Analysis of the modeling methodologies for predicting the sewing thread consumption

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Abstract

Purpose – This paper aims to provide a rapid and accurate method to predict the amount of sewing thread required to make up a garment.

Design/methodology/approach – Three modeling methodologies are analyzed in this paper: theoretical model, linear regression model and artificial neural network model. The predictive power of each model is evaluated by comparing the estimated thread consumption with the actual values measured after the unstitching of the garment with regression coefficient R^2 and the root mean square error.

Findings – Both the regression analysis and neural network can predict the quantity of yarn required to sew a garment. The obtained results reveal that the neural network gives the best accurate prediction.

Research limitations/implications – This study is interesting for industrial application, where samples are taken for different fabrics and garments, thus a large body of data is available.

Practical implications – The paper has practical implications in the clothing and other textile-making-up industry. Unused stocks can be reduced and stock rupture avoided.

Originality/value – The results can be used by industry to predict the amount of yarn required to sew a garment, and hence enable a reliable estimation of the garment cost and raw material required.

Keywords Clothing, Predictive process, Manufacturing systems, Neural nets

Paper type Research paper

Introduction

The sewing thread is a strategic supplying for the garment industry considering the consumed important quantities. An important consideration in selecting thread after its performance and appearance have been settled is the cost. Total thread costs are made up of the costs of the thread that is actually used in a production run of garments, the thread that is wasted during sewing, and the thread stock that remains unused at the end of a contract, and the lastly, but no means the least, the cost that can arise in production or during the subsequent use of the garment because the thread was faulty. The more the required sewing thread consumption is defined precisely, the more the quantities which should be available for the garments manufacture are reduced and the unused stocks are avoided.

The objective of this survey is to determine accurately the required quantity of thread and to estimate the corresponding actual costs. Thread consumption varies not only between different types of garment but also between garments of the same type. Differences in size, style, and material of the garment determine the amount of thread used. Thread consumption is also directly related to the stitch length, stitch density and seam type (Ukponmwan *et al.*, 2000).

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Materials

Two types of fabrics have been chosen in our study. The first one is heavy, tight and destined for Jean's trousers manufacture whereas the second one is light, loose and used for shirts manufacture. These two fabrics, with different characteristics shown in Table I, have been chosen in order to cover a large range.

Four types of stitch are considered in our survey. They are the more used for sewing trousers and shirts which are the most sewn articles in Europe. These stitches are:

(1) lockstitch (301);

(2) two-thread chain stitch (401);

(3) three-thread overedge stitch (504); and

(4) safety stitch (504 + 401).

Thus, our study is essentially carried out accordingly to these four stitches. The seam is realized using two kinds of worsted cotton sewing threads having two different counts (48 and 30 tex). For each test, we realized a seam having 10 cm of length (Figure 1) varying the following parameters:

(1) the fabric thickness (e);

(2) the stitch density (stitch number/cm) (n); and

(3) the yarn count (t).

Later, the seam was unstitched and the consumed sewing thread length was measured using the "maillemeter" device accordingly to the French Standard NF G07 101.

Theoretical model

Mathematical models for predicting the sewing thread consumption were used. They were established for different stitch types on the basis of their geometrical parameters as following:

- L: the sewing length;
- c: the sewing width;

Characteristics	Fabric 1 (Jean trousers)	Fabric 2 (shirt)
Weave	Twill	Plain
Warp density (picks/cm)	21	22
Weft density (ends/cm)	15	20
Weight (g/m^2)	422	172
Thickness (mm)	0.91	0.27

Table I.
Fabrics properties

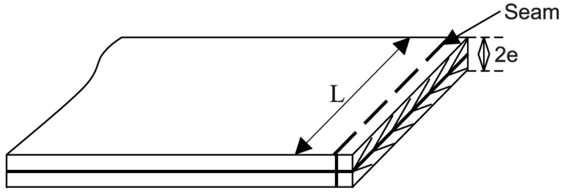

Figure 1.
Seam configuration

- n: the stitch density (stitch number per centimeter);
- e: the fabric thickness; and
- d: the thread diameter.

The lockstitch model

This stitch is formed by a needle thread passing through the material and interlocking with a bobbin thread, both threads are meeting in the center of the seam. Stitch looks the same top and bottom. For 301 lockstitch seams, it is generally recommend to use the same thread count for both the needle and bobbin. Consequently, the two yarns (needle and bobbin threads) have the same diameter. The amount of the sewing thread (Q_{301}) needed for the 301 lockstitch, whose geometry is represented in Figures 2 and 3, is estimated by the following formula:

$$Q_{301} = Q_a + Q_b$$
$$Q_{301} = 2L(1 + 2ne + nd(\pi - 1))$$

where Q_a: consumption of needle thread, Q_b: consumption of bobbin thread, and $Q_a = Q_b = L(1 + 2ne + nd(\pi - 1))$.

The three-thread overedge stitch model

The 504 stitch is formed with one needle thread and two looper threads, the looper threads are forming a purl on the edge of the seam (Figure 4).

The amount of the sewing thread (Q_{504}) needed for this stitch is predicted by the following formula:

$$Q_{504} = (Q_1 + Q_2 + Q_3)nL$$
$$Q_{504} = 2L\left(\frac{3}{2} + 4ne + nc + n\sqrt{c^2 + \frac{1}{n^2}} + 3nd(\pi - 2)\right)$$

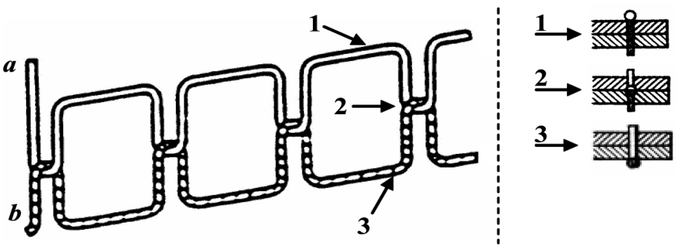

Figure 2.
Stitch configuration in a lockstitch seam

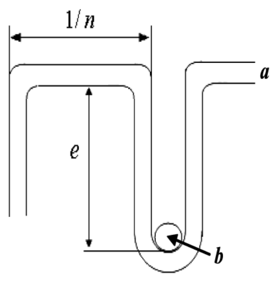

Figure 3.
Thread interlacing for 301 lockstitch

where Q_1: needle thread consumption,

$$Q_1 = \frac{1}{n} + 4e + 2d(\pi + 1);$$

Q_2: upper looper thread consumption,

$$Q_2 = \frac{1}{2n} + 2e + 2c + 2d(\pi - 2);$$

Q_3: lower looper thread consumption,

$$Q_3 = 2\sqrt{c^2 + \frac{1}{n^2}} + \frac{3}{2n} + 2e + 2d(\pi - 3).$$

The two-thread chainstitch model

The 401 stitch is formed by one needle thread (1) passing through the material and interlooped with one looper thread (*a*) and pulled up to the underside of the seam. The geometry and the chainstitch thread interlacing are represented, respectively, in Figures 5 and 6.

The amount of the sewing thread (Q_{401}) needed for the 401 chainstitch, whose geometry is represented in Figure 6, is estimated by the following formula:

$$Q_{401} = (Q_1 + Q_a)nL$$
$$Q_{401} = L(4 + 4ne + nd(3\pi - 1))$$

where Q_1, needle thread consumption,

$$Q_1 = \frac{1}{n} + 4e + d(\pi + 1);$$

Q_a, looper thread consumption,

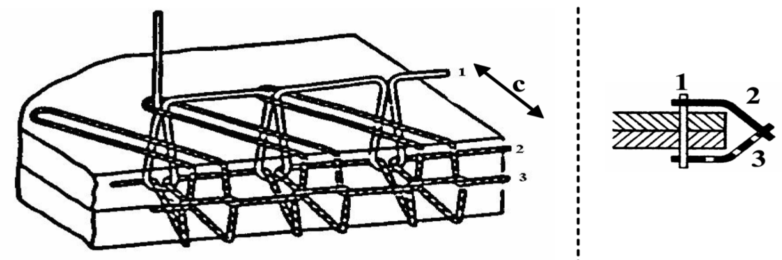

Figure 4.
Stitch configuration for three-thread overedge stitches (504)

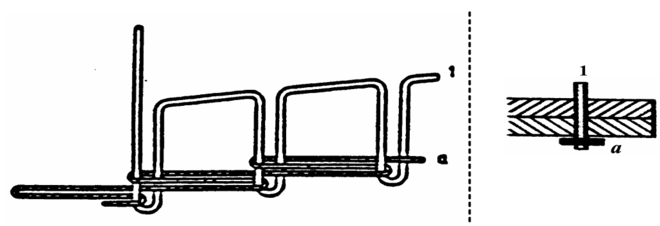

Figure 5.
Stitch configuration for two-thread chain stitches

$$Q_a = \frac{3}{n} + 2d(\pi - 1).$$

The thread safety stitch model

The 516 (401 + 504) stitch consists in a single needle (401) combined with a thread overedge stitch (504) that are formed simultaneously. The consumption thread of the 516 stitch is calculated with the following formula:

$$Q_{(504+401)} = Q_{504} + Q_{401}$$

$$Q_{516} = nL\left(\frac{7}{n} + 12e + 2c + 2\sqrt{c^2 + \frac{1}{n^2}} + d(9\pi - 13)\right)$$

To calculate a circular yarn diameter, the following general equation suggested in literature (Seyam and El-Sheikh, 1994) was used:

$$d(\text{inches}) = \frac{1}{29.30\sqrt{\phi\rho_f N}}$$

where ϕ, yarn packing fraction (ration of yarn density to fiber density); ρ_f, fiber density; and N, yarn count in cotton system.

The yarn packing fraction is a function of yarn structural parameters, which are influenced by spinning method, twist level, fiber diameter, and fiber cross-sectional shape. We have used a value of 0.6 and 1.34, respectively, for the packing fraction and the fiber density (Seyam and El-Sheikh, 1994). To obtain the d value in centimeter, the following expression of the yarn diameter was used:

$$d(\text{cm}) = \frac{1}{251.37} \times \sqrt{T_{\text{tex}}}$$

All the theoretical models explained above were used to predict the consumption of the sewing thread for both fabrics. The results relative to the 301 lockstitch varying the thickness from 0.27 to 3.64 mm and the stitch density between 3 and 6 are reported on Figure 7. This figure illustrates a considerable gap between the estimated and the actual consumptions (about 90 percent of the estimated consumption values are outside of the confidence interval calculated at a confidence level of 95 percent). The relative errors vary from 14.52 to 35 percent. Similar results were obtained for the other stitch types.

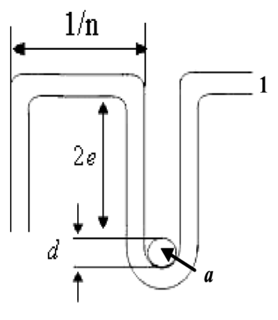

Figure 6.
Interlacing of threads for 401 chainstitch

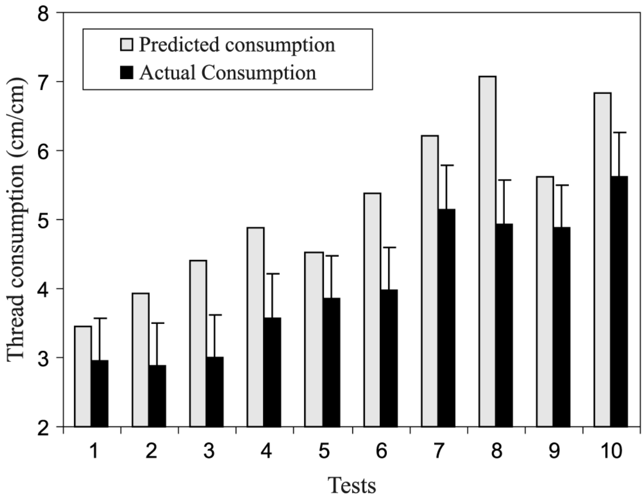

Figure 7.
Comparison between estimated and actual consumption of sewing thread in the case of the 301 lockstitch

The weakness of the theoretical models can be explained by the negligence of many other parameters such as the yarn tension, the cloth compression and the stitch distortion.

Design of experiments

Design of experiments dates from the beginning of the twentieth century with the works of Fisher. But, the theoretical aspect of the proposed approach has delayed the application of this technique in factories to the sixties thanks to the works of Taguchi in Japan who clarified and simplified the utilization of this method (Sado and Sado, 2000). The main objective of this statistical technique is to reduce the number of tests carried out when many parameters are studied by passing from a complete factorial plan to a fractional one in which one or many combinations of levels are excluded and to determine the more significant parameters.

In order to determine the factors that really influence the yarn consumption and reveal the possible interactions between these factors, a design of experiments was developed to model the sewing thread consumption by using a multiple linear regression.

Table II shows the control factors that we have considered in our survey with their respective levels.

The design of experiments was developed using the software "Minitab", it contains 256 tests ($4 \times 2 \times 4 \times 2 \times 4$).

Table II.
Factors included in the design of experiments

Factors	Levels
Type of stitch	301; 401; 504; 516
Type of cloth	Jean trousers; shirt
Stitch density (*n*)	3; 4; 5; 6
Linear density (*t*)	48 tex; 30 tex
Cloth thickness (*e*)	*e*; 2*e*; 3*e*; 4*e*

In order to identify the principal factors and interactions affecting the sewing thread consumption, two types of diagrams were realized (Figures 8 and 9).

According to the Figure 9, the analysis of the experimental design (Harter, 1970) has revealed the following results with a reliability of 95 percent:

- The stitch type is the most significant factor. Therefore, our design has been divided into four under-designs, which are analyzed separately.
- The cloth thickness and the stitch density have significant effects.
- The cloth type has a statistically negligible effect.
- The yarn count has not any effect.
- The meaningful interactions are:

  Stitch density × thickness fabric, and

  Yarn count × thickness fabric.

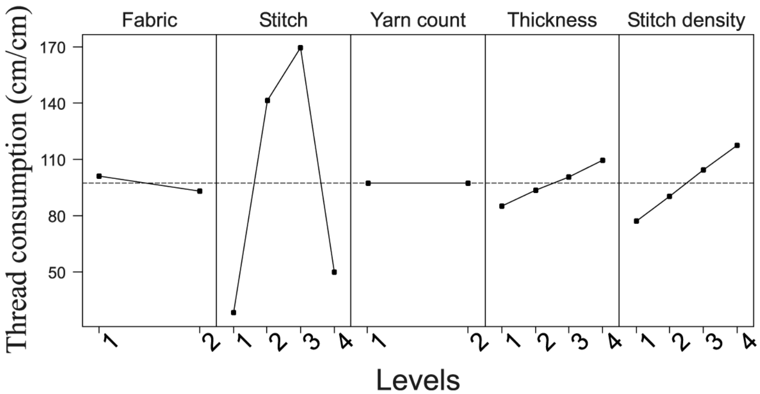

Figure 8.
Diagram of principal effects

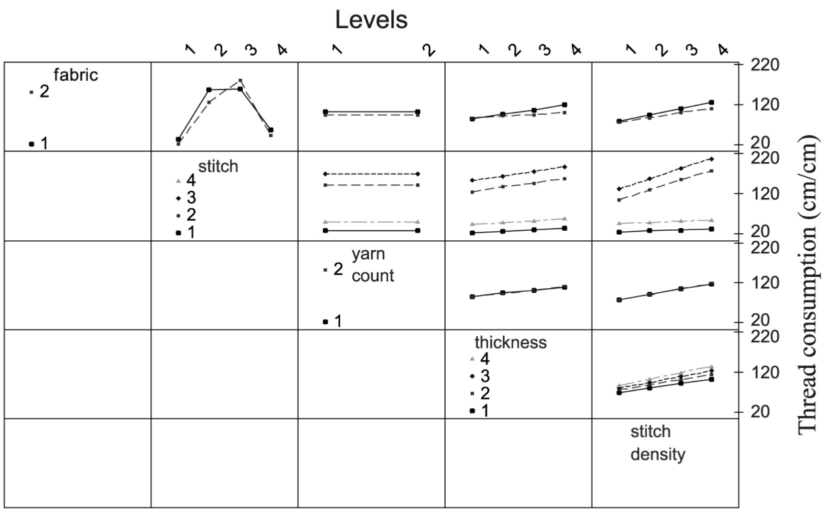

Figure 9.
Diagram of interactions

Modeling by multiple linear regression

For each stitch type, we have established a linear regression model coupling the thread consumption (Q) to the most influent factors:

- the stitch density (n);
- the fabric thickness (e);
- the yarn count (t);
- stitch density × thickness fabric interaction ($n \times e$); and
- yarn count × thickness fabric interaction ($t \times e$).

In the case of the 301 lockstitch, the linear model obtained on the basis of 32 tests is the following:

$$Q_{301} = 22.8 - 9.5e - 0.89n + 19.1e \times n - 0.28e \times t; \quad R^2 = 95\,\text{percent}$$

This model has been validated by an analysis of variance (Saporta, 1990) ($F = 130.9$ and $p = 0.00$). Furthermore, Figure 10 shows a high correlation between the actual values and those calculated by this model (the regression coefficient R^2 is about 0.95). The relative error for this model varies from 0.22 to 17.65 percent.

The relative linear models for the other stitch types are presented in Table III.

Compared to the results of the theoretical models, the gap between the predicted and the actual consumptions has been reduced. This improvement is essentially attributed to the selection of the most significant factors, with the help of experimental design, to build the sewing thread consumption model.

Neural network modeling

A neural network is composed of simple elements operating in parallel, which are inspired from biological nervous systems. As in nature, the network function is

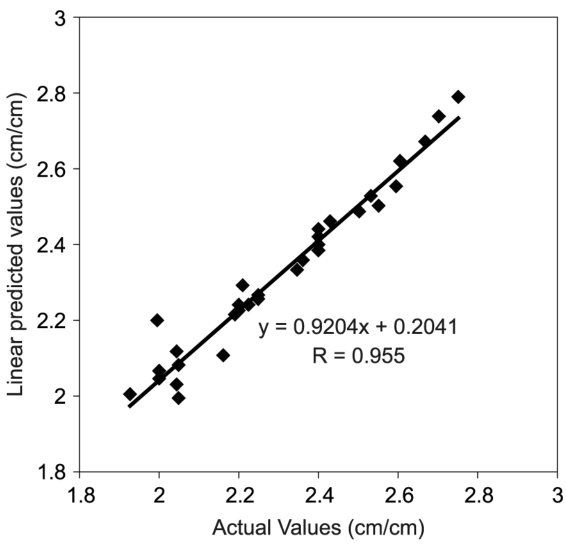

Figure 10. Relationship between actual values and linear predicted values for 301 lockstitch

determined largely by connections between its elements. A neural network is usually adjusted, or trained, so that a particular input leads to a specific output (Dreyfus *et al.*, 2004). Figure 11 shows the neural network architecture that we have programmed under the software "Matlab".

Thus, a feed-forward neural network was created using three units in the input layer (corresponding to the three experimentally determined inputs [The cloth thickness (e), the stitch density (n) and the yarn count (t)]), one hidden layer and one unit in the output layer (corresponding to thread consumption (Q)). After trial, the number of the hidden neurons was fixed at three. The data were all scaled to lie between -1 and $+1$ and the hyperbolic tangent sigmoid function (tan sig) was used as activation function for the hidden neurons and the linear function for the output neuron.

This structure is known as multilayer perceptron (MLP).Training MLP in a supervised manner with the error backpropagation algorithm which is based on the error correction rule constitutes a feed forward backpropagation network. There are three distinctive characteristics each neuron in the network includes a non-linearity output; there are one or more layers of hidden neurons and the network has a high connectivity determined by the structure between layers. The performance of the obtained model was evaluated with the root mean square error (RMSE) and the correlation coefficient (R^2) between the computed output and desired target.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (\hat{y}_i - y_{i,\mathrm{real}})^2}{n}}$$

To test our network, we have divided each under-plan of experiences formed of 32 tests into two samples:

(1) A training sample, which contains 22 random tests.

(2) A validation sample that contains the 10 remaining tests.

Type of stitch	R^2	F	p	Regression model
504 Three-thread overedge stitch	96.1	1094	0.00	$Q_{504} = 36.1 - 0.2e + 17.9n + 39.1n \times e$
401 Two-thread chainstitch	94.7	817.32	0.00	$Q_{401} = 38.8 - 2.58e - 0.453n + 19.5n \times e$
(401 + 504) Safety stitch	95.6	4161.4	0.00	$Q_{516} = 33.3 - 3.1e + 18.7n + 40.5n \times e$

Table III. Linear models relative to the other stitch types

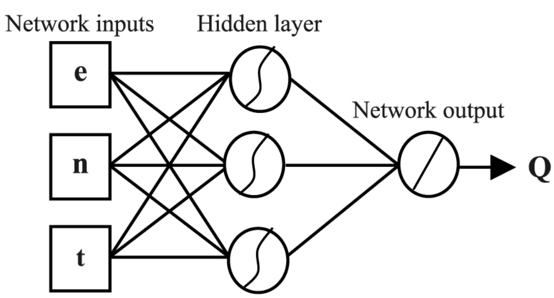

Figure 11. A multilayer neural network architecture

Thus, for the obtained neural model, the regression coefficient between the actual values and the predicted ones is equal to 0.98, and the relative errors were the lowest, comparing to the other models, varying from 0.84 to 7.12 percent.

Figure 12 shows the accuracy of the obtained values using the validation sample to test this neural network model.

Comparison of the performance of the three different models

In order to assess the performance of the theoretical, statistical (based on regression equations) and neural-network models for predicting the thread consumption, we calculated the relative error, the coefficient of determination R^2 and the RMSE for each type of stitch, and then we calculated the average for each parameter. The obtained results for the three models were summarized in Table IV.

It can be seen that the maximum relative error among the different stitch models is lowest for the neural network model. Moreover, the correlation coefficients of the neural network models are greater or comparable with those relative t the theoretical and statistical models.

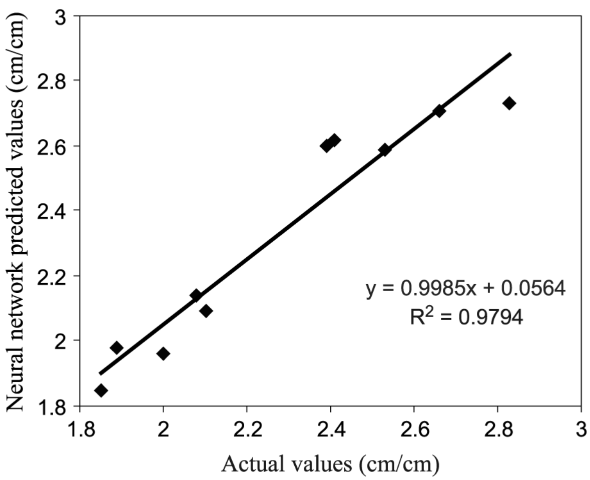

Figure 12. Relationship between actual values and neural network predicted values for 301 lockstitch

Table IV. Comparison between the three predicting models

Stitch type	Theoretical model R^2	Theoretical model Error percentage	Theoretical model RMSE	Statistical model R^2	Statistical model Error percentage	Statistical model RMSE	Neural network R^2	Neural network Error percentage	Neural network RMSE
Lockstitch (301)	0.92	35	0.428	0.95	8	1.89	0.98	4	0.103
Three-thread overedge stitch (504)	0.79	5.65	0.787	0.991	6.19	4.4	0.99	0.79	0.176
Safety stitch (516)	0.99	5.29	0.787	0.997	1.18	1.82	0.99	0.86	0.138
Two-thread chainstitch (401)	0.72	8.33	0.414	0.987	1.72	1.2	0.98	2.17	0.133
Average		*13.57*	*0.604*		*4.27*	*2.33*		*1.96*	*0.137*

As for the RMSE values, it is worthwhile to note that the neural network models perform better giving an average RMSE value equal to 0.137.

Thus, the obtained results show that the neural network models give the best performance comparing to the other models for predicting the sewing thread consumption.

Significance for industrial application

The study illustrates the feasibility of the sewing data and predicting neural models for thread provisioning management. Objective characterization of principal sewing parameters such as cloth thickness, yarn count and stitch density which are specific to each garment will allow to estimate the sewing thread consumption. This is particularly useful for the apparel industry in provisioning the sewing thread and determining the required stocks. In fact, the predicting neural system proposed in this survey is composed of several models, which perform forecasts on various stitch types and fabrics. It provides rapidly an accurate prediction of the sewing thread quantity required to make up a garment. Thus, the unused stocks will be reduced and stock rupture will be avoided. Consequently, this predicting system allows a more reliable estimation of the garment cost.

Conclusions

In this survey, three models were proposed in order to predict the sewing thread consumption. First of all, mathematical models were established for different stitch types (301, 401, 504, 516) on the basis of the geometrical parameters such as the sewing length, the stitch density, the fabric thickness, etc. The obtained results have shown an important gap between the calculated and the actual consumptions.

Secondly, with the help of the design of experiments, we have measured the importance of the parameters influencing significantly the sewing thread consumption. Both the regression analysis and the neural network, allow predicting the quantity of yarn required to sew a garment. Yet, the predictions from the neural network showed higher accuracy than those provided by the regression analysis. In fact, the neural network model has the best results for the task of predicting sewing thread consumption with a reliability of 95 percent and more. This study is quite interesting for industrial applications where samples are taken for different fabrics and garments, thus a large data is available. Another advantage of using a neural network approach is that when new data belonging to another region of the training data domain are available, the neural network can be updated by retraining, thus it can be expected to perform significantly better.

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