The Transfer Of Results Of Process Trials Into Mass Production Of Knitwear

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One of the most important tasks of product development is to carry out process trials using new raw materials and new processes and to transfer the experience of these trials into mass production. In knitwear factories this experimental work is done in trial lots. The paper presents the methods used by technologists in one of the largest Hungarian knitwear factories, which make it possible to improve the reliability of transfer of trial results into mass production.

HABSELYEM Knitting Mill is one of the largest Hungarian knitting companies, at present employing more than 4,000 people, with a yearly production of about 20 million garment pieces. It was originally founded in 1923 and its traditional product group is ladies' underwear made on warp knitting tricot machines and on circular knitting machines, mainly from synthetic filament, viscose rayon, acetate and triacetate yarns and modal/polyester blendings. During the last decade leisurewear articles have come to the front, made of cotton/polyester blendings. Fabrics are dyed and finished by the company's own dyehouse or on commission for Habselyem. The ready-made garments are cut and sewn in the company's big subsidiary works in different parts of the country.

Aim And Tasks Of Process Trials

One of the most important tasks of product development in the knitting industry is to carry out process trials using new materials and new processes and to transfer the experience gained from these trials into mass production. To accomplish this with good results it is vital to arrange the trials in the right way, i.e. in a way which leads to sufficient experience for mass production. In knitting factories the usual method for this is to produce trial lots. In the course of these trials production conditions are recorded, the necessary measurements and tests are made, and at the end of the trial the finished product will be thoroughly examined in regard to technical and economical factors in order to establish technical specifications.

Thus, production of trial lots has to be planned in the following way:

1. It has to ensure that both the chosen machinery and process are suitable to manufacture the product in question.
2. Tests must verify that the product will have the required substantial functional properties.
3. Wearing and laboratory tests must verify that the product really provides the required properties.
4. The process trial must disclose problems in the production process and in the product itself which have to be eliminated before starting mass production.

Clearly it is advantageous if the process trail can be carried out in this way but there are some limits at the same time:

1. Process trials are always better controlled and subject to less risks than mass production.
2. For production or business reasons sometimes the development period of a new product has to be very short. In this case it is not possible to carry out process trials under optimal circumstances.
3. Process trials cost a lot, consequently their quantity is less than optimal.

The Problem

Both the requirements and limitations listed above, require a careful analysis of the results of process trials. Since the process trial usually gives a number of pieces of products, which generally have different statistical parameters. These can be dealt with and analysed by statistical methods. It provides a way to see some tendencies from a limited number of results.

In the following part of my paper I am giving an account of our initiative at Habselyem Knitting Mill in the use of statistical methods in our process trials in knitted fabric production. Until recently it has been confined practically to calculation of the arithmetical mean. Deviations from the mean have been only "surveyed" and we have only provided comments without statistical background, like: "results show a wide range" or "the trial lot seems to be too small to enable us to draw unambiguous conclusions".

It has become even more and more evident that this method was not satisfactory. Sometimes during mass production we have had unpleasant shocks when we could not reliably reproduce the parameters prescribed on the basis of the process trial. In order to improve this situation we have decided to use mathematical statistical analysis of results of process trials. This is especially important in cases when we put into use a new yarn type or a new technology which results in a fabric with unknown properties.

One of the most important and most characteristic parameters of our fabrics is their area density (given in grams per square metre) which can be considered as complex product of several different parameters. It is, at the same time, one of the basic data of calculation. This is, therefore, the parameter which must be and has been analysed most carefully by statistical methods. I want to show you in the following paragraphs the methods and the main results of this analysis.

Statistical Formulae

After having measured the area density "m" of fabrics in question we can calculate and document the following data:

arithmetical mean $$\bar{m} = \frac{\sum_{i=1}^{n} m_i}{n}$$

range $$R = m_{max} - m_{min}$$

standard deviation $$s = \sqrt{\frac{\sum_{i=1}^{n} (m_i - \bar{m})^2}{n-1}}$$

coefficient of variation $$v = \frac{s}{\bar{m}} \cdot 100\ (\%)$$

confidence limits and level of significance. $$q = \pm t \frac{s}{\sqrt{n}}$$

Let me give some comments on the above calculations.

The number of specimens (n) is usually small. Our trial lot in practice is normally one dye lot i.e. about 150kg. This is the normal capacity of a dyeing machine. Our pieces taken from the knitting machine weigh roughly 15kg each, a dye lot therefore generally consists of ten pieces. Fabric is expensive so we do not want to use too much of it as a specimen. From previous experience we know that the specimen for measuring area density can be taken out about at one third of the fabric width and about at one meter distance from the end of the piece. (Area density of course, varies across the piece: it is highest at the edges and lowest in the middle of the knitted fabric and the function can be represented by a parabola). If we take out the specimen from the place mentioned it represents a good mean.

We take out, therefore, one specimen from each piece, so we have usually ten specimens from one trial lot. This is the reason why we have to use "n-1" when calculating standard deviation. This relatively small number of data will be used also in significance analysis.

Our final aim is to give the tolerance limit for the area density with a certain statistical level. As statistical level we can accept 99.9% because of the small number of specimens. The result of our calculation is the value of area density in this form:

$\bar{m} \pm q$ (g/m²) with 99.9% probability.

Significance test is an important part of our new concept. We use it when we want to decide if the deviation between process trial and mass production can be considered only to be transient or to be caused by a real difference between production methods.

Two of the many types of significance tests we usually use:

1. When it is to be decided if the difference means between process trial (m_t) and mass production ($\bar{m}$) is significant or ($\bar{m}_m$) not, we use the formula

$$t = \frac{(\bar{m}_t - \bar{m}_m)}{s_m \div \sqrt{n}}$$

Where "s_m" is the standard deviation of specimens taken out from the mass lot. The calculated value of "t" will be compared with the standard t-chart at a degree of freedom of "n-1".

2. When it is to be decided if the difference of standard deviations between process trail (s_t) and mass production (s_m) is significant or not. "s_m" is dealt with as known value. The formula is:

$$X^2 = n\,(s_t \div s_m)^2$$

And the value of X^2 will be compared with the appropriate chart, again at a degree of freedom of "n-1".

In a knitting factory area density is a value which is very strongly influenced by production circumstances. It is influenced by machine setting parameters, yarn quality parameters and other technological effects. Because of their complexity it is very difficult to keep all the circumstances on a constant level, always and everywhere. Consequently, area density unavoidable, fluctuates, but this fluctuation must be kept within a reasonable range. At our company we allow a range of ±10% which means that

$$\frac{m_{max} - M}{M} \leq 0{,}1 \text{ and } \frac{M - m_{min}}{M} \leq 0{,}1$$

("M" is the prescribed value of area density).

On the one hand we have examined whether our real fabrics remain in this range in mass production, i.e. we have checked whether area density, when tested in mass production, scatters within the range ±q with minimum 99% probability.

On the other hand, we want to know if our technical data, given by the process trials, are trustworthy enough. We have

TABLE 1 - [illegible] of [illegible] fabrics

Fabric Code	Fabric character	Prescribed area density g/m²
A	Reverse locknit	125
[illegible]		110
[illegible]		100
D	Locknit	105
[illegible]		80
F		70
[illegible]		70
H	Stretch	104
I	Stabilized fabrics combination of pillar stitches and long underlaps/	80
J		85
K		65
L	Laces	70
[illegible]		80
[illegible]		78
O	[illegible] velour fabrics	125
[illegible]		125
[illegible]		127
[illegible]		125
[illegible]		145

Table 2/a - Data of Fabrics A to C

Statistical characteristics		Fabric A		Fabric B		Fabric C	
Name	Symbol	Process trial	Mass prod.	Process trial	Mass prod.	Process trial	Mass prod.
Number of specimens	n	11	297	26	113	13	131
Range, g/m²	R	111-102	138--102	116-97	118--100	93-90	110--91
Mean, g/m²	$\bar{m}$	107,8	119,8	109,7	107,1	91,9	101,3
Prescribed value, g/m²	M	125		110		100	
Tolerance limits at ±10%, g/m²		112,5-137,5		99-121		90-110	
Confidence interval at 99% probability, g/m²	q	±3,18	±1,0	±2,0	±1,0	±0,9	±0,8
Percentile confidence interval, %	q'	±2,3	±0,8	±1,8	±1,0	±0,9	±0,8
Standard deviation, g/m²	s	±3,3	±6,6	±3,7	±4,3	±1,0	±3,8
Coefficient of variation, %	v	3,1	3,4	3,7	4,0	1,1	3,6

Table 2/b - Data of Fabrics D to F

Statistical characteristics		Fabric D		Fabric E		Fabric F	
Name	Symbol	Process trial	Mass prod.	Process trial	Mass prod.	Process trial	Mass prod.
Number of specimens	n	8	236	12	713	10	357
Range, g/m²	R	100-105	111--94	91-74	91--83	69--66	77--45
Mean, g/m²	$\bar{m}$	103,1	1019	79,8	79,1	67,4	65,3
Prescribed value, g/m²	M	105		80		70	
Tolerance limits at ±10%, g/m²		94,5-115,5		72-88		63-77	
Confidence interval at 99% probability, g/m²	q	±2,1	±0,5	±4,1	±0,4	±0,8	±0,6
Percentile confidence interval, %	q'	±2,0	±0,5	±5,1	±0,5	±1,2	±0,8
Standard deviation, g/m²	s	±1,7	±3,1	±4,8	±4,4	±0,8	±4,3
Coefficient of variation, %	v	1,6	2,0	5,8	5,5	1,2	8,6

TABLE 2/c - Data of fabrics G to I

Statistical characteristics		Fabric G		Fabric H		Fabric I	
Name	Symbol	Process trial	Mass prod.	Process trial	Mass prod.	Process trial	Mass prod.
Number of specimens	n	11	208	8	142	10	308
Range, g/m²	R	79-62	79-61	108-94	113--97	82-77	96-64
Mean, g/m²	$\bar{m}$	70,1	69,8	102,4	104,9	79,9	83,5
Prescribed value, g/m²	M	70		104		80	
Tolerance limits at ±10%, g/m²		63-77		93,6-114,4		72-88	
Confidence interval at 99% probability, g/m²	q	±5,2	±0,9	±6,1	±0,8	±1,9	±0,8
Percentile confidence interval, %	q'	±7,4	±1,0	±5,9	±0,6	±2,3	±0,8
Standard deviation, g/m²	s	±5,5	±3,8	±5,1	±3,8	±1,9	±4,3
Coefficient of variation, %	v	7,9	5,4	5,0	3,6	2,3	5,2

TABLE 2/d - Data of fabrics J to L

Statistical characteristics		Fabric J		Fabric K		Fabric L	
Name	Symbol	Process trial	Mass prod.	Process trial	Mass prod.	Process trial	Mass prod.
Number of specimens	n	12	31	11	119	10	50
Range, g/m²	R	68-59	73--59	73-60	70--58	72--68	73--55
Mean, g/m²	$\bar{m}$	64,0	64,5	66,5	65,1	70,2	67,8
Prescribed value, g/m²	M	65		65		70	
Tolerance limits at ±10%, g/m²		58,5-71,5		58,5-71,5		63-77	
Confidence interval at 99% probability, g/m²	q	±2,8	±1,2	±4,1	±0,6	±3,6	±1,3
Percentile confidence interval, %	q'	±4,4	±1,9	±6,1	±0,9	±5,2	±2,0
Standard deviation, g/m²	s	±3,2	±2,7	±4,3	±2,4	±3,8	±3,7
Coefficient of variation, %	v	4,9	4,1	6,5	3,6	5,2	5,4

TABLE 2/e - Data of fabrics M to O

Statistical characteristics		Fabric M		Fabric N		Fabric O	
Name	Symbol	Process trial	Mass prod.	Process trial	Mass Prod.	Process trial	Mass prod.
Number of specimen	n	10	56	10	52	22	343
Range, g/m²	R	69-62	72-54	78-73	88-68	131--116	135--107
Mean, g/m²	$\bar{m}$	84,8	61,2	75,2	74,7	124,5	121,2
Prescribed value, g/m²	M	69		76		125	
Tolerance limits at ±10%, g/m²		62,1-75,9		68,4-83,6		112,5-1375	
Confidence interval at 99% probability, g/m²	q	±2,5	±1,6	±1,6	±1,4	±2,3	±0,7
Percentile confidence interval, %	q'	±3,9	±2,5	±2,2	±1,9	±1,9	±0,5
Standard deviation, g/m²	s	±2,5	±4,5	±1,6	±4,0	±4,5	±4,5
Coefficient of variation, %	v	3,9	7,4	2,2	5,4	3,6	3,9

prescribed, for instance, a value of area density which has to be kept, but we have to know with how much probability it can be kept in mass production. In cases when the average values and standard deviation of area density are different in trial lot and in mass production — and this is practically always the case — we make a significance test. This shows whether the difference was given by different machine settings or other technological parameters or it is only an accidental difference which can be explained by statistical reasons. This is very important to know because in the first case we, as technologists, have to take steps to correct the possible fault, whereas the latter case requires no intervention.

The investigation has been made on 19 warp knitted fabrics as shown in Table 1. The results are summed up in Tables 2/a and 2/g.

In the assesment of the range (R) we have set out from the requirement that it must not be more than ±10% of the prescribed value. We have ascertained that ten of the tested fabrcs in the trial lot have a smaller range in area density than allowed, nine of them have a larger deviation at least in one direction.

When comparing range in the trial lot with that in mass production we can ascertain that it is wider in every case in mass production. It means that we could not control the production circumstances in mass production as well as in process trials.

In accordance with this, standard deviation (s) in mass production is, in most cases, bigger than it was in process trials. Exceptions seem to be only fabrics E, G, H, J and K but differences in these cases are only partly proved by significance test to be significant. Only fabrics G and K show significant difference between mass production and process trial: standard deviation in mass production is significantly smaller in these cases than it was in process trial. This is very important because we definitely know that both the process trial and the mass production had been made on the same machine and produced by exactly the same technology which is a determining factor. Unfortunately, it is not always possible to keep this optimal circumstance in mass production. Our machines are of different ages and types and it is not always possible to produce the total quantity of the ordered lots on the same machines. This is the reason — and it is also proved by the above calculations — why it is so difficult to maintain good uniformity of production lots.

TABLE 2/f - Data of fabrics P to R

Statistical characteristics		Fabric					
		P		Q		R	
Name	Symbol	Process trial	Mass prod.	Process trial	Mass prod.	Process trial	Mass prod.
Number of specimen	n	10	267	13	28	11	71
Range, g/m²	R	129-115	99--129	12[illegible]-131	127--112	137--123	14[illegible]--110
Mean, g/m²	$\bar{x}$	122,9	116,5	125,3	119,0	131,0	127,1
Prescribed value, g/m²	M	125		127		125	
Tolerance limits at ±10%, g/m²		112,5-137,5		114,3-139,7		112,5-137,5	
Confidence interval at 99% probability, g/m²	q	±4,2	±1,0	±3,4	±1,9	±4,4	±1,7
Percentile confidence interval, %	q'	±3,4	±0,8	±2,7	±1,6	±3,3	±1,3
Standard deviation, g/m²	s	±4,2	±6,0	±4,0	±4,0	±4,5	±5,4
Coefficient of variation, %	v	3,4	5,2	3,2	3,4	3,5	4,3

TABLE 2/g - Data of fabric S

Statistical characteristics		Fabric S	
Name	Symbol	Process trial	Mass prod.
Number of specimen	n	10	231
Range, g/m²	R	146-137	165--111
Mean, g/m²	$\bar{x}$	141,3	133,5
Prescribed value, g/m²	M	145	
Tolerance limits at ±10%, g/m²		130,5-159,5	
Confidence interval at 99% probability, g/m²	q	±4,6	±1,5
Percentile confidence interval, %	q'	±3,1	±1,1
Standard deviation, g/m²	s	±4,5	±9,7
Coefficient of variation, %	v	3,2	7,2

Process Trial

In case of fabrics C, F, I, N and S standard deviation of area density had been significantly less at process trial than it was in mass production. The reliability of mass production was, consequently, not good enough. The reasons are: manufacturing on different machine types, delicate finishing process (e.g. brushing in case of fabric S) which is difficult to control and use of yarns from different producers which is also a very critical factor.

For the rest of the fabrics significance test does not show significant differences between process trial and mass production so we can state for these fabrics that standard deviation of trial lots and mass production are statistically not different.

We have paid great attention to the difference between calculated mean value and prescribed value of area density. In each case analysed the stipulation that their difference must not exceed 10% has been realised. We have also found that confidence limits (q) make, even at 99% statistical reliability, narrower interval than the one which could be allowed by the prescribed ±10% tolerance limit. This means that our mass production has sufficient reliability, because less than 1% of the measured data are out of the ±q limit. (To facilitate the comparison we have calculated q also in percentage of the mean; in the Tables this is given as q').

This is in accordance with our practical experience because there are relatively only a few fabrics in our production the area density of which deviates by more than 10% from the prescribed value.

TABLE 3 - Results of Significance Tests

Fabric	Significance test of means of process trial and of mass production	Significance test of standard deviations of process trial and of mass production
A	-	-
B	-	-
C	-	x
D	-	-
E	-	-
F	-	x
G	-	+
H	-	-
I	-	x
J	-	-
K	-	+
L	-	-
M	-	-
N	-	x
O	-	-
P	-	-
Q	-	-
R	-	-
S	-	x

Remarks:

- \- Difference is not significant
- \+ Standard deviation of process trial is significantly bigger than that of mass production
- x Standard deviation of process trial is significantly smaller than that of mass production

It would be advantageous if data analysis of process trial could make it possible to sift out occasional uncertainties before starting mass production. To examine this possibility we have made a comparison between average area density of trial lots and that of mass production. Calculations have showed that the difference is never significant (Table 3), i.e. standard deviation of area density at process trial is with good statistical reliability the area density developing during mass production. It means that process trials had been well performed, and the data can be repeated.

Prescribed area density is fixed on the basis of the process trial. As mentioned previously, our trial lots consist usually 10 pieces (n = 10). If we want to achieve a statistical reliability of 99.9% and a percentage value of standard deviation (v) of 5%, accuracy (h) of area density of mass production can be estimated as follows:

$$h = \frac{t \cdot v'}{\sqrt{n}} = \frac{3.3 \cdot 5}{\sqrt{10}} = \pm 5.2\%$$

This is acceptable for production.

It often happens that we have only a small quantity of yarn for trials or time is very short — and we make less pieces in a trial lot. Supposing that number of pieces (n) is only 5, estimated accuracy for mass production is 7.4% on 99.9% statistical reliability. It means — and it is very well confirmed in practice — that lower numbers of pieces in trial lots strongly reduce reliability.

Conclusions

Our investigation has given a good basis for improving the estimation of area density value in mass production. The previously established statistical formulae had been used at our company only in laboratories (in evaluation of yarn or fabric breaking tests etc) but not in evaluation of process trials. This is significant not only for our company but for other Hungarian knitwear factories, too. We do hope that this method, put recently into practice, will improve the reliability of our process trials and that of mass production.

References

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