondary consideration in view of the small inventories maintained, although expectations of a price increase can influence the mill to take a slightly "longer" inventory position than otherwise. The very close coupling between ordering and production is illustrated by Figure 4, which shows mill production and shipments to the mill of acetate filament yarn. So far as quarterly data can discern, shipments (and hence orders) and production move almost perfectly in phase. Mill stocks rarely exceed two months' supply measured by the current quarter's production, and seem to hold in the vicinity of one month's supply. From 1952 through 1956, mill stocks fell outside the range of 3.8 to 6.6 weeks in only one quarter.

Spun yarn is normally used for filling, with the staple or tow being ordered in a manner similar to the ordering of filament yarn for filling. Due allowance must be made for the additional production time (in integrated mills) involved in spinning. Since staple is available in less varieties than yarn, it can safely be ordered farther ahead, with price expectations playing a more important role in this decision.

Pricing Policy.--The gray goods market is for the

FIGURE 4



most part quite competitive. The output of one mill does not vary appreciably in quality from that of another mill producing the same standard weave. As a result, the individual mill does not "set" prices, but must rely upon market forces.

Since the cost of the fiber is such a large part of the selling price of the fabric, the mills try to pass on to their customers any significant increases in fiber costs.⁸ The converter, in turn, has little option but to eventually pay the higher price and attempt to pass on the increase to his customers. The key word, "eventually" plays an important role, for the converter (especially if he has anticipated the increase) can decide to defer buying for the moment in the hope of a future price reduction, drawing on inventories in the meantime. If all of the converters are in a position to hold out long enough, the mills may be forced to sell at the lower price in order to avert still more costly shutdowns.

⁸Simultaneous increases in all competitive fiber prices are assumed here. If instead a unilateral increase were to occur in, for instance, rayon yarn prices, the mill could readily pass this on, being prepared to shift production to other fibers should customer resistance develop against rayon.

CHAPTER IV

RAYON AND ACETATE PRODUCTION

HISTORICAL BACKGROUND

The history of the man-made cellulose fiber industry in the United States can be broken roughly into four periods. The first is the period of monopoly prior to 1920 during which the American Viscose Corporation, operating under patent protection, exploited the early "artificial silk" market.

The second period, which lasted from 1920 through the depression, witnessed rapid technological progress which converted rayon from a novelty into a legitimate textile fiber with a multitude of end uses. This progress made possible a rapid reduction in price, accompanied by increasing demand, and encouraged the entry into the industry of most of the present producers. One of the outstanding developments of the period was the introduction of the acetate process, which considerably widened the end use potential of the man-made fibers.

The third period, extending from the mid-thirties through the 1940's, was devoted to the consolidation and

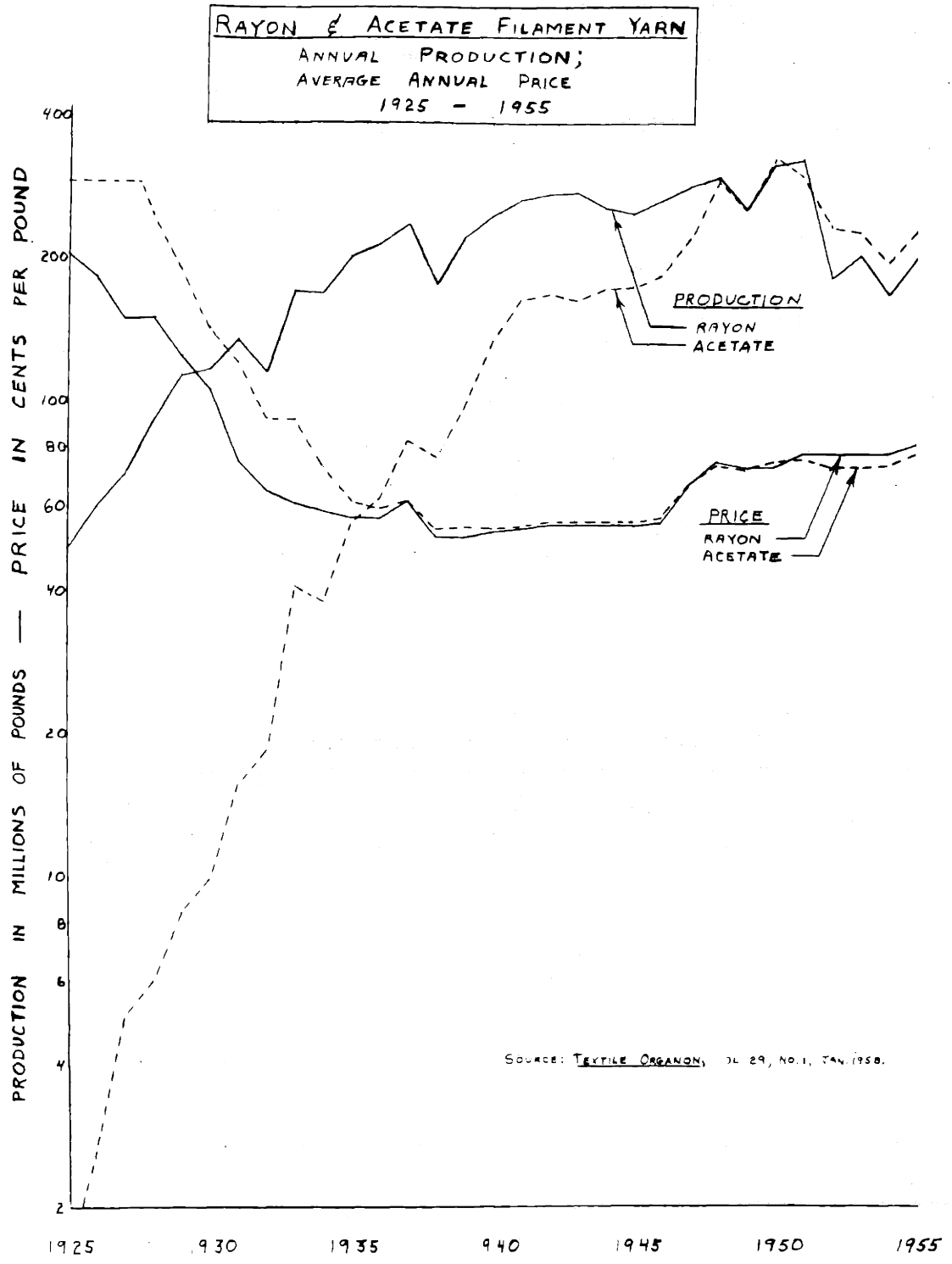
gradual expansion of the gains made during the earlier periods. Technological progress continued at a diminished rate, markets were expanded, and the relationship of rayon and acetate vis-a-vis the natural fibers were more or less firmly established.

The final period covers roughly the 1950's when, for the first time since the depression, capacity has exceeded demand over a lengthy period. Losses to the newer man-made fibers and to imported rayon may account for some of this decline.

Figure 5 presents annual series for price and production of man-made cellulose yarn. The dominating effects of long-term growth are the most outstanding features of both curves. However, if the growth trends are disregarded, the existence of cyclical behavior becomes more apparent. The over-all cyclical behavior of the two appear to be related, both with respect to timing and amplitude. Markham has observed that there is a very close correlation between these long period cycles and standard reference data for the business cycle.¹ This implies that both production and price are adjusted by producers to meet the requirements of large-scale changes in economic conditions. It cannot justifiably be assumed, however, that this same behavior is employed in the short run. In fact, the following discussion

¹Markham, p. 125.

FIGURE 5



will attempt to show that short run behavior is very much different from this.

The two-year textile cycle is somewhat less apparent in the production data for rayon and acetate than it is for consumption of some of the natural fibers. There is a decided tendency, nevertheless, for production peaks to be registered in the odd numbered years and troughs to be registered in the even numbered years, as would be expected from the textile cycle. Markham has observed that price is considerably less sensitive to this two-year cycle than production. This suggests that over the shorter span of the textile cycle, production is adjusted more readily than price in attempts by producers to cope with fluctuating demand.

PRODUCTION AND INVENTORY POLICIES

Time series of a much shorter period than the annual data thus far presented must be examined in order to gain any insight into short run producer behavior. Markham made an exhaustive study of production and inventory data for viscose yarn for the period 1929 through 1949.² For every period of slackened demand, the percentage change of output and price over the entire slack period was determined, together with the timing of such changes. It was determined that a time lag of several months existed between a sustained

²Ibid., p. 135.

increase in inventories and a reduction in output. Furthermore, an additional lag of from one to several months occurred between production changes and price reductions. On the average, an output curtailment of 25% was a necessary prerequisite to a price reduction. Both production and price responses seemed to be sensitive to the rate of inventory accumulation as well as to its magnitude. During periods of recovery, similar responses were noted, except that production schedules were restored more rapidly, whereas price increases followed much more cautiously.

The behavior of the rayon producer, deduced from this study, was summarized as follows:

A decrease in orders not usually encountered in the seasonal or irregular fluctuations within the year would be met by curtailing production. This would seem to follow since output is more sensitive than price to the textile cycle. Should the decrease in orders be, in fact, a result of a two-year cyclical downturn, business will shortly recover and price will have been left largely undisturbed. But should the decrease in orders prove to be a result of a business recession, price will be reduced also, but in the meantime output will have already been curtailed.

There is one slightly unfortunate aspect to the analysis conducted by Markham as its conclusions relate to the industry at present. Prior to 1949, under the aegis of a strong growth pattern, the normal production status was at full capacity. Markham could only find eight instances of a significant departure from capacity output. Under such conditions, production could rarely be increased in the face of increasing demand (in the short run), and one

would expect the producer to hesitate considerably before departing from full production after extended periods of surplus demand. Such behavior is even more reasonable if the pattern of costs are considered. Unit costs, in this industry with heavy fixed charges, tend to increase as soon as output is reduced below capacity, and continue to increase steadily until approximately 75% capacity is reached.³ Thereafter, further cutbacks in production result in rapidly increasing costs.

Since the late 1940's, conditions in the industry have altered somewhat drastically. Whereas 100% capacity operation had long been considered normal, (and 75% capacity adequate cause for price reductions), the industry since 1951 has operated consistently far below capacity, and frequently at a level low enough to endanger profits.⁴ Production during 1955 for rayon and acetate was 827.9 million pounds, only 74% of available capacity.⁵ It is not surprising, therefore, that producers have not continued to follow exclusively the production policies of the pre-1949

³Ibid., p. 150.

⁴For example, Celanese Corporation's net income dropped from 40 million dollars in 1950 to 9.2 million dollars in 1952. The company's 1952 annual report attributes the drop to the fact that "the textile industry throughout the world is in a badly depressed condition... accumulation of inventories during the Korean War have been difficult to overcome."

⁵This data excludes the production of high tenacity yarn for industrial use.

era. In the presence of over capacity, the response of production to demand changes is apt to be more rapid on the downturn, and more symmetrical with respect to both ups and downs, than previously noted.

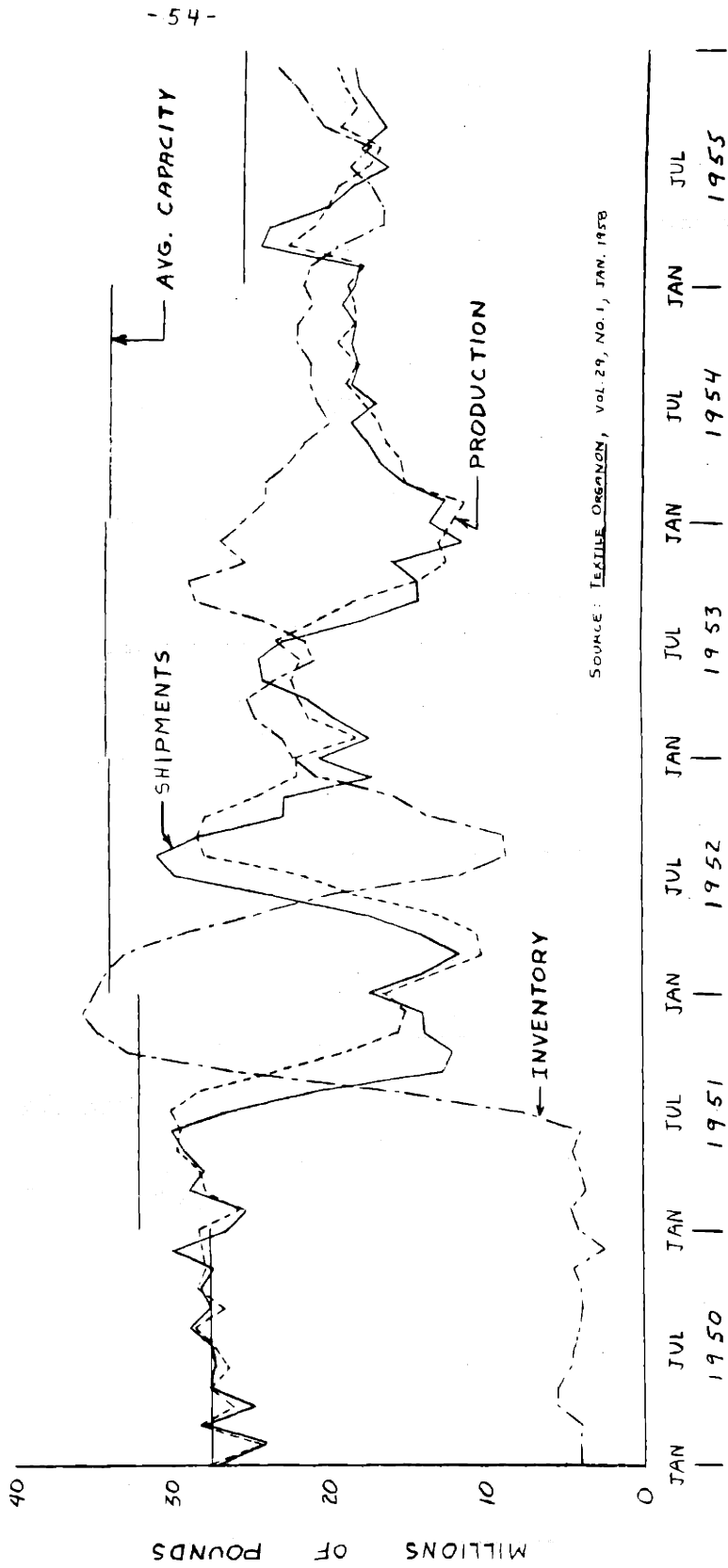
Figure 6 presents monthly data for production, shipments and inventories of acetate filament yarn from 1950 through 1955. The year 1950 is representative of the earlier period of prosperity, with inventories held at a nominal level as substantial order backlogs kept production at capacity. The downturn of the second half of 1951 conformed quite closely to Markham's model, as production cutbacks lagged behind reduced demand by up to two months, while inventories built up rapidly. The sharpness of this decline, and the long period of reduced demand which followed, has led to a considerable modification in producer behavior. Inventories are now maintained at a substantial level (approximately one month's production) to provide immediate delivery service. Furthermore, the need for establishing control over these expanded inventories is now recognized, with the result that production is adjusted more rapidly to severe shifts in demand than previously. Note, for example, how much more rapidly production responded to the decline of 1953 in comparison with that of 1951.

PRICING POLICY

Price Leadership.--The structure of the rayon and

FIGURE 6

ACETATE FILAMENT YARN
MONTHLY
PRODUCTION, SHIPMENTS, INVENTORY;
AVERAGE MONTHLY CAPACITY
1950 - 1955



SOURCE: TEXTILE ORGANON, VOL. 29, NO. 1, JAN. 1958

acetate producing industry has much bearing on the pricing policy followed. There are only thirteen firms in the industry, the top five of which accounted for 88% of total production in 1948.⁶ With this degree of concentration, one might expect to find some interdependence of behavior between the various producers. In fact, there existed for many years a clear pattern of price leadership within each of the two sectors of the industry. The great majority of rayon list price changes were initiated by American Viscose Corporation, and almost all changes in acetate list prices were initiated by Celanese. The pattern is still sufficiently dependable with respect to list price that Textile Organon, the primary source of basic statistics for the trade, publishes prices and dates of price changes of the two leaders as data for the industry.⁷

The interrelationship between rayon and acetate prices is somewhat more complex. During the early period of acetate production, a significant price differential existed and price changes appear to have occurred independently. In April, 1937, the price of acetate yarn achieved approximate parity with rayon yarn, and price changes by Celanese thenceforth seemed to follow the lead of American Viscose, lagging

⁶The five leading firms, in order of size, are American Viscose, Celanese, Dupont, Tennessee Eastman, and Industrial Rayon. Source: Morgan Stanley and Co., Memorandum on the Rayon Industry (New York: Morgan Stanley and Co., 1949), p. 5.

⁷Textile Organon, Vol. 29, No. 1, January, 1958, p. 29.

behind from 0 to about 21 days, until 1949. There has been a break in this pattern during the 1950's, however, perhaps under the pressure of adverse market conditions. Of the ten price changes announced on 150/40 yarn since 1949, American Viscose has led Celanese on one, lagged on two, and the remaining seven have occurred independently.⁸ Price movements of staple have shown a closer relationship during this period, with the lead shared about equally by the two companies.

Off-List Selling.--The problem with studying list price behavior arises from the possibility of "off-list" selling, either through open discounts or more subtle means. For example, when the full impact of the depression burst upon the rayon industry, off-list selling was widely used in an effort to bolster output. This continued despite a collusive agreement among the producers to fix prices.⁹ Since January 1, 1937, however, there have been no open discounts offered, including quantity or term discounts. The

⁸Data on price changes from Textile Organon. 150/40 is a standard yarn frequently used as a market indicator. The 150 refers to denier, and the 40 refers to filament count; i.e., this is a 150 denier yarn constructed of 40 continuous filaments. A variety of filament counts are available for the more popular deniers.

⁹An anti-trust action was subsequently filed against most of the leading rayon producers (Celanese was not involved), and on July 3, 1937, a cease and desist order was issued. By that time, however, the agreement had long since fallen into disuse and the current pattern of price leadership was established.

existence of covert off-list sales today cannot be denied, although the magnitude of such sales are difficult to estimate. Prices can be shaded by such a simple expedient as more readily classifying yarn as second rather than first quality, seconds selling normally at a discount. Markham states that "all of the available evidence indicates that list prices are trustworthy in moderately normal times but are virtually meaningless for the years 1930-32."¹⁰ The 1950's also seem to fall outside Markham's definition of "normal." At any rate, it is probable that off-list sales have been a greater factor during the recent past than during the pre-1949 period.

Off-list sales are frequently initiated by the smaller producers. These companies are less capable of sustaining low levels of output than the large producers and are also faced with more highly elastic demand curves. Both factors tend to encourage off-list sales when demand slackens. Since output is concentrated so heavily in the hands of the large producers, the price-cutting activities of small companies are most significant as barometers of future action by the majors.

Price Stabilization,--One aspect of policy which seems to be unchanged during the present period is the desire for a stable price. This desire on the part of the producer is

¹⁰Markham, p. 128.

promotional in nature and dates from the earliest days of rayon production. One of the most distressing characteristics of natural fibers, to the mill, is its unstable price. Traded widely in free markets, silk, cotton, and wool prices undergo frequent, violent swings. Only by hedging can the mill avoid considerable speculation risk. Hence, a stable rayon price constitutes a significant selling point. Rayon producers have exploited this advantage to the maximum possible extent, even offering price guarantees during the 1930's. On occasion American Viscose, the largest rayon producer, has announced its intention to maintain prices throughout the next quarter, in effect insuring its purchasers' inventories. Since 1950 there have been only six list price changes for 150 denier acetate yarn, strongly indicating an interest in continuing this long standing price policy despite the prevalence of discount selling.

Price Competition.—There is still another factor influencing price which should not be overlooked: the direct effect of prices of competing fibers. During the decade from 1920-1930, when rayon was in competition primarily with silk, rayon price movements were quite closely related to changes in silk prices. There was, of course, a considerable damping effect, and rayon underwent a more drastic secular downtrend, but the basic relationship is clear. Today, it is quite doubtful that silk

prices have any bearing on rayon prices. Even in 1932, only 20% of rayon production was in direct competition with silk. Total silk consumption is now less than 1% of rayon and acetate production.¹¹ On the other hand, rayon and acetate now compete quite directly with cotton, so that the relative prices of cotton and rayon can have considerable impact upon demand. It was estimated in 1947, in hearings before the House Committee on Agriculture, that an increase in the price of cotton from \$.25 per pound to \$.40 per pound, or a corresponding decrease in the price of rayon would result in the following losses to cotton (gains to rayon):¹²

100% of the thermal insulation market
66% of the tablecloth and napkin market
66% of the women's underwear market
50% of the curtain fabric, domestic
thread, and men's pajama markets
32% of the total cotton fiber market.

Although these estimates by the committee are probably too drastic, they nevertheless provide a measure of the magnitude of competition between these fibers. An examination

¹¹Textile Organon, Vol, 29, No. 1, January 1958, p. 44.

¹²U.S. Congress, House of Representatives, Special Subcommittee on Cotton of the Committee on Agriculture, Hearings on the Study of Agricultural and Economic Problems of the Cotton Belt, 80th Congress, 1st Session, 1947. These estimates assume unlimited rayon production capacity, and ignore the possible impact of other synthetic fibers.

of cotton versus rayon and acetate prices during the past several years reveals a definite correlation, which implies that competition is intense.

None of the foregoing discussion provides a sound basis for assuming that rayon and acetate producers act directly to equate their prices with the price of cotton. First of all, there remains the producers' policy of price stabilization. Secondly, it is more likely that if demand is as sensitive as the House Committee believed in 1947, the cellulose fiber producers act in the direction of closing the price differential with cotton merely by responding to shifts in demand. Regardless of the mechanism through which it operates, the existence of inter-fiber competition is an important element in the pricing of the man-made cellulosic fibers.

CHAPTER V

A DYNAMIC MODEL -- STRUCTURE AND CHARACTERISTICS

The preceding chapters have provided a qualitative description of production and distribution for a major sector of the textile industry. The remainder of this thesis is concerned with the development of an abstract model that will be representative of the system previously described. Before proceeding with the detailed analysis, it is pertinent to review briefly the philosophy of digital simulation.¹ This is followed by a discussion of the scope of the model.

THE SIMULATION APPROACH

There are no mathematical techniques available today sufficiently powerful to describe the operation of a complex system. This is not to say that a mathematical analysis of such a system has never been undertaken. In most instances, however, the assumptions required to arrive at a soluble statement render the results highly

¹A more extensive treatment of this subject is available in two Master's Theses presented in the School of Industrial Management in June, 1957.

- a) Melvin H. Blitz, "Digital Computers as Simulators of Dynamic Industrial Problems."
- b) Henry Weber, "The Dynamic Behavior of Business Systems by the Simulation Technique."

suspect.

One alternative approach, in attempting to analyze a complex system, is straight-forward experimentation with the system itself. Unfortunately, this empirical approach fails simply because it is impractical--one can hardly expect, for example, to successfully manipulate large sectors of the textile industry.

Simulation presents a middle ground between the extremes of mathematical analysis and experimentation. It can be defined as "the technique of using a numerical and logical model to reproduce the operating characteristics of a real physical system."² The individual elements of the system are represented in mathematical terms and then "tied together" by relationships abstracted from the real system. The process of abstraction is the key to developing a useful model. Goode states:

Simulation is not easy; it requires deep understanding of the problems being solved. Just as the physicist must decide what factors are a priori, irrelevant to his experiment, so must the system designer be able to point out simplifications which will lessen the detail in setting up the system but will not vitiate the results."³

²Richard W. Conway, "Digital Systems Simulation," (Unpublished paper, Dept. of Industrial and Engineering Administration, Cornell University, January, 1958).

³Harry H. Goode, "Simulation, Its Place in System Design," Proceedings of the Institute of Radio Engineers, Vol. 39, No. 12, December 1951, pp. 1501-6. (As quoted by Blitz.)

The method of utilizing a simulation model has already been briefly suggested. Since the model does not constitute an explicit mathematical statement, one can not solve for unknown parameters in the usual sense. The model rather incorporates the essential characteristics of, and time-relationships between, the individual components of the system. It can therefore be manipulated in an experimental manner, much as the system itself would have been studied had that been possible. If the model is a good representation of the actual system, the experimental results will be applicable to the system as well as to the model.

The method of constructing a simulation model makes it particularly useful for studying the dynamic behavior of the system. The model, being dependent upon a time base, can be examined at each instant of time. It is possible, therefore, to witness the continuing response of the model to systematic variation of any or all inputs to the system. Furthermore, the importance to the response of any individual component or group of components can be seen quite readily by merely altering the desired components.

The particular experiments that could be conducted with a model are virtually limitless. However, the mode of experimentation and the validity of the results will be largely dependent upon the structure of the model, and

particularly upon the foundation of assumptions underlying that structure.

STRUCTURE OF THE MODEL

The extreme diversity of endeavors covered by the term "textile industry" makes it both possible and necessary to exclude significant sectors of the industry: necessary, because the extensive investigation required to incorporate all major sectors could not be accomplished within the scope of a thesis; possible because the sectors excluded are relatively independent of those included in the model.

The first criterion for inclusion has been the interests of the producers of rayon and acetate fiber. Any sector whose behavior could be expected to influence rayon and acetate production has been included under this criterion. For example, rayon and acetate compete quite widely with cotton and are woven generally on the cotton system. It is necessary, therefore, to consider the implications of this competition, especially in view of the relative ease with which mills can change-over from one fiber to another. On the other hand, little rayon or acetate is woven on the woolen or worsted systems, and since woolen goods are distributed through different channels than are cotton, rayon, and acetate goods, the entire woolen sector has been excluded. The other synthetic fibers constitute a more difficult problem. Some,

such as orlon, are woven mostly on the woolen system, or blended with wool, and can thus be excluded on the same grounds as wool. Some, however, come directly into competition with rayon and acetate. These latter are not included in the belief that cotton represents the primary competitive fiber for rayon and acetate.

Reference to Figure 1, (Page 4) which depicts the process flow for most of the industry, indicates two additional sectors which can be omitted without severely disturbing relationships within the remaining sectors. These are knit goods and industrial goods. Knit goods follow roughly a parallel, but essentially separate production-distribution path from that of woven goods for consumer use. Their exclusion weakens the model primarily to the extent that there is competition between knit and woven goods at the retail level, but this competition is not great. Industrial goods are truly a separate product all the way back to the fiber producer, distributed in a quite different manner. The bulk of the industrial output of rayon and acetate is for use in automobile tires as reinforcing cord and fabric. The fiber itself is considerably stronger and is extruded in much larger deniers than filament for textile uses.⁴ Hence, its exclusion seems

⁴Filament yarn for consumer goods are produced at an average denier of 150, whereas high tenacity yarn for industrial use is produced at an average denier over 1500. Source: Textile Organon, Vol. 29, No. 1, January, 1958, p. 16.

to be logically well justified.

INDUSTRY PARAMETERS INCORPORATED INTO THE MODEL

Figure 2 (Page 12) indicates those sectors of the textile industry which are included in the model. It is now necessary to select the parameters that should be considered. Once again, the justification for a selection process is practicality. Ideally, any parameter which might influence the production of rayon and acetate should be included--one of the strengths of the simulation technique is its ability to incorporate a large number of parameters. The dividing line, therefore, between those included and those excluded is highly arbitrary, and is based upon the need to hold the study within reasonable bounds. It is hoped, of course, that the parameters considered are of sufficient importance to yield a useful first approximation which could eventually be refined by the incorporation of additional parameters.

The parameters incorporated in the model are:

1. Requisitions.--This is the quantitative measure of demand and must be regarded as the prime moving force in the system. Retail requisitioning is considered as an independent input, leading to ordering at successive levels throughout the system.
2. Orders.--A fundamental decision process at any level is the establishment of the size

and timing of ordering. This is the basic decision process to be explored by the model, since it provides the means of propagating demand through the system. Each level receives requisitions from its customers and issues orders to its suppliers.

3. Unfilled requisitions and lost requisitions.--

Requisitioning in excess of ability to ship goods can give rise to one of two situations: either the requisitions build up a backlog of unfilled requisitions, or some of the requisitions which could not be filled are withdrawn by the prospective buyer, i.e., "lost" to the system. The existence of unfilled requisitions at all levels is easily substantiated, but the possibility of lost requisitions is subject to some question. The individual firm, of course, experiences lost requisitions whenever it is unable to satisfy its customers. Most of this demand is merely transferred to other firms. The situation is not so simple when the entire industry is considered. In this case, there is little or no possibility of substituting for the unavailable product, and one could argue that the buyer will be forced to wait indefinitely until his requisition can be

satisfied. A complicating factor, however, is the characteristic seasonal demand pattern facing the textile industry. If demand goes unsatisfied at the end of a season, it will certainly not reappear until next year (at the start of the same season), and there is no assurance that it will reappear at all. Without attempting to prejudge this argument over the deferrability of demand in the textile industry, lost requisitions are included in the model in the belief that experimentation with the model could cast further light on the problem.

4. Inventories.--Substantial inventories are maintained at all levels of the distribution system. The size and composition of these inventories will significantly influence ordering patterns.
5. Shipments.--Shipments are of secondary interest. They are generated in response to demand, and are the medium for moving goods through the system to satisfy demand.
6. Price.--Two characteristics of behavior, subject to influence by price, are considered. The first concerns the impact of price on demand in imperfect competition, where the

competition lies between cotton and the cellulosic fabrics. Relative price is viewed as a factor which helps to determine the distribution of total demand between the two classes of fibers. A second impact of price is the importance of buyers' expectations in determining the size of inventory to be carried under a given set of conditions. At some levels, inventories will tend to be increased in the face of an anticipated price rise, and vice versa.

INDUSTRY PARAMETERS EXCLUDED FROM THE MODEL

The following is a list of several parameters which could usefully be included in a more extensive simulation model:

1. Cash position.--In an industry characterized by small operators, the ability of the firm to finance its desired commitments could be a factor of substantial importance. This is pointed out by a recent article in the Wall Street Journal which stated:

The textile industry... is particularly sensitive to "tight money" conditions, since most unfinished apparel fabrics are bought by small converters... who operate largely on borrowed money. The converters reportedly have been keeping inventories to a bare minimum all year because of financing difficulties, and mill men fear last month's hike in the interest rate on bank loans discouraged

them from rebuilding stocks.⁵

This situation is not limited to times of extremely tight conditions in the money market, but represents a rather general restriction on the dynamic behavior of the system. Limitations on the availability of cash could be expected to influence the speed of response of the system to any sudden increase in demand.

2. Capital investment.--The total stock of capital equipment places a ceiling on productive output at any given time. This ceiling is not of great importance when output is in a range well below capacity. Nevertheless, in the general case it is a restriction which should be considered.
3. Manpower.--There are many aspects of the manpower situation which might be of importance to the over-all system behavior. The availability of sufficient manpower to meet all production requirements is an obvious restriction on output. Additional manpower can always be obtained, of course (at a price), however, the need for training new workers can not be avoided. Restrictions

⁵George J. Church, "Cotton Cloth Mills Forced to Revise Guess of When Market Will Rally," Wall Street Journal, September 9, 1957, p. 6.

created by unions which might curtail rapid changes in output are also of interest.

Weber has constructed a model which incorporates some of these features.⁶

4. Parameters which affect consumer demand.--

The assumption that consumer demand is entirely independent of the system being studied is not entirely defensible. Demand is undoubtedly influenced by, for example, the level of personal income. Income, in turn, may well be responsive to conditions in the textile industry which, by virtue of its size, is an important factor in the national economy. Promotional activities by the industry are probably a more direct and important factor in determining demand.⁷ Although much advertising and promotion is directed at allocating available demand between firms, there is reason to believe that such activities do affect the demand confronting the entire industry. In the first place, the fact that the rayon and acetate industry faces competition implies that promotion could influence its share of

⁶Weber, pp.22-30.

⁷In the study of dynamic behavior, determination of the timing of an event (e.g., consumer demand) is of as much interest as determination of its magnitude.

total demand. In addition, intensive advertising might well stimulate a shift in the timing of demand, as when people purchase winter garments ahead of the season in response to heavy promotion.

5. The competitive relationships among rayon, acetate, and the non-cellulosic fibers.--

These relationships should be explored to determine their bearing upon the functioning of the system. An interesting aspect that might be studied is the impact of technological competition, wherein one fiber is improved to the point where it seriously displaces others in some sectors of the market.

6. Fashion.--The impact of fashion trends is widely held to be the most important single factor for determining the dynamic behavior of the textile industry. To the extent that dealers handling fashion merchandise reflect this belief in their ordering policies, this factor has been incorporated into the model. In addition, there are important characteristics of fashion which might warrant further study. The most difficult problem, at the outset, is the need for a quantitative measure of "fashion." Since the aspect of

fashion of primary interest to this model is its effect on the demand for rayon and acetate fiber, it is conceivable that a fashion index reflecting this demand could be created. In other words, a high index would be assigned to a fashion which was greatly enhanced by the use of acetate yarn as opposed to a fashion for which acetate fabrics simply don't "look right." Admittedly, such an index is a crude instrument, but it is a necessary prerequisite to explicitly including fashion within a model.

The fashion "cycle," through which new styles are created and ultimately filter down to mass consumption items, could be introduced as an independent input to the system. This cycle reflects the relatively long-term process by which new styles are created in the world's fashion centers; are adopted as "the fashion" in the high priced market; are later imitated and incorporated into the styles presented to the mass, semi-fashion markets.⁸

⁸Melvin T. Copeland and W. Homer Turner present a detailed discussion of this "cycle" in Production and Distribution of Silk and Rayon Broad Goods (New York: The National Federation of Textiles, Inc., 1935), pp.60-65.

7. Other.--There is an endless list of factors which one could suggest for inclusion in a simulation model. Each such candidate should be critically examined for its probable impact upon the demand for rayon and acetate fiber, both in terms of magnitude and timing of demand. Despite the apparent desirability of including as many parameters as possible, the risk of introducing unnecessary distortion should also be considered. It is impossible to exactly duplicate the real system, regardless of the amount of detail included. Somehow a compromise must be reached between extreme detail, with the accompanying likelihood of large distortion and computational complexity; and simplicity of structure, with the danger of omitting vital relationships.

CHAPTER VI

A DYNAMIC MODEL -- DETAILED FORMULATION¹

INTRODUCTION: THE USE OF DIFFERENCE EQUATIONS

The vehicle for presenting this model is the difference equation. Each variable can be classified as either a rate (e.g., shipments) or a quantity (e.g., inventory level). A quantity is measured, or calculated, at a particular instant in time (frequently represented as time k). The entire time span to be studied is divided into very small, equal time periods, Δt , such that any rate may be regarded as constant over Δt . At each instant, k , between time periods, every quantity is calculated based upon rates and quantities for previous periods. Rates for the time period $k\Delta t$ to $(k+1)\Delta t$ are then calculated, based upon these quantities and previous rates and quantities.

It is important to note that a variable is distinguished as a rate or a quantity only in its definition. If it is a quantity, the instant of time at which it applies is indicated by the subscript k . However, if it

¹The approach to this formulation is based upon previous work of Professor Jay W. Forrester, some of which is described by Blitz, Chapter VI.

is a rate, the subscript k indicates that the rate holds over the time period $k\Delta t$ to $(k+1)\Delta t$.

The unit of measure employed at all stages in the system is pounds of fiber. For example, consumer demand is expressed as pounds of fiber per week, rather than in terms of product units or dollars. In this manner, the problem of converting between units at different levels, as the product is modified, is avoided. To be entirely consistent, one should account for that portion of the product that is wasted at each stage, such as unusable cuttings in the fabrication of garments. This refinement, however, has not been included in the model because it is believed to be unimportant to the dynamics of the system.

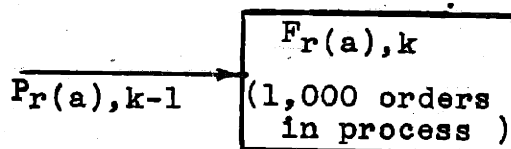
All equations are written to represent the aggregate behavior of like participants in the market. It will frequently be useful to refer to the behavior of a single individual (e.g., the consumer who can decide whether or not to purchase at a given time), but this is valid only to the extent that the individual is typical of the aggregate being represented.

In speaking of aggregates, it is desirable to recognize the fact that individual responses within the aggregate occur at varying times. Consider a simple example:

One thousand retailers decide to order a variety of garments from 500 manufacturers. Each retailer

calculates the size of his order, selects his particular source or sources, and sends in the order. Now, even if we assume that all of these retailers have acted during the same period of time, it is unrealistic to expect all goods to be received at the identical instant in the future. Some of the orders may have been urgent requirements, placed by telephone and shipped special delivery from manufacturers who carry finished stock, so that delivery was accomplished within twenty-four hours or less. At the other extreme are orders placed well ahead of the season and not even desired for several months. The manufacturer must first order his materials, then fabricate the garment, and finally the retailer will receive delivery. Between these two extremes falls the bulk of the orders, with deliveries distributed over time in something resembling a normal distribution.

Exponential delays are employed as the mechanism for generating a reasonable distribution of response to a given input. A simple exponential delay can be represented schematically, in the above illustration, as follows:

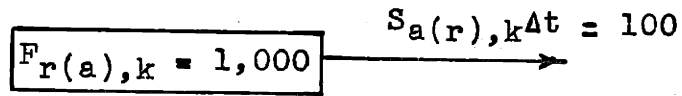


where $P_r(a), k-1$ = Rate at which Purchase orders were placed by

retailers on apparel manufacturers during period k-1, k.

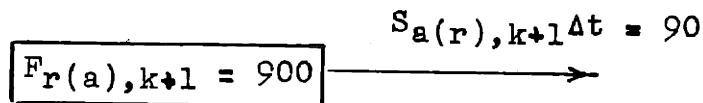
$F_{r(a),k}$ = Total orders in process at time k. (Assuming no orders previously in process.)

If the average "delay" (elapsed time between issuance of an order and receipt of goods) is 10 time periods, then 1/10 of the remaining backlog will be shipped each period. Hence, during the next time period:

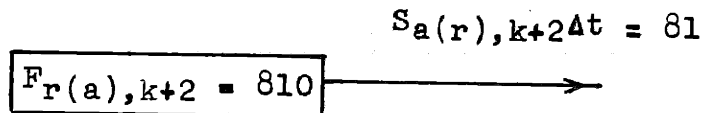


where $S_{a(r),k}$ = rate of shipments from apparel manufacturers to retailers.

and the next:



and the next:



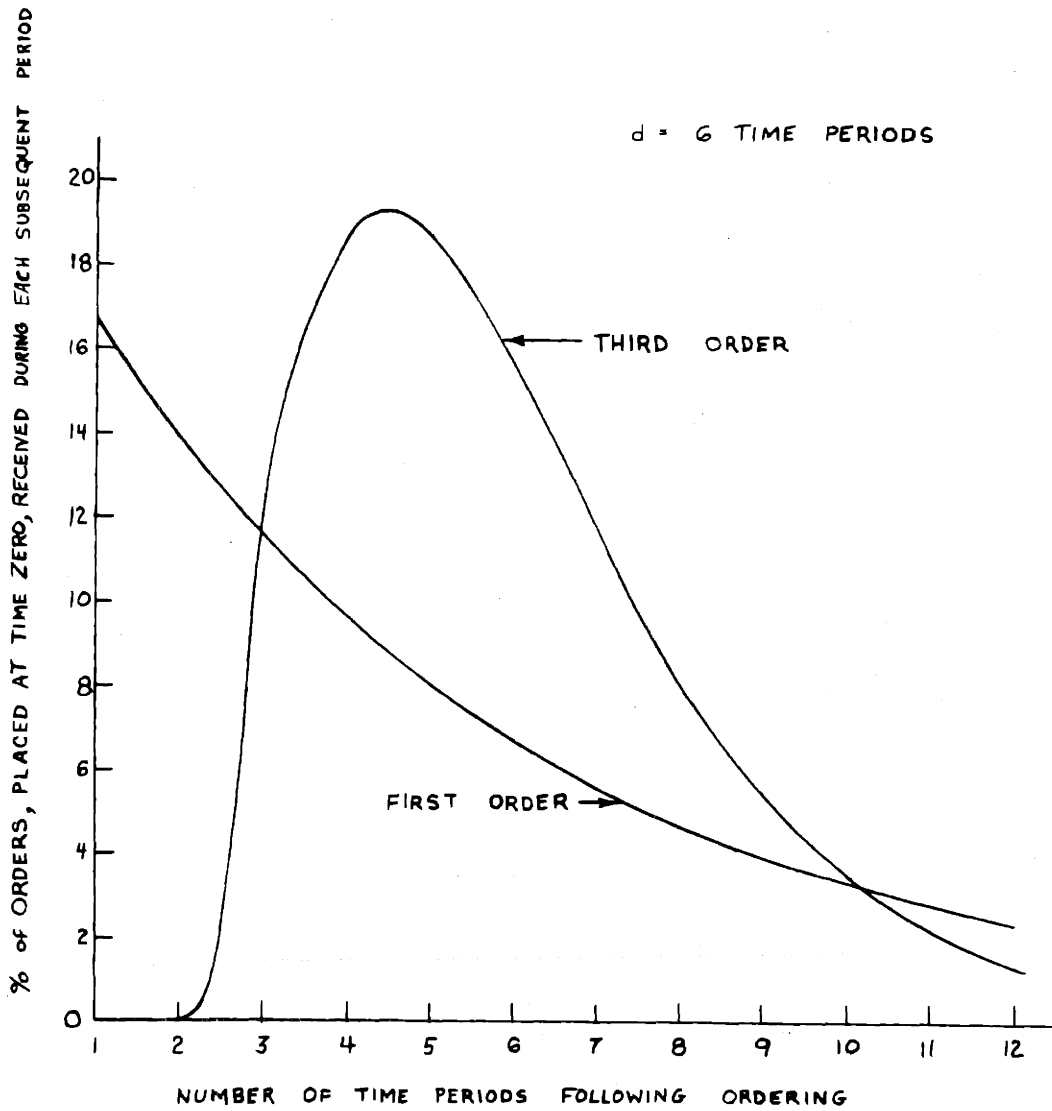
and so on.

The distribution of shipments over time, in response to the original 1,000 orders, is shown in Figure 7 for a delay of 6 time periods.

By cascading two or more such delays in sequence,

FIGURE 7

DISTRIBUTION OF RECEIPTS FROM
ORDERS ENCOUNTERING FIRST OR
THIRD ORDER EXPONENTIAL
DELAYS



the shape of the distribution of shipments is altered, approaching a fixed "pipeline" delay for large numbers of delays. The model utilizes only first or third order delays as approximations to the distributions one might expect in given situations. Figure 7 also shows the nature of the response, in the illustration, for a third order exponential delay.

One other characteristic of aggregate behavior should be noted. Any individual arrives at a decision to order at relatively infrequent intervals. Since many individuals are involved, however, it seems reasonable to assume that ordering between, say, the retail and apparel manufacturing level occurs on a continuous basis. Hence, no distortion is introduced by recalculating conditions after each short time interval Δt .

Since consumer demand is regarded as an independent input to the system, it will be useful (as in Chapter III) to begin with the retail level and work "up." Many of the basic relationships are repeated in essentially the same form at all levels, hence only the retail level need be discussed in detail.

RETAIL LEVEL

Accounting relationships.-- The relationships considered at the retail level are shown schematically in

Figure 8.² Let us examine the events occurring during the time period between the instants of time $k-1$ and k . Retail requisitions (i.e., consumer demand), arriving at the rate $R_{r,k-1}$ are added to a backlog of unfilled requisitions. This backlog is a formalism to describe that body of consumers who have decided to purchase but have as yet been unable to locate the item that they are looking for. One of three things can happen to a consumer in this group. If he finds the item (and purchases it), a shipment is registered and both backlog and retail inventory are reduced by the amount of the sale. If he cannot locate the item, and decides not to purchase, only the backlog is reduced. Finally, if he cannot locate the item, but is willing to wait until at least the next period to try again, no change is made in either the backlog or inventory. For the period $(k-1)\Delta t$ to $(k)\Delta t$, let

$R_{r,k-1}$ = Rate of requisitioning by consumers to retail

$S_{r,k-1}$ = Rate of shipments to consumers

$L_{r,k-1}$ = Rate of loss of consumers from unfilled requisition backlog

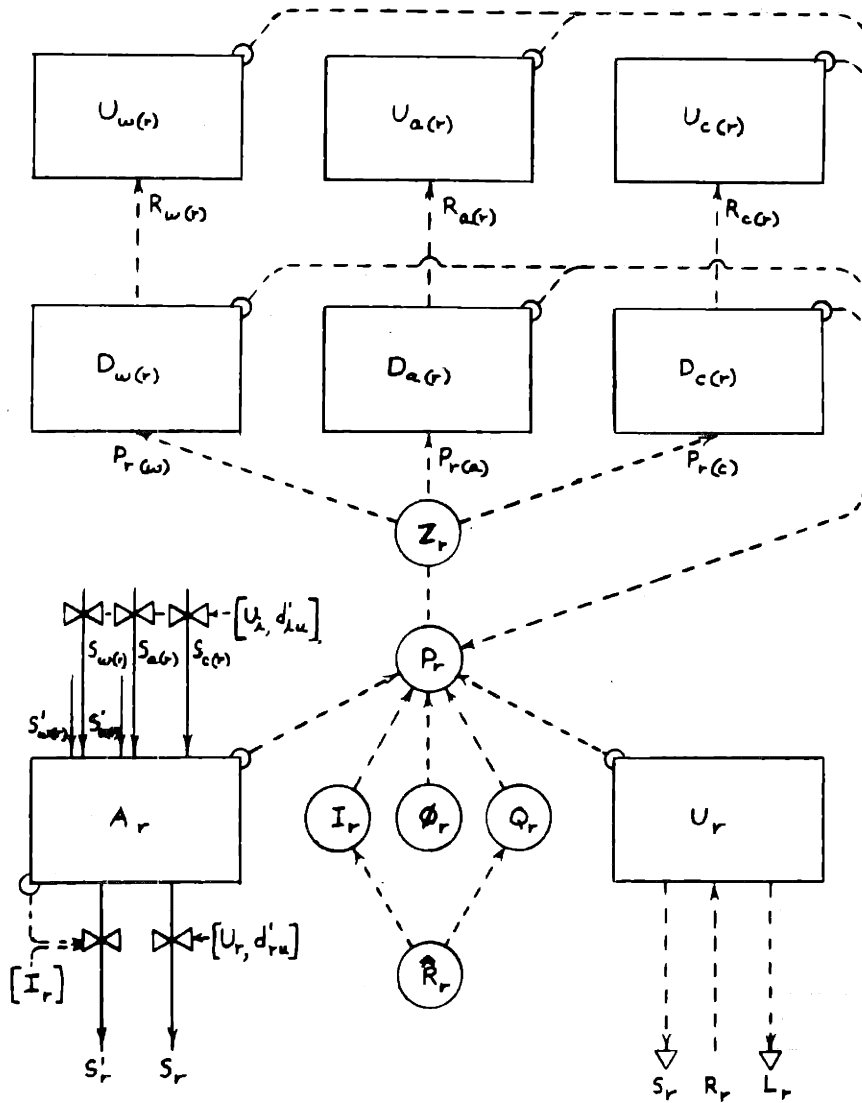
Then the quantity of unfilled requisitions at time k can be represented as

$$\begin{aligned} U_{r,k} &= U_{r,k-1} + (R_{r,k-1} - S_{r,k-1} - L_{r,k-1})\Delta t \\ &= \text{unfilled requisitions at time } (k-1) + \text{total} \end{aligned}$$

²See Appendix E for an explanation of flow chart symbols; and Appendix A for a listing of all notation.

FIGURE 8

MODEL STRUCTURE
RETAIL LEVEL



requisitions received - total requisitions filled and lost between (k-1) and (k).

Thus far, we have been talking only of information, in the form of requisitions. A similar accounting relationship holds true for the physical goods themselves. (It should be noted again that both physical goods and information are expressed in like units, and that there is a one to one correspondence between the two.) Consider the time period (k-1,k) again. Shipments are received from all suppliers throughout the period, and are added directly to inventories. In a manner quite analogous to the treatment of unfilled requisitions, there are three possible things that can occur to an item of inventory during this time period: it can be shipped to a consumer if it satisfies the requisitioning requirements of a particular individual; it can be carried over for possible sale during the next period; however, if the item has been on the floor for a long time, and the season is drawing to a close, it is frequently undesirable to keep it in stock any longer, and such items are disposed of at whatever price they will bring, through the mechanism of markdown sales. It is assumed here that markdown sales do not diminish the backlog of unfilled requisitions, but rather stimulate their own demand. (Had the item been applicable to any requisition in the backlog, it would previously have been sold.)

For the period k-1, k,

$S'_{r,k-1}$ = Rate of markdown sales

$S_{w(r),k-1}$ = Rate of receipt of shipments at retail from wholesale level

$S_{a(r),k-1}$ = Rate of receipt of shipments at retail from apparel manufacturing level

$S_{c(r),k-1}$ = Rate of receipt of shipments at retail from converter level

$S'_{w(r),k-1}$ = Rate of receipt of distress shipments from wholesale

$S'_{a(r),k-1}$ = Rate of receipt of distress shipments from apparel manufacturing

The inventory on hand at time k

$$\begin{aligned} A_{r,k} &= A_{r,k-1} + [(S_{w(r),k-1} + S_{a(r),k-1} + S_{c(r),k-1}) - \\ &\quad (S_{r,k-1} + S'_{r,k-1}) + (S'_{w(r),k-1} + S'_{a(r),k-1})] \Delta t \\ &= \text{the inventory on hand at time (k-1) +} \\ &\quad \text{(all shipments received from suppliers - all} \\ &\quad \text{shipments to consumers) during the period} \\ &\quad \text{k-1, k.} \end{aligned}$$

Requisition and shipment flows.--The two basic accounting relationships, establishing inventory and backlog levels, have been defined. It is now necessary to design the mechanism for controlling the flows in and out of these two reservoirs. The rate of requisitioning by consumers at retail, R_r , has been taken as an independent flow.

Consider next the rate of shipments to consumers (exclusive of markdown sales).

The shipments that can be made during any one period are limited to the unfilled requisitions on hand at the beginning of the period. Here, again, a formalism is being introduced which should not create much distortion: any requisition received during period $k-1$, k can be filled no sooner than during the following period, k , $k+1$. Since the time period can be made arbitrarily small, the approximation to over-the-counter sales can be made as close as desired.

If all sales were over-the-counter, and if every requisition received could be filled immediately, then the shipments, $S_{r,k}$, during period k , $k+1$ would exactly equal the backlog of requisitions $U_{r,k}$ at time k . These assumptions are true for some, but not all retail sales. Many consumers spend much time looking, before finally finding the desired item; whereas, for this model, over-the-counter sales implies that a consumer walks into a store and immediately finds and purchases the item that he wants. It follows, therefore, that even under ideal circumstances the average requisition will stay in the unfilled requisition category for more than one time period. This average waiting period is termed the "unfilled requisition delay," d_{ru} , and will be regarded as a constant. Its value is small at the retail level, of the order of magnitude of one week.

The assumption of "ideal circumstances," wherein the consumer can locate the item desired in an "optimum" length of time, is often violated. The average length of time required to locate a desired item will depend upon the level of inventory, and upon the accuracy with which the product mix in inventory reflects consumers' desires. Markdown sales will be relied upon to prune unwanted items out of inventory, so that the latter factor can be viewed as more or less constant. However, if inventory levels are relatively low, a longer period is apt to be needed to satisfy consumer requirements, and vice versa. We will therefore introduce the concept of an "ideal inventory level" which is presumed to create the optimum waiting conditions mentioned above. Departure of actual inventories from this level will modify the unfilled requisition delay.

$$d'_{ru,k} = d_{ru} \left[\frac{I_{r,k}}{A_{r,k}} \right]^{1/2}$$

where $I_{r,k}$ = ideal retail inventory level at time k

The modified unfilled requisition delay = unfilled requisition delay multiplied by the square root of the ratio of ideal to actual inventory levels.

The square root is introduced because a fully proportional modification seems to be a bit too drastic. One would not expect a large increase in average delay until actual

inventories had fallen substantially below ideal levels; and one would expect only moderate improvement even if inventories rose very much in excess of ideal.

The normal shipping rate to the consumer is determined by assuming that unfilled requisitions are characterized by a first order exponential delay.

$$S_{r,k} = \frac{U_{r,k}}{d'_{ru,k}}$$

The normal shipments to consumers during period $k, k+1$ are equal to $1/d'_{ru,k}$ times the unfilled requisition backlog at time k .

Markdown sales provide a means by which excess inventory can be eliminated without waiting for the independent action of the consumer. In particular, it is those items which are not selling, or which are closing out the season, that should be discarded. It will be assumed that the relationship between actual and ideal inventory provides an index of the volume of markdown sales. If past sales have been running behind expectations, inventory will have built up and the likelihood of markdown sales will be far greater than in the reverse situation.

$$\begin{aligned} S'_{r,k} \Delta t &= a_{r1} (A_{r,k} - I_{r,k}) ; I_{r,k} \leq A_{r,k} \\ &= 0 ; I_{r,k} > A_{r,k} \end{aligned}$$

where a_{r1} is a constant less than 1.

Markdown sales equal a fraction of the difference between ideal and actual inventory

The value of a_{r1} reflects the time over which an unbalanced inventory will be corrected. A plausible time would be three weeks, in which case a_{r1} would have a value of $\frac{\Delta t}{3}$.

The rate at which unsatisfied customers drop out of the unfilled backlog category is assumed to be a fixed percentage of the size of the backlog. In other words, on the average people will wait only a certain time before losing interest in making a purchase. Once again, the distribution of lost requisitions will be approximated by a first order exponential delay, so that

$$L_{r,k} = \frac{U_{r,k}}{d_{r1}}$$

where d_{r1} is the average delay before unfilled requisitions are withdrawn from the backlog.

Lost requisition = $1/d_{r1}$ times the unfilled requisition backlog.

The value assigned to d_{r1} will reflect an assumption as to the deferrability of consumer demand. Infinitely deferrable demand, which means that the consumer will wait forever, if necessary, to get the item that he wants, is equivalent to $d_{r1} \Rightarrow \infty$. It seems probable that d_{r1} has a fairly large value relative to d_{ru} (unfilled requisition

delay), yet small enough to imply a significant leakage of demand due to unavailable merchandise.

Shipments from supply sources are the result of conditions at the source. These flows are all determined in a manner analogous to normal shipments and markdown sales from the retail level to consumers.

Ordering criteria.--It is feasible, as has already been pointed out, to assume that ordering is taking place continuously over time, despite the discrete nature of individual decisions. Let us now examine the ordering process for a fictitious retailer who has all of the problems of the actual retailer, yet behaves in the manner of the aggregate, ordering continuously. This retailer must set his purchasing rate at time k , for the period $k, k+1$. His decision cannot be changed until time $k+1$, and hence must be designed to place a "correct" number of orders into the supply system during the forthcoming period. We shall define "correct" as follows:

At any time, k , there exists an "ideal ownership position" which the retailer would like to occupy. This position is calculated so as to best satisfy present and expected future demand. Ownership, in this sense, includes both physical inventory and all goods ordered but not yet received. The ordering rate is calculated so that the total orders placed during period $k, k+1$ shall equal this ideal

ownership position less the actual ownership position as of time k .

It is apparent that ideal ownership must include a substantial amount of ordering for future delivery. The individual retailer, ordering a specific item, will have a fair knowledge of the time required to obtain delivery on that item. He will avoid ordering earlier than necessary for obvious reasons, and in general will attempt to order so as to receive the goods near the time he expects to sell them. In the aggregate, then, retail ordering for future delivery will be conditioned by the nature of delays encountered at the supplier levels. Figure 9a represents the cumulative distribution of receipts over time from orders placed at time k . The shaded area is inverted and plotted in Figure 9b. This curve defines the percentage of the total order that will be needed at time $(k+\mu)$, which should be on order as of time k . In other words, $K_{r\mu}$ percent of all goods desired at time $k+\mu$ have lead times equal or greater than μ and hence should be on order at time k . One minus $K_{r\mu}$ percent of these goods have shorter lead times and need not be ordered yet. This concept will be extremely useful in developing an ideal ownership equation.

Ideal ownership is defined as follows:

$$= + I_{r,k} + Q_{r,k} + U_{r,k} + \phi_{r,k}$$

where $I_{r,k}$ = Ideal inventory at retail

FIGURE 9a

CUMULATIVE DISTRIBUTION OF RECEIPTS
FROM ORDERS PLACED AT TIME A
WITH THIRD ORDER EXPONENTIAL DELAY

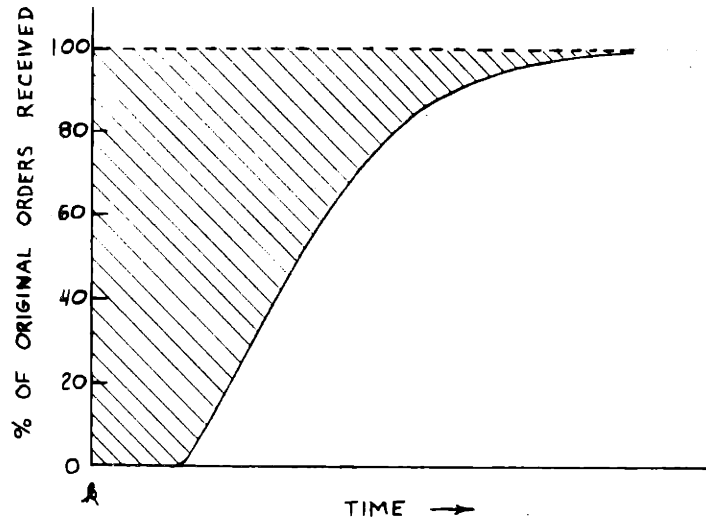
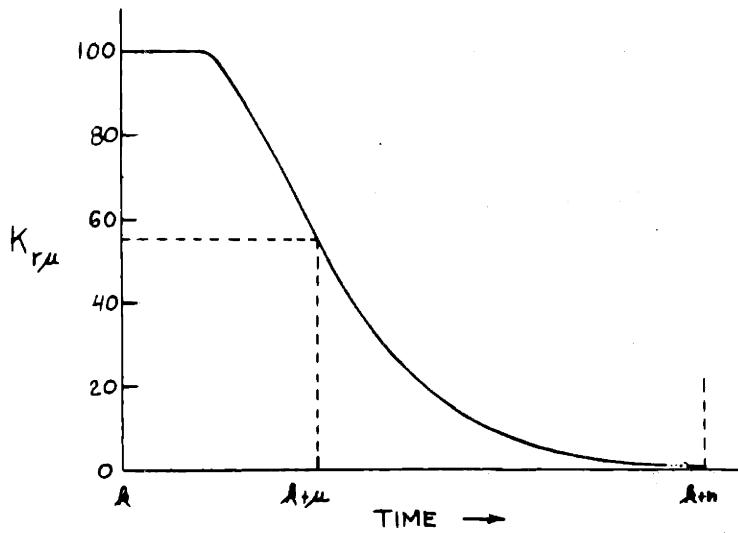


FIGURE 9b

PERCENTAGE OF GOODS DESIRED AT TIME $A+\mu$
HAVING LEAD TIMES EQUAL OR GREATER THAN μ



$Q_{r,k}$ = Ideal or desired quantity of orders in process

$U_{r,k}$ = Unfilled requisitions on hand

$\phi_{r,k}$ = A weighted average of expected future requisitions

The first two terms represent a form of overhead for doing business. Retailers "know," for particular items, the turnover that can be expected. In the aggregate, the inventory required to support a given rate of sales is likewise determinable. Similarly, back-up support in the form of orders in-process is required in accordance with the expected rate of demand.

Given a forecast of demand from the present through to the "planning horizon," I and Q can be stated explicitly. Ideally, we would like the inventory on hand today to consist mostly of items for sale today, with a declining percentage devoted to expected future sales. A simple exponential weighting system is employed to approximate the requisitioning rate upon which to base this ideal inventory position. Present and near future demand is weighted heavily, at the expense of demand expected in the distant future.

$$\text{Let } \hat{R}_{r,k} = \int_0^{\infty} B_{r\mu} \hat{R}_{r,k}(\mu) d\mu$$

where $\hat{R}_{r,k}$ is a weighted average of future requisition rates, to be used for planning purposes.

$B_{r\mu}$ is the weight assigned to the μ th period in the future. For a planning horizon of n periods,

$$B_{r\mu} = \frac{1}{n[1-e^{-1}]} e^{-\frac{\mu}{n}}$$

We can now define ideal inventory and orders in process:

$$I_{r,k} = a_{r2} \sqrt{\hat{R}_{r,k}}$$

where a_{r2} is a constant

$$Q_{r,k} = d_{rs} \hat{R}_{r,k}$$

where d_{rs} is a weighted average

of all delays encountered at supply sources, with weights assigned in accordance with the relative volume of orders going to each source.

$$d_{rs} = Z_{rw} (d_{wD} + d'_{wu}) + Z_{ra} (d_{aD} + d'_{au}) + Z_{rc} (d_{cD} + d'_{cu})$$

where the Z 's are weights such that $Z_{rw} + Z_{ra} + Z_{rc} = 1$ and the d 's represent various delays at each level.

The square root relationship between ideal inventory and expected requisitioning rate merely reflects the fairly widespread use of such a relationship in establishing

inventory policy. It implies that retailers do not adhere as rigidly to a fixed turnover ratio as they claim. Quite obviously, a doubling of demand would necessitate less than a two-fold increase in inventory as a base for supporting such demand. In contrast, the direct relationship for orders in process indicates a desire to keep d_{rs} number of time periods worth of sales on order at all times.

The last two terms of the ideal ownership equation, U and ϕ represent the component of ownership required to meet present and future requisitioning. The reason for including unfilled requisitions is more readily seen from the discussion in Appendix C. However, it may help to imagine a condition of inadequate supply, in which the requisition backlog becomes very large, followed by a sharp decline in consumer demand. In the latter situation, I , Q and ϕ , all dependent on expectations of consumer demand, become small and no new ordering is generated despite the sizeable backlog. This situation is averted by including $U_{r,k}$ in the ideal ownership equation.

$\phi_{r,k}$ represents the total commitment which should and can be placed by the retail level against expected future demand.

$$\phi_{r,k} = \int_{\mu=0}^{\mu=n} [K_{r\mu} \hat{R}_{r,k}(\mu) + \mathcal{I}_{r,k}(\mu) - \mathcal{I}_{r,k}(\mu)] d\mu$$

The expression under the integral consists of two

components. The first, $K_{r\mu}\hat{R}_{r,k}(\mu)$, represents the total orders which should have been placed through and including time k , so as to satisfy expected consumer demand at time $k+\mu$ (we are concerned only with orders placed "for delivery" at time $k+\mu$). If the forecast for $k+\mu$ has been consistent from period to period, this term accurately expresses the total commitment as of time k against expected demand at time $k+\mu$. However, if the forecast has been rising or falling, an adjustment is called for, as indicated by the terms $\mathcal{J}_{r,k}(\mu) - \mathcal{L}_{r,k}(\mu)$.

In the face of a rising forecast, some provision must be made for the fact that it is now too late to correct all past under-ordering. Some of the goods we should have (but did not) ordered previously will arrive after time $k+\mu$ if ordered today. Since we can foresee the loss of some sales as a result of insufficient merchandise on hand at time $k+\mu$, our total commitment at this time (k) should be somewhat less than $K_{r\mu}\hat{R}_{r,k}(\mu)$. The term $\mathcal{L}_{r,k}(\mu)$ represents the cumulative adjustment that has been made for this reason.

By similar reasoning, it can be shown that the total commitment should be increased above $K_{r\mu}\hat{R}_{r,k}(\mu)$ when the forecast has been declining. We take cognizance of the fact that previous over-ordering on long-lead items does

not completely relieve us of the responsibility for ordering the shorter lead items which may represent a different class of merchandise. We must anticipate now the probability of markdowns on the over-ordered items, and cannot correct the situation (entirely) by under-ordering today. The cumulative effect of such over-ordering for time μ is represented by the term $S_{r,k}(\mu)$. $L_{r,k}$ and $S_{r,k}$ are defined more rigorously in Appendix C.

The actual ownership position is simply actual inventory plus the total of all orders in process

$$= A_{r,k} + F_{r,k}$$

where $F_{r,k}$ = orders from retail, in-process at time k .

The complete ordering equation is therefore:

$$P_{r,k} \Delta t = I_{r,k} + Q_{r,k} + U_{r,k} + S_{r,k} - [A_{r,k} + F_{r,k}]$$

Disposition of orders.--Orders from the retail level are directed to three levels of supply: wholesale, apparel, manufacturing, and converting. In general, small retailers will tend to use wholesalers as a source, while the large outlets will seek a primary source. Only merchandise for sale as piece goods is obtained directly from the converter. It will be assumed, therefore, that the

percentage of aggregate ordering directed to each level is not affected by the dynamics of the system and may be taken as constant for a considerable span of time.

Let;

$Z_r(i)$ = The percentage of retail orders directed to the i^{th} level, where $i = a$ (apparel manufacturing), w (wholesale), and c (converting).

Then the ordering rate to the i^{th} level during period k is given by

$$P_{r(i),k} = Z_r(i) P_{r,k}$$

Orders directed to any given level will experience delays from causes other than actual manufacturing or order filling. These are essentially order and material handling delays occurring both at the retail and, say, the apparel manufacturing level. Following the ordering decision, the retailer must type and record the formal order and mail it (or perhaps merely telephone it). The apparel manufacturer receives and records the order, possibly after some additional delay if he is busy. Then he "processes" it, checking against inventories, generating production schedules, and so on. After production, additional paperwork is required, the article is packaged and shipped, only to go through some more processing at the retail store before it finally appears on the sales floor.

All orders issued by the retail level, to apparel manufacturers, which currently are subject to any of these activities, are considered to be included in the reservoir labeled $D_{a(r)}$ [See Figure 8]. The various delays are lumped together only to simplify the model. There is no inherent reason why a large number of specific delays could not be identified individually. It might well be advantageous, for example, to segregate delays occurring before from those occurring after the manufacturing process.

The quantity of orders in the delay at time k is determined by an accounting relationship

$$D_{a(r),k} = D_{a(r),k-1} + [Pr(a),k-1 - R_{a(r),k-1}] \Delta t$$

= orders in the delay at time $k-1$, + new orders added from retail, less requisitions removed by the apparel manufacturer for processing during the period $k-1, k$.

The flow out of the delay (rate of removal of requisitions) is approximated by a third order exponential. Using functional notation³

$$R_{a(r),k} = f(D_{a(r),k} ; d_{aD})$$

where d_{aD} is the average waiting period experienced by orders in the delay.

³The exact form of function f is given in Appendix B.

Requisitions enter an unfilled requisition backlog at the apparel manufacturing level which is entirely analogous to the requisition backlog at the retail level, except that it represents an actual file of written requisitions. The quantity of orders in the backlog (from retail) is $U_a(r),k$, hence the total orders in-process from retail to apparel manufacturing is $U_a(r),k + D_a(r),k$. It follows that the grand total of orders in-process, issued by the retail level is given by

$$F_{r,k} = \sum_i [D_i(r),k + U_i(r),k] ; i = w,a,c.$$

Forecasting.--It was noted that the criteria for ordering at the retail level assumed a forecast for each period of time in the planning future. The method for establishing this forecast could have a sizable impact on the dynamic behavior of the system. The characteristics described in Chapter III serve as a guide for the formulation of a forecasting procedure for the model. Many possible refinements are omitted in the interest of simplicity, although they could be added, or alternative methods explored, without requiring any fundamental change in the basic model.

In evaluating a forecasting method, it should be recalled that the objective is to approximate aggregate behavior of retailers, rather than to devise a "good" forecasting system. The technique suggested concentrates

upon the distinction between advance ordering, for delivery in the future, and reordering for almost immediate delivery. Advance ordering for a given year relies heavily upon the previous year's performance.

$$\text{Let } \hat{R}_{r,k}^{(1)}(k+\mu) = R_{r,k+\mu-N}$$

where N = number of time periods in a year.

The advance ordering forecast of consumer requisitioning rate for $k+\mu$, made at time k , equals the requisitioning rate at the corresponding time the previous year. In other words, it is assumed that the previous year provides the best estimate of next year's performance.

$$\text{Let } \hat{R}_{r,k}^{(2)}(k+\mu) = R_{r,k-1} \frac{\Theta_{r,k+\mu-N}}{\Theta_{r,k-1}}$$

where $\Theta_{r,k}$ = the seasonal index for time k .

The reordering (short-range forecast) for $k+\mu$, made at time k , equals the requisitioning rate during the past period $(k-1,k)$ adjusted by the ratio of the seasonal index for the forecast period to the seasonal index for last period. This amounts to a direct projection of current demand to the forecast period. The seasonal index is defined

as follows:

$$\Theta_{r,k} = \Theta_{r,k-N} + a_{r3} \left(\frac{\tilde{R}_{r,k}}{R_{r,k}} - \Theta_{r,k-N} \right)$$

where a_{r3} is a smoothing constant ($a_{r3} \leq 1$) which determines the relative weight of this season's performance in adjusting the seasonal index. Only corresponding periods one year apart enter into the determination of the seasonal index for the period.

$\tilde{R}_{r,k}$ is a smoothed and seasonally adjusted requisitioning rate.

$$\tilde{R}_{r,k} = \tilde{R}_{r,k-1} + a_{r4} (\Theta_{r,k} R_{r,k} - \tilde{R}_{r,k-1})$$

where a_{r4} is a smoothing constant for the seasonally adjusted demand rate. a_{r4} should be small enough for smoothing to take place effectively over a period of 6 months to 1 year.

The actual forecast to be used in planning for time $k+\mu$ will be a weighted average of the long-range and short-range forecasts described above. When μ is large relative to n , the forecasting horizon, the long-range forecast $[\hat{R}_{r,k}^{(1)}(\mu)]$ will be weighted heavily. When μ is small, the heaviest weight will be assigned to the short-range forecast $[\hat{R}_{r,k}^{(2)}(\mu)]$.

$$\hat{R}_{r,k}(\mu) = \frac{\mu}{n} \hat{R}_{r,k}^{(1)}(\mu) + \left(1 - \frac{\mu}{n}\right) \hat{R}_{r,k}^{(2)}(\mu)$$

WHOLESALE LEVEL

There is no important difference between the formulation of the model for the wholesale level and that for the retail level. The same ordering criteria and forecasting techniques are employed, subject only to variations in details such as the values assigned to constants. The complete set of equations for the retail level is presented in Appendix D.

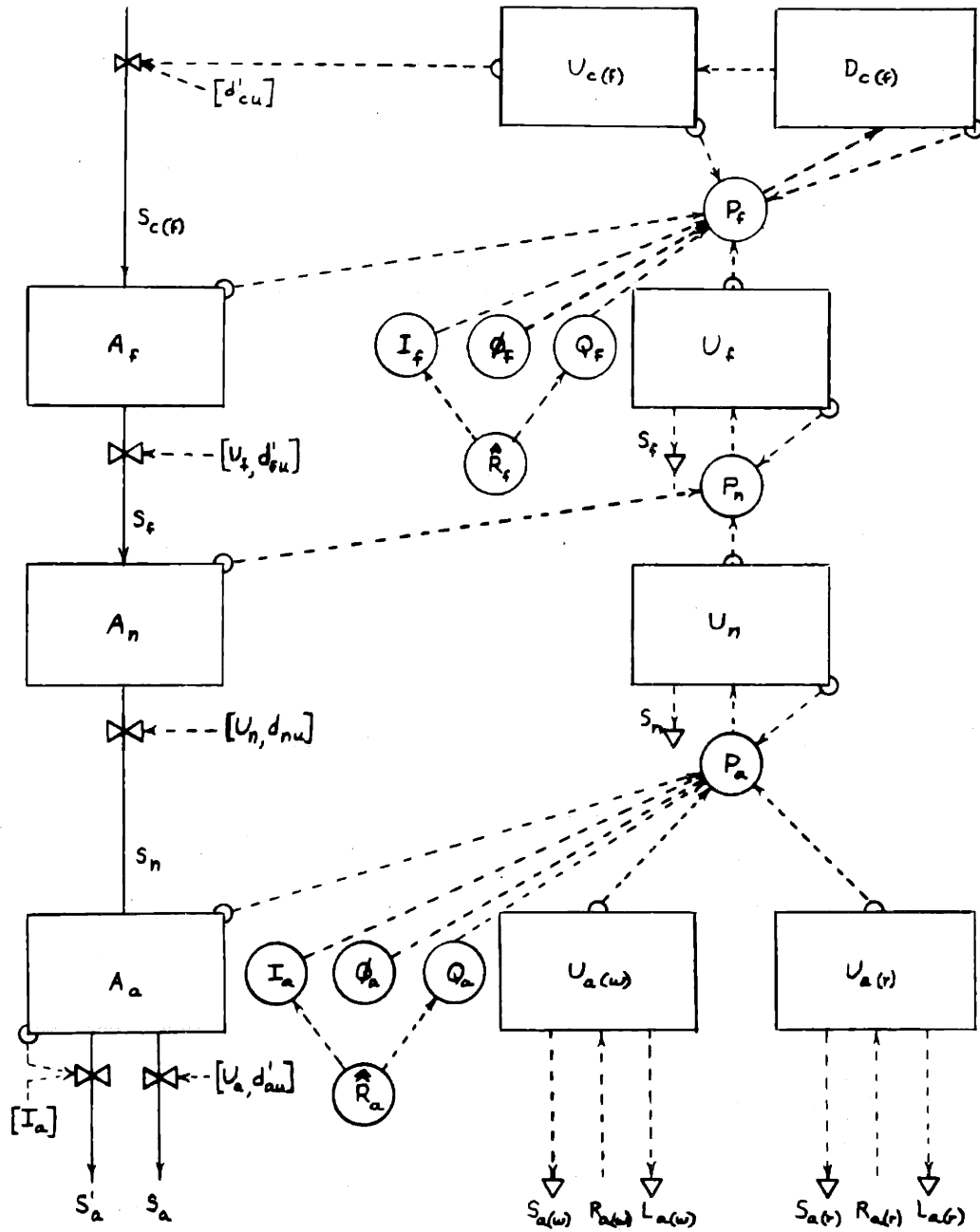
APPAREL MANUFACTURING LEVEL

Many of the essential characteristics of the retail level are repeated at the apparel manufacturing level. However, the manufacturing process does introduce some unique features not heretofore encountered.

Figure 10 presents the flow pattern for the apparel manufacturing level, indicating three distinct stages. Although information flow within an organization occurs more rapidly than between distant organizations, it is nevertheless valid to isolate the individual steps involved.

Finished inventory stage.--Requisitions are received from both the retail and wholesale levels, entering a classified backlog. The accounting relationship for

FIGURE 10
MODEL STRUCTURE
APPAREL MANUFACTURING LEVEL



the backlog is

$$U_{a(i),k} = U_{a(i),k-1} + [R_{a(i),k-1} - S_{a(i),k-1} - I_{a(i),k-1}] \Delta t;$$

i = r (retail), w (wholesale)

Similarly, the inventory accounting relationship is

$$A_{a,k} = A_{a,k-1} + [S_n, k-1 - S_{a,k-1} - S'_{a,k-1}] \Delta t$$

where S_n is the rate of "shipments" from the manufacturing line to finished inventory.

The flow rates out of backlog and inventory are similar to flows at the retail level. Although the average unfilled requisition delay is longer than that at retail, a first order exponential is again assumed.

$$S_{a(i),k} = \frac{U_{a(i),k}}{d'_{au,k}}$$

$$\text{where } d'_{au,k} = d_{au} \left[\frac{I_{a,k}}{A_{a,k}} \right]^{1/2}$$

Excess inventories are reduced by markdown sales independent of current requisitioning, as at retail,

$$S'_{a,k} = s_{a1} (A_{a,k} - I_{a,k}) ; A_{a,k} \geq I_{a,k}$$

$$= 0 ; A_{a,k} < I_{a,k}$$

These distress shipments are allocated between the retail

and wholesale levels in proportion to the current requisition backlog for those levels

$$S'_{a(i),k} = \left[\frac{U_{a(i),k}}{U_{a,k}} \right] S'_{a,k} \quad ; \quad i = r, w$$

Requisitions will be withdrawn from the backlog at an increasing rate as the delay encountered at the apparel manufacturing level increases. In effect, retailers will tend to cancel orders which have not been delivered when needed. Since the average requisition delay is d_{au} , it is possible to identify $\frac{U_{a(r),k}}{d_{au}}$ as the desired, or normal shipping rate to the retail level. It is assumed that the rate of withdrawal of requisitions from the backlog is a fixed percentage of the difference between this desired shipping rate and the actual shipping rate

$$L_{a(r),k} = a_{a2} \left[\frac{U_{a(r),k}}{d_{au}} - S_{a(r),k} \right] \quad , \quad L_{a(r),k} \geq 0$$

where a_{a2} is a constant, $0 < a_{a2} < 1$

A plausible value for a_{a2} would probably lie in the range of 0.1 to 0.25.

This equation can be put in a slightly different form by substituting for $S_{a(r),k}$

$$\begin{aligned} L_{a(r),k} &= a_{a2} \left[\frac{U_{a(r),k}}{d_{au}} - \frac{U_{a(r),k}}{d'_{au,k}} \right] \\ &= a_{a2} \left[\frac{1}{d_{au}} - \frac{1}{d'_{au,k}} \right] U_{a(r),k} \quad ; \quad d'_{au,k} > d_{au} \end{aligned}$$

Production orders will be generated solely on the basis of conditions at the finished inventory stage. Orders placed into production during the period $k, k+1$, are given by

$$P_{a,k\Delta t} = I_{a,k} + Q_{a,k} + U_{a,k} + \phi_{a,k} - [A_{a,k} + F_{a,k}]$$

There is no significant delay between the issuance of an order and its receipt at the factory, hence the total orders in process,

$$F_{a,k} = U_{n,k}$$

The relatively naive forecasting method used at the retail level is repeated for the apparel manufacturer in the belief that it constitutes an adequate first approximation. Note that the manufacturer of a single, highly seasonal product will generate a very low forecast toward the end of the season. This will lead to a reasonable ordering pattern: I, Q and ϕ become small, and new production orders are issued only to the extent that the unfilled requisition backlog, U , exceeds actual goods in process and in finished inventory.

Production stage.--Events occurring at the production stage are extremely straightforward. Shipments to finished inventory are approximated by a third order

exponential delay for unfilled requisitions. Considering the manufacturing process in the aggregate, this appears to offer a far more realistic approximation than the first order delay used heretofore.

$$S_{n,k} = f [U_{n,k} , d_{nu}]$$

where d_{nu} is the average manufacturing time

The procedure for ordering raw materials (fabric) into production also differs from the ordering criteria considered previously. Requisitions, once placed into production, are never withdrawn. Furthermore, production is never initiated without a requisition, hence there is no lost demand or distress shipments to be accounted for. Only immediate fabric requirements are ordered in the exact quantities required. No attempt is made to anticipate future requirements or to maintain inventory in-process. The ordering equation reduces to

$$P_{n,k\Delta t} = U_{n,k} - [A_{n,k} + F_{n,k}]$$

= unfilled requisitions on hand less
inventory + total orders in-process

Raw material (fabric) stage.--Events at the raw material stage resemble the production stage in that there is no lost demand or distress shipments. Shipments out of

fabric inventory into production can be approximated by the usual first order delay

$$S_{f,k} = \frac{U_{f,k}}{d'_{fu,k}}$$

There are at least two ways in which the ordering equation might be formulated. Consider the fact that the three stages of the apparel manufacturing level are normally contained within a single organization.⁴ Information at the finished inventory stage is available almost instantly at all stages. One would expect the ordering of fabrics to be based directly upon this information and any inferences (forecasts) that might be drawn from it concerning future customer behavior. However, it is first necessary to plan the manufacturing requirements to satisfy expected customer demand. This step is represented formally in the model by the order P_a from finished inventory to the production stage. Furthermore, the flow chart (Figure 10) indicates that this order is transmitted almost without delay to the fabric inventory stage. It is therefore valid, and will be convenient, to consider the ordering of fabrics as if the raw material stage were an independent level with no information available save for the pattern of incoming requisitions. In effect, all of the pertinent information

⁴The operations of jobbers are so closely related to those of the integrated manufacturer that, for the purpose of this model the jobber is included in the category of apparel manufacturer.

has been incorporated into the production order P_a , which is the basis for requisitions at the fabric stage.

The ordering equation is therefore

$$P_{f,k}\Delta t = I_{f,k} + Q_{f,k} + U_{f,k} + \phi_{f,k} - [A_{f,k} + F_{f,k}]$$

The term ϕ represents total desired orders in-process to meet future requirements, based upon known average delivery time.

$$\phi_{f,k} = \int_{\mu=0}^{\mu=n} K_{f\mu} \hat{R}_{f,k}(\mu) d\mu$$

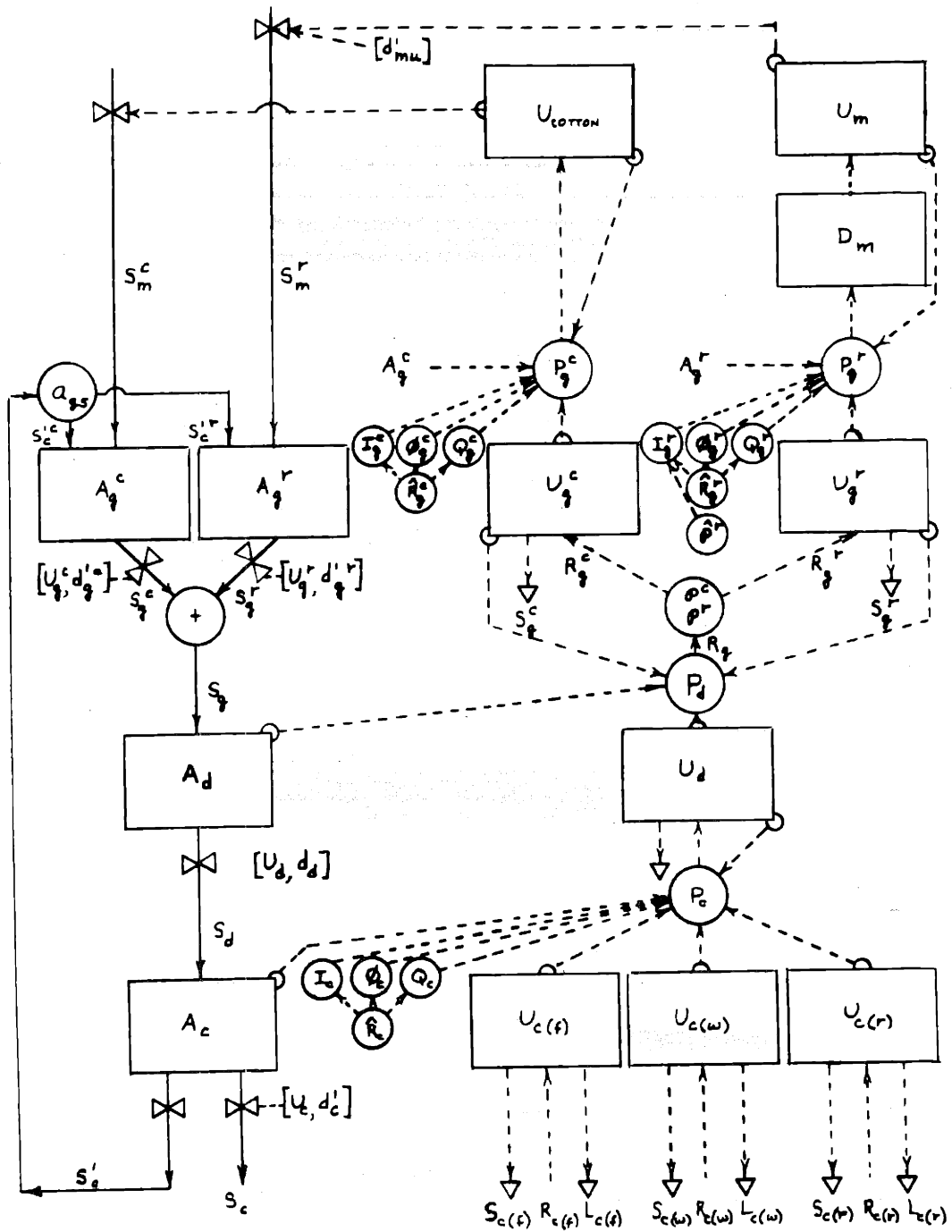
CONVERTER LEVEL

The converting level resembles the manufacturing level in structure, with three discrete stages (Figure 11). The role of the commission finisher is unimportant and will be neglected, with all decision processes resting in the hands of the converter.

Distress shipments from the converter have been omitted. Instead, excessive finished inventory is "drained" back into gray goods inventory for subsequent refinishing. Effects resulting from the reduced quality of such goods are disregarded. The rate of this flow is established in the same manner as markdown sales at other levels.

The ordering equation at the finished fabric stage,

FIGURE 11
MODEL STRUCTURE
CONVERTER LEVEL



for the finishing of gray goods, conforms to the usual pattern. The objective is to sustain an in-process and finished inventory adequate to support the expected volume of business in the face of known dyeing and finishing times. The problem of assuring an adequate supply of gray goods to meet finishing requirements is left for the subsequent decision made at the gray inventory level.

A somewhat different forecasting technique is applied by the converter, perhaps due to the long lead time with which he is faced, both in finishing and in obtaining gray fabric from the mill. The converter's forecast will be approximated by superimposing the known seasonal pattern on a long-term trend.⁵

$$\text{Let } T_{c,k} = T_{c,k-1} + a_{c5} \left[\frac{\tilde{R}_{c,k}}{\tilde{R}_{c,k-1}} - T_{c,k-1} \right]$$

where $T_{c,k}$ is a trend index, and a_{c5} is a smoothing constant which determines the relative weight assigned to current trend vs. past trend

Then the forecast requisition rate for $k+\mu$ is

$$\hat{R}_{c,k(k+\mu)} = \frac{\tilde{R}_{c,k} [T_{c,k}]^\mu}{\theta_{c,k+\mu-N}}$$

⁵This approach is suggested by Charles C. Holt of The Carnegie Institute of Technology in an unpublished paper entitled "Forecasting Seasonals and Trends by Exponentially Weighted Moving Averages," April 2, 1957.

= the current requisitioning rate, adjusted for trend by projecting the current smoothed trend ratio μ periods into the future, and adjusted for seasonal fluctuations on the basis of last year's (smoothed) seasonal index for the forecast period.

The ordering of gray goods constitutes the main point at which the converter's behavior departs from that of the apparel manufacturer. The converter, of course, is confronted with a far more staple raw material than any thus far encountered, together with an extremely long lead time. These factors make price a more significant factor at this stage than at any preceding level. Two aspects of behavior induced by material prices are incorporated in the model:

- a) price competition between cotton and the cellulose fibers and
- b) the impact of price expectations on inventory policy.

Effect of price competition.--To the extent that cotton fabrics can be substituted for rayon and acetate fabrics, competition between the two groups will be affected by price. In the extreme case of perfect competition, a small reduction in the price of either fabric group would shift all buying from one to the other. The actual situation corresponds more to a "normal" relative volume between the two groups which is departed from, in the short run, in response to price changes and, in the

long run, in response to changing fiber technology, consumer buying habits, and so forth. Figure 11 indicates that requisitions to the gray inventory level are split into two groups, those for rayon and acetate fabrics and those for cotton fabrics. The normal percentage of total requisitions directed to the cellulosic fibers is defined as an adjustable "constant," a_{g5} , whose value is about 25% based on recent industry data as published in Textile Organon. This "constant" is increased or decreased in proportion to the ratio of cotton price to rayon and acetate fiber price.

$$a_{g5,k} = \frac{\tilde{P}_k^c}{P_k^r} a_{g5}$$

where P_k^r = average price of rayon and acetate staple at time k.

\tilde{P}_k^c = smoothed price of raw cotton fiber at time k.

$$= \tilde{P}_{k-1}^c + a_{g6} (P_k^c - \tilde{P}_{k-1}^c)$$

The smoothing constant a_{g6} has a value equivalent to no more than 2 or 3 weeks.

Rapid fluctuations in cotton price make it desirable to introduce a small amount of smoothing. In contrast, rayon and acetate prices change too infrequently to justify smoothing.

The use of fiber price rather than gray fabric price involves an implicit assumption that is not entirely justifiable. It is a valid assumption only when fabric prices rapidly and accurately reflect changes in fiber prices. Although the mill would like to pass on price changes in this manner, the gray goods market will not invariably support such a practice. For this model, fiber prices will be accepted as a useful indicator. The movement of fabric prices could be determined only with a more complete description of the cotton sector than is available.

Summarizing, requisitions to the rayon and acetate backlog are given by

$$R_{g,k}^r = a_{g5,k} R_{g,k}$$

and $R_{g,k}^r + R_{g,k}^c = R_{g,k}$

Total requisitions consist of only the two groups, rayon and acetate, and cotton.

It is important to note that the price of cotton is introduced as an independent input to the system, whereas the price of rayon and acetate will be determined at the producer level.

Effect of price expectations.--The ordering of rayon

and acetate gray goods is somewhat sensitive to expected price changes. If, for example, a price reduction is anticipated, ordering will be curtailed in the hope that a lower price will prevail by the time the order must be placed. This objective can be accomplished by adjusting ideal inventory to reflect price anticipation. The usual formulation of ideal inventory is

$$I_{g,k}^r = a_{g7} \sqrt{\hat{R}_{g,k}^r}$$

where a_{g7} is a constant

$$\text{Let } a_{g7,k} = \frac{\hat{P}_k^r}{P_k^r} a_{g7}$$

where \hat{P}_k^r is the expected average price of rayon and acetate staple.

That is, the "constant" is adjusted in proportion to the expected change in fiber price. An expected price reduction of 20% will generate a reduction in ideal inventory of 20% and hence a lower ordering rate than otherwise. Now, assume that P_k^c provides a good estimate of \hat{P}_k^c

$\frac{\hat{P}_k^r}{P_k^r}$. (Increasing cotton prices indicate a proportionate forthcoming increase in rayon and acetate price, and vice versa).

Then

$$I_{g,k}^r = a_{g7,k} \sqrt{\hat{R}_{g,k}^r}$$

$$\text{where } a_{g7,k} = \frac{P_k^c}{\hat{P}_k^c}$$

$$\text{and } \hat{R}_{g,k}^r = a_{g5,k} \hat{R}_{g,k}$$

The forecast upon which fabric ordering is based utilizes the same technique as at the converter finished inventory level. Only total requisition rate need be forecast, the proportion between the two fabric groups being based upon the current ratio $a_{g5,k}$.

Ordering of fabrics from the cotton sector is based solely upon the ordering criteria which have been used for previous levels, without regard to price. This is a departure from reality which is justified only on the grounds that the model being constructed is aimed at a study of the rayon and acetate sector. The cotton sector is introduced as a passive element, necessary to balance the system, but not to be examined in itself. For the same reason, the cotton mill level is represented only by a single, third order delay rather than as a multi-stage system.

MILL LEVEL

Structurally the mill level resembles the apparel

manufacturing and converting levels, with three inventory stages. Figure 12 presents the flow pattern at the mill. All quantities and rates are determined as at the apparel manufacturing level, except as noted below.

Production ordering differs substantially from the policies employed at lower levels. The mill is concerned with stabilizing production, and with producing to order rather than building up substantial finished stocks. The term, ϕ , concerned with ordering in anticipation of future demand, is therefore dropped from the ordering equation, which becomes

$$P_{m,k}\Delta t = I_{m,k} + U_{m,k} + Q_{m,k} - [A_{m,k} + F_{m,k}]$$

The tendency toward stabilizing production is reflected in the determination of I and Q , which are based on smoothed values of past requisitions rather than upon forecast requisitions.

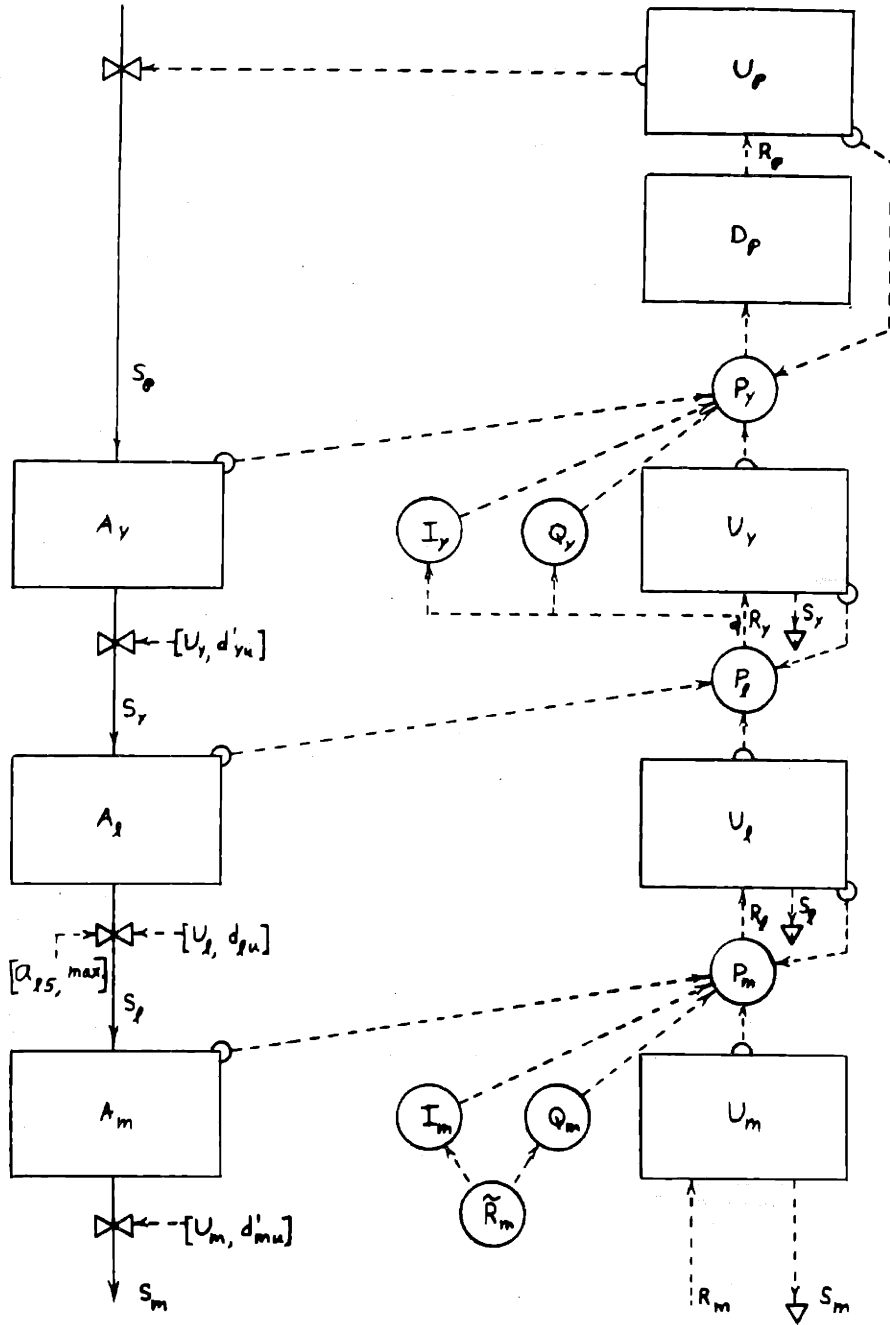
$$I_{m,k} = a_{m2} \sqrt{\tilde{R}_{m,k}}$$

$$Q_{m,k} = d_{1u} \tilde{R}_{m,k}$$

This smoothing has the effect of slowing the response of production to changes in demand. The constant a_{m2} is much smaller than its counterpart at other levels, in keeping with the mill's desire to minimize finished inventories.

The ordering of raw material into production is a

FIGURE 12
MODEL STRUCTURE
MILL LEVEL



direct process, as at the apparel manufacturing level, with the exception that a capacity limitation is inserted.

$$P_{1,k}\Delta t = U_{1,k} - [A_{1,k} + F_{1,k}] ; \max = a_{1,5}$$

The mill will not, in other words, order material into production at a rate which exceeds its loom capacity, but rather will restrict the ordering rate to that known capacity. It follows, of course, that the equation for determining shipping rate from production (which is based upon a third order exponential delay) is also limited by the maximum production rate. A sustained rise in the requisitioning rate above capacity will, therefore, merely serve to increase the backlog of requisitions in production.

Ordering of raw materials (yarn and staple) from the producer is almost as simple. Short lead time and ready availability make it unnecessary for the mill to plan very far in advance. The ordering equation is

$$P_{y,k}\Delta t = U_{y,k} + I_{y,k} + Q_{y,k} - [A_{y,k} + F_{y,k}]$$

In this case, Q and I are based upon current requisitioning rates, since requisitions into raw material inventory reflect the smoothing of demand already applied at the finished inventory stage.

PRODUCER LEVEL

Production orders generated at the finished inventory

level of the producer are in most respects like their counterpart at the mill level. The objectives are to meet fluctuations in demand by jointly adjusting production and inventories, with little interest in anticipating future demand. The ordering equation is

$$P_{p,k} \Delta t = I_{p,k} + Q_{p,k} + U_{p,k} - [A_{p,k} + F_{p,k}]$$

It is interesting to observe that , where I and Q are based upon heavily smoothed values of demand (as at the mill level), the result is a stabilizing of production at the expense of finished inventory. Since stabilized inventory is also an objective of the producer, I and Q must be based primarily on recent requisitioning rates.

$$I_{p,k} = a_{p2} \sqrt{\tilde{R}_{p,k}}$$

$$Q_{p,k} = d_{eu} \tilde{R}_{p,k}$$

$$\text{where } \tilde{R}_{p,k} = \tilde{R}_{p,k-1} + a_{p4} (R_{p,k-1} - \tilde{R}_{p,k-1})$$

the smoothing constant a_{p4} having a relatively high value.

Another distinction between the producer and the mill is that the producer can exert some control over prices. Prices will respond to sustained pressure on inventories and production, in the hope of modifying the incoming requisition rate. The modification is achieved

through the impact of prices on behavior at the converter level. It is assumed that the change in price at time k is proportional to a smoothed value of past changes in inventory and production requisition backlog. If inventory has been rising and backlog has been declining steadily, prices will be reduced continuously until the joint trend is reversed

$$p^r_k = p^r_{k-1} + a_{p7} (\tilde{\Delta U}_{e,k} - \tilde{\Delta A}_{p,k})$$

$$\text{where } \Delta A_{p,k} = A_{p,k} - A_{p,k-1}$$

$$\Delta U_{e,k} = U_{e,k} - U_{e,k-1}$$

$$\tilde{\Delta A}_{p,k} = \tilde{\Delta A}_{p,k-1} + a_{p8} (\Delta A_{p,k} - \tilde{\Delta P}_{k-1})$$

$$\tilde{\Delta U}_{e,k} = \tilde{\Delta U}_{e,k-1} + a_{e5} (\Delta U_{e,k} - \tilde{\Delta U}_{e,k-1})$$

The significance of the various constants is important. a_{p7} is a proportionality factor and controls the magnitude of the price response to sustained changes in conditions. The smoothing constants a_{p8} and a_{e5} control the speed of response of price changes. Small values on these constants will make price highly sensitive to changes in demand (as reflected by changes in inventories and backlog). Large values would cause price changes to lag behind changed demand so far as to be almost irrelevant. In view of recent conditions in the rayon and acetate industry, with the prevalence of off-list selling

(all prices in the equations refer to net, rather than to list) short term smoothing is undoubtedly appropriate.

CHAPTER VII

A DYNAMIC MODEL--EVALUATION AND SUGGESTIONS FOR FURTHER STUDY

OBJECTIVES AND LIMITATIONS OF THE MODEL

The objective of a simulation model is to accurately describe the operation of a complex system. The model that has been presented is intended to serve as a first step in the direction of this goal by portraying the framework within which production and distribution occur. It is essentially a large skeletal structure in which the rough proportions of certain outstanding characteristics of the textile industry are reflected. This approach resembles in many respects that of an anthropologist attempting to reconstruct the anatomy of a prehistoric man. He must first seek to describe the underlying skeletal structure with a sense of perspective as to the relative size, shape and position of the various parts. Given this start, he can then focus attention on the details of each part and its relationship with its neighbours. Finally, he will be in a position to place flesh on the bones, filling in all the additional information needed to create a true-to-life representation of a living man.

The model of Chapter VI, in like manner, cannot be regarded as a complete and accurate replicate of the rayon and acetate sector of the textile industry. It will have achieved a notable success if it provides the necessary start toward such a model--if its framework is sound enough to guide further studies in depth of individual sectors and interrelationships; and to support all of the "flesh"--the additional information--required of a complete model.

SUGGESTIONS FOR FURTHER STUDY

The path for research towards a fully workable model of the textile industry appears to be clearly outlined by the foregoing discussion. Research in depth is needed to refine and improve upon the structure as it now stands. Research in breadth is needed to extend the framework and to fill it out.

Research in depth.--This vital and difficult area can be summed up by the phrase: "take a closer look." This could take the form of a detailed examination of one particular level in the chain of distribution, such as the converting level. The researcher must literally live with converters to gain an appreciation of all of the subtleties and complexities of their behavior; ultimately to distill from such knowledge only those characteristics which affect the dynamics of the entire system.

A "close look" can also examine a more restricted

vertical sector in which the interrelationships between different levels are (perhaps) simpler and easier to see. For example, women's hosiery is manufactured and distributed in a manner that is somewhat independent of other textile products. Considerable data could be obtained to support a study of this nature, in contrast to the scarcity of data for the industry model. Another example would be the careful tracing of the life cycle of a single fabric, such as rayon pigment taffeta. This type of study seems to offer an excellent method for gaining insight into the workings of fashion, since a single fabric will respond far more violently to swings in fashion than will the entire industry.

Finally, and perhaps most important, there remains ample room for improvement and elaboration of the working relationships in the model. The continuous form of aggregate model that has been developed poses a significant challenge toward creating workable equations. Forecasting relationships, pricing policies, ordering policies and other equations must all function reasonably well over wide ranges of conditions, yet be simply stated and reflect the aggregate behavior being simulated.

Research in breadth.--When faced with the tremendous potential of simulation, it is difficult to suppress the desire to achieve a complete representation of the real system. The objections to attempting such a course at the

outset need not be restated again. Eventually, it should be both possible and useful to incorporate all significant parameters into the model--to place the flesh of cash flow, manpower, capital investment and others on the skeleton of production and distribution. There is, however, another area of "research in breadth" which should, together with "research in depth," precede such elaboration. This area is concerned with extending the model framework beyond limits that have thus far been established.

One extension might be into the consumer sector. The weakness of the present assumption concerning markdown sales is sufficient justification for this extension, although there are many others. It has been assumed that the quantity of markdown sales has no effect upon consumer demand. Yet it seems reasonable to suppose that consumer behavior will reflect actions taken by retailers. In particular, if retailers have had recourse to an undue amount of markdown sales, would not future consumer demand be reduced in response to this action? Other actions by retailers and others within the industry, such as advertising, should be examined to evaluate their impact upon the consumer.

Still another extension might consider the relationship between cotton and the cellulosic fibers. Before this relationship can be explored in depth, it would probably be worthwhile to extend the model into the cotton sector (at

and above the mill level). Similarly, extensions to incorporate the effects of competition with other synthetic fibers should be considered.

Utilization of the model.--The gulf that separates the present model from a fully representative, workable model does not mean that it need not be operated. Quite to the contrary, manipulation of the model could be extremely useful. The purpose of such manipulation would not be to study the real system, however, but rather to seek insight into the most fruitful areas for further research. For example, experimentation could indicate the sensitivity of the system dynamics to manufacturing delays, or to forecasting errors, or to ordering policies, etc. Research could then concentrate upon those elements that are of importance to dynamic behavior, leaving less important elements in the form of rough approximations.

The size and complexity of the textile industry provides an imposing challenge to the art of simulation. Success, in the form of a representative and complete model, will not be easy to achieve; but it offers the most promising avenue yet known for approaching an understanding of the often troublesome and mysterious dynamic behavior of the industry.

APPENDIX A

NOTATION

Conventions

- 1) The time subscript k , on a quantity, indicates the instant at which that quantity is defined.
- 2) The time subscript k , on a rate, indicates that the rate applies over the period $k, k+1$.
- 3) The first subscript on a variable indicates the level to which the variable applies. A second subscript is sometimes used, in parentheses, to denote the level to which the variable is going, or from which it originated. For example,

$P_r(a)$ = retail purchasing rate to the apparel manufacturing level

$R_a(r)$ = requisitioning rate at the apparel manufacturing level from the retail level

- 4) The time subscript follows the "level" subscripts, separated by a comma.

$A_{r,k}$ = retail inventory, at time k

- 5) A time symbol following the variable, in parentheses,

indicates the time or time period at which the variable is directed.

$\hat{R}_{r,k}(k+\mu)$ = Forecast retail requisition rate for time $(k+\mu)$, generated at time k . This is frequently written in the shorter form $\hat{R}_{r,k}(\mu)$.

- 6) The basic unit is pounds of fiber. Quantities are expressed in this unit, while rates are expressed in pounds of fiber per week.

Variables

- A Actual Inventory, quantity
- D Delayed order quantity in transit between levels, subscripted to next higher level
- F Quantity of orders in-process
- I Ideal inventory, quantity
- l Expected rate at which requisitions will be lost
- L Expected cumulative quantity of lost requisitions
- L Rate at which requisitions are lost
- O Cumulative orders already placed, quantity
- P Purchase order rate from a given level
- p Price
- Q Desired quantity of orders in-process at a given requisitioning rate
- R Requisitioning rate into the given level
- λ Expected rate of distress shipments
- \mathcal{L} Expected cumulative quantity of distress shipments

- S Shipping rate from a given stage [The primed rate S' , refers to distress shipments over and above normal shipments.]
- T Trend index
- U Unfilled requisition backlog, quantity
- θ Seasonal index
- ϕ Desired quantity, of expected future demand, ordered to date

Constants

(All factors that do not vary with time)

$a_{\lambda l}$ Constant. The first subscript identifies the level to which it applies. The second subscript is a numerical identification to distinguish between constants at a given level.

Individual constants are defined by the equations in which they appear.

$d_{\lambda D}$ Time delay in transmitting orders between the previous level and level λ .

$d_{\lambda u}$ Time delay in filling orders at level λ .

f Functional identification of third order exponential delay

$K_{\lambda \mu}$ The percentage of all goods needed by level λ at time $(k+\mu)$ which should have been ordered up to and including time k , based upon the known distribution of delivery times. Sometimes written $K_{\lambda, k(k+\mu)}$

$B_{A\mu}$ A weighting constant for establishing a requisitioning rate for planning purposes.

$Z_{A(i)}$ The percentage distribution of orders from level A to the various levels i .

Subscripts

Production-distribution levels.--

r	<u>retail</u>	
w	<u>wholesale</u>	
a	<u>apparel manufacturing-</u>	finished inventory stage
n		- production stage (<u>needle trades</u>)
f		- raw material (<u>fabric</u>) stage
c	<u>converting level</u>	- finished inventory stage
d		- <u>dyeing and finishing</u> stage
g		- raw material (<u>gray fabric</u>) stage
m	<u>Mill level</u>	- finished inventory stage
l		- production (<u>loom</u>) stage
y		- raw material (<u>yarn and fiber</u>) stage
p	<u>Producer level</u>	- finished inventory stage
e		- production (<u>extrusion</u>) stage
i)		
A)	generic level identification	

Time Subscripts

k	Absolute time scale	- present
t	" " "	- general
μ, u	relative time scale (forecast)	
n	limit of relative time scale (forecast horizon)	

Superscripts

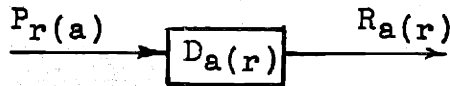
- ^ forecast
- ⤴ planning figure
- ~ exponentially smoothed
- (1) advance ordering forecast
- (2) reordering forecast
- c cotton fiber
- r rayon and acetate fiber

APPENDIX B

EXPONENTIAL FUNCTIONS¹

Third Order Exponential Delay

A third order delay corresponds to the cascading of three first order delays. For purposes of illustration, consider the delay encountered by orders from the retail level to the apparel manufacturing level. This can be represented as:



$$\text{where } R_{a(r),k} = f(D_{a(r),k} ; d_{aD})$$

The explicit form of this function is given by:

$$R_{a(r),k} = R_{a(r),k-1} + \frac{\Delta t}{d_{aD}} \left[\frac{3X_{a(r),k-1}}{d_{aD}} - R_{a(r),k-1} \right]$$

$$\text{where } X_{a(r),k} = X_{a(r),k-1} + \Delta t \left[\frac{D_{a(r),k-1}}{d_{aD}} - R_{a(r),k-1} \right]$$

¹The formulations presented in this appendix are described and derived by Jack Pugh in "Nth Order Delays" (unpublished paper, memo D-7, Industrial Dynamics Group, School of Industrial Management, M.I.T., December 2, 1957).

K Function

The cumulative distribution (over time) of receipts from an exponential delay is essentially the step response of that delay. The K function, which has been defined as the percentage of goods desired μ time periods in the future having lead times equal or greater than μ , is equivalent to 1 minus the step response (where the goods referred to all come from the same delay). The value of K is therefore given by:

$$K = e^{-\frac{mt}{d}} \sum_{j=1}^m \frac{t^{j-1} m^{j-1}}{(j-1)! d^{j-1}}$$

where m = the order of the delay

d = the delay constant

For the retail level, $m = 4$ (the cascading of a third plus a first order delay) and $d = d_{rA}$. The cascading of a third and first order delay to obtain $m = 4$ is valid, in this formulation, only when the third order delay is three times as long as the first order delay.

APPENDIX C

DERIVATION OF RETAIL ORDERING EQUATION

The retailer orders so as to achieve the best possible balance between supply and demand. In its simplest form, this balance could be expressed as follows:¹

$$\int_k^{k+1} P_t dt = \int_0^k R_t dt + I + Q - \int_0^k P_t dt$$

The orders placed during the period $k, k+1$ equal the cumulative total of consumer demand since the "beginning of time" $[\int_0^k R_t dt]$ (to which is added an ideal inventory and ideal orders-in-process quantity), less the cumulative total of orders placed prior to time k $[\int_0^k P_t dt]$.

The concept, that the order during period $k, k+1$ should be such as to bring into balance cumulative "requirements" and cumulative ordering, will serve as the

¹Integral notation will be used because it is convenient in portraying cumulative quantities.

The subscript r , denoting retail level, will be omitted throughout this appendix to simplify the appearance of the equations. Where higher (supply) levels are indicated, the subscript a , for apparel manufacturing, will be used to represent all suppliers.

basis for development of an ordering equation. It will be necessary to elaborate considerably upon the simple equation presented above.

Cumulative requirements.--The retailer does the bulk of his ordering in advance, that is, he normally orders now for delivery at some time in the future. This requires, of course, some foreknowledge or forecast of future requirements. We shall utilize a time scale in which k denotes the present time, $k+u$ denotes some time in the future, and $k+n$ denotes the limit of planning into the future. Cumulative requirements, therefore, will include known and anticipated consumer demand through time $k+n$.

$$\int_0^{k+n} R_t dt = \text{cumulative consumer demand through time } k+n$$

It has been asserted, however, that retailers order in anticipation of varying delivery lead times.² Requirements must therefore exclude that portion of future (expected) consumer demand for which orders need not yet

²See Chapter VI, ordering criteria. An objection to this approach to ordering lies in the fact that goods will not be received as ordered. For example, if all forecast demand were concentrated at time $k+u$, the present ordering rate would be $K\hat{R}$. Receipts from this ordering, however, would be distributed in accordance with the delay at the supplier, some arriving before, some after $k+u$. The justification for using this ordering policy lies in the attempt to simulate behavior, rather than produce a perfect system; and in the beneficial effect of dealing with aggregates rather than individuals.

be placed:

$$\int_k^{k+n} [1 - K_k(u)] \hat{R}_k(u) du$$

The term under the integral represents the percentage of demand forecast for time $k+u$ [The forecast being made at time k] that need not be ordered until some period subsequent to $k, k+1$. This is integrated over all u in the future through the planning horizon $k+n$.

Cumulative requirements differ from cumulative consumer demand in one further respect. Due to inadequate inventories, a small percentage of total consumer demand is permanently lost at any given time. Effective demand, for purposes of establishing ordering requirements, excludes all demand that has been so lost.

$$\int_0^k L_t dt = \text{cumulative consumer demand that has been } \underline{\text{lost}} \text{ through time } k.$$

Since we are considering forecast consumer demand through time $k+n$, it is also necessary to exclude forecasts of lost demand:

$$\int_k^{k+n} \mathcal{L}_k(u) du$$

where the term under the integral represents the cumulative forecasts of lost demand for time $k+u$ [forecasts made up to time k].

This term is developed below in more detail.

Cumulative requirements may now be stated as follows:

$$I_k + Q_k + \int_0^{k+n} R_t dt - \int_k^{k+n} [1 - K_k(u)] \hat{R}_k(u) du - \int_0^k L_t dt - \int_k^{k+n} \mathcal{L}_k(u) du = \text{cumulative requirements for ordering during period } k, k+1.$$

Cumulative ordering.--All orders are placed for delivery at some specified time in the future.³ For convenience, define a new variable $O_k(u)$ representing the cumulative total of orders placed for delivery at time $k+u$, orders issued up to time k .

$$O_k(u) = \int_0^k P_t(u) dt$$

Then, cumulative orders placed are simply

$$\int_0^{k+n} O_k(t) dt$$

Effective cumulative orders, however, are not the same thing as orders placed. We are only interested in those orders which were, or will be, effective in satisfying consumer demand. In instances where over-ordering has

³It would be more precise to speak of orders for delivery during some time period, such as $k+u, k+u+1$. Where a period is required, reference to time $k+u$ may be interpreted as specifying the period $k+u, k+u+1$.

occurred, the resulting surplus inventory is disposed of through markdown sales without directly reducing consumer demand. So far as the system is concerned, the excess goods have been dumped or burned. Cumulative orders placed must be reduced by the cumulative amount of such disposals to arrive at an effective value

$$\int_0^k S'_t dt = \text{cumulative markdown sales}$$

It is also necessary to account for forecasts of future over-supply which will terminate in markdown sales.

$$\int_k^{k+n} S_k(u) du$$

The term under the integral represents the cumulative forecasts of over-supply for time $k+u$ [forecasts made up to time k]

Orders placed are also occasionally withdrawn when the manufacturer is unable to supply the desired goods. The withdrawals are represented as lost demand to the apparel manufacturer.

$$\int_0^k L_{at} dt = \text{cumulative withdrawals of orders from apparel manufacturing level}$$

In a similar manner, effective orders are increased above orders actually placed by the extent of distress shipments from manufacturers. These shipments will be used to

satisfy consumer demand despite the fact that they have not been officially ordered (in contrast to the treatment of distress sales to consumers).

$$\int_0^k S'_at dt = \text{cumulative distress shipments from apparel manufacturing level}$$

Cumulative effective ordering may now be stated as follows:

$$\int_0^{k+n} O_k(t) dt - \int_0^k S'_t dt - \int_k^{k+n} \int_k(u) du - \int_0^k L_a dt + \int_0^k S'_a dt = \text{cumulative orders previously placed that still remain "effective" for offsetting ordering requirements.}$$

Ordering equation.--The order to be placed during period k, k+1 is given by the difference between cumulative requirements and cumulative effective orders.

$$\int_k^{k+1} P_t dt = \left[I_k + Q_k \right] + \left[\int_0^{k+n} R_t dt - \int_0^k L_t dt \right] - \left[\int_0^{k+n} O_k(t) dt - \int_0^k S'_t dt - \int_0^k (L_a + S'_a) dt \right] - \left[\int_k^{k+n} (1-K_k(u)) \hat{R}_k(u) du + \int_k^{k+n} (L_k(u) - \int_k(u)) du \right]$$

Order placed during period k, k+1 equals

- 1st term: Ideal inventory and orders in-process level, plus
- 2nd term: Cumulative net demand through planning horizon, i.e., total demand experienced in past less all demand actually lost in the past, less
- 3rd term: Net effective orders already placed against cumulative net demand, i.e., Total orders ever placed, less inventory actually "dumped" because demand was inadequate for supply, less goods on order which we anticipate having to "dump" because of a reduced forecast since last period, less all orders placed but subsequently cancelled, plus all distress shipments ever received
[Terms (1+2) - Term 3 constitutes an "open to buy" category.],
less
- 3rd term: This term represents that portion of "open to buy" which we do not or should not order at this time, i.e., all items whose lead times are such as to permit ordering in a future period plus that part of future demand which we expect to evaporate because we won't have the goods on hand when we need them, less recent over-ordering for which we do not wish to compensate.

The ordering equation can be restated in a simple form by incorporating the following accounting relationships:

$$\text{Unfilled orders } U_k = \int_0^k [R_t - S_t - L_t] dt$$

$$\text{Actual inventory } A_k = \int_0^k [S_{at} + S'_{at} - S_t - S'_t] dt$$

$$\text{Goods on order } F_k = \int_0^{k+n} O_k(t) dt - \int_0^k [S_{at} + L_{at}] dt$$

Noting that

$$\int_0^{k+n} R_t dt = \int_0^k R_t dt - \int_k^{k+n} \hat{R}_k(u) du ,$$

direct substitution yields:

$$2^{\text{nd}} \text{ term: } \int_0^k [R_t - L_t] dt + \int_k^{k+n} \hat{R}_k(u) du$$

$$= U_k + \int_0^k S_t dt + \int_k^{k+n} \hat{R}_k(u) du$$

$$3^{\text{rd}} \text{ term: } - \int_0^{k+n} O_k(t) dt + \int_0^k L_{at} dt + \int_0^k [S'_t - S'_{at}] dt$$

$$= - F_k - \int_0^k S_{at} dt + \int_0^k [S'_t - S'_{at}] dt$$

$$= - F_k - \int_0^k S_{at} dt + [-A_k + \int_0^k (S_{at} - S_t) dt]$$

$$= - F_k - A_k - \int_0^k S_t dt$$

Combining the 2nd and 3rd terms

$$= U_k - F_k - A_k + \int_k^{k+n} \hat{R}_k(u) du$$

and the complete ordering equation becomes

$$\int_k^{k+1} P_t dt = I_k + Q_k + U_k - F_k - A_k + \int_k^{k+n} [K_k(u) \hat{R}_k(u) - \mathcal{L}_k(u) + \phi_k(u)] du$$

$$= I_k + Q_k + U_k + \phi_k - F_k - A_k$$

Forecasting lost demand.--The problem of adjusting the ordering rate to compensate for expected future losses in demand, $\mathcal{L}_k(u)$, can best be discussed by starting with a condition of equilibrium. In this case there will be losses in demand or distress shipments and the ordering equation can be stated in the following simple form:

$$P_k(u) \Delta t = [\hat{R}_k(u) - O_k(u) - [1 - K_k(u)] \hat{R}_k(u)] \Delta t$$

$$= [K_k(u) \hat{R}_k(u) - O_k(u)] \Delta t$$

Assume now that the forecast was revised upward during $k-1, k$, so that $\hat{R}_k(u) > \hat{R}_{k-1}(u)$. We have under-ordered in the past in relation to the new forecast. Expecting some non-deferrable demand, it does not pay us to make up for all past under-orders (as our simple

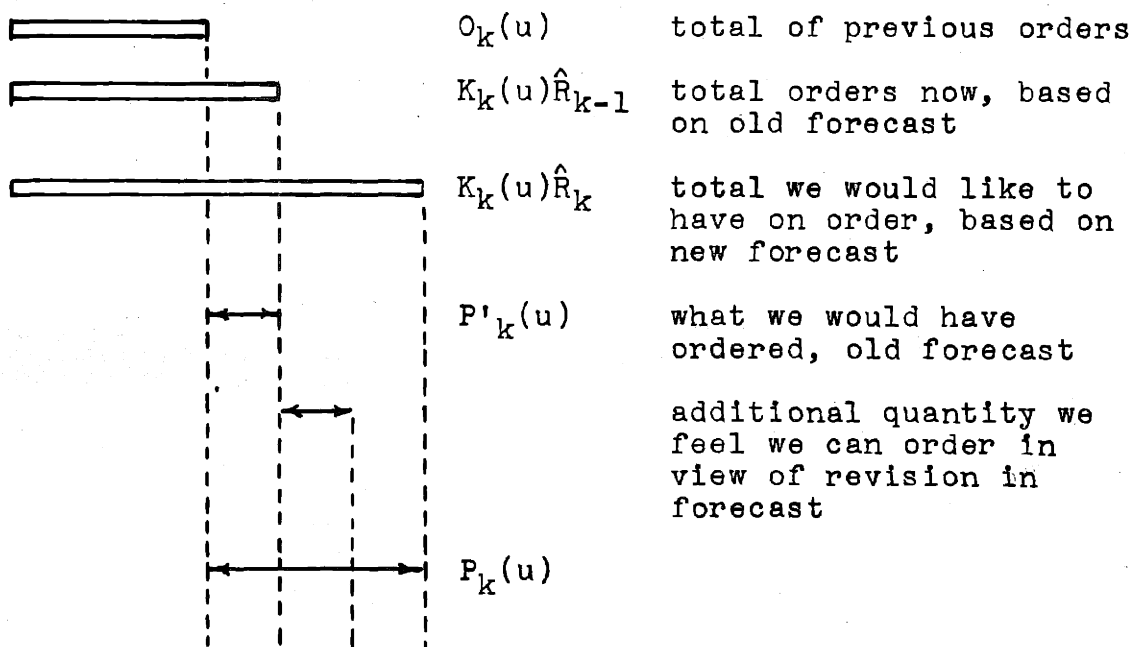
ordering equation would do). Instead, we will only make up that part of it which we expect to be deferrable (or, taking another viewpoint, we will only make-up orders on those items for which we can get delivery in reasonable time after $(k+u)$).

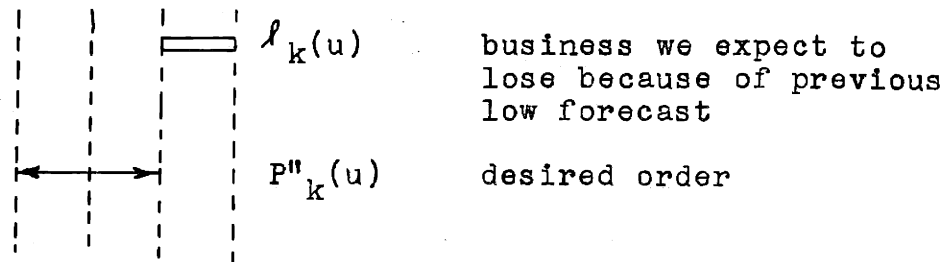
Let
$$P'_k(u) = K_k(u) \hat{R}_{k-1}(u) - O_k(u)$$

The order we would have placed had the forecast remained unchanged.

We still want to order all of this, plus an additional quantity, a $K_k(u) [\hat{R}_k(u) - \hat{R}_{k-1}(u)]$, where a represents the percentage of the increase which we feel justified in ordering.

The relationship between various quantities is shown below:





hence

$$l_k(u) = (1-a) K_k(u) [\hat{R}_k(u) - \hat{R}_{k-1}(u)] ; \hat{R}_k(u) > \hat{R}_{k-1}(u)$$

The forecast rate of loss in demand for time $k+u$ is proportional to the change in forecast for $k+u$ occurring between $k-1$ and k , multiplied by the ordering lead time factor $K_k(u)$.

and

$$P''_k(u) = P_k(u) - l_k(u)$$

The desired ordering rate = the equilibrium ordering rate reduced by the forecast rate of loss in demand.

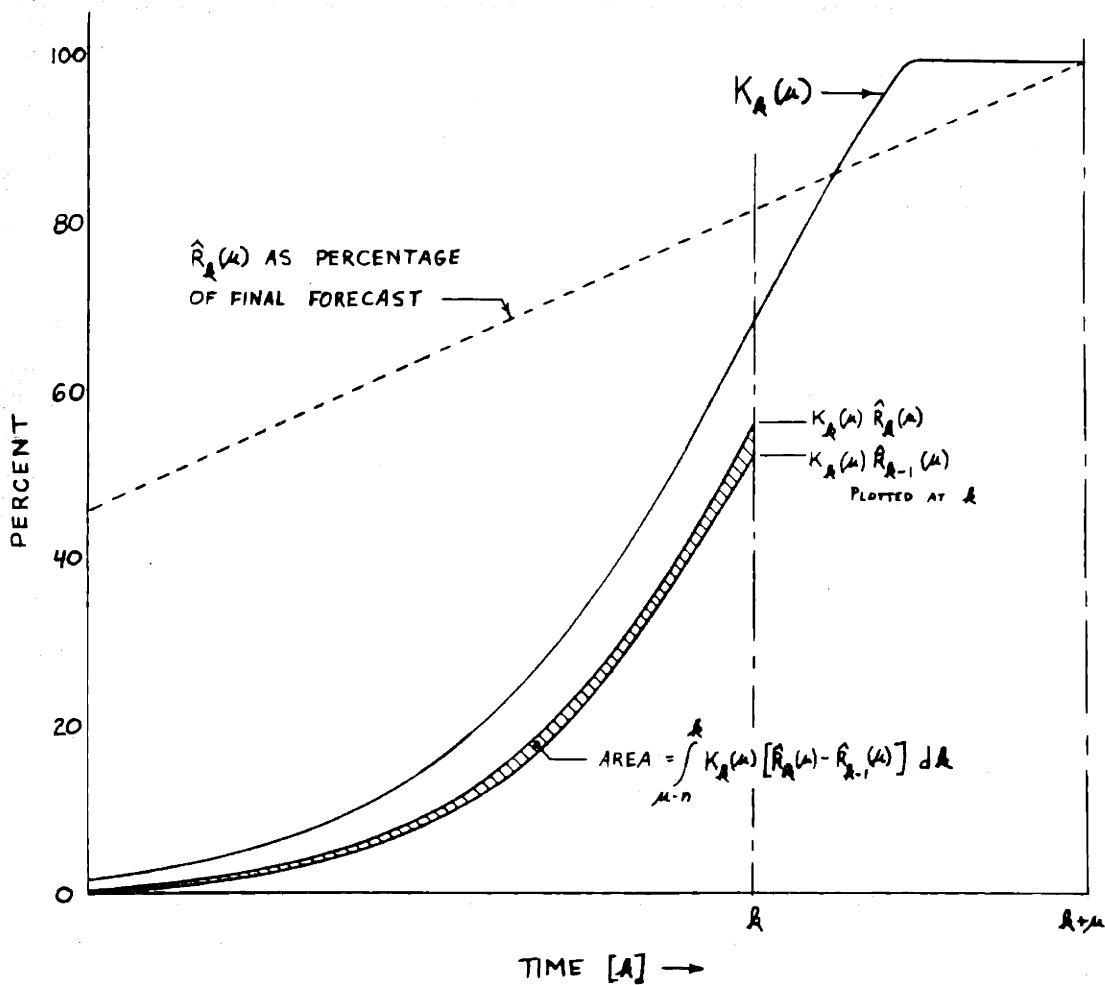
The cumulative effect of such forecast losses can be seen in Figure 13 which indicates a circumstance in which the forecast rises continuously. The shaded area represents the cumulative difference in ordering, as of time k , which exists between ordering based on the new versus ordering based on the previous forecast, that is

$$\int_{u-n}^k K_t [\hat{R}_t(u) - \hat{R}_{t-1}(u)] dt$$

The cumulative expected loss in demand at time $k+u$, as of time k , is a fixed percentage $(1-a)$ of the shaded area, or

FIGURE 13

CUMULATIVE ORDERING FOR DELIVERY
AT TIME $R + \mu$ WITH A
CONTINUOUSLY RISING
SALES FORECAST



$$\begin{aligned}
 \mathcal{L}_k(u) &= \int_{k+u-n}^k (1-a) K_t(u) [\hat{R}_t(u) - \hat{R}_{t-1}(u)] dt \\
 &= \mathcal{L}_{k-1}(u) + \int_{k-1}^k (1-a) K_t(u) [\hat{R}_t(u) - \hat{R}_{t-1}(u)] dt \\
 &= \mathcal{L}_{k-1}(u) + K_k(u) \Delta t
 \end{aligned}$$

= The previous cumulative expected loss plus the expected loss arising out of a revised forecast in the current period.

Forecasting over-ordering.--The problem of forecasting over-ordering is entirely analogous to the foregoing, with expectations of over-supply resulting from a declining forecast. The expected surplus arising between $k-1$ and k is given by

$$A_k(u) = (1-a) K_k(u) [\hat{R}_{k-1}(u) - \hat{R}_k(u)] ; \hat{R}_k(u) < \hat{R}_{k-1}(u)$$

where the constant a is not necessarily the same as the constant in the equation for forecast lost demand.

It should be noted that this entire analysis is based upon the assumption that goods ordered for delivery at time $k+u$ are not entirely interchangeable with goods ordered for delivery at other times. Hence, if an order is placed incorrectly (based upon an erroneous forecast) at time k , the error can never be fully rectified. The adjustments resulting from recognizing an expected over

or under-supply have the effect of preventing future orders from attempting to make-up for past mistakes. Therefore, even if the forecast merely fluctuates about an average, correct value, ordering will and should take notice of this effect.

APPENDIX D

COMPLETE EQUATIONS--RETAIL LEVEL

(1) Consumer demand

$$R_{r,k} = \text{independent}$$

(2) Unfilled requisitions

$$U_{r,k} = U_{r,k-1} + [R_{r,k-1} - S_{r,k-1} - L_{r,k-1}] \Delta t$$

(3) Actual inventory

$$\begin{aligned} A_{r,k} = & A_{r,k-1} + [S_{w(r),k-1} + S'_{w(r),k-1}) \\ & + (S_{a(r),k-1} + S'_{a(r),k-1}) + S_{c(r),k-1} \\ & - (S_{r,k-1} + S'_{r,k-1})] \Delta t \end{aligned}$$

(4) Modified unfilled requisition delay

$$d'_{ru,k} = d_{ru} \left[\frac{I_{r,k}}{A_{r,k}} \right]^{1/2}$$

(5) Sales

$$S_{r,k} = \frac{U_{r,k}}{d'_{ru,k}}$$

(6) Markdown (distress) sales

$$S'_{r,k} \Delta t = a_{r1} [A_{r,k} - I_{r,k}] ; I_{r,k} \leq A_{r,k}$$

(7) Lost consumer demand

$$L_{r,k} = \frac{U_{r,k}}{d_{r\phi}}$$

(8) Orders (to suppliers)

$$P_{r,k} \Delta t = I_{r,k} + Q_{r,k} + U_{r,k} + \phi_{r,k} - [A_{r,k} + F_{r,k}]$$

(9) Ideal inventory

$$I_{r,k} = a_{r2} \sqrt{\hat{R}_{r,k}}$$

(10) Ideal orders-in-process

$$Q_{r,k} = d_{rs} \hat{R}_{r,k}$$

(11) Anticipation of future demand

$$\phi_{r,k} = \sum_{\mu=0}^n [K_{r\mu} \hat{R}_{r,k}(\mu) \Delta t + \mathcal{I}_{r,k}(\mu) - \mathcal{L}_{r,k}(\mu)]$$

(12) Actual orders-in-process

$$F_{r,k} = \sum_i [D_i(r),k + U_i(r),k] ; i = w, a, c$$

(13) Planned requisitioning rate

$$\hat{R}_{r,k} = \sum_{\mu=0}^n B_{r\mu} \hat{R}_{r,k}(\mu)$$

(14) Composite delay

$$d_{rs} = Z_{rw}(d_{wD} + d'_{wu}) + Z_{ra}(d_{aD} + d'_{au}) + Z_{rc}(d_{cD} + d'_{cu});$$

$$Z_{rw} + Z_{ra} + Z_{rc} = 1$$

(15) K function

$$K_{r\mu} = e^{-\frac{\mu}{d_{rs}}} \sum_{j=1}^{\mu} \frac{\mu^{j-1}}{(j-1)!} \frac{1}{d_{rs}^{j-1}}$$

(16) Forecast requisitioning rate

$$\hat{R}_{r,k}(\mu) = \frac{\mu}{n} \hat{R}_{r,k}^{(1)}(\mu) + (1 - \frac{\mu}{n}) \hat{R}_{r,k}^{(2)}(\mu)$$

(17) Cumulative forecast over-ordering

$$S_{r,k}(\mu) = S_{r,k-1}(\mu) + d_{r,k}(\mu)\Delta t$$

(18) Cumulative forecast under-ordering

$$L_{r,k}(\mu) = L_{r,k-1}(\mu) + l_{r,k}(\mu)\Delta t$$

(19) Orders in process between retailers and suppliers

$$D_{i(r),k} = D_{i(r),k-1} + [P_{r(i),k-1} - R_{i(r),k-1}]\Delta t$$

(20) Weighting function

$$B_{r\mu} = \frac{1}{n[1-e^{-1}]} e^{-\frac{\mu}{n}}$$

(21) Long range forecast requisitioning rate

$$\hat{R}_{r,k}^{(1)}(\mu) = R_{r,k+\mu-N}$$

(22) Short range forecast requisitioning rate

$$\hat{R}_{r,k}^{(2)}(\mu) = R_{r,k-1} \cdot \frac{\theta_{r,k+\mu-N}}{\theta_{r,k-1}}$$

(23) Orders to each supplier

$$P_{r(i),k} = Z_{r(i)} P_{r,k} ; i = w, a, c$$

(24) Requisitions received by each supplier

$$R_{i(r),k} = f(D_{i(r),k} ; d_{iD}) ; i = w, a, c$$

(25) Seasonal index (requisitions)

$$\theta_{r,k} = \theta_{r,k-N} + a_{r3} \left[\frac{\tilde{R}_{r,k}}{R_{r,k}} - \theta_{r,k-N} \right]$$

(26) Smoothed requisitioning rate

$$\tilde{R}_{r,k} = \tilde{R}_{r,k-1} + a_{r4} (\theta_{r,k} R_{r,k} - \tilde{R}_{r,k-1})$$

(27) Forecast over-ordering

$$d_{r,k}(\mu) = (1 - a_{r5}) K_{r,k}(\mu) [\hat{R}_{r,k-1}(\mu) - \hat{R}_{r,k}(\mu)] ;$$

$$\hat{R}_{r,k-1}(\mu) > \hat{R}_{r,k}(\mu)$$

(28) Forecast under-ordering

$$l_{r,k}(\mu) = (1 - a_{r6}) K_{r,k}(\mu) [\hat{R}_{r,k}(\mu) - \hat{R}_{r,k-1}(\mu)] ;$$

$$\hat{R}_{r,k-1}(\mu) \leq \hat{R}_{r,k}(\mu)$$

APPENDIX E

FLOW CHART SYMBOLS

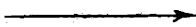
used in figures 8, 10, 11, 12



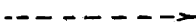
Rectangle encloses a quantity, e.g., inventory.



Circle denotes an operation performed on the parameters which enter. The nature of the operation, or its result, is indicated by the notation within the circle.

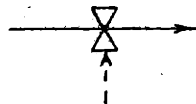


Flow of goods.



Flow of information.

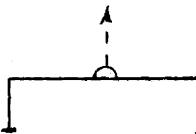
} Accompanying notation identifies a rate.



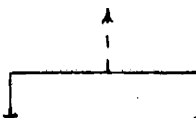
Incoming information controls rate of flow of goods, as if with a valve.



Terminus of flow.



Information obtained does not affect contents of rectangle.



Information obtained represents removal from rectangle. Contents are reduced by like amount.

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