12. Use of Measurement in Prediction Technology

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Learning objectives

At the completion of this topic the student will have and understanding of:

- the commercial importance of objective measurement in topmaking and blend engineering and how prediction formulae are developed and used,
- an insight into the flexibility of prediction and its benefits.

Key terms and concepts

Topmaking, Wool Combing, Blend Engineering, Price Optimisation, Raw Wool Specification for Top, TEAM, Processing Prediction

Introduction to the topic

This topic is in 3 parts:

- Use of Measurement in Sheep Production
- Use of Measurement in Greasy Wool Commerce, and
- Commercial Use Of Prediction Technology.

The first two parts summarise details of the use of measurements and part three provides a more detailed study of processing prediction, how it originated, its development and its use in industry today in the purchasing of greasy wool, mill monitoring for quality control (QC) and in risk management.

In particular part three discusses the use of the TEAM suites of equations and provides practical examples of how mills and topmakers can adjust the general formulae to suit specific operating conditions.

This topic discusses the additivity effects of raw wool selection and the decision making process in the setting of raw wool specification and blend engineering along with strategies topmakers employ to optimise price whilst meeting technical top specifications with processing predictions.

The topic discusses other forms of prediction models and the pitfalls of only fitting data rather than fully validating data sets.

12.1 Use of measurement in sheep production

Wool growers aim to market wool that is uniform in:

- fibre diameter
- length
- strength
- colour.

By doing this they maximize their financial returns from the available resources they have at their disposal. A uniform product is obtained by optimising breeding strategies, husbandry practices, nutrition and environmental factors with good management and testing. A non-uniform product will be discounted in the market place.
They of course face a number of constraints that affect the ‘quality’ of the wool they offer for sale. These include:

- The genetics or breeding of the sheep
- Nutrition
- Environment
- Husbandry practices throughout the year
- Natural variation (within fleece and environmental variation)
- Clip preparation which encompasses pre shearing/during shearing/post shearing periods of management.

Therefore, the factors which impinge on the test results obtained from wool on any particular farm enterprise are:

- Breeding
- Sheep Selection
- Husbandry Practice
- Nutritional Factors
- Environmental Factors.

Objective testing of wool is an important tool in the production and marketing of wool. There are a number of levels of testing wool, each has its specific use and benefits. For example, mid-side sampling prior to shearing or samples tested during shearing can be used in selection of specific animals. At another level pre-sale sampling and testing at the wool store prior to auction can be used on-farm for pasture management, setting weed management strategies and indeed managing the flock to maximize the value of the clip by changes in mob or enterprise management. Atkins (2004), however, debates whether such measurements are useful retrospectively. They can assist the grower to optimise selling options, understand their product and to provide a guide to the value of the wool to purchasers.

The use of measurement in clip preparation is covered in the Wool Marketing and Clip Preparation unit but it can be summarised as providing a textile fibre that processors can use with confidence and to maximise returns to the wool grower.

**12.2 Use of measurement in greasy wool commerce**

One just has to look at a greasy wool sale catalogue today to see the importance of greasy wool measurement in the selling system. Approximately 80% of sale lots are now sold with greasy wool measurements, of mean fibre diameter, yield, length and strength.

A considerable amount of work has been done since the AWC (1973) technical report on objective measurement of wool in Australia to illustrate the benefit of selling wool with objective measurements. Today, something like 3% of the variation in price received by wool at auction can be attributed to the provision of objective measurement, especially the staple measurements of length, strength, CV of length and position of staple breaks (PoB) (Woolmark – Pricemaker, no longer active).

This apportionment of price variation is purely for the provision of the information and is separate from the values attributed to the degree of the actual attribute in question. The percentage oscillates around this figure and at present it is 2% for superfine wool (17.0 – 18.5μm) and 6% for fine to strong merino wool (18.6 – 24.0μm) (AWI).

Measurement has an important part to play in the controlling of purchases of greasy wool for mill use. This is achieved through good objective specifications that are underpinned by the use of objective measurement.
Specifications for mill consignments depend on:

- Type of product the mill is to produce
- Price
- Processing ability of machinery (e.g. ability to handle vegetable matter).

Specifications may vary depending on product mix and need to be monitored, evaluated and reviewed! To use specifications correctly and to optimise their use requires an understanding of the final product and requirements of each process. To produce any fabric, considerations must be given to the yarn specification, top requirements, but ultimately the GREASY wool.

The greasy wool specification starts with the fabric type and weight and this dictates the yarn requirements, the top attributes and thus the greasy wool inputs necessary to meet such requirements. In it simplest form a greasy wool specification starts with the yarn requirements.

The industry standard for spinning worsted yarn is 40 fibres in the cross section. More commonly the 'spin limit' for pure new wool yarns about 45 fibres in the cross section. In semi-worsted processing between 45–55 fibres are required in the cross section and woollen yarns have between 110 –120 fibres.

Calculating the yarn requirement
In 1945, the basis of yarn specification was laid down with the development of the Martindale Formulae. This used the count of the yarn with a given number of fibres in the yarn cross section to allow the calculation of the fibre diameter of the wool required to meet those requirements. The formula is as follows:

\[ \text{No. of Fibres in the Yarn cross-section (fX)} = \frac{(916.9 \times \text{tex})}{\text{um}^2} \]

Once the diameter is known, the hauteur of top length falls into place and then a greasy wool specification can be developed with the use of processing prediction formulae (i.e. TEAM prediction formulae, see below).

A typical greasy wool specification is provided below. Note: no values are provided as they will vary with the type of top required and the level of variation acceptable to any specific processor:

**Australian greasy wool specification**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean fibre diameter</td>
<td>μm</td>
</tr>
<tr>
<td>Maximum range for any component lot</td>
<td>± μm</td>
</tr>
<tr>
<td>Average millimetre length</td>
<td>mm</td>
</tr>
<tr>
<td>Maximum range for any component lot</td>
<td>± mm</td>
</tr>
<tr>
<td>Average strength</td>
<td>N/ktex</td>
</tr>
<tr>
<td>Minimum for any component lot</td>
<td>N/ktex</td>
</tr>
<tr>
<td>Mean VM content</td>
<td>%</td>
</tr>
<tr>
<td>Maximum in any component lot</td>
<td>%</td>
</tr>
<tr>
<td>VM exclusion (if any)</td>
<td>%</td>
</tr>
<tr>
<td>Predicted Top Length as per TEAM 2 (or TEAM 3)</td>
<td>mm Hauteur</td>
</tr>
</tbody>
</table>

*All components to be measured for length and strength
*Mill to receive both Core and Staple Combined certificates
*Other Additional Items

Details of ranges are typical values are provided in Lecture 1, Topic 3 – Late Stage Wool Processing unit: Topmaking or Blend Engineering.
A typical blend specification format is:

Contract Reference
Mean Fibre Diameter 21 μm
Maximum range for any component lot ± 1.0 μm
Mean Staple Length 87 mm
Maximum range for any component lot ± 15 mm
Mean Staple Strength 36 N/ktex
Minimum for any component lot 26 N/ktex
Vegetable Matter Base 1.0 %
Maximum in any component lot 3.0 %
VM type exclusion no seed/shive
Predicted Top Length as per TEAM 70 mm Ha

*All component lots to be measured for length and strength
*Copies of both combination test certificates must be supplied
*Additional Items:

____% fleece ____% skirtings ____% lambs wool
____ colour (i.e. good, average, poor)

Mills control their deliveries by checking deliveries for:

- Combination certificates (Core and Staple)
- Consignment Packing List received
- All bales have arrived according to the Consignment Packing List
- Check details on the Consignment Packing List against details on the Combination certificates
- Check greasy wool Specification set by the mill against the details on both combination certificates.

The mill can ensure effective processing results by:

- Inspecting all greasy wool
- Process entire consignment as one batch
- Use appropriate and random blending based on scientific measurement and international standards
- Calculate blend ratios
- Monitor and record production through random sampling (provides results on both the wool and machinery)
- Test and record information regularly.

Usually wool has been tested with core and grab tests to determine:

- Micron (um) and variation (CVd)
- Yield (%)
- Vegetable matter (VM)
- Length and variation (mm/ CV length %)
- Strength and the position of break (N/Ktex and POB%).

These are the basic requirements for processing prediction. There are still some sale lots that are not fully tested and use of these wools in processing batches reduces the prediction efficiency and results in more variable outcomes. It also reduces a mill's ability to manage its quality control programs effectively.

**Test certificates**

Objective measurement is an integral part of the preparation, marketing and processing of Australian wool. To ensure reliable tests are conducted on the wool, the Australian Wool Testing Authority operates on international standards from the International Wool Textile Organisation and Standards Australia.
Test Certificates are available at a number of levels and for different tests. In Australia, AWTA Ltd issues IWTO Certificates. Using IWTO Certificates allows trading under the auspices of the IWTO Regulations and thus covers trading partners during the transaction under the provisions of the Arbitration Agreement, Standard Contracts and Other International Decisions and Agreements – commonly called The IWTO Blue Book.

- IWTO Greasy Wool Core Test Certificates
- IWTO Staple Length and Strength Certificates
- Colour Certificates (greasy, scoured, carbonised)
- IWTO Combined Certificates (Core and Staple Certificates)
- IWTO Scoured and Carbonised Certificates
- Greasy Wool Guidance Reports are available but have no official status particularly in a claims situation for poor quality or not meeting specifications.

**Combined certificates**

- IWTO Combined Certificate (Core)
  1. Micron, yield and vegetable matter
- IWTO Combined Staple Test Certificate
  2. Length, strength and position of break

IWTO Combined Certificates are issued post sale using pre-sale tests results. The wool is not re-sampled, but individual sale lots codes are recorded by the exporter who requests average results for the consignment (when all the wool is purchased and batched by the exporter). In Australia, Combined Certificates are issued by the Australian Wool Testing Authority Ltd.

### 12.3 Commercial use of prediction technology

This section introduces the concepts of early stage processing prediction and the TEAM equations (TEAM 1988).

For a period of some 20+ years, the worsted wool combing industry has had the use of prediction technology through the TEAM 2 suite of equations. The first set of equations which evaluated which raw wool attributes were important in the prediction of processing performance, were subsequently put through validation trials and we finally obtained in 1988, what we refer to today as, the TEAM 2 General Formulae; viz. Hauteur, CVHa and Romaine. Since then there has been a number of opportunities to determine how these equations are performing.

These formulae have produced considerable benefits to the early sectors of the worsted pipeline, from growers to spinners; but the particular beneficiaries are the topmaking and combing sectors of the trade. The TEAM 2 suite of formulae, released in 1985, followed extensive industrial trials of over 650 consignments in 21 mills throughout the world (Douglas and Couchman 1997). Since that time, there have been improvements in early-stage processing machinery, lubricants and blend construction to a point where today the formulae are now predicting differently (Team 3 2005):

- Hauteur +5.1mm,
- CVHa −2.5% and
- Romaine +2.1%.

**The TEAM 2 equations**

The discussion is mainly limited to the TEAM equations as they are commonly used, are easier to understand and are being employed in the development of additional uses as we speak today. The points raised in relation to TEAM do however transcend across all prediction methods.

TEAM was the first of the predictions, since then we have seen the development of fibre length distribution predictions (Allen 1991) and yarn predictions. All of these have their uses and will be developed further.
Let us then start with the original TEAM equations, developed by CSIRO, AWC (now Woolmark) and AWTA. These are quite simple equations, for the prediction of hauteur, CV of hauteur and romaine. They are mathematically transparent yet are very misunderstood and under-utilised. A stronger understanding of the basic statistical principles underpinning these equations would reduce the abuse, greatly assist their use, and offer opportunity to manipulate wool purchases for financial gain. These formulae are in general use today but are now being super-ceded by an upgrade – TEAM 3 (2005). To simplify the discussion we will start with the TEAM 2 formulae as they have fewer variables and there is more written about their development and use and later provide details of the TEAM 3 formulae. The principles and philosophy are the same.

A recent decision by IWTO will see the general introduction of the TEAM 3 formulae into regular use with a start date of 1st July 2006. This lag phase is to allow traders and mills to be completely educated in the change-over effects. This is an important feature associated with wool trading. Some mills are, however, likely to continue using TEAM 2 as they have a large background of data and experiential values to call upon.

If they are blending non-measured wool into a consignment it is easier to only have to estimate the length, strength and position of mid-breaks rather than other more difficult parameters like CVL and CVD, which are in TEAM 3, when these values are not available.

**Understanding TEAM 2**

TEAM 2 is a series of simple published formulae for predicting the length characteristics of combing wool. All the data used to derive the formulae were based on commercial consignments, as it is consignments, and not individual sale lots, which are normally processed.

These formulae rely on just 5 input variables and rely on multiple regression techniques. This has its own set of peculiarities and these are discussed later.

The TEAM 2 General Formulae for the prediction of:

1. **Hauteur:**
   \[ Ha = 0.52L + 0.47S + 0.95D - 0.19M^* - 0.45V - 3.5 + MA \]

2. **Coefficient of Variation of Hauteur:**
   \[ CVHa = 0.12L - 0.14S - 0.35D + 0.20M^* + 49.3 + MA \]

3. **Romaine:**
   \[ Rom. = -0.11L - 0.14S - 0.35D + 0.94V + 27.7 + MA \]

where

- **Ha** = Theoretical Hauteur (mm);
- **CVHa** = Theoretical Coefficient of Variation of Hauteur (%);
- **Rom.** = Theoretical Romaine (%);
- **L** = Staple Length (mm);
- **S** = Staple Strength (N/ktext);
- **D** = Fibre Diameter (µm);
- **M^*** = Adjusted Percentage of Middle Breaks (M) (%) (all values of M up to 45% are replaced by a value of 45% for M^*). For values of M greater than 45% the measured value itself is used as M^*).
- **V** = Vegetable Matter Base (%);
- **MA** = Mill Adjustment factor, note: the value of 0 should be used if unknown.

The values used in these formulae are those found on the Combination Certificates. The averages for the consignment are first calculated before applying the formulae. This is an important consideration especially for the M^* value which is only modified once the average is calculated. It is also an important issue with the TEAM 3 equations when CVD and CVL are used. It is especially important for these attributes as the combination of them requires translating of each of these to a variance, combining the variances and then re-calculating the CV and thus the mean.

These formulae are now accepted by IWTO within the IWTO Staple Testing Regulations.
The well used industry standard TEAM 2 equations have recently been replaced by what are called the TEAM 3 equations. The reason for this was that over the past 20 years or so there have been changes to machinery, comb settings, lubricants and anti-static emulsions which resulted in mills today obtaining different results. They are now combing longer hauteur, lower CVHa and higher romaine (or noil). In addition, with the advent of newer test instruments such as Laserscan, OFDA and extension of the software for the ATLAS length:strength testing instrument, more measurements are available for the raw wool inputs. This has resulted in a revision of the original TEAM 2 equations and the TEAM 3 developments to better reflect current commercial and combing practices.

It is interesting to reflect on the differences in commercial practices as when TEAM 2 was developed many of the combing batches used to develop the formula were purchased without pre-sale length and strength tests and over time topmakers and combers have gained considerable experience in the use of such measurements and have altered their buying patterns to take advantage of the information provided.

CS1 and CS2 formulae
There are other prediction models available and individual mills and topmakers have, with technical assistance, developed mill or client specific formulae.

There are two publicly available formulae (Mahar et al. 1994) that, whilst useful for other reasons, are not widely used. They do have a higher level of mathematical sophistication and are somewhat more difficult to understand and use. These are the CS1 and CS2 formulae, sometimes called SIRO 1 and SIRO 2. The gains in prediction accuracy and precision from these are marginal, but they do offer other significant benefits such as top length distributions and statistics for spinners.

These predictions are a suite of equations and are not easy to adjust for specific conditions and are therefore sometimes seen as "black box" equations. For clarification, CS1 is for sale lot prediction and CS2 is the formula which can predict the fibre length distribution (Almeter graph) as well.

Current performance of TEAM 2
Differences in the slope for the three processing parameters are observed (Couchman 1996), e.g. as the predicted value increases the actual value increases (or decreases) at a greater rate. i.e. there is a multiplying factor rather than a constant change over the range.

Table 12.1 illustrates the wide range of slope coefficients between predicted and actual, (1 being a constant change) in a number of mills throughout the world today.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Slope</th>
<th>Coefficient Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hauteur</td>
<td>1.2</td>
<td>3.1</td>
</tr>
<tr>
<td>CVHa</td>
<td>0.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Romaine</td>
<td>0.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

What we are seeing is increasing Hauteur at the same time as decreasing CVHa's and increasing Romaine. Some of effects on the former two are as a consequence of the latter but the question is by how much?

That is of interest in itself in the financial use of TEAM formulae as will be discussed later. If we take hauteur prediction as an example, the average result for the 8 mills in this study illustrate that the TEAM equation is, on average, behaving well.
However, if we look at the individual mill results, covering 181 consignments, in this stylised graph, we can see that each is quite different. The other feature of note is that all of the mills are processing significantly better than the predicted value. This phenomenon is not surprising and is in line with the details outlined in the TEAM Report of 1988, for making mill adjustments.

Many people who use TEAM only think of hauteur but there are interactions between the three processing outcomes and whilst there are times when they should be viewed in isolation, it is vitally important to look at them in combination, as there are financial considerations attached particularly to the romaine prediction, but also the CVHa prediction if a mill is pursuing a particular outcome.

If we look at the correlation \(r^2\) values) between predicted and actual results, once again we are observing a considerable range (Table 12.2).

| Table 12.2 Correlation coefficient \(r^2\) range for TEAM in 8 mills in 1996. Source: Couchman, Capronex Pty Ltd (2006). |
|-----------------------|----------------------|--------|
| Parameter            | Correlation Coefficient | Range |
| Hauteur              | 0.4                  | 0.97   |
| CVHa                 | 0.02                 | 0.94   |
| Romaine              | 0.17                 | 0.88   |

A cursory glance might indicate a poor relationship exists in some instances, but it is not as simple as this. A closer look at the data reveals that those with a “poor relationship” generally have a very narrow range of predicted values in the first place. This is one of the shortcomings of using regression model equations for predictions. It is also not out of the question to suggest that each mill will process differently and that specific raw wool characteristics in the orders for any one mill may also be quite tight in range and therefore have little bearing on the specific raw wool equation coefficient in the TEAM formulae. This will also have a bearing on these relationships and correlation results.

**Differences in performance**

When we see differences in TEAM’s performance, especially slope effects, the obvious question is ...how much of what we see is due to changes to processing conditions, machinery advances and speeds, differences in crimp definition and frequency (style effects) or spinners tightening specifications for such things as CVHa and short fibre content, rather than processing inefficiencies or even poor prediction performance?
Similarly we can ask, for those consignments which fail to meet the predicted outcome or are not in line with a particular mill's abilities: "are these failing because of poor prediction, poor raw wool input, high levels of process variation in the mill or processing errors for that batch"? In my experience, most are the result of identifiable mill deficiencies during the processing of those batches. The obvious rejoinder is "that is OK but what about those which process considerably better than predicted?"

There is no doubt, that style effects are present, however with current blend engineering practices, the probability of processing a full batch of such wools is likely to be low, and therefore such occurrences are infrequent as demonstrated by the frequency distribution of such processing/prediction differences.

Cost effects
If we accept what is happening, then in those mills where there is increased Hauteur we need to ask the questions.....is the extra hauteur really required and who is likely to benefit most?

The merchant topmaker only increases costs by supplying raw wool which is better than required. The spinner is a significant winner with gains from increased bundle strength, evenness and lower ends down during the spinning process.

The major winner is the vertical integrated topmaker/spinner, who can alter raw wool parameters to suit a yarn outcome. Prediction suites for spinning have also been developed; Yarnspec (Lamb 1996) predicts the technical implications of changing top attributes and spinning inputs on yarn quality and faults.

Prediction Philosophy
This raises an interesting question: is TEAM, or any other prediction, Limited, Limiting or a Philosophy. I believe it to be the latter (Couchman 1996). Using the philosophical approach also opens up opportunities for wider use of prediction technology into the financial area rather than just processing outcome prediction. TEAM is adaptable; there are individual mill adjustment techniques, as well as within mill adjustments for different blends or processing lines and all of these are only a start for development of mill specific formulae.

TEAM predictions were always seen to be a starting point before mills developed their own specific formulae. In my experience, very few have felt the need or bothered to go that next step. TEAM is also versatile, as it can be used to assist in developing specifications, build consignments to meet specifications, form the basis for physical blend delivery to the scour, monitor mill performance and enable price optimisation to cheapen the order.

Mill adjustments to formulae
With this in mind, there are two approaches to mill adjustments for any prediction method:

- the QC or processing approach for both slope and intercept adjustments which alter the mean outcomes, and
- a 95% confidence limit approach for use with purchase specifications to ensure a required top outcome is achieved.

The financial effect of this is obvious but is discussed in more detail later in this topic.

Price optimisation
By manipulating the greasy wool attributes within each of the formulae it is possible to alter the cost of a combing consignment, as each raw wool attribute has differing price relativities.
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Figure 12.2(a) Value determining characteristics 2003/04: 17.0-18.5 micron merino fleece wool. Source: The Woolmark Company (2005).

Figure 12.2(b) Value determining characteristics 2003/04: 18.6-24.5 micron merino fleece wool. Source: The Woolmark Company (2005).

TEAM 3 Equations

Hauteur = 0.43L + 0.35S + 1.38D – 0.15M – 0.45V – 0.59CVD – 0.32CVL + 21.8 + MA
CV Hauteur = 0.30L – 0.37S – 0.88D + 0.17M + 0.38CVL + 35.6 + MA
Romaine = – 0.13L – 0.18S – 0.63D + 0.78V + 38.6 + MA
where MA = mill adjustment

Note that the M* has now been replaced with M and there have been additional raw wool input variables included in both the Ha and CVHa formulae. The regression coefficients and the intercept or constant terms are also different from the TEAM 2 formulae. This is to be expected because the co-efficient changes reflect changes in combing practice and the effect of the regression statistics technique itself.

12.4 Understanding prediction residuals or (A-P) values

When processing results are analysed, one of the primary issues is to study the prediction residuals, i.e. the difference between the actual result and the predicted calculation: the (A-P) result. This value represents both the processing error and the prediction error along with measurement error. When a mill has poor-quality management, then the largest portion of the (A-P) will be related to processing inefficiency. When process control is high, then the major contributor will be prediction error or wool related.
As a general rule, the measurement error is secondary to the other sources of error. Mill settings and how they interact with specific raw wool attributes will also affect (A-P) values. For example, some mills are not set up for processing high VM wools, and thus high levels of breakage are common for such wools. This reduces Ha and increases CVHa and romaine. Other relationships with differing raw wool attributes and settings are apparent.

Prior to the review and updating of the TEAM formulae, questions were raised about their current relevance and accuracy. In particular, some groups (Oldham and Peterson 2000; Lamb 2000) suggested that, as the formulae are over 15 years old and there are significant observed differences in residual values, then the relevance of the formulae was questioned. These critics suggested a number of “prediction models” including diameter profile models as being superior in performance to the TEAM formulae. This was despite wide industry acceptance of the TEAM formulae.

Some of this criticism arose because some critics were fitting a data set with Ha compared with a validation of TEAM predictions specific to that data; a chalk and cheese comparison (Marler and Couchman 2001). Some of the poorness in fit for TEAM is associated with results coming from a single mill and therefore relate to only one set of processing conditions; but more importantly, there are other, more serious underlying considerations arising from these studies. These are discussed below.

**Prediction model development or data fitting**

Couchman (2002a, 2002b) suggested that the above studies compared a goodness of fit to a limited data set (in both range of attributes and number of observations) with a generic prediction formula (TEAM) unadjusted for the mill. In addition, some groups use the fitting model as a predictive model, without validating it on another data set. This is where a good knowledge of multiple regression techniques is required.

Couchman (1996) also showed that the overall $r^2$ value for the total data set Ha was 0.4; however, when applied to each of the eight specific mill data sets, the correlation coefficients for these mills were variable and had a range of 0.97 depending on circumstances (Table 12.3). Couchman (1996) showed that, when a data set had very limited ranges in either or both of the independent or dependent variable/s, then the $r^2$ values were likely to be low.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Correlation Coefficient</th>
<th>$r^2$ Coefficient Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hauteur</td>
<td>0.4</td>
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Work with individual mills in mill improvement programs, (Couchman unpubl.) has demonstrated that mill processing inefficiencies account for a large proportion of the variation in (A-P) values and these, rather than prediction inefficiency, result in poor correlations.

In addition, when the predicted values were over a tight predicting range, it was common for the mill in question to demonstrate a low correlation coefficient. In these cases, leverage and influence play a significant part in the analysis.

In comparison, some of the models put forward as possible replacements for TEAM have shown high correlation coefficients (Lamb 2000; Oldham and Peterson 2000). This is not surprising, as they are fits of the data and not validation of the model. This stems back to some of the basic tenets and requirements for regression analysis techniques. There are a number of rules that must be followed and that should be understood by model developers and users alike. In the view of the author, both of the recent approaches to new-style prediction models fail to meet some of these requirements.
Regressions and TEAM
A large number of texts provide details of regression analysis. Suffice to say, while we use regression models in the TEAM suite of equations, they do have some unfavourable side effects and significant shortcomings in addition to well-established rules for application.

There are two types of regression models, Type I and II; and they have some subtle differences (Sokal and Rohlf 1981). In both cases, they can have different mathematical forms, simple linear, multiple linear or indeed curvilinear with significantly different formulae to describe different curve shapes. Inherent within this premise, the two models differ.

In essence, Type I assumes that there is only one source of error, in the dependent variable, whereas Type II accepts error in both the dependent and independent variables.

Our current processing prediction models, the TEAM suite, are Type I models. Both types, however, have some common rules for applicability that must be obeyed if they are to be of any use as prediction models.

When a regression model is extended to become a prediction model, there are a number of steps to be undertaken and a number of issues to be understood:

- validation of a prediction model needs to be undertaken on a separate data set
- validation in the mill that generated the model only provides a prediction model for that mill and if it is to be used generically then the second phase validation is still required. This entails validation in wide-ranging industrial trials, such as the TEAM trials
- fitting data to a regression model does not constitute a prediction model; the latter requires validation, and
- validation trials, however, are difficult and both time consuming and costly.

If we do not validate regression models correctly, then they can and should only be identified and understood as data fitting, not prediction models.

From the published details of these newer "models", (Oldham and Peterson 2000; Lamb 2000) one has to ask whether these so-called "models" or formulae have been verified on a second independent and global data set or are they just fitting the data set to a regression model, i.e., the regression statistics are being used to derive a least squares line or line of best fit. That is a far cry from prediction model development, which requires separate validation. These models are regressions and data fits, not true prediction models.

The newer models also appear to fail some of the rules required for prediction model development and therefore must be viewed in that light. They have used restricted data in comparison to the TEAM data set. The samples processed, whilst made to the same commercial specification, had quite specific requirements for VM (maximum 1%) and strength (minimum 30N/Ktex value). They are therefore from a narrow range and not normally distributed; they are indeed skewed.

TEAM for grower lots
There is an argument that TEAM isn't sufficiently accurate on an individual grower's lot and doesn't provide accurate price discovery. It should be recognised that there are very few grower's lots processed commercially as individual batches. The converse argument is that using TEAM on a grower's lot provides an evaluation of the component contribution it makes to the commercial consignment. If better price valuation is required, then more imaginary ways of applying price models linked to process outcomes (i.e., price optimisation) are the answer.

AWTA Ltd. has recently published details of single sale lot results using the TEAM 3 equations and these show considerable improvement in predictability at the single lot level (Fish 2005).
There has been much talk about "profile" models recently (Peterson and Oldham 2000; Hansford 1994). To date, the exact details of such models are not kept public, and therefore there has been no peer review of the models or data sets from which they were drawn. In any regression type prediction model, there has to be discrete variables in the model; and thus a single value must be entered as one of the independent variables. Profile data is essentially a data series and contains a large number of variables; it thus becomes a little unwieldy to use. In "profile" models, what are these variables? A profile by nature provides many numbers. Which ones are used, and how relevant are the ones chosen? In regression statistics, we can always improve the $r^2$ value by adding extra independent variables. There is, however, always a danger of "over-fitting" the model with this approach. It is understood that the Peterson and Oldham (2000) model attempts to model fibre breakage. It derives a number that is then translated via a regression equation to provide an Hauteur estimate.

**Changes to TEAM**

Why continue with TEAM? It is 15 years old, but the TEAM formulae are, by their very nature, simple regression formulae models. They are:

- relatively easy to understand and manipulate yet, despite this, are still not used to maximum benefit, and
- remarkably robust and easily adjusted for offset differences (mill adjustment factors); and with a little more difficulty, slope adjustments are available.

The TEAM Final Report (TEAM 1988) clearly states that the general formulae are a first step in prediction technology. This approach continues with TEAM 3, with sufficient data, users should develop mill-specific formulae to better suit their requirements.

A number of topmakers and mills have made this transition and are very satisfied with the results. However, there are a large number of users who only use traditional offset adjustments (mill adjustment factors) in regular purchasing and mill decision-support systems. It is these users that will reap more benefit from the upgrading of the TEAM 3 formulae.

**How to use the TEAM formulae for:**

a) **Prediction**

The TEAM formulae have been developed for general use and therefore they do not take into account variations in processing performance between and within specific mills. If the prediction is outside the following ranges, care must be taken:

- Hauteur: Less than 55 mm and greater than 80mm
- CVHA: Less than 40% and greater than 55%
- Romaine*: Less than 3% and greater than 12%.

*Note: If the consignment consists of 100% SKIRTING wool, the TEAM 2 romaine formula will significantly underestimate the actual result. Expert advice should be sought in such cases.

It is important for growers to staple measure so as to have access to the use of prediction techniques. Without these measurements accurate prediction of hauteur and romaine is not possible and it is impossible to predict CVH or other top length distribution specifications important to the spinner.

Users, whether mills, exporters, traders or growers adding value, should maintain a record of the greasy measurement data and the difference between the processing characteristics predicted by the TEAM formulae and those actually achieved for each processing consignment (see below). By doing this, a ‘mill specific’ database can be built and used to improve the predictions for that mill.
Mill correction factors calculations
The following example has been worked using hauteur only; the technique applies also to calculating the respective mill correction factors for coefficient of variation of hauteur and romaine.

When a mill has monitored 10 to 15 consignments, the mean value of the difference between the hauteur predicted by the TEAM formula and the actual hauteur achieved can be calculated. This value then becomes the ‘Mill Correction Factor’ and is added or subtracted from the constant in the TEAM formula in subsequent calculations.

Growers processing wool in the same mill can also use these formulae to predict outcomes and fine-tune their predictions to the particular mill in Australia. This is done in the same way as developing a mill correction factor.

As these mill adjustment factors are commercially sensitive information, individual growers are unlikely to be advised of them by commission combers who are combing packages of wool.

**Table 12.4 An example of calculating a mill correction factor.**
*Source: Couchman, Capronex Pty Ltd (2006).*

<table>
<thead>
<tr>
<th>Actual Hauteur Achieved by Mill (mm)</th>
<th>Predicted Hauteur Using the TEAM Formula (mm)</th>
<th>Difference Between Actual and Predicted Hauteur (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>73.9</td>
<td>73.1</td>
<td>0.8</td>
</tr>
<tr>
<td>73.6</td>
<td>73.0</td>
<td>0.6</td>
</tr>
<tr>
<td>57.3</td>
<td>55.5</td>
<td>1.8</td>
</tr>
<tr>
<td>59.0</td>
<td>58.4</td>
<td>0.6</td>
</tr>
<tr>
<td>66.0</td>
<td>66.9</td>
<td>-0.9</td>
</tr>
<tr>
<td>58.1</td>
<td>55.8</td>
<td>2.3</td>
</tr>
<tr>
<td>58.7</td>
<td>57.7</td>
<td>1.0</td>
</tr>
<tr>
<td>61.2</td>
<td>58.8</td>
<td>2.4</td>
</tr>
<tr>
<td>58.3</td>
<td>54.3</td>
<td>4.0</td>
</tr>
<tr>
<td>59.4</td>
<td>57.9</td>
<td>1.5</td>
</tr>
<tr>
<td>65.1</td>
<td>67.2</td>
<td>-2.1</td>
</tr>
<tr>
<td>71.4</td>
<td>77.7</td>
<td>-6.3</td>
</tr>
<tr>
<td>60.6</td>
<td>60.0</td>
<td>0.6</td>
</tr>
<tr>
<td>67.6</td>
<td>66.9</td>
<td>0.7</td>
</tr>
<tr>
<td>72.9</td>
<td>72.4</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td><strong>0.5</strong></td>
<td><strong>0.5</strong></td>
</tr>
</tbody>
</table>

In this case, the mill is processing 0.5mm better than the world average. This 0.5mm therefore is the mill correction factor which is added to the formula. Using TEAM 2 as the example for simplicity sake, the ‘new’ mill specific formula looks like this:

\[ H = (0.52 \times L) + (0.47 \times S) + (0.95 \times D) - (0.45 \times V) - (0.19 \times M^*) - 3.5 + 0.5 \]

If changes are made to the mill processing conditions, such as the installation of new machinery, differences will be expected and alterations to the mill correction factor will probably then be necessary.

Mill specific formula
Processors can calculate their own 'mill specific prediction formula' using a regression equation based on the greasy wool characteristics found to be the most important for that mill. Any standard computer package containing regression analysis can be used to do this, but a good understanding of regression techniques, raw wool and processing is necessary and most mills rely on specialists with prediction technology experience to undertake such tasks. The mill may even develop separate formulae for different processing lines or different wool types once sufficient data has been accumulated. However, it must be stressed that new formulae should only be developed on LARGE databases.
The TEAM formula, together with the mill correction factor will provide the best prediction whilst a large database is being accumulated.

b. Mill/consignment monitoring

Once the best prediction technique has been developed for a particular mill, standard quality control procedures can be used to monitor the mill performance. The differences between the predicted hauteur using the TEAM formula and the actual hauteur achieved can be plotted on a time-series graph (Couchman 2002b).

**Figure 12.3** Example of a quality control chart.

This example shows the predicted and actual values plus the (A-P) residual values on the one chart for 20 batches using the same purchase specification. Phase 1 values are prior to changes being made in the mill to overcome processing irregularities and variation.

By setting boundary limits for the size of the differences, a quality control chart of mill performance can be logged. These boundaries are derived from the standard deviation (sd) of the differences between predicted and actual hauteur. The ‘inner’ and ‘outer’ limits can be applied to represent twice and three times the sd respectively. The ‘ideal’ or target difference would be zero and the ‘inner’ and ‘outer’ limits can be used as ‘warning’ and ‘action’ limits. These 2 sd values represent the 95% confidence limits and it is reasonable to expect 1:20 lots to be outside these ‘limit lines’.

If a comparison of sd difference is required between individual mill or consignment data and that of the TEAM data base, the latter sd was 3.4mm, i.e. this was the average for the world in 1985.

The limits provided in the example may not be suitable for individual mills where calculation of the differences may indicate that the standard deviation is either larger or smaller. Some mills may be less variable than others either because of the range of wool types processed or because of mill management practices. Also, as prediction techniques are improved, the spread of the differences should be reduced and tighter limits should be set.

The main purpose of the control chart is to ensure that processing results are under ‘control’. It will enable a quick judgement to be made as to whether or not an individual result is an exception. In addition, it provides a way of visually assessing if a ‘trend’ is occurring, even when the individual results are within the warning limits.
In the example in Figure 12.3 there is one result (6.3) that falls outside the ‘inner’ or warning limits. In a mill situation this should be interpreted as a warning sign and processing conditions should be checked. A topmaker might also examine the data on the particular blend to see if it differed from other similar blends. However, it must be remembered with normal variations, it can be expected that one consignment in 20 will be outside the ‘inner’ limits by chance. In the example because there has been a rise in the preceding 3 consignments it could indicate a potential problem developing rather than the 1 in 20 chance occurrence.

If a consistent trend continues over a period of time, this may indicate a change in processing performance. In this case a new prediction formula or a new mill correction factor may need to be calculated using only the recent results.

The ‘outer’ or action limits are unlikely to be exceeded unless something specific has occurred to alter the result. These limits are normally set at three times the standard deviation, which means that the values would be exceeded in only 1 in 370 instances by chance.

To obtain the full benefits of processing hauteur prediction from the TEAM formulae, in terms of both mill management and results, it is essential that mills and topmakers establish a continual database and regularly monitor results.

These characteristics should not be viewed or interpreted in isolation but in combination; for example, a required level of hauteur may be achieved at the expense of increased romaine whilst decreasing coefficient of variation etc; the latter being the least important of these three major processing characteristics.

Numerous graphs can be constructed to relate the predicted values to those actually achieved e.g:

- Hauteur versus staple strength
- Coefficient of variation of hauteur versus percentage of middle breaks, and
- Romaine versus hauteur.

Control charts for:

- Hauteur
- Coefficient of variation of hauteur, and
- Romaine

are also useful tools.

**Team general formula for the prediction of Barbe**

In addition to the hauteur fibre length formula, the TEAM project also developed a formula for barbe. Barbe is the fibre length measurement of wool tops most commonly used in China and is measured on the comb sorter.

Barbe is a weight biased measurement of fibre length in the top and is not favoured in other countries. It also has limitations because of the errors that can occur in the weighing of small quantities of fibre to determine the fibre length. For these reasons the IWS recommends the use of hauteur, a length biased measurement measured on the Almeter.

Despite the differences, mills in China can still get benefits from buying fully measured Australian wool, and using the barbe formula along with the romaine formula to determine fibre length and noil loss. This will enable the mill to monitor its performance, and undertake quality management practices.

The Barbe formula is as follows:

\[ B = 0.73L + 0.32S + 0.96D - 0.51V - 0.086M^* - 5.3 \]
As with the other three TEAM formulae, this formula can be adjusted to make the predictions more specific to the operating conditions of each individual mill in question.

Barbe can also be calculated from both hauteur and CVHa measurements as follows:

\[ B = Ha (1 + CVHa^2) \]

Care must be taken in comparing the short fibre content figures for hauteur or barbe diagram as they are significantly different. The reason for the difference is that the short fibres are generally finer and therefore weigh less and the measurement of barbe relies on the weighing of each class of fibres in the calculation of the barbe figures. The lower % in fact reports the weight biased result rather than the true length result as occurs in the Almeter Hauteur graph measurement.

In the following example (Figure 12.4), taken from the same top, it can be seen that the shape of the graph for the barbe has very few short fibres (%< 30mm) i.e. 3.1%, compared to the hauteur graph (9.5%). Remember these measurements are from the same top; it is only the different measuring technique which provides the different answer.

**Figure 12.4 Differences between Hauteur and Barbe on the same top.**
*Source: Couchman, Capronex Pty Ltd (2006).*

The use of prediction in purchase specifications and risk management

A topmaker or mill has to make a top to meet a minimum specification; below that a claim for under performance occurs. To overcome this problem, topmakers "oversupply" or provide better wool than required. The 'trick' to optimising the system is to get as close to the required specification as possible without breaking the lower (claims) barrier.

The use of prediction technology has assisted this by using differences in combing ability and an understanding of the amount of variation that occurs within the mill. Armed with this information the topmaker can design the blend to a point where they limit the risk of not meeting a specification or outcome. These 'risk' levels vary between topmakers and mills, but a common level is 20% failures, i.e. 20% of all tops made do not meet the required specifications.
This appears to be a high level of acceptance of risk as it is generally recommended that a mill should only carry a 2.5% risk level (lower end of the 95% confidence interval). To ensure the risk of producing a top outside a minimum Ha, maximum CVHa or romaine is reduced to a 1 in 40 chance; the prediction parameters should have the 95% confidence limit added to them. This is done in the same manner as the addition of the constant and mill adjustment value. This level of risk can be altered if a topmaker wishes to take a higher risk position.

The following is an example of how a topmaker (Mill Z) can calculate these "safety" margins. Assume the following for Mill Z:

- Mill Adjustment Factor (MAF) (average difference between predicted and actual result) = +4.0 mm, and
- Mill variation (variation in difference between predicted and actual result) standard deviation = 1.4 mm.

From these, the recommended adjustment would be:

\[
MAF - (2 \times s.d.) = 4 - (2 \times 1.4) = 1.2 \text{ mm}
\]

Now if Mill Z are trying to make a TEAM (Ha) prediction of 70 mm, and are processing better than predicted (MAF = +4.0 mm), but only want a 1 in 40 risk level, then Mill Z can only use 1.2 mm of the adjustment. As a result, Mill Z can purchase cheaper greasy wool because the predicted top is "shorter" (68.8 mm).

To illustrate how significant the impact of variation is, compare the experience of Mill Z with that of another mill, Mill Y. Mill Y has the same MAF but alas has higher variation, with an s.d. of 5.7 mm.

Using the same process as for Mill Z generates a TEAM (Ha) prediction of:

\[
70 - 4.0 + 11.4 = 77.4 \text{ mm}
\]

i.e. this mill requires greasy wool that will predict to 77.4 mm to be able to confidently reach 70 mm Ha with only a 1 in 40 failure rate.

There is an 8.6 mm Ha predicted difference between Mills Z and Y to achieve the same 70 mm hauteur top with a 1 in 40 chance of failure. Mill Y's requirement to source longer wool to gain the same outcome in top form will cost them money. It is important to note also that the variation levels used in the above examples are well within normal observed ranges.

These levels of process variation need to be put into context. The TEAM 2 report showed the s.d. of Ha prediction to be 3.4 mm. TEAM 3 showed the s.d. of Ha prediction to be 2.5 mm; both very similar. The above examples are therefore quite within normal boundaries of processing variation.

### 12.5 Conclusion

There is a very simple approach to prediction technology: teach the easy first, i.e., teach people to use TEAM to its maximum, then, and only then, move to more sophisticated and demanding prediction models.

Processing prediction is a very valuable tool for traders and processors alike. In the development of models, it is extremely important for the analyst to ensure that statistical basics are followed. The commercial users of prediction technology are, in the main, unsophisticated in statistics and have little understanding of the finer points of prediction versus data fitting.

As mentioned earlier, there is an opportunity to widen our horizons with prediction technology and use these techniques to examine a range of financial opportunities. For example, it is possible to determine the profitability of increasing noil removal to increase top length. I trust
that this topic has "switched on the light" to a wider opportunity for using prediction technology. Such technology is not, nor should it be, restricted just to predicting hauteur, CVHa or romaine for processing sake. It has much wider uses. It is a philosophy, and yes, TEAM is still very useful (Couchman 1996). It has yet to be used to its full potential.

Readings

The following readings are available on web learning management systems


Summary

Summary Slides are available on web learning management systems. This topic discusses the commercial use of measurement and the role it plays in topmaking, blend engineering, purchase specification, mill management and the management of risk. It provides an in-site into the commercial activity of raw wool selection to satisfy a topmaking specification and price points along with the important use of prediction formulae like TEAM 2 and TEAM 3.

References

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Notes – Topic 12 – Use of Measurement in Prediction technology


The Woolmark Company (2005), Figures prepared by K.Stott on behalf of the Australian Sheep Industry CRC.


Glossary of terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Barbe</td>
<td>Average top length in a weight biased length measurement</td>
</tr>
<tr>
<td>CVHa</td>
<td>the coefficient of variation of Hauteur</td>
</tr>
<tr>
<td>Hauteur</td>
<td>Average top length in a cross section biased length measurement</td>
</tr>
<tr>
<td>IWTO</td>
<td>International Wool Textile Organisation; the world's premier wool industry body, based in Brussels, which oversees the trading and testing standards for wool</td>
</tr>
<tr>
<td>Mill</td>
<td>Correction Factor – the average difference between the predicted and actual result from a single mill using TEAM for Hauteur, CVH, Romaine or Barbe predictions</td>
</tr>
<tr>
<td>Prediction Models</td>
<td>mathematical formulae used to predict processing outcomes</td>
</tr>
<tr>
<td>Profiles</td>
<td>usually fibre diameter profiles of staples measuring the diameter at set points along the staple</td>
</tr>
<tr>
<td>Romaine</td>
<td>the short fibre (noil) removed from a top during combing, expressed as a % of clean weight</td>
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<tr>
<td>TEAM</td>
<td>Trials Evaluating Additional Measurement</td>
</tr>
<tr>
<td>Yarnspec</td>
<td>a spinning prediction package developed by CSIRO</td>
</tr>
</tbody>
</table>