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RESEARCH ARTICLE

Reducing waste in garment factories by intelligent planning of optimal cutting orders

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ABSTRACT
The design and production of apparel industry are a combination between the arts, the engineering, and the technology section. This paper enhances to find the optimal distribution of higher investment of raw materials by depending on artificial intelligence algorithms; the production orders in cut department with the studied company were reviewed. The waste rate, the number of layers, the number of markers for each executed order were studied and analyzed. Methodology of this study is examined under Genetic Algorithms for creating programs starting from a high level analysis of the problem by using code to express the problem. As a powerful optimization technique; The new scheduling method includes the movement of orders when comparing with the original process to reduce in the percentage of waste of fabric by 2.62%, As well as reducing the number of spreading layers by optimizing the cutting table from 56 to 25 layers, and reducing the number of markers from 6 to 3 markers. The method that gained could be applied in the cutting department and provide the extra knowledge in managing and handling the manufacturing system.

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KEYWORDS
Garment; production chain; intelligent planning; cut order plan

1. Introduction

The textile industry is one of the world's major industries regarding to the new global trading system and globalization, new applied technology encountered in wider acceptance of such as photochromic and thermochromic colorants in garment technology (Younes et al., 2019, 2020) in addition to other applications. On the other hand, the garment industry as a substantial one within the supply chain of the textile industry is necessary to improve the competitiveness in the global garment market, and to offer the customer satisfaction, with an acceptable cost (Selin, 2012); It is important to know how rapidly the apparel Industry is responding to the intervention of Information Technology in the cutting room. The biggest challenges of the garment industry is to reduce the cost value (Naidu, 2019), the garment Industry contributes high percentages of the national economy of many countries due to the high added value of products that they achieve, especially by exporting products clothing (Nayak & Padhye, 2015). The Apparel Computer-aided design (CAD) tool provides a great tool to the cutting department and saves a lot of money and time (Agrawal & Datta, 2019), new biodegradable clothing could be a way to reduce the polluting effects of fashion (Younes, 2017).

A mathematical model was developed to be used in mixed integer nonlinear programming for a manual cut order plan, and a program code was created in LINGO optimization software, optimum results that cannot be manually calculated (Ünal & Yüksel, 2020). The availability of multiple solutions allows greater flexibility and permits decision makers to apply additional criteria in selecting an appropriate cutting schedule (Rose & Shier, 2007), cutting out the patterns through all plies creates a set of bundles of garment pieces, and several such lays may be required to satisfy all demands. The working arrangement of the cut-template is treated as Cut order plan (COP) to optimize cutting templates of fabric cutting function in apparel manufacturing. The customer's order presents a specific quantity of pieces with a specific marker which has quantities of pieces in different sizes, fabrics and colors. The work stages consist of preparing samples, buying raw materials, storing and checking materials, preparing all other supplies, Fabric cutting is one of the main value-adding processes in the apparel manufacturing process (Buontempo, 2019). Figure 1 shows the sequence of operations in the garments factory, the production process of garments is separated into four main phases which are designing/clothing pattern generation, fabric cutting, sewing, and ironing/packing.

Fabric cutting process serves as the major input provider for the sewing process by feeding cut panels required to sew garments, it acts as a second importance cost contributor of the manufacturing process due to the high expenditure on marker making fabric spreading and cutting, which is about 5–10% of the total manufacturing cost; Therefore, apparel manufacturers heavily focused on reducing the cost incurred in the cutting department (Nazir et al., 2014). Marker is a piece of paper where component parts of one or more garments are arranged in a way that the area of the paper is

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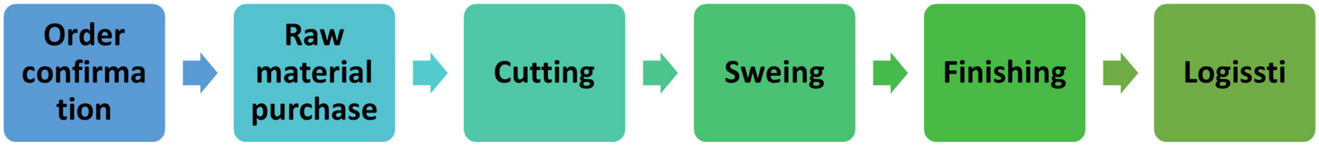

Figure 1. Garment manufacturing processes.

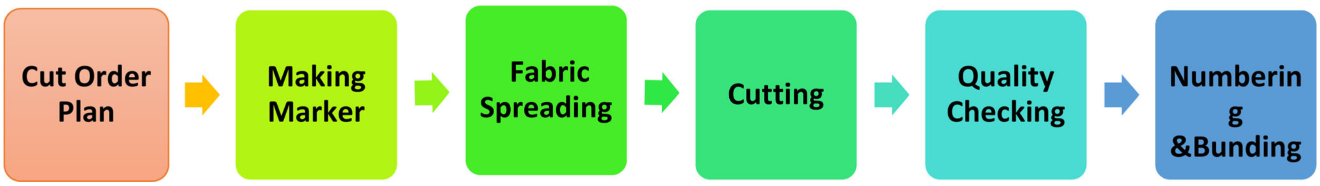

Figure 2. Works' stages of cutting department.

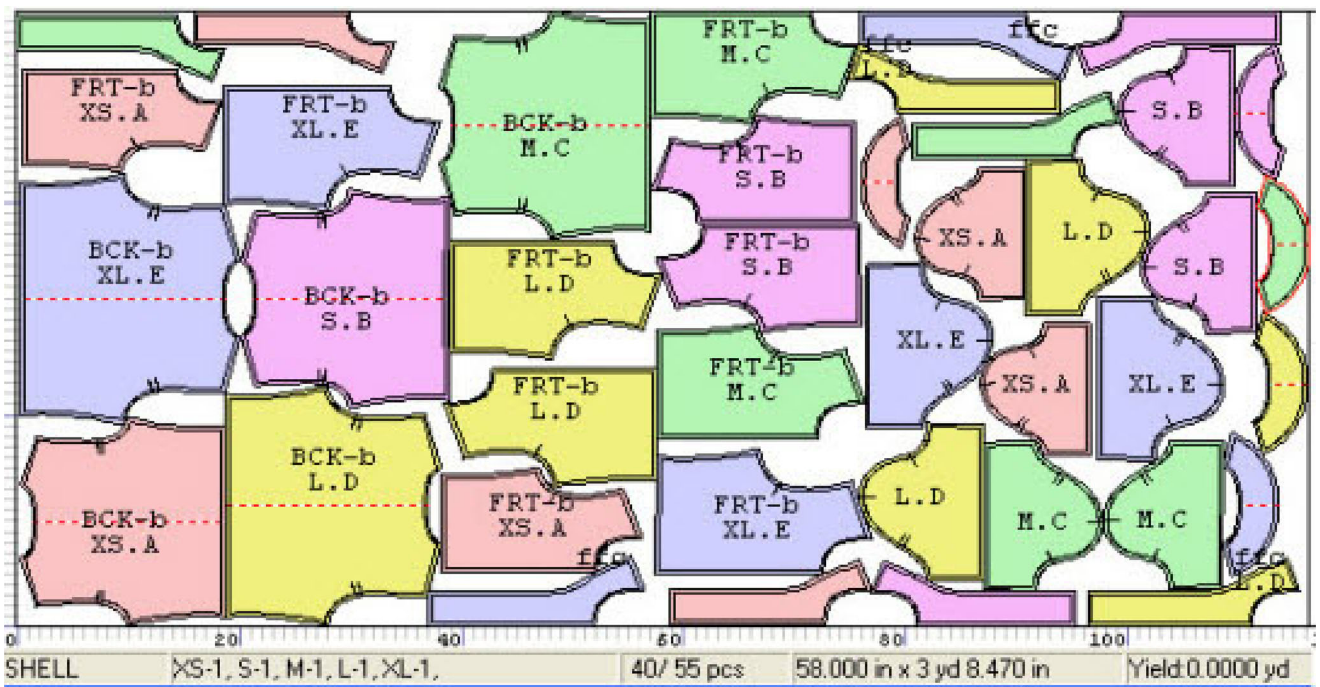

Figure 3. The marker (one garment from each size).

effectively utilized (Wong & Leung, 2008), it is located on a marker sheet and it is laid on top of the fabric lay (Fernando & Abeysooriya, 2012). Researchers highlight that an effective cut order plan results in reducing the above-mentioned cost factors of cutting process, thereby reducing the entire manufacturing cost largely (Abeysooriya, 2012). Many researches tried to reduce waste in fabric with different methods and techniques used (Kitaw & Matebu 2010). Figure 2 shows the work stages in cutting department.

The work plan of the cutting department is termed as cut order plan (COP), the number of cut pieces, the required size, the number of pieces required from each size, as well as the number of markers to be cut and the number of layers for each marker, until the order is completed. The process of preparing marker is called marker making where same sizes or different sizes patterns are organized on the marker area to achieve maximum utilization of fabrics (Fister et al., 2010). Area of the marker represents the fabric area in which the component parts will be cut-out. Figure 3 shows a marker contains four garments from five different, sizes. Garment industry, any garment manufacturer tries the best to finish the assembly work soon to increase on-time delivery and to increase machine/labor utilization to reduce production cost. Assembly line balancing is therefore a critical issue for the efficiency and competitiveness.

In Fabric Spreading, fabric plies are laid one over the other on the cutting table to form a fabric lay (Wong & Leung, 2008). The quality of the patterns resulting from the cutting process is examined to be numbered and to ensure their quantity. A number of researchers have successfully applied Genetic Algorithms to solve problems in garment manufacturing, it could solve the job sequencing optimization problem of the manual fabric-cutting process for garment manufacturing (Chan et al., 2005). In simple terms, fabric-cutting is the process of transforming roll form fabrics into cut panels, according to the requirement of stitching production modules (Peric & Babic, 2008). The marker plans produced through Garment Gerber

Table 1. Distribution of measurements using the traditional method.

Marker	Number of layers	Number of required sizes/Layer						
		S	M	L	XL	2XL	3XL	4XL
Marker1	30	0	2	1	1	0	0	0
Marker2	10	1	0	0	0	0	0	0
Marker 3	5	0	1	0	0	0	0	0
Marker 4	4	0	0	1	0	0	0	0
Marker 5	2	0	0	0	1	4	1	1
Number of each sizes		10	65	34	32	8	2	2
Total number		153						

Technology software could accomplished in different fabric widths as independent variables, markers are more productive with larger fabric widths in all styles in both genders (Naveed et al., 2020). Computer-aided pattern making is the computerized version of hand-drawn patterns, functions of the complete CAD package are pattern making, digitizing of patterns, pattern grading, and marker making, and plotting (Glock & Kunz, 2000). In the flow work manufacturing of the cutting department, the orders are received from the customer contains the design of a primary model and raw and auxiliary materials and other supplies (Chen et al., 2014). The technician does the basic marker according to the order provided, which includes sizes and number of each size, and planning this by the Gerber Technology computer design. In practice, cutting large number of pieces with different shapes often requires a well plan of assigning number of shapes on the cut template to save marker making and production time and to fulfill the cut order requirement (Haque, 2016).

This research aims to find the optimal distribution of higher investment of raw materials by depending on artificial intelligence algorithms; then studying and analyzing the waste rate, the number of layers, the number of markers for each executed order (Table 1).

2. Experimental methods and materials

2.1. Materials

Man's long sleeve shirt is order placed by a private company (Digital Net); it was made from bekah cotton with grammage (weight per unit area) 210 g/m^2. The studied order includes seven different sizes: S, M, L, XL, XXL, 3XL and 4XL. At first with the help of GERBER planner was published by Gerber Incorporation, pattern grading has been done to convert pattern for different sizes of garments.

2.2. Methods

Marker Making Pattern grading helps to create different sizes of pattern from S to 4XL. Gerber software has been used, marker width was fixed (81 cm) and marker length will be defined the fabric consumption. The maximum numbers of products to make every marker were 11 templates for different sizes of garments, which included in different portion of marker length and width to save marker making and production time. Moreover there were problem in production output and the utilization of the machine; it was analyzed by ARENA software. There are two basic methods of working in the current case study (BIG BLUE - Garment Company).

Size	Required amount
S	10
M	65
L	34
Xl	32
Xxl	8
3xl	2
4xl	2

Figure 4. Cut order 1.

In The traditional method used during the company's production of internal orders, there was no fundamental problems appear waiting for solutions, There is no importance here to the number, colors and sizes of the pieces produced. The Genetic Method is followed when receiving an external order to be executed with predetermined sizes and numbers.

2.2.1. The traditional method used in the company

After receiving the order, an order scheduling process takes place to accommodate high production performance and lower production costs; several cut order cases were employed to justify the performance of the proposed approach regarding to the technicians' experience. The technician test the ineffectiveness of the selected plans, and tend to adjust the plans according to a trial-and-error approach, therefore we need a mathematical model that perfectly controls the scheduling process.

In Figure 4 there is an order from the digital net company. This order includes a number of required garments from each size For example: 10 garments from size M, 65 garments from size L. The order will be transferred to the cut order matrix for easy handling: A = [10, 65, 34, 32, 8, 2, 2], where (A) A matrix Contained 7 columns represent a number of sizes and 1 row represent the type of fabric.

The technician needs to schedule the appropriate cut order and the least waste. The cut order will be prepared according to the expertise of the technician and the appropriate cut order will be prepared, the templates had to be treated by Gerber Technology for funding scores, and their length at fixed width (81 cm).

2.2.2. The genetic method using genetic algorithms

Methodology of this study is examined under Genetic Algorithms (GP), genetic algorithms is an automated method for creating programs starting from a high level analysis of the problem, where a genetic algorithm begins is a requirement of a productive issue by using code to express the problem. In order to achieve this, the basic characteristics needed to develop the GA program must be defined:

1. A set of variables and constants considered the inputs to the genetic process.

Table 2. The experimental parameters.

Marker	Number of layer	Fabric length (m)	Fabric width (cm)	Usage percent %
Marker 1	32	2.52	81	85.20
Marker 2	8	1.68	81	73.78
Marker 3	10	2.44	81	81.18
Marker 4	2	2.55	81	84.00
Marker 5	2	2.00	81	70.39
Marker 6	2	1.94	81	87.20
Total	56	13.13		

2. Basic mathematical dependencies group.
3. The fitness function, which measures the degree of fit of each chromosome within the population, to determine the most appropriate solutions.
4. Parameters of operating the genetic program.
5. The final criterion by which the genetic program will end and present the results.

To succeed the genetic process, it was necessary to set constraint that define the production process and distinguish it from others, in order to ensure optimal results.

The second cutting order presents the importance of the proposed algorithm, as the algorithm solved the problem of the extra pieces as a result of traditional planning method that depends on the experience of the technician. The algorithm deals with the inefficient distribution of the pattern and helps to get the required number within the cut order without producing extra pieces.

This algorithm was designed depending on mathematical equations to get the correct distribution, and then use of genetic algorithms to conduct the largest possible number of experiments and selecting the best case, it depends on obtaining a zero matrix at the end of the experiment (i.e. obtaining the required number of pieces of clothing) with the lower number of patrons and layers in the used area of the cutting table.

3. Experimental results

The work orders of the cutting department are called Cut Order Plan (COP), which it plans the entire cutting process; number of markers needed, sizes to be included in each marker; quantity of garments from each size needs to be included in the mark and the number of fabric plies that will be cut from each marker. The parameter of the fabric width is fixed and its value is 81 cm, according to the width of used fabric (Table 2).

The number of patterns within a single marker the minimum and maximum number of garments is determined in order to enhance the validity of the results of the genetic algorithm used. The Maximum numbers of garments in the marker were 13, and Minimum number w 1 marker.

After the data is being collected, all the data is used to make a similar model as the flow of assembly

i. The length of the cutting table determines the length of the required period, which is 11 meters in the studied company

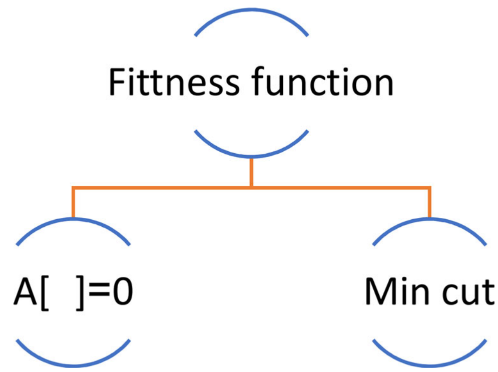

Figure 5. Fitness function parameter.

Table 3. Distribution of measurements cut order 1 using the genetic algorithm.

Marker	Number of layers	Number of required sizes/Layer						
		S	M	L	XL	2XL	3XL	4XL
Marker 1	16	0	3	1	1	0	0	0
Marker 2	1	2	1	2	0	0	2	2
Marker 3	8	1	2	2	2	1	0	0
Number of each sizes		10	65	34	32	8	2	2
Total Number		153						

ii. The height of the cutting knife determines the number of plies of the fabric used for the cut order (the minimum and maximum number of plies), which are determined according to used fabric.

Maximum number of plies in the lay is 45 plies, and Minimum number is 1 ply, the genetic algorithm was designed to obtain an ideal marker.

A zero-cut order matrix was obtained without Additional garments, and the fewest possible plies as shown in Figure 5. Table 3 shows the results obtained from the genetic algorithm applied, where the order was distributed on 3 markers only, the first of 16 layers with 3 garments of size M, 1 garment of size L, 1 garment of size XL. The second of 1 layer with 2 garments of size s, 1 garment of size M, 2 garments of size L, 2 garments of size 3XL, 2 garments of size 4XL. The first of 8 layers with 1 garment of size S, 2 garments of size M, 2 garments of size L, 2 garments of size XL, 1 garment of size 2XL.

4. Discussion

That is illustrated in the Figures 6–8, and a greater utilization of the available space on the cutting table. The Figure 6 shows distribution method the garments in marker 1, Figure 7 shows distribution method the garments in marker 2, and the last one shows distribution method the garments in marker 3 (Table 4).

The three markers mentioned were entered on the Gerber program in order to compare the consumption ratio and the marker length, Figure 9.

The consumption percentage factor of the fabric usage was depended, as it is an important factor in calculating the cost, which constitutes 70% of the total cost in the cut section according to Figure 10 (Nazir et al., 2014).

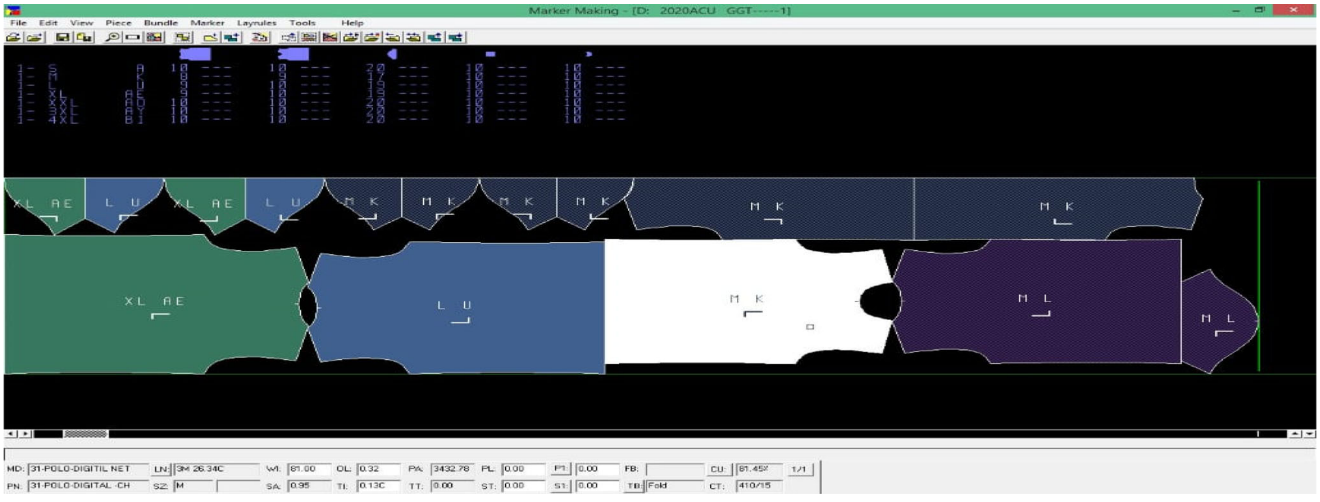

Figure 6. Marker 1 on GERBER.

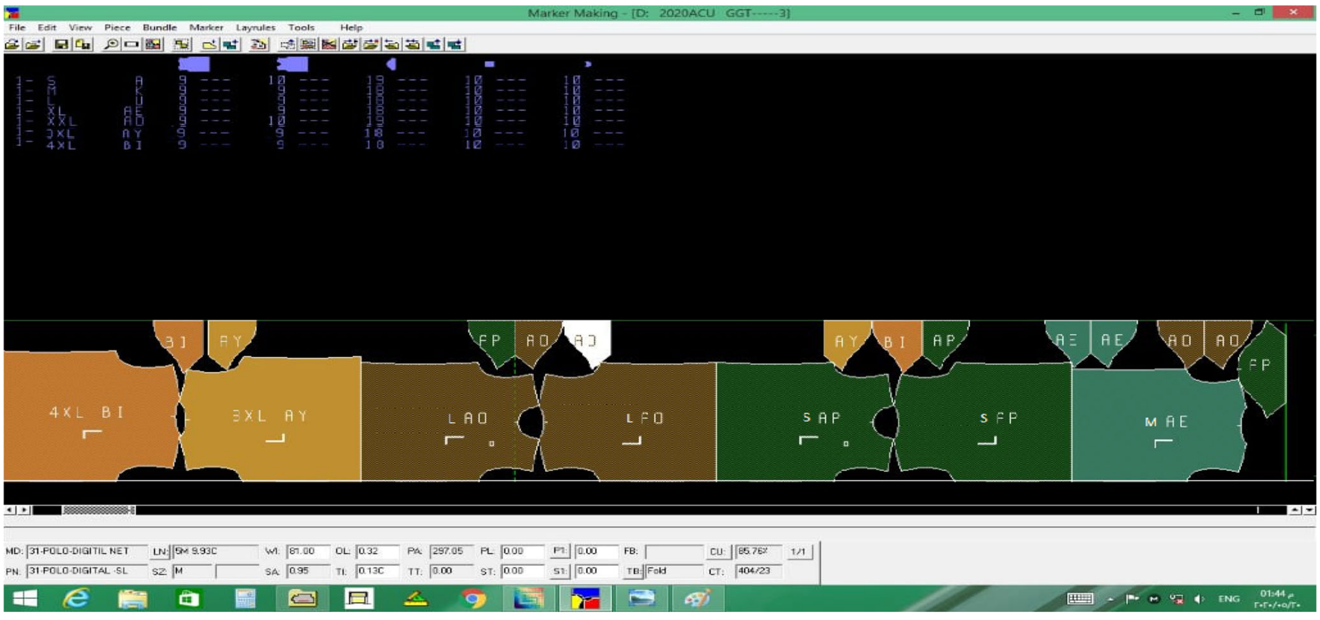

Figure 7. Marker 2 on GERBER.

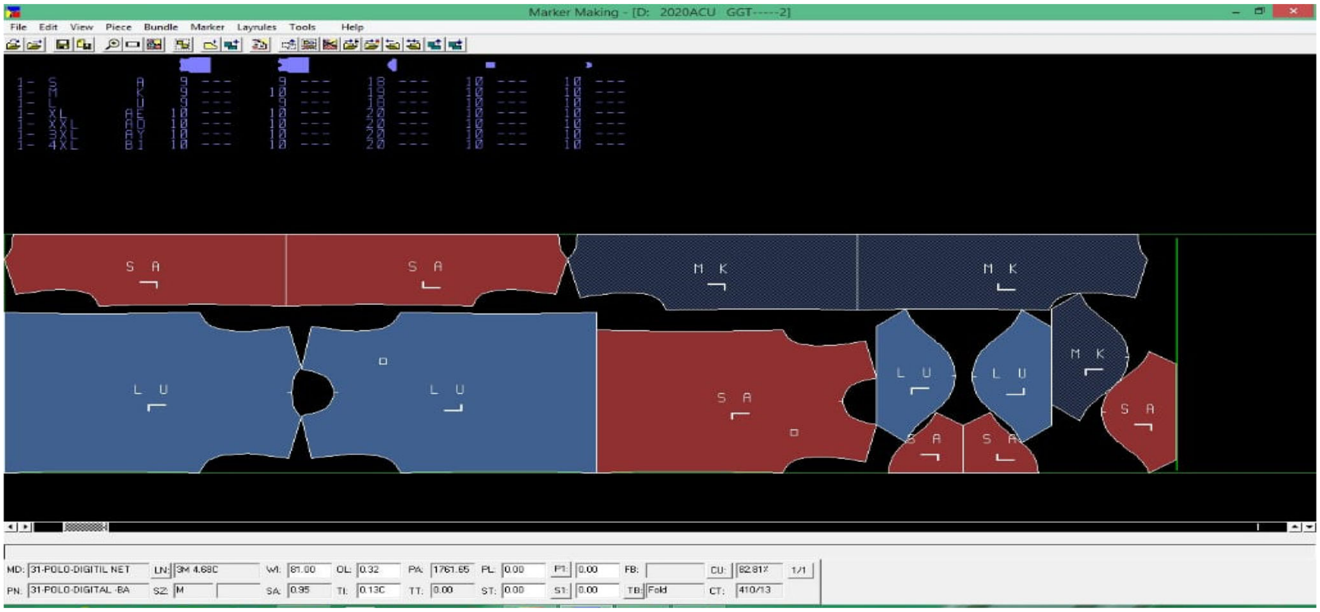

Figure 8. Marker 3 on GERBER.

Table 4. Use percentage in the suggested method.

Marker	Number of layer	Fabric length (m)	Fabric consumption %
Marker 1	16	3.26	81.4
Marker 2	1	3.4	82.81
Marker 3	8	5.9	85.76
Total	25	12.56	

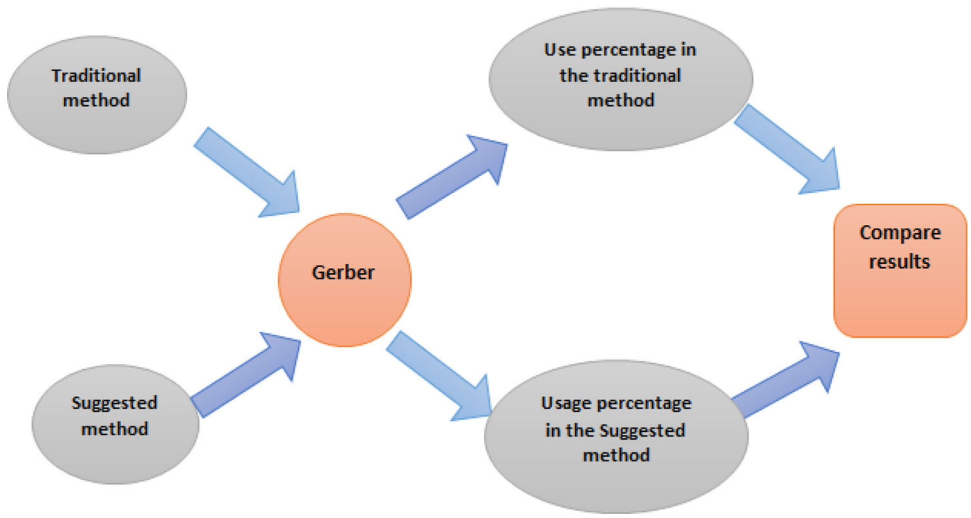

Figure 9. Research methodology.

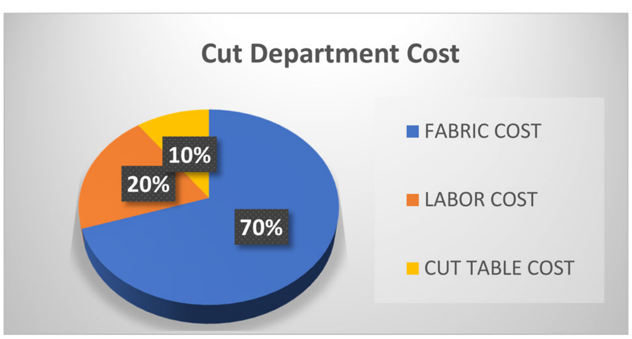

Figure 10. Cut department cost.

The listed results solving of cut order plan problem, and a significant amount of arithmetic operations are required if conventional heuristic algorithms being used.

After taking the values, a comparison was made between the two methods, shown in Table 5, where reducing the number of markers will lead to reducing the preparation of the marker and saving the cost of patron paper, as well as reduces the total number of layers will lead to save the time spreading and optimum utilization of cut table space, and raise the rate of fabric consumption.

The following diagram in Figure 11 confirms that the novel method is capable in finding optimized solutions than the heuristic based commercial software available in the market.

Experimental results indicated that the proposed method can yield better solutions compared to the available methodologies of generating cut-order plans available in apparel industry as below:

- The fabric usage percentage, increased from 80.88% to 83.5%.
- The number of spreading layers of fabric has decreased from 56 to 25.
- The number of markers required has decreased from 6 markers to 3 markers.

A simulation of a new production order has been performed to test the proposed algorithm shown in Figure 12, the first column shows the required sizes, second one the required garments from the costumer, and the last one shows the produced garments in the factory.

We notice that there is a big difference between the required garments and produced garments and the reason for this is the poor decision-making mechanism by the technician.

The order parameters were entered into the algorithm and the result was shown in Table 6 where only the required quantities were obtained without any additions.

And after validating the algorithm graphical interface has been created to give flexibility in usage by the operators, it contains icons for inputting certain parameters as shown in Figure 13 which are production order and max and min number of temples. When the icons are filled out correctly, the ideal distribution will be given in the form of an excel report for easy handling.

5. Conclusion

A line balancing algorithm is developed for cutting department, the proposed algorithm applies genetic algorithms to reduce the effort and time spent by technicians in ready-to-wear companies, since the preparation of the cutting

Table 5. Comparison between the two methods.

The comparison component	Genetic method	Traditional method	Result
Number of marker	3	6	Reducing the preparation of the marker
Number of layers	25	56	Reducing the cost of spread the fabric
Fabric consumption (%)	83.30	80.88	Reducing fabric cost

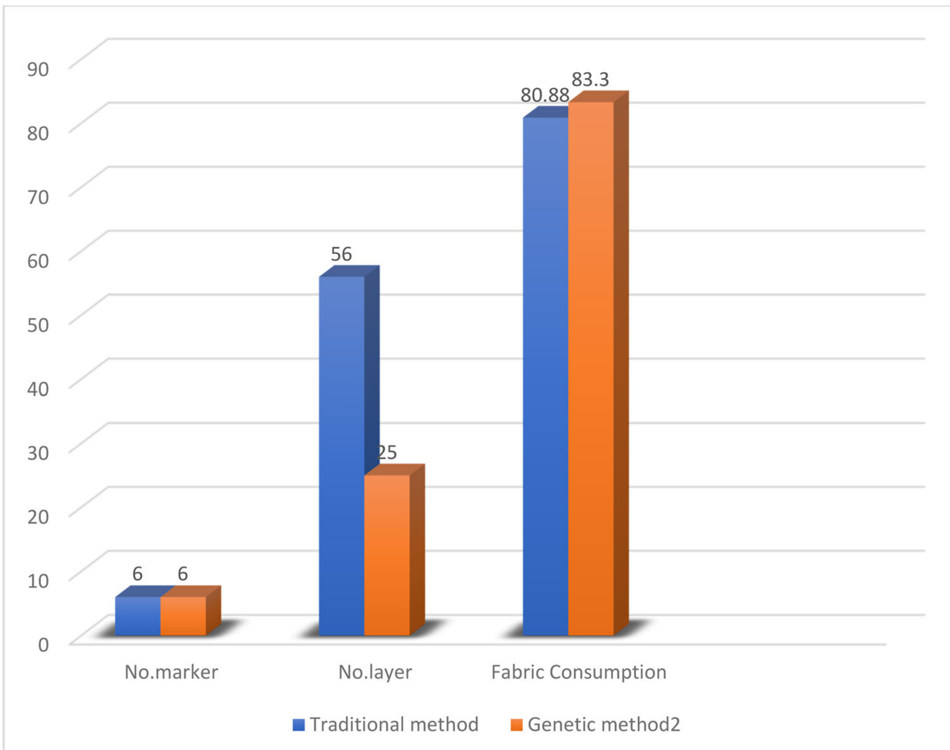

Figure 11. Discuss the result.

Size	Required amount	Produced amount
Xxs	37	40
Xs	37	40
S	94	101
M	156	167
L	186	199
Xl	186	199
Xxl	155	166
3xl	94	101

Figure 12. Cut order 2.

order plan is done manually and based on the technician's experience. Experimental results indicated that an improvement was found in the percentage of fabric usage, as the percentage increased from 80.88% to 83.5%. The number of spreading layers of fabric has reduced from 56 in the traditional method to 25 in the genetic one, thus reducing spreading the cost and time required, in addition to reducing the number of markers required from 6 markers to 3 markers, thus reducing the cost of design. This study can be extended in several sectors in the garment factories, multiple

Table 6. Distribution of measurements cut order 2 using the genetic algorithm.

		Number of required sizes/Layer							
Marker	Number of layers	XXS	XS	S	M	L	XL	XXL	XXXL
Marker1	31	0	0	2	0	4	4	1	2
Marker 2	32	0	0	1	2	1	1	1	1
Marker 3	23	1	1	0	4	1	1	4	0
Marker 4	7	2	2	0	0	1	1	0	0
		37	37	94	156	186	186	155	94
Total number					945				

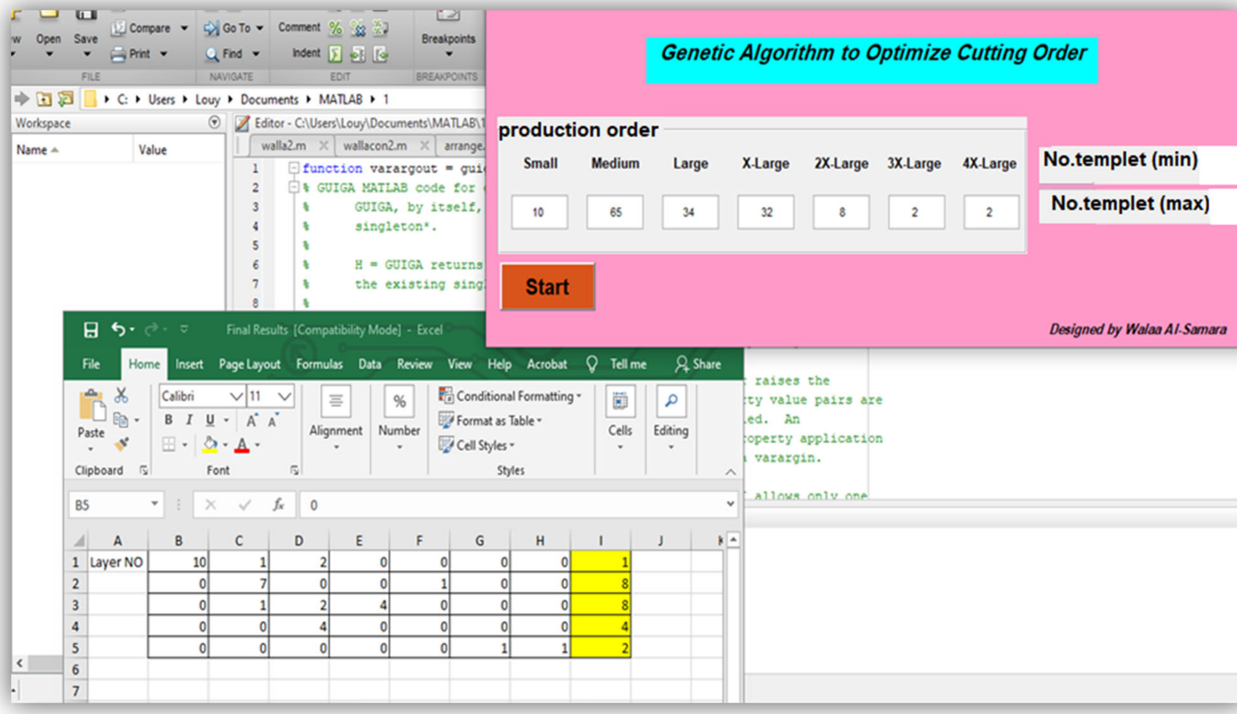

Figure 13. Graphical interface.

objectives integrating production line efficiency, and reliability and the extension of further researches. The percent research helps technician to do the basic marker according to the order provided (sizes and number of each size, and planning); An as a result, cutting large number of pieces with different shapes often requires a well plan of assigning number of shapes on the cut template to save marker making and production time and to fulfill the cut order requirement which will be advantage for the garment industry.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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