12

Economics of staple yarn production

12.1 Yarn economics

12.1.1 Cost and price

At the risk of stating the obvious, a distinction between cost and price must be drawn. Costs are incurred by the producer and the price is what is asked upon selling the product. Under non-monopoly conditions, price is determined by availability of the product already in the market and the quality of the product being offered for sale. The difference between price and cost is profit (or loss). The cost of a yarn may be divided into several categories. More than half is from the cost of fiber, part represents sales costs, and the rest comes from costs associated with the conversion of fiber (in the bale form) to yarn (wound on cheeses or cones). Buying fiber is a very important factor, not only in controlling costs, but also in determining mill performance. Buying involves specialized skills that require an ability to assess value in the raw material. A knowledge is required of what is needed to produce a yarn satisfactory to the customer and what is needed to give acceptable performance in the mill.

12.1.2 Conversion costs

Conversion costs are a major component of the total. Evaluation of conversion costs involves a knowledge, not only of how the fibers interact with the machinery, but also of the commercial importance of yarn quality and cost. Major subdivisions of the conversion costs are (a) direct labor costs, (b) overhead costs, (c) capital costs of machines, (d) space costs, and (e) power costs. An assessment of cost proportions in 1995, calculated from ITMF data, indicated that, for a 30/1 combed cotton rotor yarn produced in the USA, 52% of the costs were attributable to the cost of fiber. Some conversion costs are shown in Table 12.1. The extra combing process (which is not universally used) affects the issue. Nevertheless, it is clear that labor costs in rotor spinning no longer dominate the conversion cost structure. This is different from previous decades when the labor cost dominated. Despite this, the 1990s saw a surge in ring spun cotton products for apparel coming from the Far East. In the USA, rotor

Table 12.1 Conversion costs for 30/1 combed cotton rotor yarn in 1995

Labor	10.4%
Depreciation	41.5%
Interest	18.5%
Waste	15.5%
Energy	8.3%
Aux materials	6.0%

spun cotton yarn has become common for denim products and ring spinning has become increasingly confined to underwear products; most other apparel products are imported and almost all of these are ring spun. A basis for estimating the current yarn market is provided by the sampling used by Uster Corporation for their statistics [1] and the result is shown in Table 12.2. Notable facts are that (a) the USA and Europe are prime users of rotor spinning, (b) the USA now has a diminished ring spinning capacity, (c) Asia is a strong supplier of ring spun yarns, and (d) Europe is the primary manufacturer of worsted yarns.

Some private data are given in Table 12.3 and other private data show that the cost of fiber in some more recent operations in advanced regions of the world can reach 70% of the total. Operating expenses in more recent operations are generally closely guarded secrets and it would be improper to disclose them here. The relative reductions of labor costs have a strong influence on the conditions of international trade but this has been offset by the effect of international trade agreements. The above data may be compared to the figures presented by Thompson [2] in 1982. He showed that in North America the breakdown for a 30/1 yarn was 26.4% labor, 43.9% capital (i.e. depreciation), 10.6% for energy, and 18.8% for space. These may be compared to 9.3%, 60.7%, 19.1%, and 10.9%, respectively, for the Far East. The total cost for Far

Table 12.2 Estimated yarn supply percentages in 1997

			W Europe	North America	Asia	South America	Africa, Middle East	E Europe	Total
Cotton	Ring	Carded	29	3	15	25	24	4	100
Cotton	Ring	Combed	47	3	29	7	10	4	100
Cotton	Rotor	Carded	35	25	13	11	12	4	100
65/35 P/C	Ring	Combed	3	3	39	8	34	13	100
50/50 P/C	Rotor	Carded	25	68	–	–	2	5	100
Polyester	Ring		38	11	25	11	4	11	100
Worsted	Ring		70	–	–	15	8	7	100

Table 12.3 Percentage conversion costs for 36/1 combed cotton ring yarn

	1978			1988		
	Prep	Spin	Wind	Prep	Spin	Wind
Labor	43.3	52.9	52.2	37.0	39.0	43.8
Overhead	26.1	21.9	22.4	23.9	21.7	27.1
Depreciation	15.2	10.9	13.4	23.6	18.6	18.7
Energy	15.4	14.3	11.9	15.4	20.6	10.3
Totals	100	100	100	100	100	100

Eastern countries was 72% of the North American cost. European total costs were said to be similar to the North American ones. The reason for the move of yarn manufacturing centers to the Far East is quite clear, as are the inequalities in capital investment, energy, and labor costs. It also helps explain the strong showing of rotor spinning in the USA, where the increased investment has led to substantial labor cost reductions, which have helped maintain viability.

In ring spinning, labor costs are higher. A private analysis (relating to a different European area) yielded proportions similar to those given in Table 12.3. Accounting procedures, the count and the proportions of labor cost/hr, power costs, etc., differed in this case as compared to the data cited by Thompson. However, the higher labor costs, which still dominate in the ring spinning of medium to fine yarns, are quite apparent. In the decade illustrated, labor costs for the cases cited were reduced by about 10% by investing in new and more productive machinery. The corollary to this was the rise of more than 7% in depreciation costs which was associated with the increased investment. Energy consumption in some mills has almost doubled over the last ten years.

12.2 Productivity

12.2.1 Normalized productivity

One measure of mill efficiency is the number of operator hours needed for a given task. This is a good measure because it enables comparison between mills running in various environments; it is not affected by the wage rate and it can be expressed in different ways. One way is to measure the number of operator hours to produce 100 lb of yarn. This form of normalization is represented by the acronym OHP. In the metric system, the unit of mass is 100 kg and the applicable acronym is HOK; the values for HOK are 2.2 times larger than for OHP. Basically, the units are expressed in operator hours/100 lb or kg.

12.2.2 Historical changes in operator productivity

Technologies continue to change and enable mills to run with decreasing amounts of labor. However, as the labor costs are reduced by applying new technology, the competitive advantages between high and low labor cost regions diminish. Over the last half century, the OHP level has decreased to less than 10% of what it was. This is, in large part, because of the progressive introduction of various schemes of shortened process lines and automation. Consider some practical data, which make the point. Each year sees a development in technology that further reduces the values, as shown in Fig. 12.1. The exponent of the regression curve (–0.074) suggests that the improvement each year has averaged nearly 15%.[1] The equation is exponential, which implies that the *rate* of improvement will steadily decline as the labor use factor approaches some steady value asymptotically. This estimate relates solely to one group and others may differ considerably, but the trend is common wherever considerable investment has been made. Suffice it to say that there is abundant evidence to show that labor productivity varies with time, as equipment designs evolve.

1 $10^{-0.074} = 0.843$, thus the value of OHP is, on average, 0.843 that of the previous year.

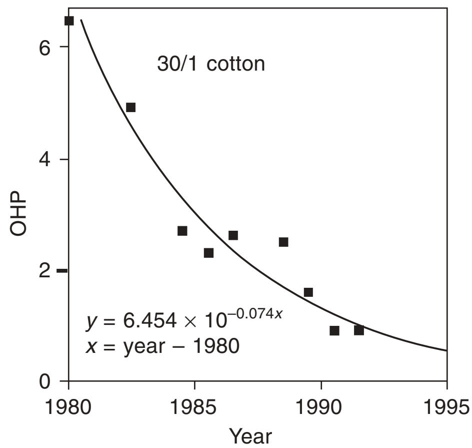

Fig. 12.1 Historical decline in OHP

12.2.3 Division of operator productivity within ring spinning

The values of OHP or HOK can be broken down by components. In rotor spinning, there are no separate winding costs as there are with ring spinning, and preparation costs are lower because of the omission of the roving stage; however, finer slivers are needed. Thus, labor costs are lower for rotor spinning than for ring spinning in the viable range of counts (Fig. 12.2(a) shows some old data). In short-staple ring spinning of fine yarns, preparation (all processes up to and including roving) takes up to 5% of the total, winding takes up to 4%, as do the combined overhead costs of management, maintenance, and general mill expenses. The rest is for spinning.

For yarns towards the coarse end of the count spectrum, preparation costs are a much larger proportion of the total. Of that, a significant part is labor cost. When expressed in terms of OHP, the example shown in Fig. 12.2(b) shows the labor needed for spinning rises rapidly with count as compared to that needed for preparation and winding.

Stryckman [3] and others have developed a series of HOK or OHP curves for various fibers and spinning systems. The types of machinery in use, the preparation, and the fiber lengths and types determine the equations. The data are good only for the time at which they were produced and for the equipment then in use. Changes are to be expected in future years. For fine counts of ring yarn, the OHP is almost directly proportional to count, as shown in Fig. 12.2(c) (each point represents a single mill). Regressions for the data are given. Data for other years have been plotted and, as expected, the results suggest that the values are time dependent. The linear relationship seems to hold up well for cotton counts above 36s. Linear regressions are given. In the five year interval shown in Fig. 12.2(c), the OHP for a 40s combed yarn appears to decrease from 2.27 to 1.66, which suggests a reduction of just over 5% per annum.

On a worldwide basis, the OHP levels off for coarse carded counts, and it is much more variable from plant to plant. In the past, regions of lower wages produced less efficiently than more advanced regions and, on a worldwide basis, performance was represented as a fairly wide band rather than a single line. With wider markets and competition, the width of that band seems to be narrowing. The balance of technology has changed and many regions of lower wages now have modern machinery.

Some idea of the relative magnitudes and the relationships to count is shown in

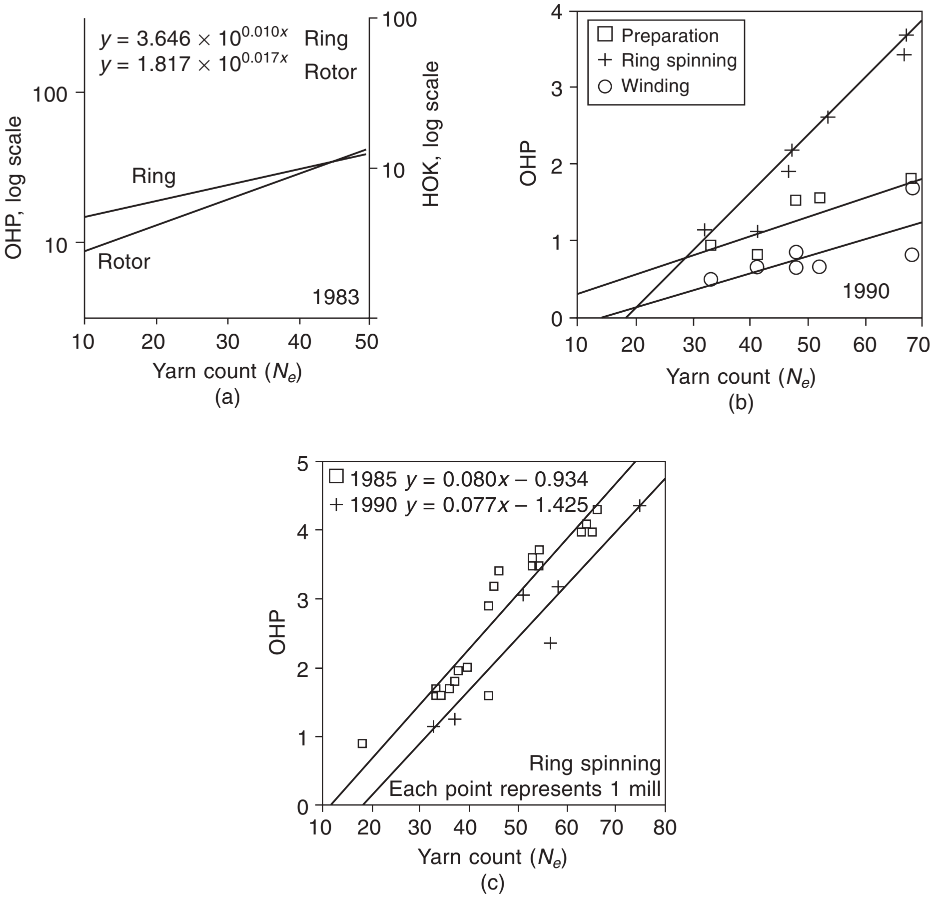

Fig. 12.2 Normalized operator productivity

Fig. 12.2(b). It will be noted that spinning increasingly becomes dominant as the count rises above 30s cotton. The balance between these is subject to changes as automation is progressively brought to bear on the labor costs in those technical areas.

For coarse count yarns, materials handling costs, which account for much of the labor charges in preparation, assume great importance. It is also interesting that winding costs become progressively more important at the lower counts. At one end of the count spectrum, quality and piecing costs are of great concern, whereas at the other end, materials handling becomes a dominant problem.

12.2.4 Operator productivity in rotor spinning

With modern industrial rotor spinning, the labor costs are about 50% of those for ring spinning. A rotor machine is often fed with sliver produced by an abbreviated preparation line; sometimes only one passage of drawing intervenes between the card and the rotor spinning machines. This reduces costs. With modern rotor spinning machines, automatic piecing is a necessity because human operators are not capable of carrying out the operation reliably at the rotor speeds now possible. As with ring spinning, automatic doffing is standard. Consequently, jobs that were once performed by human operators are now done by machine. Also, the productivity of the rotor machines on a count-for-count basis is over five times that of a ring frame. Obviously rotor spinning falls into a different category, as do most of more advanced forms of spinning. Typical values of the ratios of OHP/count are 0.025 for rotor spinning, as compared to 0.05 for ring spinning.

12.2.5 Operator assignment

Another way of judging mill efficiency is by the operator assignments. An operator of a ring spinning machine might tend many hundreds of spindles [4] and that would be his/her assignment. Assignments have increased appreciably over the years. There are some interesting consequences arising from the large number of items being controlled by a single person. Inevitably, some ends break whilst the operator is patrolling the spindle set. The cost of this operator has to be set against the savings he or she can make by repairing the broken ends. The cost of the operator depends on the wage rate but the assignment depends on the economic balance at which minimum cost, or acceptable quality, is achieved. The literature over the last half century was searched to find how the assignments and wages had changed and the results are plotted in Fig. 12.3(a); regression curves shows the differences between two common yarn types. Differences are to be expected because cotton is a natural fiber and more variable than polyester. Again, care has to be taken with comparisons, especially since the operator often has duties other than piecing.

12.3 Quality and economics

12.3.1 Yarn quality and operator assignment

Figure 12.3(a) compares spindle assignments across the world. One can note that, in 1980, the higher the wage paid, the higher was the spindle assignment. Equation [12.1] on page 308 shows that this should be expected. However, the equation can take into account neither the range of technologies in use nor the influence of differing qualities of product from the various systems.

Poor yarn quality not only degrades the price that the product will fetch, but it also imposes a cost penalty in spinning and winding. Logic suggests that operator assignment should also be influenced by the quality of the yarn produced [5]. The more weak places in the yarn, the greater is the end-breakage rate and the higher is the need for labor. Plotting data from a set of mills against their spindle assignments for like products (Fig. 12.3(b)) shows that the spindle assignment drops tremendously when the number of thin spots rises. The regression shows that the assignment for these cases was just about inversely proportionate to the number of thin spots per unit length. Some quality factors affect the immediate cost of production but the effects of others are not seen until a later process, possibly in the plant of a customer. Let these be called Category A and Category B problems, respectively. The latter are more difficult to deal with because the operators and their supervisors do not feel the effects at first hand. Nevertheless, they are very important. The major effect of Category B problems is to undermine the price of the product. Category A problems reduce the efficiency of operation but do not undermine customer confidence unless they are allowed to continue uncorrected.

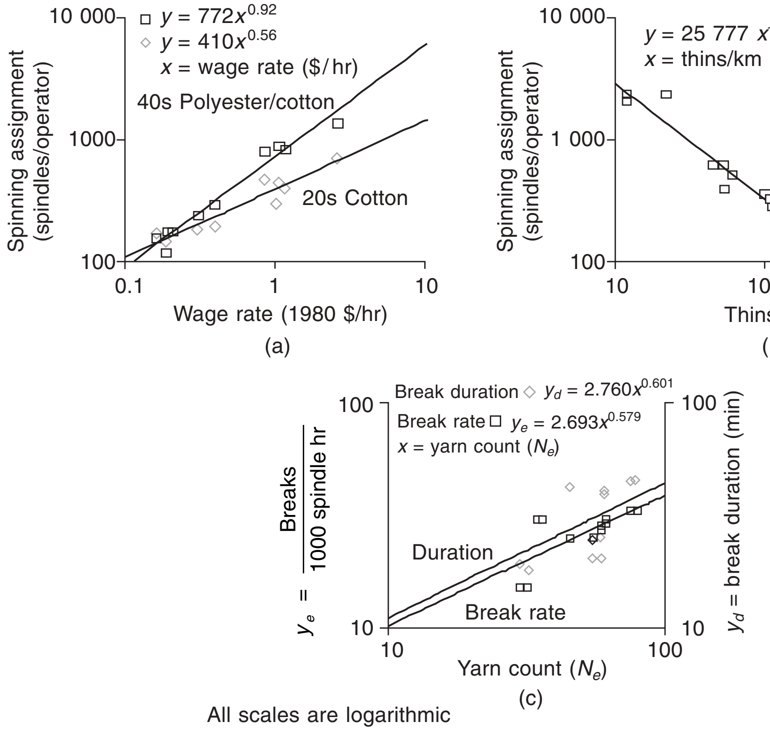

Fig. 12.3 Factors in determining spinning assignment

12.3.2 End-breaks and operator assignment

Operator assignment is strongly affected by the end-breakage rate in processing. Consequently, no discussion of the economics of spinning should avoid this aspect. A set of performance figures for a number of mills is shown in Fig. 12.3(c). As the number of 'thins' increases, so does the number of weak spots, and an operator can only serve a smaller set of spindles. In other words the assignment has to be lowered. Accurate data is difficult to acquire for several reasons, three of which are given. First, methods used by managers differ from one mill to another. Second, different fibers are in use. Third, there is a tendency for mill personnel to try to cast the performance of their mills in a favorable light. The correlations are poor but clearly both the end-break rate and the waiting time vary with yarn count. Other problems, such as the number of weak spots, are also associated with count (and other factors). Nevertheless, it is a reasonable expectation that fine yarns will be more difficult to spin than coarser ones. This is one of the reasons why a more careful choice of fibers should be made for fine yarns.

The product of the end-breakage rate and the duration of the down time enables an estimate to be made of the lost production. Taking the data in Fig. 12.3(c) at face value, the loss in production during the time a break waits for repair is y_d minutes (or $\{y_d/60\}$ hrs), the production between breaks is $1000/y_e$ hrs and the percentage loss in production is approximately $y_e y_d/600$. The maximum probable value of loss due to end-breakage in those data was 2.37% and the loss was very roughly proportional to count. On this basis, spinning a 30s count might bring a loss of machine productivity of just less than 1%. Besides machine productivity losses, the cost of labor increases due to the end-breakages. However, since the figures are very dependent on the fibers and practices used in a given mill, they can do little more than give an order of magnitude.

Correlation between the loss in production and pneumafil waste collection is usually poor because pneumafil continues to be collected even when spinning continues. Examining thousands of spindles has shown that fiber is always being removed from the fiber stream entering the twist triangle during the spinning process. Furthermore, the amount removed is affected by the quality of the fibers. The waste figure increases if there is a large short-fiber content. Unfortunately, the short-fiber content is highly variable at this point. Of the 2% or 3% pneumafil waste levels common in ring spinning of cotton yarns, up to 0.6% is due to the continuous loss.

12.4 Cost minimization

12.4.1 Theoretical assignment

For simplicity, let it be assumed that X spindles in a set are equally spaced around a circle and that end-breakages occur randomly. Further, assume that the operator deals with each end-break in sequence and never turns back. Under stable conditions, as the operator deals with one break and moves to the next, there is a probability that an end breaks somewhere else in the spindle set; that spindle then becomes unproductive. There will always be u spindles not producing, and, on average, they have to wait t hours before they are repaired. During the waiting time, the set fails to produce ptu out of the ptX lb/hr expected, where p is the productivity of one spindle in lb/hr. If the assignment is increased, there is a saving in labor costs, but the efficiency of the machine is reduced. There is a deterioration in the quality of the product because of the multiple piecings, which have to be removed in winding. The assignment has to be optimized and perhaps negotiated with the unions. It has been shown [4] that when piecing dominates the work load, the optimum assignment, a, is approximately given by:

$$a = \sqrt{[C_l/\{Bt\,(pC_w + C_f)\}]} \qquad [12.1]$$

where a = spinners assignment in spindles/operator
B = end-breakage (rate/hr)
t = average time (hr) for the operator to pass from one spindle to the next
p = productivity for one spindle (lb/hr)
C_w = cost of reprocessing the waste (\$/lb)
C_l = cost of labor (\$/hr)
C_f = fixed costs (\$/hr)
C_h = handling costs (\$/hr)
OHP = number of operator hours needed to spin 100 lb of yarn.

Bt is a function of yarn count, as is p. Thus the spindle assignment is affected not only by the economic factors, but also by the count and quality of the yarn being processed.

Equation [12.1] indicates that the fixed cost is an important factor and the other major components are the end-breakage rates, the size of the operator sets, and the cost of labor. The cost of labor may be divided into three categories, namely (a) supervisory and maintenance staff, (b) mill personnel dealing with materials handling, and (c) personnel whose task it is to keep the machinery productive – this entails the repair of end-breaks as soon as possible after they break to keep up the operational efficiency, as well as the regular maintenance. Category (a) is not normally considered part of the direct labor force because service usually continues over long periods. Consequently the costs from this source can be considered part of the fixed cost and, for the present purpose, can be lumped with costs of servicing the investment and direct maintenance costs. Category (b) is regarded as part of the handling costs, and category (c) is part of the variable cost. Spinning operator assignment can also be expressed in terms of OHP and machine productivity.

$$a = 100/[\text{OHP} \times p] \text{ spindles/operator} \quad [12.2]$$

12.4.2 Capital and fixed costs

Studies in 1990 covering many mills showed that the value of the machinery installed in a mill rises almost linearly with yarn count. Before 1990, the cost was estimated by various people to be the equivalent of up to $1 million per ton/day for each unit of count. In the twenty-first century, a new mill producing 30/1 yarn might be expected to cost perhaps $10 million for each ton/day capacity. In other words, the textile spinning industry has become a capital intensive industry.

Despite the improvement in spinning technology, piecing a ring frame is still a major consumer of labor. Piecing costs also rise roughly linearly with count (with the factor standing at about 0.45¢/lb for each unit of count). Obviously the figures alter with time, as changes in the design of the machinery modify the costs and performance; also as currencies suffer inflation. Nevertheless, it is easy to see why the average count produced tends to have reduced over the last few decades. However, there is still room for the high count producer of specialty yarns, despite the cost.

In ring spinning, the productivity per spindle is very low and since expenditures have to be paid for from the proceeds of sales, the amount that can be spent is also low. For example, consider a spindle producing 0.02 lb/hr for 7000 hr/year in an environment where the most extra charge that the market can bear is, say, 3¢/lb. The most that could be afforded is little over $4 per year per spindle. Even with a ten year payback, the most that could be spent is $40 per spindle! For a mill with 50 000 spindles, this latter figure is equivalent to $2 million, which is not a negligible sum! All of this has to be taken into account when considering monitoring and computer control. To the extent to which they can pay for themselves, they are fine, but there is little margin for cost overruns. Of course, these cost estimates are transitory and will change over the years.

In the early days, the capital (or fixed) cost of the rotor spinning machines was so high that there was a break-even count above which the spinning system was uneconomic. It was not until rotor speeds could be raised to improve the output per dollar invested that the bar of a break-even count was overcome. With rotor speeds up to 130 000 r/min now possible, the cost of building in features such as automatic piecing can be absorbed into the original price of the machine without killing the market. Early fears of substandard yarn have given way to acceptance over a wide spectrum of products. Thus, we now have a category of high capital cost machines that need relatively small amounts of labor to operate. This is in contrast to ring spinning which has a relatively low capital cost but which needs more personnel.

12.4.3 Variable costs

The cost of labor is mostly viewed as a variable cost. However, the charges for certain management and maintenance staff are regarded as administrative costs, which is part of the fixed cost category (their costs are not directly linked to production and therefore they are not viewed as direct labor costs). Of the variable costs, piecing of ring frames is the dominant portion for fine-count ring yarn production. As previously mentioned, piecing is automatic in rotor spinning, the end-breakage rate is less, and these are two of the reasons why rotor spinning needs less labor. Variable costs are important not only in the assignment equation but also as a measure of the mill's performance.

Automatic piecing for ring frames has been offered for sale by several machine manufacturers. They were technologically sound but were not commercially acceptable. The extra capital cost was an important factor in the lack of success. Nevertheless, a lower cost solution might still be offered and this would change the theoretical model that will be proposed later in this chapter. However, until an acceptable device becomes available, it is useful to analyze the operation as it now exists.

12.4.4 Handling costs

In the first half of the twentieth century, the opening line consisted of manually operated feeders and a number of cleaning and opening machines not physically connected. Operators were used to transport material from one machine to another and were also needed to feed the material into the system. In a modern plant, no operator is required for material transfers in this section of a short-staple plant. The system is now automatic from the time the bales are laid into position until the sliver emerges from the card. The only personnel required in this department are supervisory, except for the operator who puts the bales in the laydowns about once per day.

Between carding and spinning, operators are often required to move cans of sliver from one machine to another, and a few operators are needed to supervise the machinery. The introduction of automatic can changers and movers provides an alternative to the job of sliver can moving but, again, it is a case of capital expenditure being balanced against that of human operators. There is a similar choice in the zone between the processes of roving and spinning. Several degrees of automation are available for the transport and sorting of bobbins from the ring frame to the winder. On average, considerable labor is still used today in moving sliver cans, roving bobbins, spinning bobbins, and cones or cheeses of yarn. Bobbin transport systems and automated handling of the final packages have reduced the handling costs for those who can afford the capital outlay. By introducing automatic handling equipment, there is a transfer from the handling cost category to the fixed cost one. It is these sorts of transformations that increase the capital cost of the equipment and drive the industry to become ever more capital intensive.

12.4.5 Cost proportions

Costs may be divided into categories such as are shown in Fig. 12.4. Some alter almost immediately according to demand; these are described as short-term variables. Costs in other categories change little or are not controllable by management and they take place over longer periods of time; these are designated long-term variables. Administrative costs vary according to the company structure and may include items

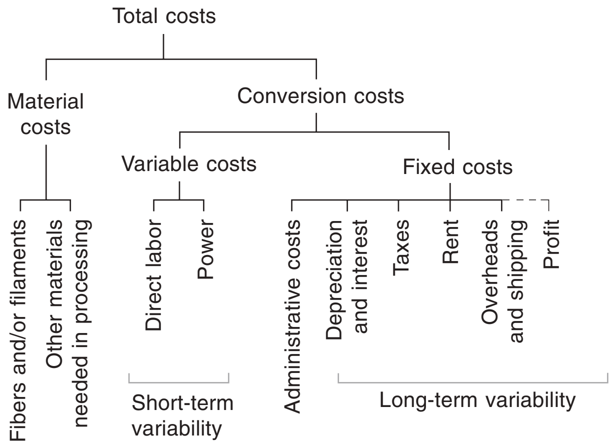

Fig. 12.4 Distribution of costs

not otherwise included in the foregoing. For the present purpose they will be taken as long-term items. Investment in new machinery nearly always incurs higher charges for depreciation and interest than the corresponding ones for the machines replaced. In fact, the machines replaced have often been written off. These charges are placed in the fixed cost category. Direct labor and power costs cover the variable costs in the mill; these have been further divided into materials handling (for short, 'handling') and other variable costs. If the total conversion cost is described by the three cost components just discussed, then:

$$\text{Total conversion cost} = C_v + C_h + C_f \qquad [12.3]$$

The variable cost, C_v, rises with spindle speed because of the increased end-breakage rates and power consumption. For a given set of equipment, this cost also rises with count because of (a) the diminished machine productivity at the higher count, (b) the increased cost of energy, and (c) the increased end-breakage rates at high counts. For simplicity, assume that the variable costs can be lumped together and described by $C_v = KN^m$, where K is a constant, N is the count and m is fixed. Since a log graph of the lumped costs on the simplified basis is a straight line of slope m, it is useful to express the relationship as:

$$\text{Log } C_v = \text{Log } K + m \text{ Log } N$$

The number of yarn packages produced is proportional to $N^{-3/2}$ and the handling costs, C_h, are proportional to those for a given set of machinery running at a specified reference speed. By arguments similar to those used for the variable costs, the log (handling costs) can be plotted as a straight line on a graph.

$$\text{Log } C_h = \text{Log } K' - (3/2) \text{ Log } N \qquad [12.4]$$

Fixed costs, C_f, are, by definition, fixed. The calculation assumes that all the equipment is in full production and there is no idleness due to malbalance of the mill. As will be discussed later, theoretical balance in a mill with a single product is achievable only in a plant that runs a single count. Where there is more than one product, it is difficult to even approach perfect balance. Most mills have a degree of malbalance.

Figure 12.5 is a plot combining all three elements for each of two cases of differing variable costs. A curve of total cost is given in each case. It will be observed that the

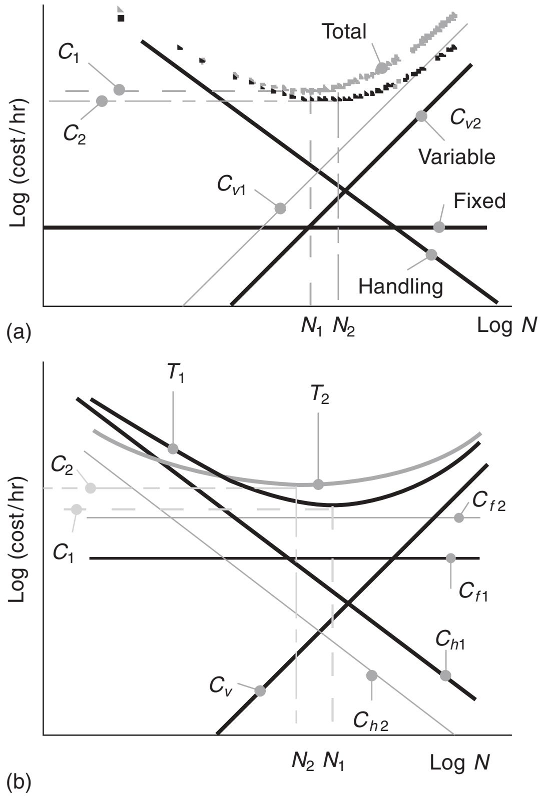

Fig. 12.5 Optimizing costs

addition of the three cost components, to give the total costs, results in curves with distinct minima. The symbol N is used for count and the appropriate subscript can be applied to whatever count system is in use. The graph shows two curves for variable costs C_{v1} and C_{v2}, which could be caused, for example, by buying inferior fiber for one case. At the count for minimum cost, the use of poor fiber increases the labor cost from C_2 to C_1 and reduces the best count from N_2 to N_1. Thus the market becomes more restricted because of the lower count. The competitive position will be eroded if the additional cost shown to the right of N_1 is not offset by the savings in fiber costs.

For a given machine, the position of the minimum cost along the count axis is controlled by factors other than fixed costs (Fig. 12.5(a)). (As an aside, if one were to imagine the case of changing one rotor spinning machine for another, the fixed costs/lb are increased but that would not affect the optimum count). Increases in handling cost move the optimum count towards the higher counts and increase the value of the optimum cost. Increases in variable costs move the optimum towards the lower counts and increase the optimum costs. It is a matter of whether the handling or variable costs predominate that determines the result. Remember that variable costs comprise direct labor and power costs. Costs of labor and power can vary quite widely from area to area, and this plays a significant role in deciding whether new major investment is justified. For example, such an analysis might be used to see whether rotor spinning should be brought in to replace ring spinning.

12.5 Operational factors

12.5.1 Automation

Perhaps the most important step in automation of modern times was the successful introduction of autodoffing. A similar process for the roving frame has been more recently introduced but is not universally accepted. Also, an automatic device for changing the travelers has been developed and this seems to work well. Each step of automation decreases the handling costs in return for an increase in capital or fixed costs.

Figure 12.5(b) shows the effect of changes in handling costs from C_{h1} to C_{h2}. An increase in fixed cost is inevitable and has to be taken into account as also shown in the same diagram. The value has been changed from C_{f1} to C_{f2}. An arbitrary ratio between the savings in labor cost and increase in fixed cost has been used for demonstration. The effects of upgrading the automatic handling equipment are to alter the best count (e.g. a shift from N_1 to N_2, as depicted in Fig. 12.5(b)) and the optimum cost. Whether or not the total cost is improved depends on the additional capital cost involved. The net result is that the total cost curve is flattened and the best count might be lowered. Automation tends to be more favorable for heavier counts and it is less sensitive to moves away from the best count. In a ring frame, automatic doffing has become standard and is now often included in the original cost of the machine. In rotor spinning and other forms of new technology, automation is almost universal.

Automatic equipment leads to a substantial reduction in operator hours needed to produce yarn but, as was said earlier, there is an extra capital cost involved. All these schemes are technically feasible, but the problem is to finance them. The whole process of substitution of capital for labor requires access to capital. Furthermore, the final cost/lb must be no more than that of any competing systems, unless there is a special feature given to the textile product that enhances its value. This is a major reason for the slow adoption of the new technologies. On the other hand, if yarn manufacturers who have to pay high wage rates are to compete, the labor content has to be reduced and there will always be an interest in increased efficiency.

12.5.2 Mill balance

Unless a mill is balanced, some machines will lie idle or work at a reduced throughput. Such a situation has an adverse effect on the economics of production. Ideally, each process stage will process approximately the same flow rate of material. The productivity of the spinning machine is a significant function of the count and is given by:

$$P = U\eta/(504\ TM\ N_e \sqrt{N_e}) \qquad [12.5]$$

where P = machine productivity (lb/spindle hour)
U = spindle speed (r/min)
η = efficiency per spinning unit
TM = twist multiple of yarn
N_e = yarn count (hanks/lb).

For practical purposes, all factors other than count vary little; the spindle productivity is inversely proportional to $N^{3/2}$ for a given spindle speed, since TM varies but little. The throughput of the opening lines is little affected by yarn count and intervening machines are weakly affected. Since mass flow must be conserved:

spinning output = output from prior stages of processing – waste generated [12.6]

A change in spindle speed, twist multiple, or spinning efficiency affects the productivity mentioned in Equation [12.5] although the major factor is the count. Hence, if there are *m* spindles in the mill per opening line, the output can be written as $P_T \approx mKN^{-3/2}$. If the net output of the opening line is K_o, then $K_o \approx m_b KN^{-3/2}$ at balance, where m_b is the number of spindles needed for balance, and $m_b \approx (K_o/K) N^{3/2}$. However, K_o/K is a constant under the stated conditions and so m_b is proportional to $N^{3/2}$. The balance is heavily dependent on count. In practice, a mill is never completely in balance but with a stable order book, machinery is installed as necessary and a rough balance may be achieved.

12.5.3 End-breakages and economics

The foregoing makes clear that spinning contributes a major portion to the cost of yarn. In ring spinning, much of that cost is caused by end-breakage. In rotor spinning and other new developments, this may be less so. In any case, it is worth considering the aspect of end-breakage in yarn production.

One factor in the end-breakage rate is the CV of strand strength. The word strand is taken to include the weak point in the twist triangle in ring spinning. An analysis of cotton yarns from a variety of mills showed a relationship between the ends-down rate and the CV of yarn strength (Fig. 12.6(a)). The correlation is imperfect because of the varying conditions in the various mills but there is a definite trend.[2] As the yarn tension increases, the stress in the strand increases and so does the end-breakage rate. The probability of an end-break depends on the probability distributions of applied stress and tenacity of the strand (Fig. 12.6(b)). The area under the intersection of the two distribution curves gives the probability of a break. The applicable tenacity is that of the weak spots in the flowing material. In the case of ring spinning, this is often located in the twist triangle and is a variable with time. In rotor spinning, the weak spot is at the point where the yarn is removed from the rotor groove (except at very high speeds). Under high speed conditions, surges in false twist increase yarn tension temporarily at the navel and the yarn breaks occur there. There is an incentive to reduce the yarn tensions and CVs of yarn strength. It is assumed that the count and

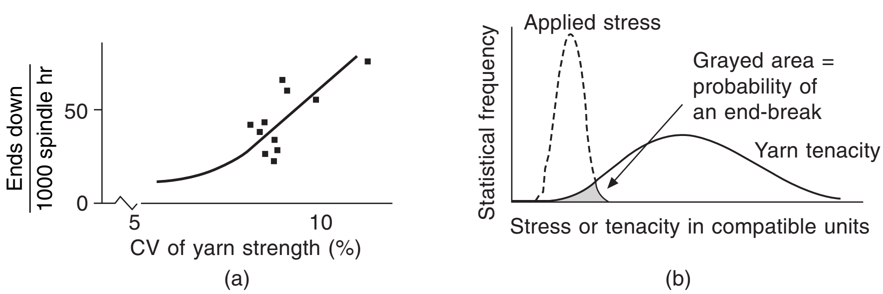

Fig. 12.6 CV of yarn strength and end-breaks

2 One obvious factor ignored in the above is the spindle speed, and another is traveler weight; in fact there was neither control nor measurement of the yarn tension which is a major reason for the poor correlation. Unfortunately, adequately controlled data of this sort is very difficult to gather in normal industrial practice.

twist are set by the market and are not a variable. As far as the economics are concerned, it is the number of piecings made and the number of bobbins containing piecings that are important. One has a large impact on the cost of spinning; the other impacts on the cost of winding and the quality of the product. There are both cost and price implications.

To emphasize the last point, consider Fig. 12.7 in which the average number of ring bobbins spun per end-break was calculated for a range of mills spinning cotton yarns of various counts. Again, this was not a fully controlled experiment because it is almost impossible to get data on a wide enough scale under fully controlled conditions. Nevertheless, there is a clear trend and the correlation coefficient was better than might be expected. The technical difficulties in spinning high count are clearly seen. Quality control from a purely economic standpoint becomes ever more important as the count rises. The number of bobbins with an end-break leaving the ring frame is one important factor in determining the work load for the winder. If the end-breakage rate in spinning is high, there is probably a high rate of intolerable yarn faults. Not only will the winder have to remove most of the piecings but it will also have to remove the accompanying yarn faults. The chance of a piecing in a bobbin is low at fairly low yarn counts. On the other hand, the chance of an end-break within a bobbin of high count yarn is much higher. The number of breaks per cheese or cone is, of course, much higher still. There is a piecing for every ring bobbin used in making a cheese or cone. In addition, there is a piecing for nearly every objectionable fault, many of which are caused by end-breaks. A few faults escape through the aspiration device used to thread up the winder. For example, at 70s count, a break in every other bobbin might give 30 + 30 = 60 or so piecings per wound cone. At 30s, the figure might drop to, say, 30 + 2 = 32 piecings per wound cone. As an economic matter, clearly poor spinning begets a poor winder performance. Both undermine what otherwise might have been good economic results. Perhaps the operator costs for piecing should be based on the production they save by intervention rather than on the number of spindles they serve.

12.6 International competition

International competition is complex and in the space available it is only possible to outline some factors. First, let us make a comparison between a high cost, highly automated mill in one region, and a less sophisticated mill in a region of lower wage

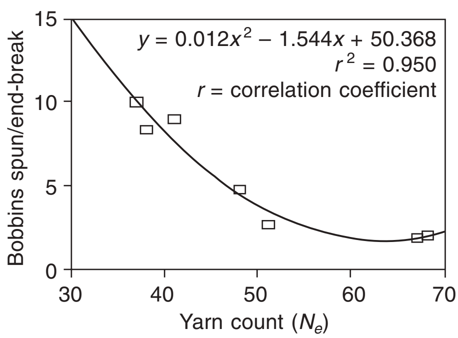

Fig. 12.7 End-breakages per bobbin

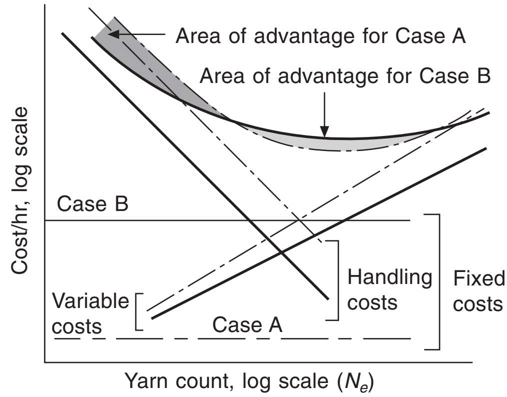

Fig. 12.8 International competition

rates (Fig. 12.8). The scenario in this case is that a mill in an advanced region with high labor costs seeks to offset the disadvantage by using automatic equipment. This means that the fixed costs are high in this case. The mill in a region of lower wage costs feels less need to invest in expensive automation. There are trade-offs that might be in favor of one group or the other, depending on costs. Remember also, that relative conditions undergo continuous change and no fixed recipe can be recommended. In the particular case shown, the highly automated, high cost mill shows an advantage only over a certain low count range. The high fixed costs have the effect of leveling the total cost curve so that it is not so sensitive to count changes. The spin limit forms a natural boundary to the right of the diagram.

As wage rates tend to equalize, these distinctions tend to disappear, but equalization of wages is a prospect for the distant future. A factor not included in the analysis is that of shipping costs. Transoceanic shipping decreases the margin of profitability. Since low labor cost producers are usually distant from the major markets in advanced countries, shipping costs offset their advantage of lower labor costs. This could be taken into account by adding shipping costs to the normal fixed costs. It might also be noted that interest rates available in some regions are less favorable than those granted elsewhere. This, too, influences the final cost. Further factors are those of quality, reliability, and promptness of delivery.

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