Impact of production methods on waste minimization in v-bed flat knitting: a case study

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ABSTRACT – REZUMAT

Impact of production methods on waste minimization in v-bed flat knitting: a case study

Sustainable development in the textile industry is challenging due to growing demand and urgent environmental impact. Waste minimization at every production stage is a promising way toward sustainability. Knitting is the most flexible textile technology for zero-waste production.

This study aims to investigate the impact of production methods on production efficiency and waste minimization using the V-bed flat knitting machine and the men`s cardigan as an example. The comparative analysis of yarn consumption and production time for different production methods (part cut and fully fashioned) was used.

Research results of men`s cardigan manufacturing by four distinct methods derived from part-cut and fully fashioned methods highlight their significant effect on yarn consumption, duration of production cycle, and cardigan performance. The fully fashioned method minimizes yarn consumption by 16.5%, with 3.9% waste compared to the part-cut method. The advanced fully fashioned method using a front knitted part with integrated cardigan pockets decreases yarn consumption by 2.6% more and incurs only 3.0% waste. This method produces the highest cardigan performance compared to the other methods due to its linking stitching and integrated knitted pockets. Within the part-cut method, using the part-shaped panel instead of the rectangular panel for sleeves leads to a 9.7 % decrease in yarn consumption and a 2.6% reduction in waste. It also leads to better product performance because of minimizing the overlocking seams. These findings underscore the importance of selecting appropriate production methods to enhance efficiency and reduce waste in knitwear manufacturing. Embracing waste reduction measures, mainly through natural yarn, holds promise for environmentally friendly garment production. This research emphasizes the need for ongoing exploration of eco-conscious manufacturing processes to promote sustainable knitwear production.

Keywords: *knitting waste, production cycle, fully fashioned method, part-cut method, product performance, sustainability, integrated pocket, zero-waste technology*

Impactul metodelor de producție asupra minimizării deșeurilor în cazul tricotării pe mașini rectilinii V-BED: un studiu de caz

Dezvoltarea durabilă în industria textilă este o provocare din cauza cererii în creștere și a impactului asupra mediului. Minimizarea deșeurilor în fiecare etapă de producție este o cale promițătoare către durabilitate. Tricotarea este cea mai flexibilă tehnologie textilă pentru producția de zero deșeuri.

Acest studiu își propune să investigheze impactul metodelor de producție asupra eficienței producției și minimizării deșeurilor, folosind ca exemplu mașina rectilinie de tricotat în V și cardiganul bărbătesc. A fost utilizată analiza comparativă a consumului de fire și a timpului de producție pentru diferite metode de producție (croire parțială și modelare completă).

Rezultatele cercetării efectuate asupra procesului de fabricație a cardiganului de bărbați prin patru metode distincte derivate din metodele croire parțială și modelare completă evidențiază efectul lor semnificativ asupra consumului de fire, duratei ciclului de producție și performanței cardiganelor. Metoda de modelare completă minimizează consumul de fire cu 16,5%, cu 3,9% deșeuri în comparație cu metoda de croire parțială. Metoda avansată, de modelare completă, care utilizează o parte frontală tricotată a cardiganului cu buzunare integrate, reduce consumul de fire cu 2,6% și generează doar 3,0% deșeuri. Această metodă produce cea mai mare performanță a cardiganului în comparație cu celelalte metode datorită asamblării și buzunarelor tricotate integrate. În cadrul metodei de croire parțială, utilizarea panoului în formă de reper în locul panoului dreptunghiular pentru mâneci conduce la o scădere cu 9,7% a consumului de fire și la o reducere cu 2,6% a deșeurilor. De asemenea, duce la o performanță mai bună a produsului datorită minimizării asamblărilor overlock. Aceste constatări subliniază importanța selectării metodelor de producție adecvate pentru a spori eficiența și a reduce deșeurile în fabricarea tricotajelor. Adoptarea măsurilor de reducere a deșeurilor, în principal prin fire naturale, este promițătoare pentru producția de îmbrăcăminte ecologică. Această cercetare subliniază necesitatea explorării continue a proceselor de fabricație ecologice pentru a promova producția durabilă de tricotaje.

Cuvinte cheie: *deșeuri de tricot, ciclu de producție, metodă de modelare completă, metodă de croire parțială, performanța produsului, durabilitate, buzunar integrat, tehnologie zero deșeuri*

INTRODUCTION

The textile industry has a significant impact on both the environment and society. This impact spans from the production process to the disposal of garments [1, 2]. Knitting is one of the three primary technologies in textile clothing manufacturing, alongside weaving and nonwoven. The second-highest environmental impact is associated with knitting, while weaving is found to have the highest environmental impact [3]. Implementing sustainable clothing manufacturing practices [4, 5] is essential as our world's resources become scarcer and the population grows. The key elements of clothing production are using eco-friendly materials [6, 7] and optimizing manufacturing processes to minimize waste at every stage [8, 9]. Some common methods to minimize waste include "zero-waste" production [10–20], reducing the amount of fabric used [21], utilizing fabric scraps for other purposes [22, 23], optimizing pattern layout to reduce fabric waste [24], properly disposing of any waste materials that cannot be reused or recycled [25–27], and upcycling [28–30]. Implementing these strategies before production can help garment manufacturers reduce their environmental impact [31] while reducing production costs.

The development of V-bed flat knitting machines [32] has transformed the production landscape by paying attention to the end product's quality and the equipment's technological possibilities. Manufacturers using V-bed flat knitting used various production methods, each impacting waste generation by up to 50%. These machines create different fabric types, facilitating the shaping of pre-sized parts with integrated knitted parts [33–36]. Each production method requires special knitting and making-up processes. Effective collaboration between design and pattern-making teams is necessary to minimize waste during the design process to achieve success [14, 17]. This will help reduce yarn and/or fabric consumption and enhance the utilization of knitted fabrics per garment. For this purpose, the knitting fully stitched-shaped parts of the knitted products are the most suitable method of production of knitted products in a V-bed flat knitting machine [33, 36], which requires skill and precision in garment-making and is valuable in producing high-quality garments. Using this method with integrated parts during knitting, not during the assembling process, results in the development of the seamless parts of products or complete products. This way is the premier choice among low-waste or waste-free concepts. The advent of whole garment or knit-and-wear V-bed flat knitting machines has moved the knitting industry to commercial success in the 21st century [34, 37]. This method is achieved through different knitting techniques such as whole garment (Shima Seiki, Japan) [38] or knit-and-wear (Stoll, Germany) [39], which means integrating all garment parts with bands or trimmings, accessories, and buttonholes to produce garments in a V-bed flat knitting machine. It enhances the appearance of the garment. Considerations such as garment size, fit, and intended use are essential for efficient production and waste reduction [40]. Designers can enhance knitting technology by using data and insights to create customized, seamless garments, reducing waste and production time for greater efficiency and cost-effectiveness in "ready-to-wear" fashion [41–43]. Also, this method can be suitable for producing customized products using the concept of "knit on demand" [44, 45] or mass customization for mass individualization [46]. Garment knitting technology has the potential to reduce manufacturing time and enable fast delivery to customers, even within hours [47]. However, this technique is only suitable for a limited range of garments that do not require seams [34]. The textile industry can streamline production by quickly creating customized clothing, meeting demand for personalized garments, and reducing unsold inventory. However, implementing complete garment knitting technology poses challenges, including high initial investment, prolonged preparation time, and fixed overhead costs [33, 36]. These garments offer superior fit and quality but require more time and resources than traditional knitwear. The advanced technological capabilities of knitting machines needed for complete garments pose a challenge as they require expertise to operate effectively and can be a barrier to entry for some manufacturers [48].

The examination of published literature on diverse production methods in knitwear manufacturing reveals a notable gap in comprehensive coverage. While foundational information is available in textbooks [34, 36], insights into management aspects can be found in sources such as [41, 42, 45, 46, 49] and a handful of publications [32, 35, 37, 40, 43] delve into advanced developments in V-bed flat knitting technology. Yet, a detailed analysis comparing production methods to elucidate strategies for minimizing raw material consumption, waste generation, and production time still needs to be improved.

Minimizing waste throughout knitted garments' design and production phases holds paramount importance. This imperative is particularly pronounced in knitting technologies, renowned for their considerable environmental footprint, alongside weaving.

This case study aims to conduct a comprehensive and detailed analysis of diverse production methods for V-bed flat knitting machines to minimize waste and production time. It is focused on the cut and fully fashioned methods and their derivatives. Emphasis was placed on assessing the generated production waste and the overall manufacturing time. The research findings offer valuable insights into knitwear production, aiding designers and manufacturers in enhancing product quality and optimizing the production process while minimizing waste. By leveraging these insights, manufacturers can streamline production processes, reduce waste, and sustainably produce high-quality knitwear garments.

MATERIALS AND METHODS

Materials

The men's cardigan (figure 1) of size 42 (in cm) was chosen for this study.

This cardigan is designed for men and is perfect for workouts, outdoor activities, or casual outings. It features long sleeves, a stand-up collar, a front zipper from the neck to the hem (which can be opened in two ways), and side slash pockets. The cardigans were made on a 12-gauge V-bed flat knitting machine CMS 340 TC-L from Stoll, Germany, from pure cotton yarn 50/2 Nm. Before knitting, the yarn was waxed with 0.5% wax. Plain stitches were used for the main section of the cardigan, while 1×1 rib stitches were used for the collar, cuffs, and hem.

The production methods

The two most used production methods for V-bed flat knitting machines were chosen for this study: part cut and fully fashioned. The knitted parts of the cardigan can be split into two groups for knitting the main parts (front, back, and sleeves) and the secondary parts (collar, front bands, pocket band, and pocket lining). They differ by the types of the main knitted parts presented in table 1.

The front, back, and sleeve parts were knitted as rectangular panels for the part cut method (PC-1). The other possible variant for the part cut method (PC-2) was also used: the front and back parts were knitted as rectangular panels, but the sleeves were part-shaped (table 1). The fully fashioned method ensures knitting the cardigan's front, back, and sleeves as stitch-shaped parts. The study is divided into two variants: simple fully fashioned (SFF) when knitted parts fit the paper patterns and advanced fully fashioned (AFF) when, additionally, the pocket was integrated into the front part during the knitting.

The post-knitting process of men's cardigans consists of washing the cardigan`s parts according to ISO 6330:2021 [50] using a washing machine (WM) and ironing using a hand iron or press (IM), which includes ironing all parts after washing, ironing the pocket during assembly to the front part, and final ironing of the finished cardigan. It also consists of part cutting using a round knife and/or scissors (CM) and assembling the cardigan using different machines such as the overlock machine (OM) for only part cut method, linking machine (LM), and sewing machine (SM). And consists of doing any necessary handwork (HW). The fundamental handwork operations (HW) mainly entail the removal of technical yarns from shaped knitted parts.

The summarized technological chart is presented in figure 2.

RESULTS AND DISCUSSION

The yarn consumption

The main difference in yarn consumption depends on the configuration of the main knitted parts (table 2). The secondary parts are the same (table 1) for all methods except AFF when the pocket is integrated into the front part directly during knitting.

Generally, the fully fashioned method, in which the main knitted parts are pre-sized and shaped, offers a substantial weight reduction compared to the part-cut method. Using the stitch-shaped parts (SFF) instead of the panels (PC-1) saves 25 g (15.2 %) for the front, 22 g (14.2 %) for the back, and 60 g (30.0 %) for both sleeves. This leads to a reduction of 16.5 % (107 g per cardigan) yarn consumption for the simple fully fashioned method (SFF) compared to the part cut method (PC-1).

The study results show that even small changes in the shape of panels can reduce yarn consumption. Using the part-shaped panel for sleeves in the PC-2 method leads to a 10.0 % decrease in their weight compared to the PC-1 method. It should be noted that these and similar panels can be produced on V-bed flat knitting machines in old models. Thus, the manufacturer can change the yarn consumption by

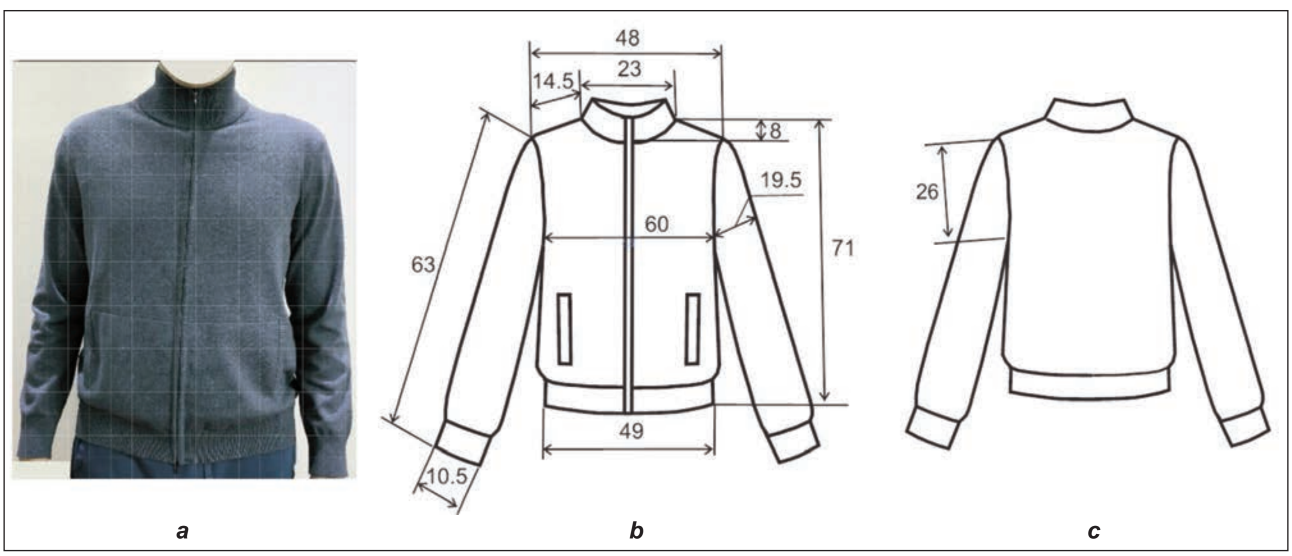


Fig. 1. The men's cardigan: *a* – real product; *b* – technical sketch of the cardigan for the front side; *c* – technical sketch of the cardigan for the backside

Table 1

THE PHOTOS OF THE KNITTED PARTS OF A MEN'S CARDIGAN DEPEND ON THE PRODUCTION METHODS

Knitted parts	Production method			
	PC-1	PC-2	SFF	AFF
Front ×1				
	Panel		Shaped S	Shaped A
Back ×1				
	Panel		Shaped	
Sleeve ×2				
	Panel	Part shaped	Shaped	
Secondary parts				-
	Pocket's lining ×1 – part-shaped			
				
	Left front band ×1, and right front band ×1 - shaped		Collar ×1 – part-shaped	Pocket's band ×2 – part-shaped

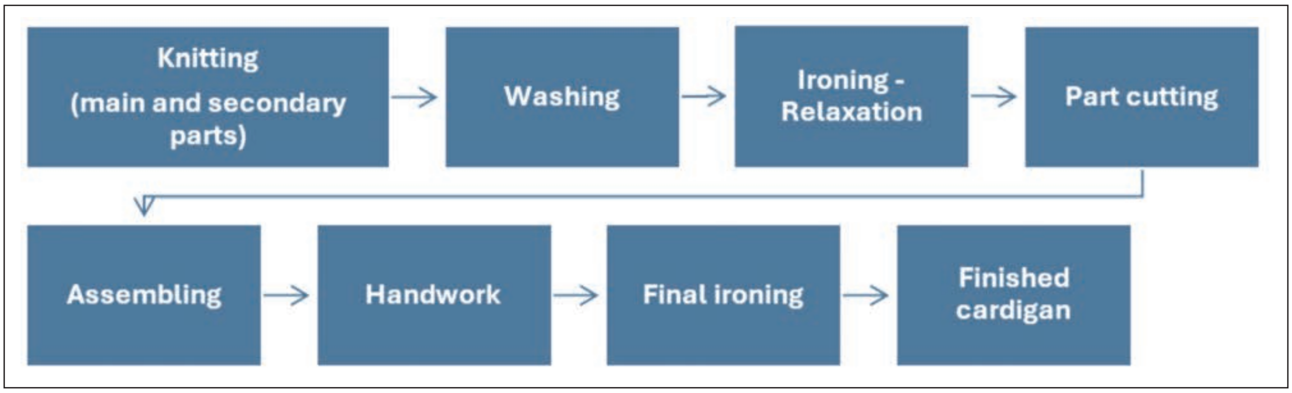


Fig. 2. Technological chat for men's cardigan

Table 2

THE WEIGHT [g] OF THE KNITTED PARTS (Mi) AND CORRESPONDENT WASTE (Wi) OF THE CARDIGAN

Cardigan`s part	**Type**	**PC-1**		**PC-2**		**SFF**		**AFF**	
		M_i	W_i	M_i	W_i	M_i	W_i	M_i	W_i
Front	Panel	165	32	165	32	-	-	-	-
	Shaped S	-	-	-	-	140	1	-	-
	Shaped A	-	-	-	-	-	-	162	1
Back	Panel	155	27	155	27	-	-	-	-
	Shaped	-	-	-	-	133	6	133	6
Sleeves	Panel	200	48	-	-	-	-	-	-
	Part shaped	-	-	180	28	-	-	-	-
	Shaped	-	-	-	-	140	2	140	2
Total main parts:		*520*	*107*	*500*	*87*	*413*	*9*	*435*	*9*
Collar	Panel	55	2	55	2	55	2	55	2
Right front band	Shaped	15	2	15	2	15	2	15	2
Left front band	Shaped	15	2	15	2	15	2	15	2
Pocket bands	Shaped	10	1	10	1	10	1	10	1
Pocket lining	Panel	36	5	36	5	36	5	-	-
Total secondary parts:		*131*	*12*	*131*	*12*	*131*	*12*	*95*	*7*
TOTAL:		651	119	631	99	544	21	530	16
The finished cardigan		532		532		523		514	
Waste in %		18.3		15.7		3.9		3.0	

slightly changing the panel`s shape using the part-cut method. A comparison of the weight of the front part with integrated pockets using the AFF method with the summary weight of the front part and the pocket lining using the SFF method has shown a 14 g decrease in yarn consumption per cardigan. It is only 2.6 % of the total weight, leading to valuable amounts within mass production. Thus, there is the possibility of changing the yarn consumption using the AFF method as well. Sustainability in clothes production emphasizes waste reduction at each production stage. In this case, it is essential to understand the effect of production methods on generated waste. As the shapes of the knitted secondary parts fit the patterns, the generated waste is not huge (table 2): 7 g for AFF and 12 g for other methods. The production waste for men`s cardigans is 18.3 % of total yarn consumption for part-cut method PC-1 with simple rectangular panels. Using the PC-2 method for sleeves only decreases waste by 2.6%. However, if pre-sized shaped main knitted parts are used, the amount of waste decreases significantly. The total waste is 3.9% and 3.0% for SFF and AFF methods, respectively.

The knitting time

Figure 3 presents the contribution of the main and secondary parts to the total knitting time for the cardigan.

Most of the knitting time is for the main parts (figure 3), and it significantly depends on the production method: around 74% for part cut and 82–86% for fully fashioned. It can be observed that the knitting time needed for pre-sized shaped front and back parts is double the time required for panels. This is because the time-consuming process of loops` transferring is used to shape the armhole and neck sections, especially for the front panel. However, the difference in the knitting time for sleeves is big. The time difference between knitting panels for sleeves and shaped sleeves is 4.3% (1.5 min) for part-shaped sleeves and 9.7% (3.4 min) for full-shaped sleeves. It can be explained that simple needle adding is used for panel widening. The loops` transferring for narrowing are simpler than the front and back panels. The fully shaped front part with integrated pockets (AFF) takes 7.5% (3.9 min) more time to knit compared to a regular fully shaped front (SFF). But it enabled to skip the knitting pocket lining separately, which took 8.5 min. Generally, it leads to 5.6 min saving time, i.e., 3.3% of total knitting time. The knitting time for other secondary parts, such as a collar, front, and pocket bands, is the same for all production methods. In conclusion, the research data shows that the fully fashioned method is time-consuming for the knitting stage. It leads to a 45% increase in the total knitting time of the cardigan compared to the part-cut method.

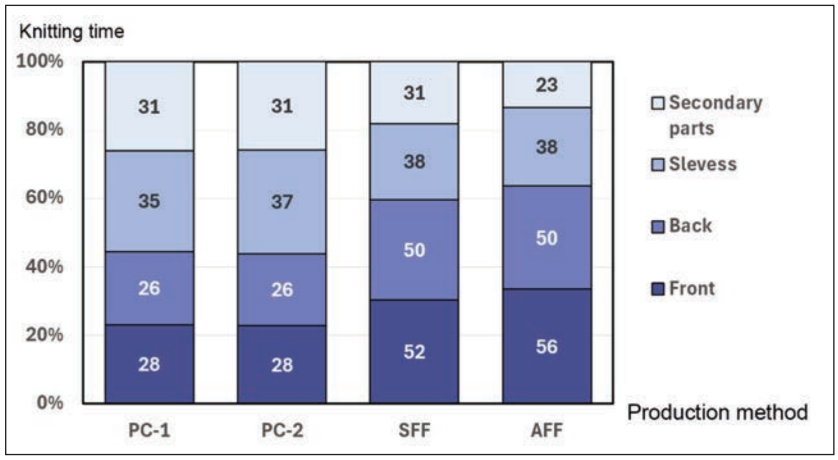


Fig. 3. The contribution of the main and secondary parts in total knitting time for the cardigan

The post-knitting time

Figure 4 presents the main stages' contribution to the cardigan's total production time. The washing, cutting, and assembly take 80% of the post-knitting time for all production methods. The assembly remains the most time-consuming stage, with 48% of the total post-knitting time for the part-cut method and up to 53% for the fully fashioned method.

The washing of knitted parts and general handwork processes remain consistent across all production methods (figure 4); they are set up for the same knitted cardigan made from the same yarn. The cutting time (figure 4) varies significantly depending on the production methods. The part-cut method requires the longest time for cutting, accounting for 13.4% (PC-1) and 10.0% (PC-2) of the total post-knitting time. In contrast, the fully fashioned method (SFF) reduces cutting time by 48.4% compared to PC-1 with the rectangular panels and 27.3 % compared to PC-2 with the shaped panels. Furthermore, the AFF method minimizes cutting time even further, 2.7% of the total post-knitting time.

The disparity between SFF and AFF methods lies in cutting the pocket lining, which is unnecessary for the second one. The assembly process primarily involves operations using linking machines (figure 4). This is a labour-intensive process that requires high operator skills and ensures high-quality products. As with the fully fashioned method, all parts of the cardigan were assembled by a linked machine. It took longer than the part-cut method, where armhole seams were overlocked. The explanation for this trend lies in the impact of the edges of the full-shaped parts, which are "clean" and require additional time to join using a loop-to-loop method on a linking machine. The assembly time for full-shaped parts is extended when joining the linking machines, in contrast to the overlocked edge of the panel parts using the part-cut method. The difference is 28.4% (23 min) for the SFF method. Integrating the pocked into the front part during knitting within the AFF method significantly reduces the time for the linking by 19.2% (20 min) less than for the SFF method. It is almost like the PC method: 3.6% (3 min) difference. The assembly stage is the longest for the SFF method and the shortest for the ADF method. The difference is 25 min, i.e., the ADF method saves 20.0% assembly time. Ironing is an important part of a cardigan`s manufacturing as it eliminates wrinkles, creases, and folds and helps the piece look better. As described in "The production methods", ironing is used a few times within the cardigan`s production: for knitted parts after washing, for the pocket during assembly

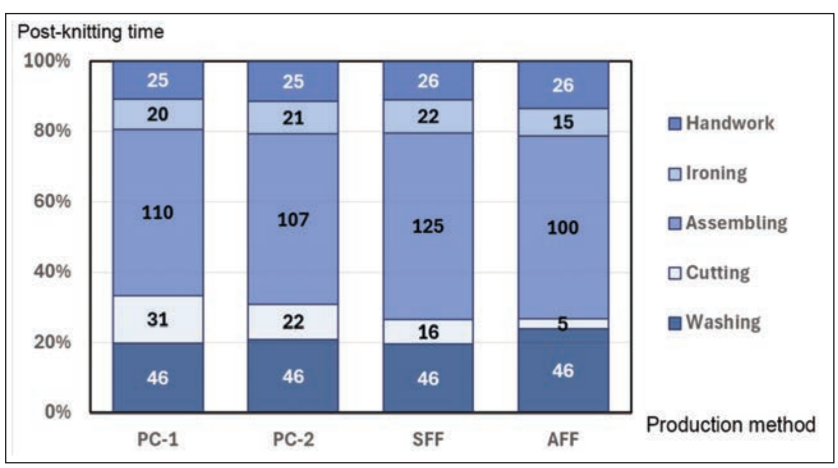


Fig. 4. The contribution of the main stages to the total post-knitting production time for the cardigan

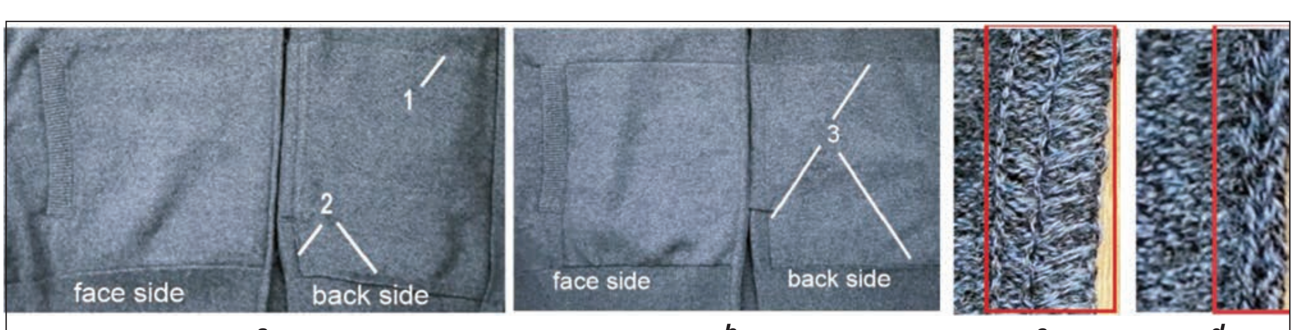
to the front panel, and for the finished product. It generally depends on the shape of the knitted parts. As plain stitches were used for the main parts of the cardigan, these stitches tend to curl coursewise onto the back side and walewise onto the face side. The shaped parts require longer ironing before assembly (figure 4) than panel parts. Thus, the partly shaped (PC-2) and shaped (SFF and AFF) parts need a correspondently 16.7% (1 min) and 28.5% (2 min) more ironing time after washing compared to rectangular panels (PC-1). On the other hand, if the pocket were integrated into the front panel during knitting (AFF), it would lead to the absence of the ironing process during assembly. The ironing stage takes up to 9.5% of the total post-knitting time. The AFF method requires less ironing time and can be characterized as more environmentally friendly because ironing is an energy-consuming stage with high humidity emissions.

In conclusion, the research data shows that the PC-1 and SFF methods are time-consuming for the post-knitting stage. Using the PC-2 method can reduce the post-knitting stage by 5.0% time. At the same time, the AFF method saves up to 16.7% of the post-knitting time. The production process duration for the three (PC-1, PC-2, and AFF) of the studied methods is similar (351, 342, and 361, respectively) and is around 351 min. The difference is only ±2.7% (±10 min). The SFF requires 16.0% (56 min) more time than other methods. The knitting takes 33.9-35.4% of total production time for PC-1 and PC-2 part-cut methods, increasing to 42.3% for SFF and 46.5% for AFF methods. The research data shows that the AFF method, with increasing time for the knitting stage, can ensure the same total production as the part-cut method. At the same time, both the energy-intensive ironing stage and the labour-intensive linking process are reduced.

Overall product`s performance

The production method used while manufacturing a cardigan significantly impacts its overall performance, quality, and aesthetic appeal. The construction of pockets and the type of stitches used for the cardigan`s assembly are important factors influencing the final product's performance. Figure 5 presents visual representations of pockets on the front parts of the cardigan, illustrating both the front and back sides.

There is a visible difference in a pocket created simultaneously with the front side (figure 5, *b*) by the AFF method and those using separate pocket lining linked to the front part (figure 5, *a*). Thus, the AFF method allows the production of knitted garments of higher quality to avoid unnecessary and bulky seams. As was mentioned above, the type of stitches used for the cardigan`s assembly depends on the type of knitted part. Using rectangular or partly shaped panels for the cardigan`s main parts requires cutting on the sides and tops to form armholes, shoulders, and necklines. It is followed by an additional stage – the overlocking of the seams to create finished sides and avoid unexpected unravelling (figure 5, *c*). The overlock seams are usually thicker and bulky. This stage is attributed to both part-cut methods. In the case of PC-2, overlocking is used for shoulders and armhole seams only, while in PC-1, the side joints of the side of sleeve stitches are overlocked. The linking stitches (figure 5, *d*) are usually used for stitch-shaped sides; they create a flat seam with a good appearance. In our case, linking was the only method for cardigan assembly by both fully fashioned methods (SFF and AFF). It was partly used for the part cut method, pocket lining joining (PC-1 and PC-2), the front and back parts, and the side of sleeve stitches (PC-2). Another advantage of linking seams is that it keeps the knitted part in the original stage; thus, it allows the unravelling of the yarn, even from ready-to-use knitted products. This is a big step toward upcycling and circularity in the knitting industry. In conclusion, it can be stated that the overall performance of men`s cardigans increased using a fully fashioned method compared to the part-cut method. Within both methods, there are separate ways to improve the quality and performance of the final product. Using part-shaped panels (PC-2) instead of rectangular panels (PC-1) is a good choice for manufacturers equipped with old models of the V-bed flat knitting machines. It will be an advanced decision for those equipped with V-bed flat knitting machines with technological capabilities for integrating additional parts, such as a pocket, into the main part during the knitting.



a *b* *c* *d*

Fig. 5. The photos of the pockets on the front and back of the finished cardigan: *a* – pocket knitted as a separate part (PC-1. PC-2, and SFF); *b* – integrated pocket (AFF); *c* – overlock stitch; *d* – linking stitch (1, 2 – sewing seam on the pocket, 3 – knitted stitch on the pocket)

CONCLUSION

The study reveals valuable insights into how men's cardigan manufacturing production methods can improve efficiency using V-bed flat knitting machines. Analysed part-cut and fully fashioned methods significantly impact yarn consumption, overall production time, and product performance. The fully fashioned method reduces yarn consumption and production waste compared to the part-cut method. Although the fully fashioned (SFF) production cycle is 16.0% longer than the part-cut (PC-1) due to increased knitting time for stitch-shaped panels, it results in a higher-quality product and promotes sustainability. The stitch-shaped panels have the greatest advantage: they allow the yarn`s unravelling at both production and consumer stages for its future upcycling. Integrating secondary parts into main parts during knitting is a promising step toward zero-waste production. For example, combining the pocket into the front part of the cardigan within the fully fashioned method reduces yarn consumption by 3.0%, waste by 0.9%, and production time by 17.9% while reducing the need for ironing and linking processes. Waste reduction and improved product performance are achievable even within the part-cut method. Using part-shaped panels for sleeves decreases yarn consumption by 9.7% and waste by 2.6% while enhancing product performance without extending the production cycle.

The main finding of this work is in understanding the balance between two objectives, namely waste minimization and production cycle reduction, for the production of high-quality products and sustainable development of the knitwear industry. This research emphasizes the importance of selecting the right production methods for knitting garments. Implementing waste reduction measures, especially with natural yarns, can significantly improve eco-friendly knitted clothing production. Manufacturers can achieve sustainable, high-quality knitwear production by choosing and applying appropriate methods.

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