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PROJECT'
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Mathematical Modelling in worsted spinning allowing the optimisation of the process and the development of CIM.

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Abstract:

The principal properties of the top sliver, an essential intermediate product in worsted spinnig, and the processing losses have been modelised taking into account the properties of the raw material and the principal card settings. These models are built from laboratory and industrial experiments. Top fibre lengths distribution and card plus comb loss rates, have been modelled on the basis of a simulation of fibre elongation, breakage and sorting. A software has been written to help the topmaker or the spinner in choosing the most effective card settings values by simulating the process. An automated, computer controlled card has been developed. It allows to set the most important settings in a few seconds, using safe and reliable procedures in severe industrial conditions.

1. INTRODUCTION

1.1. General

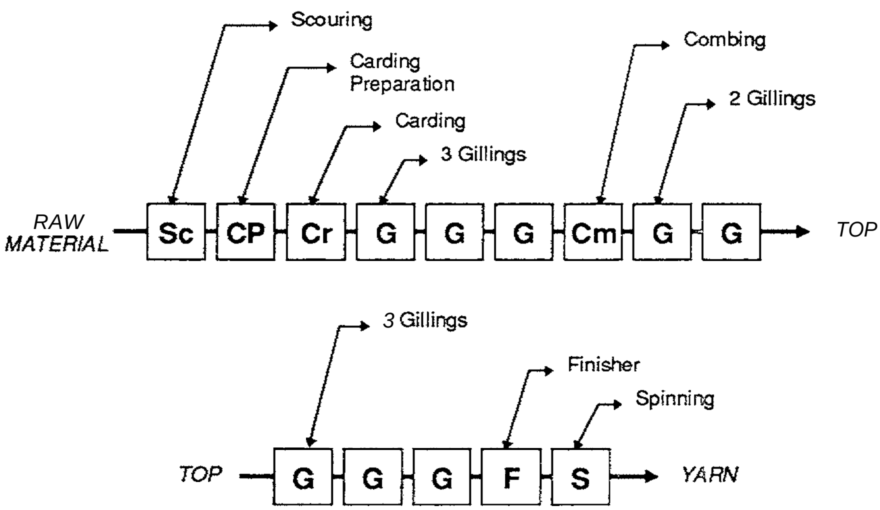


Figure 1-1: The worsted spinning process

"Worsted" spinning is a complex process involving a number of successive operations (Figure 1-1). The step of carding is required 10 open, blend, clean and parallelism the fibres from the raw material. The step of combing is introduced to get rid of small defects of fibrous or vegetal origin. The steps of gilling, finishing and even spinning correspond to drafting operations of the incoming bundle of fibres, to make it thinner and/or to get a better blend of the individual fibres and increase the parallelisation level. These operations can be subdivided in two main stages: one stage in which the raw material is transformed in a regular sliver with parallel fibres nearly exempt from impurities or defects (the 'lop"), and another stage where the top is drafted in successive steps up to the final yarn linear density, the last drafting step introducing also the torsion necessary to give strength to the yarn.

The development of a full CIM {Computer Integrated Manufacturing) in worsted spinning requires the two following conditions:

- a well established procedure for the selection of the main settings of the whole process, according to the characteristics of the raw material;
- the possibility to set the machines with the setting values defined by this procedure in a very short time and in a reliable manner.

The efforts of the research have been concentrated around the "topmaking" stage. This implied the following practical objectives:

1. the development of mathematical models of the worsted card adjusted and validated through experimental research;
2. the development of a software based on these models for the selection of the card settings in function of the raw wool properties;
3. the development of a new computer controlled card, with automated settings, using safe and reliable procedures in an industrial environment.

1.2. *The worsted card and the topmaking process*

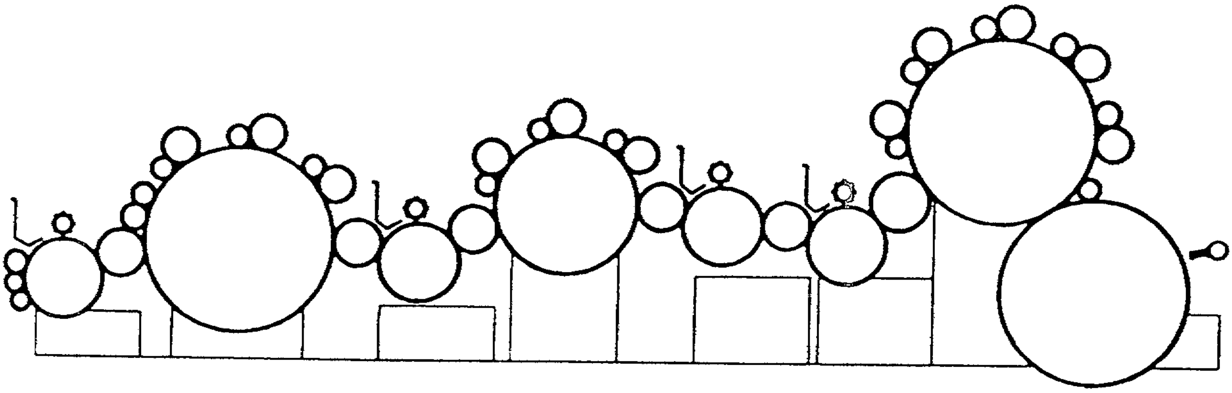


Figure 1-2: Side vue of a typical worsted card

Worsted carding takes place on roller cards fitted with various cylinders clothed with saw-tooth wires (Figure 1 -2). The work of carding is done at the interface between a main cylinder and a worker cylinder; they are 3 to 5 workers by main cylinder, each one coming with a stripper cylinder which removes the fibres from the worker's clothing back to the main cylinder's one. The raw material (scoured wool or other material in staple form) is opened and its fibres parallelised when it is simultaneously gripped by surfaces running at very different speeds (the main cylinder's surface speed is in the range 300-1000 m/min; the worker% surface speed ranges between 10 to 40 m/min).

There are numerous settings on the worsted card: speeds and clearances of the various cylinders and the production rate by unit width of the card. The settings of the card are critical for the topmaking process because a good part of fibre breakage occurs during carding and because fibre breakage during the next steps (gilling and combing) depends much on the state of the card sliver (openness, parallelism, neppiness, . ..) [1]. That means that the card settings influence largely as well the final top fibre length distribution as the amount of noil (comb losses). They are also of course critical for the rate of card losses (droppings, fly). Among these settings, those of the last main cylinder (the "swift") where the clearances are the smallest and the speeds the highest play the most important role in fibre breakage when the load is increased [9].

The card has to perform several functions :

- full opening of the wool staples, separation and partial parallelization of the fibres along the machine axis;
- thorough and homogeneous blending of the input components;
- regularization of the linear density of mass, or linear density of the output sliver;
- partial cleaning of the processed material (vegetable matter removal on wool).

Moreover, the accomplishment of these different functions implies some drawbacks whose effect has to be limited.

The card is indeed unable to perform its opening and parallelizing function without exerting mechanical stresses on the fibres, leading to distortion and breakage of fibres. In fact, the reduction in fibre length leads to a deterioration of the quality of the final yarn, loosing an appreciable valuing. Moreover, the short fibres resulting from the breakage will increase partially the two important types of fibre losses: the card losses and particularity the comb losses (also called "noil"). Therefore, for each lot of raw material to be processed, a compromise is to be searched for between, roughly speaking, the production rate and the topmaking performances.

Another carding drawback is the formation of "neps" (little fibre entanglements with a dense core), which appear especially for the finest fibres, and whose frequency increases generally with the card load and, at constant speed, the production rate. A great **part of these neps is** removed during combing, but the residual portion results in defaults of cleanliness in the final top sliver and therefore in **the yarn; on the** other **hand, a better removal of** these neps necessarily implies an increase in the amount of noil. The most effective action is thus to limit the nep frequency in the card web, by a suitable choice of the settings.

1.3. Characterisation of the raw wool

The basic measurements of the raw wool fibre properties are the mean fibre diameter, the vegetable matter content and the yield or relative wool content. In order to obtain a good estimation of fibre length and strength properties, two different approaches can be followed: one at the staple level, the other at the fibre level.

Most of the wool used for worsted processing being delivered at the greasy stage, with the wool staples intact, a “staple approach” is commercially available. Following that approach, a fast robotised instrument called ATLAS, measures three parameters in 6 seconds on each staple drawn from a representative sample (grab sampled directly on the wool bales). These parameters are the length, the strength or the maximum force during breakage divided by the staple linear density and the relative position of the break (obtained by weighing the broken parts of the staple).

Another possibility is to use single fibre measurement with added complexity but a better precision in the determination of true fibre length and strength. In the fibre approach, individual scoured wool staples are measured with a WIRA single fibre length tester (30 fibres by staple, randomly drawn). The measurement of the strength and the position of break of a derived staple (obtained by splitting a primary one) with the ATLAS apparatus gives an estimation of the required dynamometric parameters. In the future, it will be possible to derive these last properties with greater precision from the diameter profile of the fibre (work in progress at CENTEXBEL).

Part of the work done in the present research concerns the comparison of these two different characterisation of the raw wool and their relative effectiveness for the prediction of the topmaking performances (cf. 2.3).

2. TECHNICAL DESCRIPTION AND RESULTS

The present chapter contains various sections, corresponding to the principal points of research of the project.

The first section (2.1) describes a study of the influence of the card settings on the collecting power of the workers of the card. That study is of interest to link the settings of the workers to the regularization of the outgoing sliver and the thoroughness of the blending action.

The three following sections (2.2, 2.3 and 2.4) concerns the development of different models simulating the topmaking performances (top fibre length distribution, card losses and noil rates) on the basis of a description of the raw wool at different levels.

In the fifth section (2.5), prediction of sliver cleanliness is studied (on the top and third passage slivers).

Section 2.6 presents the software which has been developed for the selection of the main settings of the topmaking process on the basis of some of the previous models; a first version of this software is presently installed on the card with fully automatic settings whose development is presented in the next and last section. The model implemented in this software is the wool staple based one because only staple level characterisation is commercially available today.

The last section (2.7) presents the features of a new modem worsted card specially designed for the implementation of CIM in worsted spinning.

2.1. *Models for the collecting powers of the card*

2.1.1. Introduction

When fibres transported by the swift arrive at a carding point, part of them are collected by the worker. They will stay on it until they encounter the stripper roller which will redeposit them on the swift behind the carding point.

This process of fibres collection and recycling plays an essential role in the behaviour of the card. Indeed, the ability to blend and to regularize the fibre layer on the swift and to disentangle fibrous structures depends directly on the fibre **recycling level. Recycling has** however a drawback because it increases the risk of fibre breakage. A practical compromise is therefore to be searched for its level.

The collection of the fibres at a given worker is characterised by the *'collecting power" of this worker. The collecting power (abbreviated as *CP*) is defined as the proportion of material transferred from the swift to the worker in steady state. [f one accepts the hypothesis that every fibre arriving at a carding point has the same chance of being caught by the worker, the collecting power is the associated probability. Moreover, the mean number of collections for a given fibre (or *MNC*) is then the ratio of two fibre flows: one along the worker and the other along the swift before the stripper-worker pair. Both variables are linked by a simple relationship:

$$CP = MNC / (1 + MNC) \qquad (1)$$

The *MNC* can be easily computed from the ratio of two surface loads (weights by surface unit) called **"Swift to** Worker Surface Load Ratio" or *SWSLR* and the "Swift to Worker Speed Ratio" or *SWSR*:

$$MNC = 1 / (SWSLR * SWSR) \qquad (2).$$

Our objective was to study experimentally the influence of the card parameters and of the wool characteristics on the collecting powers of the workers and to establish models of these collecting powers which would allow to quantify the carding action in practical cases.

2.1.2. Experimental set-up

A small card with four active workers and rigid clothing has been used. Measurements of the surface loads of the workers have been obtained while the card is running using a scavenger roller.

Six different lots of wool have been used for that particular study (Table 2-1): the first five lots (Al to A5) correspond to the preliminary studies and the last one has been used for a detailed analysis of the main effects and the principal interactions. That analysis led to a first model. When grouping all the results together, a second model, including the wool properties, has been elaborated. "

	diameter	***Hauteur***
	(microns}	(mm)
A1	19.3	49.4
A2	19.1	60.9
A3	20.9	55.3
A4	21.8	68.6
A5	22.5	57.3
B	20.4	56.4

Table 2-1: Characteristics of the lots used for the study of the collecting powers

2.1.3. Development of a regression model including the effect of the fibre properties

The corresponding model is based on a regression of the transformed *SWSLR* against the logarithms of the *CWS*, the *PWS* and the *SWSR* plus the logarithm of the Hauteur (mean fibre length weighted by the fibre linear density} (see Table 2-2). The multiple correlation coefficients are satisfactory. It can be seen that the influence of the mean fibre length (Hauteur) increases with the position of the worker along the swift.

	constant	log(*PWS*)	log(*CWS*)	log(*SWSR*)	log(Hauteur)	R
Worker 1	0.82?3	0.0	0.018	-0.043	-0.050	0.906
Worker 2	0.866	-0.237	0.048	-0.039	-0.058	0.884
Worker 3	2.143	-0.018	0.049	-0.038	-0.372	0.906
Worker 4	3.431	-0.015	0.055	-0.039	-0.674	0.955

Coefficients and correlation for the transformed S *WSLR*

SWSLR = (transformed *SWSLR*)^5.430356

Table 2-2: Regression study of the collecting powers (model II)

For example, Figure 2-3 represents the *MNC* and the *CP* of the first worker in function of the current gauge value (*CWS*) and the S *WSR*. The spacing of the preceding worker has been fixed to 1.2 (worker 2) and .3 (workers 3 and 4). The Hauteur is fixed to 56.4 mm.

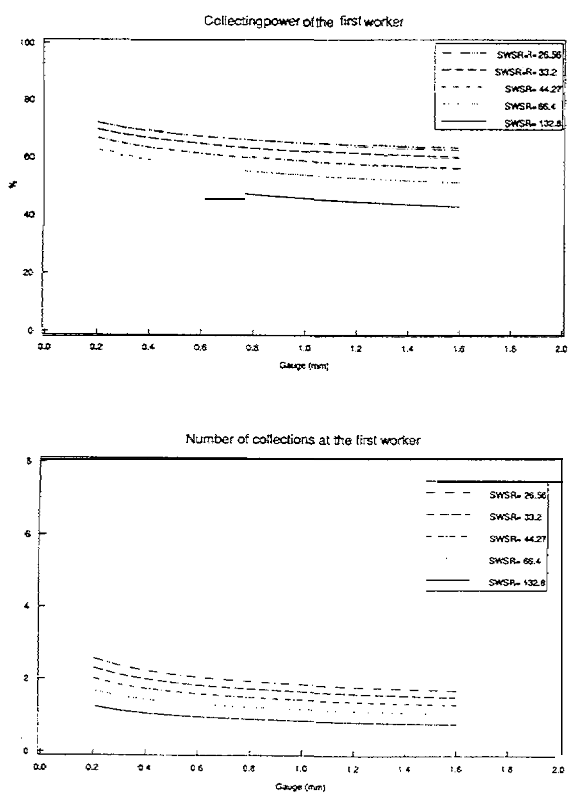


Figure 2-3: Influence of main variables on collection at worker 1

2.2. *Models for the simulation of the topmaking performances (common features)*

The term "topmaking performances" covers generally the fibre lengths distribution in the top sliver and the percentage noil produced at the combing stage; we extend if by including also the percentage losses at the card.

2.2.1. Introduction

Regression analysis has been used to determine the degree of association between the topmaking performances and the raw wool measurements [2,3,4]. Brown et alii [5] have discussed the statistical problems to be faced with when using regression equations for prediction purpose. These models do not include the effect of the machine settings (at the card or the comb); moreover they do not simulate the amount of wool loosed at the card itself.

We present here a true modelling approach to the prediction problem. In brief, a whole top and noil fibre lengths distribution is obtained by combining the simulations of the basic transformations of lengths which occur when the fibres are extended, broken or sorted. In doing so, only physically feasible results are obtained and the insertion of machine settings is largely facilitated. Besides, the *model* takes into account the correlations existing between the independent staple variables (length, strength and weak point position). Finally, as the top parameters (hauteur, coefficient of variation of hauteur, barbe, etc....), the noil rate and the amount of wool lost at the card are all computed from the same simulated distributions, possible incoherence are largely avoided.

At the beginning of the present research, some work had already been done in following the mechanistic approach to the simulation problem [6,7]. That work did not take into account the settings of the card (cylinders speeds and clearances, production rate); moreover, the percentage card losses was not predicted in this initial work

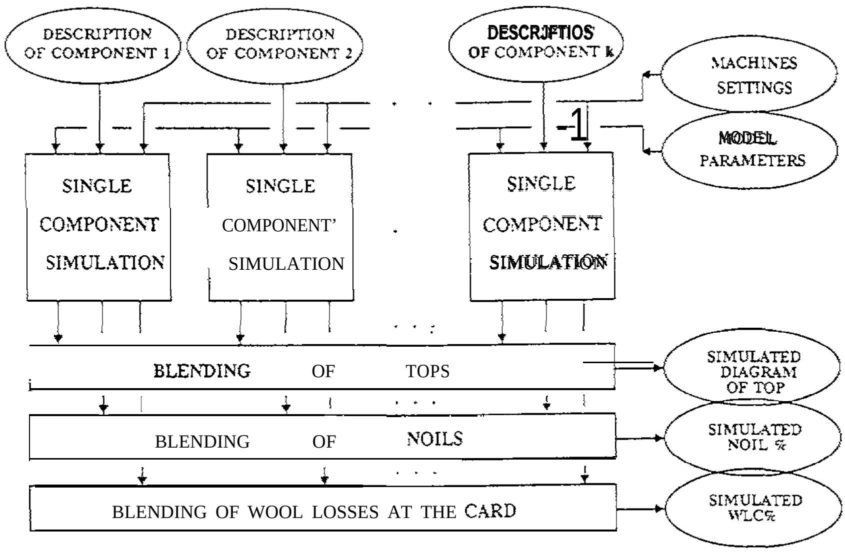
After having discussed the model's principal features, we will explain how the parameters fitting problem has been solved in this case. The experimental work and the simulation results will be discussed in the following section.

In a next section, we present also a comparison between two approaches for the simulation of the topmaking performances: one based on the wool description at the staple level and the other on the wool description at the fibre level; that last approach is promising and, as far as practical industrial methods and apparatus are available for the corresponding measures, it will probably replace the first one in the next future.

2.2.2. Principles of the simulation

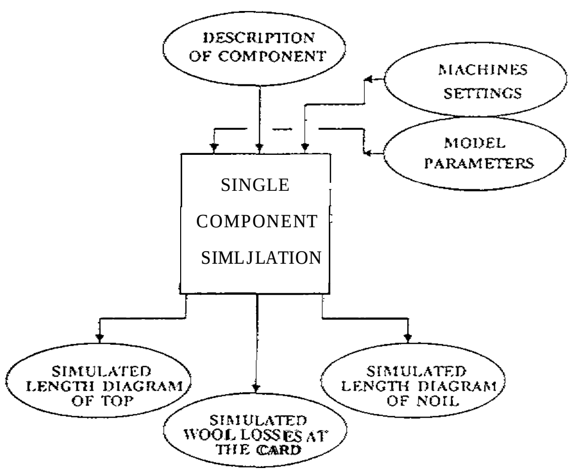
When simulating modifications of the fibre length distribution, it is important to limit the set of possible input/output relationships to the only physically feasible ones. In particular, each individual fibre should only give rise to one or more fibre segments of equal or smaller sections and whose total volume is equal to the original fibre's one. This will be the case if and only if the physical process is simulated with a combination of extension and break operations, a third operation being required to sort the fibres when separate handling is necessary. Because the input/output relationship of such a simulation model is always physically feasible, we may expect that its use at the boundary or even outside of the domain spanned by the experimental data on which it is based will at ieast not iead to unrealistic results.

in order to simulate the topmaking process, each component of the batch of wool is simulated separately (see Figure 2-4). The simulation of a single component requires specific inputs and produces a simulated fibre lengths diagram, a simulated noilage level and a simulated percentage of card losses (see Figure 2-5). The elementary operations are combined as shown in Figure 2-6. As the characteristic function of each operator depends upon wool variables measured at the farm or farms group level (diameter, vegetable matter contents, yield), the simulation is conducted separately for each farm or farms group.



Simulation of the carding and combing process for a batch of wool.

Figure 2-4: Simulation of the carding and combing process for a batch of wool



DESCRIPTION OF A SINGLE COMPONENT:
mean staple length, strength and posit. of break
mean diameter, yield, V.M. contents
level of entanglement

MACHINES AND PROCESS SETTINGS:
card production rate, main swift speed, SDSR,
main comb setting and feed, % recombing

MODEL PARAMETERS:
experimentally fitted to a particular fabrication line

Figure 2-5: Simulation of the topmaking process for a single component

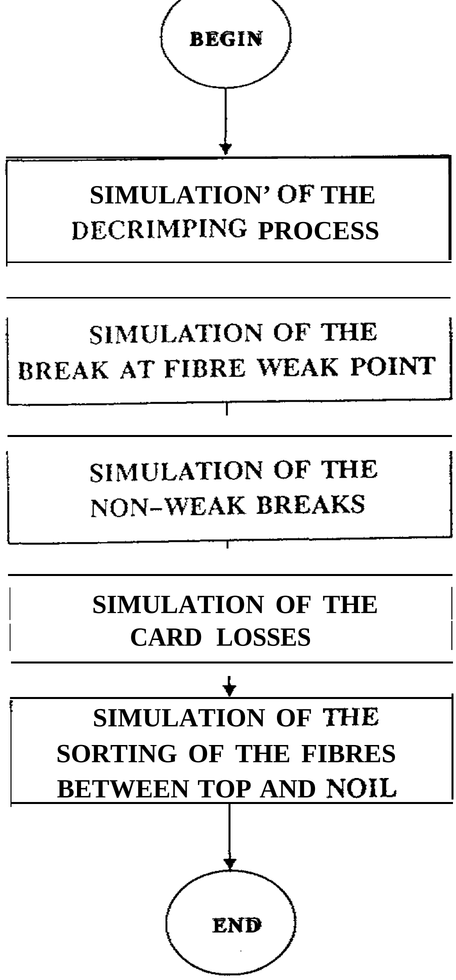


Figure 2-6: The principal steps of the simulation of topmaking for a single component

Three steps are foreseen, the two first corresponding mainly to the carding action and the last one simulating the work of sorting which is done by the combing machine.

In the first step, each class of staples (i.e. a group of staples having similar lengths, strengths and positions of break) is submitted to the following operations:

- Extension of individual fibres or partial crimp removal; this operation is based on the hypothesis that the fibre length distribution inside a staple is roughly log-normal. That hypothesis is not to be done if the wool is described at the fibre level because a full fibre lengths distribution is then available.
- Fibres break tentative at the weak point; this is performed for each length class of the extended fibres length distribution associated to a particular staple class ; the probability to break depends on the staple strength, the diameter and the fibre length; the break point along the fibre is distributed symmetrically around the weak point, its dispersion being small wen the staple strength is low and larger when it is high (resistant or "sound fibres).
- Separate accumulation of broken segments and unbroken fibres, from staple class to staple class.

The second step concerns the simulation of fibre breaking outside the weak region of the staple. Each broken segment length class is submitted to a break operation with a normal level of strength (in fact, a parameter of the model) and a wide distribution of break points symmetrical around the half of the centre of class. Unbroken segments are still accumulated separately. Broken segments may be recycled in another normal break. The number of such recycling steps is a parameter of the model.

Final[y, the sorting step takes place after having grouped together the broken and the unbroken segments (the last ones being in fact every fibre or fibre segment which has not undergone the maximum number of breaks). The card losses and the combing noil rates are computed at this stage. Correction is allowed in case of high vegetable matter contents.

The general mathematical formulation of the operators is presented in [6].

2.2.3. Construction of the breakage operator

Particular trials have been used to develop the breakage operator and to validate the model. In these trials, wider variations of the card settings have been introduced in planned experiments.

From these trials the reduction of fibre lengths between the scoured wool and the card sliver **has** been linked to the card surface load, the SDSR (swift **to** doffer speed ratio) and the entanglement level of the scoured wool. The form of the model which has been fitted to the experiments! data has been inspired by the literature [8,9].

2.2.4. Fitting the parameters of the models to experimental data

When looking for some measure of the difference between the actual top, card losses and noil results and the simulated ones, it is interesting to replace the top lengths distribution by a few statistics of practical **interest.** If those statistics have also the property to be continuously differentiable up to order two with respect to the parameters, it will considerably accelerate the convergence of the fitting problem [10].

Our choice of statistics for the top is the Hauteur distribution's mean value, coefficient **of variation,** length exceeded by 5% of the fibres and percentage of fibres below 25 mm. Adding card losses and noil contents, we get a very natural six-dimensional characterisation of the simulation output. All these statistics can be shown to be differentiable up to order one with respect to all parameters and up to order two for most of them.

The parameters of the simulation model are obtained as the solution of a non-linear least-squares optimisation problem with simple bounds on the variables. The complete algorithm is due to M. J. Il. Powell[11].

2.3. *The prediction of the topmaking performances from staple level data*

2.3.1. Experiments

53 observations

Variable	Mean	Standard Deviation	CV(%)	Minimum	Maximum	Range(%)
Length	81.39	**7.60**	**9.33**	**67.50**	**101.56**	**41.85**
Strength	**35.19**	**4.21**	**11.95**	**27.48**	**44.13**	**47.32**
Diameter	**21.17**	**2.18**	**10.27**	**16.75**	**25.30**	**40.37**
VM(%)	1.22	0.83	67.88	0.34	4.00	300.20
POB(%)	51.29	6.48	12.63	33.43	71.53	74.30
H	68.00	7.15	10.52	56.40	85.85	43.30
CVH	46.84	3.66	7.81	36.18	54.40	38.91
L5%	123.82	10.94	8.83	99.40	149.26	40.27
%<25mm	**6.97**	**2.46**	**35.32**	**0.34**	11.80	164.44
Romaine	**9.63**	**3.86**	**40.03**	**3.86**	**19.73**	**164.76**

Table 2-3: Staple simulation: characteristics of the lots

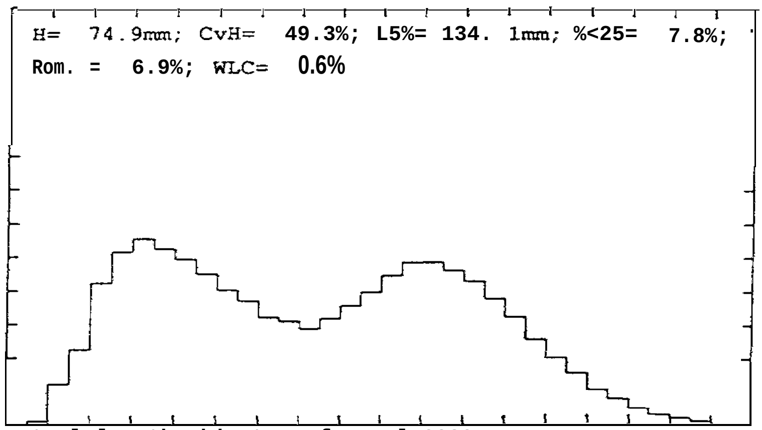
A set of 53 industrial batches has been processed in routine production implying limited variations of the settings. The raw wool characteristics of these lots are summarised in Table 2-3 (first half). The top length properties and noil levels (romaine) are also given in Table 2-3 (second half). The corresponding residual standard errors are given in Table 2-4. These errors are computed from the differences between the actual and simulated values of the processing variables.

Topmaking performances	H	CVH	L5%	Rom%	%<25mm
Standard deviations of residuals	**3.3**	**3.0**	**3.4**	**3.1**	**2.6**

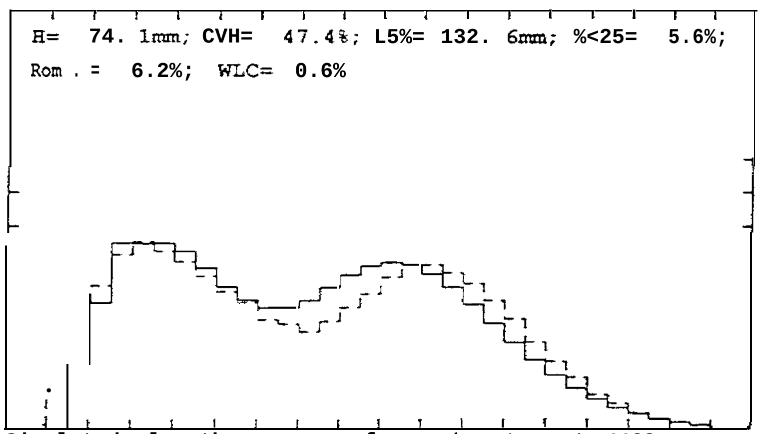
Table **2-4**

An illustration of the simulation's output is given at Figure 2-7. The simulation gives the full distribution of fibre lengths, including typical bimodal features. The noil (romaine) is predicted with a Precision similar to the Hauteur's one. Wool contents of the card losses are also simulated. The continuous line in diagram below gives the simulated histogram, the dashed line represents the actual top fibre lengths distribution.

It is important to note the wide variation of the principal characteristics of the raw material, especially in what concerns the diameter and the vegetable matter contents (VM). In regard to this variation the preceding results can be considered as satisfying. One of the weaknesses of the staple approach is in the fibre lengths characterisation: staple length, although largely correlated with single fibre length, is still an approximate estimation of it. The next section explains the work done in the framework of the present research to compare staple length and fibre length characterisation of the raw material.



Actual lengths his-t. - from al123S3. FRM



Simulated lengths hist - from . /pond_num/b 1123. FRM

Figure 2-7: Simulation of topmaking performances from staples

2.4. *The prediction of the topmaking performances from fibre level data*

2.4.1. Introduction

For a combing mill, the prediction of Hauteur and Neil on the basis of ATLAS instrument and TEAM equations still leads to relative large confidence intervals. Even if the measurement of staple length constitutes an excellent approach, the fibre length distribution, regarded as the essential characteristic, remains poorly estimated mainly due to the fact that the fibre crimp is not taken into account.

The principal objective of this point of research was to obtain a better precision for the prediction of carding and combing performances (top fibre length distribution, card losses and noil) by the introduction of a measure of fibre length distribution on raw wool as a substitute for staple length measurement.

2.4.2. Experiments

A set of 20 Australian wool lots has been processed into tops in industrial conditions. The principal settings of the carding and combing process have been varied, and the top produced has been measured for their distribution of fibre lengths with the Almeter system. The mean diameter of the wools is comprised between 17 and 29 microns.

In order to characterize the fibre length, strength and position of break properties, cliff erent methods have been used:

1. ATLAS testing of staples to get the 3 variables (to be extrapolated to fibres in modeling);
2. Almeter measurement of fibre length inside staples plus ATLAS testing of strength and p.o.b. on companion staples;
3. single fibre length measurement (30 fibres by staple) using a modified WIRA tester plus ATLAS testing of strength and p.o.b. on companion staples.

The companion staples were obtained by dividing in two the thick staples along their axis and taking thin staples in double using two neighboring ones. Testing of staples from such pairs show very similar properties (ATLAS and Almeter). This pairing was done to eliminate as much as possible the natural variation of the staple properties from the comparisons to be done between the 3 methods. From each of these pairs one staple has been measured for length, strength and position of break using the ATLAS tester. From the other staple, a sample of 30 individual fibres was measured with a modified WIRA single fibre length tester. This last staple was thereafter gilled using the special Centexbel-Linartex gill, then after alignment of its fibres by the roots at the Fibroliner (Almeter automatic grip), it was measured with an Almeter with special software.

2.4.3. Simulation

These 3 different descriptions (see 2.4.2) have been used as input to various versions of the same simulation program which was initially developed for a staple level characterisation of the wool. For the simulation of the cases 2 and 3, the first operator, which corresponds to an elongation (or uncrimping) step has been simply skipped. Only two parameters of the model (on a total of 18) have been adjusted using the 3 available databases. These parameters are directly related to fibre length properties. This gave 3 different simulation programs each using a different method to characterize the fibre length of the raw wool.

For simulation i (i = 1,2,3 above), a residual standard error or RSE(i) can be computed for each statistics of the fibre length distribution (like Hauteur, CVH, L5, etc...) and for the noil (Romaine): it is a measure of the difference between the actual and simulated values of the processing variable (in fact, the standard deviation of the set of differences) (Table 2-5).

Simulation 1: ATLAS length measurements

Topmaking performances	H	CVH	L5%	Rom%	%<25mm
Standard deviations of residuals	3.7	3.3	7.6	2.5	2.3

Simulation 2: Almeter fibre length measurements on **gilled** staples

Topmaking performances	H	CVH	L5%	Rom%	%<25mm
Standard deviations of residuals	4.5	2.8	2.7	3.9	2.5

Simulation 3: WIRA single fibre length measurement (30 fibres by staple)

Topmaking performances	H	CVH	L5%	Rem%	%<25mm
Standard deviations of residuals	3.0	2.2	3.9	2.2	2.2

Table 2-5: Simulation results with two different characterisations of the raw material

2.4.4. Conclusions of the fibre level model study

1. For most of the statistics, RSE(2) is higher than RSE(1) or RSE(3);
2. For most of the statistics, method 3 (WIRA+ATLAS) compares favorably to the two other methods; compared to method 1 (ATLAS only) the observed differences in terms of 95°A confidence interval widths amount to 2 mm for the Hauteur and 1.2 for the Romaine.

In using the Fibroliner when preparing Almeter samples from a gilled staple, it is difficult to avoid some fibre breakage. Although a particular software was used to filter the Almeter diagram of lengths associated to a single staple before using it in the simulation, the residual standard errors of the simulations are higher than for the two other methods.

The simulation of carding and combing gives better results when the raw wool fibre length distribution is measured at the single fibre level. The differences with respect to the other approaches of fibre length measurement (ATLAS staple length and ALMETER fibre length) would have been larger if a separate development, parameter adjustment and cross-validation of the fibre level model was possible. This was not the case because of the limited amount of lots available for this type of simulation (for comparison, the SIMTOP ATLAS based model, has been initially developed on the basis of a database of 80 lots).

2.5. *Models for the simulation of the sliver cleanliness*

Neps and vegetable particles contents characterise the “cleanliness” of a sliver.

Different models have been obtained using multiple regression analysis of the data collected. Backward regression has been used to reject insignificant variables.

2.5.1. Experiments

A set of 45 trials has been done on 6 different wools following as much as possible a complete 2 levels 3 factors plan for each [et. The range of the variables is given in Table 2-6; defect rates have been transformed by a square root operator to equalise their variances. The factors were the card speed and surface load and the SDSR (swift to doffer sped ratio) for the first three batches; the two levels of the SDSR have been replaced by a variation of the settings of the three last workers of the main swift (12/8/5 and 20/12Y8; settings expressed in tenths of mm} in the three other series of experiments.

45 observations

Variable	Mean	Standard Deviation	CV(%)	Minimum	Maximum	Range %
Length	**82.16**	**7.35**	8.94	**71.09**	91.98	25.06
Strength	**35.10**	**6.91**	19.69	18.22	42.88	70.27
Diameter	**20.85**	1.35	6.48	19.16	22.70	16.98
VM	1.39	1.28	91.72	0.30	3.95	261.81
%M	**53.62**	**14.22**	26.51	29.90	77.02	87.88
Neil %	**8.70**	**1.49**	17.09	5.95	11.50	63.78
√Def. Veg. /kg on 3P	**219.33**	70.01	31.92	134.84	333.40	90.53
√Def. Fibr. /kg on 3P	**233.13**	59.02	25.32	126.20	346.59	94.54
√Def. Veg. **/kg on top**	28.04	10.22	36.45	16.94	56.14	139.82
√Def. Fibr. /kg on top	22.38	8.63	38.55	7.21	38.04	137.73

Table 2-6: Characteristics of the lots used in the study of sliver cleanliness

2.5.2. Models of the cleanliness levels of the third pass sliver

The two models of the cleanliness in the third pass sliver (one for the fibrous defects and the other for the vegetable defects) are interesting for a better prediction of the noil in which these defects would normally be eliminated at the combing stage. These models have been found to have high squared multiple correlation coefficients or « Percentages of variation explained » (Table 2-7). The significant predictors are the raw wool variables (or a subset of them). It is interesting to observe that the card settings do not play a significant role in these equations. This could mean that the central point of the experimental plan is near to the optimal values. That point has been taken from current practice (in function of the wool diameter and vegetable matter content). Further experimental work will be necessary to draw final conclusions in what concerns these particular points.

Dependant variable	**√Def. Veg. /kg on 3P**
F level	2.054
Percentage of variation explained	98.031
Standard error of dependant variable	10.303
Constant	1038.725

Dependant variable	**√Def. Fibr. /kg on 3P**
F level	0.671
Percentage of variation explained	**84.847**
Standard error of dependant variable	24.098
Constant	**1602.584**

Table 2-7: Models for the cleanliness of the third pass sliver

2.5.3. Models for the cleanliness of the top

Two models for the cleanliness of the top are also available. They **have been obtained on the same basis** (Table 2-8). Supplementary data are required to validate these models and use them in the computation of the card settings.

Dependant variable	Def. Veg. /kg on top
F level	0.490
Percentage of variation explained	88.165
Standard error of dependant variable	3.734
Constant	141.926

Dependant variable	Def. Fibr. /kg on top
F level	1.862
Percentage of variation explained	91.551
Standard error of dependant variable	2.664
Constant	233.023

Table 2-8: Models for the cleanliness of the top

2.6. Software for the selection of the card and comb settings

2.6.1. Introduction

A computer program called SIMTOP has been developed for the prediction of the detailed top fibre lengths distribution and the topmaking “losses” (card losses and noil) starting from raw wool measurements data and taking into account **process** and machine settings. This software has been designed to help the topmaker in selecting the settings of the whole process, in particular those of the canal. If all the other settings are fixed (those of the combing machine are seldom modified because their are not automated) a true CIM can take place when using the automated card developed by one of the partners of the research. The settings are installed on the basis of a recipe file which can be transmitted directly to the computer of the automated card.

The simulation of the whole consignment is obtained by processing successively each individual component or sale lot.

The simulation results appear under the form of an Almeter diagram of the predicted fibre lengths distribution in the top, a prediction of the card losses (wool contents) and *a* prediction of the noilage level (Romaine).

The underlying model is designed to enable processors to maintain close control over the operations of their machinery.

SIMTOP is running on PC computers, under DOS 3.0 or higher operating system.

2.6.2. Description of the input data

The following types of data are requested to run the program: for current use, raw wool measurements data, and machine settings values, as chosen in the actual processing; to simulate a given mill or fabrication line, a special set of numerical values, the configuration data, which are computed from actual experimental results.

2.6.2.1. *Raw WOOI description*

The corresponding files are to be placed in a dedicated database.

Each raw wool data file corresponds to a single component (usually a farm’s lot) or to a consignment made of several components blended with some weights (see variable x5).

A. Structure of *the* ***raw wool*** *data* ***fifes:***

For each component in the raw wool data file, 9 variables must be given numerical values.

These variables are:

- xl: Identification of the component (or farm's lot).
- x2: Mean staple length (mm).
- x3: Mean relative position of the break measured from the tip (%).
- x4: Mean staple strength (N/ktex).
- x5: Net greasy weight of the component (kg} (only meaningful for a consignment, see further).
- x6: Mean fibre diameter (microns).
- x7: Vegetable Matter Contents (%).
- x8: Yield (Schlumberger combed dry)(%) [estimated commercial . ..].
- x9: Coefficient. of var. of staple length (%}.

B. Specification of a raw wool blend:

When running the program, it is possible to simulate a final blend by specifying several data files and associated wool weights. This blend is among the corresponding single components and / or consignments. In the last case, it is therefore a blend of blends.

It is thus possible to simulate raw wool blending at two levels, as it can occur in topmaking practice. By doing so, detailed informations at the lowest level are not lost and the precision of the simulation is not reduced.

2.6.2.2 ***Con figuration files***

Ear% configuration file contains a set of 18 numerical values computed from an experimental data base and playing the same role as the coefficients in a regression equation. A given configuration file corresponds to a particular fabrication line and must have been computed on the basis of experiments performed on the given fabrication line.

An automatic procedure for computing a parameters file starting from an experimental database is being ported to the DOS and WINDOWS operating systems.

26.2.3. ***Machine settings***

Machine settings are to be specified at run time:

- Card production rate (kg/h).
- Card width (mm).
- Main swift tangential sped (m/min).
- Swift to doffer speed ratio or SDSR.
- Level of scoured wool entanglement (a figure between 1 and 5). That setting may be used to characterize different scouring lines or different conditions of scouring without the need of building separate experimental data bases. Set to 3 for usual openness.
- Main comb setting (mm).
- Combing feed (mm).
- Recombing level (%). This corresponds to the proportion of already combed wool entering the combing machine.

2.6.3. Running the software

The user is requested to specify the various inputs with the aid of detailed and explicit menus. He has to indicate which setting of the whole topmaking process will be simulated. Such setting will correspond to good practice values obtained by experience and taking into account the local production context. For each wool type, a library of typical settings can be established (fibre diameter and strength plus the vegetal matter contents being the most indicated variables to characterise a type of wool). The simulation of the topmaking performances associated to such a group of settings can be done in one step. All the corresponding results can be visualized on the same screen. At any time during a simulation session, the user may decide to build a Carding/combing recipe on the basis of one of the simulated settings. That recipe maybe entered in a database or immediately used to settle the card and start the fabrication.

2.7. *Computer controlled worsted card with automated settings*

A new electrical cubicle with electric control board has been designed, where a programmable logic controller used as interface between the central control microcomputer and the electric control has been installed. The individual motors with speed variation allowing to modify all the important settings of the card, has been installed on the control zone of the new construction, together with electronically controlled speed variators.

Several trials have been performed on the experimental industrial card to test the microprocessor control system ensuring the speed variation of the main rollers of the card. The software realising the display of the different speeds with their limitations on the monitor screen, in order to automates their adjustments, has been implemented.

A system allowing the adjustment of the clearances of the main swift workers has been developed. This system is particularly innovative (the experimental card is probably the only card in the world having that feature) and makes all the settings of the worsted card for' the first time directly modifiable by computer.

The main difficulties, encountered and solved, were:

1. to synchronise thoroughly the motion of each side of the worker cylinders, and to check the accuracy of the displacement (0.05 mm) as the normal settings vary from 0.1 to 2 mm;
2. to ensure that the clearance between the worker and the stripper will remain constant in spite of the vertical displacement undergone by the worker;
3. to install a servo-control to ensure the reliability of the setting and safety during working;
4. to allow a remote control from the control desk, and therefore to modify the supervision software to take into account these settings.

This system has been installed on the card prototype.

3. CONCLUSIONS

The study of models of the principal functions of the worsted card required to perform specific experiments and to process a large number of industrial batches. This was necessary to define the principal variables and interactions, the forms of the models and to confirm the structure of the elementary operators. That experimental work has been followed in details, characterizing as far as possible the fibres at the various stages of the processes and building an important database. That database, completed with the settings in use along the processes and the final results is of a great practical interest in itself.

Various functions and properties of the card have been modelled. Some of these models are available under the form of a regression equation (collecting powers of the workers, mean number of collection at the various workers, vegetal matter contents on the third pass sliver, neps contents on the third pass sliver, vegetal matter contents on the top, neps contents on the top). For most of them, more data should be made available to draw robust conclusions which can be applied safely in an industrial context. Nevertheless the analysis of the main effects and interactions which has been done when developing these models has been useful for building the mechanistic model of the topmaking performances. That model simulates the modifications of the fibre lengths distribution from the raw material to the top, « weighing » also the card and the comb losses (or noil).

The staple level version of that last model has been implemented in software form to be run on an industrial card in order to guide the topmaker in the choice of the numerous settings of that essential machine in the worsted spinning process. On the basis of the raw wool description, production can therefore be easily optimised, for a given acceptable level of fibre breakage and noilage production. It is also possible to search for an optimal blend of raw materials, the performances of a blend being simulated with a good precision by the same blend of the separately produced tops, provided that the components have their properties in a reasonable range.

Effective use of the developed models would not have been possible without the availability of a fully automated card and the integration of the software in its control computer. Such a card has been studied, developed and installed in industrial context. Some practical experience is still required before a complete evaluation of its benefits can be done. Nevertheless the possibility to settle directly the principal variables of the card from optimised recipe files computed with the aid of the developed software is seen as a significant competitive advantage.

4. Acknowledgements

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