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One- Dimensional Cutting Stock Problem in Al- Mansour Company

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ABSTRACT

When short items are being cut out from long objects, the One- Dimensional Cutting Stock Problem (1D-CSP) is being appeared and caused increment in wastage material amounts, so the primary purpose of this paper is to use integer linear programming (ILP) based on Advance Interactive Mathematical Modeling System (AIMMS) software to minimize the trim losses which is resulting from one dimensional- long objects and also to reduce the total number of used stocks. Reinforcement Steel (Rebar) is used in building structure at Al-Aziziyah Housing Project by Al- Mansour Company as long objects with standard lengths and different diameters which are representing four problems according to these diameters (25 mm, 16 mm, 12 mm, and 10 mm). The implementation of that software is very effective to present optimal solutions, where the utilization stock ratio reached to (99.51%).

Keywords: One- Dimensional Cutting Stock Problem, and Optimal Solutions.

مشكلة قطع الخام أحادي البعد في شركة المنصور

الخلاصة

عند قطع أجسام قصيرة من الأجسام الطويلة تظهر مشكلة قطع الخام أحادي البعد و تسبب زيادة في كمية المواد التالفة، لذا الهدف الأساسي من هذا البحث هو أستخدام البرمجة الخطية الصحيحة أستناداً على برنامج نظام النمذجة الرياضية المتقدم لتقليل ضياعات القطع الناتجة من قطع الأجسام الطويلة أحادية البعد و كذلك لتقليل العدد الكلي من الخامات المستخدمة. حديد التسليح (القضبان) مستخدم في هيكل البناء في مشروع العزيزية للأسكان التابع لشركة المنصور كجسم طويل بطول ثابت و بأربع أقطار مختلفة تمثل أربع مشاكل حسب الأقطار (25ملم، 16 ملم، 12 ملم، 10 ملم) . تنفيذ ذلك البرنامج هو فعال جداً لتقديم حلول مثلى، حيث معدل استغلال الخام بلغ (99.51%).

الكلمات المرشدة: مشكلة قطع الخام أحادية البعد و حلول مثلى.

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INTRODUCTION:

Cutting Stock Problems (CSP) are the combination of two problems; the first one is the assortment problem, and the second one is the trim loss problem. When small pieces are being cut out from large objects, these two problems arise. The assortment problem addresses the issue of choosing proper dimensions for the large objects. The Trim Loss problem addresses the issue of how to cut out the small items from the given large objects in such a way that wastage material will be minimized.

Cutting Stock Problems (CSP) are considered as an important and active topic of researches for many decades and exists in a number of Industrial processes. Minimizing the trim losses is a problem that reaches back to the foundation of operations research. In practice, the small pieces are known as order list and the large objects are known as stock material. In the cutting process the stock material can seldom be used as a whole but some residual pieces or trim losses will be produced. Since the primary objective of the cutting process is to minimize the wastage, there are different problems in this scope ranging from application to another with diversity of dimensions and required quantities which cause a complexity to the problem like trim of steel bars, fiber industries, or wood cutting.

Literature Review:

In the literature, several versions of Cutting Stock Problems are studied in different ways of One- Dimensional (1D) scope, the researchers used different approaches to get optimal or near optimal solutions.

Apichai Ritvirool (2007) [1]: illustrate how the proposed ILP model could be applied to actual systems and the types of information that was obtained relative to implementation. The results show that the proposed ILP model can be used as a decision support tool for selecting time horizon of order planning and cutting patterns to decrease material cost and waste from cutting raw material for 1D-CSP.

Rodrigo Rabello Golfeto et al (2009) [2]: present a genetic symbiotic algorithm to solve the one-dimensional cutting stock problem with multiple objectives. And they considered two important objectives for an industry (1) cost of trim loss and (2) cost of setup. Researchers use a symbiotic relationship, between the population of solutions and the population of cutting patterns, together with a niche strategy to obtain an approximation of the Pareto-front. Results of the computational experiments with instances from a chemical-fiber company and with random instances are reported.

Claudio Arbib et al (2010) [3]:address a 1-dimensional cutting stock problem which, in addition to trim loss minimization, requires that the set of cutting patterns forming the solution can be sequenced so that the number of stacks of parts maintained open throughout the process never exceeds a given. For this problem, they propose a new integer linear programming formulation whose constraints grow quadratically with the number of distinct part types.

One- Dimensional Cutting Stock Problems (1D-CSP):

The problem in its simplest form can be described as follows. Given materials that are available in certain lengths, cut them in order to generate certain required lengths. For instance, In order to simplify the terminology, assume that we are cutting rods to desired lengths. Being a one-dimensional problem, all rods are of the same diameter and only their respective lengths differ. On the one hand, there are different lengths of available rods that we have in stock; while on the other hand; there are lengths of desired rods that are demanded by customers. A cutting plan, consisting of cutting patterns, will determine how to generate the *required rods* from the *available rods*. Suppose that there are many available lengths for which there are number of supplies of these available rods. On the other hand, there are required lengths for which there are. The cutting plan is assumed to consist of a number of distinct cutting patterns that are enumerated from plan to another [4].

There are two kinds of stocks in (1D-CSP) [5]:

a- A Standard One-Dimensional Cutting Stock Problem (S1D-CSP) is known as an NP complete one, as shown in Figure (1.1a).

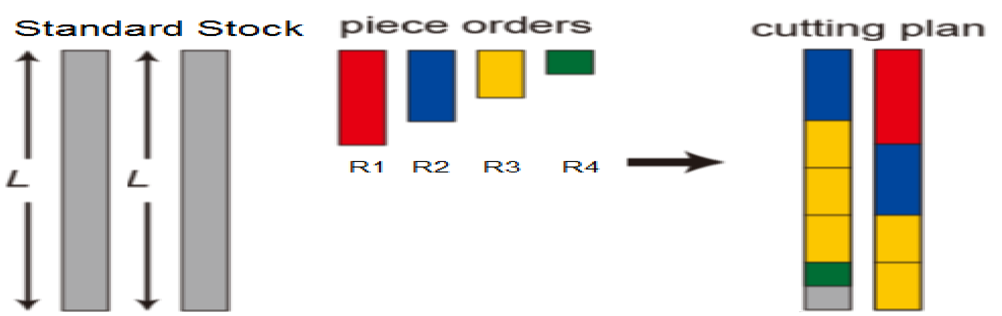
The assumptions of this problem are as follows:

• All used stock lengths should be cut to the end as much as it is possible.

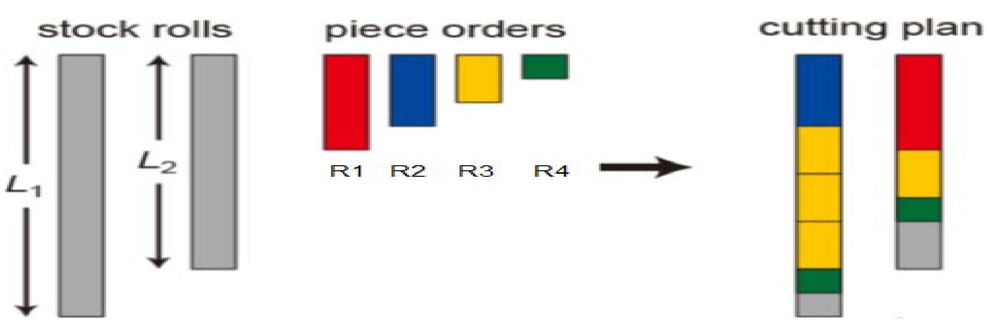
• All stock lengths are identical (with same lengths).

Application of this problem is available in pipes, steel trimming, and film rolls cutting.

b- A General One-Dimensional Stock Cutting Problem (G1D-CSP), as another kind of the one dimensional problem, trim losses can be used later. The storage stocks have different lengths. Reduction of cutting wastes is one of the main goals in the cutting process and also one of the basic purposes in the 1D-CSP.As shown in Figure (1.1b). Application of this problem is available in steel structure industries, wood strips cutting, and so on.



a. S1D-CSP



b. G1D-CSP

Figure 1.1 One-Dimensional Cutting Stock Problem (1D-CSP)

Dyckhoff's Typology of CSP:

The main features of Dyckhoff's typology are introduced by four criteria according to which Cutting problems are categorized [6]:

a- Criterion 1: dimensionality captures the minimal number (1, 2, and 3) of geometric dimensions which are necessary to describe the required layouts (patterns) completely.

b- Criterion 2: the kind of assignment of small items to large objects, there are two cases, indicated by B and V. B stands for the German "Belade problem", meaning that all large objects have to be used. V (for the German" Verlade problem") characterizes a situation in which all small items have to be assigned to a selection of large objects.

c- Criterion 3: represents the assortment of the large objects. O stands for one large object, I for several but identical large objects, and D for several different large objects.

d- Criterion 4: likewise characterizes the assortment of the small items. Dyckhoff distinguishes assortments consisting of few items (F), many items of many different lengths (M), many items of relatively few different lengths (R), and congruent lengths (C).

e-

Problem Description:

The study will focus on One-Dimensional Cutting Stock Problem (1D-CSP), the problem will involve a great number of large objects with certain length which have been minimized and divides them to many items of diversity length in a way that the Trim Loss becomes minimized and also qualified to be used in our cutting plan. So, they must be focused on the minimum number of large objects with the large possible length. According to the Dychoff's topology [7], generally in the CSP presented in this research, the problem can be classified as 1/V/I/ (M, F, R, and C).

1, in this classification, shows the number of dimension of the problem.

V: means that characterizes a situation in which all small items have to be assigned to a selection of large objects.

I: for several, but identical large objects.

M: for many items with many different lengths.

F: for assortments consisting of few items.

R: for many items of relatively few different lengths.

C: for congruent lengths.

Case Study:

Civil engineers in this project mainly strive to make the building stronger and fit within specifications. Those engineers do not consider some managerial and technical problems which reinforcement steel trimming problem is one of them.

Reinforcement steel have a standard length as a stock bars (12 meters) with different diameters (25mm, 16mm, 12mm, and 10 mm) that are used for building these residential complex ranging from foundations, columns, slabs, stairs, balconies, to front-Arch entrance activity, there are different of lengths and numbers of required items which should be fulfilled ranging from small item lengths to these item lengths which reach the stock length with high variety of amounts.

Whenever project engineers reach a new activity, they start to trim reinforcement steel bars without standard cutting plan to repeat in each activity, starting from foundations and finishing in last floor slabs. In each activity the desired lengths and diameters are different, for example reinforcement steel with 10 mm and 25 mm are used in foundation construction. It should be noted that the planning for trimming processes is done randomly and without taking into account the reinforcement steel used in other places in the same activity or in other activities, on other hand, determination of stock amounts for different diameter categories depends on civil engineer experiences, where is a tolerance amounts of loss is 10% added to the reinforcement steel amounts that are used actually in the building and it is available in the construction sketches, the experience factor differs from one engineer to another so we need to determine the rebar amounts, also minimize trim losses.

Data Collection:

Before starting of implementation activities in the project, reinforcement steel for the building should be determined by the planning department, so according to the structural drawings which give data for the required item lengths and quantities of all diameter categories (25 mm, 16 mm, 12 mm, and 10 mm) in standard lengths (12-meter) that are used in the steel structure for that housing project which are estimated with adding a tolerance percentage which reaches (10%) of the actual used amounts regarding the trim losses which will results by trim processes in consideration, so the total scheduled amounts for this project (Building- type B) equal (73 tons) divided to different diameter categories as mentioned above (40 tons, 10 tons, 18 tons, and 5 tons) respectively, These required quantities of rebar are distributed into different structural designs with variety amounts for each activity design. These quantities and item lengths will be explained in the tables below:

Table 1.1 illustrates the activities that are needed reinforcement steel (rebar).

Diameter Category				Activity
25 mm	16 mm	12 mm	10 mm	
Required	Required			Foundation
Required	Required		Required	Columns
	Required	Required	Required	Beams
	Required	Required	Required	Slabs
	Required	Required	Required	Stairs
		Required	Required	Balcony
	Required	Required	Required	Front- Arch

Table 1.2 Required lengths with number of items for rebar with (diameter 25 mm).

Required Items	1	2	3	4	5	6	7	8	9	10
Item Lengths	12	10.3	9.85	7.2	5.8	5.6	4.6	3.6	2.2	1.3
Number of Required items	482	100	12	10	20	74	196	128	128	144

Table 1.3 Required lengths with number of items for reinforcement steel with (diameter 16 mm).

Required Items	1	2	3	4	5	6	7	8	9	10
Item Lengths	6.9	6.8	5.6	5	4.8	4.6	4.4	4	3.8	3.7
Number of Required Items	12	80	60	48	21	112	72	208	24	186
Required Items	11	12	13	14	15	16	17	18	19	20
Item Lengths	3.6	3.2	2.4	2.1	2	1.9	1.6	1.4	1.3	1.2
Number of Required Items	275	48	78	30	26	36	6	18	112	54

Table 1.4 Required lengths with the number of items for reinforcement steel with (diameter 12 mm).

Required Items	1	2	3	4	5	6	7	8	9
Item Lengths	12	9.6	8.4	6.3	5.6	5.3	5.2	4.8	4.6
Number of Required Items	500	190	72	114	35	60	3	36	84
Required Items	10	11	12	13	14	15	16	17	18
Item Lengths	4.3	4.1	4	3.8	3.6	3.2	3	2.7	2.6
Number of Required Items	90	150	42	18	212	66	282	180	228
Required Items	19	20	21	22	23	24	25	26	27
Item Lengths	2.4	2.35	2.3	2.2	2.1	2	1.7	1.6	1.5
Number of Required Items	8	42	198	84	360	78	180	618	132
Required Items	28	29	30	31	32	33			
Item Lengths	1.4	1.3	1.2	1.1	1	0.8			
Number of Required Items	228	130	207	327	36	90			

Table 1.5 Required lengths with number of items for reinforcement steel with (diameter 10 mm).

Required Items	1	2	3	4	5	6	7	8
Item Lengths	12	10.5	5.2	3.6	3	2.6	2.4	2
Number of Required Items	24	19	24	44	12	72	15	56
Required Items	9	10	11	12	13	14	15	
Item Lengths	1.8	1.5	1.4	1.3	1.2	1	0.4	
Number of Required Items	163	1980	288	168	682	1170	624	

Integer Linear Programming (ILP) approach Based on (AIMMS) Software:

The LP optimal solution, which generally is non-integer, has associated a small fraction of all possible patterns. To obtain an integer solution we solve a final integer CSP after using an extra column-generation procedure [8].In general, the CSP with all its extensions and variants has been classified as NP-hard. The CSP is essentially an integer programming problem; however, a two stage approach involving an LP relaxation of the CSP at the first stage followed by a rounding-up procedure at the second stage can be applied for many variants of the CSP. This approach is frequently used for solving CSPs by applying the column generation method of Gilmore and Gomory, and an appropriate rounding of the solution of the continuous relaxation problem. An auxiliary problem arises from the LP formulation where the columns of the LP constraint matrix need to be determined. The columns of the LP constraint matrix represent all the cut patterns (i.e. the different ways of cutting the material) that can be produced from the available stock material. Columns may be generated in two ways: in advance or on-line. Advance column generation is used when all of the feasible patterns are being generated for small to medium problems. It is also used only when a representative subset is being generated for a large problem. The on-line pattern generation is used for solving large integer problems by using a column generation technique similar to that of the classic one-dimensional CSP. For the one-dimensional CSP, Gilmore and Gomory used an impressive column generation technique built into the frame of the simplex method. One of the factors that add to the complexity of the CSP is the large number of cutting patterns that may be encountered. When the CSP is expressed as an integer-programming problem, the large number of cutting patterns involved generally makes computation infeasible [9].

Integer Linear Programming (ILP) is applied by using AIMMS which gives optimal solution for getting exact solutions.

AIMMS “Advanced Interactive Multidimensional Modeling System" is a software system designed for modeling and solving large-scale optimization and scheduling-type problems.

The first step of the algorithm is to create a sub model of the cutting stock problem which contains a set of cutting patterns which will satisfy the requirements. Clearly, this initial set will not (necessarily) be optimal. This sub model is then solved. Using the resulting shadow prices in conjunction with simplex method theory, it is possible to formulate an auxiliary model (**cutting pattern generation model**) integer program. Solving this model identifies one cutting pattern which is then added to the cutting stock sub model to improve its objective (i.e. to reduce the number of raws). The cutting stock sub model with this extra pattern, is then solved. The process is repeated (using updated shadow prices) until the sub model contains the set of optimum cutting patterns. In practice, the total number of new cutting patterns generated by the cutting pattern generation model is quite small and so the overall algorithm is

very efficient. The objective becomes to minimize the total number of rebar required to make the ordered items (finals) [10].

Problem Solutions:

As mentioned earlier our problem is separated into four problems according to the different diameters. So the problems will be solved sequentially by using AIMMS software with aim to minimize the trim losses and reduce the number of used stocks, When the problem contains small pieces of required lengths and the software executes the solution model, some of pieces will not used in solution because of all of each desired item length are less than half of stock item length. So if we execute these small required item lengths, we will be forced to loss a new stock item. The remaining stock item length will consider as a trim losses. So the software leaves this small problem (**unused finals**) to the scheduler. And the scheduler will decide. We have been forced to use all required item lengths because the problem deals with civil engineers and we assumed that we are unique a scheduler to supply the reinforcement steel, the number of used stock is rounded by the red rectangular and the cutting patterns should be dominated are rounded by the black rectangular to get minimum waste as shown in the figures below:

Size of raw [cm]	=	1,200
Total # raws cut in solution	=	793
Wasted material [cm]	=	14,580
Unused finals [cm]	=	440
Total # of possible patterns	=	137
Total Time [s]	=	0.20

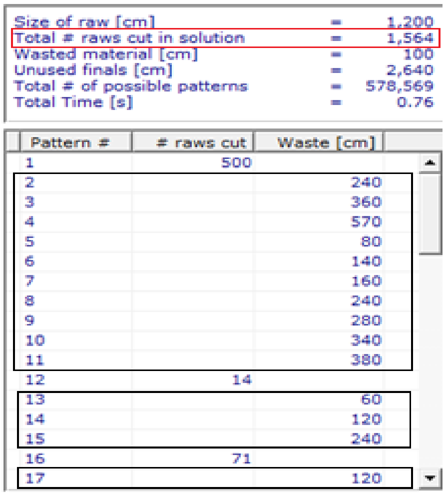
Pattern #	# raws cut	Waste [cm]
1	482	
2		170
3		215
4		480
5	10	40
6	37	80
7		280
8		120
9	17	100
10		30
11	10	20
12	16	20
13	45	60
14	12	85
15	100	40
16	64	20

Figure 1.2 Solution Details for Problem 1

Size of raw [cm]	=	1,200
Total # raws cut in solution	=	459
Wasted material [cm]	=	0
Unused finals [cm]	=	160
Total # of possible patterns	=	14,449
Total Time [s]	=	0.71

Pattern #	# raws cut	Waste [cm]
1		510
2		520
3		80
4		200
5		240
6		280
7		320
8	23	
9		60
10		90
11		120
12		240
13		
14		150
15		
16		60
17		80

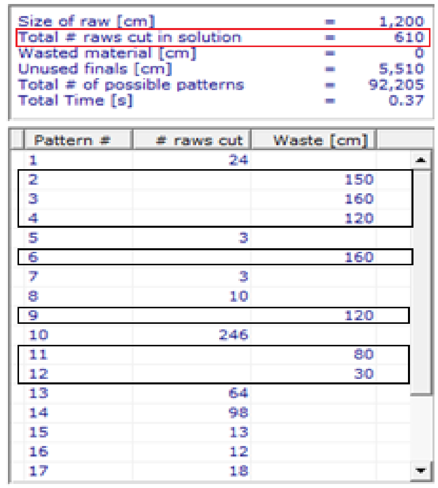
Figure 1.3 Solution Details for Problem 2.



Size of raw [cm]	=	1,200
Total # raws cut in solution	=	1,564
Wasted material [cm]	=	100
Unused finals [cm]	=	2,640
Total # of possible patterns	=	578,569
Total Time [s]	=	0.76

Pattern #	# raws cut	Waste [cm]
1	500	
2		240
3		360
4		570
5		80
6		140
7		160
8		240
9		280
10		340
11		380
12	14	
13		60
14		120
15		240
16	71	
17		120

Figure 1.4 Solution Details for Problem 3.



Size of raw [cm]	=	1,200
Total # raws cut in solution	=	610
Wasted material [cm]	=	0
Unused finals [cm]	=	5,510
Total # of possible patterns	=	92,205
Total Time [s]	=	0.37

Pattern #	# raws cut	Waste [cm]
1	24	
2		150
3		160
4		120
5	3	
6		160
7	3	
8	10	
9		120
10	246	
11		80
12		30
13	64	
14	98	
15	13	
16	12	
17	18	

Figure 1.5 Solution Details for Problem 4.

Final Computational Results:

We get the computational results for each problem, the Utilization Stock Ratio (USR) which was obtained by ILP- aided by AIMMS software- equals to (99.51%), These values represent Integer Linear Programming have given good solutions compared with these trim losses which occur in the Housing Project with percentages (92%-93%), in addition to that there is a not good saving stock there, where Utilization Stock Ratio (USR)= $\frac{\sum_{i=1}^{n} li}{m*L} \times 100\%$ equation 1-1. Where (i) represents item number i (1,2,… n), li represents item length li (l1, l2,… ln), m represent total number of used stocks, L represent standard stock lengths, and T represents total trim losses.

Table 1.6 show Final Computational Results.

ILP Results based onAIMMS software	Typology	Number of used stock (m)	Trim Loss (T-Meter)	Utilization Stock Ratio (USR)	Number of possible patterns
Problem 1 (25 mm)	1\V\I\F	794	153.4	98.71%	16
Problem 2 (16 mm)	1\V\I\M	460	10.4	99.81%	58
Problem 3 (12 mm)	1\V\I\M	1567	9.6	99.94%	62
Problem 4 (10 mm)	1\V\I\M	615	4.9	99.93%	22
Average				99.59%	

Conclusions and Recommendations:

Trim loss depends on the nature of small item lengths, where the trim loss will be decreased whenever these **small item lengths** are having halves or quarters of **large object lengths**, also when the small items have small lengths comparing with standard stock length. this helps to get optimal solutions as well as generate fast cutting patterns. The diversity among total of possible cutting patterns does not give an indicator for the diversity among the number of required items, but the **cutting patterns** that are generated to fulfill the required items are increased, when there is high variety among the small item lengths, quantities and the large object length.

It is important to study the variety of cutting pattern generation effects on setup times and labor costs. This approach can be used by the company or the ministry for all projects building and construction which depend on reinforcement steel to get future outlooks because the trim losses ranging from 7% to 8% in that project while the utilization stock ratio which is getting in this approach reach to 99.59%.

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