THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Engineering (Civil Engineering)
DEGREE

Civil Engineering	Civil Engineering
FIELD	**DEPARTMENT**

TITLE: Application Program for Minimum Loss of Reinforcing Steel

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THESIS

APPLICATION PROGRAM FOR MINIMUM LOSS OF REINFORCING STEEL

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A Thesis Submitted in Partial Fulfillment of

the Requirement for the Degree of

Master of Engineering (Civil Engineering)

Graduate School, Kasetsart University

2006

ISBN 974-9844-56-4

Ramorn Sanoamuang 2006: Application Program for Minimum Loss of Reinforcing Steel. Master of Engineering (Civil Engineering), Major Field: Civil Engineering, Department of Civil Engineering. Thesis Advisor: Associate Professor Santi Chinanuwatwong, Ph.D. 176 pages.
ISBN 974-9844-56-4

The main purpose of this study is to create an application program for minimizing loss of reinforcing steel (MinBars Program). The study is divided into three parts. The first part (C-MinBars sub-program) is to find the possible cutting patterns by combination theory and by Linear Programming to find cutting patterns which give minimum waste, and solved by the Simplex method. The second part (D-MinBars sub-program) is to find the possible cutting patterns by delayed column generation theory and by Linear Programming to find cutting patterns which give minimum waste, and solved by the Revised Simplex method. The third part ExcelTest sub-program is to brings possible cutting patterns from part 1 and part 2 and find the cutting patterns which give minimum waste by the Integer Linear Programming in MS Excel Solver.

The cutting patterns of the D-MinBars sub-program seems to be better than the C-minBars sub-program if single standard length is used. Conversely, the cutting patterns of the C-MinBars sub-program will be more effective if two standard lengths and a great deal of required lengths are used. The result of the ExcelTest sub-program is a bit more effective than the other two sub-programs mentioned above. The study can conclude that using sub-program of delayed column generation theory takes shorter time than combination theory in order to get the result.

Student's signature | Thesis Advisor's signature | 23 / 1 / 2006

ACKNOWLEDGMENT

Finishing this thesis could not have been possible without the support of my thesis advisor, Assoc. Prof. Dr. Santi Chinanuwatwong, who gave me a chance to present a suitable thesis topic. I would like to express my appreciation and thank him for his support and invaluable advice, time and knowledge. I am also thankful to my thesis committee Dr. Wiwat Sangtian and Assoc. Prof. Dr. Prasert Suwanvitaya for their useful recommendations, suggestion and appreciation to all of their lectures.

My gratitude should also be extended to the International Graduate Program in Civil Engineering, Kasetsart University for giving the opportunity to study in the program. I am impressed with all of staff in the International Graduate Program for helping me make all graduate school connections.

This success would not have occurred if I did not have the support of two great persons, my father and my mother. Their continuous support and invaluable advice gave me the strength when I felt weakened. I have nothing to give them back except the pride of graduating.

At last, I would like to thank all of my friends for the good friendship and great memories from Kasetsart University.

Ramorn Sanoamuang

January 2006

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APPLICATION PROGRAM FOR MINIMUM LOSS OF REINFORCING STEEL

INTRODUCTION

Nowadays, there is the large extent of growth of the construction industry in Thailand. It is noticeable that there are more abundant buildings which create a lot of money and increase the employment expansion.

Generally, the conceptual solution on the loss of material used in the construction is how to save as much loss as possible and how to manage the materials properly and efficiently. This means that the capital and unnecessary materials should be decreased. Thus, there are only two steps to save the materials for any construction, namely the procedure of design and construction.

For the first step, engineers must really know and understand the theory of structural design consisting of constructive analysis and structure design.

The second one is concerning with administration regarding of mean objectives in which can be formed and achieved the construction punctually with good quality but the least expense.

In general, the cost of each construction project depends on the price of materials. Good material management can make the minimum waste of material, then, reduce the cost of project. Therefore, there should be a study on the most important materials for the reinforced concrete structure. The material costs of the reinforced concrete structure are concrete, reinforcing steel and formwork. Among these materials, reinforcing steel has more waste than others. The required length of reinforcing steel varies widely, however, there are only a few standard lengths. As a result, each required length of reinforcing will be cut from standard lengths that may generate wastes from the cutting.

Since the person who is in charge doesn't realize how to use reinforcing steel effectively, the problems of the loss of materials still exist, therefore. In addition, sometimes one has not got enough background knowledge to handle reinforcing steel in reinforced concrete work. This study is concerned about the application program to helping the person who needs to arrange cutting patterns that minimize fraction of re-bar.

Objective of this study

The objective of this study is to develop the application program to find the cutting patterns which give minimum loss of reinforcing steel. There are 2 methods used to find the possible cutting patterns, 2 methods used to find the cutting patterns which give minimum waste and 2 methods used to solve the linear programming:

1. To upgrade the RSCP program under Dos to the C-MinBars under Windows.

2. To develop the D-MinBars by using the Delayed Column Generation method and solve the mathematical model by Revised Simplex method.

3. To develop a mathematical model by obtaining possible cutting patterns from C-MinBars or D-MinBars and solve by Integer Linear Programming from MS Excel solver.

4. Compare the result from three sub-programs.

Scope of this study

The application program will be separated into three sub-programs:

1. The C-MinBars: RSCP upgrade from Dos to Windows.

2. The D-MinBars: use the Delayed Column Generation method and solve Linear Programming by Revised Simplex method.

3. The ExcelTest: Create a mathematical model of possible cutting patterns and solve by Integer Linear Programming in MS Excel solver.

LITERATURE REVIEW

1. Computer program aided to arrange cutting patterns.

Gilmore and Gomory (1961) developed a modified algorithm for the cutting stock problem, which they called the column generating procedure. The main purpose of this procedure was to overcome the difficulty of many cutting patterns that were generally encountered in such type of problems. This is based on the LP-relaxation of the problem:

Minimize

$$\text{Min } z = \sum_j x_j$$

Subject to

$$\sum_j A_{ij} x_j = R_i$$
$$x_j \geq 0$$

Variable X_j indicates the number of pattern j used. A_{ij} indicates how many times item i appears in pattern j, and R_i is the requested number of item i. So there are i constraints indicating that for each item the demand has to be met. When solving the LP like this, one can also find the shadow price U_i of each constraint i. the shadow price of a constraint indicates how much the goal function could be decreased if the right-hand side of that constraint would be relaxed by one unit.

Sohail Roza (1983) studied a method for reducing the waste of materials. He began with the combination of the possible cutting forms, and then changed it to mathematical forms, and used the linear programming to solve the problem. However, the combination forms are too many. The hypotheses of his study are the following.

1. In the combination process, the remainder of material must be shorter than the shortest length in the group. If in the combination process there was the remainder of other groups longer than the shortest length, then those groups must be eliminated from the variables.

2. In the combination process the remainder of material must be shorter than the difference of the standard lengths. In this study, there were greater than or equal to two standard lengths.

3. For the same group when deducting the length of each piece from every standard length then use the standard length which gives the shortest remainder.

4. In case, the material group was composed of L1 = 3 pieces and L2 = 4 pieces. If the combination group was composed of the number of L1 less than or equal to 2 and the number of L2 less than or equal to 3, then those groups must be eliminated from the variables.

5. The numbers of standard length have no limitation.

The linear programming technique has been used as the basic tool for optimization. The IBM package MPSX/MIP-370 has been used to solve the linear programming problem. Too many variables become involved in the formulation of the one- dimensional problem and their increase is exponential with an increase in the number of the required size. Therefore, the method is less likely to get feasible solution when the required lengths are more than 20 in number.

Chinanuwatwong (1989) studied on the topic of “Control of Waste and Loss of Reinforcing Steel in Construction Projects”. There were two major procedures in his study;

1. Preparing detail cutting list of re-bar, the details included from drawing, the plan for using steel bars, number of re-bar, the length of each piece, and where it was used.

2. The combination of cutting patterns for reducing the remainder of steel from the direct cutting. The analyzing processes were the combination for generating possible cutting patterns and the linear programming to determine the shortest remainder groups. The RSCP program has been developed to find the cutting patterns which give the minimum waste. The RSCP program was able to reduce as much as the waste of the construction projects.

Wagner (1999) employed a genetic algorithm solution for one-dimensional bundled stock. This paper discussed a one-dimensional cutting stock problem in which lumber is cut in bundles. A genetic search algorithm was proposed and results compared to optimal solutions for an integer programming formulation of the problem.

Miro et al. (1999) studied in the Sequential Heuristic procedure (SHP) for optimizing one-dimensional stock cutting. The item-oriented solution in the form of SHP through a combination of approximation and heuristics was found. The algorithm was designed with some conditions and restrictions. On the basis of the proposed algorithm the computer program CUT was developed. This program was an approved and generalized version of the program COLA. (Miro Gradisar, Miroljub KLjajic, Gortan Resinovic, Joze Jesenko)

Miro et al. (1999) studied in a hybrid approach for optimization of one-dimensional cutting. The proposed approach combined two methods: the pattern-oriented LP-based method and the item-oriented sequential heuristic procedure. The purpose of such combination was its ability to cut ordered length in exactly required number of pieces and to cumulate the trim loss in one length which could be used later.

"CUTGEN1: A problem generator for the standard one-dimensional cutting stock problem" was developed by Gau and Wascher (2000). The column-generation was also used as a key of algorithm for the generation of integer solution to the one-dimensional cutting stock problem. This program was under Dos 6.0 version.

Ducatelle (2001) studied the topic of "Ant Colony Optimization for Bin Packing and Cutting Stock Problem. The Bin Packing Problem (BPP) and the Cutting Stock Problem are two classes of well-known NP-hard combinatorial optimization problems (see Dyckhoff, 1990).

In the BPP, the aim is to combine items into bins of a certain capacity so as to minimize the total number of bins, whereas in the CSP, the aim is to cut items from stocks of a certain length, minimizing the total number of stock. His study used two methods: The First Fit Decreasing Method and The Local Search Method.

2. Mathematical theory for solving the problem.

2.1 The Knapsack Problem (KP)

KP is the one of most intensively studied discrete programming problems. The reason for such interest basically derives from three facts.

1. It can be viewed as the simplest Integer Linear Programming problem.
2. It appears as sub-problem in many more complex problems.
3. It may represent a large amount of practical situation.

Recently, it has been used for generating minimal cover induced constraints and in several coefficient reduction procedures for strengthening linear programming (LP) bounds in general integer programming. During the last few decades, KP has been studied through different approaches, according to the theoretical development of Combinatorial Optimization.

In the sixties, the dynamic programming approach to the KP and other knapsack-type problems was deeply investigated by Gilmore and Gomory.

The dynamic programming

Mathematic Description

$$f_m(\bar{c}) = \max \left\{ \sum_{j=1}^{m} \bar{y}_j A_j \leq \bar{c} \ : \ A_j \geq 0 \ \mathit{as\ integer} \ \text{for}\ j = 1,\ldots,m \right\}$$

Subject to: $L_1 a_1 + L_2 a_2 + \ldots + L_m A_m \leq SL.$ $SL.$ = 10 m. or 12 m.

$$0 \leq a_j \leq \frac{SL.}{L_j}$$ and Integer, $m = n$

$\bar{c}$ is the reduced cost.

$\bar{y}$ is the shadow prices

A_j is the cutting pattern.

a_j is the number of required lengths in each pattern.

L_j is the required length.

$SL.$ is the standard length.

2.2 Combination method in Probability Theory

Permutation: $${}^{n}P_{r} = \frac{n!}{(n-r)!}$$

Combination: $${}^{n}C_{r} = \frac{n!}{r!(n-r)!}$$

"n" is the number of different length of reinforcing steel and "r" is the number of selected length for each group.

2.3 Linear Programming

Mathematical Model

Objective Equation:

$$\text{Min. } z = \sum_{j=1}^{n} C_j X_j$$

Constraint Equation:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} X_j \ (<,=,>) \ b_i$$

$i = 1, 2, 3,\ldots, m$ $\qquad$ $j = 1, 2, 3,\ldots, n$

$X_j \geq 0$

C_j is the cost coefficient.

X_j is the number of pattern.

b_i are the right-hand side/resource/demand coefficients.

a_{ij} are the proportionality/production/activity coefficients or coefficients of variation.

MATERIALS AND METHODOLOGY

Materials

Equipment

Hardware:

- PC with CPU speed 900 MHz and 256 Mbytes RAMS
- Monitor Display setting 1024 by 768 pixels
- Mouse, keyboard
- Hard drive, CD drive

Software:

- Windows 98 or upper
- Microsoft Access 2000
- Microsoft Excel 2000: add-in Solver (reference VBA).

Methodology

General

The MinBars program will be separated into 3 sub-programs

1. The C-MinBars sub-program is the program which is upgraded from RSCP program. The C-MinBars sub-program is used to find the possible cutting patterns by combination theory, find the cutting patterns which give minimum waste by Linear Programming and solve the mathematical model by the Simplex method.

2. The D-MinBars sub-program is used to find the possible cutting patterns by the Delayed Column Generation theory, find the cutting patterns which give minimum waste by Linear Programming and solve the mathematical model by the Revised Simplex method.

3. The ExcelTest sub-program is using the possible cutting patterns from the C-MinBars sub-program or the D-MinBars sub-program to create the mathematical model, find the cutting patterns which give minimum waste by the Integer Linear Programming and solve the mathematical model by MS Excel Solver.

The Particulars of the MinBars Program

1. The C-MinBars Sub-Program

1.1 Generating the cutting patterns by Combination Method

Combination theory

From the combination in the probability theory, if *N* is the number of different length of reinforcing steel and *r* is the number of selected length for grouping, then the total possible combination (C_r^n) will be:

$$C_r^n = \binom{n+r-1}{n-1}$$

Normally a cutting pattern for standard length (12 m.) should not be over five lengths. The minimum length was 0.50 m. and if fixing the length of different length, not less than 0.10 m. The numbers of different lengths following those regulations are 115 lengths. The number of all combinations: (Chinanuwatwong, 1989).

At: $N = 115$, $r = 1, 2, 3, 4$ and 5

At: $r = 1$; $C_r^n = \begin{pmatrix} 115+5-1 \\ 115-1 \end{pmatrix} = \begin{pmatrix} 115 \\ 114 \end{pmatrix} = 115$

At: $r = 2$; $C_r^n = \begin{pmatrix} 115+2-1 \\ 115-1 \end{pmatrix} = \begin{pmatrix} 116 \\ 114 \end{pmatrix} = 6070$

At: $r = 3$; $C_r^n = \begin{pmatrix} 115+3-1 \\ 115-1 \end{pmatrix} = \begin{pmatrix} 117 \\ 114 \end{pmatrix} = 260130$

At: $r = 4$; $C_r^n = \begin{pmatrix} 115+4-1 \\ 115-1 \end{pmatrix} = \begin{pmatrix} 118 \\ 114 \end{pmatrix} = 7677835$

At: $r = 5$; $C_r^n = \begin{pmatrix} 115+5-1 \\ 115-1 \end{pmatrix} = \begin{pmatrix} 119 \\ 114 \end{pmatrix} = 182637273$

So the total ways of combination are

= 115+6670+260130+7677835+182637273

= 190578023

The total groups of combination are too many. But some groups are incorrect because the combination must investigate the one important thing that is the total of length in each group not over than standard length (10m. or 12 m.). Therefore the number of groups will decrease (Chinanuwatwong, 1989).

Reducing the numbers of combination group condition. (Chinanuwatwong, 1989)

1. The required lengths are in ascending order, if any of the lengths in a group combined with a minimum length in this group is longer than 12 m., it must be eliminated from the group.

2. The total length (LC) in each group must not be longer than the standard length, which is 12 m.

3. The waste of the reinforcing steel W (i) from the result of standard length with reduced total length must not be longer than the difference between both standard lengths. In this case, it is 12-10 = 2 m. and if the waste is 3 m., the combination group could not be the variable.

4. In case of the waste of the reinforcing steel from the result of L10-LC and L12-LC, the shorter one should be used. Such as LC=9.50 m.

W12 = 12-9.5 = 2.50 m.

W10 = 10-9.5 = 0.50 m.

Use W (i) = 0.50 m., if in case of LC (i) value is between 10 m. to 12 m., use W (i) from standard length 12 m.

1.2 Linear Programming

Linear programming deals with the optimization of a linear objective function subject to a set of constraint conditions in the form of linear inequalities and/or equations.

Linear programming is characterized by the following properties (Provan, 2005):

1. The problem involves finding the best value for a given objective function, subject to a set of constraints.

2. The behavior of the model is completely determined, that is, there is no probability contributing to the objective function or constraints.

3. Each variable contributes in direct proportion to its value.

4. The variables in the objective and each constraint contribute the sum of the contributions of each variable.

5. The variables can take on continuous values subject to the constraints.

The linear programming Form has three cases as follows:

1. The number of variable equal the number of equation ($n = m$); this case will give one feasible solution per one variable; it has the answers equal the number of equation.

2. The number of variable less than the number of equation ($n < m$); this case has dependent equation = ($n - m$) equation. If the equation is correct, it can reduce some dependent equation until the number of equation will be independent equation.

3. The number of variable less than the number of equation ($n > m$); this case a variable can give many feasible solutions.

The mathematical description

General form

$$\left.\begin{matrix}\max \\ \min\end{matrix}\right\} z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$$

$$a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n \begin{Bmatrix} \leq \\ = \\ \geq \end{Bmatrix} b_i$$

$$X_j \geq 0$$

$i = 1, 2, 3, \ldots, m$ $\qquad$ $j = 1, 2, 3, \ldots, n$

X_j are the variables of the problem, and are allowed to take on any set of real values that satisfy the constraints.

c_j, b_i, a_{ij} are parameters of the problem, and provide the precise description of a particular instance of the Linear programming model.

c_j are the objective/cost coefficients.

b_i are the right-hand side /demand coefficients.

a_{ij} are the activity coefficients or coefficients of variation.

Standard form

$$
\begin{array}{llllll}
a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \ldots + a_{1n}X_n \pm X_{n+1} & & & & = b_1 \\
a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + \ldots + a_{2n}X_n & \pm X_{n+2} & & & = b_2 \\
a_{31}X_1 + a_{32}X_2 + a_{33}X_3 + \ldots + a_{3n}X_n & & \pm X_{n+3} & & = b_3 \\
\quad : \qquad : \qquad : \quad + \ldots + \quad : & & & & = \; : \\
a_{m1}X_1 + a_{m2}X_2 + a_{m3}X_3 + \ldots + a_{mn}X_n & & & \pm X_{n+m} & = b_m
\end{array}
$$

$$X_1 \geq 0 \qquad X_2 \geq 0 \quad \ldots \quad X_{n+m} \geq 0$$

Transforming a general LP into canonical form (equality form) minimization problems: Replace

Min z $= C_1 X_1 + C_2 X_2 + C_3 X_3 + \ldots + C_n X_n$

with Max -z $= -C_1 X_1 - C_2 X_2 - C_3 X_3 - \ldots - C_n X_n$

$\leq$ Constraints: Add a nonnegative slack variable indicating the difference between the LHS value and the b_i value. Specifically replace

$$a_{i1}X_1 + a_{i2}X_2 + a_{i3}X_3 + \ldots + a_{in}X_n \leq b_1$$

with $$a_{i1}X_1 + a_{i2}X_2 + a_{i3}X_3 + \ldots + a_{in}X_n + X_{n+i} = b_1, \quad X_{n+i} \geq 0$$

$\geq$ Constraints: Deduct the slack variable in that row. Specifically replace

$$a_{i1}X_1 + a_{i2}X_2 + a_{i3}X_3 + \ldots + a_{in}X_n \geq b_1$$

with $$a_{i1}X_1 + a_{i2}X_2 + a_{i3}X_3 + \ldots + a_{in}X_n - X_{n+i} = b_1, \quad X_{n+i} \geq 0$$

X_{n+i} , $-X_{n+i}$ was a slack variable.

- ($n + q > m$): m is number of equations, $n + q$ is number of variables.
- That can get only m feasible variables, ($n + q - m$) are not feasible.

Canonical Form

$$\begin{array}{llllll}
X_1 & & & + \bar{a}_{1,m+1} X_{m+1} + \ldots + \bar{a}_{1n} X_n & = \bar{b}_1 \\
& X_2 & & + \bar{a}_{2,m+1} X_{m+1} + \ldots + \bar{a}_{2n} X_n & = \bar{b}_2 \\
& & & \vdots \quad + \ldots + \quad \vdots & = \ \vdots \\
& & X_m & + \bar{a}_{m,m+1} X_{m+1} + \ldots + \bar{a}_{mn} X_n & = \bar{b}_m
\end{array}$$

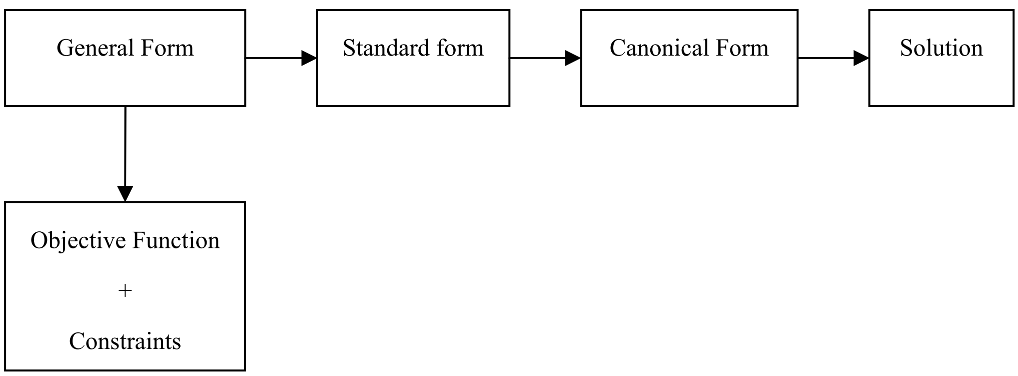


Figure 1 Step of Linear Programming Form.

1.3 The Simplex Method

1. Examine $\overline{c}_j$ in the canonical form of a basis solution.

1.1 If all $\overline{c}_j$ are positive, the solution is optimal.

1.2 If some $\overline{c}_j$ are negative, select the $\overline{c}_s$, which is the smallest of $\overline{c}_j$ that is the most negative one.

2. Examine coefficient $\overline{a}_{is}$ in column *s*.

2.1 If all $\overline{a}_{is}$ are negative, the solution is unbounded

2.2 If one or more $\overline{a}_{is}$ are positive, find the ratio $\overline{b}_i / \overline{a}_{is}$. Find the smallest value, $\overline{a}_{is}$.

3. Using $\overline{a}_{is}$ as a pivotal element, obtain a new canonical form and a new basic feasible solution by having X_s as an entering variable and X_r as a parting variable.

Minimum equality form LP's can be handled easily using the tableau set up above. Simply put the negated objective function into the tableau. The standard equality forms LP are as follow.

Min z = $C_1 X_1 + C_2 X_2 + C_3 X_3 + \ldots + C_n X_n$

$$
\begin{aligned}
a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \ldots + a_{1n}X_n &= b_1 \\
a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + \ldots + a_{2n}X_n &= b_2 \\
\vdots \quad\quad \vdots \quad\quad \vdots \quad + \ldots + \quad \vdots \quad &= \vdots \\
a_{m1}X_1 + a_{m2}X_2 + a_{m3}X_3 + \ldots + a_{mn}X_n &= b_m
\end{aligned}
$$

$$X_1 \geq 0 \qquad X_2 \geq 0 \quad \ldots \quad X_n \geq 0$$

Assume that the A-matrix has rank m then put the objective function into equality form:

$$-Z + C_1 X_1 + C_2 X_2 + C_3 X_3 + \ldots + C_n X_n = 0$$

Next, then put the whole system into augmented matrix form, with the objective function equality at the bottom. This is called a simplex tableau.

z	x_1	x_2	….	x_n	rhs
0	a_{11}	a_{12}	….	a_{1n}	b_1
0	a_{21}	a_{22}	….	a_{2n}	b_2
:	:	:	….	:	:
0	a_{m1}	a_{m2}	….	a_{mn}	b_m
1	$-c_1$	$-c_2$	….	$-c_n$	0

The reduced cost $\overline{c}_j$ still shows the increase in the objective function when X_j is increased by one unit, so by choosing a maximum negative objective row coefficient for the entering variable that objective function decreases, as it should. Thus the simplex method for min LPs is exactly the same as for the max LPs, except for the interpretation of the objective row value.

1.4 Simplex Pivot

Choose the entering variable: choose the variable X_j with a negative row value $-\overline{c}_j$ (positive reduced cost $\overline{c}_j$) to enter the basis.

If one or more $\overline{a}_{ij}$ are positive, find the pivot column from the pivot row. The pivotal element ($\overline{a}_{ij}$) = $\overline{S}\ A_j$

The pivot row (Δ) = min { $\frac{\bar{b}_i}{\bar{a}_{ij}}$: $\bar{a}_{ij} > 0$}

The variable x_{B_i} whose index i determines the minimum ratio is called the blocking variable.

Perform a simplex pivot: Pivot on the element $\bar{a}_{ij}$, where X_j is the entering variable and x_{B_i} is the leaving variable.

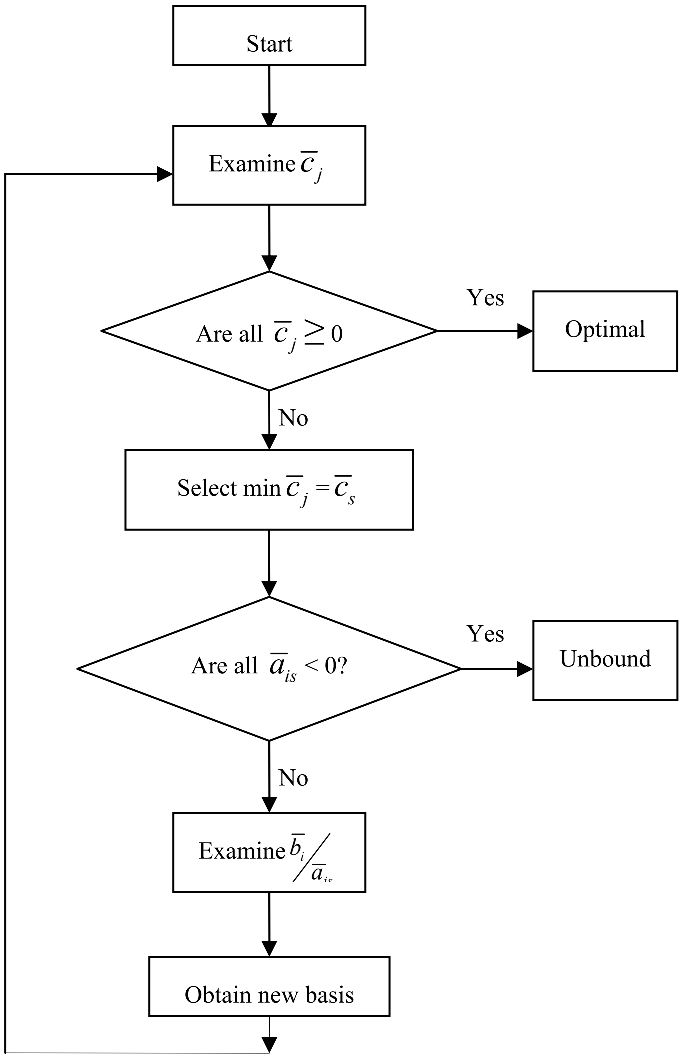


Figure 2 Flow chart of the simplex method

1.5 The combination selected the cutting pattern in MinBars program procedure (The C-MinBars Sub-Program).

1. Input the data, which in this program are element's name, number of member, type of re-bar, length of re-bar and number of re-bar in each member.

2. Calculating parts are:

2.1 Arrangement of all the possible cutting patterns by the total length of reinforcing steel in each pattern LC(i) must not be longer than 12 m. and choose the minimum waste in that pattern from the standard length 10 m. or 12 m.

2.2 Choosing the number of the possible cutting patterns of each length equal to M1 groups (default M1 = 10)

2.3 Arrangement of the possible cutting patterns to matrix form

2.4 Changing the matrix form to Linear Program.

2.5 Solving the problem by simplex method

3. The result shows the number of length in each pattern and number of standard lengths used.

2. The D-MinBars Sub-Program

2.1 Generating the possible cutting patterns by Delayed Column Generation Method

The standard lengths of reinforcing steel were 10 and 12 meters. The components of a cutting schedule are the cutting patterns. Therefore, the summation of required lengths of the reinforcing steel in each cutting pattern cannot exceed the standard length.

A cutting pattern $A_1 = \begin{Bmatrix} a_{11} \\ a_{12} \\ a_{13} \\ \vdots \\ a_{1n} \end{Bmatrix}$ must satisfy

$$a_{11}L_1 + a_{12}L_2 + a_{13}L_3 + \ldots + a_{1n}L_m \leq 10 \text{ or } 12$$

$a_{ij} \geq 0$ and integer ; $j = 1,2,3,\ldots,n$

$L_i \geq 0$ and real : $i = 1,2,3,\ldots,m$

a_{ij} is the number of required lengths in each pattern.

L_i is the required length.

The objective is to determine a set $a_1, a_2, a_3, \ldots, a_m$ of cutting patterns and the number of groups (X_j) of pattern $A_{ij} = \begin{Bmatrix} a_{1j} \\ a_{2j} \\ a_{3j} \\ \vdots \\ a_{mj} \end{Bmatrix}$ produced in order to minimize the waste.

Objective equation:

$$\text{Min } z = C_1 X_1 + C_2 X_2 + C_3 X_3 + \ldots + C_n X_n$$

Subject to:

$$a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \ldots + a_{1n}X_n = N_1$$

$$a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + \ldots + a_{2n}X_n = N_2$$

$$a_{31}X_1 + a_{32}X_2 + a_{33}X_3 + \ldots + a_{3n}X_n = N_3$$

$$\vdots \quad\quad \vdots \quad\quad \vdots \quad +\ldots+ \quad \vdots \quad\quad = \vdots$$

$$a_{m1}X_1 + a_{m2}X_2 + a_{m3}X_3 + \ldots + a_{mn}X_n = N_m$$

$X_n \geq 0$ and integer $\quad$ $\mathbf{C}_m \geq 0$ and integer $\quad$ $N_m \geq 0$ and integer

N_m is the number of required length.

2.2 The Knapsack problem solve by Dynamic Programming Algorithm.

Local objective function:

$$f_m(\overline{c}\,) = \max \left\{ \sum_{j=1}^{m} \overline{y}_j A_j \le \overline{c} \;:\; A_j \ge 0 \textit{ as integer } \text{for } j = 1,\ldots,m \right\}$$

Subject to:

$$a_1 L_1 + a_2 L_2 + \ldots + a_m L_m \le SL. \qquad SL. = 10 \text{ m. or } 12 \text{ m.}$$

$$0 \le a_j \le \frac{SL.}{L_j} \quad \text{and Integer, } m = n$$

$\overline{c}$ is the reduced cost.

$\overline{y}$ is the shadow prices.

A_j is the cutting pattern.

a_j is the number of required lengths in each pattern.

L_j is the required length.

Consider the following schematic representation:

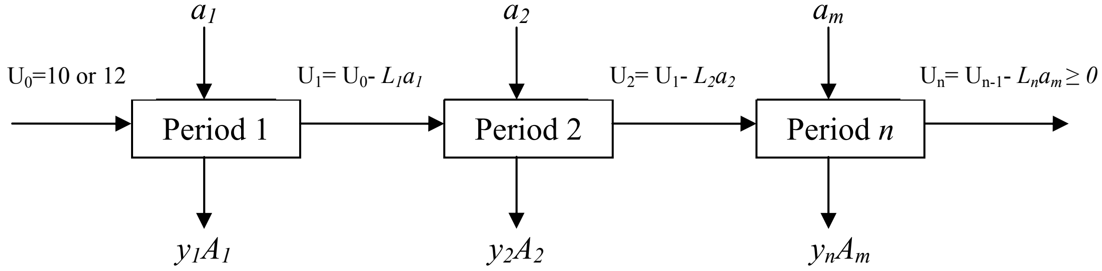


Figure 3 Dynamic Programming

2.3 The Revised Simplex Method

The Revised Simplex Method is an implementation of the standard Simplex Method that uses a shortened tableau, reconstructing only the data from the complete simplex tableau absolutely necessary the steps of the simplex method.

Initial tableau appearance:

basis	$\overline{B}$ & $-\bar{c}$				RHS
x_1	a_{11}	a_{12}	….	a_{1m}	b_1
x_2	a_{21}	a_{22}	….	a_{2m}	b_2
:	:	:	….	:	:
x_m	a_{m1}	a_{m2}	….	a_{mm}	b_m
$-\bar{c}$	$-c_1$	$-c_2$	….	$-c_m$	z_0

$\overline{B}_j$, A_j is the cutting pattern.

c_j is the standard length in each cutting pattern.

The Revised Simplex Method is simply the revised form of the Artificial Variable Method and then starts with the artificial matrix.

Revised tableau: The only values maintained in the revised tableau are (Provan, 2005);

1. The list of basis variables $x = (x_1, \ldots, x_m)$
2. The inverse matrix $\bar{S} = B^{-1}$, where $\overline{B} = [A_{B1}, \ldots, A_{Bm}]$
3. The right-hand side values $\bar{b} = \bar{b}_1, \ldots, \bar{b}_m$
4. The objective function value $\bar{z}_0$
5. The shadow prices $c_j B^{-1} = \bar{y} = (\bar{y}_1, \ldots, \bar{y}_m)$

Tableau appearance:

basis	$\bar{S}$ & $\bar{y}$				RHS
X_1	$\bar{S}_{11}$	$\bar{S}_{12}$	….	$\bar{S}_{1m}$	$\bar{b}_1$
X_2	$\bar{S}_{21}$	$\bar{S}_{22}$	….	$\bar{S}_{2m}$	$\bar{b}_2$
:	:	:	….	:	:
X_m	$\bar{S}_{m1}$	$\bar{S}_{m2}$	….	$\bar{S}_{mm}$	$\bar{b}_m$
z	$\bar{y}_1$	$\bar{y}_2$	….	$\bar{y}_m$	$\bar{z}_0$

Step of the Revised Simplex Method (Provan, 2005)

Step 1: Find the maximum negative object row coefficient: reconstruct the object row coefficient by setting reduced cost ($-\bar{c} = -c + \bar{y}A$). Choose among the $-\bar{c}$ the maximum negative $-\bar{c}$ coefficient $-\bar{c}_j$. (If none, then the current solution is optimal.)

Step 2: Perform the minimum ratio test on pivot column j to find the leaving variable: reconstruct the pivot column ($\bar{A}_j$) by using $\bar{A}_j = \bar{S}A_j$.

Apply the minimum ratio test to this column and the right-hand side values $\bar{b}$ to find the pivot row i corresponding to leaving variable x_i. (If the reconstructed column is negative, then the LP is unbounded.)

Step 3: Perform a pivot on row i and column j: insert reconstructed column j next to the inverse matrix and perform the pivot on the associated row, replacing the blocking variable x_i with the entering variable x_j. The update values of $\bar{S}$, $\bar{b}$, $\bar{z}$ and $\bar{y}$ are then the correct ones for the new basis.

Tableau appearance:

basis	$\bar{S}$ & $\bar{y}$				X_j	RHS
X_1	$\bar{S}_{11}$	$\bar{S}_{12}$	….	$\bar{S}_{1j}$	$\bar{a}_{1j}$	$\bar{b}_1$
:	:	:	….	:	:	:
X_i	$\bar{S}_{i1}$	$\bar{S}_{i2}$	….	$\bar{S}_{im}$	$\bar{a}_{ij}$	$\bar{b}_2$
:	:	:	….	:	:	:
X_m	$\bar{S}_{m1}$	$\bar{S}_{m2}$	….	$\bar{S}_{mm}$	$\bar{a}_{mj}$	$\bar{b}_m$
z (w)	$\bar{y}_1$	$\bar{y}_2$	….	$\bar{y}_m$	$-\bar{c}_j$	$\bar{z}_0$

2.4 Improving result to integer by The First Fit Decreasing Method (FFD) with Local search.

Bin Packing Problem (BPP) instances are usually solved with fast heuristic algorithms. The best of these is first fit decreasing (FFD). In this heuristic, the items are first placed in order of non-increasing weight. Then they are picked up one by one and placed into the first bin that is still empty enough to hold them. If no bin is left, the item can fit in, a new bin is started (Ducatelle, 2001).

The First Fit Decreasing algorithm (Ducatelle, 2001)

1. Sort the items in order of non-increasing length.
2. Remove the first item, and place it in the first bin that has enough space left to hold it.
3. Repeat step 2 until all items are placed in the bin.

For example:

FFD work with item numbers instead of length, bin capacity is 10 m.:

Item length 1, 2, 2, 2, 3, 3, 3, 3, 4, 4, 5, 5, 6, 7

Open new bin from maximum length

First open bin [7], [6], [5]

Free item 1, 2, 2, 2, 3, 3, 3, 3, 4, 4, 5

Place some item in bin

Bin [7, 3] [6, 4], [5, 5]

Free item 1, 2, 2, 2, 3, 3, 3, 4

If it can not be placed in bin then open new bin

Second open bin [4, 3, 3] [3, 2, 2, 2, 1]

Final bin [7, 3] [6, 4], [5, 5] [4, 3, 3] [3, 2, 2, 2, 1]

The Local Search algorithm gives very good result. This is done by opening a few randomly selected bins. Then the algorithm tries to replace up by three items in each of the existing bins of the solution by one or two of the free items, in such a way that the total content of the bin is increased without exceeding the maximum capacity. The least fill bins are destroyed, and their items become free. Then, for every remaining bin, it is investigated whether some of its current items can be replaced by free items so that the bin becomes fuller. The algorithm successively tried to replace two current items by two free items, two current items by one free current item, and one current item by one free item. In the end, the remaining free items are inserted into the FFD (Ducatelle, 2001).

For example:

The bin before local search (the bin capacity is 10):

The bins [3, 3, 3] [6, 2, 1] [5, 2] [4, 3] [7, 2] [5, 4]

Open the two smallest bins:

Remaining bins [3, 3, 3] [6, 2, 1] [7, 2] [5, 4]

Free items 2, 3, 4, 5

Try to replace 2 current items by 2 free items, 2 current by 1 free or 1 current by 1 free:

First bin: 3, 3, 3 $\rightarrow$ 3, 5, 2 new free: 4, 3, 3, 3

Second bin: 6, 2, 1 $\rightarrow$ 6, 4 new free: 3, 3, 3, 2, 1

Third bin: 7, 2 $\rightarrow$ 7, 3 new free: 3, 3, 2, 2, 1

Fourth bin: 5, 4 $\rightarrow$ stays the same

Reinsert the free items using FFD

Fourth bin: 5, 4 $\rightarrow$ 5, 4, 1

Rest in new bin: 3, 3, 2, 2

Final bins: [3, 5, 2] [6, 4] [7, 3] [5, 4, 1] [3, 3, 2, 2]

2.5 The Delayed Column Generation in MinBars program procedure (The D-MinBars Sub-Program).

1. The input data in this program are element's name, number of member, type of re-bar, length of re-bar and number of re-bar in each member.

2. To start the revised simplex method, the program needs a starting basis of the columns of cutting patterns which will allow satisfying the demand for all the number of requirement length. The initial patterns will be the ones that for the standard length cut as many copies of that standard length (SL.) as 10 m. or 12 m. will allow. Set the initial patterns and set the initial tableau.

$$\text{Pattern 1} = \begin{Bmatrix} 1 \\ 0 \\ 0 \\ \vdots \\ 0 \end{Bmatrix}, \text{Pattern 2} = \begin{Bmatrix} 0 \\ 1 \\ 0 \\ \vdots \\ 0 \end{Bmatrix}, \text{Pattern } j = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ 1 \end{Bmatrix}$$

3. Using Delayed Column Generation. The first step is to find the most negative objective row coefficient: reconstruct the object row coefficients by setting.

$$\bar{c}_j = c - \bar{y}\ A$$

4. Perform the minimum ratio test on pivot column j to find the leaving variable. Reconstruct the pivot column A_j by using $A_j = S\ A_j$. Apply the minimum ratio test to this column and the right-hand-side values b to fine the pivot row i corresponding to leaving variable X_{Bi}. (If the reconstructed column is negative, then the linear programming is unbounded)

5. Perform a pivot on row i and column j. Insert reconstructed column j next to the inverse matrix and perform a pivot on the associated row, replacing the blocking variable X_{Bi} with the entering variable X_j. The updated values of $\bar{S}$, $\bar{b}$, $\bar{z}$ and $\bar{y}$ are then the correct ones for the new basis.

6. The Auxiliary Knapsack Problem. It is unnecessary to compute all of $\bar{c}_j$, just the one with the most negative value is required. Then turn to find the most positive value of the basis solution over all the satisfy patterns. The optimization problem is therefore:

Local objective function:

$$f(\mathrm{w}) = \sum_{j=1}^{m}\sum_{i=1}^{n} \bar{y}_j A_i$$

Constraint:

$$L_1\ a_1 + L_2\ a_2 + \ldots + L_n\ a_m \leq 10$$

$$L_1\ a_1 + L_2\ a_2 + \ldots + L_n\ a_m \leq 12$$

$$0 \leq a_j \leq \frac{SL.}{L_j} \quad \text{as Integer, } m = n$$

The pattern can be solved by dynamic programming method. If many patterns have the same maximum negative reduced cost, then select the pattern by minimum waste from these patterns.

7. If the objective solution is not optimal then return to step 3 to find the new pattern with the objective function until value w ≤ 1. Thus all reduced costs are not less than 0 ($\bar{c}_j \geq 0$), and so the current solution is optimal.

8. From the result if the group number of the cutting pattern is not integer, then use the First Fit Decreasing Method (FFD) and the Local search Method to adjusting the group number to integer.

9. The result is shown in the number of patterns in each pattern and number of standard length.

For example Total number of length is 4. Standard length was 10 m. and 12m.

Length No.	Length (m.)	Total
1	7.59	8
2	5.39	8
3	2.40	12
4	2.00	12

Set initial pattern

$$\text{Pattern 1} = \begin{Bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{Bmatrix}, \text{Pattern 2} = \begin{Bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{Bmatrix}, \text{Pattern 3} = \begin{Bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{Bmatrix}, \text{Pattern 4} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{Bmatrix}$$

Set initial matrix in tableau form.

z	x1	x2	x3	x4	rhs
0	1	0	0	0	8
0	0	1	0	0	8
0	0	0	1	0	12
0	0	0	0	1	12
$-\bar{c}$	-10	-10	-10	-10	0

This starting basis and shadow prices (inverse initial matrix).

basis	$\overline{S}$ & $\bar{y}$				rhs
x1	1	0	0	0	8
x2	0	1	0	0	8
x3	0	0	1	0	12
x4	0	0	0	1	12
-z	-10	-10	-10	-10	-400

Reduced Cost for Standard 10 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_2 a_2 - \bar{y}_3 a_3 - \bar{y}_4 a_4$$

$$= 10 - 10a_1 - 10a_2 - 10a_3 - 10a_4$$

Reduced Cost for Standard 12 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_2 a_2 - \bar{y}_3 a_3 - \bar{y}_4 a_4$$

$$= 12 - 10a_1 - 10a_2 - 10a_3 - 10a_4$$

Solve the Knapsack Problem to find new pattern solved by dynamic programming method.

For standard length 10 m.; Reduced Cost = 10-10 a_1 -10 a_2 -10 a_3 -10 a_4

a_1	a_2	a_3	a_4	Remained	Reduced Cost SL=10 m.
1	0	1	0	0.01	-10
1	0	0	1	0.41	-10
0	1	1	1	0.21	0
0	1	0	2	0.61	0
0	0	4	0	0.40	-30
0	0	3	1	0.80	-30
0	0	2	2	1.20	-30
0	0	1	3	1.60	-30
0	0	0	5	0	-40

For standard length 12 m.; Reduced Cost = 12-10 a_1 -10 a_2 -10 a_3 -10 a_4

a_1	a_2	a_3	a_4	Remained	Reduced Cost SL=12 m.
1	0	1	1	0.21	-18
1	0	0	2	0.41	-18
0	2	0	0	1.22	32
0	1	2	0	1.81	2
0	1	1	2	0.21	-8
0	1	0	3	0.61	-8
0	0	5	0	0	-38
0	0	4	1	0.40	-38
0	0	3	2	0.80	-38
0	0	2	3	1.20	-38
0	0	1	4	1.60	-38
0	0	0	6	0	-48

For standard length 10 m: choose the pattern which gives maximum negative reduced cost (-40). Get the pattern = $\begin{Bmatrix} 0 \\ 0 \\ 0 \\ 5 \end{Bmatrix}$. For standard length 12 m: choose the pattern which gives maximum negative reduced cost (-48). Get the pattern = $\begin{Bmatrix} 0 \\ 0 \\ 0 \\ 6 \end{Bmatrix}$. Choose the pattern which gives the least value of the reduced cost. Get the new pattern (x5) = $\begin{Bmatrix} 0 \\ 0 \\ 0 \\ 6 \end{Bmatrix}$.The entering column is associated with $\overline{A}5 = \overline{S}\begin{Bmatrix} 0 \\ 0 \\ 0 \\ 6 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 6 \end{Bmatrix}$. Choose pivot row $\Delta = \min\{\frac{\bar{b}_i}{\bar{a}_{ij}} : \bar{a}_{ij} > 0\} = \{\frac{8}{0}, \frac{8}{0}, \frac{12}{0}, \frac{12}{6}\} = \{ -, -, -, 2\}$; Choose pivot row 4 and replace new pattern into column 4.

z	x1	X2	x3	X5	rhs
0	1	0	0	0	8
0	0	1	0	0	8
0	0	0	1	0	12
0	0	0	0	6	12
1	-10	-10	-10	-12	0

basis	$\overline{S}$ & $\bar{y}$				rhs
x1	1	0	0	0	8
X2	0	1	0	0	8
x3	0	0	1	0	12
X5	0	0	0	1/6	2
-z	-10	-10	-10	-2	-304

Reduced Cost for Standard 10 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_2 a_2 - \bar{y}_3 a_3 - \bar{y}_5 a_4$$
$$= 10\text{-}10a_1 \text{-}10a_2 \text{-}10a_3 \text{-}2a_4$$

Reduced Cost for Standard 12 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_2 a_2 - \bar{y}_3 a_3 - \bar{y}_5 a_4$$
$$= 12\text{-}10a_1 \text{-}10a_2 \text{-}10a_3 \text{-}2a_4$$

Solve Knapsack Problem to find new pattern solved by dynamic programming method.

For standard length 10 m: choose the pattern which gives maximum negative reduced cost (-30). Get the pattern = $\begin{Bmatrix} 0 \\ 0 \\ 4 \\ 0 \end{Bmatrix}$. For standard length 12 m: choose the pattern which gives maximum negative reduced cost (-38). Get the new pattern (x6) = $\begin{Bmatrix} 0 \\ 0 \\ 5 \\ 0 \end{Bmatrix}$. Choose the pattern which gives the least value of the reduced cost. Get the pattern = $\begin{Bmatrix} 0 \\ 0 \\ 5 \\ 0 \end{Bmatrix}$.The entering column is associated with $\bar{A}6 = \bar{S}$ $\begin{Bmatrix} 0 \\ 0 \\ 5 \\ 0 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 5 \\ 0 \end{Bmatrix}$. Choose pivot row Δ = min $\{\frac{\bar{b}_i}{\bar{a}_{ij}} : \bar{a}_{ij} > 0\} = \{\frac{8}{0}, \frac{8}{0}, \frac{12}{5}, \frac{2}{0}\}$ = { -, -, 2.4, -}. Choose pivot row 3 and replace new pattern into column 3.

basis	$\bar{S}$ & $\bar{y}$				rhs
x1	1	0	0	0	8
X2	0	1	0	0	8
X6	0	0	1/5	0	2 2/5
X5	0	0	0	1/6	2
-z	-10	-10	-2 2/5	-2	-212 4/5

Reduced Cost for Standard 10 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_2 a_2 - \bar{y}_6 a_3 - \bar{y}_5 a_4$$
$$= 10\text{-}10 a_1 \text{-}10 a_2 \text{-}2\ 2/5\, a_3 \text{-}2 a_4$$

Reduced Cost for Standard 12 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_2 a_2 - \bar{y}_6 a_3 - \bar{y}_5 a_4$$
$$= 12\text{-}10 a_1 \text{-}10 a_2 \text{-}2\ 2/5\, a_3 \text{-}2 a_4$$

Solve Knapsack Problem to find new pattern solved by dynamic programming method.

For standard length 10 m: choose the pattern which gives maximum negative reduced cost (-4.40). Get the pattern = $\begin{Bmatrix} 0 \\ 1 \\ 1 \\ 1 \end{Bmatrix}$. For standard length 12 m: choose the pattern which gives maximum negative reduced cost (-4.40). Get the pattern = $\begin{Bmatrix} 0 \\ 1 \\ 1 \\ 2 \end{Bmatrix}$. Choose the pattern which gives the least value of the reduced cost. Get the new pattern (x7) = $\begin{Bmatrix} 0 \\ 1 \\ 1 \\ 1 \end{Bmatrix}$.The entering column is associated with $\overline{A}7=\overline{S}$ $\begin{Bmatrix} 0 \\ 1 \\ 1 \\ 1 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 1 \\ 1/5 \\ 1/6 \end{Bmatrix}$. Choose pivot row Δ = min $\{\frac{\bar{b}_i}{\bar{a}_{ij}} : \bar{a}_{ij} > 0\}$ = $\{\frac{8}{0}, \frac{8}{1}, \frac{2\ 2/5}{1/5}, \frac{2}{1/6}\}$ = { -, 8, 12, 12}. Choose pivot row 2 and replace new pattern into column 2.

basis	$\overline{S}$ & $\bar{y}$				rhs
X1	1	0	0	-1	8
X7	0	1	0	0	8
X6	0	-1/5	1/5	0	4/5
X5	0	-1/6	0	1/6	2/3
-z	-10	-5 3/5	-2 2/5	-2	-177 3/5

Reduced Cost for Standard 10 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_7 a_2 - \bar{y}_6 a_3 - \bar{y}_5 a_4$$
$$= 10 - 10 a_1 - 5\ 3/5\, a_2 - 2\ 2/5\, a_3 - 2 a_4$$

Reduced Cost for Standard 12 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_7 a_2 - \bar{y}_6 a_3 - \bar{y}_5 a_4$$
$$= 12 - 10 a_1 - 5\ 3/5\, a_2 - 2\ 2/5\, a_3 - 2 a_4$$

Solve Knapsack Problem to find new pattern solved by dynamic programming method.

For standard length 10 m: choose the pattern which gives maximum negative reduced cost (-2.40). Get the pattern = $\begin{Bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{Bmatrix}$. For standard length 12 m: choose the pattern which gives maximum negative reduced cost (-2.40). Get the pattern = $\begin{Bmatrix} 1 \\ 0 \\ 1 \\ 1 \end{Bmatrix}$. To choose the pattern which give the least value of the reduced cost. Get the new pattern (x8) = $\begin{Bmatrix} 1 \\ 0 \\ 1 \\ 1 \end{Bmatrix}$.The entering column is associated with $\overline{A}8 = \overline{S}$ $\begin{Bmatrix} 1 \\ 0 \\ 1 \\ 1 \end{Bmatrix} = \begin{Bmatrix} 1 \\ 0 \\ 1/5 \\ 1/6 \end{Bmatrix}$. Choose pivot row Δ = min $\{\frac{\bar{b}_i}{\overline{a}_{ij}} : \overline{a}_{ij} > 0\}$ = $\{\frac{8}{1}, \frac{8}{0}, \frac{4/5}{1/5}, \frac{2/3}{1/6}\}$ = { 8, -, 4, 4}. Choose pivot row 3 and replace new pattern into column 3.

basis	$\overline{S}$ & $\bar{y}$				rhs
X1	1	1	-1	0	4
X7	0	1	0	0	8
X8	0	-1	1	0	4
X5	0	0	-1/6	1/6	0
-z	-10	-8	0	-2	-168

Reduced Cost for Standard 10 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_7 a_2 - \bar{y}_8 a_3 - \bar{y}_5 a_4$$

$$= 10\text{-}10 a_1 \text{-}8 a_2 \text{-}0 a_3 \text{-}2 a_4$$

Reduced Cost for Standard 12 m.:

$$\bar{c}_j = c - \bar{y}_1 a_1 - \bar{y}_7 a_2 - \bar{y}_8 a_3 - \bar{y}_5 a_4$$

$$= 12\text{-}10 a_1 \text{-}8 a_2 \text{-}0 a_3 \text{-}2 a_4$$

Solve Knapsack Problem to find new pattern solved by dynamic programming method.

For standard length 10 m: choose the pattern which gives maximum negative reduced cost (-2). Get the pattern = $\begin{Bmatrix}1\\0\\0\\1\end{Bmatrix}$. For standard length 12 m: choose the pattern which gives maximum negative reduced cost (-4). Get the pattern = $\begin{Bmatrix}0\\2\\0\\0\end{Bmatrix}$. Choose the pattern which gives the least value of the reduced cost. Get the new pattern (x9) = $\begin{Bmatrix}0\\2\\0\\0\end{Bmatrix}$.The entering column is associated with $\overline{A}9=\overline{S}$ $\begin{Bmatrix}0\\2\\0\\0\end{Bmatrix}$ = $\begin{Bmatrix}2\\2\\-2\\0\end{Bmatrix}$. Choose pivot row Δ = min $\{\frac{\bar{b}_i}{\bar{a}_{ij}} : \bar{a}_{ij} > 0\}$ = $\{\frac{4}{2}, \frac{8}{2}, \frac{4}{-2}, \frac{0}{0}\}$ = { 2, 4, -, -}. Choose pivot row 1 and replace new pattern into column 1.

basis	$\overline{S}$ & $\bar{y}$				rhs
X9	1/2	1/2	-1/2	0	2
X7	-1	0	1	0	4
X8	1	0	0	0	8
X5	0	0	-1/6	1/6	0
-z	-8	-8	-6	-2	-160

Reduced Cost for Standard 10 m.:

$$\bar{c}_j = c - \bar{y}_9\, a_1 - \bar{y}_7\, a_2 - \bar{y}_8\, a_3 - \bar{y}_5\, a_4$$

$$= 10 - 8a_1 - 8a_2 - 6a_3 - 2a_4$$

Reduced Cost for Standard 12 m.:

$$\bar{c}_j = c - \bar{y}_9 a_1 - \bar{y}_7 a_2 - \bar{y}_8 a_3 - \bar{y}_5 a_4$$
$$= 12\text{-}8a_1 \text{-}8a_2 \text{-}6a_3 \text{-}2a_4$$

Solve Knapsack Problem to find new pattern solved by dynamic programming method.

For standard length 10 m: choose the pattern which gives maximum negative reduced cost (-14). Get the pattern = $\begin{Bmatrix} 0 \\ 0 \\ 4 \\ 0 \end{Bmatrix}$. For standard length 12 m: choose the pattern which gives maximum negative reduced cost (-18). Get the pattern = $\begin{Bmatrix} 0 \\ 0 \\ 5 \\ 0 \end{Bmatrix}$. Choose the pattern which gives the least value of the reduced cost. Get the new pattern (x10) = $\begin{Bmatrix} 0 \\ 0 \\ 5 \\ 0 \end{Bmatrix}$.

Solve Knapsack Problem to find new pattern solved by dynamic programming method. The new pattern (x10) is to repeat pattern (x6) then the Linear Programming solution is now to cut. The results are shown in following table.

Pattern 1 = 2 x $\begin{Bmatrix} 0 \\ 2 \\ 0 \\ 0 \end{Bmatrix}$, Pattern 2 = 4 x $\begin{Bmatrix} 0 \\ 1 \\ 1 \\ 1 \end{Bmatrix}$, Pattern 3 = 8 x $\begin{Bmatrix} 1 \\ 0 \\ 1 \\ 1 \end{Bmatrix}$,

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	2	12	2-L=5.39	1.22
2	4	10	1-L=5.39	0.21
			1-L=2.40	
			1-L=2.00	
3	8	12	1-L=7.39	0.01
			1-L=2.40	
			1-L=2.00	

Total Standard Length	=	160	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	3.36	m.	
Percent Waste	=	2.15	%	
Total Standard Steel: L=10 m.	=	4	Nos.	
Total Standard Steel: L=12 m.	=	10	Nos.	

3. The ExcelTest Sub-Program

The ExcelTest sub-program is used to create a mathematical model of possible cutting patterns from C-MinBars sub-program or D-MinBars sub-program and solve by Integer Linear Programming from MS Excel solver.

3.1 Preparation Solver Add-Ins in MS Excel

1. Choose “Tools >>> Add-Ins” menu and then choose “solver Add-in”, as shown in Figure 4.

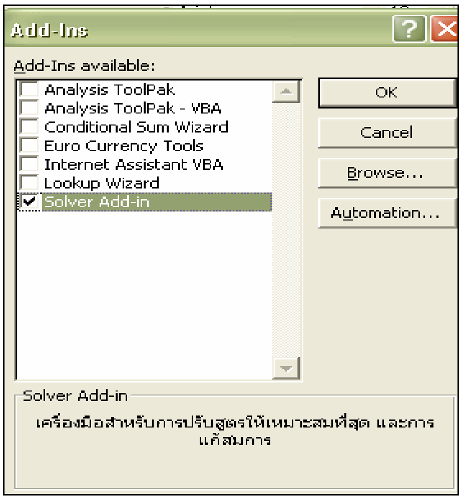


Figure 4 Solver Add-in

2. Choose “Tools >>> Macro” menu and choose “Visual Basic Editor” menu in MS Excel then choose “Tools >>> References” menu in VBA program, as shown in Figure 5.

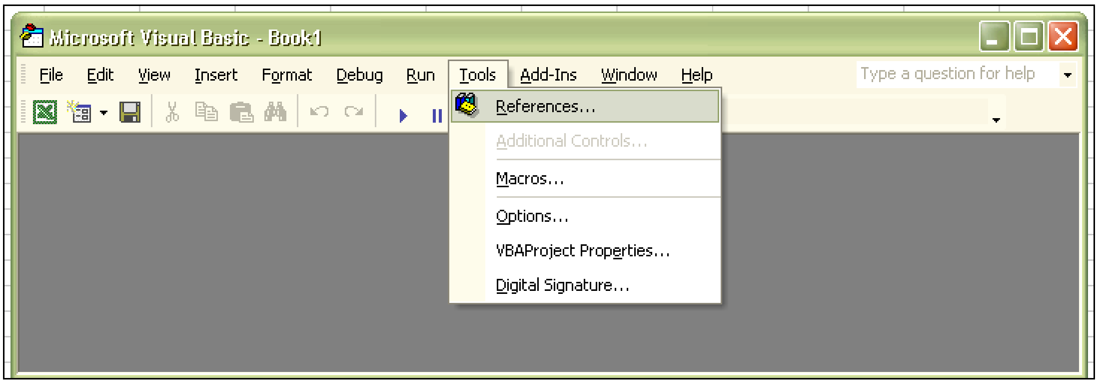


Figure 5 Setting Visual Basic for Application (VBA) in MS Excel

3.2 Excel test Procedure

1. MS Excel will receive the data from C-MinBars or D-MinBars. Set the data in “Data” worksheet, as shown in Figure 6.

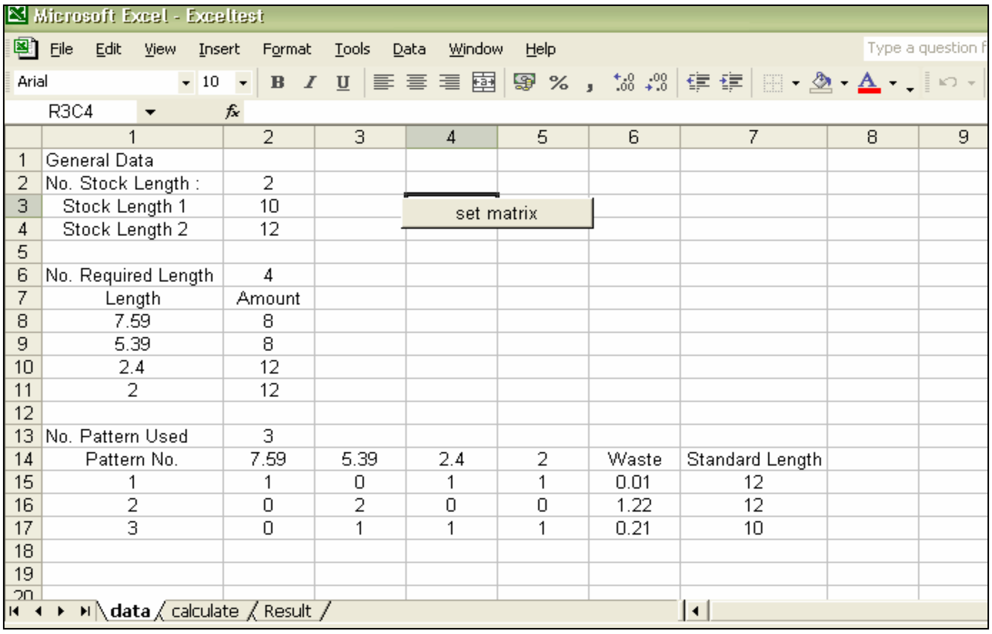


Figure 6 “data” Worksheet

2. Click “set matrix” button in “Data” worksheet then the program will get the matrix in “calculate” worksheet, as shown in Figure 7.

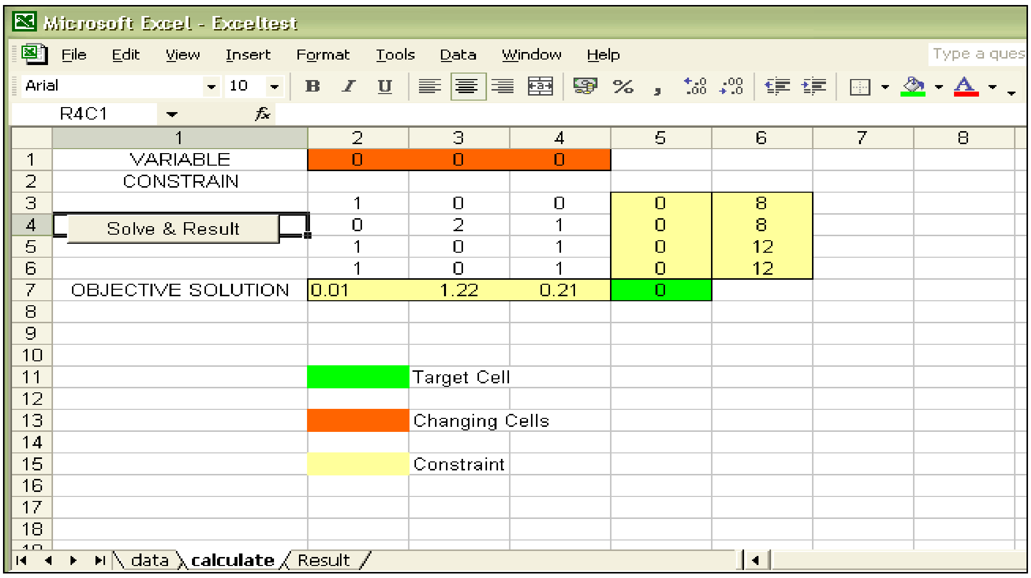


Figure 7 “calculate” worksheet

3. Click “Solve & Result” button in “calculate” worksheet, as shown in Figure 8 then the program will set data in solver parameters and solver options, as shown in Figure 9 and solve the problem by integer linear programming and the program will get the result in “Result” worksheet, as shown in Figure 10.

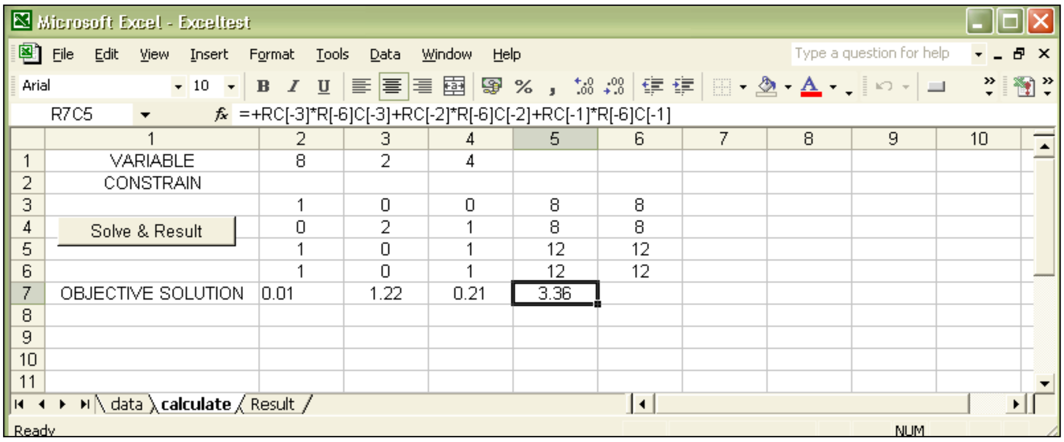


Figure 8 The result in matrix form in “calculate” worksheet

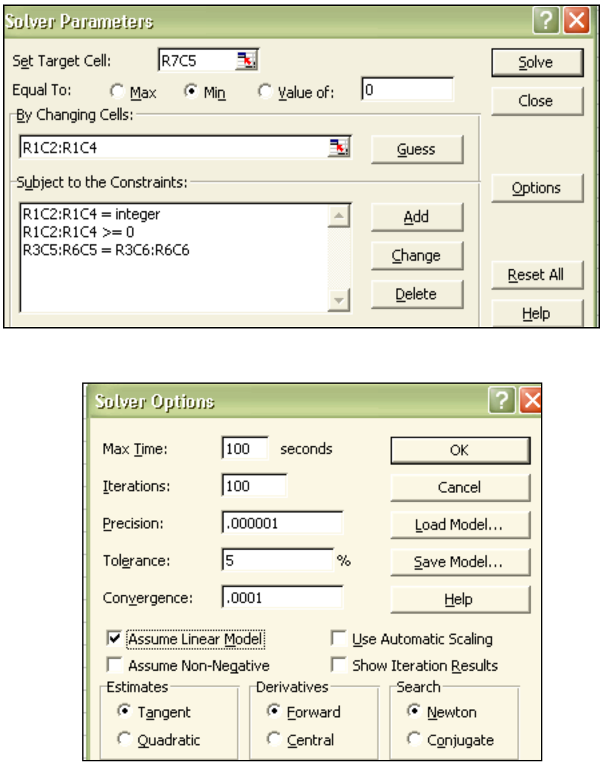
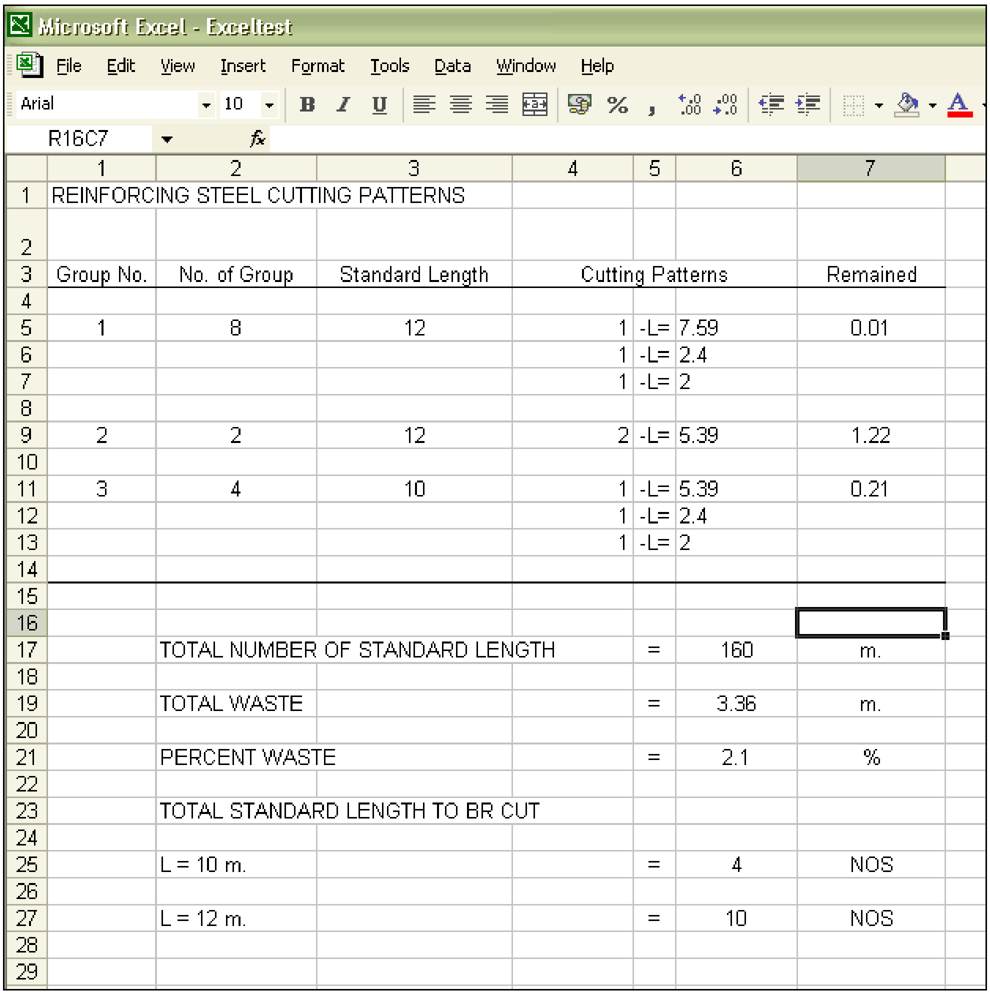


Figure 9 Setting the data in solver parameters and solver options



	1	2	3	4	5	6	7
1	REINFORCING STEEL CUTTING PATTERNS						
2							
3	Group No.	No. of Group	Standard Length	Cutting Patterns			Remained
4							
5	1	8	12	1	-L=	7.59	0.01
6				1	-L=	2.4	
7				1	-L=	2	
8							
9	2	2	12	2	-L=	5.39	1.22
10							
11	3	4	10	1	-L=	5.39	0.21
12				1	-L=	2.4	
13				1	-L=	2	
14							
15							
16							
17		TOTAL NUMBER OF STANDARD LENGTH			=	160	m.
18							
19		TOTAL WASTE			=	3.36	m.
20							
21		PERCENT WASTE			=	2.1	%
22							
23		TOTAL STANDARD LENGTH TO BR CUT					
24							
25		L = 10 m.			=	4	NOS
26							
27		L = 12 m.			=	10	NOS
28							
29							

Figure 10 The result by the solver program in Excel

RESULTS AND DISCUSSION

1. The data used for analysis in this program

In this study, there are 6 analyzed sample cases. One of them is set by the author himself. The purpose is to bar bending list. The other 5 cases are quoted from Chinanuwatwong's (One is referred by Sohail Raza, one is set by Chinanuwatwong's, and the other 3 cases are from construction projects.).

The program will give 4 comparative results in each standard length. The first one is from the C-Minbars program, the second one is from Excel Solver using parameters from C-MinBars, the third one is from the D-MinBars and the last one is from the Excel Solver using parameters from D-MinBars.

2. Examples for analysis by the program

Example 1 This case is set by the author himself, to show how to input data in the program. The reinforcing steel will be automatically separated by type and size. The data was input by different type and size, as shown in Table 1 to 3.

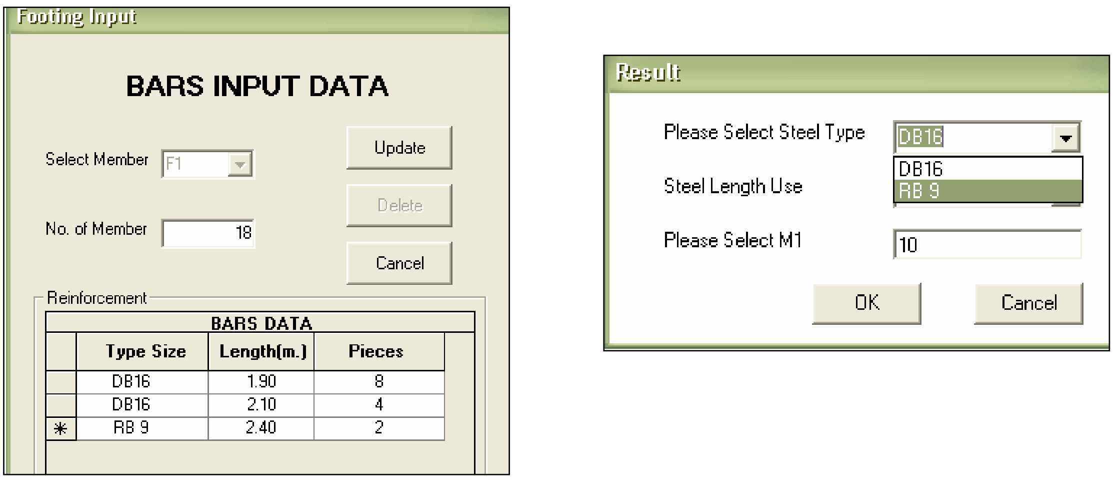


Figure 11 Inputting data and how to choose the re-bar to calculate by the program

Table 1 Bar Cutting Schedule of Example 1

COMPANY________________________________(1) Bar schedule ref.________________________________(4)

PROJECT ________________________________(2) Bar cutting no. ________________________________(5)

TITLE ________________________________ Date prepare ____________(6) Date revise____________(8)

________________________________(3) Prepare by______________(7) Check by______________(9)

member (10)	no. of mbrs. (11)	type & size (12)	length of each bar (13)	no. of bar in mbr. (14)		mem ber (15)	no. of mbrs. (16)	type & size (17)	length of each bar (18)	no. of bar in mbr. (19)	remark (20)
M1	18	DB16	1.9	8		M5	50	DB16	3.5	2	
		DB16	2.1	4				DB16	2.75	2	
		RB9	2.4	2				RB9	1.5	15	
M2	12	DB16	1.9	8		M6	12	RB9	4.1	20	
		DB16	2.5	4				RB9	3.1	24	
		DB16	2.1	4							
		RB9	3.6	2		M7	120	DB16	3.5	4	
								RB9	1.3	20	
M3	100	DB16	5.1	3							
		DB16	4.8	3							
		DB16	3.2	2							
		RB9	1.4	20							
M4	96	DB16	3.6	2							
		DB16	3.2	3							
		RB9	1.4	16							

"M" is the name of structural member.

Table 2 Summation data from the Minbars Program (DB16) used for Example 1A

Length No.	Length (m.)	Total
1	5.10	300
2	4.80	300
3	3.60	192
4	3.50	580
5	3.20	488
6	2.75	100
7	2.50	48
8	2.10	120
9	1.90	240

Total number of length is 9.

Type and size of bar is DB16.

From the MinBars program analysis, the results are separated into 3 types of selected standard length (10 m. or 12 m., 10 m. only and 12 m. only). Each type can give 4 results from 3 sub-programs. The comparisons of the results with other sub-program are showed in table 3.

Table 3 Comparison of the results with other sub-program of Example 1A

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
C-MinBars	10 or 12	43	12	0.91	11
	10	47	7	3.88	9
	12	39	13	1.10	10
ExcelTest by C-MinBars	10 or 12	46	9	0.81	4
	10	47	7	3.88	3
	12	39	N/A	N/A	N/A

Table 3 (cont'd).

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
D-MinBars	10 or 12	24	13	1.30	2
	10	25	9	2.56	2
	12	27	11	1.10	2
ExcelTest by D-MinBars	10 or 12	28	12	1.26	59
	10	26	9	2.56	3
	12	27	N/A	N/A	N/A

Note: N/A = Not Available

For: Standard Length Selected: 10 m. or 12 m.

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 43, the number of cutting patterns which give minimum waste is 12, percent waste of reinforcing steel is 0.91% and time for calculation is 11 second, the details of cutting patterns are showed in Appendix Table D1.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 46, the number of cutting patterns which give minimum waste is 9, percent wastes of reinforcing steel is 0.81% and time for calculation is 4 second, the details of cutting patterns are showed in Appendix Table D2.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 24, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 1.30% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D5.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 28, the number of cutting patterns which give minimum waste is 12, percent wastes of reinforcing steel is 1.26% and time for calculation is 59 second, the details of cutting patterns are showed in Appendix Table D6.

For: Standard Length Selected: 10 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 47, the number of cutting patterns which give minimum waste is 7, percent waste of reinforcing steel is 3.88% and time for calculation is 9 second, the details of cutting patterns are showed in Appendix Table D3.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 47, the number of cutting patterns which give minimum waste is 7, percent wastes of reinforcing steel is 3.88% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D3.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 25, the number of cutting patterns which give minimum waste to 9, percent waste of reinforcing steel is 2.56% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D7.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 26, the number of cutting patterns which give minimum waste is 9, percent wastes of reinforcing steel is 2.56% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D7.

For: Standard Length Selected: 12 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 39, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 1.10% and time for calculation is 10 second, the details of cutting patterns are showed in Appendix Table D4.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 39. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 27, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 1.10% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D8.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 27. The other results are not available.

Table 4 Summation data from the MinBars Program (RB9) used for Example 1B

Length No.	Length (m.)	Total
1	4.10	240
2	3.60	24
3	3.10	288
4	2.40	36
5	1.50	750
6	1.40	3536
7	1.30	2400

Total number of length is 7.

Type and size of bar is RB9.

From the MinBars program analysis, the results are separated into 3 types of selected standard length (10 m. or 12 m., 10 m. only and 12 m. only). Each type can give 4 results from 3 sub-programs. The comparisons of the results with other sub-program are showed in table 5.

Table 5 Comparison of the results with other sub-program of Example 1B

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
C-MinBars	10 or 12	27	9	1.50	10
	10	32	8	3.81	7
	12	25	8	3.89	6
ExcelTest by C-MinBars	10 or 12	29	9	1.45	12
	10	33	N/A	N/A	N/A
	12	27	N/A	N/A	N/A
D-MinBars	10 or 12	23	8	0.36	2
	10	18	9	2.89	2
	12	23	10	2.02	2
ExcelTest by D-MinBars	10 or 12	24	8	0.36	3
	10	20	11	2.89	3
	12	27	N/A	N/A	N/A

Note: N/A = Not Available

For: Standard Length Selected: 10 m. or 12 m.

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 27, the number of cutting patterns which give minimum waste is 9, percent waste of reinforcing steel is 1.50% and time for calculation is 10 second, the details of cutting patterns are showed in Appendix Table D9.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 29, the number of cutting patterns which give minimum waste is 9, percent wastes of reinforcing steel is 1.45% and time for calculation is 12 second, the details of cutting patterns are showed in Appendix Table D10.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 23, the number of cutting patterns which give minimum waste is 8, percent waste of reinforcing steel is 0.44% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D13.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 24, the number of cutting patterns which give minimum waste is 8, percent wastes of reinforcing steel is 0.36% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D14.

For: Standard Length Selected: 10 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 32, the number of cutting patterns which give minimum waste is 8, percent waste of reinforcing steel is 3.81% and time for calculation is 7 second, the details of cutting patterns are showed in Appendix Table D11.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 33. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 18, the number of cutting patterns which give minimum waste is 9, percent waste of reinforcing steel is 2.89% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D15.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 20, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 2.89% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D16.

For: Standard Length Selected: 12 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 25, the number of cutting patterns which give minimum waste is 8, percent waste of reinforcing steel is 3.89% and time for calculation is 6 second, the details of cutting patterns are showed in Appendix Table D12.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 27. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 23, the number of cutting patterns which give minimum waste is 10, percent waste of reinforcing steel is 2.02% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D17.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 27. The other results are not available.

Example 2 This sample is from Chinanuwatwong's research. The data was set by Sohail Raza, as shown in Table 6.

Table 6 The data used for Example 2

Length No.	Length (m.)	Total
1	4.00	100
2	3.25	100
3	2.50	150
4	2.00	250
5	1.50	170

Total number of length is 5.

From the MinBars program analysis, the results are separated into 3 types of selected standard length (10 m. or 12 m., 10 m. only and 12 m. only). Each type can give 4 results from 3 sub-programs. The comparisons of the results with other sub-program are showed in table 7.

Table 7 Comparison of the results with other sub-program of Example 2

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
C-MinBars	10 or 12	25	7	0.05	5
	10	25	6	0.27	4
	12	22	7	0.27	4
ExcelTest by C-MinBars	10 or 12	27	13	0.05	50
	10	N/A	N/A	N/A	N/A
	12	24	10	0.27	30

Table 7 (cont'd).

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
D-MinBars	10 or 12	11	13	0.05	1
	10	25	7	0.05	1
	12	11	11	1.10	1
ExcelTest by D-MinBars	10 or 12	13	12	0.05	3
	10	26	9	0.27	3
	12	13	11	0.27	3

Note: N/A = Not Available

For: Standard Length Selected: 10 m. or 12 m.

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 25, the number of cutting patterns which give minimum waste is 7, percent waste of reinforcing steel is 0.05% and time for calculation is 5 second, the details of cutting patterns are showed in Appendix Table D18

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 27, the number of cutting patterns which give minimum waste is 13, percent wastes of reinforcing steel is 0.05% and time for calculation is 50 second, the details of cutting patterns are showed in Appendix Table D19.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 11, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 0.05% and time for calculation is 1 second, the details of cutting patterns are showed in Appendix Table D23.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 13, the number of cutting patterns which give minimum waste is 12, percent wastes of reinforcing steel is 0.05% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D23.

For: Standard Length Selected: 10 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 25, the number of cutting patterns which give minimum waste is 6, percent waste of reinforcing steel is 0.27% and time for calculation is 4 second, the details of cutting patterns are showed in Appendix Table D20.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), all of the results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 11, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 0.05% and time for calculation is 1 second, the details of cutting patterns are showed in Appendix Table D20.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 13, the number of cutting patterns which give minimum waste is 12, percent waste of reinforcing steel is 0.05% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D20.

For: Standard Length Selected: 12 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 22, the number of cutting patterns which give minimum waste is 7, percent waste of reinforcing steel is 0.27% and time for calculation is 4 second, the details of cutting patterns are showed in Appendix Table D21.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 24, the number of cutting patterns which give minimum waste is 10, percent wastes of reinforcing steel is 0.27% and time for calculation is 30 second, the details of cutting patterns are showed in Appendix Table D22.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 11, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 1.10% and time for calculation is 1 second, the details of cutting patterns are showed in Appendix Table D21.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 13, the number of cutting patterns which give minimum waste is 11, percent wastes of reinforcing steel is 0.27% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D21.

Example 3 This sample is from Chinanuwatwong's research. The data was set by the author's from one continuous beam, as shown in Table 8.

Table 8 The data used for Example 3

Length No.	Length (m.)	Total
1	7.59	8
2	5.39	8
3	2.40	12
4	2.00	12

Total number of length is 4.

From the MinBars program analysis, the results are separated into 3 types of selected standard length (10 m. or 12 m., 10 m. only and 12 m. only). Each type can give 4 results from 3 sub-programs. The comparisons of the results with other sub-program are showed in Table 9.

Table 9 Comparison of the results with other sub-program of Example 3

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
C-MinBars	10 or 12	12	3	2.15	2
	10	6	3	2.15	2
	12	9	5	6.76	2
ExcelTest by C-MinBars	10 or 12	12	3	2.15	2
	10	6	3	2.15	2
	12	9	4	6.76	2
D-MinBars	10 or 12	16	3	2.15	1
	10	9	3	2.15	1
	12	10	4	6.76	1

Table 9 (cont'd).

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Pattern	No. of Pattern	Percent Waste (%)	Time (sec.)
ExcelTest by D-MinBars	10 or 12	16	3	2.15	2
	10	9	3	2.15	2
	12	10	4	6.76	2

For: Standard Length Selected: 10 m. or 12 m.

From the C-MinBars sub-program and the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 12, the number of cutting patterns which give minimum waste is 3, percent waste of reinforcing steel is 2.15% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D24.

From the D-MinBars sub-program and the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 16, the number of cutting patterns which give minimum waste is 3, percent waste of reinforcing steel is 2.15% and time for calculation is 1 and 2 second, the details of cutting patterns are showed in Appendix Table D27.

For: Standard Length Selected: 10 m. only.

From the C-MinBars sub-program and the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 6, the number of cutting patterns which give minimum waste is 3, percent waste of reinforcing steel is 2.15% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D24.

From the D-MinBars sub-program and the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 9, the number of cutting patterns which give minimum waste is 3, percent waste of reinforcing steel is 2.15% and time for calculation is 1 and 2 second, the details of cutting patterns are showed in Appendix Table D24.

For: Standard Length Selected: 12 m. only.

From the C-MinBars sub-program and the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 9, the number of cutting patterns which give minimum waste is 5 and 4, percent waste of reinforcing steel is 6.76% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D25, 26.

From the D-MinBars sub-program and the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 10, the number of cutting patterns which give minimum waste is, percent waste of reinforcing steel is 2.10% and time for calculation is 1 and 2 second, the details are showed in Appendix Table 27, 28.

Example 4 This sample is from Chinanuwatwong's research. The data was brought from one construction project that has a good control. Percent waste of reinforcing steel in this construction project is equal to 6.8 %, as shown in Table 38.

Table 10 The data used for Example 4

Length No.	Length (m.)	Total
1	1.00	990
2	2.25	597
3	2.70	884

Table 10 (cont'd).

Length No.	Length (m.)	Total
4	3.30	768
5	4.35	687
6	5.80	109
7	6.50	77
8	6.75	136
9	7.60	250

Total number of length is 9.

From the MinBars program analysis, the results are separated into 3 types of selected standard length (10 m. or 12 m., 10 m. only and 12 m. only). Each type can give 4 results from 3 sub-programs. The comparisons of the results with other sub-program are showed in Table 11.

Table 11 Comparison of the results with other sub-program of Example 4

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
C-MinBars	10 or 12	45	11	0.40	9
	10	27	11	2.05	8
	12	38	11	0.41	8
ExcelTest by C-MinBars	10 or 12	47	12	0.40	4
	10	29	13	2.05	52
	12	40	N/A	N/A	N/A
D-MinBars	10 or 12	27	13	0.56	2
	10	21	11	2.05	2
	12	21	11	0.49	2

Table 11 (cont'd).

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
ExcelTest by D-MinBars	10 or 12	31	N/A	N/A	N/A
	10	29	11	2.05	18
	12	24	11	0.49	100

Note: N/A = Not Available

For: Standard Length Selected: 10 m. or 12 m.

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 45, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 0.40% and time for calculation is 9 second, the details of cutting patterns are showed in Appendix Table D29.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 47, the number of cutting patterns which give minimum waste is 12, percent wastes of reinforcing steel is 0.40% and time for calculation is 4 second, the details of cutting patterns are showed in Appendix Table D30.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 27, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 0.56% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D30.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 31. The other results are not available.

For: Standard Length Selected: 10 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 27, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 2.05% and time for calculation is 8 second, the details of cutting patterns are showed in Appendix Table D31.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 29, the number of cutting patterns which give minimum waste is 13, percent wastes of reinforcing steel is 2.05% and time for calculation is 52 second, the details of cutting patterns are showed in Appendix Table D32.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 21, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 2.05% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D31.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 29, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 2.05% and time for calculation is 18 second, the details of cutting patterns are showed in Appendix Table D33.

For: Standard Length Selected: 12 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 38, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 0.41% and time for calculation is 8 second, the details of cutting patterns are showed in Appendix Table D34

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 40. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 21, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 0.49% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D35.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 24, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 0.49% and time for calculation is 100 second, the details of cutting patterns are showed in Appendix Table D35.

Example 5 This sample is from Chinanuwatwong's research. The data was brought from one construction project. Percent waste of reinforcing steel in this construction project is equal to 12 % because this project did not have the cutting plan of reinforcing steel and was very strict for specification. The data are showed in Table 12.

Table 12 The data used for Example 5

Length No.	Length (m.)	Total
1	2.82	72
2	2.98	2
3	3.02	72
4	3.50	228
5	3.56	9
6	3.88	24
7	3.91	12
8	4.00	72
9	6.06	6
10	6.24	12
11	6.32	15
12	6.56	15
13	8.41	27
14	9.11	9
15	9.26	9
16	11.70	6
17	11.76	6
18	11.87	9

Total number of length is 18.

From the MinBars program analysis, the results are separated into 2 types of selected standard length (10 m. or 12 m., and 12 m. only). Each type can give 4 results from 3 sub-programs. The comparisons of the results with other sub-program are showed in Table 13.

Table 13 Comparison of the results with other sub-program of Example 5

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
C-MinBars	10 or 12	74	20	2.56	22
	12	56	20	9.84	18
ExcelTest by C-MinBars	10 or 12	77	N/A	N/A	N/A
	12	58	N/A	N/A	N/A
D-MinBars	10 or 12	43	19	4.61	5
	12	35	18	6.77	4
ExcelTest by D-MinBars	10 or 12	45	18	2.56	24
	12	37	19	6.77	4

Note: N/A = Not Available

For: Standard Length Selected: 10 m. or 12 m.

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 74, the number of cutting patterns which give minimum waste is 20, percent waste of reinforcing steel is 2.56% and time for calculation is 22 second, the details of cutting patterns are showed in Appendix Table D36.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 77. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 43, the number of cutting patterns which give minimum waste is 19, percent waste of reinforcing steel is 4.61% and time for calculation is 5 second, the details of cutting patterns are showed in Appendix Table D37.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 45, the number of cutting patterns which give minimum waste is 18, percent waste of reinforcing steel is 2.56% and time for calculation is 24 second, the details of cutting patterns are showed in Appendix Table D38.

For: Standard Length Selected: 12 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 56, the number of cutting patterns which give minimum waste is 20, percent waste of reinforcing steel is 9.84% and time for calculation is 18 second, the details of cutting patterns are showed in Appendix Table D39

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 58. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is equal to 35 patterns, the number of cutting patterns which give minimum waste is equal to 18 patterns, percent waste of reinforcing steel is 6.77% and time for calculation is 4 second, the details are showed in Appendix Table D40.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 37, the number of cutting patterns which give minimum waste is 19, percent waste of reinforcing steel is 6.77% and time for calculation is 4 second, the details of cutting patterns are showed in Appendix Table D41.

Example 6 This sample is from Chinanuwatwong's research. The data was brought from one construction project. Percent waste of reinforcing steel in this construction project is equal to 15 %, the data are showed in Table 14.

Table 14 The data used for Example 6

Length No.	Length (m.)	Total
1	1.24	720
2	2.99	602
3	3.00	64
4	3.25	560
5	3.30	220
6	3.35	268
7	3.36	320
8	3.43	156
9	4.05	220
10	4.30	776

Total number of length is 10.

From the MinBars program analysis, the results are separated into 3 types of selected standard length (10 m. or 12 m., 10 m. only and 12 m. only). Each type can give 4 results from 3 sub-programs. The comparisons of the results with other sub-program are showed in Table 15.

Table 15 Comparison of the results with other sub-program of Example 6

DESCRIPTION	Standard length (m.)	No. of Possible Cutting Patterns	No. of Patterns	Percent Waste (%)	Time (sec.)
C-MinBars	10 or 12	44	13	0.35	12
	10	48	11	2.90	11
	12	52	13	1.37	11
ExcelTest by C-MinBars	10 or 12	47	N/A	N/A	N/A
	10	49	23	2.90	9
	12	55	N/A	N/A	N/A
D-MinBars	10 or 12	23	12	0.60	3
	10	23	11	2.90	2
	12	23	12	1.00	2
ExcelTest by D-MinBars	10 or 12	25	12	0.60	4
	10	24	13	3.05	100
	12	24	13	1.00	100

Note: N/A = Not Available

For: Standard Length Selected: 10 m. or 12 m.

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 44, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 0.35% and time for calculation is 12 second, the details of cutting patterns are showed in Appendix Table D42.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 47. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 23, the number of cutting patterns which give minimum waste is 12, percent waste of reinforcing steel is 0.60% and time for calculation is 3 second, the details of cutting patterns are showed in Appendix Table D43.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 25, the number of cutting patterns which give minimum waste is 12, percent waste of reinforcing steel is 0.60% and time for calculation is 4 second, the details of cutting patterns are showed in Appendix Table D43.

For: Standard Length Selected: 10 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 48, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 2.90% and time for calculation is 11 second, the details of cutting patterns are showed in Appendix Table D44.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 49, the number of cutting patterns which give minimum waste is 23, percent wastes of reinforcing steel is 2.90% and time for calculation is 9 second, the details of cutting patterns are showed in Appendix Table D45.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 23, the number of cutting patterns which give minimum waste is 11, percent waste of reinforcing steel is 2.90% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D46.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 24, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 3.05% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D47.

For: Standard Length Selected: 12 m. only

From the C-MinBars sub-program, the result of the number of possible cutting patterns is 52, the number of cutting patterns which give minimum waste is 13, percent waste of reinforcing steel is 1.37% and time for calculation is 11 second, the details of cutting patterns are showed in Appendix Table D48.

From the ExcelTest sub-program (use the possible cutting patterns from the C-MinBars sub-program), the result of the number of possible cutting patterns is 55. The other results are not available.

From the D-MinBars sub-program, the result of the number of possible cutting patterns is 23, the number of cutting patterns which give minimum waste is 12, percent waste of reinforcing steel is 1.00% and time for calculation is 2 second, the details of cutting patterns are showed in Appendix Table D49.

From the ExcelTest sub-program (use the possible cutting patterns from the D-MinBars sub-program), the result of the number of possible cutting patterns is 24, the number of cutting patterns which give minimum waste 13, percent waste of reinforcing steel is 1.00% and time for calculation is 100 second, the details of cutting patterns are showed in Appendix Table D50.

CONCLUSION

From the case study of “Application Program for Minimum Loss of reinforcing steel”, it is conclusive that the MinBars program can be used as a means to analyze the cutting patterns in order to decrease the waste of reinforcing steel cutting in reinforced concrete work. The MinBars program is divided in to 3 sub-programs.

1. The C-MinBars sub-program is upgraded from RSCP program. Both programs used the Combination theory to find possible cutting patterns. Sometimes the result of C-MinBars sub-program is a little difference with the result of RSCP program because it used the First Fit Decreasing with Local Search method for improving the result.

2. The D-MinBars sub-program is to find the possible cutting patterns by the Delayed Column Generation Method. In case of two standard lengths, if the reduced cost of both standard lengths is equal, the program could select only one pattern to calculate and cannot confirm that the result is better.

3. The ExcelTest sub-program uses the possible cutting patterns from The C-MinBars sub-program or The D-MinBars sub-program and find the result by integer programming in MS Excel Solver. The ExcelTest sub-program cannot solve the problem if the number of possible cutting patterns is too many.

From the example, the cutting patterns of the D-MinBars sub-program seems to be better than the C-minBars sub-program if single standard length is used. Conversely, the cutting patterns of the C-MinBars sub-program will be more effective if two standard lengths and a great deal of required length are used. The result of the ExcelTest sub-program will be a bit more effective than the other two sub-programs mentioned above.

From the study, it can be concluded that using sub-program of delayed column generation theory takes shorter time than combination theory to get the result because the sub-program of delayed column generation theory used less possible cutting patterns than the sub-program of combination theory and using the revised simplex method to solve the problem is faster than simplex method.

Although the result of the MinBars program is good, this depends on the certain aspect of information analyzed because the Linear Programming can select the best cutting patterns which is only equal to the number of required length.

RECOMMENDATIONS

Recommendation for Future study

1. To generate the cutting list from construction drawing or link the program with Auto-Cad.

2. The Linear Programming is not the best selective way for cutting patterns. The result of the number of the cutting patterns might be more than the required length with other methods.

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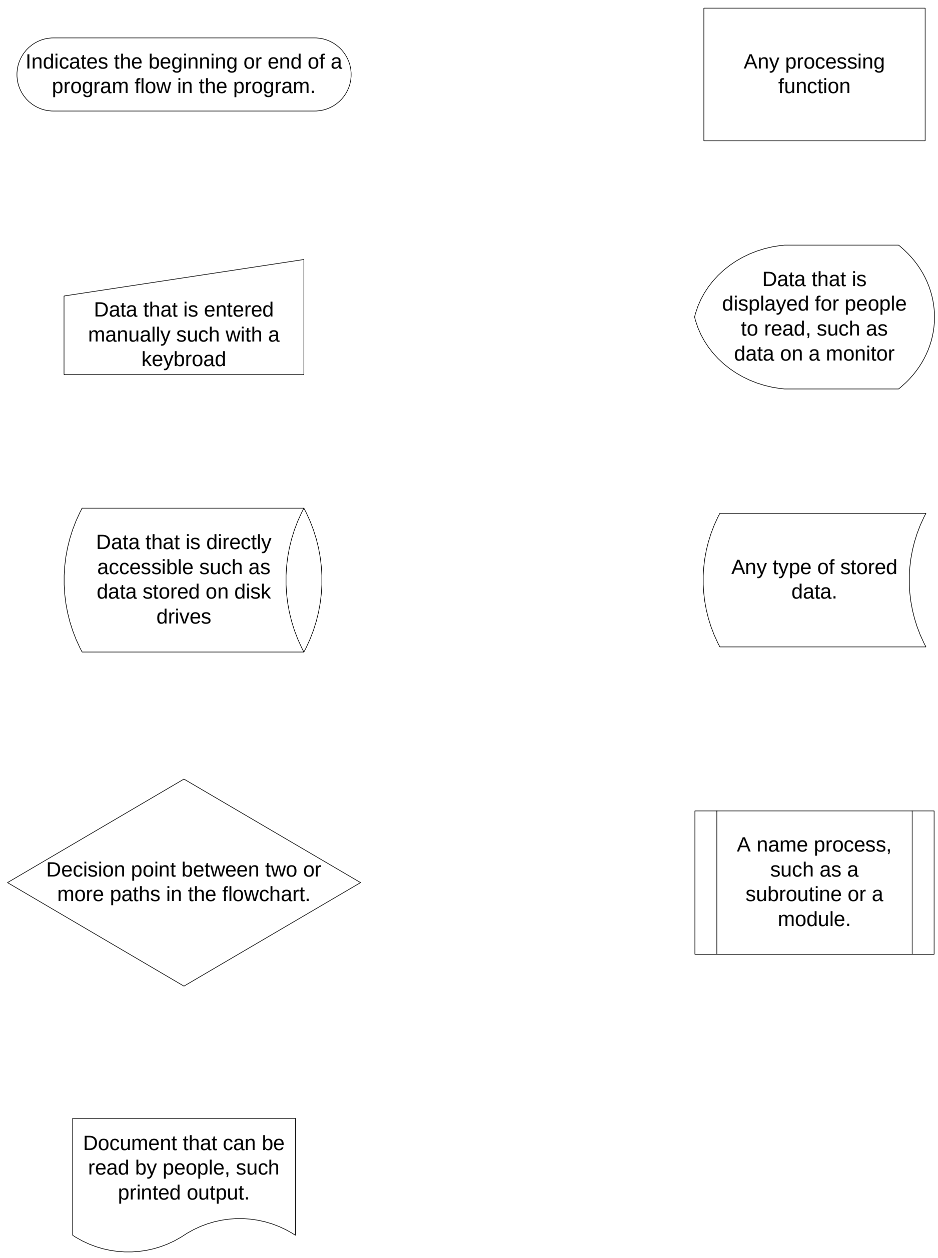
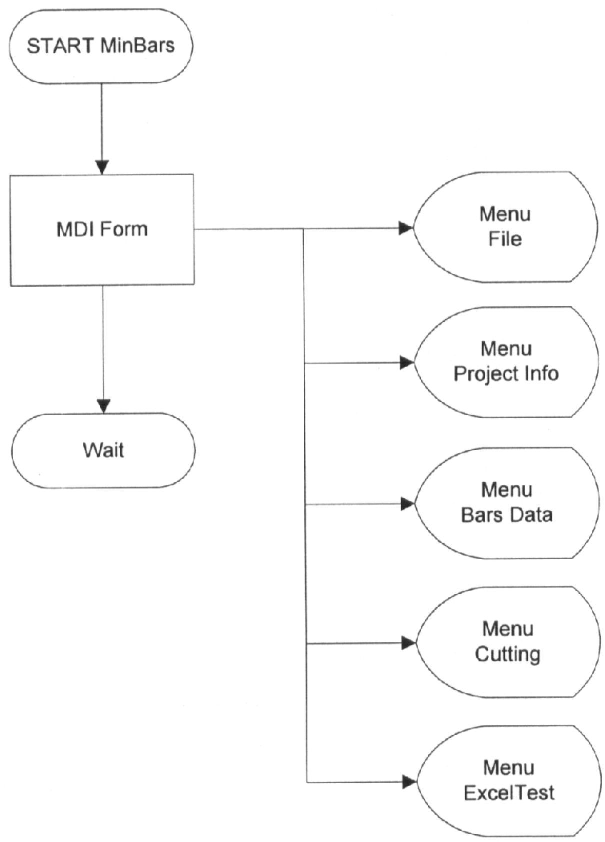
Appendix A

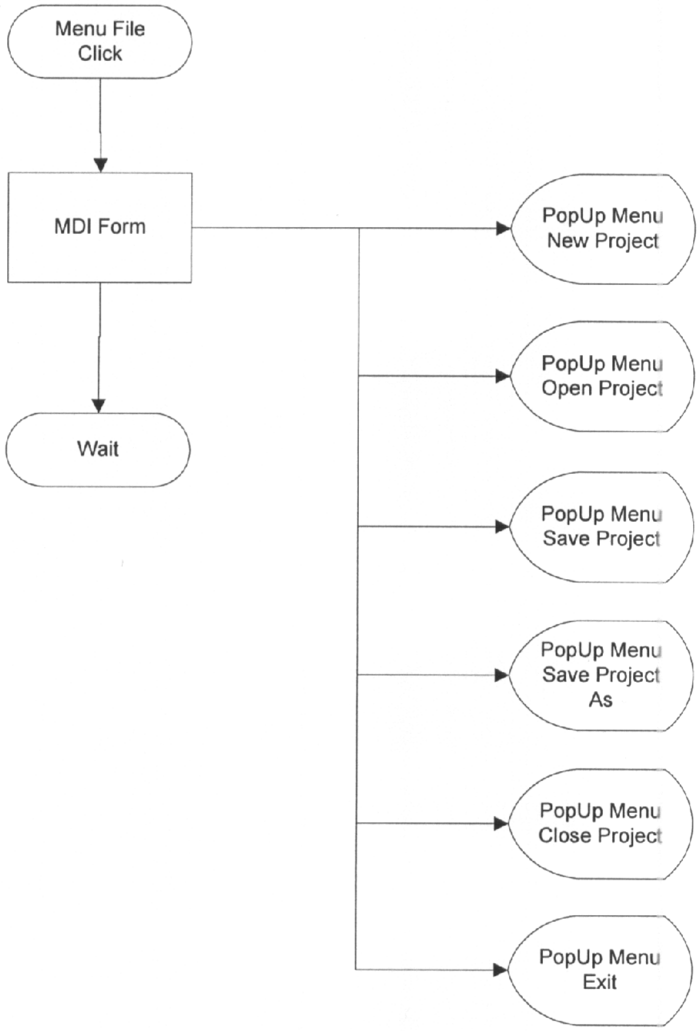
System Flow



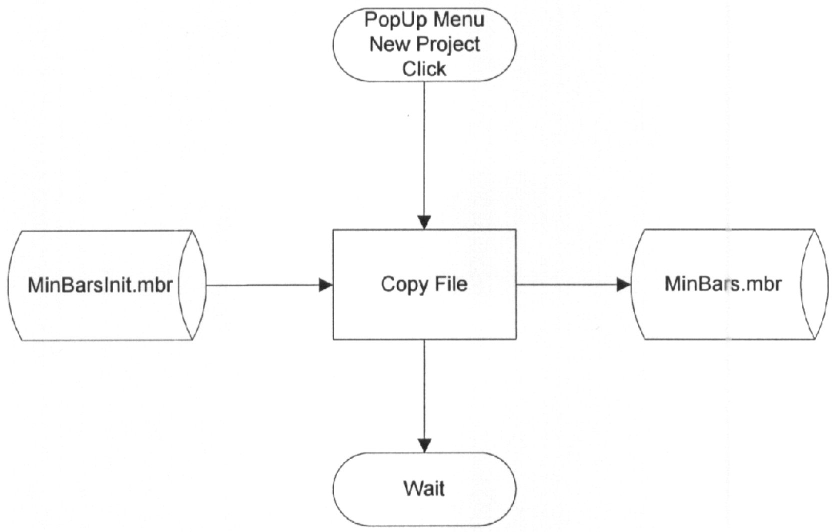
Appendix Figure A1 Sign Conventions of System Flow



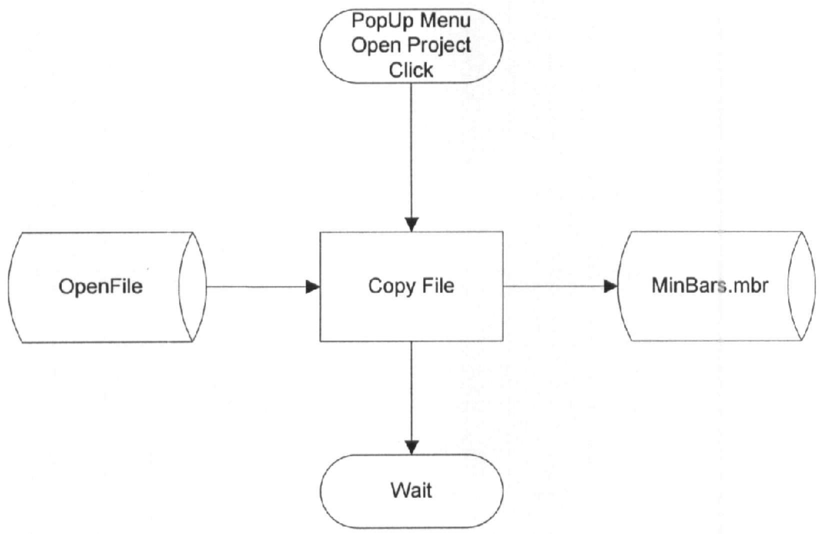
Appendix Figure A2 System Flow Start the MinBars Program



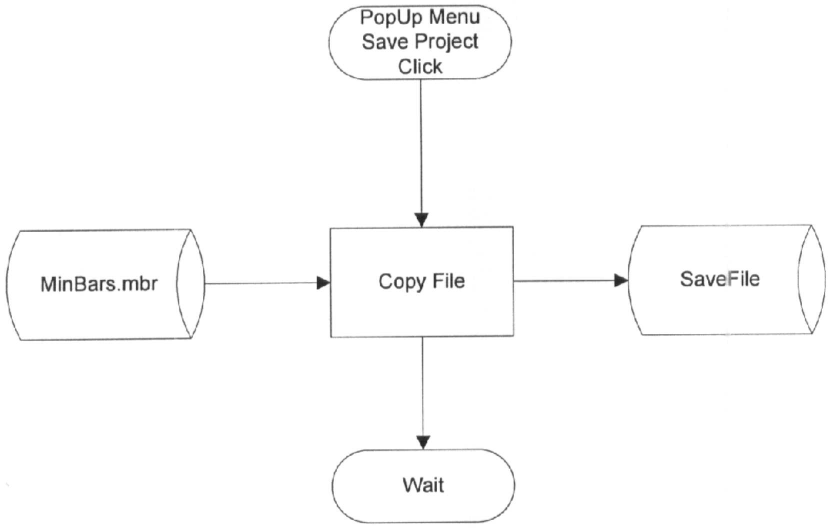
Appendix Figure A3 Menu File Click Event



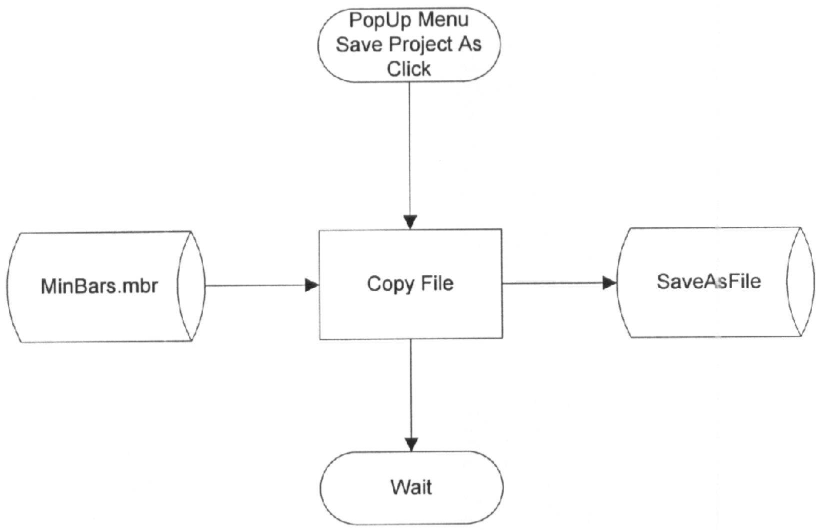
Appendix Figure A4 Pop Up Menu New Project Click Event



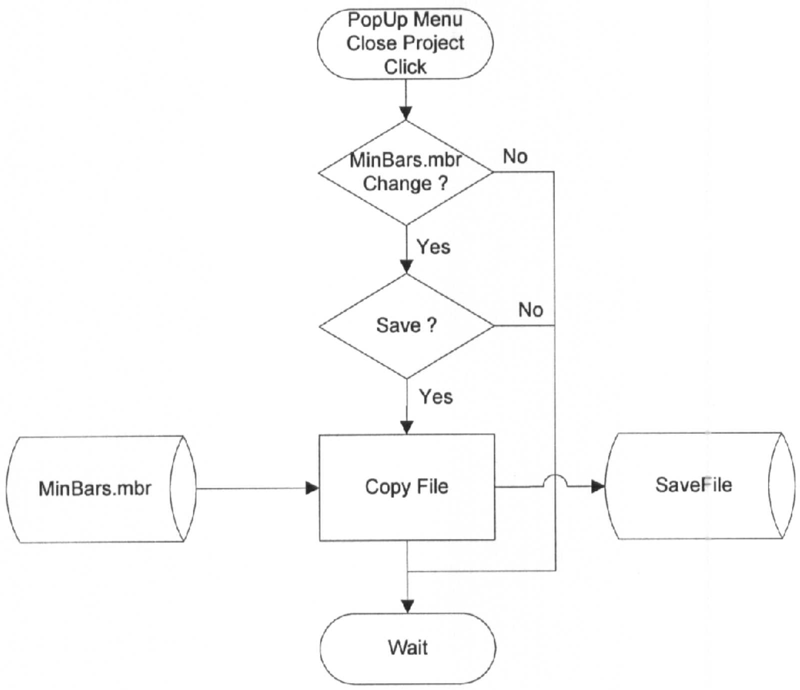
Appendix Figure A5 Pop Up Menu Open Project Click Event



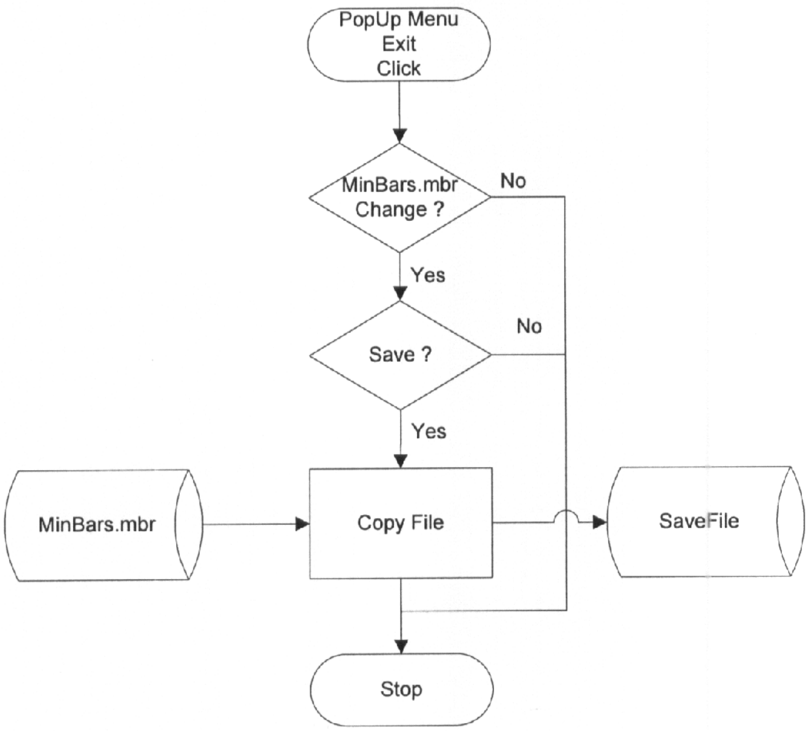
Appendix Figure A6 Pop Up Menu Save Project Click Event



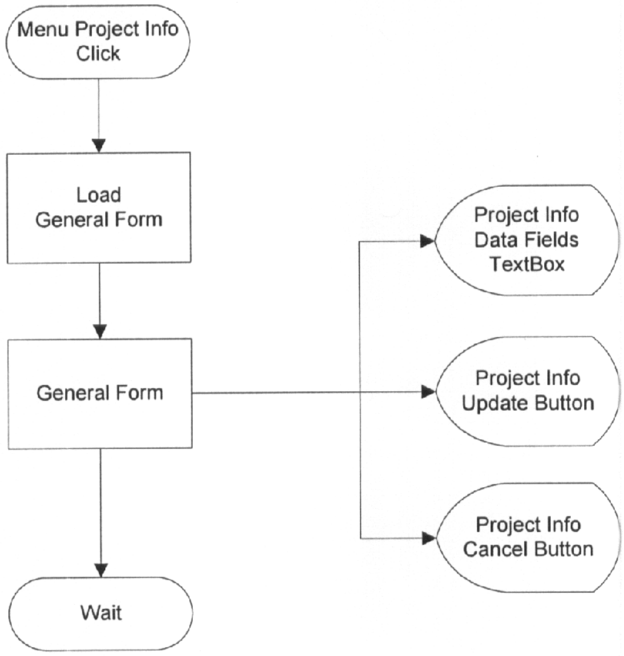
Appendix Figure A7 Pop Up Menu Save Project As Click Event



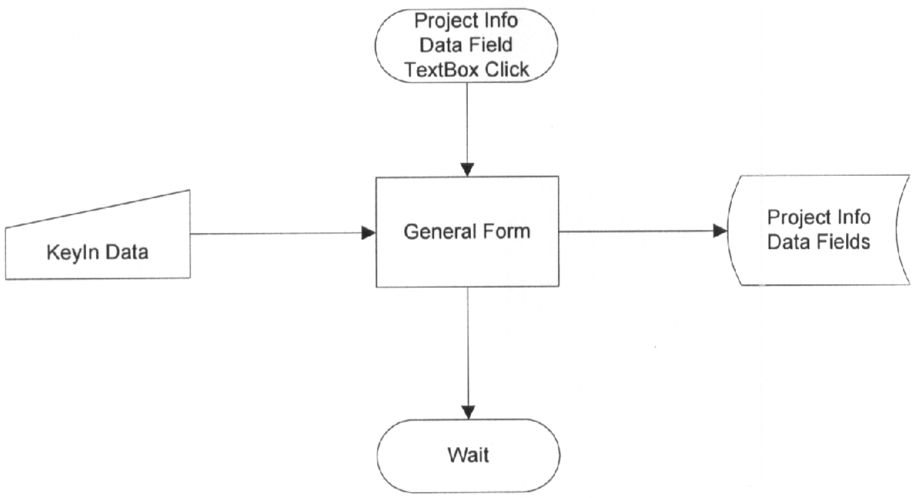
Appendix Figure A8 Pop Up Menu Close Project Click Event



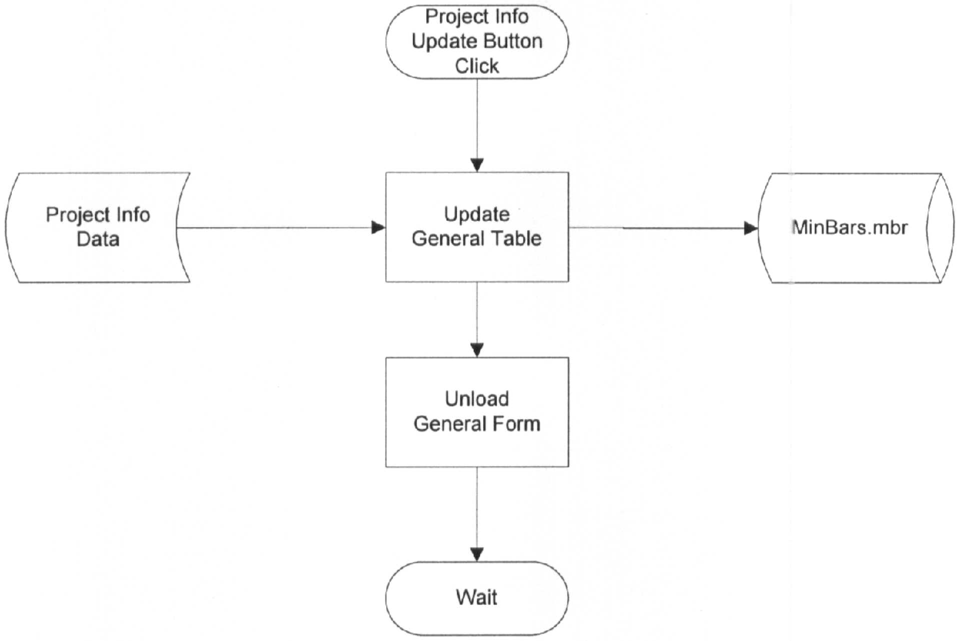
Appendix Figure A9 Pop Up Menu Exit Click Event



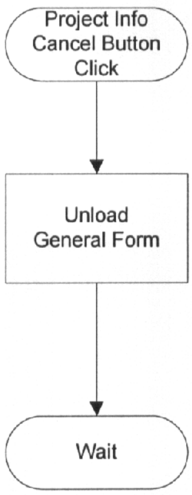
Appendix Figure A10 Menu Project Info Click Event



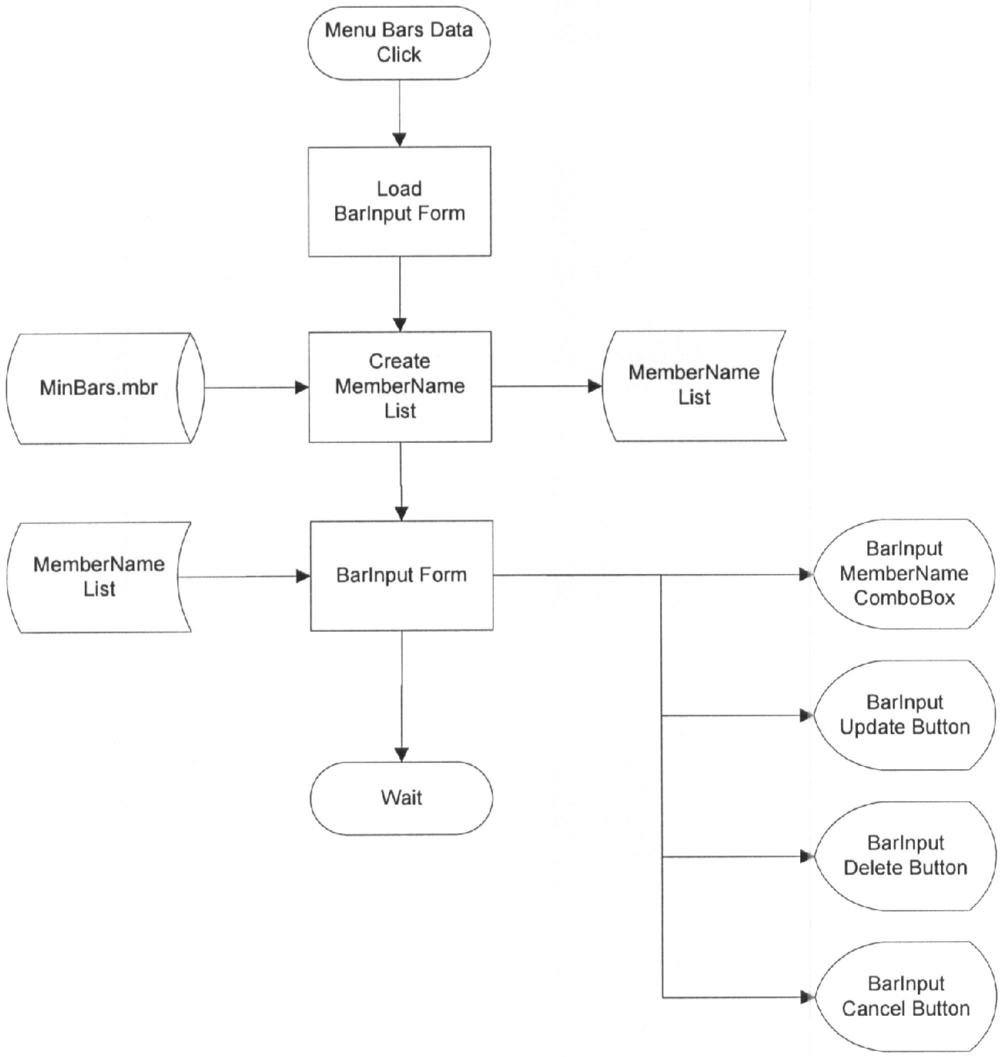
Appendix Figure A11 Menu Project Info Data Field TextBox Click Event



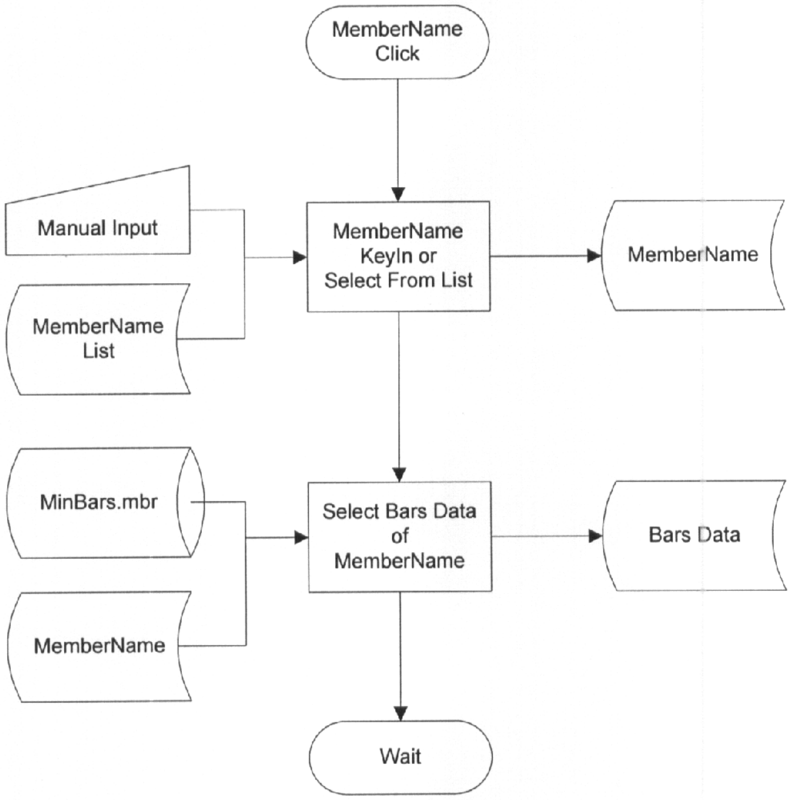
Appendix Figure A12 Menu Project Info Update Button Click Event



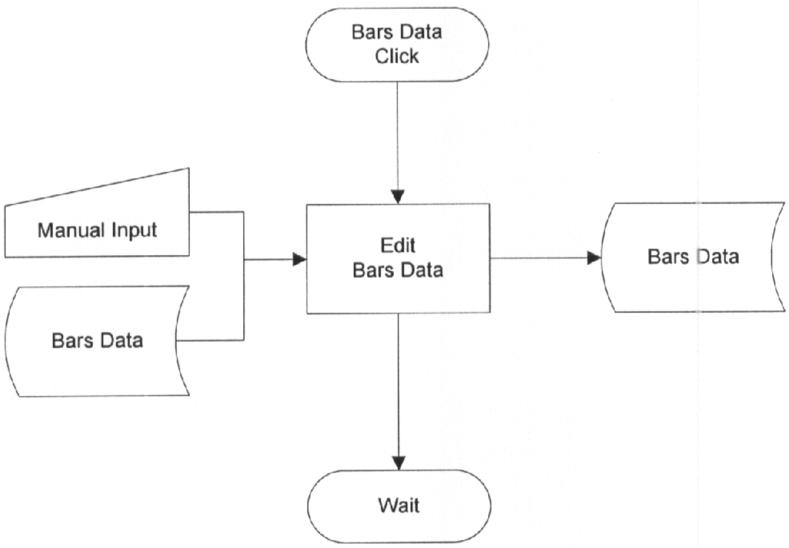
Appendix Figure A13 Menu Project Info Cancel Button Click Event



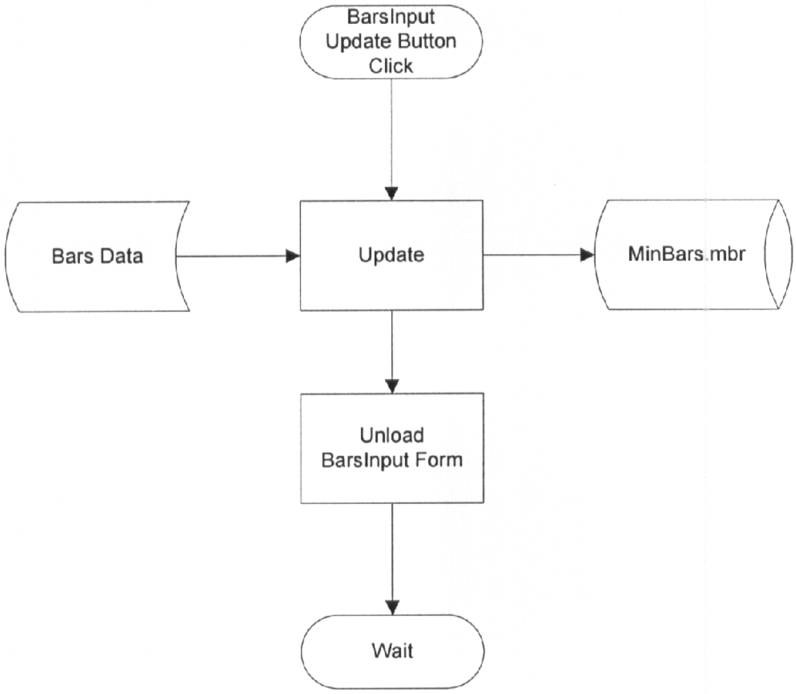
Appendix Figure A14 Menu Bars Data Click Event



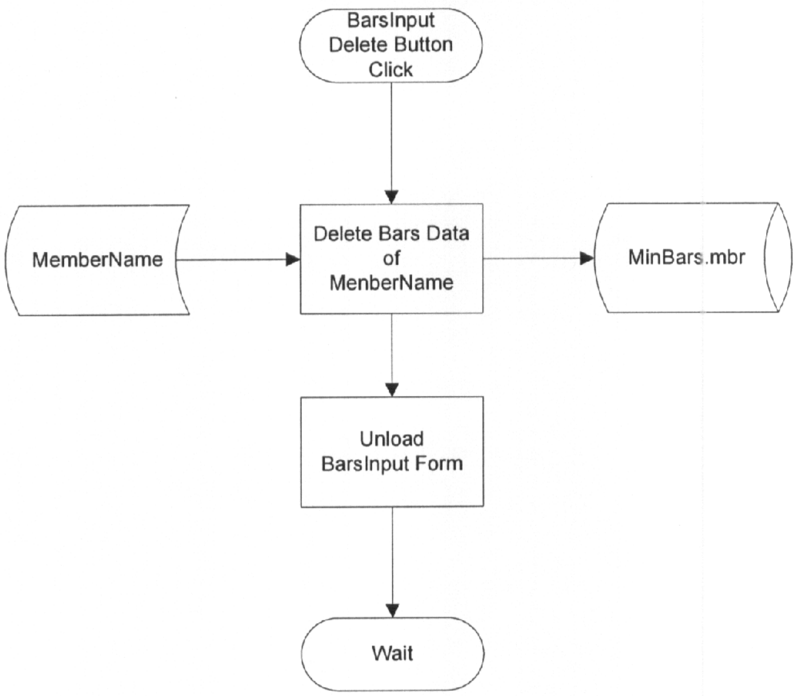
Appendix Figure A15 Member Name Click Event



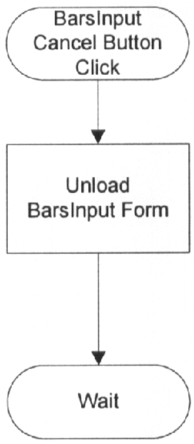
Appendix Figure A16 Bars Data Click Event



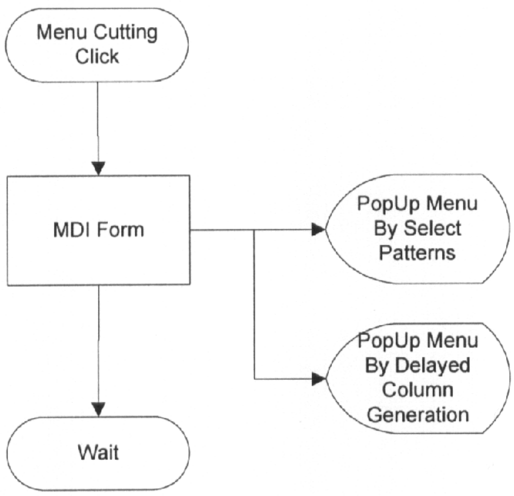
Appendix Figure A17 Bars Input Update Button Click Event



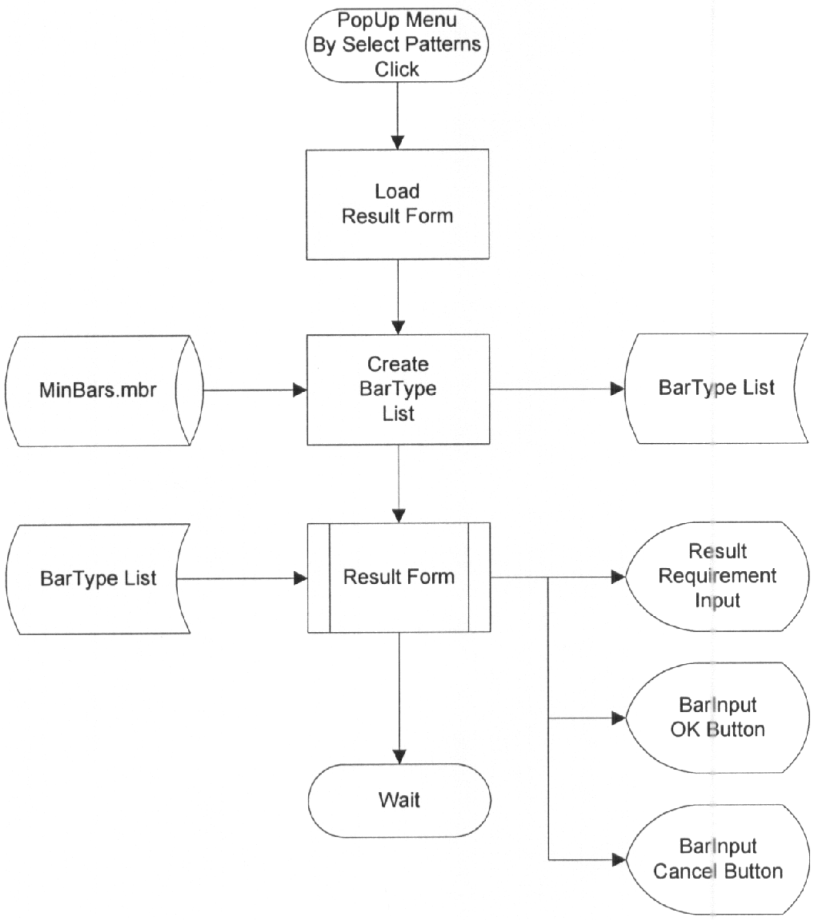
Appendix Figure A18 Bars Input Delete Button Click Event



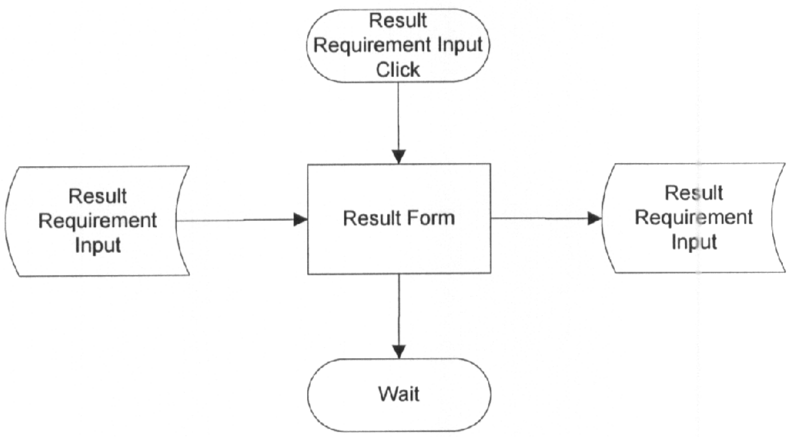
Appendix Figure A19 Bars Input Cancel Button Click Event



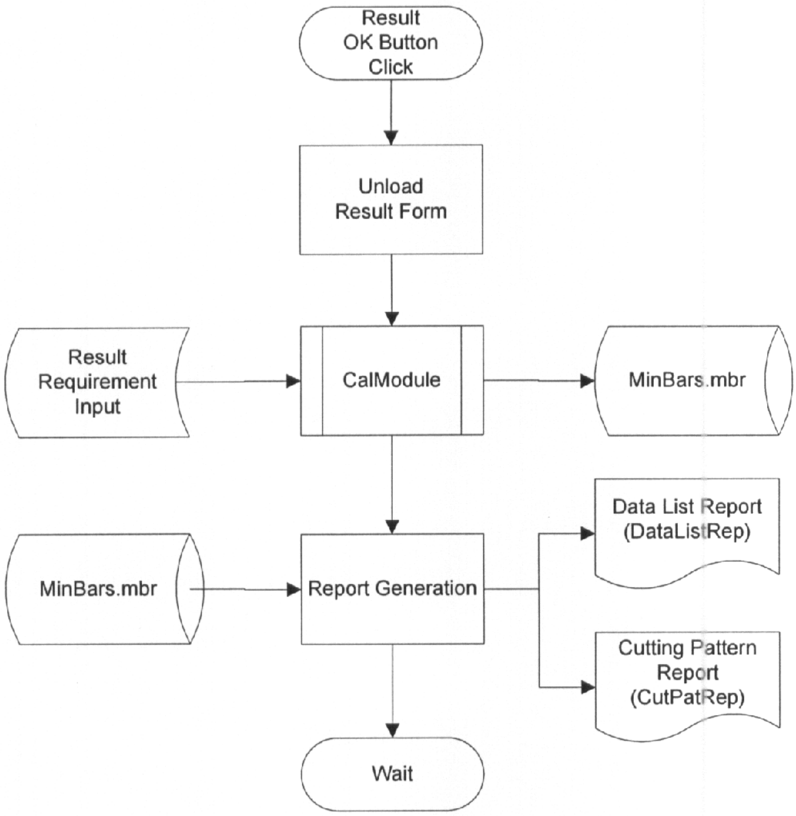
Appendix Figure A20 Menu Cutting Click Event



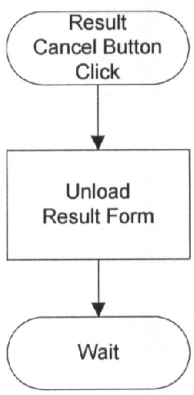
Appendix Figure A21 Pop Up menu By Select Patterns Click Event



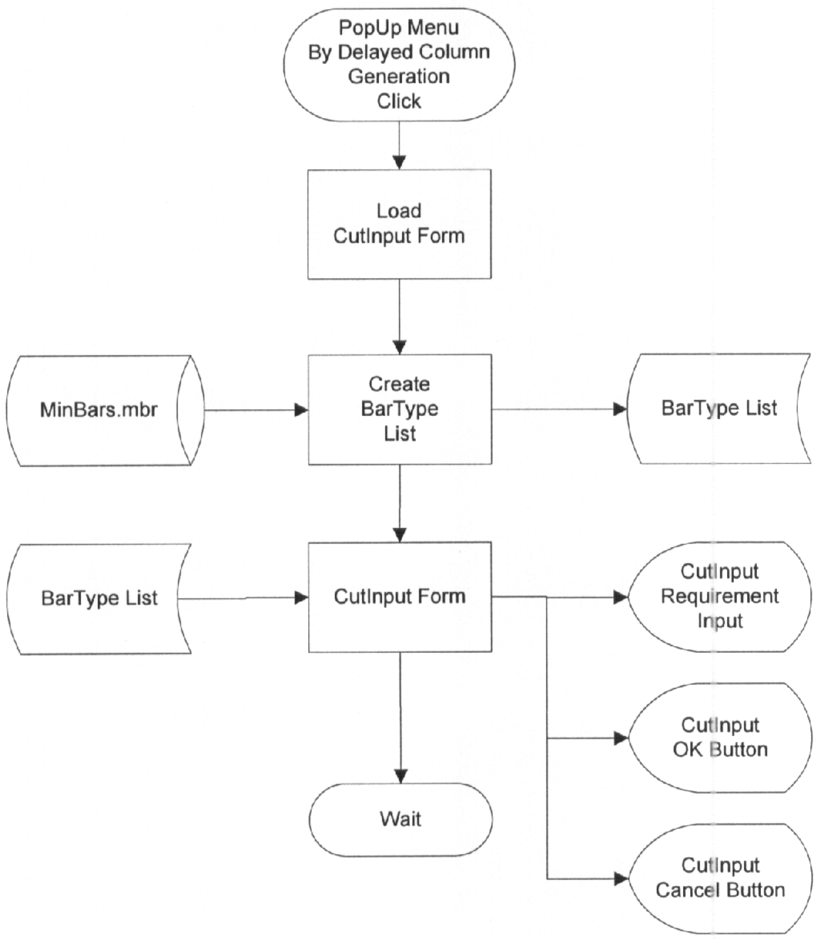
Appendix Figure A22 Result Requirement Input Click Event



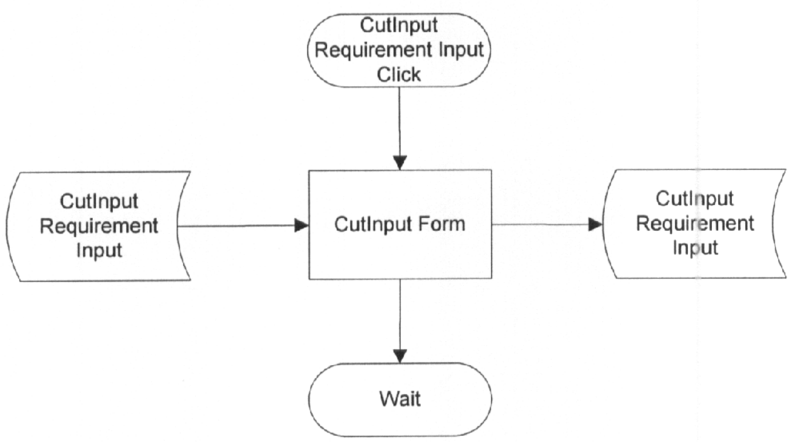
Appendix Figure A23 Result OK Button Click Event



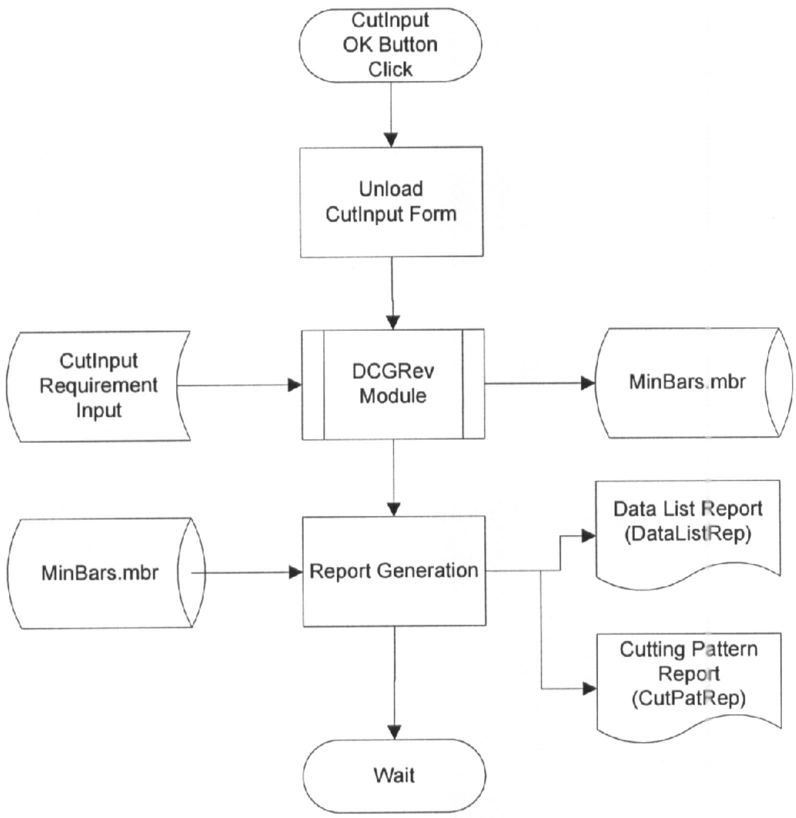
Appendix Figure A24 Result Cancel Button Click Event



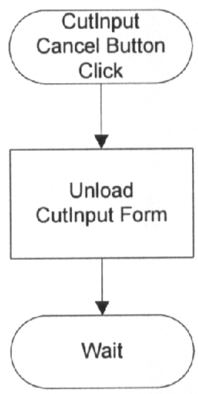
Appendix Figure A25 Pop Up menu By Delayed Column Generation Click Event



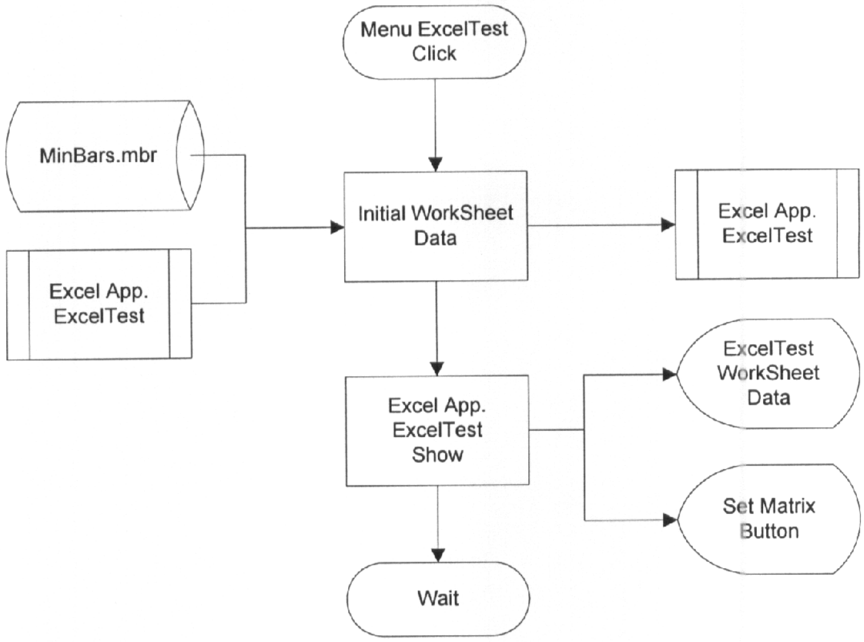
Appendix Figure A26 Cut Input Requirement Input Click Event



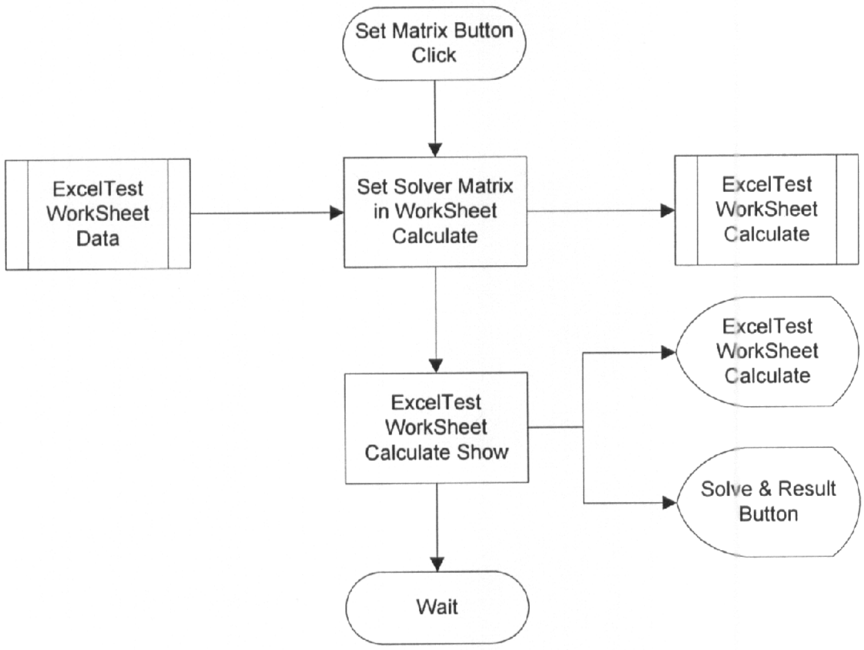
Appendix Figure A27 Cut Input OK Button Click Event



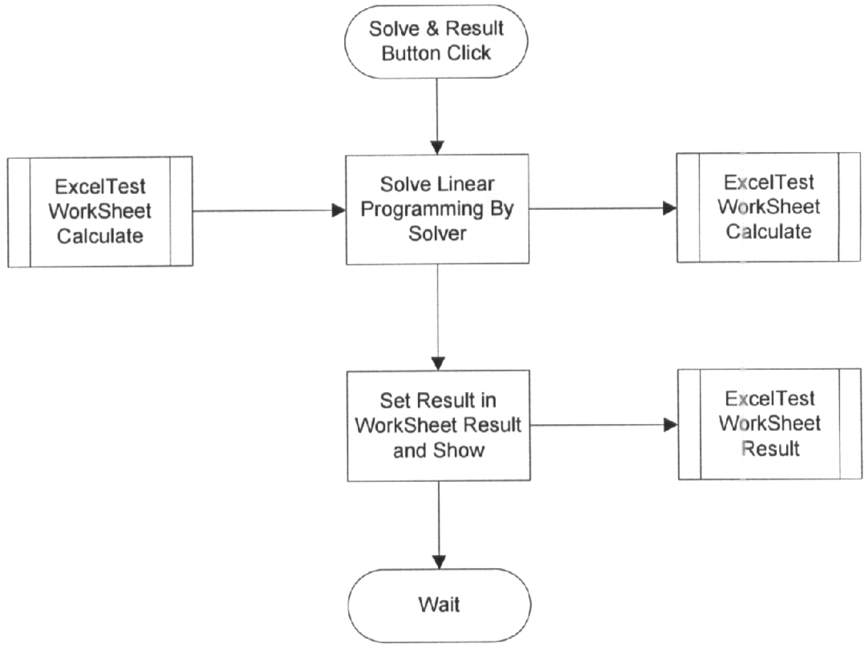
Appendix Figure A28 Cut Input Cancel Button Click Event



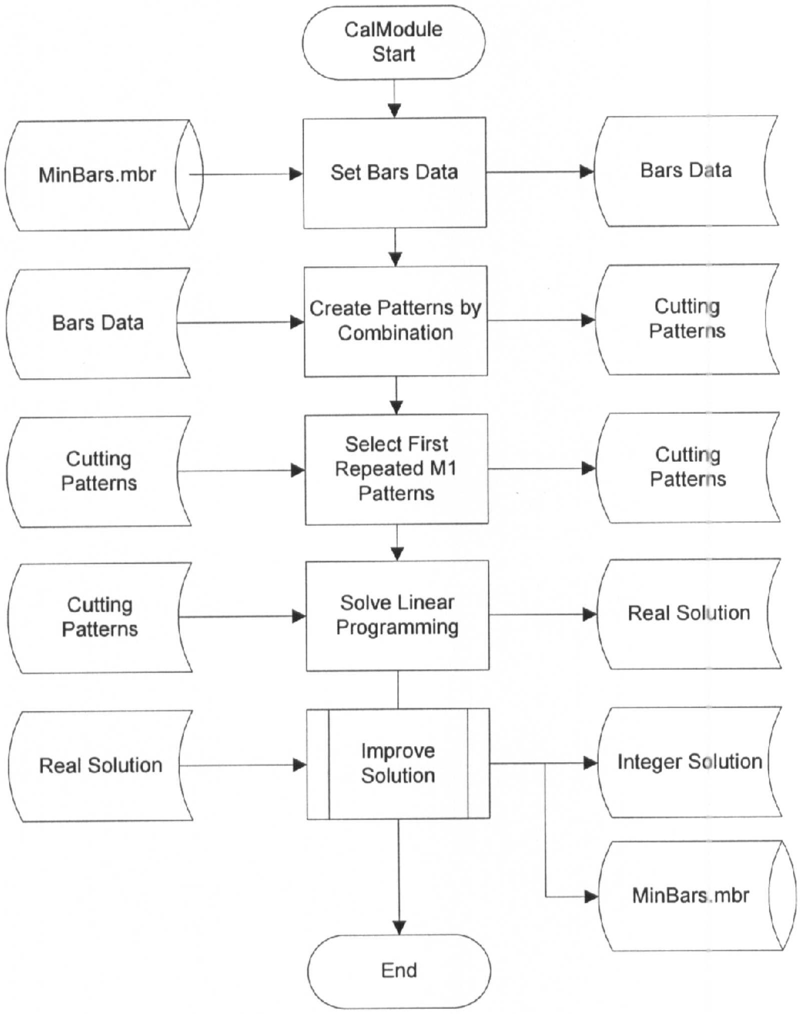
Appendix Figure A29 Menu Excel Test Click Event



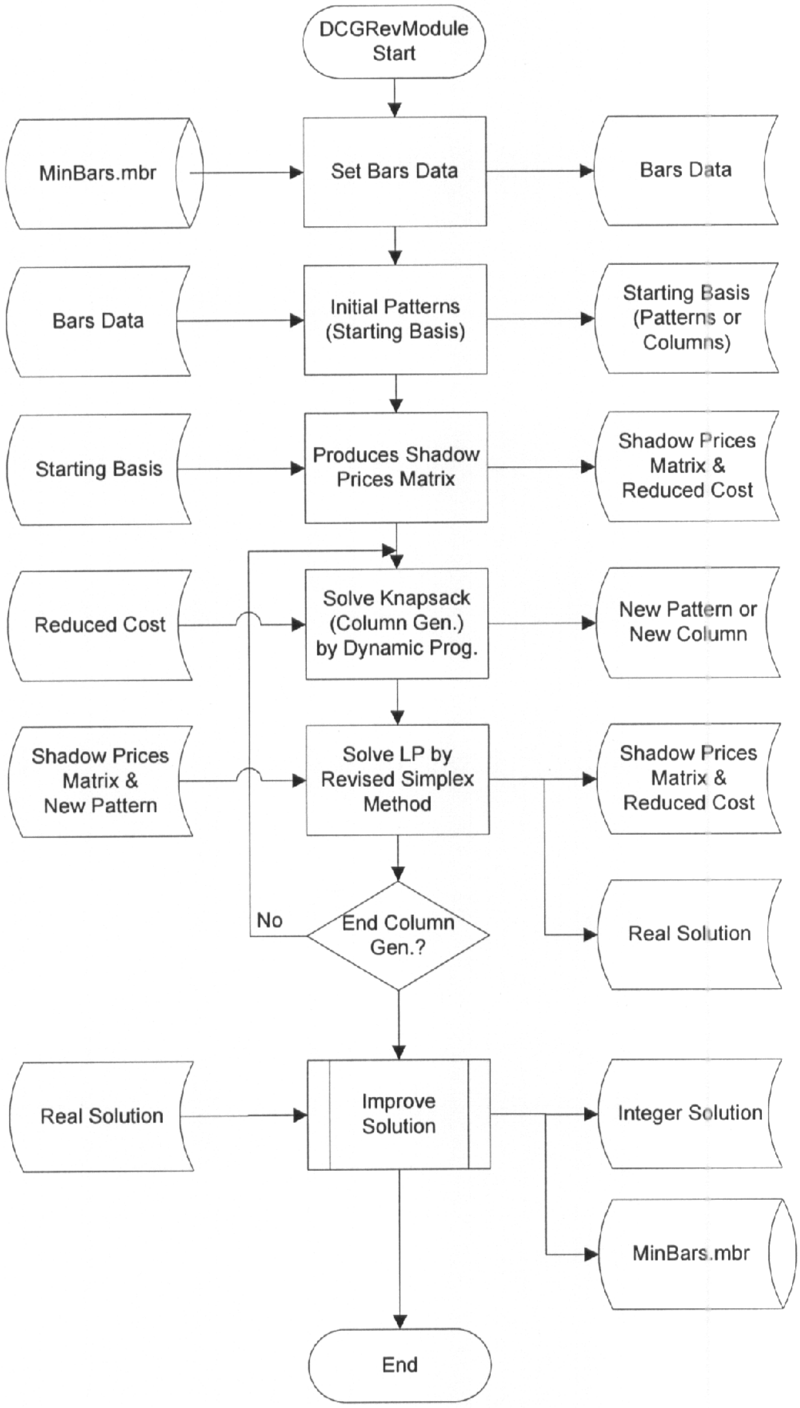
Appendix Figure A30 Set Matrix Button Click Event



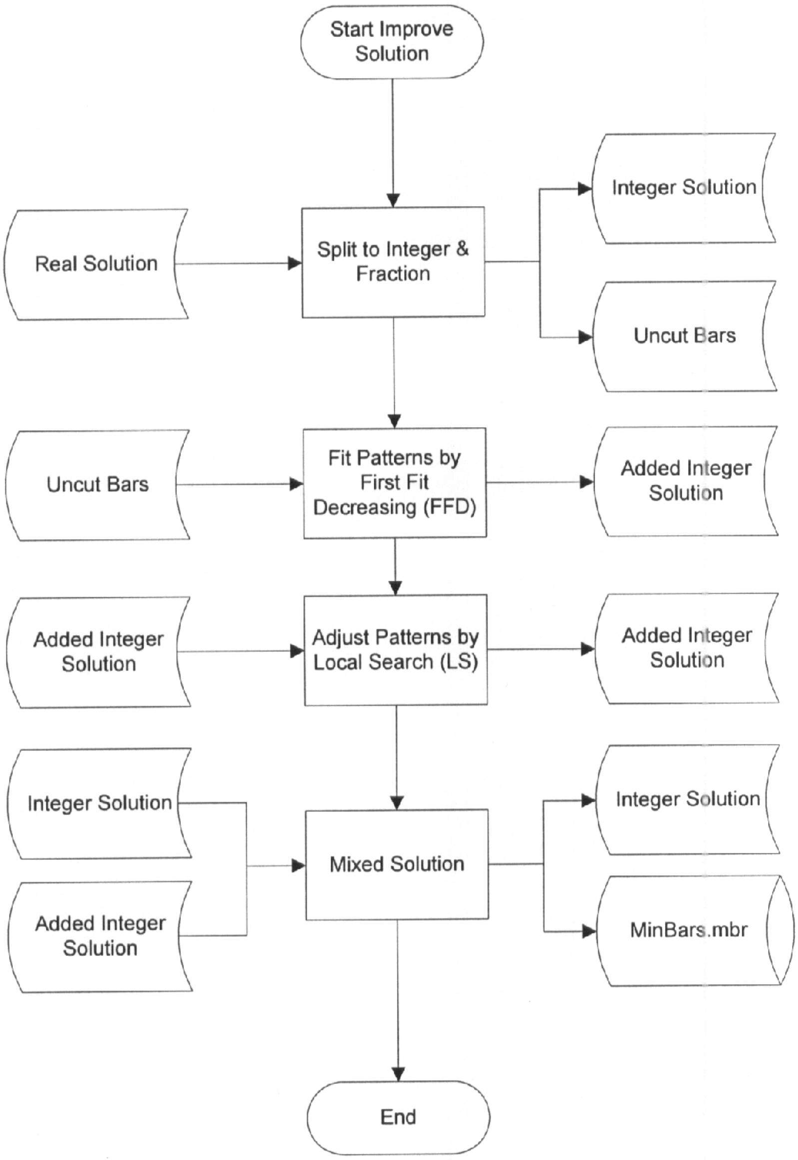
Appendix Figure A31 Solve & Result Button Click Event



Appendix Figure A32 System Flow CalModule



Appendix Figure A33 System Flow Chart DCGRevModule



Appendix Figure A34 System Flow Chart Improve Solution

Appendix B

User's Guide

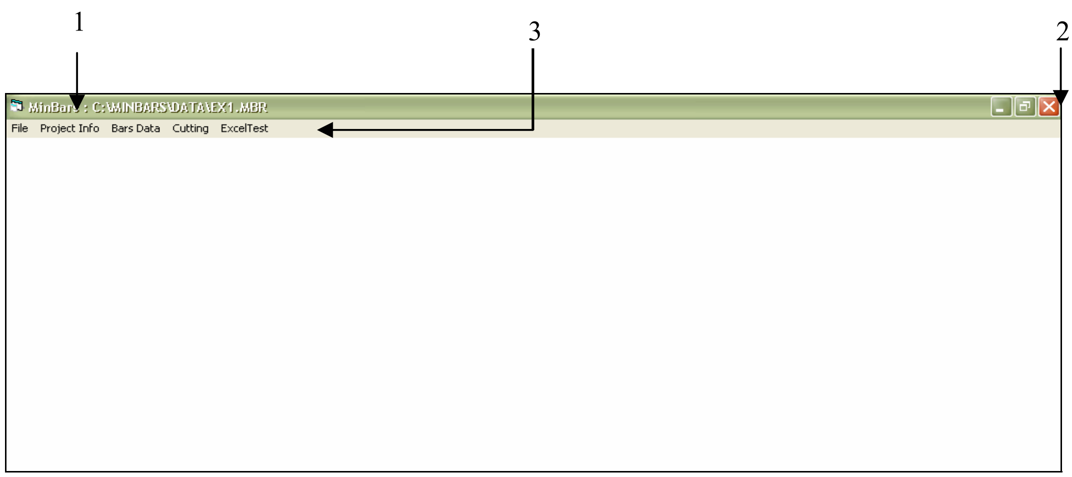
USER'S GUIDE

Starting the MinBars program

When you copy the MinBars folder to drive C, you are then ready to start MinBars program from Windows.

The MinBars program environment

The MinBars program interface consists of 3 parts of following element, as shown in Appendix Figure B1.



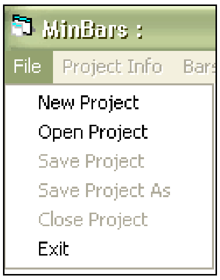
Appendix Figure B1 The MinBars Program Environment

Part 1 is called Title Bar. The duties of this part are to show the application program's name and the running file's name.

Part 2 is called Control Menu of Windows Operating System used to control windows of the program.

Part 3 is called Menu Commands used for showing the many commands of MinBars program. It has 5 menus in which each menu has many commands to use the MinBars program.

1. Menu File, as shown in Figure B2.

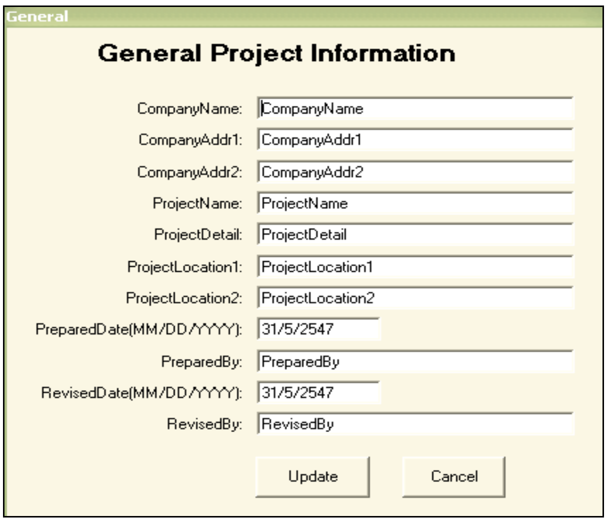


Appendix Figure B2 Show Menu File

Menu File consists of

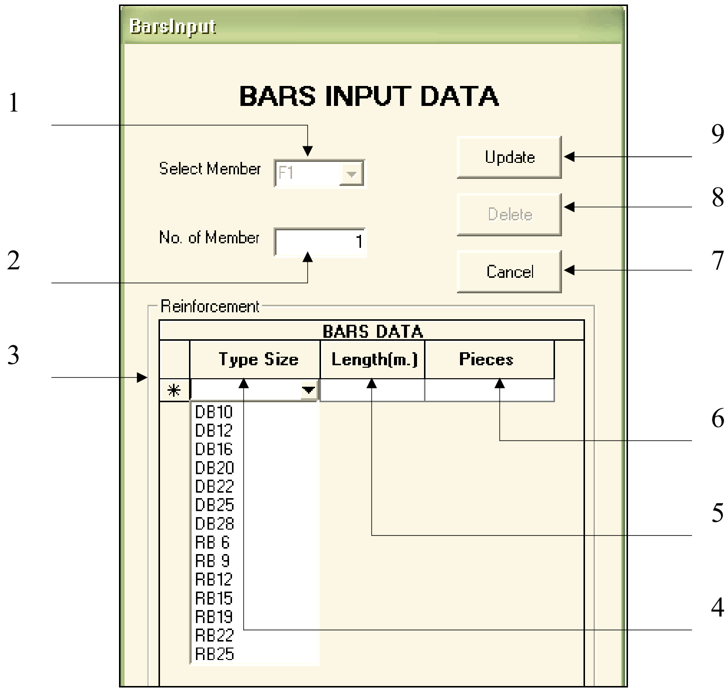
- New Project: The duty is to start new project.
- Open Project: The duty is to open old project.
- Save Project: The duty is to save the current project.
- Save Project As: The duty is to save the current project to new project's name.
- Exit: The duty is to exit MinBars program.

2. Menu Project Info; when you click on this menu, the program will show the General Project Information window, as shown in Appendix Figure B3.



Appendix Figure B3 General Project Information Window

3. Menu Bar Data; when you click on this menu, the program will show Bars Input Data window in order to input the many data to run the program, as shown in Appendix Figure B4.



Appendix Figure B4 Bars Input Data Window

Part 1 is the Select Member list box which is used for inputting the new member's name and showing old member's name.

Part 2 is the No. of Member text box which is used for inputting the number of member.

Part 3 is (*) Button; when click the button, the program will add new row in the table.

Part 4 is the Type Size list box action by choosing type of bar in list box.

Part 5 is the Length fill table which is used for inputting the bar length and the data in this fill not more than 12.

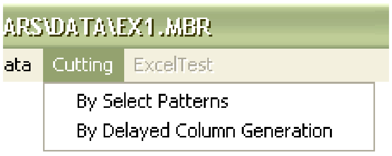
Part 6 is the Pieces fill table which is used for inputting the number of bar and the data in this fill as integer.

Part 7 is the Cancel button; when click the button, the data will be canceled.

Part 8 is the Delete button; when click the button, all of data in the current member will be deleted from database.

Part 9 is the Update button; when click the button, the program will keep the data in the database.

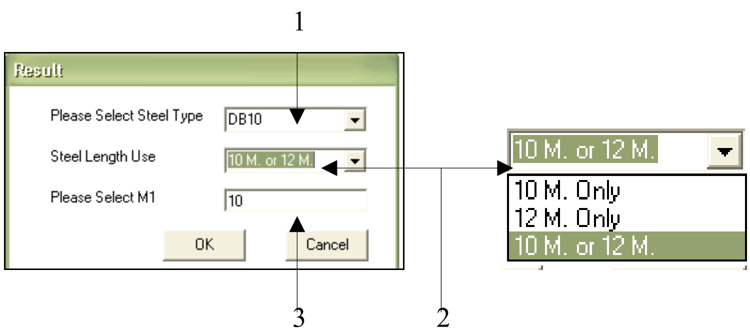
4. Menu Cutting, as shown in Appendix Figure B5.



Appendix Figure B5 Cutting Menu

Menu Cutting consists of

- By Select Patterns: The duty is to call the C-Minbars sub program, when click the program will show the calculate window, as shown in Appendix Figure B6.



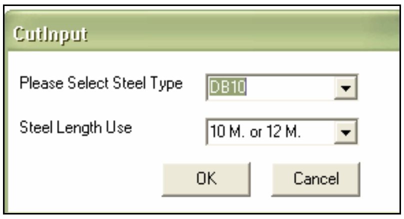
Appendix Figure B6 Cutting Window for C-MinBars

Part 1 is the Select Steel Type list box which is used for selecting the steel type for calculates.

Part 2 is the Steel Length Use list box which is used for choosing the stock length follow standard length.

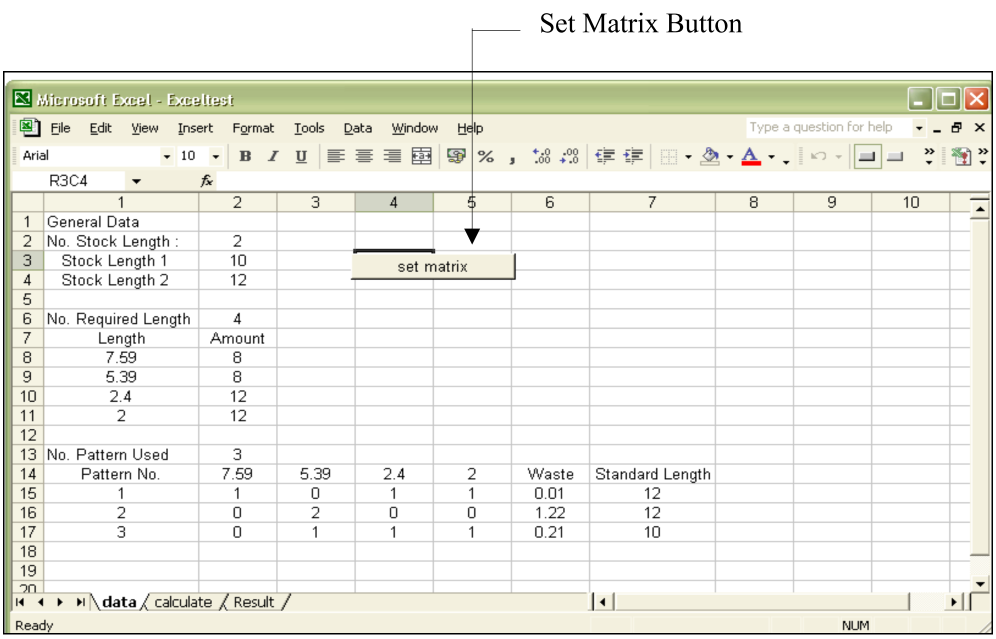
Part3 is the select M1 which is used for changing the number of patterns from combination theory.

- By Delayed Column Generation: The duty is to call the D-Minbars sub program, when click the program it will show the calculate window, as shown in Appendix Figure B7.



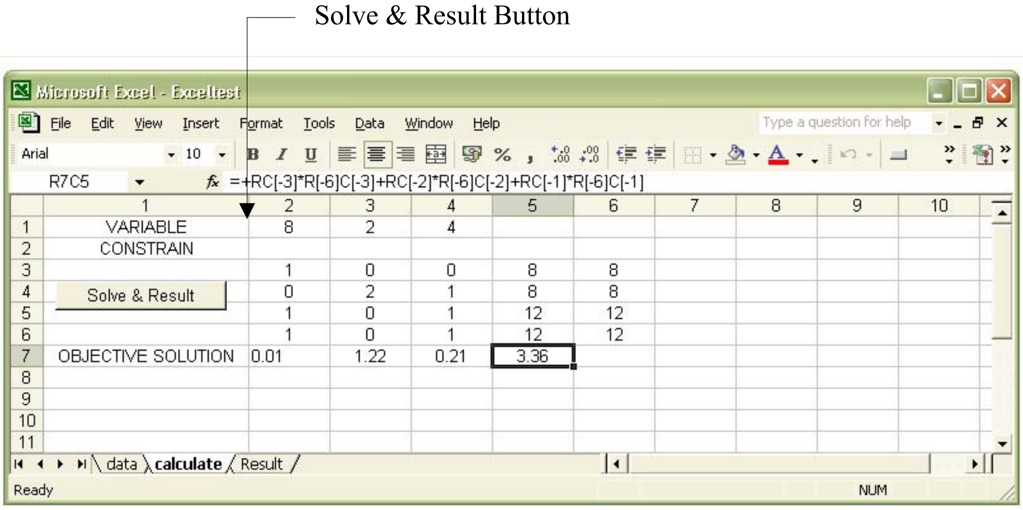
Appendix Figure B7 Cutting Window for D-MinBars

5. Menu Excel Test; when click this menu the program will called file "Exceltest.xls" from MinBars. The "data" worksheet data was sent from The C-MinBars or the D-MinBars, therefore user must run one of both sub-programs already, as shown in Appendix Figure B8.



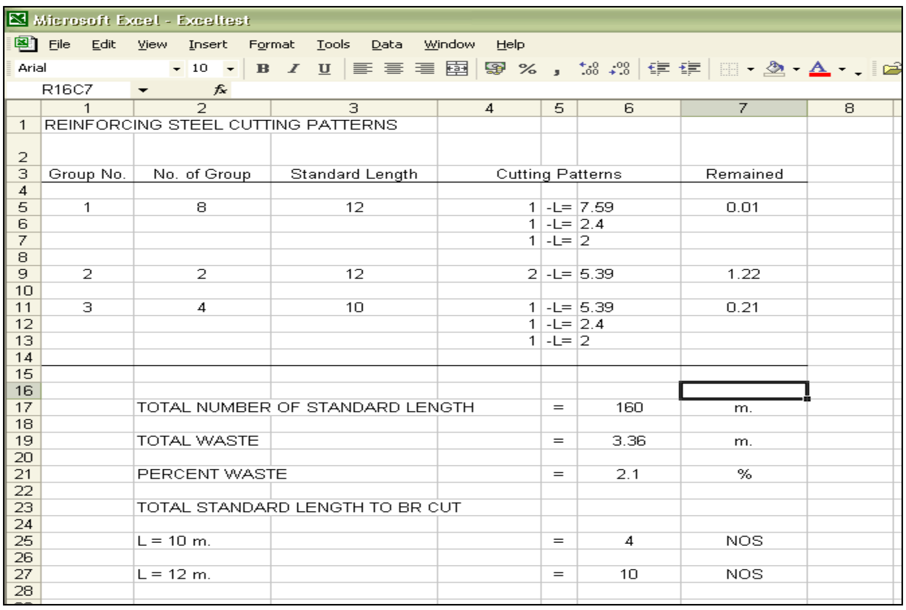
Appendix Figure B8 "data" Worksheet

Set Matrix button is used for setting the possible cutting pattern in "data" worksheet to matrix form in "calculate" worksheet, as shown in Appendix Figure B9.



Appendix Figure B9 "calculate" Worksheet

Solve & Result button is used for solving the matrix by Integer Linear Programming, the result, as show in Appendix Figure B10.



Appendix Figure B10 "Result" Worksheet

Appendix C

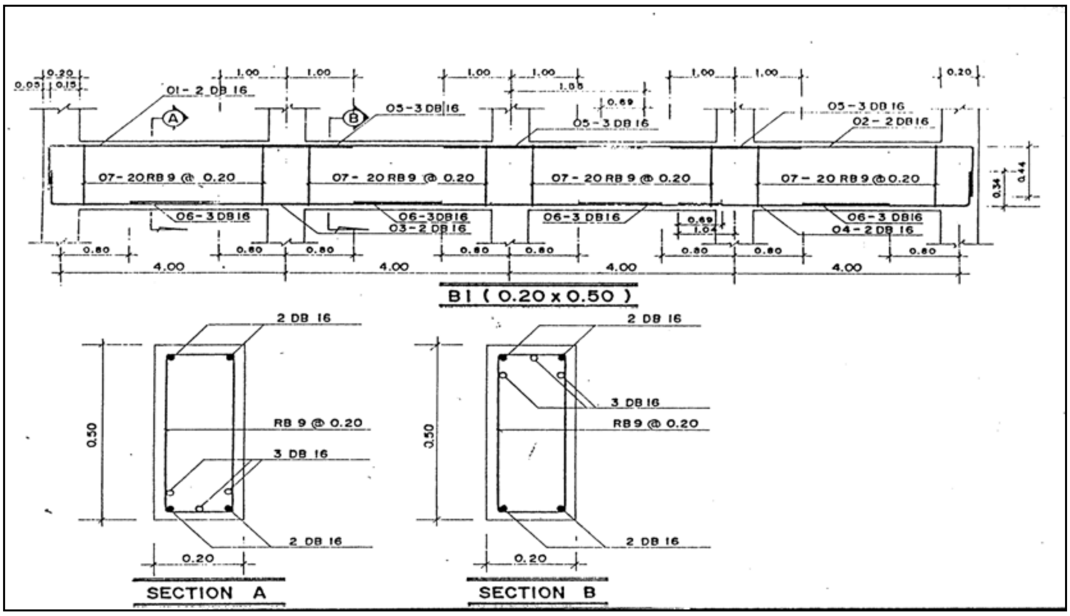
Program Preparation

PROGRAM PREPARATION

The bar bending list made from detail drawing or shop drawing, that follows the construction drawing. In the design part, the arrangement of reinforcing steel and the lap length position of reinforcing steel depend on structure type and structure dimension of element. In the market, the standard length of reinforcing steel has two sizes; 10 m. and 12 m. The meticulous and difficult processes of reinforcing steel works are preparing bar bending list due to it have many details and it must follow the specification (ACI or E.I.T). The specification are concrete covering, embedded length, lap length, lap position, hook allowance, shape of re-bar.

Bar bending schedule

The bar bending list will be created from the detail drawing or shop drawing (Appendix Figure C1) and input in the bar bending schedule (Appendix Table C1).



Appendix Figure C1 Sample of shop drawing

From table the meaning of each fill in the table.

(1) = Company Name

(2) = Project Name

(3) = Title of Bar Bending Schedule

(4) = Drawing Number

(5) = Bar Bending Schedule Number

(6) = Date Modified

(7) = Prepare Name

(8) = Edit Date

(9) = Checker's Name

(10) = Element Name

(11) = Reference Number of Re-Bar from Shop drawing

(12) = Type and size of Reinforcing Steel (RB means round bar normally sizing have 6, 9, 12, 15, 19, 22, 25 mm. and DB means deformed bar normally sizing have 10, 12, 16, 20, 25, 28, 32 mm.)

(13) = Number of Members

(14) = Number of Bar in Member

(15) = Total Number of Bar in members

(16) = Length of each Bar

(17) = Total Length of Bars

(18) = Total weight of Bars

(19) = Shape Code

(20)–(24) = Dimensions of Bar following Bar Shape

(25) = Radii allowance from Bend and Hook Allowance

Appendix Table C1 Bar Schedule List

COMPANY____(1) Drawing ref.____(4)

PROJECT ____(2) Bar schedule no. ____(5)

TITLE ____ Date prepare ______________(6) Date revise______________(8)

____(3) Prepare by________________(7) Check by_______________(9)

member (10)	bar mark (11)	type & size (12)	no. of mbrs. (13)	no. of bar in mbr. (14)	total no. (15)	length of each bar (16)	total length (17)	total wt. (18)	shape code (19)	A (20)	B (21)	C (22)	D (23)	E (24)	r (25)

<u>Bar cutting schedule</u>

After the bar bending schedule, the next step is to create the bar cutting schedule (Appendix Table C3). The cutting schedule will have the same type and size of reinforcing steel by classification type and size of reinforcing steel from bar bending schedule.

From table the meaning of each fill in the table.

(1) = Company Name

(2) = Project Name

(3) = Title of Bar cutting Schedule

(4) = Bar Bending Schedule Reference

(5) = Bar Cutting Schedule Numbre

(6) = Date Modified

(7) = Prepare Name

(8) = Edit Date

(9) = Checker Name

(10),(15) = Element Name

(11),(16) = Number of Members

(12),(17) = Type and size of Reinforcing Steel (RB means round bar normally sizing have 6, 9, 12, 15, 19, 22, 25 mm. and DB means deformed bar normally sizing have 10, 12, 16, 20, 25, 28, 32 mm.)

(13),(18) = Length of each Bar

(14),(19) = Total Number of Bar in members

(20) = Remark

Appendix Table C2 Bar Cutting Schedule

COMPANY____(1) Bar schedule ref.____________________________________(4)

PROJECT ____(2) Bar cutting no. ____________________________________(5)

TITLE ____ Date prepare _____________(6) Date revise______________(8)

____(3) Prepare by_______________(7) Check by_______________(9)

member (10)	no. of mbrs. (11)	type & size (12)	length of each bar (13)	no. of bar in mbr. (14)		member (15)	no. of mbrs. (16)	type & size (17)	length of each bar (18)	no. of bar in mbr. (19)	remark (20)

<u>ACI specification for reinforcing steel (1994).</u>

Formula to calculate the steel length for specified specifications.

Embedded length

Basic development L_{bd} can be calculated as follow:

b) For tension zone

- For steel size 36 mm. or smaller

$L_{db} = 0.04(A_b)\,(fy)/\,(f'c^{1/2})$ unit : force use pound

$L_{db} = 0.04(\pi/4)\,(d_b^2)\,(fy)/\,(f'c^{1/2})$: length use inch

Must be not less than

$L_{db} = 0.0004\ d_b\ fy$

- For top tension steel (L_{bt})

$L_{dt} = 1.4\ L_{bd}$

However, it must be not less than 30 cm.

c) For compression zone

- $L_{db} = 0.02(d_b)(fy)/(\ f'c^{\ 1/2})$
- $L_{db} = 0.0003(d_b)(fy)$

However, it uses maximum value but not less than 20 cm.

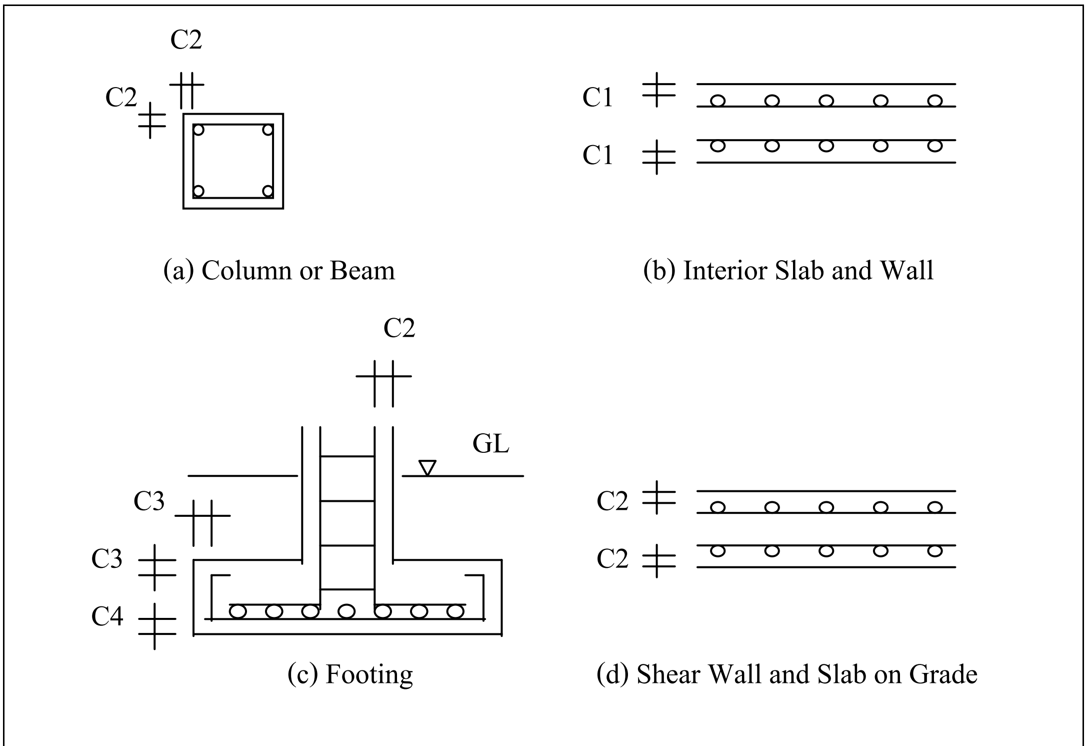
Concrete covering

Minimum concrete cover

Cast in place concrete

Appendix Table C3 Covering Specification (ACI)

COVER	EXPOSED TO WEATHER OR EARTH	NOT EXPOSED TO WEATHER OR EARTH
C1	50	25
C2	50	40
C3	50	-
C4	75	-



Appendix Figure C2 Covering Specification (ACI)

Lap length

a) For tension zone (L_{lt})

- For bottom steel

$L_{lt} = 1.3\ L_{db}$

- For top steel

  $L_{lt} = 1.3\ L_{dt}$

  However, it must be not less than 30 cm.

b) For compression zone

  $L_{lc} = L_{db}$ For compression steel or

  L_{lc} >or = 0.0005(fy) (d_b) or

  L_{lc} >or = 30 cm.

Shape code

Follow the reinforcement bending standard. The length can be calculated by formula in each shape code.

Hook allowance

E.I.T. Standard

- Minimum size of hook diameter of deformed bar

  For: DB12 to DB16 = 5 d_b

  For: DB20 to DB25 = 6 d_b

- Minimum size of hook diameter of round bar

  For: RB6 to RB25 = 5 d_b

Calculation formula for hook length

a) 90^o Bend & Hook

For: RB6 to RB25 and DB10 to DB16

$n = 12d_b + (\pi/4)(5d_b+1d_b)-(2.5d_b+1d_b) = 13.21d_b$

For: DB19 to DB25

$n = 12d_b + (\pi/4)(6d_b+1d_b)-(3d_b+1d_b) = 13.50d_b$

b) 180^o Hook

For: RB6 to RB25 and DB10 to DB16

$h = 4d_b + (\pi/2)(5d_b+1d_b)-(3d_b+1d_b) = 9.42d_b$

For: DB19 to DB25

$h = 4d_b + (\pi/2)(6d_b+1d_b)-(3d_b+1d_b) = 11.0d_b$

Appendix D

The details of example

Appendix Table D1 Cutting Patterns by C-MinBars (SL. = 10 m. or 12 m.) of Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	80	12	1-L=3.50	0.05
			1-L=2.75	
			3-L=1.90	
2	11	10	1-L=3.60	0.00
			2-L=3.20	
3	13	12	2-L=3.50	0.00
			2-L=2.50	
4	20	12	1-L=3.50	0.05
			1-L=3.20	
			1-L=2.75	
			1-L=2.50	
5	10	10	2-L=4.80	0.40
6	131	10	1-L=3.50	0.10
			2-L=3.20	
7	180	12	1-L=5.10	0.10
			1-L=3.60	
			1-L=3.20	
8	160	12	1-L=4.80	0.20
			2-L=3.50	
9	120	12	1-L=5.10	0.00
			1-L=4.80	
			1-L=2.10	
10	1	12	1-L=3.60	1.40
			2-L=3.50	
11	1	12	1-L=3.50	2.10
			2-L=3.20	

Appendix Table D1 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
12	1	12	2-L=3.20	0.60
			2-L=2.50	

Total Standard Length	=	8,432	m.	Standard Length Select: 10 m. or 12 m.
Total Waste	=	76.20	m.	
Percent Waste	=	0.91	%	
Total Standard Steel: L=10 m.	=	152	Nos.	
Total Standard Steel: L=12 m.	=	576	Nos.	

Appendix Table D2 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from C-MinBars: 46 Patterns, SL. = 10m. or 12m.) of Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	120	12	1-L=3.50	0.00
			2-L=3.20	
			1-L=2.10	
2	32	10	1-L=3.60	0.00
			2-L=3.20	
3	24	12	2-L=3.50	0.00
			2-L=2.50	
4	80	12	1-L=4.80	0.0.0
			2-L=3.60	
5	80	12	1-L=3.50	0.05
			1-L=2.75	
			3-L=1.90	
6	10	12	2-L=3.20	0.10
			2-L=2.75	

Appendix Table D2 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
7	136	10	1-L=5.10	0.10
			1-L=4.80	
8	84	12	1-L=4.80	0.20
			2-L=3.50	
9	164	12	1-L=5.10	0.20
			1-L=3.50	
			1-L=3.20	

Total Length of Standard Length	=	8,424	m.	Standard Length Select: 10 m. or 12 m.
Total Waste	=	68.20	m.	
Percent Waste	=	0.81	%	
Total Standard Steel: L=10 m.	=	168	Nos.	
Total Standard Steel: L=12 m.	=	562	Nos.	

Appendix Table D3 Cutting Patterns by C-MinBars and ExcelTest (use the Possible Cutting Patterns from C-MinBars: 47 Patterns, SL. = 10 m. only) of Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	12	10	2L=3.50	0.50
			1-L=2.50	
2	32	10	2-L=3.60	0.30
			1-L=2.50	
3	100	10	2-L=3.50	0.25
			1-L=2.75	
4	244	10	1-L=3.50	0.10
			1-L=3.20	
5	56	10	2-L=3.50	3.00

Appendix Table D3 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	120	10	1-L=3.60	0.50
			1-L=2.10	
			2-L=1.90	
7	300	10	1-L=5.10	0.10
			1-L=4.80	

Total Standard Length	=	8,680	m.	Standard Length Select: 10 m. only
Total Waste	=	324.20	m.	
Percent Waste	=	3.75	%	
Total Standard Steel: L=10 m.	=	868	Nos.	

Appendix Table D4 Cutting Patterns by C-MinBars (SL. = 12 m. only) of Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	41	12	1-L=3.50	0.05
			1-L=2.75	
			3-L=1.90	
2	12	12	1-L=3.50	0.00
			2-L=3.20	
			1-L=2.10	
3	1	12	1-L=3.20	0.00
			2-L=2.50	
			2-L=1.90	
4	11	12	2-L=3.20	0.10
			2-L=2.75	

Appendix Table D4 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
5	296	12	1-L=5.10	0.20
			1-L=3.50	
			1-L=3.20	
6	192	12	1-L=4.80	0.10
			1-L=3.60	
			1-L=3.50	
7	107	12	1-L=4.80	0.10
			1-L=3.20	
			1-L=2.10	
			1-L=1.90	
8	37	12	1-L=3.50	0.05
			1-L=3.20	
			1-L=2.75	
			1-L=2.50	
9	3	12	1-L=5.10	0.00
			2-L=2.50	
			1-L=1.90	
10	1	12	1-L=5.10	0.00
			1-L=4.80	
			1-L=2.10	
11	1	12	2-L=3.50	1.80
			1-L=3.20	
12	1	12	3-L=2.50	0.70
			2-L=1.90	
13	1	12	3-L=1.90	6.30

Total Standard Length = 8,448 m. Standard Length Selected: 12 m. only

Total Waste	=	92.20	m.
Percent Waste	=	1.10	%
Total Standard Steel: L=12 m.	=	704	Nos.

Appendix Table D5 Cutting Patterns by D-MinBars (SL. = 10 m. or 12 m.) of Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	18	12	1-L=5.10	0.20
			1-L=3.50	
			1-L=3.20	
2	68	10	1-L=5.10	0.10
			1-L=4.80	
3	20	10	1-L=5.10	0.05
			1-L=2.75	
			1-L=2.10	
4	231	12	1-L=4.80	0.20
			2-L=3.50	
5	192	12	1-L=5.10	0.10
			1-L=3.60	
			1-L=3.20	
6	39	12	2-L=3.20	0.10
			2-L=2.75	
7	12	12	4-L=2.50	0.10
			1-L=1.90	
8	99	12	1-L=3.50	0.00
			2-L=3.20	
			1-L=2.10	
9	45	10	5-L=1.90	0.50
10	1	12	2-L=5.10	1.80

Appendix Table D5 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
11	1	12	1-L=4.80	0.50
			1-L=3.50	
			1-L=3.20	
12	1	10	1-L=3.20	1.30
			2-L=2.75	
13	1	10	1-L=2.10	2.20
			1-L=1.90	

Total Standard Length	=	8,466	m.	Standard Length Select: 10 m. or 12 m.
Total Waste	=	110.20	m.	
Percent Waste	=	1.32	%	
Total Standard Steel: L=10 m.	=	135	Nos.	
Total Standard Steel: L=12 m.	=	593	Nos.	

Appendix Table D6 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from D-MinBars: 28 Patterns, SL. = 10 m. or 12 m) Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	41	10	2-L=2.10	0.10
			3-L=1.90	
2	21	10	5-L=1.90	0.50
3	12	12	4-L=2.50	0.10
			1-L=1.90	
4	36	12	2-L=3.20	0.10
			2-L=2.75	

Appendix Table D6 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
5	12	12	1-L=3.50	0.00
			2-L=3.20	
			1-L=2.10	
6	93	10	1-L=3.50	0.10
			2-L=3.20	
7	231	12	1-L=4.80	0.20
			2-L=3.50	
8	69	10	1-L=5.10	0.10
			1-L=4.80	
9	192	12	1-L=5.10	0.10
			1-L=3.60	
			1-L=3.20	
10	26	10	1-L=5.10	0.05
			1-L=2.75	
			1-L=2.10	
11	13	12	1-L=5.10	0.20
			1-L=3.50	
			1-L=3.20	
12	1	10	1-L=3.20	1.30
			2-L=2.75	

Total Standard Length = 8,462 m. Standard Length Select: 10 m. or 12 m.

Total Waste = 106.20 m.

Percent Waste = 1.26 %

Total Standard Steel: L=10 m. = 251 Nos.

Total Standard Steel: L=12 m. = 496 Nos.

Appendix Table D7 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from D-MinBars: 26 Patterns, SL. = 10 m. only) of Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	300	10	1-L=5.10	0.10
			1-L=4.80	
2	48	10	2-L=3.50	0.50
			1-L=2.50	
3	20	10	2-L=3.50	0.90
			1-L=2.10	
4	244	10	1-L=3.50	0.10
			2-L=3.20	
5	96	10	2-L=3.60	0.70
			1-L=2.10	
6	100	10	2-L=3.50	0.25
			1-L=2.75	
7	2	10	2-L=2.10	0.10
			3-L=1.90	
8	46	10	5-L=1.90	0.50
9	1	10	4-L=1.90	2.40

Total Standard Length	=	8,570	m.	Standard Length Selected: 10 m. only
Total Waste	=	214.20	m.	
Percent Waste	=	2.56	%	
Total Standard Steel: L=10 m.	=	857	Nos.	

Appendix Table D8 Cutting Patterns by D-MinBars (SL. = 12 m. only) of Example 1A

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	21	12	1-L=4.80	0.00
			2-L=3.60	
2	101	12	1-L=5.10	0.00
			1-L=4.80	
			1-L=2.10	
3	231	12	1-L=3.60	0.05
			1-L=3.50	
			1-L=2.75	
			1-L=2.10	
4	178	12	1-L=4.80	0.20
			1-L=3.50	
5	130	12	1-L=3.60	0.10
			2-L=3.20	
			1-L=1.90	
6	26	12	2-L=3.20	0.10
			2-L=2.75	
7	175	12	1-L=5.10	0.20
			1-L=3.50	
			1-L=3.20	
8	28	12	1-L=3.50	0.05
			1-L=2.75	
			3-L=1.90	
9	24	12	1-L=5.10	0.00
			2-L=2.50	
			1-L=1.90	
10	1	12	1-L=3.60	1.40
			2-L=3.50	

Appendix Table D8 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
11	1	12	1-L=3.20	2.25
			1-L=2.75	
			2-L=1.90	

Total Standard Length	=	8,448	m.	Standard Length Selected: 12 m. only
Total Waste	=	92.20	m.	
Percent Waste	=	1.10	%	
Total Standard Steel: L=12 m.	=	704	Nos.	

Appendix Table D9 Cutting Pattern by C-MinBars (SL. = 10 m. or 12 m.) of Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	258	12	9-L=1.30	0.30
2	452	10	7-L=1.40	0.20
3	9	12	8-L=1.50	0.00
4	36	10	2-L=3.10	0.00
			1-L=2.40	
			1-L=1.40	
5	72	12	3-L=3.10	0.00
			1-L=1.40	
			1-L=1.30	
6	24	12	1-L=4.10	0.30
			1-L=3.60	
			1-L=1.50	
			2-L=1.40	

Appendix Table D9 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
7	216	10	1-L=4.10	0.00
			3-L=1.50	
			1-L=1.40	
8	1	10	6-L=1.50	1.00
9	1	10	6-L=1.30	2.20

Total Standard Length	=	11,416	m.	Standard Length Select: 10 m. or 12 m.
Total Waste	=	171.00	m.	
Percent Waste	=	1.50	%	
Total Standard Steel: L=10 m.	=	706	Nos.	
Total Standard Steel: L=12 m.	=	363	Nos.	

Appendix Table D10 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from C-MinBars: 29 Patterns), SL. = 10 m. or 12 m.) of Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	260	12	9-L=1.30	0.30
2	430	10	7-L=1.40	0.20
3	93	12	8-L=1.50	0.00
4	6	10	2-L=3.10	0.00
			1-L=2.40	
			1-L=1.40	
5	12	12	3-L=3.10	0.00
			1-L=1.40	
			1-L=1.30	

Appendix Table D10 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	24	12	1-L=3.60	0.00
			1-L=2.40	
			1-L=1.40	
			2-L=1.30	
7	240	10	1-L=4.10	0.00
			3-L=3.10	
			1-L=1.40	
8	2	10	3-L=2.40	0.00
			2-L=1.40	
9	1	10	6-L=1.50	1.00

Total Standard Length	=	11,410	m.	Standard Length Select: 10 m. or 12 m.
Total Waste	=	165.00	m.	
Percent Waste	=	1.45	%	
Total Standard Steel: L=10 m.	=	703	Nos.	
Total Standard Steel: L=12 m.	=	365	Nos.	

Appendix Table D11 Cutting Patterns by C-MinBars (SL. = 10 m. only) of Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	337	10	7-L=1.30	0.90
2	476	10	7-L=1.40	0.20
3	36	10	1-L=3.10	0.00
			1-L=2.40	
			3-L=1.50	

Appendix Table D11 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
4	39	10	1-L=4.10	0.00
			1-L=3.10	
			1-L=1.50	
			1-L=1.30	
5	55	10	3-L=3.10	0.70
6	24	10	1-L=3.60	0.20
			2-L=3.10	
7	201	10	1-L=4.10	0.00
			3-L=1.50	
			1-L=1.40	
8	1	10	3-L=1.40	3.20
			2-L=1.30	

Total Standard Length	=	11,690	m.	Standard Length Selected: 10 m. only
Total Waste	=	445.20	m.	
Percent Waste	=	3.81	%	
Total Standard Steel: L=10 m.	=	1,169	Nos.	

Appendix Table D12 Cutting Patterns by C-MinBars (SL. = 12 m. only) of Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	266	12	9-L=1.30	0.30
2	428	12	8-L=1.40	0.80
3	75	12	8-L=1.50	0.00
4	36	12	2-L=4.10	0.00
			1-L=2.40	
			1-L=1.40	

Appendix Table D12 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
5	144	12	1-L=4.10	0.20
			2-L=3.10	
			1-L=1.50	
6	24	12	1-L=4.10	0.10
			1-L=3.60	
			3-L=1.40	
7	1	12	6-L=1.50	0.20
			2-L=1.40	
8	1	12	2-L=1.40	1.40
			6-L=1.30	

Total Standard Length	=	11,700	m.	Standard Length Selected: 12 m. only
Total Waste	=	455.00	m.	
Percent Waste	=	3.89	%	
Total Standard Steel: L=12 m.	=	975	Nos.	

Appendix Table D13 Cutting Patterns by D-MinBars (SL. = 10 m. or 12 m.) of Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	240	12	1-L=4.10	0.00
			1-L=1.40	
			5-L=1.30	
2	24	12	1-L=3.60	0.00
			1-L=3.50	
			4-L=1.40	
			1-L=1.30	

Appendix Table D13 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
3	96	12	3-L=3.10	0.00
			1-L=1.40	
			1-L=1.30	
4	36	10	1-L=2.40	0.00
			5-L=1.40	
			2-L=1.30	
5	17	12	7-L=1.50	0.10
			1-L=1.40	
6	460	10	1-L=1.50	0.10
			6-L=1.40	
7	144	12	1-L=1.50	0.00
			1-L=1.40	
			7-L=1.30	
8	1	10	3-L=1.50	1.30
			3-L=1.40	

Total Standard Length	=	11,294	m.	Standard Length Select: 10 m. or 12 m.
Total Waste	=	49.00	m.	
Percent Waste	=	0.44	%	
Total Standard Steel: L=10 m.	=	461	Nos.	
Total Standard Steel: L=12 m.	=	557	Nos.	

Appendix Table D14 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from D-MinBars: 24 Patterns, SL. = 10 m. or 12 m.) of Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	318	12	1-L=1.50	0.00
			1-L=1.40	
			7-L=1.30	
2	20	12	3-L=3.10	0.00
			1-L=1.40	
			1-L=1.30	
3	1	10	2-L=3.60	0.00
			2-L=1.40	
4	228	10	1-L=4.10	0.00
			1-L=3.10	
			2-L=1.40	
5	12	12	1-L=4.10	0.00
			1-L=1.40	
			5-L=1.30	
6	22	12	1-L=3.60	0.00
			1-L=3.50	
			4-L=1.40	
			1-L=1.30	
7	36	12	1-L=2.40	0.00
			5-L=1.40	
			2-L=1.30	
8	410	10	1-L=1.50	0.10
			6-L=1.40	

Total Standard Length = 11,286 m. Standard Length Select: 10 m. or 12 m.

Total Waste = 41.00 m.

Percent Waste	=	0.36	%
Total Standard Steel: L=10 m.	=	639	Nos.
Total Standard Steel: L=12 m.	=	428	Nos.

Appendix Table D15 Cutting Patterns by D-MinBars, set SL. = 10 m. only, Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	240	10	1-L=4.10	0.00
			1-L=3.10	
			1-L=1.50	
			1-L=1.30	
2	12	10	2-L=3.60	0.00
			1-L=1.50	
			1-L=1.30	
3	48	10	1-L=3.10	0.00
			2-L=1.50	
			3-L=1.30	
4	18	10	2-L=2.40	0.00
			4-L=1.30	
5	100	10	4-L=1.50	0.00
			1-L=1.40	
			2-L=1.30	
6	490	10	7-L=1.40	0.20
7	247	10	7-L=1.30	0.90
8	1		2-L=1.50	0.00
			5-L=1.40	
8	1	10	1-L=1.40	4.70
			3-L=1.30	

Total Standard Length = 11,570 m. Standard Length Selected: 10 m. only

Total Waste	=	325.00	m.
Percent Waste	=	2.81	%
Total Standard Steel: L=10 m.	=	1,157	Nos.

Appendix Table D16 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from D-MinBars: 20 Patterns, SL. = 10 m. only) of Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	1	10	1-L=4.10	5.90
2	1	10	1-L=1.50	8.50
3	8	10	4-L=1.50	0.00
			1-L=1.40	
			2-L=1.30	
4	499	10	7-L=1.40	0.20
5	206	10	7-L=1.30	0.90
6	118	10	2-L=4.10	0.30
			1-L=1.50	
7	18	10	2-L=2.40	0.00
			4-L=1.30	
8	3	10	1-L=4.10	0.00
			1-L=3.10	
			1-L=1.50	
			1-L=1.30	
9	285	10	1-L=3.10	0.00
			2-L=1.50	
			3-L=1.30	
10	12	10	2-L=3.60	0.00
			1-L=1.50	
			1-L=1.30	

Appendix Table D16 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
11	7	10	2-L=1.50	0.00
			5-L=1.40	

Total Standard Length	=	11,580	m.	Standard Length Selected: 10 m. only
Total Waste	=	335.00	m.	
Percent Waste	=	2.89	%	
Total Standard Steel: L=10 m.	=	1,158	Nos.	

Appendix Table D17 Cutting Patterns by D-MinBars, set SL. = 12 m. only, Example 1B

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	240	12	1-L=4.10	0.00
			1-L=1.40	
			5-L=1.30	
2	24	12	1-L=3.60	0.00
			1-L=1.50	
			4-L=1.40	
			1-L=1.30	
3	144	12	2-L=3.10	0.00
			2-L=1.50	
			2-L=1.40	
4	36	12	1-L=2.40	0.00
			5-L=1.40	
			2-L=1.30	
5	62	12	7-L=1.50	0.10
			1-L=1.40	
6	264	12	8-L=1.40	0.80

Appendix Table D17 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
7	183	12	3-L=1.40	0.00
			6-L=1.30	
8	1	12	4-L=1.50	0.40
			4-L=1.40	
9	1	12	5-L=1.40	1.10
			3-L=1.30	
10	1	12	3-L=1.30	0.00

Total Standard Length	=	11,472	m.	Standard Length Selected: 12 m. only
Total Waste	=	227.00	m.	
Percent Waste	=	2.89	%	
Total Standard Steel: L=12 m.	=	956	Nos.	

Appendix Table D18 Cutting Patterns by C-MinBars (SL. = 10 m. or 12 m.) of Example 2

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	8	12	8-L=1.50	0.00
2	41	12	6-L=2.00	0.00
3	25	10	4-L=2.50	0.00
4	50	12	2-L=3.25	0.00
			1-L=2.50	
			2-L=1.50	
5	33	12	3-L=4.00	0.00
6	1	12	1-L=4.00	0.00
			4-L=2.00	
7	1	10	6-L=1.50	1.00

Total Standard Length	=	1,856	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	1.00	m.	
Percent Waste	=	0.05	%	
Total Standard Steel: L=10 m.	=	26	Nos.	
Total Standard Steel: L=12 m.	=	133	Nos.	

Appendix Table D19 Cutting Pattern by ExcelTest (Bring the Possible Cutting Patterns from C-MinBars: 27 Patterns, SL. = 10 m. or 12 m.) of Example 2

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	2	12	2-L=4.00	0.00
			1-L=2.50	
			1-L=1.50	
2	2	10	1-L=4.00	0.00
			4-L=1.50	
3	19	12	1-L=4.00	0.00
			2-L=2.50	
			2-L=1.50	
4	5	12	1-L=4.00	0.00
			1-L=2.50	
			2-L=2.00	
			1-L=1.50	
5	9	12	2-L=4.00	0.00
			2-L=2.00	
6	25	10	4-L=2.50	0.00
7	2	10	1-L=4.00	0.00
			1-L=2.50	
			1-L=2.00	
			1-L=1.50	

Appendix Table D19 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
8	1	10	2-L=2.50	0.00
			1-L=2.00	
			2-L=1.50	
9	1	10	1-L=2.50	0.00
			3-L=2.00	
			1-L=1.50	
10	50	12	1-L=4.00	0.00
			2-L=3.25	
			1-L=1.50	
11	7	12	8-L=1.50	0.00
12	36	12	6-L=2.00	0.00
13	1	10	6-L=1.50	1.00

Total Standard Length	=	1,856	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	1.00	m.	
Percent Waste	=	0.05	%	
Total Standard Steel: L=10 m.	=	32	Nos.	
Total Standard Steel: L=12 m.	=	128	Nos.	

Appendix Table D20 Cutting Patterns by C-MinBars and D-MinBars (SL. = 10 m. only) of Example 2

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	30	10	1-L=4.00	0.00
			4-L=1.50	
2	33	10	5-L=2.00	0.00
3	37	10	4-L=2.50	0.00

Appendix Table D20 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
4	50	10	2-L=3.25	0.00
			1-L=2.00	
			1-L=1.50	
5	35	10	2-L=4.00	0.00
			1-L=2.00	
6	1	10	2-L=2.50	5.00

Total Standard Length	=	1,860	m.	Standard Length Selected: 10 m. only
Total Waste	=	5.00	m.	
Percent Waste	=	0.27	%	
Total Standard Steel: L=10 m.	=	186	Nos.	

Appendix Table D21 Cutting Patterns by C-MinBars and D-MinBars, ExcelTest (use the Possible Cutting Patterns from D-MinBars: 13 Patterns, SL. = 12 m. only) of Example 2

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	15	12	8-L=1.50	0.00
2	35	12	6-L=2.00	0.00
3	37	12	4-L=2.50	0.00
			1-L=2.00	
4	50	12	1-L=4.00	0.00
			2-L=3.25	
			1-L=1.50	
5	16	12	2-L=4.00	
6	1	12	2-L=4.00	1.50
			1-L=2.50	
7	1	12	1-L=2.50	3.50
			3-L=2.00	

Total Standard Length	=	1,860	m.	Standard Length Selected: 12 m. only
Total Waste	=	5.00	m.	
Percent Waste	=	0.27	%	
Total Standard Steel: L=12 m.	=	155	Nos.	

Appendix Table D22 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from C-MinBars: 24 Patterns, SL. = 12 m. only) Example 2

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	3	12	3-L=4.00	0.00
2	44	12	1-L=4.00	0.00
			2-L=3.25	
			1-L=1.50	
3	47	12	1-L=4.00	0.00
			2-L=2.50	
			2-L=1.50	
4	4	12	4-L=2.50	0.00
			1-L=2.00	
5	3	12	2-L=3.25	0.00
			1-L=2.50	
			2-L=1.50	
6	3	12	2-L=3.25	0.00
			1-L=2.00	
			1-L=1.50	
7	3	12	3-L=2.50	0.50
			2-L=2.00	
8	7	12	4-L=2.50	0.50
			1-L=1.50	
9	2	12	8-L=1.50	0.00
10	39	12	6-L=2.00	0.00

Total Standard Length	=	1,860	m.	Standard Length Selected: 12 m. only
Total Waste	=	5.00	m.	
Percent Waste	=	0.27	%	
Total Standard Steel: L=12 m.	=	155	Nos.	

Appendix Table D23 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from D-MinBars: 13 Patterns, SL. = 10 m. or 12 m.) of Example 2

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	16	12	3-L=4.00	0.00
2	50	12	1-L=4.00	0.00
			2-L=3.25	
			1-L=1.50	
3	37	12	4-L=2.50	0.00
			1-L=2.00	
4	35	12	6-L=2.00	0.00
5	15	12	8-L=1.50	0.00
6	1	10	2-L=4.00	0.00
			1-L=2.00	
7	1	10	2-L=2.50	1.00
			2-L=2.00	

Total Standard Length	=	1,856	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	1.00	m.	
Percent Waste	=	0.05	%	
Total Standard Steel: L=10 m.	=	2	Nos.	
Total Standard Steel: L=12 m.	=	153	Nos.	

<u>Appendix Table D24</u> Cutting Patterns by C-MinBars and D-MinBars (set SL. = 10 m. only) and C-MinBars (SL = 10m. or 12m.) and ExcelTest (use the Possible Cutting Patterns from C-MinBars: 12 Patterns, D-MinBars: 9 Patterns) of Example 3

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	4	10	1-L=5.39	0.21
			1-L=2.40	
			1-L=2.00	
2	8	10	1-L=7.59	0.01
			1-L=2.40	
3	4	10	1-L=5.39	0.61
			2-L=2.00	

Total Standard Length	=	160	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	3.36	m.	
Percent Waste	=	2.15	%	
Total Standard Steel: L=10 m.	=	16	Nos.	

<u>Appendix Table D25</u> Cutting Patterns by C-MinBars: set SL. = 12 m. only, Example 3

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	4	12	1-L=5.39	0.21
			1-L=2.40	
			2L=2.00	
2	8	12	1-L=7.59	0.01
			1-L=2.40	
			1-L=2.00	
3	3	12	2-L=5.39	1.22

Appendix Table D25 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
4	1	12	1-L=5.39	1.81
			2-L=2.40	
5	1	12	1-L=2.40	5.60
			2-L=2.00	

Total Standard Length	=	168	m.	Standard Length Selected: 12 m. only
Total Waste	=	11.36	m.	
Percent Waste	=	6.76	%	
Total Standard Steel: L=12 m.	=	14	Nos.	

Appendix Table D26 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from C-MinBars: 12 Patterns, SL. = 12 m. only) of Example 3

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	4	12	1-L=7.59	0.01
			1-L=2.40	
			1-L=2.00	
2	4	12	1-L=7.59	0.41
			2-L=2.00	
3	2	12	2-L=5.39	1.22
			1-L=5.39	
			2-L=2.40	
4	4	12	1-L=5.39	1.80
			2-L=2.40	

Total Standard Length	=	168	m.	Standard Length Selected: 12 m. only
Total Waste	=	11.36	m.	

Percent Waste	=	6.76	%
Total Standard Steel: L=12 m.	=	14	Nos.

Appendix Table D27 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from D-MinBars: 16 Patterns, SL. = 10 m. or 12 m.) of Example 3

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	2	12	2-L=5.39	1.22
2	4	10	1-L=5.39	0.21
			1-L=2.40	
			1-L=2.00	
3	8	12	1-L=7.59	0.01
			1-L=2.40	
			1-L=2.00	

Total Standard Length	=	160	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	3.36	m.	
Percent Waste	=	2.15	%	
Total Standard Steel: L=10 m.	=	4	Nos.	
Total Standard Steel: L=12 m.	=	10	Nos.	

Appendix Table D28 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from D-MinBars: 16 Patterns, SL. = 12 m. only) of Example 3

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	1	12	4-L=2.40	0.40
			1-L=2.00	
2	4	12	2-L=5.39	1.22
3	8	12	1-L=7.59	0.01
			1-L=2.40	
			1-L=2.00	

Appendix Table D28 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
4	1	12	3-L=2.00	6

Total Length of Standard Length	=	168	m.	Standard Length Selected: 12 m. only
Total Waste	=	11.36	m.	
Percent Waste	=	6.76	%	
Total Standard Steel: L=12 m.	=	14	Nos.	

Appendix Table D29 Cutting Patterns by C-MinBars (SL. = 10 m. or 12 m.) of Example 4

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	140	12	1-L=4.35	0.00
			1-L=2.25	
			3-L=1.80	
2	93	12	1-L=3.30	0.15
			3-L=2.25	
			1-L=1.80	
3	266	12	2-L=3.30	0.00
			2-L=2.70	
4	6	12	2-L=4.35	0.00
			1-L=3.30	
5	175	12	1-L=4.35	0.00
			2-L=2.70	
			1-L=2.25	
6	109	12	1-L=5.80	0.05
			1-L=4.35	
			1-L=1.80	

Appendix Table D29 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
7	77	12	1-L=6.50	0.10
			3-L=1.80	
8	136	12	1-L=6.75	0.15
			1-L=3.30	
			1-L=1.80	
9	250	12	1-L=7.60	0.05
			1-L=4.35	
10	1	12	1-L=4.35	0.30
			1-L=3.30	
			1-L=2.25	
			1-L=1.80	
11	1	10	2-L=2.70	0.10
			2-L=2.25	

Total Standard Length	=	15,046	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	60.40	m.	
Percent Waste	=	0.40	%	
Total Standard Steel: L=10 m.	=	1	Nos.	
Total Standard Steel: L=12 m.	=	1,253	Nos	

Appendix Table D30 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from C-MinBars: 16 Patterns, SL. = 10 m. or 12 m.) of Example 4

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	9	12	2-L=4.35	0.00
			1-L=3.30	

Appendix Table D30 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
2	139	12	1-L=4.35	0.00
			1-L=2.25	
			3-L=1.80	
3	263	12	2-L=3.30	0.00
			2-L=2.70	
4	178	12	1-L=4.35	0.00
			2-L=2.70	
			1-L=2.25	
5	3	12	2-L=3.30	0.00
			3-L=1.80	
6	109	12	1-L=5.80	0.05
			1-L=4.35	
			1-L=1.80	
7	243	12	1-L=7.60	0.05
			1-L=4.35	
8	76	12	1-L=6.50	0.10
			3-L=1.80	
9	1	12	1-L=6.50	0.10
			2-L=2.70	
10	91	12	1-L=3.30	0.15
			3-L=2.25	
			1-L=1.80	
11	7	10	1-L=7.60	0.15
			1-L=2.25	
12	136	12	1-L=6.75	0.15
			1-L=3.30	
			1-L=1.80	

Total Length of Standard Length	=	15,046	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	60.40	m.	
Percent Waste	=	0.40	%	
Total Standard Steel: L=10 m.	=	7	Nos.	
Total Standard Steel: L=12 m.	=	1,248	Nos	

Appendix Table D31 Cutting Patterns by C-MinBars and D-MinBars (SL. = 10 m. only) of Example 4

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	134	10	1-L=4.35	0.25
			3-L=1.80	
2	238	10	1-L=4.35	0.10
			1-L=3.30	
			1-L=2.25	
3	119	10	1-L=2.70	0.10
			4-L=1.80	
4	151	10	3-L=3.30	0.10
5	314	10	1-L=4.35	0.25
			2-L=2.70	
6	109	10	1-L=5.80	0.15
			1-L=2.25	
			1-L=1.80	
7	77	10	1-L=6.50	0.20
			1-L=3.30	
8	136	10	1-L=6.75	0.55
			1-L=2.70	
9	250	10	1-L=7.60	0.15
			1-L=2.25	

Appendix Table D31 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
10	1	10	1-L=4.35	1.15
			1-L=2.70	
			1-L=1.80	
11	1	10	2-L=1.80	6.40

Total Length of Standard Length	=	15,300	m.	Standard Length Selected: 10 m. only
Total Waste	=	314.40	m.	
Percent Waste	=	2.05	%	
Total Standard Steel: L=10 m.	=	1,530	Nos.	

Appendix Table D32 Cutting Pattern by ExcelTest (Bring the Possible Cutting Patterns from C-MinBars: 29 Patterns, SL. = 10 m. only) of Example 4

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	151	10	3-L=3.30	0.10
2	89	10	1-L=2.70	0.10
			4-L=1.80	
3	31	10	3-L=2.70	0.10
			1-L=1.80	
4	241	10	1-L=4.35	0.10
			1-L=3.30	
			1-L=2.25	
5	250	10	1-L=7.60	0.15
			1-L=2.25	

Appendix Table D32 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	69	10	1-L=6.50	0.20
			1-L=3.30	
7	279	10	1-L=4.35	0.25
			2-L=2.70	
8	165	10	1-L=4.35	0.25
			3-L=1.80	
9	2	10	1-L=4.35	0.55
			1-L=3.30	
			1-L=1.80	
10	136	10	1-L=6.75	0.55
			1-L=2.70	
11	8	10	1-L=6.50	0.80
			1-L=2.70	
12	3	10	1-L=5.80	0.90
			1-L=3.30	
13	106	10	1-L=5.80	0.15
			1-L=2.25	
			1-L=1.80	

Total Standard Length	=	15,300	m.	Standard Length Selected: 10 m. only
Total Waste	=	314.40	m.	
Percent Waste	=	2.05	%	
Total Standard Steel: L=10 m.	=	1,530	Nos.	

Appendix Table D33 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from D-MinBars: 23 Patterns, SL. = 10 m. only) of Example 4

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	2	10	1-L=6.50	3.50
2	2	10	2-L=2.70	0.10
			2-L=2.25	
3	153	10	3-L=3.30	0.10
4	116	10	3-L=2.70	0.10
			1-L=1.80	
5	109	10	1-L=5.80	0.15
			1-L=2.25	
			1-L=1.80	
6	75	10	1-L=6.50	0.20
			1-L=3.30	
7	136	10	1-L=6.75	0.55
			1-L=2.70	
8	250	10	1-L=7.60	0.15
			1-L=2.25	
9	234	10	1-L=4.35	0.10
			1-L=3.30	
			1-L=2.25	
10	198	10	1-L=4.35	0.25
			2-L=2.70	
11	255	10	1-L=4.35	0.25
			3-L=1.80	

Total Standard Length = 15,300 m. Standard Length Selected: 10 m. only

Total Waste = 314.40 m.

Percent Waste = 2.05 %

Total Standard Steel: L=10 m. = 1,530 Nos.

Appendix Table D34 Cutting Patterns by C-MinBars (SL. = 12 m. only) of Example 4

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	140	12	1-L=4.35	0.00
			1-L=2.25	
			3-L=1.80	
2	93	12	1-L=3.30	0.15
			3-L=2.25	
			1-L=1.80	
3	175	12	1-L=4.35	0.00
			2-L=2.70	
			1-L=2.25	
4	266	12	2-L=3.30	0.00
			2-L=2.70	
5	6	12	2-L=4.35	0.00
			1-L=3.30	
6	109	12	1-L=5.80	0.05
			1-L=4.35	
			1-L=1.80	
7	77	12	1-L=6.50	0.10
			3-L=1.80	
8	136	12	1-L=6.75	0.15
			1-L=3.30	
			1-L=1.80	
9	250	12	1-L=7.60	0.05
			1-L=4.35	

Appendix Table D34 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
10	1	12	1-L=4.35	1.65
			1-L=3.30	
			1-L=2.70	
11	1	12	1-L=2.70	0.75
			3-L=2.25	
			1-L=1.80	

Total Standard Length	=	15,048	m.	Standard Length Selected: 12 m. only
Total Waste	=	62.40	m.	
Percent Waste	=	0.41	%	
Total Standard Steel: L=12 m.	=	1,254	Nos.	

Appendix Table D35 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from D-MinBars: 24 Patterns, SL. = 12 m. only) of Example 4

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	250	12	1-L=7.60	0.05
			1-L=4.35	
2	136	12	1-L=6.75	0.15
			1-L=3.30	
			1-L=1.80	
3	77	12	1-L=6.50	0.10
			2-L=2.70	
4	54	12	2-L=5.80	0.40
5	258	12	2-L=4.35	0.00
			1-L=3.30	

Appendix Table D35 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	364	12	1-L=4.35	0.00
			2-L=2.70	
			1-L=2.25	
7	77	12	1-L=3.30	0.15
			3-L=2.25	
			1-L=1.80	
8	258	12	2-L=3.30	0.00
			3-L=1.80	
9	1	12	1-L=5.80	0.05
			1-L=4.35	
			1-L=1.80	
10	1	12	3-L=3.30	0.30
			1-L=1.80	
11	1	12	2-L=2.70	0.30
			2-L=2.25	
			1-L=1.80	

Total Standard Length	=	15,060	m.	Standard Length Selected: 12 m. only
Total Waste	=	74.40	m.	
Percent Waste	=	0.49	%	
Total Standard Steel: L=12 m.	=	1,255	Nos.	

Appendix Table D36 Cutting Pattern by C-MinBars (SL. = 10 m. or 12 m.) of Example 5

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	63	12	1-L=3.50	0.18
			2-L=2.82	

Appendix Table D36 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
2	2	10	2-L=3.50	0.02
			1-L=2.98	
3	22	10	1-L=3.88	0.08
			2-L=3.02	
4	11	12	3-L=3.50	1.50
5	9	10	1-L=3.56	0.12
			1-L=3.50	
			1-L=2.82	
6	5	10	1-L=3.91	0.05
			2-L=3.02	
7	12	12	3-L=4.00	0.00
8	24	10	1-L=3.91	0.05
			2-L=3.02	
9	12	10	1-L=6.24	0.26
			1-L=3.50	
10	15	10	1-L=6.32	0.18
			1-L=3.50	
11	15	10	1-L=6.56	0.18
			1-L=3.50	
12	27	12	1-L=8.41	0.09
			1-L=3.50	
13	9	10	1-L=9.11	0.89
14	9	10	1-L=9.26	0.74
15	6	12	1-L=11.70	0.30
16	6	12	1-L=11.76	0.24
17	9	12	1-L=11.87	0.13
18	1	12	1-L=3.91	0.33
			2-L=3.88	

Appendix Table D36 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
19	1	10	2-L=3.50	3.00
20	1	10	3-L=3.02	0.94

Total Standard Length	=	2,698	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	69.06	m.	
Percent Waste	=	2.56	%	
Total Standard Steel: L=10 m.	=	169	Nos.	
Total Standard Steel: L=12 m.	=	84	Nos.	

Appendix Table D37 Cutting Patterns by D-MinBars (SL. = 10 m. or 12 m.) of Example 5

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	9	12	1-L=11.87	0.13
2	6	12	1-L=11.76	0.24
3	6	12	1-L=11.70	0.30
4	9	10	1-L=9.26	0.74
5	9	10	1-L=9.11	0.89
6	18	12	1-L=8.41	0.09
			1-L=3.50	
7	13	10	1-L=6.56	0.42
			1-L=3.02	
8	15	10	1-L=6.32	0.18
			1-L=3.50	
9	12	10	1-L=6.24	0.26
			1-L=3.50	
10	6	10	1-L=6.06	0.44
			1-L=3.50	

Appendix Table D37 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
13	8	12	2-L=4.00	0.09
			1-L=3.91	
14	4	12	3-L=3.50	1.50
15	9	12	1-L=8.41	0.03
			1-L=3.56	
16	2	10	1-L=6.56	0.46
			1-L=2.98	
17	17	12	1-L=3.50	0.04
			3-L=2.82	
18	1	10	1-L=3.50	0.46
			3-L=3.02	
19	18	10	2-L=2.82	4.36

Total Standard Length	=	2,756	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	127.05	m.	
Percent Waste	=	4.61	%	
Total Standard Steel: L=10 m.	=	68	Nos.	
Total Standard Steel: L=12 m.	=	173	Nos.	

Appendix Table D38 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from D-MinBars: 24 Patterns, SL. = 10 m. or 12 m.) of Example 5

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	9	12	1-L=11.87	0.13
2	6	12	1-L=11.76	0.24
3	6	12	1-L=11.70	0.30
4	9	10	1-L=9.26	0.74

Appendix Table D38 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
5	9	10	1-L=9.11	0.89
6	1	10	1-L=6.56	3.44
7	2	10	2-L=3.50	0.02
			1-L=2.98	
8	3	10	2-L=3.56	0.06
			1-L=2.82	
9	15	10	1-L=6.32	0.18
			1-L=3.50	
10	69	12	1-L=3.50	0.18
			3-L=2.82	
11	3	10	1-L=3.56	0.40
			2-L=3.02	
12	12	12	2-L=4.00	0.09
			1-L=3.91	
13	6	10	1-L=6.06	0.44
			1-L=3.50	
14	26	10	1-L=3.50	0.46
			3-L=3.02	
15	24	12	2-L=4.00	0.12
			1-L=3.88	
16	12	10	1-L=6.24	0.26
			1-L=3.50	
17	27	12	1-L=8.41	0.09
			1-L=3.50	
18	14	10	1-L=6.56	0.42
			1-L=3.02	

Total Standard Length	=	2,698	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	69.05	m.	
Percent Waste	=	2.56	%	
Total Standard Steel: L=10 m.	=	169	Nos.	
Total Standard Steel: L=12 m.	=	84	Nos.	

Appendix Table D39 Cutting Patterns by C-MinBars (SL. = 12 m. only) of Example 5

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	3	12	3-L=3.02	0.12
			1-L=2.82	
2	1	12	2-L=3.02	0.00
			2-L=2.98	
3	12	12	3-L=3.02	2.94
4	23	12	3-L=3.50	1.50
5	4	12	1-L=3.91	0.97
			2-L=3.56	
6	12	12	2-L=3.88	0.74
			1-L=3.50	
7	3	12	2-L=3.91	0.68
			1-L=3.50	
8	72	12	1-L=4.00	1.00
			2-L=3.50	
9	9	12	1-L=9.26	2.74
10	6	12	1-L=11.70	0.30
11	6	12	1-L=11.76	0.24
12	9	12	1-L=11.87	0.13
13	6	12	1-L=6.06	0.10
			1-L=3.02	
			1-L=2.82	

Appendix Table D39 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
14	12	12	1-L=6.24	0.12
			2-L=2.82	
15	15	12	1-L=6.32	0.04
			2-L=2.82	
16	15	12	1-L=6.56	5.44
17	27	12	1-L=8.41	0.57
			1-L=3.02	
18	9	12	1-L=9.11	0.07
			1-L=2.82	
19	1	12	2-L=3.91	0.62
			1-L=3.56	
20	1	12	1-L=3.02	8.98

Total Standard Length	=	2,916	m.	Standard Length Selected: 12 m. only
Total Waste	=	287.06	m.	
Percent Waste	=	9.84	%	
Total Standard Steel: L=12 m.	=	243	Nos.	

Appendix Table D40 Cutting Patterns by D-MinBars (SL. = 12 m. only) of Example 5

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	9	12	1-L=11.87	0.13
2	6	12	1-L=11.76	0.24
3	6	12	1-L=11.70	0.30
4	9	12	1-L=9.26	2.74
5	18	12	1-L=8.41	0.09
			1-L=3.50	

Appendix Table D40 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	15	12	1-L=6.56	1.44
			1-L=4.00	
7	2	12	1-L=6.32	0.04
			2-L=2.82	
8	9	12	1-L=6.32	1.68
			1-L=4.00	
9	6	12	1-L=6.06	0.10
			1-L=3.02	
			1-L=2.82	
10	24	12	2-L=4.00	0.12
			1-L=3.88	
11	9	12	1-L=9.11	0.07
			1-L=2.82	
12	4	12	3-L=3.91	0.27
13	9	12	1-L=8.41	0.03
			1-L=3.56	
14	70	12	3-L=3.50	1.50
15	21	12	3-L=3.02	0.12
			1-L=2.82	
16	12	12	1-L=6.24	0.12
			1-L=2.82	
17	1	12	3-L=3.02	2.94
18	1	12	2-L=2.98	6.04

Total Standard Length = 2,820 m. Standard Length Selected: 12 m. only

Total Waste = 191.06 m.

Percent Waste = 6.77 %

Total Standard Steel: L=12 m. = 235 Nos.

Appendix Table D41 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from D-MinBars: 24 Patterns, SL. = 12 m. only) of Example 5

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	9	12	1-L=11.87	0.13
2	6	12	1-L=11.76	0.24
3	6	12	1-L=11.70	0.30
4	9	12	1-L=9.26	2.74
5	1	12	1-L=9.11	2.89
6	12	12	2-L=4.00	0.09
			1-L=3.91	
7	12	12	2-L=4.00	0.12
			1-L=3.88	
8	22	12	3-L=3.02	0.12
			1-L=2.82	
9	70	12	3-L=3.50	1.50
10	6	12	1-L=6.06	0.10
			1-L=3.02	
			1-L=2.82	
11	6	12	1-L=6.32	0.04
			2-L=2.82	
12	12	12	1-L=6.24	0.12
			2-L=2.82	
13	9	12	1-L=8.41	0.03
			1-L=3.56	
14	12	12	1-L=8.41	0.09
			1-L=3.50	

Appendix Table D41 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
15	18	12	1-L=6.56	1.44
			1-L=4.00	
16	9	12	1-L=6.32	1.68
			1-L=4.00	
17	8	12	1-L=9.11	0.07
			1-L=2.82	
18	4	12	3-L=3.88	0.36
19	1	12	2-L=2.98	6.04

Total Standard Length	=	2,820	m.	Standard Length Selected: 12 m. only
Total Waste	=	191.06	m.	
Percent Waste	=	6.77	%	
Total Standard Steel: L=12 m.	=	235	Nos.	

Appendix Table D42 Cutting Patterns by C-MinBars (SL. = 10 m. or 12 m.) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	12	10	8-L=1.24	0.08
2	116	12	4-L=2.99	0.04
3	64	12	2-L=3.25	0.02
			1-L=3.00	
			2-L=1.24	
4	138	12	2-L=3.25	0.03
			1-L=2.99	
			2-L=1.24	
5	61	10	3-L=3.30	0.10

Appendix Table D42 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	99	12	1-L=4.05	0.01
			2-L=3.35	
			1-L=1.24	
7	320	12	2-L=4.30	0.04
			1-L=3.36	
8	35	10	1-L=3.43	0.02
			1-L=3.30	
			1-L=3.25	
9	120	12	1-L=4.05	0.03
			1-L=3.43	
			1-L=3.25	
			1-L=1.24	
10	68	12	2-L=4.30	0.05
			1-L=3.35	
11	1	10	1-L=4.05	1.28
			1-L=3.43	
			1-L=1.24	
12	1	10	2-L=3.35	0.00
			1-L=3.30	
13	1	10	1-L=3.30	3.45

Total Standard Length	=	12,210	m.	Standard Length Selected: 10 m. or 12 m.
Total Waste	=	43.34	m.	
Percent Waste	=	0.36	%	
Total Standard Steel: L=10 m.	=	111	Nos.	
Total Standard Steel: L=12 m.	=	925	Nos.	

Appendix Table D43 Cutting Patterns by D-MinBars and ExcelTest (use the Possible Cutting Patterns from D-MinBars: 25 Patterns, SL. = 10 m. or12 m.) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	68	12	2-L=4.30	0.05
			1-L=3.35	
2	174	12	1-L=4.05	0.21
			2-L=3.25	
			1-L=1.24	
3	46	12	1-L=4.05	0.01
			2-L=3.35	
			1-L=1.24	
4	320	12	2-L=4.30	0.04
			1-L=3.36	
5	21	10	1-L=3.30	0.10
6	156	10	1-L=3.43	0.02
			1-L=3.30	
			1-L=3.25	
7	54	10	2-L=3.35	0.05
			1-L=3.25	
8	16	12	4-L=3.00	0.00
9	150	12	4-L=2.99	0.04
10	62	10	8-L=1.24	0.08
11	1	12	1-L=3.30	0.96
			2-L=3.25	
			1-L=1.24	
12	1	10	2-L=2.99	0.30
			3-L=1.24	

Total Standard Length = 12,240 m. Standard Length Selected: 10 m. or 12 m.

Total Waste	=	73.34	m.
Percent Waste	=	0.60	%
Total Standard Steel: L=10 m.	=	294	Nos.
Total Standard Steel: L=12 m.	=	775	Nos.

Appendix Table D44 Cutting Patterns by C-MinBars (SL. = 10 m. only) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	10	10	1-L=3.25	0.04
			1-L=3.00	
			3-L=1.24	
2	185	10	3-L=2.99	0.04
3	64	10	2-L=3.25	1.03
			1-L=3.00	
			2-L=1.24	
4	86	10	1-L=3.43	0.02
			1-L=3.30	
			1-L=3.25	
5	80	10	3-L=3.25	0.25
6	134	10	2-L=3.35	0.00
			1-L=3.30	
7	160	10	2-L=3.36	0.03
			1-L=3.25	
8	35	10	2-L=3.43	0.15
			1-L=2.99	
9	110	10	2-L=4.05	0.66
			1-L=1.24	
10	338	10	2-L=4.30	0.16
			1-L=1.24	
11	1	10	2-L=2.99	4.02

Total Standard Length	=	12,530	m.	Standard Length Selected: 10 m. only
Total Waste	=	363.34	m.	
Percent Waste	=	2.90	%	
Total Standard Steel: L=10 m.	=	1,253	Nos.	

Appendix Table D45 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from C-MinBars: 49 Patterns, SL. = 10 m. only) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	153	10	1-L=3.43	0.02
			1-L=3.30	
			1-L=3.25	
2	25	10	2-L=3.36	0.03
			1-L=3.25	
3	40	10	1-L=3.25	0.03
			1-L=3.00	
			3-L=1.24	
4	251	10	1-L=3.36	0.04
			1-L=3.35	
			1-L=3.25	
5	12	10	1-L=3.36	0.04
			2-L=3.30	
6	2	10	1-L=3.25	0.04
			1-L=2.99	
			3-L=1.24	
7	5	10	1-L=3.35	0.05
			2-L=3.20	
8	6	10	1-L=3.35	0.10
			1-L=3.30	
			1-L=3.25	

Appendix Table D45 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
9	5	10	1-L=4.05	0.12
			1-L=3.35	
			2-L=1.24	
10	2	10	1-L=3.36	0.14
			2-L=3.25	
11	388	10	2-L=4.30	0.16
			1-L=1.24	
12	26	10	1-L=3.30	0.20
			2-L=3.25	
13	2	10	1-L=3.43	0.22
			1-L=3.36	
			1-L=2.99	
14	1	10	1-L=3.43	0.28
			1-L=3.30	
			1-L=2.99	
15	1	10	2-L=3.00	0.28
			3-L=1.24	
16	1	10	2-L=3.36	0.29
			1-L=2.99	
17	1	10	1-L=3.36	0.29
			1-L=3.35	
			1-L=3.00	
18	18	10	2-L=2.99	0.30
			3-L=1.24	

Appendix Table D45 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
19	1	10	1-L=4.05	0.47
			1-L=3.30	
			2-L=1.24	
20	107	10	2-L=4.05	0.66
			1-L=1.24	
21	186	10	3-L=2.99	1.03
22	9	10	2-L=3.25	0.25
23	1	10	2-L=2.99	4.02

Total Standard Length	=	12,530	m.	Standard Length Selected: 10 m. only
Total Waste	=	363.34	m.	
Percent Waste	=	2.90	%	
Total Standard Steel: L=10 m.	=	1,253	Nos.	

Appendix Table D46 Cutting Patterns by D-MinBars (SL. = 10 m. only) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	388	10	2-L=4.30	0.16
			1-L=1.24	
2	110	10	2-L=4.05	0.66
			1-L=1.24	
3	134	10	2-L=3.35	0.05
			1-L=3.25	
4	160	10	2-L=3.36	0.03
			1-L=3.25	
5	21	10	3-L=3.30	0.10

Appendix Table D46 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	156	10	1-L=3.43	0.02
			1-L=3.30	
			1-L=3.25	
7	12	10	3-L=3.25	0.20
8	64	10	1-L=3.25	0.03
			1-L=3.00	
			3-L=1.24	
9	197	10	3-L=2.99	1.03
10	10	10	1-L=3.25	0.04
			1-L=2.99	
			3-L=1.24	
11	1	10	1-L=3.30	3.71
			1-L=2.99	

Total Standard Length	=	12,530	m.	Standard Length Selected: 10 m. only
Total Waste	=	363.34	m.	
Percent Waste	=	2.90	%	
Total Standard Steel: L=10 m.	=	1,253	Nos.	

Appendix Table D47 Cutting Patterns by ExcelTest (use the Possible Cutting Patterns from D-MinBars: 24 Patterns, SL. = 10 m. only) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	4	10	1-L=4.30	5.70
2	1	10	8-L=1.24	0.08
3	1	10	2-L=3.35	0.00
			1-L=3.30	

Appendix Table D47 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
4	156	10	1-L=3.43	0.02
			1-L=3.30	
			1-L=3.25	
5	160	10	2-L=3.36	0.03
			1-L=3.25	
6	133	10	2-L=3.35	0.05
			1-L=3.25	
7	21	10	3-L=3.30	0.10
8	13	10	3-L=3.25	0.25
9	198	10	3-L=2.99	1.03
10	386	10	2-L=4.30	0.16
			1-L=1.24	
11	110	10	2-L=4.05	0.66
			1-L=1.24	
12	64	10	1-L=3.25	0.03
			1-L=3.00	
			3-L=1.24	
13	8	10	1-L=3.25	0.04
			1-L=2.99	
			3-L=1.24	

Total Standard Length = 12,530 m. Standard Length Selected: 10 m. only

Total Waste = 363.34 m.

Percent Waste = 2.90 %

Total Standard Steel: L=10 m. = 1,253 Nos.

Appendix Table D48 Cutting Patterns by C-MinBars (SL. = 12 m. only) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	52	12	1-L=4.05	0.00
			1-L=3.36	
			1-L=3.35	
			1-L=1.24	
2	104	12	4-L=2.99	0.04
3	64	12	2-L=3.25	0.02
			1-L=3.00	
			2-L=1.24	
4	186	12	2-L=3.25	0.03
			1-L=2.99	
			2-L=1.24	
5	33	12	3-L=3.30	2.10
6	107	12	1-L=4.05	0.01
			2-L=3.35	
			1-L=1.24	
7	268	12	2-L=4.30	0.04
			1-L=3.36	
8	32	12	3-L=3.43	1.71
9	59	12	1-L=4.05	0.03
			1-L=3.43	
			1-L=3.25	
			1-L=1.24	
10	120	12	2-L=4.30	0.10
			1-L=3.30	
11	1	12	2-L=4.05	0.47
			1-L=3.43	

Appendix Table D48 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
12	1	12	2-L=3.35	0.76
			1-L=3.30	
			1-L=1.24	
13	1	12	1-L=3.25	7.51
			1-L=1.24	

Total Standard Length	=	12,336	m.	Standard Length Selected: 12 m. only
Total Waste	=	169.34	m.	
Percent Waste	=	1.37	%	
Total Standard Steel: L=12 m.	=	1,028	Nos.	

Appendix Table D49 Cutting Patterns by D-MinBars (SL. = 12 m. only) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	153	12	2-L=4.30	0.05
			1-L=3.35	
2	25	12	1-L=4.05	0.03
			1-L=3.43	
			1-L=3.25	
			1-L=1.24	
3	40	12	3-L=3.25	0.47
			1-L=1.24	
4	251	12	2-L=4.30	0.04
			1-L=3.36	
5	12	12	1-L=4.05	0.01
			2-L=3.35	
			1-L=1.24	

Appendix Table D49 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
6	2	12	3-L=3.30	0.86
			1-L=1.24	
7	5	12	3-L=3.25	1.01
			1-L=1.24	
8	6	12	2-L=3.25	0.02
			1-L=3.00	
			2-L=1.24	
9	5	12	4-L=2.99	0.04
10	2	12	2-L=3.25	0.03
			1-L=2.99	
			2-L=1.24	
11		12	1-L=4.05	1.22
			1-L=3.43	
			1-L=3.30	
12	1	12	1-L=2.99	7.77
			1-L=1.24	

Total Standard Length = 12,288 m. Standard Length Selected: 12 m. only

Total Waste = 121.34 m.

Percent Waste = 1.00 %

Total Standard Steel: L=12 m. = 1,028 Nos.

Appendix Table D50 Cutting Patterns by ExcelTest (Bring the Possible Cutting Patterns from D-MinBars: 24 Patterns, SL. = 12 m. only) of Example 6

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
1	1	12	1-L=3.25	8.75
2	116	12	4-L=2.99	0.04
3	91	12	1-L=4.05	0.01
			2-L=3.35	
			1-L=1.24	
4	128	12	1-L=4.05	0.03
			1-L=3.43	
			1-L=3.25	
			1-L=1.24	
5	9	12	3-L=3.43	0.47
			1-L=1.24	
6	6	12	3-L=3.36	0.68
			1-L=1.24	
7	73	12	3-L=3.30	0.86
			1-L=1.24	
8	9	12	3-L=3.25	1.01
			1-L=1.24	
9	302	12	2-L=4.30	0.04
			1-L=3.36	
10	86	12	2-L=4.30	0.05
			1-L=3.35	
11	64	12	2-L=3.35	0.02
			1-L=3.30	
			2-L=1.24	

Appendix Table D50 (cont'd).

Set No.	Number of Set	Standard Length	Pattern	Remain Portion
12	138	12	2-L=3.25	0.03
			1-L=2.99	
			2-L=1.24	
13	1	12	1-L=4.05	1.22
			1-L=3.43	
			1-L=3.30	

Total Standard Length	=	12,288	m.	Standard Length Selected: 12 m. only
Total Waste	=	121.34	m.	
Percent Waste	=	1.00	%	
Total Standard Steel: L=12 m.	=	1,028	Nos.	