Innovative approaches to optimized cutting planning in the garment industry

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ABSTRACT – REZUMAT

Innovative approaches to optimized cutting planning in the garment industry

The garment industry is responsible for large amounts of waste. The current line of making the industry sustainable imposes rethinking of all stages, from design to assembling. The research starts from the observation that the optimization of the cutting plan is resourceful regarding the reduction of waste. The paper proposes an original software dedicated to the planning of cutting. The markers for a given product, onto which are arranged one to four sizes are characterized by four parameters: coefficient of utility of fabric, total length of the fabric, number of layers and length of the marker. The use of the software is demonstrated for the product coat, to which the best marker is established. Numerical results show how variable the coefficient of utility can be, thus how important is the optimization of markers before cutting the fabric. For the product coat, whose patterns are long (the dimension along the length of the fabric is significantly bigger than the dimension along the width) the utility coefficient is optimized from 57% to 78%. Several observations (applying to all markers) are noticed regarding the shape of the patterns and the number of sizes on a marker. The software should be of interest to companies which assemble garment pieces. The mathematical model and logic applied within the software are validated using an experimental study on the product's dress and coat, to which the practical coefficients of utility are 75% and 87% respectively.

Keywords: *cutting, garment industry, planning of cutting, coefficient of utility of fabric, digitalization*

Abordări inovatoare în planificarea optimizată a croirii în industria de îmbrăcăminte

Industria de îmbrăcăminte este responsabilă pentru cantități mari de deșeuri. Tendința actuală de creare a unei industrii durabile impune regândirea tuturor etapelor, de la proiectare până la asamblare. Cercetarea pornește de la observația că optimizarea încadrării este o resursă importantă, în ceea ce privește reducerea deșeurilor. Lucrarea propune un software original dedicat planificării croirii. Încadrările pentru un produs dat, pe care sunt aranjate una până la patru mărimi, sunt caracterizate de patru parametri: coeficientul de utilizare a materialului, lungimea totală a materialului, numărul de straturi și lungimea încadrării. Utilizarea software-ului este demonstrată pentru produsul palton, căruia i se stabilește cea mai eficientă încadrare. Rezultatele numerice arată cât de variabil poate fi coeficientul de utilizare, deci cât de importantă este optimizarea încadrărilor înainte de croirea materialului. Pentru produsul palton, ale cărui tipare sunt lungi (dimensiunea de-a lungul lungimii țesăturii este semnificativ mai mare decât dimensiunea de-a lungul lățimii), coeficientul de utilizare este optimizat de la 57% la 78%. Rezultă mai multe observații (aplicabile tuturor încadrărilor) cu privire la forma tiparelor și numărul de mărimi de pe o încadrare. Software-ul ar trebui să fie de interes pentru companiile care produc articole de îmbrăcăminte. Modelul matematic și logica aplicate în cadrul software-ului sunt validate prin intermediul unui studiu experimental asupra produselor rochie și sacou, la care coeficienții experimentali de utilizare sunt de 75%, respectiv 87%.

Cuvinte-cheie: *croire, industria de îmbrăcăminte, planificarea croirii, coeficient de utilizare a materialului, digitalizare*

NTRODUCTION

Presently, society is strongly involved in assessing the harmful effect of technology on the environment and in finding solutions to diminish or remove this effect. The large amount of waste, generated by industrial activities i.e., electronics [1], plastics [2], textiles [3, 4], pharmaceutics [5–7], chemical [8], manufacturing and building [9] and by the social activities [10] are relevant parts of the issue.

Consequently, international political and economic organizations plan to invest important resources in implementing new concepts regarding the design, manufacturing, and use of products.

For instance, at the European level, in 2020, the European Commission communicated, under the title "European Green Deal" the new circular economy action plan, including proposals on more sustainable product design and reducing waste. In 2021, the European Parliament adopted a resolution on the new circular economy action plan demanding additional measures to achieve a carbon-neutral, environmentally sustainable, toxic-free, and fully circular economy by 2050 [11].

The textile and garment industry is responsible for polluting water, spreading greenhouse gas and landfilling. The impact of manufacturing fibres and different fabrics, assembling clothing and discarding wasted products by the users is documented in Europe by the European Parliament [12]. Reducing waste is a target not easy to achieve. The solutions, as a result of multidisciplinary research, should be identified for all stages beginning with the manufacturing of fabric and ending with the customs of users.

Fabric as a raw material represents about 60% of the production expenses in this field, demanding an effective utilization of fabric resources. Consequently, it is essential to lower the overall price of raw materials and achieve an optimal rate of use while fulfilling every need by limiting the length of the demanded fabric [13]. Significant interest has been demonstrated in resolving this issue because a minor adjustment to the arrangement of the fabric-cutting procedure could result in substantial cost savings [14]. Marker planning constitutes one of the textile industry's most vital planning procedures. The main purpose is to create a set of markers to be used as cutting instructions or cutting templates in a cutting procedure [15].

The industry's current methods for marker planning vary from manual ad hoc processes to dedicated software [16, 17]. Nevertheless, a lot of apparel manufacturers prefer to generate this plan using the expertise of a planner or industrial software.

As there are no scientifically based guidelines to plan the cutting and no specific software, the present paper addresses the design and planning of the cutting process as the most important step in obtaining high efficiency in using the fabric and, thus, in reducing the waste. The idea of the necessity to reduce waste in the assembling garment stage and a mathematical approach regarding the utility coefficient of fabric was developed by the authors in previous works [18, 19]. Our research started from the following notices:

- The fabric used by a company which assembles garments generates most of the waste, thus its use must be first optimized;
- The garment industry uses specific CAD programs, which generate markers. However, all software applications optimize the arrangement of patterns based on data provided by the human operator. This data includes the number of sizes to be arranged on the marker and which sizes to be associated; the orientation of the patterns depending on the grainline and the nature of the fabric; and the number of products in the order for each size (which is generally different). Thus, the making of markers is not fully automated. CAD applications only achieve the best arrangement for a plan given as input data by a human operator;
- To get a high utility coefficient, it is necessary to imply human intelligence in planning cutting. Previous research went to trying to find the best arrangement of patterns on the marker [16, 20–25].

The present paper proposes a new software to plan the cutting, whose results should be implemented in the existing CAD applications, to ensure high utility coefficients. By estimating the characteristic parameters for the entire production (i.e., the total length of fabric required, the number of layers, and the fabric's coefficient of utility), this software optimizes the cutting plan and can substantially reduce fabric consumption and, therefore, costs and the amount of resulting waste. The theoretical approach is intended to be tested within an experimental program.

MATERIALS AND METHODS

The marker is a surface on which the patterns are arranged. It is subsequently used to cut fabric. Considering the cost of fabric, it is very important to use the fabric efficiently. Furthermore, reducing waste is a major goal of the current policies to make the industry sustainable. The method proposed in this paper is based on simulations performed in an original software, which estimates three characteristic parameters for the whole production: total necessary length of fabric, number of layers and coefficient of utility of fabric.

Figure 1 presents a logical scheme of the process which provides an optimal cutting plan. For a given order, the input data is total number of pieces of garment (N), the number of sizes to be placed on a marker (m), the width of the fabric (l), the loss at the end of the layer (p), the area of patterns for one, two, three and four sizes on a marker ($A1$, $A2$, $A3$, $A4$) and the length of the marker for one, two, three and four sizes arranged on it ($L1$, $L2$, $L3$, $L4$).

The criteria to establish which arrangement is the best are as follows:

- Coefficient of utility of fabric, which should be maximum;
- Estimated total length of the fabric, which should be minimum;
- Number of layers, which should be as few as possible;

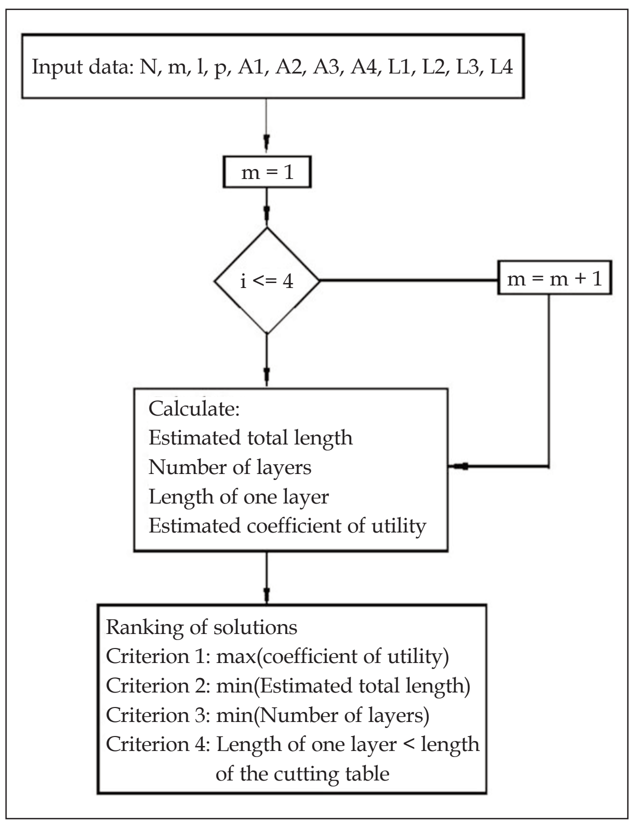


Fig. 1. Logical scheme on which the program is based on

- Length of the marker, which should be less than the length of the cutting table.

No matter what the product is, the planning of cutting needs to know the patterns and the characteristics of the fabric (such as width and grainline). The patterns are generated by the designer of the model and are provided in different electronic formats, compatible with general CAD software and specific software used in the garment industry.

As a rule, the sum of the patterns' areas represents the useful area of the fabric. The ratio between the useful area and the total area of the fabric is called the utility coefficient:

$$C = \frac{\sum \text{Area of patterns}}{\text{Total area of fabric}} \cdot 100 \text{ [\%]} \quad (1)$$

The utility coefficient may be computed for one marker or for the whole area of the fabric, which is the final parameter of interest for the cutting planner.

If all patterns are generated and the number of multiplications is known, it is the task of the human operator to plan the cutting. They encounter the problem of deciding which patterns should be assigned to one marker because there are a lot of combinations possible. There must be stated a decision criterion, which is proposed to be the utility coefficient of fabric.

In the case of unique pieces or a small number of pieces in each size, there are few solutions for combining patterns in arrangements on the marker or even only one if the piece is unique. In this case, the utility coefficient depends mainly on the shape of the patterns (long or compact), grainline and colours or geometry of the patterned fabric. The utility coefficient is expected to be small. However, the waste, in absolute value, is not important.

In the case of a large series of production, which implies the assembling of hundreds or thousands of products in the same model, the utility coefficient becomes very important because the waste can be economically and environmentally unacceptable. The arrangement of patterns must be optimized so that the fabric is used most efficiently and the total waste is minimized. For this purpose, a software application was written as VBA. Figure 2 shows the interface of the program, called "Planning of production" consisting of four frames with image and text controls and a series of five command buttons.

The frames "Model" and "Pattern" allow the operator to load an image of the model and the image of a generic pattern.

The frame "Input data" contains label and text controls for 12 parameters, which must be entered by the user. The calculus algorithm considers the following data:

- Total number of pieces (*N*) – imposed in an order;
- Number of sizes on a marker (*m*) – at the choice of the user (*m* = 1, 2, 3 or 4 in the algorithm). The number *m* was limited to four for practical reasons. The length of the cutting table determines the maximum length of the marker (the length of the cutting table varies depending on the company). The program and the simulations were used for a company where the cutting table is seven meters in length. Four sizes on a marker use up to 4…6 meters in length, depending on the model. An order usually

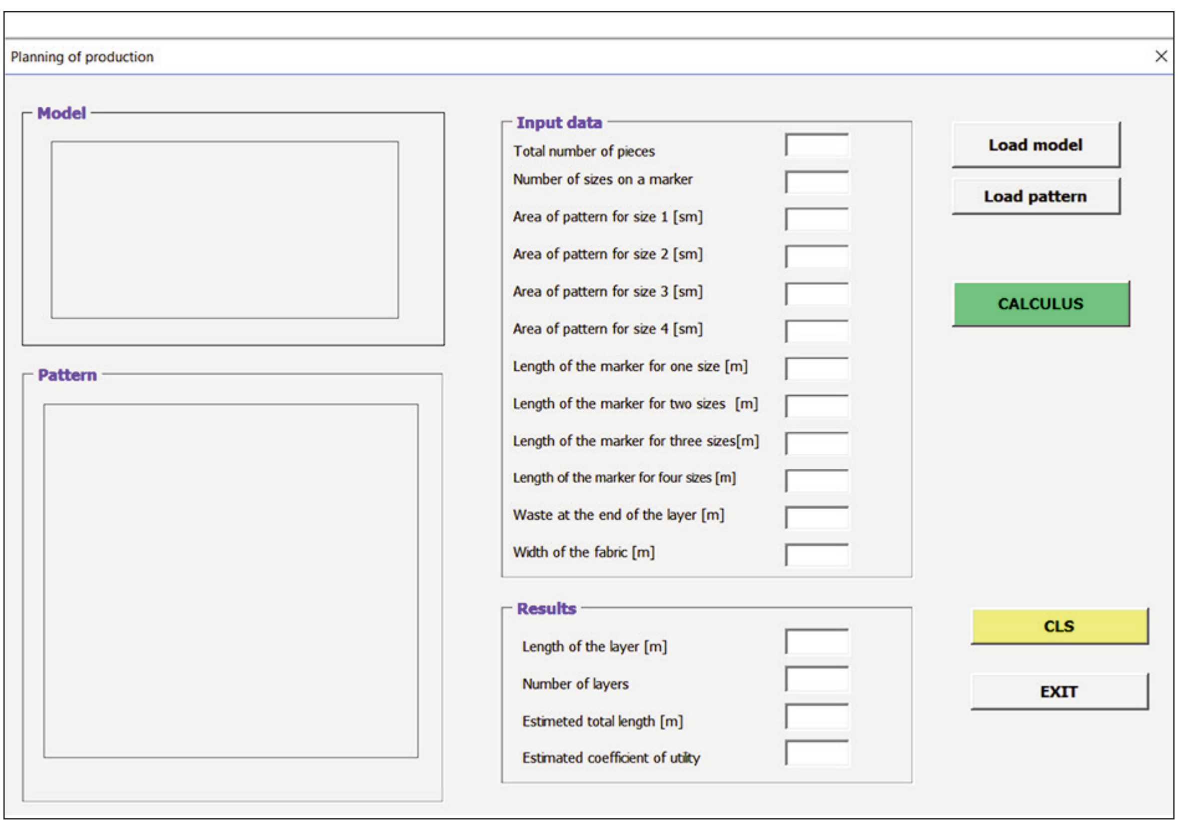


Fig. 2. Graphical user interface of the program

contains 8, 10 or more sizes, which should be organized into smaller groups;

- Area of the pattern for sizes 1, 2, 3, 4 ($A1…A4$) and Length of the marker for 1, 2, 3 or 4 sizes on one marker ($L1…L4$). These parameters can be obtained within any CAD application for garment design, by simulating one piece of each size;
- Waste at the end of the layer (p). The length of a layer can be less or equal to the length of the table. At the beginning and end of the layer, a short amount of fabric must be foreseen. The total extra fabric is denoted p;
- Width of the fabric (l). This parameter may be smaller than the actual width of the fabric if necessary, depending on its margins manufacturing.

The frame "Results" displays four numerical results:

- Length of the layer (L_{layer});
- Number of layers (n);
- Estimated total length (L);
- Estimated coefficient of utility (c).

The command button "Calculus" runs the algorithm, consisting of the following steps:

$$n = \frac{N}{m}, \quad (2)$$

$$L = N \cdot L1, \text{ if } m = 1, \quad (3)$$

$$L = N \cdot \frac{L2}{2}, \text{ if } m = 2, \quad (4)$$

$$L = N \cdot \frac{L3}{3}, \text{ if } m = 3, \quad (5)$$

$$L = N \cdot \frac{L4}{4}, \text{ if } m = 4, \quad (6)$$

$$L_{layer} = \frac{L}{n}, \quad (7)$$

$$c = 1/(L \cdot l) \cdot n \cdot \left(\sum_{i=1}^{4} A_i - p \cdot l\right) \cdot 100 \quad (8)$$

The command button "CLS" erases data from all text controls and the command button "Exit" closes the program.

RESULTS AND DISCUSSION

The program "Planning of production" was used to generate the optimal cutting plan for different products. The preliminary data "Area of patterns" and "Length of the marker" for one, two, three and four sizes were generated with Gemini CAD [26], a professional software for arranging patterns on the marker.

The product used to illustrate the use of the program is a coat. For numerical simulation we consider it to be the object of an order of 200 pieces in four sizes (38, 40, 42, 44). The image of the product and the input data used in simulations is given in table 1.

The simulations were run for m = 1, 2, 3 and 4, at different combinations of two and three sizes. The results of the simulations are synthesized in table 2.

The numbers in table 2 allow the following observations:

- The utility coefficient of fabric varies between 57% and 78%, depending on the number of sizes assigned to one marker.

The final choice for the cutting plan is, thus, m = 2. It ensures the highest coefficient of utility, at a minimum consumption of fabric. 78% of 200 meters in length are useful. The waste is only 71 meters. The worst solution is m = 1, with a waste of 95 meters from a total length of 220 meters. The optimization saves 24 meters of fabric and improves the productivity of cutting because the number of layers is half reduced. The study's findings indicate that the proposed software is an effective tool for optimizing cutting planning in the apparel industry. The industry's emphasis on waste reduction is consistent with the increasing focus on sustainability and resource conservation using advanced digitization and technology [27, 28]. The simulations run for different products lead to the conclusion that the coefficient of utility can be improved by (10…15)%. However, there is a general remark to notice: the coefficient of utility is smaller for long patterns (such as long coats, dresses, and pants) and higher for compact ones (such as shirts and short coats).

Table 1

INPUT DATA (PRODUCT COAT)

ID	Parameter	Numerical data
1	Total number of pieces	200
2	Number of sizes on a marker	1…4
3	Area of the pattern for size 1 (38)	1.16
4	Area of the pattern for size 2 (40)	1.20
5	Area of the pattern for size 3 (42)	1.32
6	Area of the pattern for size 4 (44)	1.49
7	Length of the marker for 1 size on one marker	1.10
8	Length of the marker for 2 sizes on one marker	2.0
9	Length of the marker for 3 sizes on one marker	3.45
10	Length of the marker for 4 sizes on one marker	4.28
11	Waste at the end of the layer	0.06
12	Width of the fabric	1.60

Table 2

RESULTS OF THE SIMULATIONS FOR M = 1, 2, 3, 4 (PRODUCT COAT)				
Followed parameters	**m=1**	**m=2**	**m=3**	**m=4**
Length of the layer (m)	1.10	2.00	3.45	4.28
Number of layers	200	100	67	50
Estimated total length (m)	220	200	230	214
Estimated coefficient of utility (%)	56.82	77.81	69.02	73.16
Total necessary area (m^2)	352	320	368	342.4
Wasted area (m^2)	151.99	71.01	114.01	91.90

EXPERIMENTAL STUDY

The theoretical approach was validated with an experimental program, developed in an assembling company.

The actual coefficient of utility of the fabric was computed with the following data:

- Total weight of the cut pieces of the product:

$$W_{\text{cut products}} = \sum_{i=1}^{k} n_i \cdot w_i \qquad (9)$$

with n_i = number of products in size *I*; w_i = weight of a products in size *I*; i = 1…k (numer of sizes).

Practically, several products of each size were weighted and for each size, the mean value was introduced in equation 9.

- Total weight of the available fabric:

$$W_{\text{available fabric}} = \sum_{j=1}^{m} L_j \cdot w_L \qquad (10)$$

with L_j = length of fabric in roll j; w_L = weight per meter for the fabric; j = 1…m (number of rolls).

The utility coefficient becomes:

$$C_u = \frac{W_{\text{cut products}}}{W_{\text{available fabric}}} \qquad (11)$$

Experimental data are presented below for two products: Dress (table 3) and Short coat (table 5).

The order for the product dress comprises sizes 34 to 50 in different numbers and four colours, in a total count of 2046 products.

The simulation with the program "Planning of production" provided the optimum solution for two sizes on a marker, with a theoretical coefficient of utility 0.77. Table 4 displays the results of the program for the product dress in the colour light green, required in 492 copies (first line in table 3). The best arrangement results with the association of sizes as shown in table 4. As the required number in sizes is different,

Table 3

LENGTH AND WEIGHT OF THE AVAILABLE FABRIC (DRESS)				
Colour	**Number of products**	**Available length (m)**	**Weight (kg)**	
	492	1595	268.27	
	630	1435	241.36	
	467	1640	275.84	
	457	2258	379.78	
Total	2046	6928	1165.24	

Table 4

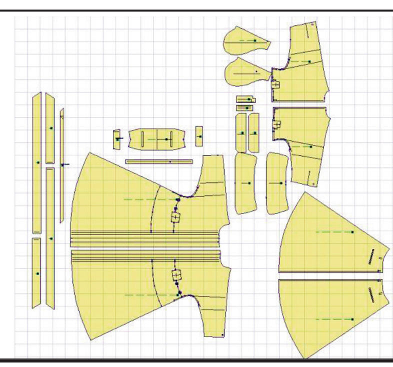
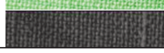
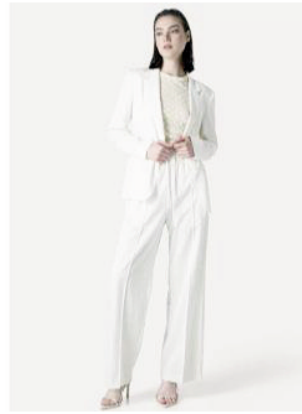
SUMMARY OF PLANNING THE CUTTING FOR 492 PRODUCTS DRESS IN COLOR GREEN					
Associated sizes	**Products**	**L_{total} (m)**	**L_{waste} (m)**	**Cu**	**Generic pattern of the dress**
36–48	24/size	102	23	77.4	
40–46	58/size	232	53	77.0	
40–44	88/size	366	85	76.8	
42	104	424	96	77.3	
Remaining Products on supplementary layers	48	108	27	75.4	
Total	492	1232	284	77	

Table 5

LENGTH AND WEIGHT OF THE AVAILABLE FABRIC (SHORT COAT)

Colour	Number of products	Available length (m)	Weight (kg)
	73	137.24	28.59
	37	69.50	14.48
	304	547.26	114.01
	33	62.34	12.99
	88	165.44	34.47
	23	43.24	9.01
	190	357.20	74.42
	22	41.36	8.62
Total	770	1423.57	296.58



there are supplementary layers for the rest of the 48 pieces.

Before the cutting, the rolls of fabric were counted, and the length and weight were computed (table 3). The total weight of the 2046 products is 879.8 kg, resulting in an actual coefficient of utility C_u = 0.754.

The order for short coats, in sizes from 34 to 52 and 8 colours, counts a total of 770 products.

The available fabric is characterized by parameters in table 5.

The simulations provided an optimum solution of four sizes on a marker, with an estimated coefficient of utility 0.89.

The total weight of the cut pieces is 259.5 kg, resulting in a coefficient of utility C_u = 0.87.

The experimental results for both products validate the theoretical model.

CONCLUSIONS

Briefly summarizing, the cutting plan optimization, using simulations on original software, provided consumption of fabric and waste for different arrangements of the patterns on the marker. The simulations considered a maximum number of four sizes on a marker, as a reasonable number suited for the most frequently used cutting tables. The hierarchy of the solutions was based on four criteria ranked by importance: coefficient of utility, total length of the fabric, number of layers, and length of the marker.

The simulations provided numerical data for more solutions, to which the coefficient of utility of fabric is substantially variable, and an optimum arrangement of patterns on the marker can be chosen.

The program was used for several products of a garment assembling company, and the actual coefficient of utility was computed with measured data. The results validated the theoretical approach, as the difference between the real and theoretical coefficients is less than 2%.

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