Solving a real problem in plastic industry: A case in trimm-loss problem

Ivan Renata, Siana Halim
Industrial Engineering Department, Petra Christian University
Jl. Siwalankerto 121-131 Surabaya
Email: m25414056@john.petra.ac.id, halim@petra.ac.id

Abstract: In this paper we present a cutting plane model for solving a problem in a cast polypropylene (CPP) plastic film manufacturer. The company produces plastic rolls from plastic pellets with widths ranging from 3050 mm to 3250 mm. The plastic rolls are trimmed according to customer's orders. Before this work has been done, the PPIC department's scheduled the machines and arranged the plastic trim compositions manually. In this work we solve the plastic trimming problem by applying the trim loss model. We used the visual basic for application (VBA) based program to Excel. We then use the model outcomes for optimizing the machine scheduling process. We proposed modified earliest due date for scheduling the machine that represents the realities in the company.
Keywords: Trim loss problem, machine scheduling, earliest due date, permutation.

Introduction

In recent years, real-world trim loss (or cutting stock) problems has challenged researchers in optimization areas. This because of the diversity of the problems. There are many solutions that have been developed in practice. Delorme *et al.* (2016), modeled the bin packing and cutting stock problem, Furini and Malaguti (2013), use the mixed-integer model to solve the cutting-stock problem for multiple stock size, Kallrath *et al.* (2014), solved the real-world cutting stock problem in the paper industry. Besides of modelling in the linear programming, many researchers also solved those problems heuristically. Cui *et al.* (2017) developed new model and proposed two-phase heuristics algorithm to solve the cutting problem with usable leftovers. Tanir *et al.* (2016), proposed heuristic dynamic programming to solve the cutting stock problem in steel industries. While Rietz and Dempe (2008) used the linear relaxation called a gap to solve that problem.

In this work we model a cutting plane for solving a problem in a cast polypropylene (CPP) plastic film manufacturer. The plastic is used as food packaging. The company produces plastic rolls from plastic pellets with widths ranging from 3050 mm to 3250 mm. The plastic rolls are trimmed according to customer's orders. The waste produced from trimming large plastic rolls are recycled into second grade plastics pellets. This second grade plastics pallets will be sold to other company and of course the profit is lower than the primary product of this company. Before this work has been done, the company PPIC department's scheduled the machines and arranged the plastic trim compositions manually. We use the modified earliest due date (EDD) algoritm to schedule the jobs, so that the waste produced from trimming large plastcis rolls is minimized.

Model

Trim-Loss Problem

$$Min\ \sum_{j=1}^{n} W_j . X_j + \sum_{i=1}^{m} L_i((\sum_{j=1}^{n} a_{ij} X_j) - D_i) \qquad (1)$$

$$s.t \quad \sum_{j=1}^{n} a_{ij}X_j \geq \; D_i \quad i = 1, \dots, m \tag{2}$$
$$W_j, a_{ij}, X_j, D_i \geq 0, j = 1, \dots, n \tag{3}$$
$$W_j, a_{ij}, X_j, D_i, \quad integer \tag{4}$$

where,
W_j = *Waste* produced if the large plastic roll is trimmed using permutation j
L_i = Length of product – i
a_{ij} = number of product i if the plastic roll is trimmed using permutation j
X_j = Decision variable for permutation j
D_i = Demand for product i
n = number of feasible permutation
m = number of product

Here, product is the small plastic roll, which is produced by trimming the large plastic roll.

The objective function of this model, equation (1), is minimizing waste. Total number of products produce by trimming the large plastic roll should not exceed the demand (2), all of variables are non-negative (3) and integer (4).

Machine Scheduling

Before scheduling the machine, we have to calculate the time needed to process a job (p_j) and convert the total waste in mass (Kg). The mass of total waste can be calculated using the following equations.

$$Mass = Volume \; \times \rho \tag{5}$$
$$Volume = Thickness \times Length \times \sum Width \tag{6}$$
where,
$\rho = 0.91 \; gr/cm^3 = 0.91 * 1000 \; Kg/m^3$

The time needed is formulated as follows:
$$Time = \frac{Length}{Velocity} \times N \tag{7}$$
The velocity of the machine depends on the thickness of the plastics.

We used modified earliest due date (EDD) to solve this problem. The EDD is modified such that the waste produced by each jobs in a parallel system is minimum. In this case the decisions variables are due date, time for finishing a job in each machine and weight of a job. The weight of the job is calculated by dividing due date to priority of that job. The priority value is decided by the company. Due date in this scheduling problem is not a date, but only a priority number, since the customers do not give the exact due date. The larger the priority number means the due date is short.

For every scheduled job, first we calculate the waste differences if the jobs are produced by Egan 1 or Egan 3 (since both machines are identic) and Egan 2. Then, we defined the weighted due date as waste difference divided by weight. Sort the weighted due date descending (see Table 5 as an example) and we will get the sorted job. Job 1 should be scheduled in advance, since it can cause greater waste if it is scheduled on an unsuitable machine. The company also can give a certain priority to a job base on the customer demand. The developed software for solving this problem, has flexibility in determining the job priority. It can be calculated as waste different devided by weight or directly determine by the company.

Numerical Example

The company has three machines for rolling the plastic, Egan 1, Egan 2 and Egan 3. Egan 1 and Egan 3 can roll the plastic sheet with width from 2900 mm to 3100mm, while the Egan 2 can roll the plastic sheet with width from 3100mm to 3300mm. There are two types of plastic, transparent and metallic. Metallic plastic is produced by coating the transparent one, and it is coated after the transparent plastic is trimmed according to its order. Additionally, the plastic thickness is also varying. It depends on the customer's order. However, one roll plastic will have the same thickness. So in this case, we only need to model the trim loss problem for transparent plastic which is already grouped base on its thickness.

In this model, we first find the feasible permutation. For example, there is an order coded as OPUS 731 #25 25 12000. This code means, the plastic's type is OPUS 731, with thickness 25μm and length 12000m. The customer need 20 rolls plastic with length 920 mm, 23 rolls with length 1000mm and 38 rolls with length 1040 mm. Since the order has max length 1040mm, it is better to use Egan 2, which can roll plastic up to 3300mm. From the large roll, i.e. 3300mm, it can produce max 3 small rolls with the same length (see Table 1). All possible permutations from the number of small rolls is depicted in Figure 1.

Table 1. Number of small rolls with the same length can be produced from the large one

Machine	Length	Max	Number
Egan 2 3300mm	920mm	3	0,1,2,3
	1000mm	3	0,1,2,3
	1040mm	3	0,1,2,3

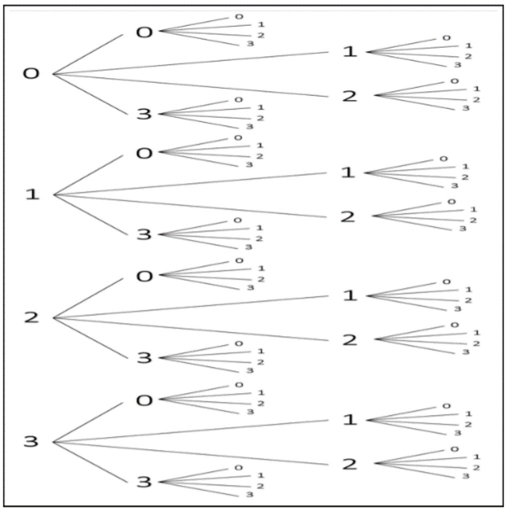

Figure 1. All possible permutation

Not all possible permutations have feasible solution. We will erase the non-feasible solution (see Table 2, permutation no.5 and no. 7) before we calculate the optimum solution. We also erase the permutation that has waste greater than or equal one of the small roll lengths (see Table 2, permutation no. 3)

Table 2. Permutation

E2	OPUS 731 #25 25 12000									
3300	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
920	1	0	1	1	2	0	2	3	0	1
1000	0	0	1	2	1	1	2	0	3	1
1040	2	3	0	0	1	2	1	0	0	1
Waste	300	180	1380	380	-580	220	-1580	540	300	340
Stat	Y	Y	N	Y	N	Y	N	Y	Y	Y

However, since machine Egan 2 can be adjusted from 3100mm -3300mm, then we can adjust the permutation so that the total length of trimming products is in between 3100mm-3300mm. In the adjusted permutation algorithm, we check the feasibility solution and the total of trimming length is in range of the machine setting. The adjusted permutation of this case is given in Table 3. There are ten permutations with total length 3100 – 3120.

Table 3. Adjusted permutation

Min	Max	Permutation									
3100mm	3300	1	2	3	4	5	6	7	8	9	10
Item 1	920	3	2	1	0	2	1	0	1	0	0
Item 2	1000	0	1	2	3	0	1	2	0	1	0
Item 2	1040	0	0	0	0	1	1	1	2	2	3
Total length		3100	3100	3100	3100	3100	3100	3100	3100	3100	3120
Waste		340	260	180	100	220	140	60	100	20	0

Using the adjusted permutation and excel solver for solving equation (1) - (4) we get the optimal result as listed in Table 4. The demand is fulfilled with the total waste 2780mm. The company should produce 27 rolls of OPUS 731 #25 25 12000, and after trimming the large rolls, it produces total waste 2780mm (in total width of small rolls).

Table 4. Solution

Product length	920mm	1000mm	1040mm
Total products	20	23	38
Demand	20	23	38
Diff	0	0	0
Total waste	2780mm		
N	27		

Scheduling the Machines

Before scheduling the machines, we need to calculate the time needed and the convert the waste from length to Mass (Kg). To convert the waste length to Mass we use equation (4). In our case, since all unit measurements in this case are in mm, then

$$Mass(kg) = \frac{Thickness \times Length \times \sum Width}{10^6} \times 0.91$$

$$Mass(kg) = \frac{25 \times 12000 \times 2780}{10^6} \times 0.91 = 758.94\ kg$$

The time needed is calculated using equation (5). In our case since the plastic thickness is 25μm, then the machine velocity is 248m/min. The more thickness the product, the slower the velocity of the production process of the machine is. So, to produce 27 large rolls of OPUS 731 #25 25 12000 we need

$$Time = \frac{12000}{248} \times 27 = 1306.45\ min = 21.77\ hour$$

The objective of the machines scheduling is to minimize makespan. As it is stated, the company has three machine, Egan 1, Egan 2 and Egan 3. Machines Egan 1 and Egan 3 are identic. Those machines work in parallel, and work based on the given jobs. There is no preemption in the process while the machines operate.

In this study, due to the processing time needed in calculating the adjusted permutation, the scheduling is limited only for seven jobs, and in every jobs it has maximum seven types of small plastic roll width. We use $R_m||L_{max}$ to notate this condition. For scheduling, we need to know the jobs, mass of the produced waste, time needed to process the jobs for every machine, and the priority of the jobs (weight).

We applied the modified EDD to schedule the jobs. The modified EDD calculation for this small example is given in Table 5. The sorted job is given in the last column of Table 5, and the respective Gant chart is depicted in Figure 2. For this example, Job 1 is scheduled in machine Egan 1, or Egan 3; Job 3 can be done also in Egan 1 or Egan 3 since those two jobs have the smallest waste if they are produced in Egan 1 or Egan 3. Since in the Figure 2, we already scheduled the Job 1 in Egan 1, then the Job 3 should be scheduled in Egan 3. Egan 1 and Egan 3 now are occupied, so Job 2 only can be scheduled in Egan 2; the last Job 4 also should be scheduled in Egan 2, since Egan 1 and Egan 3 are occupied. The total waste produced using this proposed schedule is 981.7 Kg, and the time completion for the whole orders (makespan) is 21.77 hours.

Table 5. Scheduling Case Example

Job	weight = DueDate / Priority	Waste E1 (Kg)	Waste E2 (Kg)	Waste E3 (Kg)	Waste Diff (Kg)	JobPriority= Waste.Diff/ weight	#Roll E1 (Hour)	#Roll E2 (Hour)	#Roll E3 (Hour)	Sorted Job
1	weight=1/2 = 0.5	0.0	824.5	0.0	824.5	1648.9	21.77	21.77	21.77	Job 1
2	weight=1/1=1	160.5	370.2	160.5	209.7	209.7	3.87	3.87	3.87	Job 3
3	weight=2/1 = 2	0.0	457.7	0.0	457.7	228.9	11.29	11.29	11.29	Job 2
4	weight=2/1 = 2	384.1	611.5	384.1	227.4	113.7	7.90	7.90	7.90	Job 4

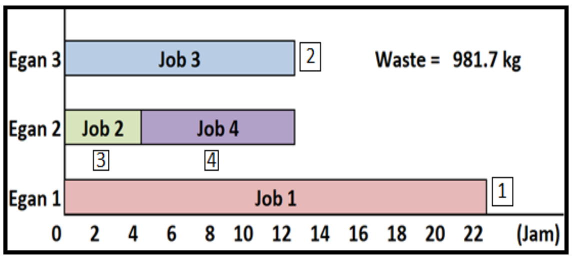

Figure 2. Scheduling Result in a Gant Chart

Conclusion

We solve the problem for a plastics company to minized the plastics waste produced by trimming large plastics rolls. Additionally, we also schedule the jobs so that the plastics waste is minimized. We modeled the problem using trim-loss problem and modified earliest due date algorithm for scheduling the jobs. So far, the algorithm only works for daily basis scheduling and the company wants to schedule based on weekly basis. The weekly basis scheduling for minimizing waste will be our future research.

References

Cui, Y., Song, X., Chen, Y., and Cui, Y.P., (2017), New model and heuristic solution approach for one-dimensional cutting stock problem with usable leftovers, *Journal of the Operational Research Society*, 68(3), pp. 269-280.

Delorme, M., Lori, M., and Martello, S., Bin packing and cutting stock problems: Mathematical models and exact algorithms, (2016), *European Journal of Operation Research*, 255, pp. 1-20.

Furini, F., and Malaguti, E., (2013), Models for the two-dimensional two-stage cutting stock problem with multiple stock size, *Computers & Operation Research*, 40, pp. 1953-1962.

Kallrath, J., Rebennack, S., Kallrath, J., and Kusche, R., (2014), Solving real-world cutting stock-problems in the paper industry: Mathematical approaches, experience and challenges, *European Journal of Operation Research*, 238, pp. 374-389.

Ritz, J., and Dempe, S., (2008), Large gaps in one-dimensional cutting stock problems, *Discrete Applied Mathematics,*156(10), pp. 1929-1935.

Tanir, D., Ugurly, O., Guler, A., and Nuriyev, U., (2016), One-dimensional Cutting Stock Problem with Divisible Items, research paper: https://arxiv.org/ftp/arxiv/papers/1606/1606.01419.pdf