Solving the Cutting Stock Problem for a Steel Industry

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Abstract. The problem of stock cutting takes an important place in the steel industry, as it is in many sectors. It is desired to ensure a minimum amount of waste in every manufacturing factory. Reaching the minimum level of waste reduces the costs of factories and companies and strengthens the possibility of making profits. In this way, it is ensured that our resources are used correctly in our developing world. In this study, the Cutting Stock Problem has been handled, in order to minimize the amount of waste within the scope of the complete the study and to solve this problem. In this study, first of all, the size of the steel to be used in line with the customer's request, the process of taking the steel plates from the stock and the molds of the parts to be cut are prepared by the production planning department, and these operations are carried out with the program used in the factory. Then the dies are sent to the workshop for cutting, where they are cut. Before creating the model, the data of the molds made for the previous cut are collected. In order to create the correct mathematical model, the data are collected by making simultaneous measurements at the cutting table. The cutting Stock Problem is used to formulate the molds prepared for cutting and the amount of waste loss is calculated. Determined parameters and constraints GAMS software is used to create a mathematical model using the GAMS MIP (Mixed Integer Programming) method and then analyze the created model. As a conclusion, we investigated 3 different scenarios. According to those experiments, the study with the proposed scenario can achieve a better production line especially about time and waste amount. Those developments can be important earnings for a real production line.

Keywords: Cutting Stock Problem · Mathematical modelling · Mixed integer programming · Production efficiency · Waste minimization

1 Introduction

Cutting stock problem has a big part on metal, paper and vary of different production and construction industry. Generally, Two-dimensional cutting stock problems are used for getting some refined parts from raw material with cutting sequences. For getting needed parts one or multiple cutting sequences can be used and we can get different refined parts from the same raw material. After the cutting sequences some trashes can be appear. If

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the quality of waste parts are suitable, the producer can reuse that parts for a new cutting sequence. Therefore getting the best profit and efficiency from raw materials, companies and engineers try to find and develop the most suitable cutting pattern. These patterns get shaped according to customer order like shape, amount and size. Cutting patterns can provide some advantages like efficiency, less waste, more fitted parts with the same raw material (like metal sheets, or paper blocks). The cutting patterns shown in the Fig. 1.

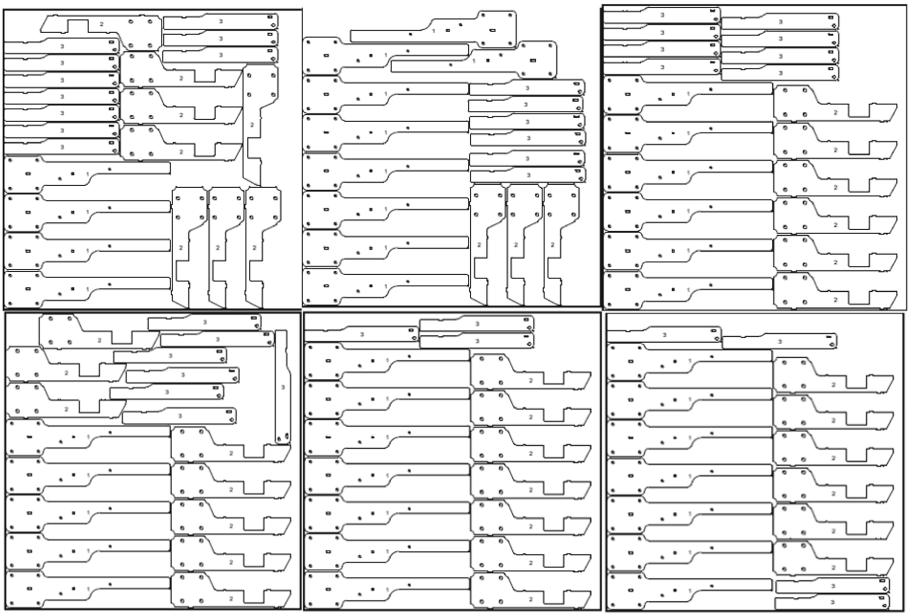

Fig. 1. Cutting patterns

In this study, YILGENCİ's laser cutting patterns for rollers and trailer parts and chassis parts are used. As a raw material, metal sheets are used. With that material and cutting patterns, the producer tries to get two demented roller parts. For getting less trash and satisfy customer needs, these metal cutting patterns optimization is studied. Most optimal patterns and less trash can be calculated, with different methods according to customer needs and constraints. Nowadays companies and producers have to vary different solution methods for different types of materials and needs. They can work vertical and horizontal stripes or t-shape lines. On the other hand, to get the non-geometric wrought parts the heuristic models can be more suitable. These solutions include large and hard mathematical models because of that, those problems are categorized as Np-hard problems. In the study, to optimize the proposed model for finding the most optimal cutting pattern a mathematical modeling is developed and solved with the help of GAMS software. In addition, some production constraints are included into the model, such as; size, amount of needed finished parts, and size of sheets. After implementing the first sequence, the iterations for getting new parts from trashes are used. With these constraints and several iterations, the objective of the study is to minimize the trash and ensure customer needs.

2 Problem Definition

In engineering, the cutting stock problem is used for getting machined parts with specific dimensions from raw material. That raw material can be a block of wood, metal sheet, or paper roll. The main aim of the cutting stock problem is to get the maximal machined part from raw material while minimizing the waste. The cutting stock problem is classified as an optimization problem in math. These optimization problems can contain very complex computations. Those complex computations are named as Np-Hard problem.

For solving those complex calculations vary of different engineers and mathematicians implement different methods and tries to get the most optimal solution. Generally, those methods evolve to a heuristic method. The basis of the heuristic method is self-discovering. Some solutions are getting shapes from past experiences. These strategies rely on the use of easily accessible, if loosely applicable, information to guide problem-solving for people, machines, and abstract topics. The cutting stock problem that is used in the literature is mainly to solve the problems in the metal industry and in the woodworking sector. With heuristic approaches, the most common method is the column generation method. Column generation is a method for dealing with linear programs with an exponential number of variables. It is the dual of intersection generation, which handles linear programs with an exponential number of constraints. In the article, Tieng et al. [1] and Albayrak [2] investigated the heuristic methods. Similar to their studies Dammak [3] and Malaguti [8] included the two-dimensional cutting stock problem in their studies. On the other hand, Demircan [4], Tanır [5], Struckmeier [6], Gbemileke et al. [7], and Kasımbeyli [9] discussed the one-dimensional cutting stock problem in their research.

3 Methodology

The MIP (Mixed Integer Programing) model is developed and solved with the help of GAMS in order to transfer the cutting drawings prepared for the stock cutting problem. The laser cutting benches obtain minimum waste from the steel plates to be cut. The following Fig. 2 represents the important steps of the study.

In this section, the data that are used as parameters will be explained in details. Also the variables and the model indices are introduced under this section.

Model indices and parameters are as follows for a product that includes 3 parts in the production.

$scrap_i$: The scrap amount
$first_i$: The number of 1st part in the pattern
$second_i$: The number of 2nd part in the pattern
$third_i$: The number of 3rd part in the pattern
ct_i: The cutting time
p: The price of the product

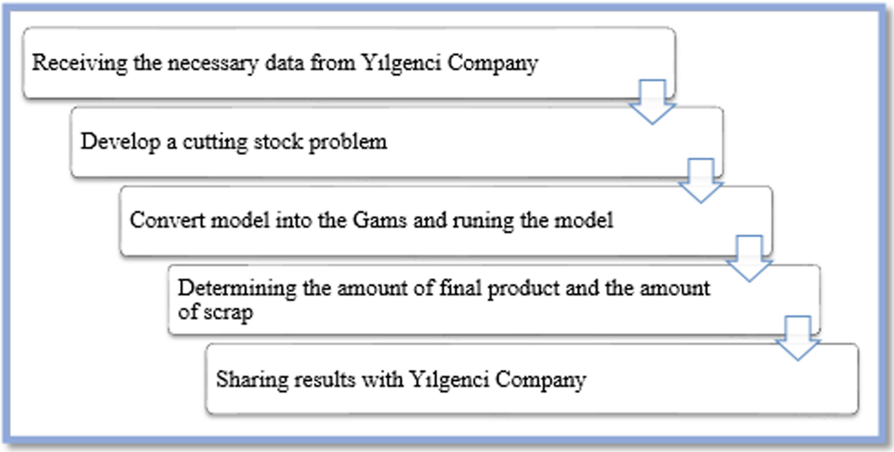

Fig. 2. Important steps of the study

c: The square centimeter waste cost
h_1: The holding cost of one first
h_2: The holding cost of one second
h_3: The holding cost of one third
oq: The order quantity per week
ch: The cutting hour capacity per week
cm: The cutting minutes capacity per week

Model variables are as follows:

x_i: Takes value 1 if the number pattern i is cut, 0 otherwise
y: Takes value 1 if the number of products produced, 0 otherwise
z: The number of products that the firm will produce to maximize its weekly profits

3.1 Mathematical Model

The objective function is Maximize total profit. In Eq. (1),there are holding cost for each part in the pattern and total scrap cost. The difference between the price multiplied with the number of products produced and total cost maximizes our objective function.

$$z = py - c\left(\sum_i scrap_i x_i\right) - h_1\left(\sum_i first_i x_i\right) - h_2\left(\sum_i second_i x_i\right) - h_3\left(\sum_i third_i x_i\right) \quad (1)$$

Equation (2) shows that cutting time. The number pattern i cut is restricted with cutting hour capacity per week.

$$\sum_i ct_i x_i < cm \quad (2)$$

Equation (3) shows that number of produced products. The number pattern i cut must satisfy the order quantity per week.

$$\sum_i x_i < oq \tag{3}$$

In Eq. (4), due to the structure of the product (depending on the product tree) there is 1 Part1 in 1 Trailer Hitch, therefore the number of Trailer Hitches produced cannot be greater than the total number of Part1 in the cut templates.

$$\sum_i first_i x_i > y \tag{4}$$

In Eq. (5), due to the structure of the product (depending on the product tree) there is 1 Part2 in 1 Trailer Hitch, therefore the number of Trailer Hitches produced cannot be greater than the total number of Part2 in the cut templates.

$$\sum_i second_i x_i > y \tag{5}$$

Equation (6) shows that due to the structure of the product (depending on the product tree) there is 1 Part3 in 1 Trailer Hitch, therefore the number of Trailer Hitches produced cannot be greater than the total number of Part3 in the cut templates.

$$\sum_i third_i x_i > y \tag{6}$$

In Eq. (7), y is the number of product produced.

$$y \geq 0 \text{ that must be integer} \tag{7}$$

In Eq. (8), x_i is the pattern i cut.

$$x_i \geq 0 \text{ that must be integer} \tag{8}$$

With those equations, the integer variables are obtained.

3.2 Data Collected

The company shared with us the patterns, product quantity, waste amount, cutting time, price and holding costs. Yılgenci Company shared with us the patterns, product quantity, waste amount, cutting time, price and holding costs. According to Table 1 and 2, current and proposed solution have several patterns. The patterns have different No. 1 Sub Product Quantity, No. 2 Sub Product Quantity, No. 3 Sub Product Quantity, Waste Amount and Cutting Time respectively. While the proposed solution has 6 patterns, current solution has just 5 patterns. Holding costs are remaining the same for each solution.

Table 1. Proposed gams input

	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5	Pattern 6
No. 1 sub product quantity	4	9	6	5	7	7
No. 2 sub product quantity	8	3	6	8	7	6
No. 3 sub product quantity	10	6	8	7	3	4
Waste amount (cm^2)	10.35	10.5	10.9	10.8	11.25	11.47
Cutting time (min)	26.28	25.59	25.3	25.29	24.02	23.38
	Final production amount	Price	Cost	Holding cost 1	Holding cost 2	Holding cost 3
	38	315.894	0.5	2	0.5	0.3

Table 2. Current gams input

	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5
No. 1 sub product quantity	19	19	0	0	0
No. 2 sub product quantity	0	0	25	13	0
No. 3 sub product quantity	1	1	0	20	16
Waste amount (cm^2)	6.07	6.07	7.65	6.75	15.2
Cutting time (min)	34.1	34.1	32.41	35.13	15.2
Final production amount	Price	Cost	Holding cost 1	Holding cost 2	Holding cost 3
38	315.894	0.5	2	0.5	0.3

3.3 Product Requirements and Their Weights

S700 MC high-strength steel plates are preferred for the automotive industry. S700 MC are highly resistant to impact and useful in cold forming and are highly resistant in the load-bearing area. The S700 MC which is going to covered are used in the steel trailer connection piece. S700 MC is produced in many sizes. The S700 MC are going to used in the project which is shown in Table 3.

Table 3. Product requirements

	Raw material type	Raw material proportions
1	S700-MC	1500 mm × 1500 mm
2	S700-MC	1500 mm × 1500 mm
3	S700-MC	1500 mm × 1500 mm
4	S700-MC	1500 mm × 1500 mm
5	S700-MC	1500 mm × 1500 mm
6	S700-MC	1500 mm × 1500 mm

3.4 Output Data

According to Table 4 proposed solution has pattern 2.4 and 5 respectively. The absolute and relative gap is a little different than 0. Total waste for each pattern is 407.7 and the time for each pattern is 962.08. For finding the total cutting time. the number of pattern used and total waste for each pattern used multiplied in each pattern and the multiplication will summed up. The employees are working 8 h in per day. By dividing total cutting time hour to 8 the total cutting time can be found.

Table 4. Proposed Gams output

	Pattern 2	Pattern 4	Pattern 5
Waste amount	10.5	10.8	11.25
Cutting time	25.59	25.29	24.02
Number of pattern used	12	24	2
Total waste for each pattern	126	259.2	22.5
Total time for each pattern	307.08	606.96	48.04
Total waste amount			
Total waste for each pattern		Total time for each pattern	
407.7		962.08	
Total cutting time (min)	Total cutting time (hrs)		Total cutting time (day)
962.08	16.034		2.004

According to Table 5 pattern 2.3 and 4 are used in current solution. The absolute gap and relative gap remains as expected. The total waster for each pattern is 249.44

and the total time for each pattern is 1303.83. Total cutting time in a day is 2.716. When the proposed and current solution difference is clearly represented that the proposed solution gives better solution.

Table 5. Current gams output

	Pattern 2	Pattern 3	Pattern 4
Waste amount	6.07	7.65	6.75
Cutting time	34.1	32.41	35.13
Number of pattern used	17	5	16
Total waste for each pattern	103.19	38.25	108
Total time for each pattern	579.7	162.05	562.08
Total waste amount			
Total waste for each pattern		Total time for each pattern	
249.44		1303.83	
Total cutting time (min)	Total cutting time (hrs)		Total cutting time (day)
1303.83	21.73		2.716

4 Conclusion

In this study. a laser cutting machine of YILGENCİ company and their real production data for cutting stock problem in the metal industry is used. The main aim of the cutting stock problem is to get the maximal machined part from raw material while minimizing waste. The cutting stock problem is classified as an optimization problem in math. These optimization problems can include too complex computations. Those complex computations are known as Np-Hard problems. In that way. YILGENCİ's cutting stock patterns for cutting sequence are optimized. In this study. the objective is to minimize the waste amount and satisfy needed parts by developing better cutting patterns. Programming and analyzing sections are made via GAMS software.

In the solution and optimization phase. Different scenarios are formed with different types and amounts of cutting patterns. Those formed cutting patterns were used to create different cutting scenarios. Scenarios include the different types and number of cutting planes.

After the implementation phase. a proposed model was created. To make comparisons with the current situation. several experiments are done with the proposed model. The GAMS outputs of the proposed model can satisfy the final product amount and same cost with the current situation. However. with the proposed scenario. better waste amounts are achieved (for the proposed scenario we have 1.342. for the current situation 1.568). The proposed scenario has more optimal total cutting time. The cutting time difference is 338 min. At the same time. there is a suitable gap in the GAMS outputs such as; the absolute gap:0.900000 and the relative gap:0.000012.

To sum up according to the study. the proposed scenario can achieve a better production line especially about time and waste amount. Those developments can be important earnings for the YILGENCİ's production line.

Acknowledgement. In a world where our resources dwindling every day the concept of optimization is spreading expeditiously each passing day. the try to the resources more efficiently and take an efficient steps for reducing cost. The optimum usage of raw materials in the steel industry is one of the main reasons that cannot be ignored as well as in many sectors.

The Cutting Stock Problem handled and the studies progressed in that way in this study.

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