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Potentialities of Reducing Textile Waste in the Manufacturing of Garments from Striped Fabrics

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Abstract
Certain material losses are still tolerated in traditional garment manufacturing process. Only 80% of textile materials purchased by industry companies are used for their main purpose. The other 20% lost in garment cutting process are landfilled, incinerated, reused or recycled. Further technical progress is not able to minimise fabric waste significantly. Possibilities to reduce fabric waste have to be found in the garment designing and development process. Styles from cross directionally striped fabrics have raised material losses because of their specific design and fabric pattern. The 1st experiment with a striped T-shirt showed that fabric waste could be critical due to disconformities of the style design with the fabric pattern. The 2nd experiment showed that it is possible to reduce fabric waste by conforming the length of the style with the fabric pattern. Length tolerance – acceptable slight variations in the length of the style which does not change the design and visual perception of the garment style should be determined by designers and used in industry processing of manufacturing orders. The authors of the article developed methodology to perform the work process in an automated way. Certain manipulations of the design of a garment style directly in its manufacturing process have never been done before, however they could be very effective in producing medium and large manufacturing orders as they would help to reduce post-industrial fabric waste, material consumption, as well as the product cost.

Key words: *material waste, fabric consumption, product costs, striped fabric, sectional marker, pattern matching.*

Introduction

The fast fashion business model has created constant customer demand for the replacement of garments [1, 3]. Purchased clothes are worn for a relatively short time, and then they are discarded to make way for new ones. Following the demands of customers, garment companies constantly generate new styles and collections. During the last decade, the apparel industry has become the fastest growing fibre consumer [10]. Having serious competition in the market and much less time for well-considered planning and designing, only 60% of the clothing produced by apparel companies succeeds in selling, while 40% of goods remains unsold or even do not reach shops [2]. The linear economy model (take-make-waste) currently used in the apparel industry and immoderate clothing consumption leads to enormous quantities of textile waste [3].

Textile waste can be divided into two groups: pre-consumer and post-customer waste. Post-consumer waste is created by garment consumers themselves – it is worn out, damaged and unwanted clothing [1]. Pre-consumer waste, also called post-industrial waste, is obtained from leftover raw materials generated in the textile material and garment production process. They are fibres, yarns, off-cuts, selvages, roll ends, and rejected materials [4, 5, 10]. In the garment manufacturing process, the biggest part of textile waste is generated by cutting garment components from a 2D flat plain or patterned textiles to create 3D ready goods. Different kinds of research reports state that cutting waste comprises 15-25% of the total textile material consumption [2, 4, 5]. It means that only 80% of high quality textile materials purchased by industry companies is used for their main purpose. The other 20% is landfilled, incinerated, reused or recycled [2].

It is also established that the biggest part of textile waste constitutes mixed and synthetic fibres [2, 3, 7, 9, 10]. As they are non-biodegradable and do not degrade in landfills, they should be recycled. Non-biodegradable waste could be used for insulation products in the construction industry. However, there is a lack of equipment and technologies to do it in an efficient way [6]. Only a very small part of post-industrial waste is used to create other goods, for example, as reinforcing structures in differents kind of composite materials [11-16]. 80% of textile waste is landfilled or incinerated, thereby wasting raw materials, energy and creating serious environmental problems [1, 8, 9].

To prevent or at least minimise pre-consumer textile waste, the clothing industry has to start to use the circular economy model (take-make-waste) to find new and advanced work methods for all its three phases: product designing and manufacturing, waste collection, sorting and recycling [3].

The most important and urgent restructurings should be carried out in the garment development process, as improvements in this phase can affect the generation of textile waste most of all as well as influence waste collection, sorting and recycling.

Kinds of textile waste and their origin in garment manufacturing

Long time observations of the fabric cutting process in more than 50 enterprises in two different countries – Latvia and Serbia, showed that the traditional gar-

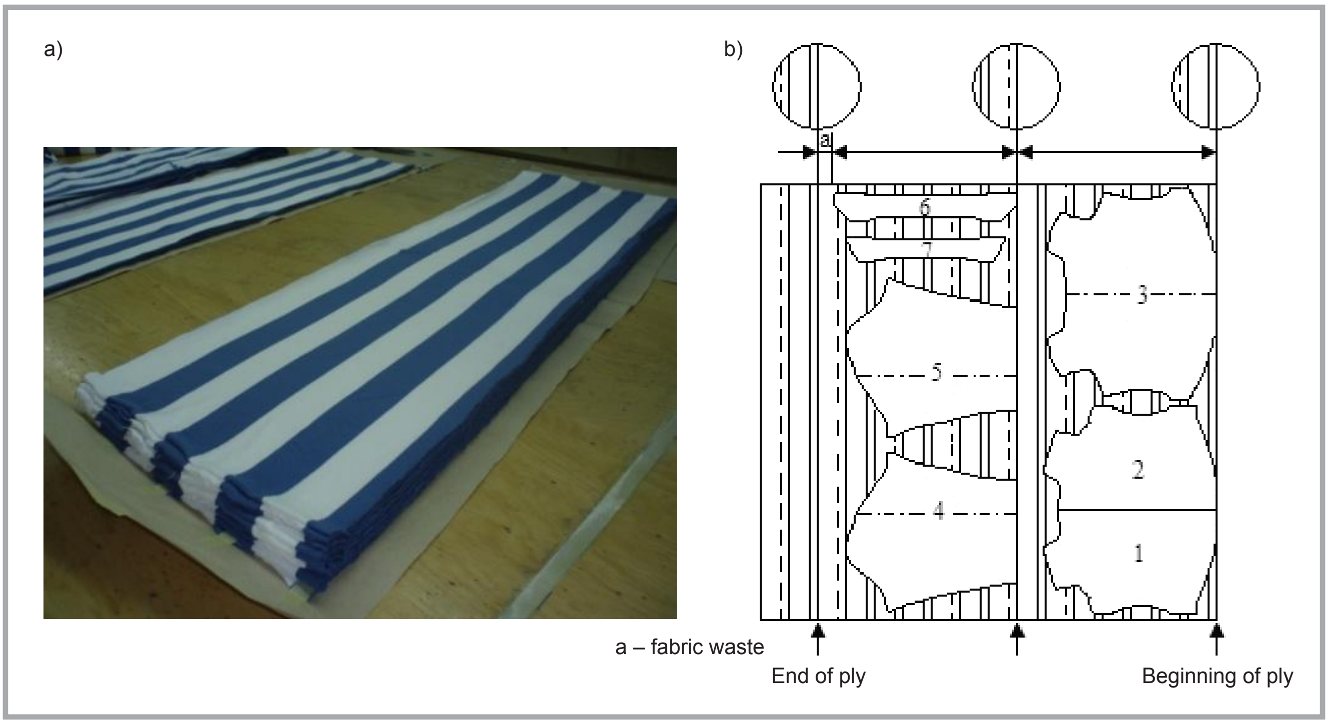

Figure 1. *Separate sections of laid fabric a) and a sectional marker for striped material, a – fabric waste.*

ment manufacturing process tolerates certain material losses, which can be divided into two groups:

- *objective fabric losses* – because of complicated and fixed shapes of garment components, the necessity to match the fabric pattern on ready goods, and specific qualities of the textile materials (different qualities of the material in the direction of warp and weft, fabric pattern, pile, aming others);
- *subjective fabric losses* – caused by variability in the textile material structure and by the incomplete nesting, spreading and cutting methods used.

Technical progress is helping to reduce *subjective fabric losses*. Material nesting software and automated cutting systems have made the fabric cutting process highly efficient [17-21]. The most advanced continuous single ply cutting process has become fully independent on variable textile material structures [22, 23]. Cut planning and scheduling improvements to reduce fabric waste are still very actual and are described in several of the latest papers [24-32]. However, further reduction of fabric use and with it also material waste with the help of technical innovations is very much limited [2].

The biggest part of *objective fabrics losses* are dependent on the design of a garment style. In its development process, the shapes of components and the requirements for pattern matching are clarified and accepted. Working with industrial collections, designers have to respect general limitations of the garment manufacturing process – efficient use of raw materials, technological equipment, time and labour [17, 18]. However, different numbers of ordered goods, garment sizes and materials as well as specific off-manufacturing conditions make the production of every certain order very much unique. In today's practice the accepted design of a garment style – shapes and dimensions of its components – stays fully fixed and unchangeable in its entire manufacturing process. However, the shapes and dimensions of the components directly influence marker efficiency, fabric use and material waste during fabric cutting. Till now no flexible and direct connection between garment designing and the manufacturing process has been created and used.

Existing limitations in manufacturing garment styles from horizontally striped fabrics

Garment styles form cross directionally striped woven or knitted textiles, such as T-shirts, loose shirts, blouses and tunics are traditional parts of garment collections. They are critical because of two actual industry problems – increased material consumption and fabric waste. Most often the styles from striped materials have simple constructive solutions. Their large dimension components help to retain the initial regular rhythm and geometry of the fabric pattern, which is an important part of the style design. The necessity to match the fabric pattern in between components involves material multi-ply spreading, cutting process time, labour intensivity as well as, increasing fabric consumption [33, 34]. Markers are created directly on a fabric (manually) or its pattern image (in a semi-automated way) using many specific work methods and principles [35].To make the coordination of stripes easier, pattern pieces are grouped in separate sections created from body components, sleeve components or combining both in one section [33], (see ***Figure 1***). To produce all garments in the same way with a coordinated pattern, the marker always has to be started in the same position of the fabric pattern repeat. Often even separate sections have to follow this rule. Later, because of this requirement, a certain part of the fabric in all its width has to be cut off and discarded as waste (***Figure 1.b***, a – amount of fabric which is cut off and discarded as waste in all its width).The larger the repeat of the striped fabric, the larger the material waste [35].

There are three other causes of fabric waste when producing garments from cross directionally striped fabrics: large dimensions of the components, which

Figure 2. a) T-shirt with narrow stripes: width of stripes 6 mm, repeat of the fabric 12 mm and b) a T-shirt with wide stripes: width of stripes 20 mm, repeat of the fabric 40 mm.

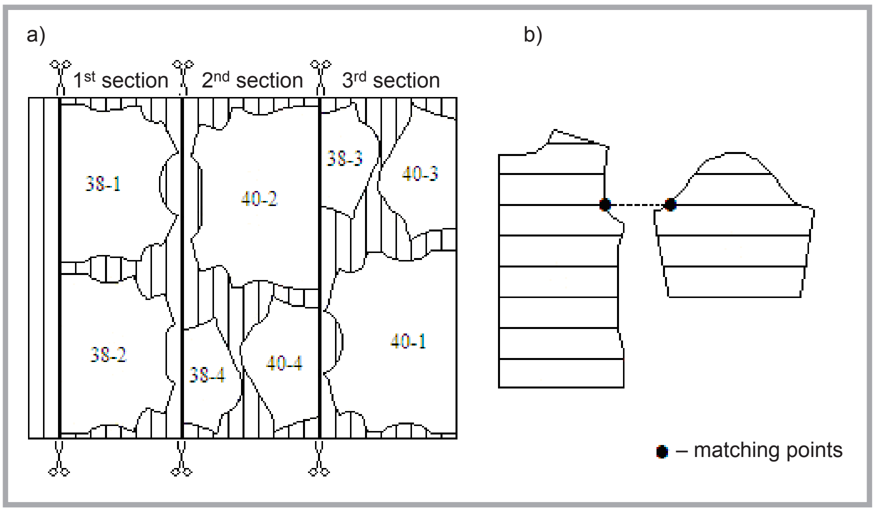

Figure 3. a) Three sections of the marker for sizes 38 and 40 and b) matching of stripes of the front and sleeve components.

are difficult to place efficiently on a fabric; the necessity to match fabric stripes in joining places of the components, and the necessity to match the pattern on the symmetrical components.

First experiment

The first experiment was performed to see how the pattern of striped fabric influences fabric use. A traditional style of T-shirt was chosen for the experiment (see ***Figure 2***). Markets were created for 11 sizes 34-52 for two materials with different widths of cross directional stripes.

Materials used in the experiment

Two knitted fabrics (100% cotton) with stripes in the direction of the material wales were used. The width of the materials was 148 cm, and that of the markers 145 cm. The materials had a symmetrical placement of different width stripes: the 1st material – width of stripes 6 mm and repeat of the fabric 12 mm (***Figure 2.a***), the 2nd material – width of stripes 20 mm and repeat of the fabric 40 mm (see ***Figure 2.b***).

Marker making principles

All sizes were divided into couples. Sectioned markers with 3 separate sections were created, placing pattern pieces in the following way:

- 1st section – the front and back of a T-shirt of the smallest size placed (for example, in ***Figure 3.a*** 1st section with a front and back of size 38),
- 2nd and 3rd sections – the front or back of a larger size T-shirt and one sleeve of both T-shirts placed (for example, in ***Figure 3.a*** 2nd section with a back of size 40 and two sleeves).

The straight edges of pattern pieces, which have to match the direction of stripes in ready garments were placed on a stripe (the hem lines of the front and back, sleeve hem lines). Certain fabric allowances were added to the opposite edges – shoulder and neck lines, as well as armhole lines to coordinate the pattern precisely during the second spreading of roughly cut components (using manual cutting) or during shifting and slight distortion of pattern pieces (using semi-automated cutting) [34]. As in ready T-shirts, stripes must also be coordinated in seam places, attention was paid to coordinating stripes on the edges of pattern pieces where components would be joined.

Markers for material with narrow stripes

The width of the stripes did not influence the placement of the pattern piece in the cross direction of the fabric (width of stripes 6 mm, repeat of fabric 12 mm). The efficiency of fabric use in its width depended only on the size of the T-shirts, (dimensions of pattern pieces) placed in the markers. The smaller the size, the more unused material had to be left in-between pattern pieces and vice versa. It was seen that the traditional principle of grouping sizes – joining the smallest size with the largest one and then to move to medium sizes – was not efficient in creating sectional markers. Thus, it was necessary to create two groups of sizes – a small size group (sizes 34-44) and a big size group (sizes 46-52). In the small size group, pattern pieces of two different sizes were combined in the traditional way (34/44, 36/42, 38/40). The length of the markers was dependent on that of the longest pattern piece placed in all three sections: the front of the smallest size (1st section) and the front and back of the largest size (2nd and 3rd sections).

For large sizes: 50-52 the space in sections 2 and 3 to place pattern pieces of sleeves was already so small/narrow that the length of the sections became dependent on the length of the two sleeves (placed one after the other) and not on that of the longest component (front or back). As the total length of the two sleeves was larger than that of the front/back of the t-shirt, the marker length increased (see ***Table 1***).

Markers for material with wide stripes

The marker length was influenced by two factors: the length of the pattern pieces placed in the markers and also the fabric repeat (width of stripes 20 mm, repeat of fabric 40 mm). It was necessary to increase the length of the separate sections to start the next section from the new repeat of the fabric. As the stripes of the fabric were wide and visually expressive, it appeared necessary also to match the fabric pattern in-between body parts (front/back) and sleeves (see ***Figure 3.b***). This additional condition influenced the placement of the pattern pieces in the markers for large sizes (46/48 and 52/54). Sections 2 and 3 became dependent on the mutual placement of the two sleeves. The size of the T-shirt was larger, the placement of the sleeves in the markers was less efficient (it was less possible to mutually shift them in the cross direction of the material), see ***Table 1***.

Analysing markers created for fabric with wide stripes, it was seen that a certain part of fabric waste was dependent on the conformity of the fabric repeat and length of the pattern pieces, determining the length of the section. In marker 34/36 the length of the 1st section had to be extended for half of the fabric repeat despite the fact that body components of size 34 exceeded the previous fabric repeat by only 2.0 cm (full fabric repeat 4 cm). During the cutting process, 2.0 cm of fabric in its full width was cut off and discarded as waste. When producing large quantities of t-shirts from this couple of sizes, the amount of waste material would be serious.

In the marker for sizes 50/52, a similar situation appeared with the sleeves. In sections 2 and 3 the sleeves were pattern pieces, which determined the length of the section. Because of the necessity to match the fabric pattern (in-between body parts and sleeves), more than one fabric repeat had to be left in-between two sleeves placed in opposite directions. As a result the length of the 2nd and 3rd sections exceeded for 4 cm, but total marker length – 8 cm (as one pair of sleeves was placed in two sections – 2 and 3).

To understand how serious and even appalling fabric loses are tolerated, a very simple example would suffice to illustrate: if a company produces 100 pieces of T-shirts from a 34/36 marker (from 212 metres of fabric), 2 meters of high quality fabric will be cut into small 2 cm stripes and fully discarded as waste. The situation will be even worse with a 50/52 marker – producing 100 goods from 252 meters of fabric, where 8 meters of fabric will be cut into 4 cm narrow stripes and discarded.

Table 1. *Marker length and marker efficiency for narrow and wide stripe T-shirts.* ***Note:*** ** – Marker efficiency = (Area of all pattern pieces in the marker/Total area of the marker)x100.*

Sizes in markers	Marker length, cm		Marker length difference, cm	Marker efficiency, %*	
	Narrow stripes	Wide stripes		Narrow stripes	Wide stripes
34/36	201.6	212.0	10.4	71.6	65.3
38/40	204.0	212.0	8.0	73.9	71.1
42/44	207.6	220.0	12.4	74.5	70.6
46/48	210.8	228.0	17.2	74.2	64.6
50/52	234.0	252.0	18.0	70.9	68.3

Table 2. *Marker length for original and reduced length T-shirt.*

Markers	Marker length, cm		Marker length difference, cm	Marker efficiency, %		Marker efficiency difference, %
	Original length	Reduced length		Original length	Reduced length	
34/36	212.0	208.0	-4.0	65.3	72.4	-7.1
38/40	212.0	212.0	0.0	71.1	70.2	+0.9
42/44	220.0	220.0	0.0	70.6	69.6	+1
46/48	228.0	228.0	0.0	64.6	64.1	+0.5
50/52	252.0	244.0	-8.0	68.3	71.3	-3
						-7.7

Second experiment

It was decided to conduct a second experiment and to try to improve the conformity of the length of the T-shirt with the repeat of the fabric. On the basis of the results of the 1st experiment, it was decided to reduce the length of the T-shirt by 2.0 cm and the length of the short sleeves by 1.3 cm. All pattern pieces of the style were corrected, with gradation performed to get all required sizes. New markers were created for the fabric with wide stripes (pattern repeat 4 cm).

After the changes made, the length of the markers for sizes 34/36 decreased by 4 cm and that of marker 50/52 by 8 cm. This would give serious material savings working with large production orders for these sizes. However, the length of the other markers did not change. When manufacturing the T-shirt in any ordered quantities for every size, the slight length reduction made will definitely give reduced total material consumption and fabric waste. Marker efficiency increased for marker 34/36 and 50/52, but at the same time it slightly decreased for other markers (see ***Table 2***). For a production order with equal quantities for every size, the total fabric waste will decrease by 7.7%.

However, it should be mentioned that equal quantities for every size are not typical in garment manufacturing, and therefore changes in fabric consumption and waste will strongly depend on the parameters of every specific manufacturing order: style design, quantities ordered for every size, and material qualities (the width and that of stripes).

Discussions

The 2nd experiment proved that it is possible to reduce *objective fabric losses* by conforming the length of the garment style to the fabric pattern. A slight reduction in the length of the body part and short sleeves did not give visually noticeable changes in the design of the T-shirt. However, by doing this, a certain amount of fabric could be saved, thereby reducing final fabric consumption and waste.

Length tolerance – acceptable changes of length while not changing the visual perception of the garment style should be determined by a designer and included in the technical documentation of a style. Its values will be dependent on the specific parameters of every style. Obviously, the *length tolerance* will be small, or even unacceptable, for short and close fitting styles when the length of the style is strictly determined by its proportions or completion with other styles [36].

For styles of fabrics with cross directional stripes, the *length tolerance* can be comparatively larger. To save the geometry of the pattern, most often these styles have simple construction solutions and large dimension components. From the one side, the simple construction solutions plus the necessity to match the fabric pattern always gives increased material use, but from the other side, these styles can have a comparatively large *length tolerance* (possibility to reduce the length while not changing the visual perception of the design) and good potential to reduce the total fabric consumption and waste.

Necessary corrections in the pattern pieces of a style (reducing the length) would not be complicated, for example, creating markers in a semi-automated way by nesting software for striped/checked materials (23), (such as "Mosaic" by Lectra, "Visual Nest" by Morgan Tecnica, "Match It" by Bullmer, "In Vision" by Gerber, among others). Already the garment industry is using cut planning software which screens a large number of different nesting variants and chooses the most efficient one [37, 38]. Similar software should be developed for striped/checked materials, including in it the possibility to use the *length tolerance* option [36]. The work process could be the following:

1. The user inserts the *length tolerance* of the style – the value (in cm/mm) by which the length of the style could be reduced to match it with the fabric pattern.
2. Markers are created for all sizes of the order in a semi or fully automated way;
3. Software detects markers in which the longest component in the section exceeds the end of the fabric report up to the *length tolerance*;
4. Software calculates how large fabric waste will be, taking into account the number of garments ordered from "critical markers";
5. Software calculates the total fabric consumption and compares it with fabric waste obtained from "critical markers";
6. Software changes the length of the pattern pieces of the style to the value necessary (cm/mm) to reduce the length of the "critical markers";
7. Software creates new markers for all sizes of the order;
8. Software calculates the total fabric consumption for the order and compares it with the original variant.

The work steps described are only general. During the development of appropriate software, they have to be checked with new experiments.

Conclusions

In this paper the marker making of garment styles from cross directionally striped materials was analysed to reduce fabric consumption and waste for certain production orders. The main reasons for increased fabric losses were determined. As a result of the two experiments performed, the following conclusions were made:

1. The reasons for *objective fabric losses* for styles from intricate fabrics are the fixed shapes and dimensions of garment styles and fixed fabric patterns.
2. Material consumption and fabric waste of styles of fabrics with cross directional stripes can be reduced by conforming the length of the style to the fabric pattern repeat.
3. The design of a garment style should contain certain flexible parameters to ensure efficient material use directly in its manufacturing process. *Length tolerance* – acceptable changes of length while not changing the visual perception of the style – should be determined by a designer and used to reduce fabric consumption and with it fabric waste.
4. Styles of fabrics with horizontal stripes have good potential for the use of *length tolerance* because of the simple construction solutions and large dimension of their components.
5. Specialised software should be developed to reduce fabric consumption and fabric waste with the help of the *length tolerance* in an efficient way.
6. Certain manipulations of the design of a garment style directly in its manufacturing process have never been done before; however, they could be easily performed and are very effective in producing medium and large manufacturing orders.
7. The product designing and manufacturing method described will help to efficiently reduce post-industrial fabric waste, material consumption, as well as product cost.

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