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Cut Order Planning Under Cost, Time and Waste Constraints in Furniture Industry

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ABSTRACT

The study addresses the optimization of fabric cutting of production in the furniture industry, aiming to minimize costs and improve production efficiency. The problem is defined as the need to optimize variables such as marker type, quantity, and the number of plies to reduce wastage. A marker is a fabric layer placed in a single or multiple plies on which the cutting layout for the pattern is placed. The methodology involves analyzing the current system, identifying problem symptoms, and developing models for cut order planning. The research focuses on minimizing fabric-cutting costs by making optimal marker types and plies decisions. A mixed integer linear programming (MILP) model is formulated to optimize fabric-cutting decisions, leading to cost savings in production processes. The results indicate the potential for improved cut-order planning, increasing potential savings, reducing production timelines, and enhancing overall operational performance by considering cost, time, and waste constraints.

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1. Introduction

Every product presented to consumers incurs costs for the companies. A company's success is greatly influenced by its ability to manage costs and maintain a healthy profit margin. Within the furniture industry, a substantial portion of the expenses can be attributed to fabric costs. Approximately three-quarters of the production expenses in the clothing industry are dedicated to raw materials (Zhezhova,2019). Also, cut order planning holds substantial importance in material cost management, particularly as fabric expenses typically constitute over 50% of the total manufacturing cost (Wong, W. K,2008).

Consequently, enhancing the utilization of textile materials can lead to significant cost savings. Due to this, furniture companies are exceptionally diligent when it comes to selecting and cutting fabrics. They are keenly interested in optimizing these areas to reduce expenses and boost efficiency.

Improving a fabric-cutting department would indirectly benefit an entire factory in the furniture sector. Enhancing the productivity of raw material utilization and reducing production costs start with optimizing the fabric-cutting stage, making it a crucial step in the overall development of the factory. Fabric cutting optimization encompasses a two-fold process. The initial step entails marker optimization, which aims to minimize wastage through strategically arranging fabric pieces on markers. As seen in Figure 1, a marker represents a collection of fabric plies, typically comprising multiple plies stacked as a single or double ply, forming the foundation for the subsequent cutting layout placement. The second step involves cut order planning, which aims to minimize fabric usage by selecting each product's marker type (ranging from single to six) and determining the number of fabric plies in each spreading. The goal is to optimize the overall fabric consumption during the cutting process.

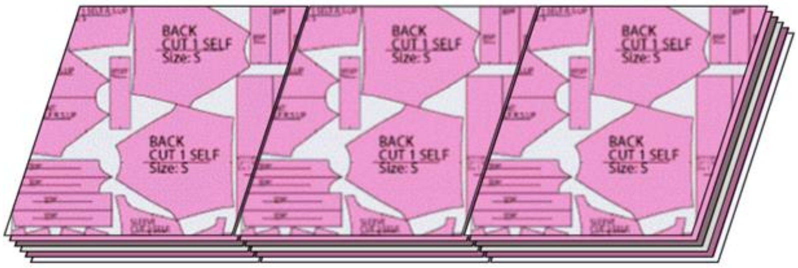

Fig. 1. An Illustration of Marker.

This research addresses the furniture industry and aims to optimize fabric cutting to minimize costs and wastage. A furniture company aims to minimize wastage in the process of identifying quantity, multiples, and number of markers of fabrics. In addition to the furniture industry fabric cutting-quilting operations, there would be some imbalances in the current system, such as the workload of one line being less than the other in the current system of the orders received while creating the weekly plan. These imbalances create bottlenecks between the lines, causing disruption of the production plan and delays in order deliveries.

Any improvement in the fabric-cutting department indirectly contributes to the development of the factory in general since the first step in increasing the productivity of the number of raw materials used in production and reducing the costs incurred for production is the fabric-cutting stage. Therefore, the first step is to identify the symptoms of the problem and the main problem in the fabric-cutting stage.

In furniture industries, the marker layout is generally identified by some software in the companies before the marker type selection and since there is more than one marker type, it is not clear which marker type the incoming order will be cut. Since there is no specific fabric cut order plan, marker length, plies and number are determined manually without considering the fabric cost, other costs (cardboard, nylon, paper, labor cost), grouping cost, cutting cost and laying cost. As a result of the manual selection, costs such as the amount of waste of the products, the paper, nylon, and grouping costs vary. In addition, markers are determined based on fabric waste only. Since costs, including cardboard, paper, spreading and grouping, which vary according to each marker type are not considered, the marker type is not optimally determined.

After the identification of marker placement during the fabric cutting phase, the fabrics are cut according to the marker type, plies and length and these fabrics are sent to stations such as tailoring, upholstery and packaging. This study addresses optimizing fabric cutting to minimize costs and enhance production efficiency. It aims to identify the best marker type, quantity, and plies to reduce wastage. A mixed integer linear programming (MILP) model is proposed to minimize the overall cost associated with fabric cutting by making decisions regarding the marker type and the number of plies in each spreading while ensuring that the specified quantity of orders for each product is fulfilled. By optimizing these parameters, the model effectively aims to reduce the expenses incurred during the fabric cutting process.

2. Literature review

Fabric costs are a substantial component of expenditure within the furniture industry. Optimal utilization of fabric and efficient marker usage are pivotal for cost management. Researchers have concentrated their efforts on investigating these aspects to pinpoint the factors influencing market efficiency and fabric usage. We mainly review the studies that tackle the Cut Order Planning (COP) issue, addressing diverse objectives within different industrial sectors. Since each industry has unique constraints and demands, it is imperative to account for specific manufacturing contexts when formulating solution methodologies.

Wong et al. (2005) introduce a problem involving planning the production (spreading and cutting) schedule to minimize operatives' idle time and fulfill the fabric cut-piece requirements from different sewing production lines. They solve the problem by a genetic algorithm. Later, Wong et al. (2008) address a COP problem that aims to minimize overall manufacturing costs by creating viable cutting order plans that consider materials, machinery, and labor based on the specifics of retail orders, including quantity, size, and color for apparel manufacturers.

Pamuk (2016) conducted a study on marker efficiency and found that fabric width, fabric spreading modes, bundle selection, and auto-mark strategy significantly impact marker efficiency. They test 64 markers, which are prepared using the Gerber AccuMark Version 9 CAD system. Fabrics with a width of 160 cm exhibited the highest marker efficiency, while face-to-face spreading, alternate bundling, and alternate directions, and placing fabrics with the highest area first in the auto-mark strategy were found to improve marker efficiency.

Another research study by (Zhezhova et al.,2019) emphasized the influence of various types of cut markers on the cutting and utilization of fabric. They examine how the width of the cut marker impacts the effectiveness of material use and explore the effects of different cut markers on reducing waste and maximizing the yield of usable textile material. Additionally, they investigate whether certain types and widths of cut markers prove more efficient in minimizing material waste and optimizing fabric utilization.

Jankoska (2020) explores the effect of different fabric types and sizes on the cut order plan for men's jackets in the fashion industry. They focus on using fabric more efficiently and improving the process of creating pattern markers for making clothing. Fabric properties, such as differences between the front and back sides, direction, symmetry, and design repetition, affect how pattern pieces can be organized, posing challenges. This article examines the influence of fabric type, size, and design on marker utilization for men's jacket production. The results revealed that larger sizes and non-patterned fabrics resulted in higher material utilization in markers. This study sheds light on the impact of fabric characteristics on marker utilization by a CAD application.

Another research in the fashion industry is proposed by Fister et al. (2008) and the core focus lies in optimizing markers within the clothing industry, centering on the identification of the most effective combination of markers to efficiently fulfill work orders. They propose a greedy method that maximize the number of eliminated pieces in a marker, while evolutionary algorithms employ computer-simulated evolutionary processes to determine the marker composition. Comparative evaluations of these algorithms demonstrated evolutionary algorithms' superiority, particularly in minimizing the number of markers. This study contributes to the field by providing insights into marker optimization and its cost implications.

Ünal et al. (2020) aim to optimize the efficiency of preassembly operations in the fashion industry, focusing particularly on the processes of marker making, spreading, and cutting. They developed a MILP model, which decides the cut order plan to enhance fabric utilization. On the other hand, Jankoska (2020) focuses on using fabric more efficiently and improving the process of creating pattern markers for making clothing. Fabric properties, such as differences between the front and back sides, direction, symmetry, and design repetition, affect how pattern pieces can be organized, posing challenges. This article examines the influence of fabric type, size, and design on marker utilization for men's jacket production. Tsao et al. (2020) address a COP problem in the apparel industry, aiming to minimize total costs by determining optimal fabric usage, the number of sections, and garment size assignments while meeting demand.

In summary, these studies contribute to our understanding of marker efficiency, fabric utilization, and cost optimization in the apparel industry. The findings underscore the significance of factors such as fabric width, spreading modes, bundle selection, marker type, and cut order planning in achieving efficient resource utilization and cost reduction. We focus on the furniture industry's cut-order processes considering the furniture sector's conditions and requirements.

This research sets itself apart from previous literature by offering optimization of marker efficiency and cut order planning, taking into account various other costs, including waste, time, and expenses related to materials such as cardboard, nylon, and labor. Moreover, the revenue generated by the company's selling leftover waste has been integrated and factored into the objective function.

3. Model formulation

We focus on a cut-order planning problem. Accordingly, for companies operating in the furniture sector, decisions such as marker type, quantity, and the number of plies are significant for the efficiency of production considering time, wastage, waste-time, and cost constraints. Companies can use their capacities most effectively only with a properly planned capacity method, in other words, it is critical to determine the improvement methods that will increase line efficiency depending on the demand amount and delivery time parameters. The aim is to identify decisions such as marker type, number of plies, and pieces are taken from the initiative of a single person, and these decisions are optimized by considering time, wastage, waste, and cost constraints.

While creating the mathematical model, some assumptions about the system were made. These assumptions are as follows: (1) operations take place at a single table at the laying and cutting station, (2) the maximum number of plies in each spreading can be 25.

3.1. Sets

I: Spreadings $i \in \{1,2,3 \dots I\}$

j : Products $j \in \{1,2,3 \dots J\}$

K: Marker Types $k \in \{1,2,3 \dots K\}$

C: The fabric types and colors $c \in \{1,2,3 \dots C\}$

3.2. Parameters

Y_{max} : The maximum number of plies

M : The length of the fabric-cutting table

B : The spreading unit cost of 1 meter of fabric

P : The grouping unit cost

H : The cutting unit cost

L: Unit price of waste fabric

G_{jk}: The grouping time of maker k of product j

F_c: The unit cost of the fabric c

A_{jk} : The length of the marker k of the product j

D_{jk} : The other costs including cardboard, paper, labor of the marker k of the product j

S_{jc} : The number of demands of the fabric c of the product j

E_{jc} : The stock allowance rate of the fabric c of the product j

V_{jk} : The cutting time of marker k of product j

T_{jk} : The length of the waste of marker k of product j

3.3. Decision variables

$$X_{ijk} = \begin{cases} 1, & \text{If marker k of the product j is selected in spreading i,} \\ 0, & \text{Otherwise} \end{cases}$$

Y_{ijc} : The total number of plies of the fabric c of the product j in spreading i.

W_{ij} : The number of plies of the product j in spreading i.

Z_{ijck} : Linearization variable for $Y_{ijc} * X_{ijk}$. The total number of plies of the fabric c of the product j in spreading i after marker selection.

Q_{ijk} : Linearization variable for $W_i * X_{ijk}$. The number of plies in spreading i after marker selection.

3.4. Model formulation

$$\text{Min} \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} D_{jk} * X_{ijk} + [\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{c=1}^{C}\sum_{k=1}^{K} Z_{ijck} * A_{jk}] * B + [\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} X_{ijk} * G_{jk}] * P +$$

$$[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} X_{ijk} * V_{jk}] * H + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{c=1}^{C}\sum_{k=1}^{K} Q_{ijk} * T_{jk} * F_c - [\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} Q_{ijk} * T_{jk}] * L$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} Y_{ijc} \leq Y_{max} \qquad \forall i \qquad (1)$$

$$\sum_{k=1}^{K} A_{jk} * X_{ijk} \leq M \qquad \forall i,j \qquad (2)$$

$$\sum_{k=1}^{K} X_{ijk} = 1 \qquad \forall i,j \qquad (3)$$

$$Z_{ijck} \leq M * X_{ijk} \qquad \forall i,j,c,k \qquad (4)$$

$$0 \leq Z_{ijck} \qquad \forall i,j,c,k \qquad (5)$$

$$Z_{ijck} \leq Y_{ijc} \qquad \forall i,j,c,k \qquad (6)$$

$$Z_{ijck} \geq Y_{ijc} - (1 - X_{ijk}) * M \qquad \forall i,j,c,k \qquad (7)$$

$$Q_{ijk} \leq M * X_{ijk} \qquad \forall i,j,c,k \qquad (8)$$

$$0 \leq Q_{ijk} \qquad \forall i,j,c,k \qquad (9)$$

$$Q_{ijk} \leq W_{ij} \qquad \forall i,j,c,k \qquad (10)$$

$$Q_{ijk} \geq W_{ij} - (1 - X_{ijk}) * M \qquad \forall i,j,c,k \qquad (11)$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} k * Z_{ijck} \geq S_{jc} \qquad \forall j,c \qquad (12)$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} k * Z_{ijck} \geq S_{jc} * E_{jc} + S_{jc} \qquad \forall j,c \qquad (13)$$

$$\sum_{c=1}^{C} Y_{ijc} = W_{ij} \qquad \forall i,j \qquad (14)$$

$$\sum_{c=1}^{C=slippery} Y_{ijc} \leq [W_{ij}]/2 \qquad \forall i,j \qquad (15)$$

$$Y_{ijc}, W_{ij}, Z_{ijck}, Q_{ijk} \geq 0, X_{ijk} \in \{0,1\} \qquad \forall i,j,c,k \qquad (16)$$

This mathematical model aims to minimize total costs. The objective function aims to minimize all costs by dividing them into five parts: other costs, spreading the cost, grouping cost, cutting cost and fabric cost and maximizing obtained revenue from fabric waste. To minimize the other expenses of each marker such as cartoon and paper costs, the total other expenses are obtained if a marker k of the product j is selected in spreading i. While adding the spreading cost to the objective function, the length of the fabric, how many plies are laid and the spreading unit cost are calculated. While the grouping cost was minimized, the total grouping time of the cut products and the grouping unit cost were taken into consideration. While calculating the cutting cost, the cutting time and cutting unit cost in each cut marker were considered. In order to minimize the fabric waste cost, the total length of waste fabric, the number of plies and fabric unit costs are taken into account when adding them to the objective function. In addition to these costs, since the waste fabrics can be sold the total revenue from waste fabric is subtracted from total costs.

Constraint (1) satisfies that the number of plies should not exceed the maximum number of plies in each spreading. The maximum number of plies is taken into account as the blade sharpness can cut the limited fabric height. Constraint (2) ensures that the length of each spreading is shorter or equal to the length of the fabric cutting table. Constraint (3) ensures that only one product and marker type can be selected in each spreading. Constraints (4) and (5) are the linearization constraints for the multiplication of Y_{ijc} and X_{ijk}. Fifth constraint, Z_{ijck} must be zero if X_{ijk} equals zero. On the other hand, when X_{ijk} equals 1, Z_{ijck} must be equal to the product of Z_{ijck} and X_{ijk}. Constraints (6) and (7) are to ensure that Z_{ijck} is always non-negative and smaller than Y_{ijc}. To force, Z_{ijck} equal to Y_{ijc} in case X_{ijk} equals one, constraint (8) is added. Constraints (9) to (11) are linearization constraints for W_{ij}*X_{ijk}. With constraint (12), we make sure that the number of orders for each product is met. In constraint (13), it is aimed to prevent the production of more stock than the amount of stock permission determined for each product. The constraint calculates the total number of plies in each spreading for each product (14). Since some of fabrics are slippery, these fabrics cannot be cut without combining other fabrics in a spreading, in other words, these fabrics cannot be alone while being cut. Therefore, these types of fabrics can form the maximum half of the plies of a spreading and other fabrics are placed between these fabric types while cutting. Constraint (15) It is used for placing slippery fabrics between the plies. Finally (16), there are non-negativity and binary constraints.

4. Case study

We will focus on a company specializing in the production of home furniture. These types of furniture are produced as seats, sofas, burgers, arms of the seats and sofas, and frames of the sofas. The initial phase in the production of furniture involves several stages, which the upholstery fabrics are used to undergo. One of the primary stages in the fabric preparation process is fabric spreading. At this stage, employees are responsible for spreading the fabrics onto tables using two distinct methods: manual spreading or automatic machine spreading. These fabrics, which are then spread, are cut according to the selected marker type and placement. After the cutting stage, the fabrics are grouped according to the piece requirements to be sewn in the tailoring stage. The tailors sew the fabrics when it comes to the tailoring stage after grouping. While there are 34 tailors in this stage, the fabrics are sent to the contract for sewing when the order is in excess. After the fabric sewing phase is completed, the seat, sofa, arm, and case production stages continue according to the type of product ordered. These can be examined in the following sections.

The prepared plan is sent to production, and the fabric is taken from the warehouse according to the plan. The next step is the selection of the marker type, which varies in the form of single, double, triple, etc. An example of the marker type of a product is shown in Figure 2. As shown in Figure 2, the single marker contains patterns for one product. When the marker type is double, patterns for the same products shown in Figure 2 are placed on it, and software in the company provides the optimal layout of each marker type. Accordingly, each type has a different placement on the fabric; thus, the fabric waste rate changes. After the personnel working in the production department decides with which type of marker the fabrics will be cut in line with the incoming orders, they program the marker layout, an example of which is shown in Figure 3. Next, when the paper is laid on the table, the fabrics are placed onto the paper. Then, two machines automatically cut each fabric according to the optimization program result. There are some limitations of the machines here. Each machine can serve three tables. The second machine is not enough for wide fabrics because the first machine can cut fabrics with a maximum width of 216 cm, while the second can cut fabrics with a maximum width of 180 cm. After the cutting process, the pieces are sent to the grouping tables, and grouping is done to make them suitable for sewing. The grouped fabrics are sent to the sewing tables, where appropriate sewing operations are performed. After the sewing process, it is sent to the department where the upholstery processes are made. In the upholstery process, there are five lines which are sofa, arm, frame, seat, and bergère assembly. After the upholstery process is completed, products are packaged. Then the finished products are grouped and shipped.

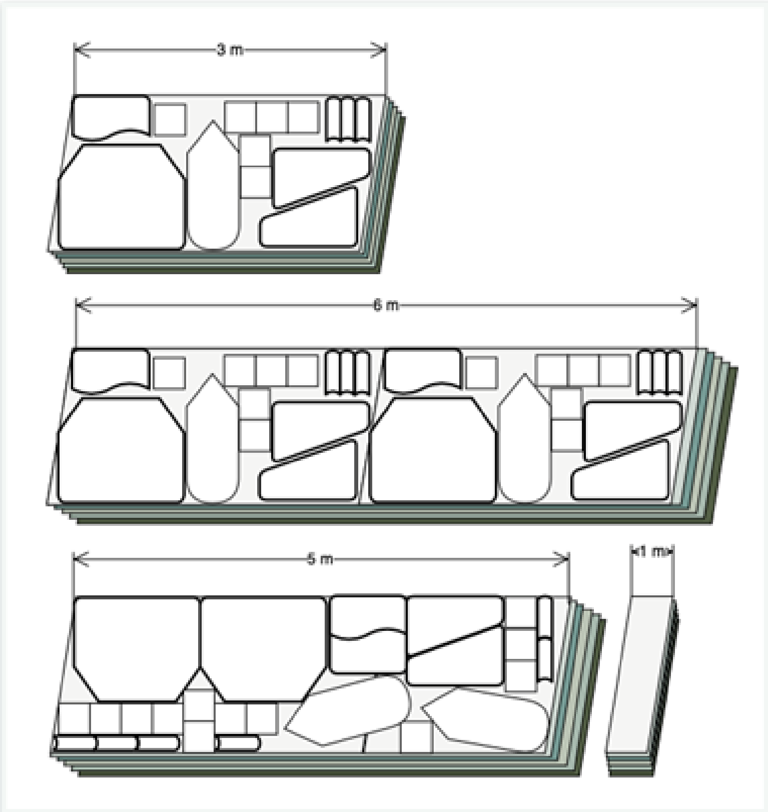

Fig. 2. Markers.

In Figure 3, we present an illustration that aims to define the concept of a marker. The visualization of a marker is provided to enhance the clarity of understanding of our mathematical model. Markers are multiple plies of fabric on which the cutting pattern is placed. In Figure 3, the top photo shows a single marker. The number of markers can be single, double, triple, and a maximum of 6. The shapes that can be seen on the fabric represent the parts of a product, such as armchairs and sofas, that will be cut from the fabric. In the factory, the placement of these pieces on this fabric is optimized using a program called Gemini. In the system, the lengths of a single marker of each product are known. Moreover, the fabric lengths of multiple markers are calculated as multiples of a single marker. In other words, if the single marker is 3 m, as can be seen in Figure 3, the length of the fabric meter of the double marker is expected to be 6 meters in the system. However, since marker placement is optimized each time, the location of the pieces on the fabric may change, and the fabric length may be reduced. as seen in Figure 2.

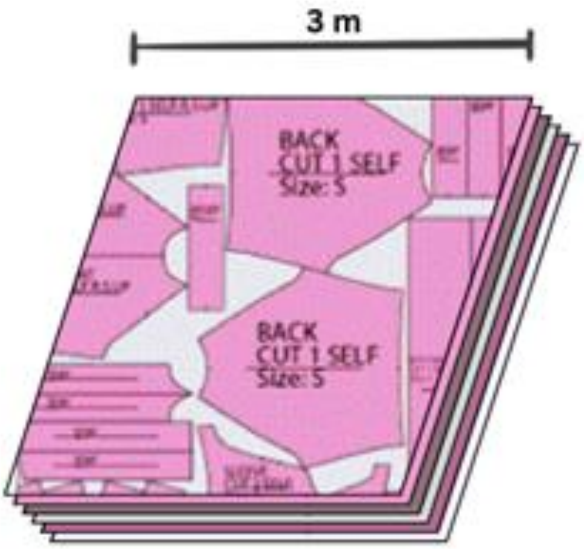

Fig. 3. An Example of Marker Layout.

This study aimed to minimize the total amount of waste fabric used by selecting the type of marker according to demand, starting from single to six for each product and determining the number of fabric plies in each spreading.

5. Computational Results

The experiments were carried out, and illustrative results were obtained to demonstrate the efficacy of the approach. Table 1 displays two distinct datasets providing information on markers and fabric. The marker dataset details various parameters for each marker type, including grouping time, marker length, additional costs, cutting time, and fabric waste length. Conversely, the fabric dataset offers information on each product's color, such as the fabric's unit cost, the quantity of orders, and the stock allowance rate. The proposed model is tested with the data, which we call the demo data, given in Table 1.

Table 2 gives the optimal solution of the demo data, and the desired order rate for all three products is met by making two spreading and cutting. Double markers were selected for the first product; 24 plies were cut in the first spreading, and 12 plies were spread in the second. In the second product, a single marker is selected and cut into two pieces in the first spreading. In the second spreading, triple markers were chosen, and 14 plies were cut. Finally, in the first layer of the third product, 4 layers are cut in the single marker, while in the second spreading, 8 pieces are cut in the triple marker.

Table 1. The Dataset of Marker and Fabric.

Marker Data

Marker (k)	Grouping Time	The Length of Marker	Other Costs	Cutting Time	The Length of Waste Fabric
Job 1					
2	5	10	40	15	2
3	7	16	50	15	1
Job 2					
1	7	10	20	15	4
2	9	12	30	20	2
3	12	14	40	30	1
Job 3					
1	9	20	23	17	6
2	12	22	26	23	10
3	16	24	28	28	5
4	20	30	30	39	5

Fabric Data

Fabric (c)	The Unit Cost of Fabric	Demand	Stock Allowance Rate
Job 1			
1	12	23	10
2	18	23	10
3	50	23	10
Job 2			
1	12	23	10
2	18	1	1
3	12	28	5
Job 3			
1	50	20	20
2	100	5	2
3	1000	1	0

Table 2. The Results of Demo Data.

Product	Spreading	Fabric and Color	Marker Type	Number of Plies
1	1	2	2	12
1	1	3	2	12
1	2	1	2	12
2	1	2	1	1
2	1	3	1	1
2	2	1	3	8
2	2	3	3	9
3	1	1	1	1
3	1	2	1	2
3	1	3	1	1
3	2	1	3	7
3	2	2	3	1

Upon comparing the number of orders with the number of products cut, specifically for the initial product with 69 orders, the model yields a total of 72 products, calculated as (2*24) + (2*12) (marker type*ply number). Given the first product's 10% stock allowance rate, one stock is allotted for each item. Consequently, it is determined that 72 products should be manufactured.

Through the methods developed in the cutting order planning segment of the research, the automation of cutting order planning, which was previously reliant on employee experience, was achieved. Moreover, the selection of the marker type, considering waste exclusively, facilitates decision-making that encompasses waste, time, and cost, as established by this study. These advancements led to a noteworthy 20% enhancement in cost efficiency within the cutting-order planning of the targeted company.

The results obtained from the developed methodology, considering total cost, fabric consumption, time allocation, number of fabric lays, and product quantity criteria, are displayed in Table 3, juxtaposed with the outcomes of the current system. In terms of total cost, there is an evident gain of roughly 30 ₺ when comparing the results for two randomly selected products. Additionally, there is an enhancement of approximately half a meter in total fabric consumption. While the results from the current system were achieved in a shorter overall time span, the developed model factors in waste, time, and other expenses to provide an outcome, consequently yielding the optimal result at reduced costs.

Table 3. The Costs Analysis of The Program for Only Two Product.

	Current System	**Output of the Program**
Total cost ($)	9.928,76	9.898,85
Total Usage Fabric Amount (m)	115,73	115,31
Total time (min)	19,41	20,59
Total Spreading Number	2	3
Total Product Number	2	2
Total Saving		**29,91**

Table 4. The Annual Costs Analysis of The Program for Daily Production.

	Current System	**Output of the Program**
Approx. Total cost ($)	1.429.741.440	1.425.434.400
Approx. Total Usage Fabric Amount (m)	16.665.120	16.604.640
Approx. Total time (min)	2.795.040	2.964.960
Approx. Total Saving		**4.307.040**

In the current, a minimum of 400 products are produced daily in the factory. Considering this daily production, the annual savings have been calculated, and the results are shown in Table 4. According to these results, a total saving of more than 4.3 million dollars is achieved using the proposed model instead of the method in the current system. More than 15 thousand meters of fabric was saved from being wasted. Moreover, the total time increased by only 6% of the time required in the current system. In this scenario, total saving is maximized with a minimum increase in total time.

6. Conclusion

This study begins with a thorough assessment of the fabric cutting-quilting process, identifying the challenges and bottlenecks in marker type selection in a company. Initially, decisions in the company were made solely based on the intuition of experienced employees. However, in response to the company's request, this study is conducted to connect this intuitive process to an analytical system. A MILP model is developed and customized to align with the focused industry's standards and the firm's specific requirements, and it undergoes testing using real data. This implementation effectively curbed significant wastage and led to a noticeable increase in the company's profit margins. The study's results demonstrate promising potential for enhancing the efficiency and efficacy of cut-order planning. Considering cost, time, and waste constraints, the study contributes to streamlined resource allocation, reduced production timelines, and improved overall operational performance.

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