DEFINITION OF ASSESSMENT CRITERIA FOR NESTING SOFTWARE TOOLS IN TEXTILE PRODUCTION

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Abstract: *The arrangement of textile sewing patterns for cutting aims to minimize the amount of residual material, which in most cases is unusable and discarded. This paper proposes criteria for evaluating software products for arranging elements that are suitable for textile production. These criteria are related to the degree of use of the material, the overall efficiency of the algorithms, and the time for their execution. Data on dress, coat, and blouse were used. A software tool for complex, express, automated evaluation of algorithms for arranging elements has been developed, including software modules for research, analysis, and categorization of software products. A comparative analysis is made of software products for arranging cutting elements, depending on their use and availability. It has been found that the choice of appropriate software for arranging elements depends on the complexity of the items to be arranged and on what evaluation criterion is appropriate for the respective production of garment patterns. The obtained results can be used to develop systems to evaluate the performance of algorithms and software tools. Also, they can be used in the training of future specialists in the subject area.*

Keywords: *Computational simulation, Compaction behavior, Fabrics, Image processing, 2-dimensional nesting problems, Genetic algorithm*

1. INTRODUCTION

The arrangement of textile elements for cutting is a widely studied problem. This task aims to minimize the amount of residual material, which in most cases is unusable and discarded. The reduction of this type of waste has an impact on production costs [1]. This is an important factor in textile production [2].

The process of arranging elements on a cutting fabric is in most cases automated. In some of the smaller textile industries, manual arrangement by an operator is still used. This can lead to longer cutting times and increase the amount of waste material.

People can solve problems with the arrangement of cutting elements relatively well through the use of intuition and spatial thinking. In a production environment, solving such problems by people is usually not feasible or cost-effective. Also, it is not profitable if you have to hire several employees to perform this activity.

Computer-aided automation of tasks for arranging textile cutting elements offers a variety of solutions to this problem. Academic and industrial teams have conducted research in this regard for over fifty years [3].

Unlike humans, computers do not have intuition or spatial thinking. For this reason, algorithmic strategies for generating solutions have been developed. In textile production, the problem is often more complex and requires additional presentation and modeling of additional constraints and objectives.

Effectively arranging the cutting patterns is a difficult problem to solve. This is because the elements have an irregular shape, specific to each product. For this reason, the search for an optimal solution in most cases is impossible, as the cases are specific, it takes a long time to perform optimization procedures, and a large number of possible solutions are obtained. For this reason, software products and computational algorithms are proposed, through which sufficiently acceptable solutions are achieved for more groups of possible problems in the arrangement of textile patterns for cutting.

From the analysis of the available sources, several groups of software products can be summarized. They are summarized in Table 1. There are three main groups of software. Browser-based applications work directly in an Internet browser and do not require additional installation on a local device such as a personal computer, laptop, tablet, or mobile phone. The second group is computer programs that need to be installed on a local device. Finally, there are scientific developments that present solutions to problems related to the arrangement of patterns.

The main subgroups in which the product programs can be summarized are open access and paid. Free products usually have limited functionality. They have a small number of settings and use one optimization method. Due to the limitations of the specific method used, it is not applicable in some specific cases. The advantage is that the authors provide information about the algorithm used. For example, the DeepNest application (https://deepnest.io) uses a genetic algorithm. The principle of "box packing" is applied, in which objects are approximated to rectangles, which simplifies the calculation process and reduces the time for decision-making by the algorithm. To reduce errors, a rounding tolerance is used for the corners of the rectangles.

More than one optimization algorithm is used for paid software products. The difference is that the manufacturer does not say what algorithm is used in their product. For example, for Nest & Cut (https://nestandcut.com), the manufacturer states that the application uses "advanced optimization algorithms", without specifying which ones. Paid software products can also be linked to the purchase of fabric cutting equipment. An example of such a product is CutNest (https://www.mirisys.com), which comes with the manufacturer's cutting equipment.

The advantages of using software products for arranging details are:

- ✓ Reduce the operating time of the machine. It is realized by reducing the path of the cutting tool, double cutting to avoid the appearance of hanging threads;
- ✓ Effective use of textile material. Reducing the residual material leads to a reduction in waste. In the case of high-cost materials, this also leads to a reduction in production costs;
- ✓ Reduction of manual labor. By automating processes such as importing CAD files, you can drastically reduce CAM preparation time. The time to convert from CAD file to NC code can be significantly reduced.

Table 1. *Types of software tools for arranging sewing patterns for cutting*

Type	Subtype	Advantages	Limitations	Reference
Internet browser-based	Free	Direct access from anywhere in the world	Require an Internet connection	[4]
	Commercial	Requires registration, trial versions available	The limited-time of use; Requires an Internet connection	
Computer software	Free	They are installed and work without additional requirements	A limited set of features	[3]
	Commercial	Greater functionality; Trial versions are available	In most cases, they are related to the purchase of equipment	
Scientific research		Effective methods for arranging irregularly shaped elements	Only pseudocode algorithms are available	[5]

The third important group is the scientific developments in the field of optimization of the available cutting sewing patterns. The research is aimed at modifying to improve the existing optimization algorithms for arranging irregularly shaped textile details. Optimization algorithms such as “Genetic algorithm (GA)”, “Ant colony optimization (ACO)”, “Particle Swarm Optimization (PSO)”, and “Imperialist Competitive Algorithm (ICA)” are used for this purpose.

Table 2 summarizes the analysis of the most commonly used algorithms. They are grouped into six groups. These programming procedures have been studied since the problem of arranging cutting elements was defined. Some algorithms offer high-speed data processing, but low efficiency and obtain large amounts of waste material. Due to the limitations of the independent use of algorithms, they are suitable for solving specific tasks. Hybrid algorithms, which combine the work of several algorithms, have a more universal application. Of course, at the expense of longer execution time, compared to the independent use of algorithms for arranging elements.

Table 2. *Nesting algorithms*

Name	Advantages	Limitations	Reference
Rectangular parts nesting algorithms	Practical algorithm	The high complexity of the calculations works only with rectangular details	[6]
Enclosure algorithms	Wide application	A large amount of waste material, low efficiency	[7]
Heuristic nesting algorithms	Wide application	It is limited to a small number of elements	[8]
Bottom-left nesting algorithm	High-speed data processing simplified computational procedures	They need to work together with search algorithms	[9]
Space searching algorithms	They use any process to find the optimal location of the elements	They do not detect the gaps between the elements effectively enough	[10]
Hybrid algorithms	Combine the advantages of several algorithms	Longer calculation time	[11]

In summary, the problem of cutting textile elements can be defined as arranging irregularly shaped elements in a rectangular field of known dimensions without overlapping. They should take up little space in the field.Irregularly shaped elements are defined as simple polygons. In cases where the elements include curves, they are approximated by their minimum polygon. In it, a series of tangents to the curve form the polygonal edges.

Whether it is a software product or a research development, there is a need to evaluate the results obtained.

Comparative analyzes of the presented algorithms have been performed [12], [6]. Different authors point to different accuracy within their study. This is indicative that the accuracy of the application of an algorithm depends largely on the type of problem to be solved by arranging elements for cutting textiles.

More commonly used criteria in practice are the calculation time and the efficiency of the arrangement of the elements, which is the ratio between the area filled by the elements and the empty fields between them, expressed as a percentage [5]. It is necessary to look for more evaluation criteria that would give a more complete picture of the work of the respective software product or the proposed algorithm. The use of evaluation criteria has the potential to show the limitations of the software product used, within the solved problem of arranging textile elements for cutting. This thesis was confirmed by Breaz et al. [13]. The authors propose to use image processing techniques in assessing the effectiveness of arranging elements in a given field. Such techniques can also be used to evaluate the performance of algorithms for arranging textile elements.

The purpose of this paper is to define criteria for the evaluation of software products for the arrangement of elements that are suitable for textile production.

2. MATERIAL AND METHODS

The software products Gemini CAD, Nest&Cut, DeepNest, SVGNest were used. *Gemini CAD* (Gemini CAD Systems SA LECTRA company, Iași, Romania) is a commercial software product for clothing design. It offers functions for arranging patterns that are optimized for cutting textile fabrics. *Nest&Cut* (ALMA, France) is a commercial online tool that has a 30-day trial. The tool arranges the elements using several optimization algorithms. It has functions for simulation of textile cutting. Also, the obtained result can be downloaded as a DXF file. *DeepNest* (https://deepnest.io) is a free application. It has many setup functions, such as several processor cores, allowable error values, and sorting methods. He uses the Genetic Algorithm to arrange the elements. The result can be downloaded as a DXF or SVG file. SVGNest (https://svgnest.com). Free online tool. Works only with SVG files. It offers several setup functions.

The test of the software products is made by patterns for dresses, coats, and blouses.

Criteria presented in the available literature were used to evaluate the performance of software products [13], [5]. These criteria are relationships that do not depend directly on the unit of measure in which the variables involved are measured. For this reason, image processing techniques can be easily applied and the number of pixels can be used. These pixels can be converted to distance and area, for example in mm.

Height of filling with elements ***(H)***. Represents the ratio between the previously mentioned area of textile material and that filled with elements, expressed as a percentage. This ratio is defined by the following formula:

$$H = \frac{H_e}{H_T} * 100, \% \quad \textbf{(1)}$$

where H_e is the height filled with elements; H_T – the height of the area set by the operator.*Fill function* ***(F)***. It describes the empty space between the elements. The parameters of the area filled with elements and that of the empty space between them are included in the fill function, in the form of a weighted sum. The function is calculated as follows:

$$A_F = L * W \qquad \textbf{(2)}$$

$$F = a * \left(\frac{\sum_{i=1}^{N} A_{e(i)}}{A_F}\right) + b * \left(1 - \frac{A_S}{A_F}\right) \qquad \textbf{(3)}$$

where A_s is the area of the empty space between the elements; A_F – an area filled with elements; L – length, W – width of the rectangle described around the elements; Ae is the area of an element; the values a=0,7 and b=0,3 were determined by Hopper [14].

Degree of use of the material ***(D$_F$)***. It presents the relationship between the difference in the areas of the elements, that of the empty space between them, and the area of the area selected by the operator for the placement of the elements. the degree of use of the material is described by the formula:

$$D_F = \frac{(A_e - A_S)}{A_T} * 100, \% \qquad \textbf{(4)}$$

where A_e is an area filled with elements; A_s – the area of the empty space between the elements; A_T – the area of the area set by the operator.

The overall efficiency of the algorithm ***(E$_T$)***. Represents the ratio of the sum of the areas of the elements and the total area they occupy, expressed as a percentage. The mathematical dependence of this relation has the form: of placement

$$E_T = \frac{\sum_{i=1}^{n} A_{e(i)}}{A_F} * 100, \% \qquad \textbf{(5)}$$

where A_e is the area of an element; n – number of elements; A_F – an area filled with elements.

Execution time ***(t)***. Represents the time from the start of the sorting algorithm to the result measured in s.

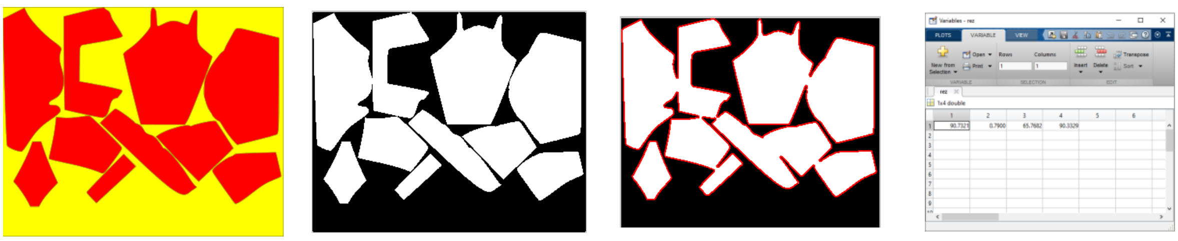
In the present work, an algorithm for evaluating the performance of software products for arranging elements is proposed. Image processing and analysis techniques were used. The algorithm is implemented in the Matlab software system (The MathWorks Inc., Natick, MA, USA). In general, it is presented in Figure 1.

Stage 1. Includes loading the RGB image of the solution for arranging elements of the corresponding algorithm.

Stage 2. Convert the image to black and white and filter. The filter adjustment factors have been experimentally established. A Disk filter is used.

Stage 3. Determining the areas occupied by the elements in the image. The Regionprops function is used.

Stage 4. Defining the criteria for evaluating the arrangement of the elements of the image.



Stage 1 Stage 2 Stage 3 Stage 4

Fig. 1: *Visualization of the main stages of the work of an algorithm for evaluating the work of software products*

The algorithm is presented as pseudocode in Table 3. After loading the image, it is converted to black and white. This is followed by filtering and clearing the image. Finally, the area of the elements is determined and the parameters for evaluating the sorting algorithm are examined.

Table 3. *Pseudocode of the proposed algorithm for evaluating the work of software products*

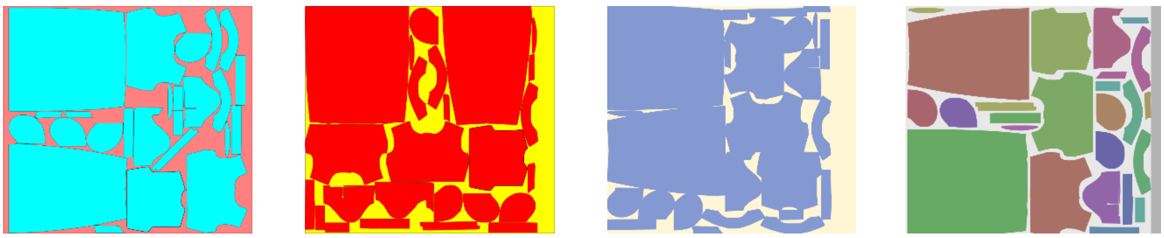
Stage	Function	Pseudocode
A	Loading image	i=imread('n2.png')
B	Convert to black and white image	i1=im2bw(i)
C	Filter and clear the image	h = fspecial('disk', 2); i2=imfilter(i1,h); i2=imfill(i2,'holes'); i2=double(i2)
D	Determining the characteristics of the area with elements	s = regionprops(i2,'all');
E	Height of filling with elements	he=s.MinorAxisLength; ht=length(i2(:,1)); h=(he/ht)*100
F	Fill function	a=0.7; b=0.3; ae=s.Area; af=s.MajorAxisLength*s.MinorAxisLength abb=s.BoundingBox(3)*s.BoundingBox(4) as=abs(ae-abb); f=a*(ae/af)+b*(1-(as/af))
G	Degree of use of the material	at=ht*length(i2(1,:)); df=((ae-as)/at)*100
H	Overall efficiency	et=(ae/abb)*100

A summary analysis of the obtained results was made with the method "Correspondence Analysis" [15]. The method is a technique for visualizing, detecting, and presenting the relationship between categories of data. It uses a graph called the Correspondence Map, which depicts the relationships between the data. The method is implemented in a software product Statistica 12 (TIBCO Software Inc., Palo Alto, CA, USA).

3. RESULTS AND DISCUSSION

As a result of the performed analyzes and calculations, visualizations of the work of the compared nesting software tools are presented. The results of the evaluation of the operation of these Internet tools and computer programs are shown and commented on. Finally, the results obtained are compared with those of the available literature.

Figure 2 shows the results of arranging elements of a dress. It consists of 25 elements. The efficiency of filling the fabric is shown, which determines the respective software used. It can be seen that Gemini CAD, SVGNest, Nest & Cutwork with the highest efficiency. The lowest efficiency was obtained with DeepNest.



a) Gemini CAD 80%   b) DeepNest 77%   c) SVGNest 81%   d) Nest&Cut 81%

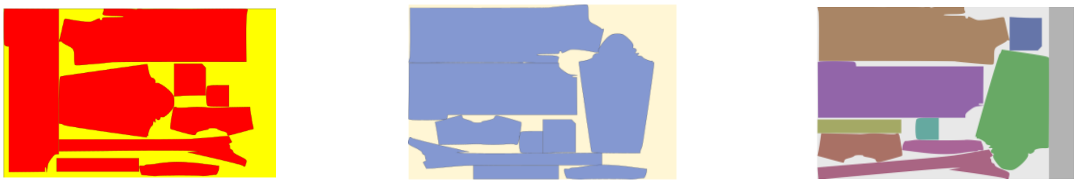
Fig. 2: *Comparative analysis of software products for arranging elements of a dress*

Table 4 shows the results of a comparative analysis of the arrangement of elements of a dress. The highest value of H – the height of filling with elements, relative to the height of the fabric is obtained with Gemini CAD, followed by SVGNest. Again, the Gemini CAD shows the appropriate value of the weighted ratio between the empty space and the one filled with elements (F). Next on this indicator is Nest & Cut. As can be seen from the table, the material utilization rate (D_f) and the overall efficiency of the algorithms (E_t) are highest with SVGNest and lowest with Nest&Cut. The set data processing time is 120 s for the three algorithms and 10 s for Nest&Cut.

Table 4. *Results of a comparative analysis of the arrangement of patterns for a dress*

Parameter / Software	H, %	F	D_f, %	E_t, %	t, s
Gemini CAD	89,76	0,77	79,80	89,37	120
DeepNest	89,27	0,79	80,91	93,44	120
SVGNest	91,00	0,81	79,72	94,29	120
Nest&Cut	88,43	0,76	74,03	89,32	10

Figure 3 shows the results of arranging elements of a coat. It consists of 9 elements.



a) DeepNest b) SVGNest c) Nest&Cut

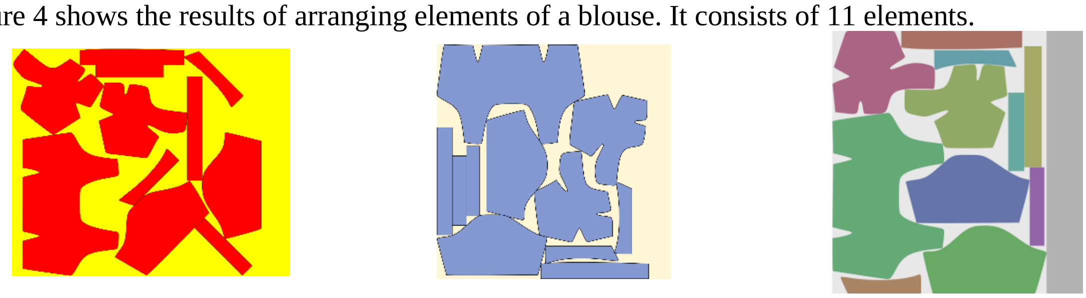
Fig. 3: *Comparative analysis of software products for arranging elements of a coat*

Table 5 shows the results of a comparative analysis of the arrangement of elements of a coat. The highest value of H – the height of filling with elements, relative to the height of the fabric is obtained at SVGNest. Both SVGNest and Nest&Cut show appropriate values of the weighted ratio between the empty space and the one filled with elements (F). Last in this indicator is DeepNest. As can be seen from the table, the material utilization rate (D_f) and the overall efficiency of the algorithms (E_t) are highest with SVGNest and lowest with DeepNest. The set data processing time is 120 s for the three algorithms and 10 s for Nest&Cut.

Table 5. *Results of a comparative analysis of the arrangement of patterns for the coat*

Parameter / Software	H, %	F	D_f, %	E_t, %	t, s
DeepNest	89,84	0,71	55,48	80,51	120
SVGNest	95,08	0,79	63,34	85,10	120
Nest&Cut	93,72	0,79	80,36	88,72	10

Figure 4 shows the results of arranging elements of a blouse. It consists of 11 elements.



a) DeepNest b) SVGNest c) Nest&Cut

Fig. 4: *Comparative analysis of software products for arranging elements of a blouse*

Table 6 shows the results of a comparative analysis of the arrangement of blouse elements. The highest value of H – the height of filling with elements, relative to the height of the fabric is obtained at DeepNest. Both SVGNest and Nest&Cut show appropriate values of the weighted ratio between the empty space and the one filled with elements (F). Last in this indicator is DeepNest. The results show that the material utilization rate (D_f) and the overall efficiency of the algorithms (E_t) are the highest in Nest & Cut and the lowest in DeepNest. The set data processing time is 120 s for the three algorithms and 10 s for Nest&Cut.

Table 6. *Results of a comparative analysis of the arrangement of patterns for the blouse*

Parameter / Software	H, %	F	D_f, %	E_t, %	t, s
DeepNest	93,53	0,57	21,63	62,14	120
SVGNest	91,76	0,75	57,96	81,96	120
Nest&Cut	90,27	0,77	80,24	88,93	10

Figure 5 shows a map of compliance for software products and evaluation criteria. The two dimensions on which the data are presented accurately describe 99,9% of their inertia. This shows that two dimensions are sufficient to evaluate the operation of the algorithms for arranging elements. The evaluation criteria stand out for the individual software products. The material utilization rate (D_f) is closest to Gemini CAD. The fill height with elements (H) has the highest values for DeepNest. The weighted ratio between the empty space and that filled with elements (F), as well as the overall efficiency of the algorithms is closest to SVGNest and Nest & Cut.

The results of the "Correspondence Analysis" show that the choice of the appropriate algorithm will depend on the type of elements to be arranged and on what evaluation criterion is appropriate for the respective production of garment patterns.

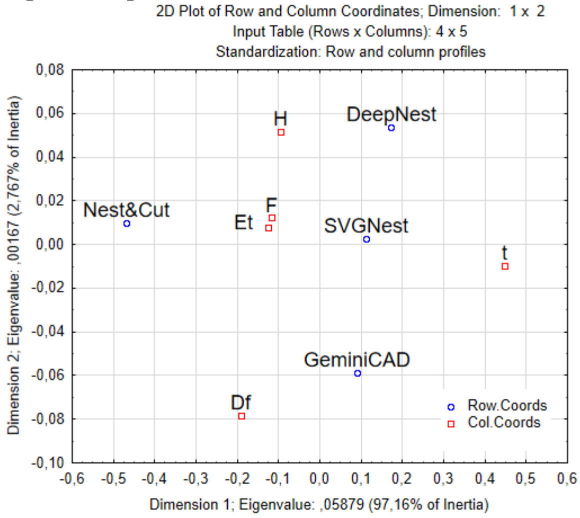


Fig. 6: *Correspondence map of software and assessment criteria*

The results obtained in the present work complement those of the available literature. Comparative analyzes of software tools are presented, which can be summarized in two groups, depending on their use and availability: online based and local; commercial and free.

The DeepNest software, which uses a basic Genetic Algorithm, uses a method to approximate rectangles. For this reason, it performs less efficiently when arranging elements with a complex shape than other algorithms. This result complements the claim of Xie et al. [2008] that algorithms with an approximation of elements to rectangles have a high complexity of the computing apparatus and are effective when working only with rectangular details.

Although SVGNest has only a few possible settings, this online tool can be successfully used to arrange complex shapes, using the material much more efficiently than the other free DeepNest tool. The two commercial software Gemini CAD and Nest&Cut are comparable in terms of results, but Gemini CAD is optimized for the arrangement of textile elements for cutting, which is its main advantage in the task solved in this paper.

The proven effectiveness of CAD systems for clothing design and offers functions for arranging cut elements, complement the claims of Kazlacheva [3], according to which the design of clothing is the most important process in clothing design. Mistakes made during the development of basic structures can hardly be avoided in the next stages of design and technological production. The importance of design makes it the last automated stage in the whole sequence of activities that make up the design of clothing.

The results obtained in this way complement the conclusions of Sasikala et al. [10], who points out that combining several algorithms is much more efficient than using stacking algorithms alone, but on the other hand, it takes longer to calculate.

4. CONCLUSION

In the present paper, a total of five criteria are proposed for the evaluation of software products for the arrangement of elements that are suitable for textile production. These criteria are related to the degree of use of the material, the overall efficiency of the algorithms, and the time for their execution.

Developed, researched, and used in the work software tool for complex, express, automated evaluation of algorithms for arranging elements, including software modules for research, analysis, and categorization of nesting software products. The software includes tools for processing and analyzing digital images and calculating criteria for evaluating nesting software.

A comparative analysis is made of software products for nesting cutting elements, depending on their use and availability.

It has been shown that the choice of an appropriate nesting algorithm depends on the complexity of the items to be arranged and on what evaluation criterion is appropriate for the respective production of garment patterns.

The main reasons for the inefficient operation of nesting algorithms for cutting textile fabrics are analyzed. It was found that the effectiveness of software products mainly depends on the complexity of the ordered elements and the optimization algorithm used.

The results reported in the available literature have been supplemented. Procedures suitable for evaluating software products and algorithms for arranging textile elements are proposed.

The following developments may be related to reducing the limitations of the proposed algorithm and the inclusion of more reasonable criteria to participate in the evaluation of software products for arranging elements.

The results obtained in the present work can be used in the development of systems for evaluating the performance of algorithms and software tools. They can be used in the training of future specialists in the subject area.

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