ASSESSMENT OF STOCK LENGTH FOR ONE DIMENSIONAL CUTTING STOCK PROBLEM (1D-CSP) WITH SUSTAINABLE TRIM LOSS

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ABSTRACT

The cutting stock problem is cutting of orders of a certain number of small pieces from available large pieces in stock in such a way that trim loss is minimized. The main objective of this problem is to minimize the scrap which is called trim loss. There are various methods which were studied earlier focusing on the minimization problem of the waste. In the present paper, we have designed the algorithm which predicts the length of the stock with the basic aim to minimize the trim. The stock length has been determined with the constraint of lower and upper bounds with respect to the length which is desirable in view of the demand and the transportation respectively.

Initially, we have introduced the variable t as the percentage of the pre-defined sustainable trim. By fixing t , the value of the stock-length and its corresponding actual trim loss has been calculated for different combinations of the order lengths. It has been observed that the variable t plays a key role in deciding the number of various stock lengths of different measures and to control the total trim loss.

KEYWORDS: Cutting Stock Problem, Sustainable Trim Loss, Assessment of Stock Length

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INTRODUCTION

A cutting stock problem (CSP) is a problem that includes cutting of large pieces available in stock to produce smaller pieces (called items) in order to meet a given demand. In case of One Dimensional, the cutting is planned to minimize the waste of stock length used and maximize profit. The main objective of the cutting plan is to obtain the required number of small pieces from the available stock lengths with minimum trim loss. Many methods have been derived either with exact or heuristic approaches for solving the 1D-CSP. These approaches are used for generating cutting patterns by considering combinations of order length that can be cut from a given stock length.

Now, the focus of research has been shifted to apply multiple criteria approaches to optimize CSP. In 2008 Rodriguez & Vecchiotti [11] introduced a method where the cutting stock algorithms were linked with decision-support tools, the input to the algorithm being selected by criteria defined by a decision-support tool enabling better business performance and Dikili et al.[3] developed a new heuristic approach to 1D-CSP with multiple stock lengths which broadens the view for the solution compared to the use of single sized stock material.

The purpose of this paper is to develop a mathematical model to assess the stock length for solving 1D-CSP for Transmission tower manufacturing industry. The determination of the stock length is acceptable when the expected trim loss is minimum, transportation is feasible and warehousing is manageable. The main objectives of all researchers working in this direction are to minimize the waste and maximize the profit. Thus, there is need for

an easy approach to operate and interpret cutting stock problem for improving operational efficiency. Therefore, this model will determine the stock length and produce the cutting patterns which will result in minimizing the trim loss.

This paper is organized as follows: Section 2 explains Problem definition and mathematical formulation. Algorithm is given in section 3. Section 4 covers the illustrative example to demonstrate practical application of the model. Section 5 presents the comparative study with the model developed by Power et al [10]. Section 6 presents the concepts and illustrations of minimization of number of stock lengths assessed. Finally, the last section 7 concludes the proposed study.

Problem Definition and Mathematical Formulation

In one-dimensional cutting stock problem, different lengths of available stock play a crucial role in determining the trim loss. The main objective of the paper is to assess stock length in such a way that the further minimization of the trim loss may be claimed in comparison to the earlier methods dealing with 1DCSP in which the prescribed stock lengths have been considered. Our study is totally focused on Transmission tower manufacturing Industry. It may be noted that the length of stock depends on the following issues:

- Due to the limitations on the modes of transportation, the upper bound of the length of the stock cannot exceed 14 meters.
- The minimum size of the stock length has been fixed as 7 meters as the production of stock length less than this measure (7 m) is not feasible (financially) for the supplier.

Considering the working space constraint of the Industry and to reduce the manpower at working space for sorting, we have proposed cutting of at most two types of order lengths in each step of cutting. In view of aforesaid, we have therefore imposed the upper (14 meters) and the lower (7 meters) bound of the stock to be determined.

We are now set to define our problem exclusively as follows:

Given: $l_1, l_2, \dots, l_n$ the order lengths (arranged in descending order with respect to length) with the corresponding required number of pieces $d_1, d_2, \dots, d_n$ respectively.

Let, $u (= 7 \text{ mts})$ be the lower bound and $U (= 14 \text{ mts})$ be the upper bound of the stock length respectively. Also U_j ($j = 1, 2, \dots, k$) denote the stock lengths to be determined where k depends on the cutting process for a particular dataset.

t_j trim loss corresponding to the stock length U_j .

C_j a real number which is to be determined in terms of sustainable trim loss, pre-defined by the industry.

U_{ij} combinations of order lengths l_i and l_j such that $u \leq U_{ij} \leq U$

p_{ij} number of order length l_i being cut from the stock length U_j

Keeping in view the practical approach of cutting in Tower Industries, we design the mathematical model as follows:

Objective: To determine the stock length U_j , satisfying the condition $u \leq U_j \leq U$ such that the trim loss should be minimum, we define the model of CSP as:

$$\min \sum_{j=1}^k t_j \text{ (minimization of trim loss)} \quad (1)$$

$$t_j \geq 0 \forall j$$

subject to the condition

$$U_j = \max_j \{ U_{ij} : U_{ij} = \alpha l_i + \beta l_j \text{ and } u \leq U_{ij} \leq U, i = 1, j = 2, \dots, n ; i < j; \alpha, \beta \text{ are positive integers} \} \quad (2)$$

Note: i is assumed to be 1, because the order length l_1 being the largest among all order length is considered to be cut at the initial stages.

$$\sum_{j=1}^k p_{ij} = d_i \quad (\text{demand constraint}) \quad (3)$$

$$\text{Where, } p_{ij} = \begin{cases} =0, & \text{if the order length } l_i \text{ is not cut} \\ & \text{from the stock length } U_j \\ >0 \text{ (integer),} & \text{if the order length } l_i \text{ is} \\ & \text{cut from the stock length } U_j \end{cases}$$

$$t_j = (U_j - (\alpha l_i + \beta l_j)) \leq C_j \quad (4)$$

$$\text{Where, } C_j = \frac{t * U_j}{100} \quad (5)$$

($t\%$ trim loss may be permissible for the
stock length U_j)

Initially, the combinations are made by combining the first order length say l_1 with rest of the order lengths i.e., l_j where $j = 2, 3, \dots, n$. The first order length l_1 (being the largest in the order list) is considered to be cut at the first stage of the cutting process as the smaller lengths can be adjusted easily later.

Define: $U_{1j} = \alpha l_1 + \beta l_j$ for $1 \neq j$; α, β are non-negative integers; $j = 2, 3, \dots, n$

Now select the combination of the order lengths with the maximum value which lies between u and U .

i.e., $\$ = \{U_{1j} : u \leq U_{1j} \leq U\}$ for $1 \neq j; j = 2, 3, \dots, n$

Now define,

$$U_1 = \max_{U_{1j} \in \$} U_{1j} \quad (j = 2, 3, \dots, n) \quad (6)$$

U_1 has been determined as the first stock length; it is used to cut as many combinations as possible of the order lengths, as long as the trim loss after cutting is sustainable to the industry.

Computation of the Constant C_1

Referring (5) a constant is computed depending on the pre-defined sustainability of the industry. In order to have smooth and profitable running, the industry can sustain the trim loss ($t\%$) that ranges from 1% to 3%.

Therefore, for first stock length U_1 the constant C_1 is calculated as

$$C_1 = \frac{U_1 * t}{100} \quad (7)$$

$$\text{such that, } \min(U_1 - U_{1j}) \leq C_1 \text{ for some values of } j \quad (8)$$

The stock length U_1 determined is used to cut the combination U_{1j} , at this point the trim loss will be zero since $U_1 = U_{1j}$.

Now, consider the required number of pieces to be cut, ie. d_1 and d_j of the corresponding order lengths l_1 and l_j respectively, used for the combination of U_{1j} . Various cases are to be considered for further processing:

Case I: $d_1 = d_j$, the cutting of both the order lengths l_1 and l_j for fixed j , is completed.

Case II: $d_1 < d_j$, the cutting process of l_1 is completed and for l_j order length, $d_j - d_1$ required number of pieces are left to cut.

Case III: $d_1 > d_j$, the cutting process of l_j is completed and for l_1 order length, $d_1 - d_j$ required number of pieces are left for cutting.

These three cases may arise for all values of j for which (8) holds.

Considering the case I, we shall arrange the remaining $(n - 2)$ order lengths in descending order with respect to length and proceed as above up to the cutting of next two order lengths. The new combination U_{1k} obtained

$$U_{1k} = \alpha l_1 + \beta l_k; k \neq j$$

such that $\{U_{1k} : u \leq U_{(1k)} \leq U\}$. The obtained U_{1k} is checked with U_1 [cf.(6)] such that

$$\min(U_1 - U_{1k}) \leq C_1 \text{ for some values of } k; (9)$$

for C_1 refer (7).

If (9) satisfies then it undertakes the cutting process from stock length U_1 [cf. (6)]. During this cutting process, we may again come across the three cases and continue till the order length l_1 is cut entirely.

If (9) does not satisfy, we define

$$U_2 = \max_k U_{1k};$$

for $1 \neq k; k = 2, 3, \dots, n; k \neq j$.

U_2 is considered as the second new stock length and the corresponding sustainable trim C_2 has been computed as C_1 (refer (5)). Hence,

$$C_2 = \frac{U_2 * t}{100} \text{ which is pre-defined sustainable trim loss.}$$

Subject to case II, we know that $d_j - d_1$ number of pieces of order l_j is remaining in the cutting procedure. The remaining $(n - 1)$ order lengths are again rearranged in the descending order with reference to the length viz. $l_1, l_2, \dots, l_{n-1}$ with required number of pieces $d_1, d_2, \dots, d_{n-1}$ respectively. Following the same technique described above, we obtain the combinations of the order length say U_{1k} and check the conditions [cf. (2), (9)]. If (9) satisfies, then this combination can be cut using U_1 or else we determine the obtained U_{1k} as U_2 the second new stock length and then we again come across with three cases and the process is continued to cut the required pieces of order lengths.

In view of case III, we know that the cutting process of order length l_1 is not completed, it is left with $d_1 - d_j$ number of pieces to be cut, so again the combinations are obtained after arranging the left order lengths in descending, if

the combination U_{1k} obtained satisfy the condition (2) and (9) then it is cut using stock length U_1 else U_{1k} is considered as the second new stock length U_2 and the corresponding sustainable trim C_2 is been computed.

This process continues till all the required pieces of the order lengths are exhausted.

Note: The new stock length determined should be tested with the previously assessed stock length, to check whether the new stock length can be used for any previously determined stock length which lies within the sustainable trim loss.

At the end of the cutting process we may come across two cases viz.,

- $U_{1m} < u$, then we have to consider the lower bound of the stock length $u = 7$ mtrs, since the stock length less than 7 mtrs is not feasible by the supplier to supply.
- There is always a possibility that only one order length is left to cut. In this case, the order lengths will be cut using already determined stock lengths in multiple pieces, if required.

ALGORITHM

- Read the order length l_i and demand d_i , and arrange them in descending order.
- *function caller A for criteria II* (to find the larger sized order length preset to 35% to 40%) go to line number 33
- do while ($n > 0$)
- for $i = 1$ to $n - 1$
- for $j = 2$ to n
- calculate $U_{ij} = \alpha l_1 + \beta l_j$; α, β are positive integers
- goto 4 for $j \leq n$
- goto 3 for $i \leq n - 1$
- $U_{ij} = \max_j(U_{ij} : u \leq U_{ij} \leq U)$
- $U_j = U_{ij}$ (assessment of 1st order length U_j and then subsequent) ; for $j = 1, 2, \dots, n$
- calculate $C_j = \frac{t * U_{ij}}{100}$; $t = 2$
- if $t_j = \min(U_j - U_{ij} \leq C_j)$
- *Note:* Proceed for cutting plan;
- check l_i in array // checking using function call A for Criteria II
- if found store U_j in an array1; $j = 1, 2, \dots$ // store stock length used to cut larger sized order length –Criteria II
- $w_j + 1$; U_j is used to cut a combination, increment $w_j, j = 1, 2, \dots, n$ // used for Criteria I
- calculate $t_j = U_j - U_{ij}$
- if $d_1 = d_j$
- remove l_i, l_j and d_i, d_j from the order list.
- $n = n - 2$
- if $d_1 < d_j$
- remove l_1 and d_1 and update $d_j = d_j - d_1$

- $n \leftarrow n - 1$
- if $d_1 \geq d_j$
- remove l_j and d_j and update $d_1 = d_1 - d_j$
- $n \leftarrow n - 1$
- else
- $U_j = U_{ij} ; j = 2, 3, \dots$: repeat for $U_3, U_4, \dots$ if $t_j = \min(U_j - U_{ij} \geq C_j)$
- if $U_{ij} \leq u$
- $U_j = 700$
- calculate $gt_j = gt_j + t_j$
- go to line no 3 till $l_i = 0, d_i = 0$
- print U_j, gt_j
- *Function callee A*
- large=calculate 40% of n (total number of order lengths)
- for $i = 1$ to large
- push l_i in array for $i \leq \text{large}$; go to line 3

Note: Minimization of stock length assessed

Criteria I

- select U_j for $w_j \geq 2$
- continue cutting plan with selected stock lengths U_j

Criteria II

- continue cutting plan using stock length store in array1

Criteria III

- calculate 40% of total stock TU_j
- select stock length $U_j \geq TU_j$; store it in array2 and continue the cutting plan

Note: Function for cutting plan after minimization of stock length assessed

- do while ($n > 0$)
- for $i = 1$ to $n - 1$
- for $j = 2$ to n
- calculate $U_{ij} = \alpha l_1 + \beta l_j$; α, β are positive integer
- goto 3 for $j \leq n$
- goto 2 for $i \leq n - 1$
- $U_{ij} = \max_j(U_{ij} : u \leq U_{ij} \leq U)$
- for $i = 1$ to len(array2)

- if $\text{array2}[i] \geq U_{ij}$
then if found proceed for cutting process
else go to line 8 for next i
- calculate $t_j = U_j - U_{ij}$
- if $d_1 = d_j$
- remove l_i, l_j and d_i, d_j from the order list.
- $n = n - 2$
- if $d_1 < d_j$
- remove l_1 and d_1 and update $d_j = d_j - d_1$
- $n =$
- if $d_1 \geq d_j$
- remove l_j and d_j and update $d_1 = d_1 - d_j$
- $n =$
- else
- $U_j = U_{ij} ; j = 2, 3, \dots$: repeat for $U_3, U_4, \dots$ if $t_j = \min(U_j - U_{ij} \geq C_j)$
- if $U_{ij} \leq u$
- $U_j = 700$
- calculate $gt_j = gt_j + t_j$
- go to line no 1 till $l_i = 0, d_i = 0$
- print U_j, gt_j

COMPARATIVE STUDY

A comparative study of this proposed model was done with the model on first order sustainable trim developed by Powaret al.(2013). They have determined the sustainable trim loss t_s^1 , based on which the cutting patterns are generated whereas this model deals with calculating a constant based onbearable trim loss sustained by the industry which ranges from 1% to 3% . They have considered the model in two categories with cutting two order lengths at a time; Category I- when the required numbers of pieces of order lengths are integral multiples of each other and Category II- when the required numbers of pieces of order lengths are prime numbers. In both the categories they have determined the cutting of order lengths two at a time in order to satisfy the requirement of minimum work area, less manpower and in particular the acceptable trim within the range of the industry whereas this model also considers cutting of two order lengths at a time with α and β times, where $\alpha, \beta = 1, 2, \dots, n$. The comparison was done on the number of stock lengths used, trim loss per stock length, total stock length used and total trim loss.

Table 1: Cutting Plan According to Powar et al. Model

S. No.	Order Lengths (in cm)	Pieces To Cut	Trim Loss (in cm)	Used Stock Lengths(in cms)
1	230	2	30 x 16 = 480	1150 x 16 = 18400
	660	1		
2	750	1	0 x 24 = 0	750 x 24 = 18000
3	800	1	0 x 13 = 0	800 x 13 = 10400
4	310	1	0 x 36 = 0	1200 x 36 = 43200
	890	1		
5	310	4	10 x 1 = 10	1250 x 1 = 1250
	890	0		
6	400	1	0 x 39 = 0	950 x 39 = 37050
	550	1		
7	400	2	0 x 4 = 0	800 x 4 = 3200
	550	0		
8	460	1	0 x 21 = 0	1100 x 21 = 23100
	640	1		
9	460	0	20 x 1 = 20	1300 x 1 = 1300
	640	2		
Total			510	155900
Total Trim Loss(%)				0.33%

It has been observed that the model with assessment of stock length has less trim loss (.026) in comparison to the model being proposed by Powar et al (.32%).

The cutting plan at 2% sustainable trim loss, refer Table 2.

Table 2: Cutting Plan

S. No	Order Lengths in cm	Pieces to Cut	Stock Assessed	No. of Stock Used	Trim Loss in cms	Used Stock Length in cms
1	800	3	$U_1=1400$	3	0	4200
	300	32				
2	740	24	1400	20	400	28000
	320	40				
3	740	4	1400	4	80	5600
	640	23				
4	730	46	$U_2=1370$	19	0	26030
	640	19				
5	730	27	$U_3=1330$	13	0	17290
	300	26				
6	730	14	$U_4=1270$	14	0	17780
	540	39				
7	540	25	$U_5=1030$	16	0	16480
	490	16				
8	540	9	1030	9	90	9270
	480	39				
9	480	30	$U_6=960$	21	0	19950
	470	21				
10	480	9	960	4	0	3840
11	480	1	$U_7=700$	1	220	700
Total Trim Loss / Total Stock Used					1000	149350
Trim Loss %					0.67	

The number of stock length U_j assessed for the above data set is six ie. $j = 1, 2, \dots, 6$ for order lengths $l_i, i = 1, 2, \dots, 10$. At the end, one piece of order length 480 is left to cut. If it is cut using the stock lengths previously assessed then the trim loss obtained will be very high, so it can be cut using the minimum stock length ($u = 7mts$).

Illustration for Criterion I

Referring table 6.2 the stock lengths satisfying criterion I are 1400, 1030, 960 therefore the cutting plan using the stock length satisfying this criterion is, please refer table 3

Table 3: Cutting Plan

S. No	Order Lengths in cm	Pieces to Cut	Stock Assessed	No. of Stock Length Used	Trim Loss in cms	Used Stock Length in cms
1	800	3	1400	3	0	4200
	300	32				
2	740	24	1400	20	400	28000
	320	40				
3	740	4	1400	4	80	5600
	640	23				
4	730	46	1400	19	0	26600
	640	19				
5	730	27	1400	13	0	18200
	300	26				
6	730	14	1400	14	0	19600
	540	39				
7	540	25	1030	16	0	16480
	90	16				
8	540	9	1030	9	90	9270
	480	39				
9	480	30	960	21	210	20160
	470	21				
10	480	9	960	4	0	3840
11	480	1	700	1	220	700
Total Trim Loss / Stock Used					4300	152650
Trim Loss %						2.8

Illustration for Criterion II: The stock lengths satisfying the criterion II are 1400, 1370, 1330, 1270 refer table 6.2. The cutting plan using criterion II, please refer table 4.

Table 4: Cutting Plan

S. No	Order Lengths in cm	Pieces to Cut	Stock Assessed	No. of Stock Length used	Trim Loss in cms	Used Stock Length in cms
1	800	3	1400	3	0	4200
2	300	32				
3	740	24	1400	20	400	28000
4	320	40				
5	740	4	1400	4	80	5600
6	640	23				
7	730	46	1370	19	0	26030
8	640	19				
9	730	27	1330	13	0	17290
10	300	26				
11	730	14	1270	14	0	17780

Table 4 Contd.,						
12	540	39				
13	540	25	1270	16	3840	20320
14	490	16				
15	540	9	1270	9	2250	11430
16	480	39				
17	480	30	1270	21	6720	26670
18	470	21				
19	480	9	1030	4	1240	5080
20	480	1	700	1	220	700
Total Trim Loss / Stock Used					14750	163100
Trim Loss %						9.0

Illustration of Criterion III: The stock length satisfying the criterion III are 1400, 1370, 1030, 960, please refer table 6.2. The cutting plan using criterion III is, refer table 5.

Table 5: Cutting Plan

S. No	Order Lengths in cm	Pieces to Cut	Stock Assessed	No. of Stock Length used	Trim Loss in cms	Used Stock Length in cms
1	800	3	1400	3	0	4200
	300	32				
2	740	24	1400	20	20	28000
	320	40				
3	740	4	1400	4	20	5600
	640	23				
4	730	46	1370	19	0	26030
	640	19				
5	730	27	1370	13	40	17810
	300	26				
6	730	14	1370	14	100	19180
	540	39				
7	540	25	1030	16	0	16480
	490	16				
8	540	9	1030	9	10	9270
	480	39				
9	480	30	960	21	10	20160
	470	21				
10	480	9	960	4	0	3840
11	480	1	700	1	220	700
Total Trim Loss / Stock Used					2920	151270
Trim Loss %						1.9

The table 3 to 5 shows the cutting plans of various criteria. Trim loss generated may vary on the data set used. Therefore, it is recommended to check the trim loss using various criteria and select the criteria which best suits the sustainable trim loss acceptable by the industry.

CONCLUSIONS

It has been noticed that the assessment of stock lengths, to cut different order sets for 1DCSP, has resulted in minimum trim loss. The stock length determined at every step is checked against the sustainable trim loss. At the end the model computes the total trim loss which has been observed to be very minimal. Three criteria are discussed which can be used to lower the number of stock length assessed for the feasibility of the supplier and also which supports acceptable sustainable trim loss for the industry. This model can help industries to choose the appropriate level of stock to minimize the total costs and manage warehousing.

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