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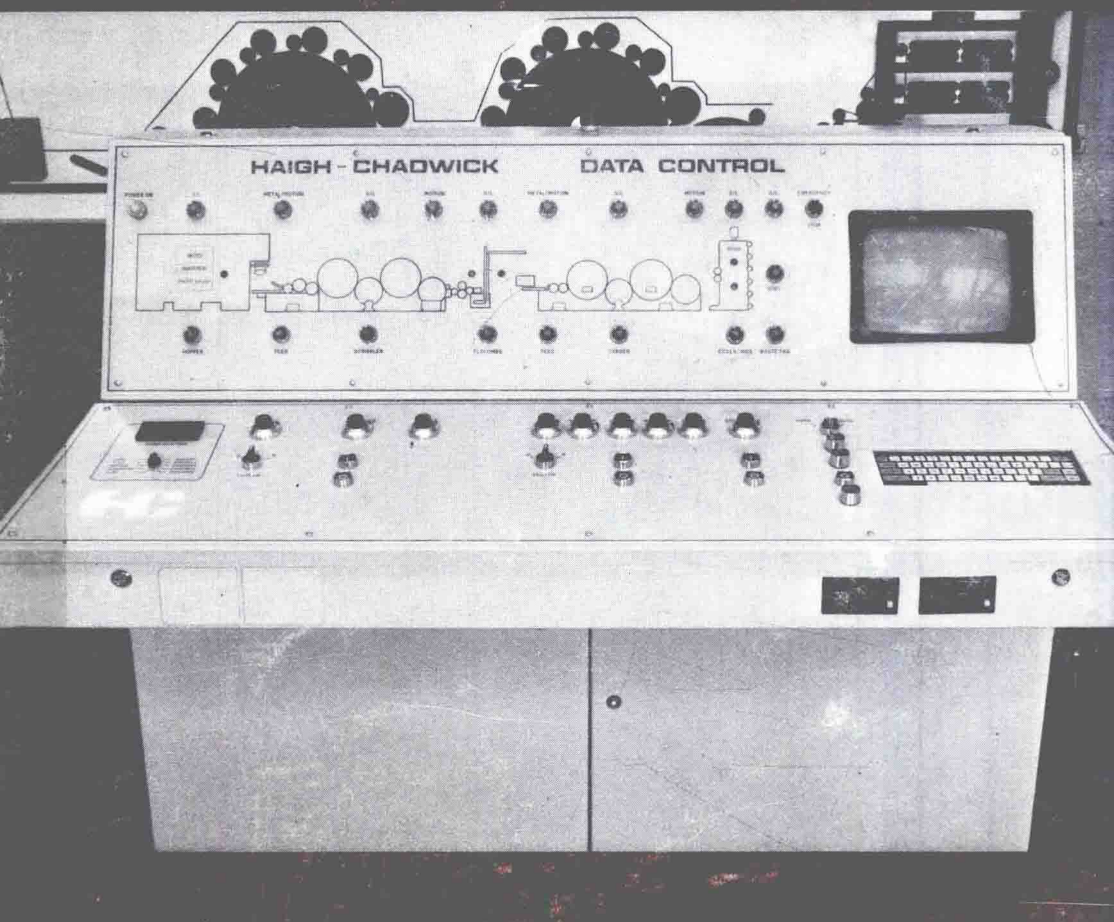
Woollen-yarn Manufacture

D A Ross, G A Carnaby, and J Lappage



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A critical appreciation of recent developments by
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TEXTILE PROGRESS

WOOLLEN-YARN MANUFACTURE

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1. INTRODUCTION

Many people and organizations are currently discussing the future of woollen-yarn manufacture, so it is a most appropriate time at which to review this topic. While the authors have conducted an extensive literature search on woollen-yarn manufacture, in particular, that published since 1970, the bibliographical references are restricted to those considered to be the most relevant both before and after that date.

For the purposes of this review woollen yarn is defined as yarn made of any fibre(s) that has been processed on a card with at least one intermediate crossfeed, the card web being divided into slubbings or rovings by a condenser, and the slubbings spun at drafts of up to about 2.0 to form yarns.

While woollen carding and spinning have developed continuously if slowly over the last century, this is a processing system that is still wool-oriented and produces yarn that is in wide demand for its 'woollen' texture and bulk properties. It is still the major system by which very short (mainly wool) wastes and recovered fibres can be converted into yarns for fabrics that are then finished to produce very acceptable products. Nevertheless, the high capital cost of woollen-yarn-producing machinery in relation to its productivity, particularly for yarns of medium to low linear density, and the high labour cost associated with woollen carding and spinning, place this system in a difficult competitive situation with other yarn-manufacturing systems, where major increases in productivity associated with substantial decreases in labour requirements have been achieved.

During the last decade, there has been a major decrease in staff numbers in research-and-development laboratories in the Northern Hemisphere involved with the many aspects of woollen processing. Since the majority of scientific publications have come from such organizations rather than from textile manufacturers or producers of synthetic fibres, there has been a considerable decrease in scientific information on woollen processing from Northern Hemisphere sources. On the other hand, during this time and currently continuing, there has been a major increase in woollen-yarn production in New Zealand, particularly for the manufacture of carpets. About 80% of the New Zealand wool clip is processed on the woollen system – about 60% into carpet yarns – so research at the Wool Research Organisation of New Zealand (WRONZ) has largely been involved with the manufacture of carpets from woollen yarns. Thus WRONZ is now a major source of technological information on woollen-yarn manufacture and this may affect the authors' selection of material.

Over the last decade, few books or reviews have been published that deal specifically with woollen-yarn manufacture. For the early stages of processing, Stewart[1] has written a comprehensive book on 'Woolscouring and Allied Technology', a topic also reviewed by Wood[2] from an Australian viewpoint. Szaloki[3, 4] has published books on 'Opening, Cleaning and Picking' and on 'High-speed Continuous Card Feeding'. Townend[5] has reviewed aspects of his 50 years of carding research in 'Nep Formation in Carding'. Van der Merwe[6] has reviewed the 'Development and Basic Principles of the Woollen System', and Brearley and Iredale[7] have written a text on the 'Woollen Industry'. Reviews on aspects of woollen processing have been produced by Nutter[8] and Dyson *et al.*[9], while Happey[10] has edited 'Contemporary Textile Engineering' which contains reviews by Richards on the woollen system, Parkin and Iredale on long-staple yarn manufacture, Happey on recycling fibres and waste textiles, Douglas on quality control and data-logging techniques, Lord on textured yarns and fabrics, Ince on carpets and needlefelts, and Schofield on microprocessors and associated micro-electronic devices. Crawshaw[11] and Crawshaw and Ince[12] have presented reviews on carpet yarn and carpet manufacture that cover most areas of woollen-yarn manufacture, and a seminar report edited by Story[13] reviewed the relationship between wool characteristics and their importance in yarn and carpet manufacture and subsequent product performance. Ross[14] presented a brief review of woollen-yarn manufacture.

The present review outlines the location and production of the woollen industry and describes raw materials and their preparation for processing. A major section deals with woollen cards and carding, with emphasis on carding theory and the factors limiting productivity. Developments in woollen spinning are reviewed with some discussion of woollen-yarn structure and of related spinning systems. A more detailed study is made of wool characteristics and their importance in processing, products, and product performance. Yarn properties and some subsequent treatments are examined, and there is a section dealing with research-and-development requirements of the woollen industry, with particular reference to increasing productivity.

2. THE WOOLLEN INDUSTRY AND ITS RAW MATERIALS

2.1 Woollen-yarn Production

Table 2.1, from 'Woolfacts'[15], details the production of woollen and worsted yarns in 1982 in seven major manufacturing countries: U.S.A, U.K., Italy, Japan, Germany (Federal Republic), France, and Belgium. These countries represent some 70 – 80% of the estimated world woollen- and worsted-yarn production. The table details both the total yarn production in each country and the production of yarns containing at least 50% of wool, which are described as 'chiefly wool'.

Table 2.1
1982 Yarn Production

	Woollen			Worsted		
Country	Total m kg	Chiefly Wool m kg	CW Total (%)	Total m kg	Chiefly Wool m kg	CW Total (%)
Italy	244	111	45	268	84	31
Japan	109	59	55	206	77	37
U.S.A.	97	40	41	387	15	4
U.K.	61	50	81	59	26	45
Germany (FR)	46	21	45	74	33	45
Belgium	41	16	39	36	20	56
France	38	20	54	81	22	27
Total	636	317	50	1111	277	25

Whereas the total quantity of worsted yarn produced in 1982 was considerably higher than that of woollen yarn, there was 14% more 'chiefly wool' woollen yarn produced than worsted yarn, from which it may be concluded that wool is much more important in woollen processing than in worsted. Over the past five years, the amount of 'chiefly wool' woollen yarns has been approximately constant at 50% of the total woollen yarn manufactured, while the percentage on the worsted system has been only half of this. Whereas 81% of the woollen yarn produced in the U.K. was 'chiefly wool', there was only 40% in the U.S.A. The low figure of only 4% for 'chiefly wool' worsted yarns in the U.S.A. indicates how flexible and non-wool-specific is the worsted system.

Italy, Japan, and the U.S.A. were together responsible for 70% of the total woollen and 77% of the total worsted yarn production. They are particularly dominant in the woollen-apparel field rather than in woollen carpet yarns. Berrini[16] has reviewed the woollen sector of the Italian textile industry in terms of production, capacity, and international trade. The total production of yarns spun on the woollen system is estimated at about one million tonnes[17].

A detailed study of wool usage in the U.S.S.R., Eastern Europe, and Yugoslavia in 1983 has been made by Morris[18]. Wool consumption in this area is about 450m kg clean per annum, of which about 200m kg are imported – two-thirds by the U.S.S.R. The total man-made-fibre production is about 2.3m tonnes per annum. A trend of slowly increasing wool consumption is predicted. It is difficult to obtain comprehensive data for this region, but perhaps half of the wool used is processed on the woollen system, which represents about 30% of the total woollen-yarn production.

A wide range of fibre types from animal hairs to silk is processed on woollen machinery, alone or in blends, frequently with wool.

2.2 Location and State of the Industry

In a review of trends in wool-yarn production, Everall[19] noted for 1981 and predicted for 1988–89 the location and production of wool-woollen yarns. The data in Table 2.2 are for wool-woollen yarns only and show that the production of wool-woollen yarn is evenly divided with 36% in industrialized countries (as compared with 54% for worsted) and 30–31% in Eastern Europe and developing countries (16% for worsted).

Table 2.2
Location and Percentage of Woollen-yarn Production in 1981 and Predicted Values for 1988–89*

Region	Percentage of World Production	
	1981	1988–89
Industrialized countries	36	34
Eastern Europe	30	30
Developing countries	31	32
South America	3	4

*From Everall[19].

Over the last decade, the woollen/worsted division in industrialized countries and Eastern Europe has been static. In developing countries, however, the growth in woollen-yarn production has easily outstripped that in worsted. Comparatively small increases in production are predicted for South America and the developing countries, while the industrialized countries and Eastern Europe will remain as the major producing and consuming countries.

Over the last decade, many woollen manufacturers in Europe have gone out of business. Many of these were manufacturers of bulk lines of woollen products, whereas the specialist and higher-quality manufacturers have been better able to withstand the downturn in trade. For example, the Scottish woollen industry, which in general has a quality image, produced only 7% of U.K. woollen yarn ten years ago but today it produces 20%, and few Scottish mills have closed in recent years.

Currently, many in the woollen industry consider that the most recent fall in production levels has reached a minimum, and there is a feeling of reasonable optimism for some improvement in trade over the next few years. The industry will now be more quality- and fashion-conscious and will consist of smaller specialist horizontal units than before, with fewer fully integrated vertical mills. The increased fashion element, which complements the versatility of the woollen industry and its ability to handle small lots of fibre, also provides the opportunity for profitable production. The corollary to this situation is that the woollen-apparel industry seems unlikely to become a major man-made-fibre consumer where very large lots must be processed to be profitable. The use of man-made fibres as blend components to increase processing efficiency or product performance will no doubt continue to increase.

It is a widely held view in the industry that the cost of apparel woollen yarns is increasing relative to the cost of worsted yarns and that this trend is putting woollen yarns at a competitive disadvantage. This situation may have arisen from the increased productivity of many worsted machines and the resulting relative decrease in the cost of replacement with worsted machinery of similar productivity.

On the other hand, it is also accepted that, whereas the productivity of individual cards increases as card width is increased, or older cards are upgraded, the achievable productivity per unit of card width has nevertheless tended to level out. Resulting from this and the very high capital cost of new cards, comparatively few new cards have been installed in the last five years. Those that have been installed have been mainly in the hosiery and carpet-manufacturing sectors, where sufficient return on the capital required has been foreseen by the manufacturers. In view of the over-all low levels of business confidence generally, the long-term future of the woollen-processing industry must be of concern to wool producers. Incidentally, there is no longer a manufacturer of woollen cards or spinning frames in the U.S.A.

In all markets, there is a trend to fabrics of lighter weight, a trend that does not favour woollens. For example, Harris tweeds have changed from being heavy (600–700 g/m^2; 18–20 oz/yd^2) fabrics to being medium-weight (440–500 g/m^2; 13–15 oz/yd^2) fabrics. This trend, together with the cost of fine woollen yarns, has encouraged the development of woollen finishes on worsted knitwear as well as alternative ways of manufacturing woollen-type yarns.

However, there is also a continuing trend from formal to informal apparel fabrics, which favours woollen yarns. Indeed, the unique character of woollen yarns is their major selling point in many product areas.

The association of high-quality wool-woollens with the older age group is of concern to manufacturers who emphasize the need for colour, design, and product-styling that will appeal to the younger market. This is important to the industry if it is to compete in the future with radical changes in fashion based on advances in substitute products. Perhaps the most successful substitution of traditional woollen styles of warm and comfortable clothing has been that achieved by quilted fabrics, which now dominate the casual-coating markets.

Wilson[20] and Russell[21] have reviewed the use of wool in knitwear. Lambswool and Botany sweaters use mainly 19–24-μm wool, Shetland and Breton sweaters 26–31-μm, and Aran, Icelandic, and Norwegian products 30–36-μm. Wilson estimated that less than 5% of knitwear was finer than 20 μm and about 20% coarser than 27 μm. On the basis of 55% Botany types, 30% Shetland, and 15% lambswool, he concluded that about 45% of knitwear was woollen and 55% worsted. About one-third of the total worsted-yarn production but only 10% of the woollen-yarn production is used in apparel knitwear.

Knitwear is expanding and was estimated to have 22% of the apparel market in 1970 and 27% by 1980. Over recent years, some 55% of knitwear entering international trade has come from the Far East and associated countries, such as Hong Kong, Korea, Macau, Taiwan, and Mauritius, the great majority of this knitwear being woollen Shetland or lambswool products.

2.3 Raw Materials

2.3.1 Range of Fibres

A major strength of the woollen-processing system is its ability to handle fibres of virtually all types, diameters, and lengths, both natural and synthetic. Such raw materials may range in price from a few cents/kg for some reprocessed fibres to well over $100/kg for exotic animal fibres.

2.3.2 Natural Fibres

Woollen yarns, in particular, those for milled woollen products, provide the major end-use for short fibres, whether they be noils from worsted combing or reprocessed fibres. It has been estimated that some 60 000 tonnes per annum of noils and reused wool are used in woollen yarns. The major user of reprocessed fibres is Italy, which consumed 80 000 tonnes in 1982, while India used 13 000 tonnes. Taiwan, South Korea, and Poland are importing increasing quantities of used cloth for reprocessing. The production and processing of recovered fibres has been reviewed[22].

The National Industrial Materials Recovery Association held a conference in London in 1978, entitled 'Richer for Rags', on the recovery and reuse of textile wastes. Sagar[23] estimated pre-spinning wastes at 5–8% of production, fabric-production wastes at 1.5%, cut-and-sew at 12–15% for woven fabrics and 20–25% for knitted fabrics, and carpet-manufacturing wastes at about 12% of total production.

As a result of the versatility of the system in its ability to process such a wide range of materials, fibre blends and products can be rapidly changed to meet new market situations. This is a major advantage of the woollen system. Buying the many components for a woollen blend enables buying skills to be used that may well determine the profitability of the whole manufacturing operation. The development of a wide range of synthetic fibres compatible with both blending with wool and processing on woollen machinery has enabled the manufacturer to respond to fashion changes and changes in the supply of raw materials. Some fibres, such as angora-rabbit hair, which are difficult, if not impossible, to process alone can be processed in blends with little difficulty.

In the period under review, there has been a continuous flow of new information to add to the already large body of knowledge regarding the variety of fibres used in woollen spinning. Some of the more relevant review articles and book chapters are given in references 24–29. Von Bergen[24] covers the topic from sheep breeds, wool types, specialty hair fibres, reclaimed wool and secondary raw materials, and carpet wools, through sorting, carbonizing, blending, and scouring to processing. While Cook's Handbook[25] is somewhat dated, it gave a full coverage of the topic, and Moncrieff[26] has updated the information for man-made fibres. An interesting if dated series of articles was published by Bellwood[30] in 1961 and covers raw materials and blending for a wide range of woollen yarns, many of which are today perhaps of more academic than practical interest.

2.3.3 *Synthetic Fibres*

About half of the fibres processed on the woollen system are synthetic, many as blends with wool, but increasingly as 100% synthetic. The majority of synthetic fibres were developed so that they could be processed with a minimum of problems on woollen machinery. There is comparatively little published information on the performance of individual synthetic fibres and blends on the woollen-yarn-manufacturing system. The major fibre manufacturers publish technical bulletins on the processing of their fibres on the woollen system, for example, Courtaulds plc – Courtelle on the Woollen System, No. 5/77; Montedison U.K. Ltd – Processing of Meraklon (polypropylene) on the Woollen, Worsted, and Semi-worsted Systems, MK 038203-E; E.I. du Pont de Nemours & Co. Inc. – Processing Dacron and Nylon on the Woollen System, TSB-N25, 1971, and D-256, 1972. Such bulletins stress the suitability of these fibres for processing on conventional woollen machinery and then indicate potential problem areas, which may be associated with differences from wool, such as the hydrophilic nature of the fibre, its bulk, inter-fibre friction, tenacity, and dyeing, spinning, or pilling properties. As with wool, the suitability of the cardwire and card settings to the fineness of the fibre is stressed, and, because of the high tenacity of many synthetic fibres, the selection of a staple length compatible with the width or type of the tape on the condenser is important. Some fibres, e.g., polyester and acrylic, may be spun at higher drafts than are normal for wool, whereas polypropylene is usually spun at lower drafts. Pajgrt and Reichstader[31] have reviewed the processing of polyester fibre on the woollen system.

Apparel fibres are usually in the range from 2.5 to about 7 dtex, while carpet fibres range from 10 to 20 dtex. The staple lengths for apparel range from about 30 to 80 mm, with 50–60 mm usually recommended, while carpet woollen fibre ranges up to 160 mm, about 100 mm being normally recommended. A wide range of fibre types in terms of lustre, cross-section, pilling, and heat-shrinkage properties is available.

Manufacturers stress the need for thorough blending of individual merge (batch) numbers, though at the same time avoiding excessive opening and carding, which may result in neps and more fibre breakage. Because of the bulk of many synthetic fibres, increased drop rates on the hopper, with lighter pan loadings, are recommended. With such fibres, heavier and wider travellers are normally recommended for spinning. Polyester and acrylic fibres have a major hold on the apparel market, with an increase in polypropylene fibre in the upholstery and carpet market. Polyamide fibres have become the dominant fibre for carpet manufacture while rayons, acrylic fibres, and polyester fibres have continued to lose ground. Polypropylene fibre for outdoor carpets and in blends with wool has increased its share of the carpet market, while wool consumption in carpets has remained fairly constant.

3. PRE-CARDING AND BLENDING

3.1 Introduction

The area of woollen processing in which there has been the greatest change over the last decade is that of pre-carding – opening, dusting, wool-scouring, blending, lubricant addition, material transport, and card-feeding. It has been necessary to upgrade blending equipment if maximum returns are to be achieved from investments in new carding and spinning equipment. In the woollen-carpet field, the move has been towards both tufted plain-shade and Berber-yarn carpets, both of which require a high degree of fibre-blending if a satisfactory product is to be produced with the avoidance of a high proportion of seconds and faults, particularly stripey carpets.

3.2 Greasy-wool Preparation

3.2.1 Sorting

It was formerly the practice to sort wool carefully according to its 'quality' (fineness) and length. However, it has come to be realized that only minor, if any, advantages are obtainable from detailed fleece-sorting, and this, combined with the high labour costs of sorting, has resulted in a major decrease in sorting, even at the very top end of the woollen trade. Where appropriate, machine sorting, with its greater throughput and low cost, is used, especially for sorting non-fleece wool into length groups.

3.2.2 Cleaning and Opening

Greasy wools are usually cleaned and opened in preparation for scouring by single- or double-drum openers, cyclic openers, picker teasers (wool pluckers, fleece breakers), step blenders, or de-cotters[32].

In a series of papers, Taylor[33–36] has investigated the performance of greasy-wool openers. He developed a motorized screen changer[33], involving the use of lightweight screens both to increase the efficiency of dirt removal and to make cleaning easier. He studied the effects of the frequency of cleaning and the size and type of holes in the screen in relation to the removal of fibre and dirt from the blend. The results indicated that screens should preferably be cleaned on a continuous basis to maximize dirt removal. However, since only 5% of the dirt was removed, along with a considerable amount of short fibre, a more radical approach was required. Taylor[34] achieved dirt removals of up to 16% with a double-drum opener, which was more effective than a step blender; a combination of the two was the most effective. The amount of dirt entering the scour was significantly reduced and resulted in worth-while savings by reducing the suspended solids and the volume of the scour effluent. Taylor[35] recommended dusting screens of 1.6-mm mild steel with round holes 9.4–12.7 mm in diameter, with equidistant centres and an open area of 50%. This gave optimum dirt removal without excessive loss of fibre.

Taylor[36] also developed an opener with a self-cleaning teeth assembly, which provided consistent opening of different types of greasy wool according to the operator's requirements. A series of trials showed the effects of fixed teeth, opening-drum speed, throughput, and wool type on the degree of greasy-wool opening.

For opening cotted wool, the Tracgrip Decotter[37] represents a major advance, particularly in its use of a hydraulic-drive system, which gives the operator instant control of the degree of opening, together with an instant stop-and-reverse function, which is both a safety factor and a means that allows 'foreign objects' or jams to be cleared without damaging the machine.

3.2.3 Scouring

As the sorting of fleeces into types became unprofitable and the technical limitations of this operation became appreciated by the trade, together with the increasing cost of water and particularly the increasing costs of disposal of scouring effluent, so the centres for wool-scouring have moved from the developed industrialized countries to the wool-producing countries. The major technical developments in scouring that have been taken up by industry have been made at WRONZ in New Zealand, and these are described and discussed in the book 'Woolscouring and Allied Technology' by Stewart[38].

The major advances have centred around the development of wool- and effluent-handling systems by which scouring is achieved at a lower cost and greater efficiency. Major savings in floor space and therefore building costs were associated with the introduction of the 'mini-bowl' concept, together with the effluent-handling system. Energy-savings associated with mini-bowl scouring have been large and were further increased with the development of weighbelt feeders for the scour and the improved efficiency of wool-dryers. Increasing automation and the monitoring and control of the output regain associated with dense packaging direct from the dryer have led to the development of the DRYCOM System[39, 40] for dryer control, which can result in substantial energy-savings. Such a unit could no doubt be adapted for other loose-stock-drying operations.

A brief review covering some aspects of scouring technology from an Australian viewpoint has been produced by Wood[41].

3.3 Opening and Blending

It has come to be realized that a uniform blend is most important and essential if maximum card and yarn throughput is to be achieved with minimum problems, so major improvements have been made in the field of blending, particularly of large lots for carpet manufacture. This is of increasing importance, since the capital cost of woollen cards has increased substantially while the potential maximum throughput has been reached. Further, the increasing manufacture of plain-shade and Berber carpets has focussed the attention of manufacturers on the need for more even blending where some blend components may represent as little as 1% of the blend. Berber manufacture also emphasizes the need to avoid the separation of components after blending while the blend is being conveyed to the card bin or hopper, often pneumatically. Similarly the increased demand for broadloom pale-shade plain carpets, in which faults associated with poor blending frequently show up as streaks, has often resulted in substantial losses owing to product downgrading or customer claims. Most large modern blending plants can be used to double-blend, and this is now the accepted norm for all but the simplest blends.

Croft[42] commented on the need for good blending if maximum productivity is to be achieved from updated carding and spinning equipment. He differentiated between short-term blending – the initial proportioning of the different ingredients to be used in a mix – and long-term blending of the whole batch.

There has been a marked increase in the number of weigh-bin blenders to increase the accuracy of weighing the components. Croft[43] recommended a 50–100-kg weighbox into which the components are layered, followed by a transfer conveyer to the spiked apron of a hopper. For very large blends, an individual weigh-hopper may be used for each component or for pre-blended components, but this is unusual if there are more than, say, four or five components.

Blends may be baled to avoid excessive conveying and component separation associated with pneumatic transport systems or the centrifugal forces associated with some bin-spreading systems. Bale-breaking hoppers are increasingly used in the carpet industry, often in conjunction with an automatic blending bin immediately preceding the card hopper[44].

Major woollen-blending-machinery manufacturers, such as Temafa, Trützschler, and Houget Duesberg Bosson, offer large blending bins with a capacity of 5–15 tonne; these have automatic layering and emptying systems, which are particularly suited to carpet-yarn manufacture. Cardwell[45] outlined manual, semi-automatic, and automatic batch-blending techniques. Bottomley[46] reviewed a Temafa plant suitable for wool, synthetic fibres, or blends.

Whereas intermittent shakers are widely used for cleaning, blending, and the initial opening of blends, continuous inclined step blenders are becoming more common in view of their higher throughput. Adequate cleaning reduces the frequency of card fettling, a major cause of downtime on the card. The final opening is usually carried out with a Cockspur or Fearnought, which, though it has little cleaning effect, results in a well-opened blend, which is essential to avoid damaging the card clothing and thus ensure its maximum life. Richards[47] has reviewed those factors that he considered were important in blend preparation for maximum mixing. He commented on the need for individual components to be of a similar degree of openness or density to ensure even blending and to minimize component separation during handling.

Methods for assessing the efficiency of opening, cleaning, and blending equipment are described by McCreight[48], who also gives performance and operational data for typical mill opening-room equipment.

3.4 Theory of Blend Formulation

Various general texts available on woollen spinning[49–51] give scant attention to the principles of blend selection other than to point out that this usually involves a compromise between blend quality, availability of materials, and price. However, in the period under review, there have been significant and rapid developments in the theoretical treatment of this important management decision. These all centre on the application of the techniques of linear programming to the set of measurement results that might be considered as a necessary and sufficient technical description of a carpet blend, as shown in Table 3.1[52].

Table 3.1
Wool Parameters for Woollen Carpet-yarn Blends

Parameter	Method of Measurement	Values Used
Colour	NZS 8707:1984	$Y - Z$; Y*
Length after carding	WRONZ method (card, gill, Almeter)	hauteur, mm barbe*, mm % < 20 mm * % > 150 mm*
Bulk	WRONZ Bulkometer	cm^3/g
Fibre diameter	IWS–TM24	μm; % < 28 μm*
Medullation	IWS–TM24	% by number
Contamination (VM)	IWTO–19–76	% by mass

*These additional parameters may be omitted in many cases.

Different sets of parameters may be necessary to specify the quality of blends of other fibres or blends of wool and man-made fibres, but in principle this approach produces a major new blending technology. Several workers have explored the possible application of linear programming to blends of both wool and cotton for woollen and worsted processing[53–59].

In recent work at WRONZ, however, the technique has been applied specifically to the question of wool blends for woollen spinning into carpet yarns. In this instance, it has been shown that the problem may be expressed mathematically when r lots of wool are considered as follows:

$$(Y-Z)_1.x_1 + (Y-Z)_2.x_2 + \ldots + (Y-Z)_r.x_r < (Y-Z)_B.x_B,$$

$$\text{HAUTEUR}_1.x_1 + \text{HAUTEUR}_2.x_2 + \ldots + \text{HAUTEUR}_r.x_r > \text{HAUTEUR}_B.x_B,$$

$$\text{BULK}_1.x_1 + \text{BULK}_2.x_2 + \ldots \text{BULK}_r.x_r > \text{BULK}_B.x_B,$$

$$\mu\text{m}_1.x_1 + \mu\text{m}_2.x_2 + \ldots + \mu\text{m}_r.x_r > \mu\text{m}_B.x_B,$$

$$\text{MED}_1.x_1 + \text{MED}_2.x_2 + \ldots + \text{MED}_r.x_r > \text{MED}_B.x_B,$$

$$\text{VM}_1.x_1 + \text{VM}_2.x_2 + \ldots + \text{VM}_r.x_r < \text{VM}_B.x_B,$$

$$x_1 + x_2 + \ldots + x_r = x_B,$$

$$j = 1, 2, \ldots, r,$$

$$x_j > 0,$$

where x_j is the quantity of the *j*th type to be used;
x_B is the quantity of blend required; and
the $(Y-Z)$, HAUTEUR, etc., values are the values for these properties that specify the components and the desired blend.

The task then is to minimize W, where

$$W = \text{COST}_1.x_1 + \text{COST}_2.x_2 + \ldots + \text{COST}_r.x_r.$$

The importance of this development stems from the ease with which these equations may be solved for quite large data bases by the use of modern computers. This means that it is practicable to prepare auction buying-schedules by solving the above problem many hundreds of times so as to ensure a constant flow of blended wool of the same quality while minimizing the over-all cost.

3.5 Application of Blending Technology

Most New Zealand wool is processed in blends with wools of other countries or with synthetic fibres. While a mixture of art and science is still needed to put together a blend that best meets a manufacturer's requirements, nevertheless, since there are measurements for an increasing number of wool characteristics together with an increasing knowledge of the importance of these properties in both processing and product performance, it is now possible to put together blends on a quantitative rather than a subjective basis. Over the last few years, there have been major advances in the field of data-handling, with the result that modern computer technology provides an ideal tool for blending to specification.

While the concept of blend selection by computer is not new, it is only in the last five years that this technique has been developed by Carnaby *et al.*[60–62] to reach the status of a commercial development project for New Zealand mills, although it is not yet available to overseas wool processors. Consider, for example, a mill manufacturing a two-ply woollen yarn for a cut-pile carpet. If the mill samples every blend it uses for this yarn, then, at the end of, say, a year, the blends that performed well both in yarn manufacture and subsequent carpet manufacture and performance can be identified. These blends may now be analysed in terms of their main characteristics, mean fibre diameter (μm), fibre length after carding (mm), loose wool bulk (cm^3/g), colour (tristimulus $Y - Z$ for yellowness), medullation (%), and VM (%). A technical specification for a blend to suit the particular mill's requirements can then be written to cover each of these wool characteristics. It should be noted that the wools used in this blend are not specified in terms of breed or age of sheep, style category, shearing date, or fault (other than VM). Such terms are necessary for farmer and broker marketing and they are descriptive of factors of relevance to the grower but not of importance in manufacture.

Every lot of wool that is sold at auction in New Zealand, representing about 80% of the clip, is appraised by the New Zealand Wool Board for a market-support scheme. The assessment, together with other measured data, is converted by WRONZ into values for each of the six important wool characteristics, which are then computerized. If a mill now wishes to buy a 50-tonne lot to its specification, then the computer, through the linear-programming technique, can select those auction lots that in combination will meet the specification at the least cost. Many hundreds of tonnes of wool have, in fact, now been processed in computer-blending trials for woollen carpet yarns to the satisfaction of the mills concerned.

It will be appreciated that a wide range of associated commercial information, such as location, transport costs, finance costs, forward-buying schedules, etc., together with other technical safeguards, is incorporated into the programme. Of major interest has been the number of wool types now used in woollen carpet blends but which were not considered for use before this computer-blending technology was introduced. This must inevitably lead to a situation in which the processing and product performance of all wools and blends can be accurately predicted.

The most recent development in this programme has been the application of computer-blending technology to wool-auction-purchasing strategies[63].

3.6 Premium Component for a Woollen Carpet Blend

Arising from a seminar on the relation between wool characteristics and processing, a draft specification was drawn up for the parameters of a premium carpet-blend component, which could be expected to return a price premium to the producer[64]. From the manufacturers' point of view, this is as follows:

staple length	about 100 mm;
fibre diameter	as high as possible;
medullation	as medullated as possible, provided that fibre strength and elasticity are satisfactory;
kemps	absent;
crimp	helical, with as high a frequency as possible for maximum bulk and resilience;
handle	crisp;
colour	good;
soundness	reasonable;
lustre	normally as low as possible;
spinnability	high;
settability	high;
contaminants	free from VM and other contaminants;
openness	maximum fleece openness with no cotts.

The following factors are important from the farmers' point of view:

high fleece weight of clean wool;
consistent acceptable price premium;
high fertility of the sheep.

Such a premium-blend component is not currently obtainable from any one breed of sheep, but it can be considered as a guide to farmers of manufacturers' requirements. There are some conflicts within the specification; thus it is not possible to obtain very heavily medullated wools without having a large number of very coarse heavily medullated fibres with poor tensile properties, and, further, such wools usually have a considerable kemp content and are frequently not very bulky. From the farmers' point of view, stipulating a staple length of about 100 mm may mean that the sheep have to be shorn at an inappropriate time, while high bulk is frequently associated with a low fleece weight.

3.7 Recovery of Waste Fibre for Reuse

The last decade has seen a move in the fibre-recycling industry from the U.K. to Italy, India, and South Korea, while the quality of many Italian woollens produced from recycled fibre has made them very competitive. Problems of sorting and dyeing mixtures of recovered fibres have increased with the increasing use of synthetic fibres[65]. While many rags are still acid-carbonized before recovery, the use of this treatment is decreasing as more multi-swift rag pullers, often with from three to six swifts, are increasingly being used. Any decrease in quality or increase in fibre contamination is compensated for by the lower processing cost. As well as being used in woollen