Power Transformer Department

Core Steel Slitting Problem Analysis

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Production Control Services

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Objective

To devise an economically justifiable technique for minimizing the edge trim waste and/or the creation of excess inventory. At present there are apparently two quite different problems - slitting Silectron and slitting Trancor. For the Silectron there are many sizes (at 1/2" increments) available for slitting. But for the Trancor -- 85% of the stock is in 30 inch wide reels. Since efforts are being made to have the Silectron received in the same pattern as the Trancor and since the present Silectron losses are relatively small, the proposed solutions deal exclusively with the Trancor problem.

General Considerations

Various assumptions have been made in the proposed solutions:

1. If possible, no narrow width material should be generated. This is true whether or not there is to be a narrow-width customer.

2. Weekly reanalysis and processing will be continued.

3. Inventory limits will be established for each size at levels conducive to optimal profit.

4. A cost of carrying inventory figure will be established for comparative evaluation purposes.

5. Cost of waste losses for various widths will also be established (material plus applicable overhead less scrap credit).

6. The established principles of ABC inventory control will continue to be used.

Manual Techniques

The first key consideration is the amount of money the present plan is costing. Unless it can be reduced below its present level, there is little incentive for going to more elaborate computer-type solutions. At the point that operating costs (clerical expense, excess waste losses, and additional cut inventory) exceeds $500 to $1000 per week, detailed computer analysis would certainly be desirable. This will be more specifically discussed in later sections.

The present manual plan, of course, can undoubtedly be improved through establishing a more effective set of rules and a more formal computational procedure. This appears to be the most profitable approach to take -- that of modernizing the manual method.

This leads to two phases of the problem:

1. Planning a set of rules so as to maximize the opportunity for making effective utilization of available combinations and existing inventory.

2. Testing and evaluating the various sets of rules in some manner so that the best plan can be adopted.

With this background then, let us examine in detail one specific set of rules for solving the weekly Transformer steel slitting problem. Here are the key features of the plan:

. The basic analysis is in terms of an average or standard reel 30 inches wide.

. The inventory is expressed in terms of pounds/inch so as to provide a simple, consistent unit of measure.

. The requirements are expressed in terms of standard reels' worth, obtained by using pounds/inch as intermediate calculation.

. A table of all possible perfect combinations is generated prior to any processing. This encompasses only those sizes with net requirements during the week under consideration.

. The combinations problem is solved first in terms of standard reels.

. Next, actual reels are assigned to fulfill the cutting plan.

. Finally, an evaluation is made as to the amount of overage and waste generated. This is designed so as to permit cross-checking to catch errors in calculation.

With the high-lights listed above, let's now go through the step-by-step processing required.

1. In order to determine the weight of a standard reel for each week the inventory figures are added together and divided by the number of reels. This figure is then rounded up or down to give a convenient guide post. The poundage figure is then divided by the width to convert to pounds/inch.

2. The reels in inventory are then listed on a sheet in sequence by weight. Beside each pounds figure the equivalent pounds per inch value is placed. In a going business this can be simplified by maintaining a card file for reel inventory. There would be one card for each reel showing on it the reel number, the weight, and the pounds per inch. This file could be kept in sequence by weight and a special mark put on those reels which had been in stock for more than six weeks (see Exhibit A).

3. The requirements would continue to be determined in the same manner as at present with the gross requirements being reduced by existing cut inventories. These net requirements then would be converted to pounds per inch by dividing the pounds needed by the width needed. Requirements, in terms of this new

unit of measure, would then be divided by the average reel value. The resultant answer would tell the requirements in terms of number of reels' worth. Experimentation would probably indicate that some allowance could be made for a slitting variance from an integral number of reels. For instance, if the standard reel was 230 pounds per inch and the net requirements for a given size were 250 pounds per inch then the net requirements for that size could probably be expressed as 1+ reels rather than 2 reels. With this one exception, the rule would be to express requirements as the next highest integral number of reels.

4. A table of perfect combinations would be generated. This could be done by listing down the left hand margin the various sizes required for the week and combination numbers across the top of the work sheet. Starting with the largest size required you could then clerically determine the various combinations which go to make up a perfect 29-1/2 inch match. For instance, here is a sample set of rules used by one of our girls in deriving the 76 combinations (see Exhibit B for first 14) possible for the week of 3/18 which was analyzed.

   . Subtracted number working with from 29-1/2; used balance for checking combinations. If original number was small also subtracted two and three times its value from 29-1/2.

   . Kept a list of each of the numbers multiplied by 2, 3, and 4 to check additional combinations.

   . Remembered that 5-3/4 plus 4-1/4 equalled 10, often a good combination.

   Another approach for generating these combinations readily is by using a triangular graph (see Exhibit C). This might permit a more positive generation of combinations but would have to be approached with care in regard to preparation of the graphs and teaching girls their use. The main drawback to the graphical technique is that combinations using more than three individual sizes cannot be determined.

5. With a formalized work sheet showing the requirements, in terms of reels, for each size, specific combinations could then be selected. A suggested series of rules is:

   . Start with the greatest width.

   . Look up all perfect combinations for the width selected and write down the number of reels required for the mating widths. Select the best combinations on the basis of:
      a. total quantity of mating widths needed
      b. pounds per inch matching if all require less than 1 reel
      c. avoiding the generation of excess inventory in forbidden widths

- Post the number of reels to be cut of the combinations selected against each size effected. Keep a running balance of the remaining requirements for each width.

- Repeat the process until the problem is reduced to a few remaining sizes. At this time it may be necessary to use 28 inch reels or to generate excess inventory so as to meet the week's needs.

- After all requirements have been met certain alternate combinations may be tried to see if waste can be reduced or excess inventory generated in more usable widths.

A simple means has been devised for testing to see if a certain solution is the best possible. This is a negative type of test since it does not tell you how to get a better solution or even if a better solution can definitely be obtained, but it does tell you the absolute minimum number of reels which can be cut and the absolute minimum number of width-inches which will be surplus. This test is made by multiplying the number of reels required by the width of that requirement. These products are then added together and the total divided by 29-1/2. If there is any remainder after division, then the number of reels must be increased to the next integral value; the minimum amount of surplus width-inches can be calculated by subtracting the remainder from 29-1/2. This surplus can show up in any one of three ways:

- in the use of 28 inch reels.

- in the generation of excess edge trim.

- in the generation of excess inventory.

In the problem which was performed the minimum number of reels is 22 and the minimum excess width-inches is 21-1/2 (see Exhibit D).

6. With the combinations established the problem can then be reduced to simply selecting the right reels for the right combinations. This is aided by looking at the planned overages so that the smaller reels are used where the overage (total pounds) is the greatest. This procedure is quite systematic, but cannot be easily expressed in terms of a rigid series of rules. In general, you start by assigning any oversized reels needed, then by using the undersized reels where they will do the most good, and finally by fitting in other reels so as to minimize excess inventory (see Exhibit D).

7. With actual reels now selected, a specific evaluation and measurement of the effectiveness of the assignments can be made. This consists of comparing the excess edge trim and the excess cut poundage with the total pounds required for that week. In the example used the edge trim was reduced to the absolute minimum (1/2 inch each reel) and the excess inventory was reduced to less than 10% of the total requirements (see Exhibit E). An interesting point here is that a cross check can be made on the accuracy of

the data and calcualtions by computing the excess inventory figure in the following manner:

Total weight of reels to be cut less the edge trim less the net requirements in pounds per week yielding the excess inventory created.

This figure when compared with the summation of the last column on Exhibit E will show whether any errors have occurred. In the example which was used this technique discovered two errors in the data prepared by Operations Research. The first of these was in the computation of pounds per inches on the inventory values and the second is the net requirement for 14 inch material. This should have been 293 pounds per inch rather than 253. As can be seen this will change the result somewhat; however, it is anticipated that the amount of loss would, if anything, be decreased by this change.

In conclusion, then, the suggested series of rules could be processed in approximately 5 to 10 clerical hours after training and should yield systematically better results than the present procedure. In addition the format of the computation is such as to lend itself readily to computer optimization. Therefore, by following this type of program rather than the one suggested by Operations Research you will be getting ready to later pursue a more sophisticated and powerful solution.

Computer Simulation Technique

If a more thorough analysis and study is desirable, then the use of a computer (anywhere from a C.P.C. up to a 705 or UNIVAC) would be definitely justified. There are two levels at which a computer solution can be approached:

1. The purely theoretical, optimal solution derived through solving certain Linear Programming type equations. This will be discussed in more detail in the next section.

2. The second and probably more applicable technique is by programming a computer to solve the problem much the way the girl does today. The advantage, of course, would be in the speed with which a solution could be generated, the accuracy of the solution and the ability (time-wise) to experiment by comparing the results obtained through using different sets of rules.

If a controlled experiment were made using the data from about four widely different weeks, a definite statistically provable answer might result. This would answer two different questions:

- is one set of rules consistently better than any other set?

- how much spread is there between the results obtained from different techniques?

If one set of rules is consistently better than any other then this can be translated into an effective manual procedure. Or if there is very little difference between the various solutions then any one of the set of rules, performed manually, is perfectly adequate. However, if there is substantial spread and no one set of rules is always best, an operating computer solution might well be desirable on a going basis.

This particular project would have a high interest and reward level for the time spent. It would be a fine way for one of your people to become quite familiar with computer programming and processing since the design of an experiment involves a logical simulation of the manual procedures.

There are a number of reasons for doing this type of comparative evaluation on a computer. They include the ability to set up a relatively rigorous and specifically defined procedure, the elimination of personal bias and manual errors and the ability to operate with a controlled mix during a comparatively short period of time.

In setting up such a project it would probably be desirable to have consultative assistance in the original programming and experiment design. This will enable you to get the show on the road more quickly and less expensively with more assurance of usable worth-while results.

Mathematical Optimal Solutions

It was suggested that the slitting problem might be solved through the technique known as Linear Programming. However, the approach generally used in this type of problem produces matrices (tables) so large as to be unwieldy and expensive to solve. It is our concept that this problem can be handled on an optimal basis by separating it into two phases, similar to what was done in the manual technique. By a method known as "Transportation Solution" the combination selection problem could be performed on a computer with the guarantee that the best combinations would be chosen. Secondly, the specific inventory assignment problem could be handled through a manual "Simplex" solution method.

Although the techniques described above are in advanced mathematical areas it has been demonstrated by a group at Carnegie Tech and at the RAND Corporation that these methods can be readily taught to operating people; moreover the actual solution techniques have already been programmed for various computers.

If it is desired to pursue this final approach, it would be necessary to have professional mathematical assistance so that the problems could be set up right in the first place; however, if the losses are great enough, this type of research might well be warranted and could pay dividends of a high magnitude.

Summary

With all this discussion then, the following recommendations are made:

1. The present manual system be improved through the adoption of an effective set of rules and a formal computational routine. The plan described in this writeup might well serve as a basis for a better manual approach.

2. If a more thorough analysis is desired, then work should be initiated on a computer simulation experiment. This would permit provable selection of the best set of rules and possibly continue with actual use of the computer for week-to-week answers.

3. Finally, if a real research project is desired, work should be initiated on the possibilities of a Linear Programming type solution to the problem.

Exhibit A

In Stock

TRANCOR STEEL

"Mill Coils"

Week Ending 3/18

28" Reels		30" Reels		30" Reels	
Pounds	Pounds/in.	Pounds	Pounds/in.	Pounds	Pounds/in.
6940	248 X	4700	157 X	7260	242
7100	254	4900	163 X	7280	243
		4950	165 X	7320	244
		5120	171 X	7320	244
		5170	173	7340	244
		5340	178	7360	245
		5440	181	7400	247
		5620	187	7400	247
		5740	191 X	7440	248
		6050	202 X	7460	249
		6100	204	7500	250
		6130	204	7500	250
		6200	206 X	7540	251
		6220	207 X	7560	252
		6220	207 X	7560	252
		6220	207	7560	252
		6320	211 X	7600	253
		6430	214 X	7600	253
		6520	218	7600	253
		6620	221	7620	254 X
		6660	222	7620	254
		6700	223	7700	256
		6700	223	7700	256
		6740	224 X	7780	259
		6820	228 X	7800	260
		6850	228 X	7820	260
		6880	229 X	7840	261
		7060	236 X	7900	263
		7140	238 X	7950	265 X
		7140	238	7980	266 X
		7200	240	8120	271 X

"X"ed coils used in week's cutting

TABLE OF 30" COMBINATIONS

Exhibit B

Comb. #	1	2	3	4	5	6	7	8	9	10	11	12	13	1
Max Width	16				14						13			
16	1	1												
14			1	1	1	1	1							
13								1	1	1	1	1	1	1
12														
11-1/2														
10-1/2								1						
10			1						1					
9-1/2				1										
9					1					1				
8-1/2											1			
8		1				1					1	1		
7-1/2	1					1				1				
6-1/2					1				1				1	
6	1			1				1						
5-3/4							1						1	
5-1/2		1	1				1							3
4-1/4							1					2	1	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0

30" Reel Selection Graph

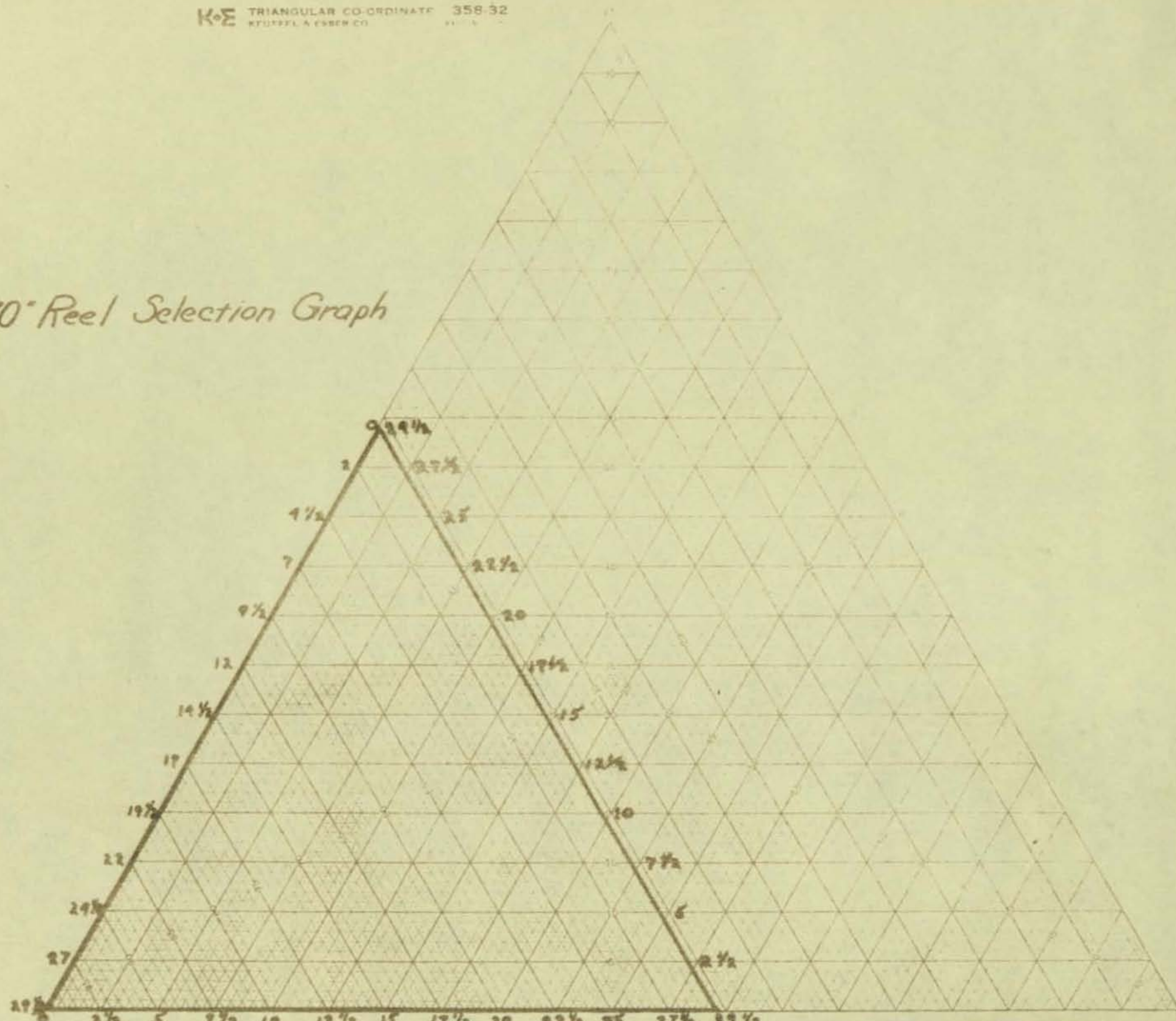

Exhibit C

REEL COMBINATION SELECTION TABLE

Exhibit D

Comb. # → Width	Regts	1	5	13	15	24	29	25	26	41	35	56A	101	58A
16	1	1												
14	1*		1											
13	1			1										
12	5				3	2								
11-1/2	13				3		3	2	5					
10-1/2	5							2		2	1			
10	5								5					
9-1/2	4										2		2	
9	7		1				6							
8-1/2	4											1	1	2
8	5								5			1		
7-1/2	4	1						2				1		
6-1/2	3		1	1										1
6	4	1			3									1
5-3/4	1			1										
5-1/2	1*					1						1		
4-1/4	3			1						2				
Reel Width		30	30	30	30	30	30	30	30	30	30	30	28	30
No. of reels		1	1	1	3	1	3	2	5	1	1	1	1	1
Restrictions			≥253											
Weight reels (#/in) ↓		163	254	157	207 214 224	165	191 207 211	271 266	228 228 229 236 238	202	171	206	248	265

Transformer Slitting

- $600 per week loss beyond edge trim
- Distribution Transformer 20 ton per week $8000 per week
- Feel that they need a narrow width customer

transportation and prepare for ship

If no narrow width customer lose 10/ton/ ~~width~~ week instead 1 1/2 ton

5 hrs/wk on Combination and determination

Little cost associated with excess size generation --
if Cost of Carrying inventory = 25% per year
1 extra week stock of N$
Extra Cost = N$ x $\frac{1}{52}$ x 25% = ($\frac{1}{2}$ of 1%) N$
if N$ = $\frac{1}{5}$ $ Used or Extra Cost = .1% of $cut

$120, 000 per wk
. 1% = $120 per wk

carrying 1 1/2 wk cut size inventory

$\frac{3/2}{52}$ x 25% x avg. weekly wage (3/4 of 1%)
= $800 per wk

How to measure comparative solutions

Different problem Trancor-Silectron today since width available in Silectron

always pick combination weights (for cutting) from central portions of
wt distribution -- use 6000 + 6000
ie rather than 5000 + 7000

. Line up Inventory by wt ascending sequence
. Use equivilent length U/M (#/in, ft)
. Formal L/o -- patterned calculation
. Triangular graph for discovering possible combinations -- up to 3 (+ doubles) sizes
. optimal -- reduced size -- Transportation -- Solution
. Testing -- Computer -- Solution . . .
1. if variance low
2. or 1 set of rules consistently better than manual solution best answer; if neither 1 nor 2 is true then computer analysis weekly advantageous
. Manual
Separate Inventory Selection from combination selection problem by using a standard size reel 30" x 7000 lbs.
Translate req'ts to Reel Multiples - (next largest)

T. T. Kwo

Use continuous roll -- stipulating a min length to cut - (smallest reel)

Sizes/Combinations = perfect

Minimize Excess & Wastage

Transportation Solution of Combination Selection
Matrix

combinations

Sizes	1	2	3	......	Reels worth Req'ts	~~Bk~~ Excess Reels
	x	x	x			
	x	xx				
			x			
	x					
		x	x			
Unwanted Sizes						

pick 1st set; try alternates
evaluate per excess reels (wanted - unwanted sizes)

Inv. weights ascending seq. group by #200 range	Selected Combinations							No. of reels Available
reels to cut.								

Measurement technique
- Linear vs. non-linear cost evaluation
- $ summary of various costs
  - excess
  - wastage
  - setups
  - inventory

Computation Procedure Improvement

Test to see what happens if no small size customer

General Proceedings of the Power Transformer
Lamination Steel Slitting Problem

June 20, 1955
Manufacturing Services Division
Production Control Services
New York City

General Proceedings of the Power Transformer Lamination Steel Slitting Problem

Called By .... Production Control Services

Time & Location .... June 20, 1955 at the New York Office

Participants

Mr. R. Habermann, Jr. Analytical Eng. Apparatus Sales	Mr. H. F. Dickie Production Control Services
Mr. W. Hoag Power Transformer Dept.	Mr. D. C. Dopp Production Control Services
Mr. T. T. Kwo Home Laundry Department	Mr. B. Grad Production Control Services
Mr. F. C. McClintock Power Transformer Dept.	Mr. E. C. Throndsen Production Control Services
Mr. R. W. Newman Operations Research & Synthesis	

Problem Presentation and Current Approach

Details of the problem, which were initially set forth and distributed by Mr. Throndsen in May, were restated by Mr. McClintock. Important facts highlighted were:

1. Current steel usage is approximately 175 tons per week with an anticipated rate of 300.

2. Based upon the expected rate of 300 tons, the past six months have shown a loss of $600 per week in scrap beyond the normal edge trim. This is approximately 1/2 of 1% loss.

3. Until recently, Distribution Transformer was taking 20 ton per week of the narrow widths.

The current method of solution was presented by Mr. Hoag who distributed a set of working papers used during the preceding week.

New Approaches

After briefly exploring a computer application and indicating the problem was too vast for an optimum solution by present day methods and equipment, Mr. Newman presented a formalized manual approach somewhat similar to the current one.

Assumptions were made (stated in his write-up distributed at the meeting) which they felt necessary to define the problem and framework within which to operate. Using one of the assumptions, that coil width and length may be treated separately, they sought a normalizing process and decided upon lbs. per inch (i.e., the equivalent weight of a coil one inch in width). This converted the unit of measure to one that may be more readily handled and visualized.

Thirteen operating rules were formalized to use as a guide in making the combinations and reel selections. These rules were not considered to be final as product conditions could change which would warrant their review. Likewise, since the rules were based upon the original assumptions, a change in management policy would necessitate a reappraisal of the operating rules.

One way to evaluate the performance of a system would be to plot on a control chart the ratio of certain critical quantities. So long as the points remained within the limits established, no action would be required; out of limits would require investigation by supervision before releasing the slitting schedule.

Mr. Newman felt he would like to do more testing on his approach and would keep us informed of the results.

Mr. Grad stated he thought there were 3 possibilities, dependent upon the amount of loss.

1. There is the possibility for a computer solution if the losses become great. However, because a purely optimum solution is not considered feasible at this time the problem could be approached by making all known perfect combinations manually and then forming a matrix of the remaining sizes for a computer solution.

2. The possibility of a testing procedure on a computer also exists. This would allow the rapid testing of a number of different rules or sets of rules each week to determine if one set is consistently better than others or if there is very little spread in the results and no one set the best.

3. An improved and formalized manual system may well provide the immediate answer. This is explained more fully and an example shown in an attachment by Mr. Grad.

Mr. Kwo held somewhat the same views expressed by Mr. Newman and Mr. Grad about the improbability of a perfect optimum solution on a computer. If, however, the size of the matrix could be reduced to approximately 20 by 150 it would then be feasible for known computer programs. One way of reducing the combinations would be to assign each size a weighted factor and then eliminate all those below a certain figure. The remaining sizes could be solved by a computer leaving the others for a manual solution since their importance would be relatively small.

Mr. Haberman suggested that in a linear program or iterative technique it is possible to stop the solution somewhere near the lower end and still be close to a working value since the perfect solution may not warrant the extra expense.

He also emphasized the need for an evaluation or measurement of any method to maintain control of the operation. One such unit of measure would be that of dollars. This could be arrived at by assigning an ascending value with time to excess inventory, an inventory carrying charge, and the dollar value for scrap.

It was pointed out that some economic basis might be found for developing small width users as a means of reducing excess inventory or losses.

Summary

Evolved from the meeting were these two important points:

1. A solution approach.

2. A concept of management.

It was pointed out that since the only thing gained by an optimum solution in the middle sizes is less excess inventory, it would be more economical to sub-optimize. In that regard, it was considered most expedient to improve and formalize the manual system and concurrently maintain very close control over the procedure and results in order that it may be reevaluated at a later date for a mechanized approach.

To determine if it will be necessary for the department to have a narrow width outlet, it was suggested that the previous months could be tested, disregarding the outlet, and determine the trend and position they would be in today. The possibilities of cultivating a narrow width outlet on an economic basis should also be considered if it is shown that too much excess inventory is created.

It was considered extremely important that some type of measurement be established and maintained that would give the magnitude of dollars involved in the operation since the application of a computer is dependent almost solely on the possible savings to be realized.

Mr. Throndsen stated that if a decision was made in view of subsequent evaluations to employ a computer, the Production Control Services would be glad to assist in the programming or in what ever ways possible.

D C Dopp

E. C. Throndsen/D. C. Dopp - PRODUCTION CONTROL SERVICES, Materials Services Department - 570 Lexington Avenue

New York, June 14/55
RW Newman/h

STEEL SLITTING PROBLEM

Introduction

E. C. Throndsen, Consultant, Manufacturing Consulting Services, asked OR & S for a solution to the Power Transformer Department's problem of slitting large steel Mill Coils. A copy of the data supplied by Mr. Throndsen, together with a May 20, 1955 supplement is attached as Appendix "J".

Each week the sizes of steel required for the following week's manufacture are accumulated and a clerk attempts to assign each size to one or more of a series of Mill Coils then in stock. This selection is done to minimize the scrap losses and maintain the minimum inventory of rarely used sizes and a minimum to nominal inventory of the larger and more frequently called for sizes. Wastage has been averaging about 4½ tons of steel per week which represents about $90,000 loss per year. Management is additionally concerned less changes in product mix suddenly cause much greater losses and inventory unbalances.

We do not consider the slitting problem the basic one in this area: it is a symptom rather than a cause. Forty individual laminations are currently required to manufacture the power transformer line. It is apparent that this great variety of material requirements, manifesting itself in this one area in the form of a slitting difficulty, is symptomatic of a disease which must be hampering the entire manufacturing activity. More comments will be made on these factors later.

Basis of Approach

Four central ideas have dominated our concept of the slitting problem:

I. Wastage, as distinguished from excess inventory, occurs from not utilizing the total width of the Mill Coils.

II. For the purposes of manipulation, coil width and length (weight) may be treated separately.

III. The pattern of usage shows a large enough variation in required widths so that (in general) no width need be lost as scrap except the ¼" trim of each edge.

IV. The smaller sizes which Management does not wish to have in inventory in excess of current requirements can be kept at very low overage by matching them against the best possible combination of available coil lengths.

Methodology

Our solution can best be understood by following through a typical calculation. For this purpose, actual data were abstracted at random from those supplied by Mr. Throndsen. Exhibit A of Appendix J gives the requirements of Transcor Steel to meet the needs of the week starting 2/28/55. Exhibit C, Page 1 of the same report gives the inventory of Transcor Mill Coils in stock for the week ending 3/18/55. (These data are the nearest to the date of 2/28/55 which were supplied.)

Proceed as follows:

I. Record the coil sizes required for the week as indicated in Appendix K. Underline those sizes for which a minimum overage is wanted as determined by Management. (Appendix J, Supplement Page 1, Rule 9 a and b.)

II. Below the coil sizes, record the required pounds of steel for that size.

III. Subtract the pounds of these sizes currently in inventory to determine the amount for cutting.

IV. Convert these to equivalent "lengths" (equivalent pounds of s strip 1" wide) by dividing the weight required by the width of each coil size. The sizes have now been normalized and may be manipulated by adding and subtracting.

V. Arrange the weights of the available Mill Coils in weight order (by widths) as indicated in Appendix L. Divide these weights by the width of the Mill Coils. The resulting "lengths" are now on the same basis as the required slit coils.

VI. It is immediately apparent that some overage must be made. A "length" of only 16 units is required of the 13" size and the shortest Mill Coil is 160 units.

VII. There can be no wastage (as distinguished from overage) if coil sizes are chosen so that these widths add up to the useful width of the Mill Coils. The slitter must take a $\frac{1}{4}$" trim on each Mill Coil edge to result in a straight, accurate cut. Therefore, the useful width of the coil is currently $\frac{1}{2}$" less than the Mill Coil width.

> <u>DECISION RULE 1</u>. CHOOSE ONLY COMBINATIONS FOR SLITTING WHICH ADD UP TO THE FULL USEFUL WIDTH OF THE MILL COIL.

VIII. It is more difficult to find the combinations which meet the criteria of Decision Rule 1, as the size of the required slit coil increases or as the width of the Mill Coil decreases: therefore, start by making matched sets utilizing the larger coils, and dispense with them at a time when sufficient sizes are available for matching. A good breaking point seems by inspection to be the 12" size. (Experience may dictate larger sizes than 12" to be the "break even point" in this respect.)

> <u>DECISION RULE 2</u>. CHOOSE THE LARGEST COIL SIZE FOR MAKING THE FIRST MATCHED SET.

In the example being considered, 16" was the largest size: 75 units are required. By inspection, it is economical to utilize the shortest coil length (160 units as shown in Appendix L) for the 5 3/4 coil, as this has heavy inventory restrictions upon it. The 169 unit length coil was chosen and matched with 6" and $7\frac{1}{2}$" coils to meet the criterion of Rule 1.

> <u>DECISION RULE 3</u>. CONTINUE THE PROCESS OF ELIMINATING THE LARGER SIZES DOWN TO BUT NOT INCLUDING 12" WIDTH.

IX. It is advantageous to choose coils from stock which match as closely as possible the actual length of steel required. This, in general, can be done by inspection. The process can be simplified by dividing the total length required by 2, 3, etc. until lengths near the medium length in stock is obtained. It is then fairly easy to match the required lengths by addition or subtraction.

> DECISION RULE 4. MATCH THE LENGTH OF A SIZE AS CLOSELY AS PRACTICAL (THIS GENERALLY MEANS WITHIN A UNIT OR TWO) WHEN THAT SIZE WILL BE DEPLETED BY THE PARTICULAR SLITTING INVOLVED.

X. The Mill Coil lengths near the medium lengths are less valuable for manipulative purposes, and reduction of overages, than those at the extremes. It is, therefore, desirable to utilize the coil length toward the middle of the region whenever practical.

> DECISION RULE 5. WHENEVER PRACTICAL, CHOOSE COIL LENGTHS NEAR THE MIDDLE OF THE COIL LENGTH DISTRIBUTION.

XI. The coil widths inventory which Management wishes to control most strictly should be paired next, since the available matching sizes and the distribution of coil lengths are greater at this point.

> DECISION RULE 6. WHEN THE LARGER SIZES ARE COMPLETED, MATCH THE SIZES IN WHICH INVENTORY SHOULD BE MOST STRICTLY CONTROLLED.

XII. The $\frac{1}{4}$" sizes, must in general, be doubled or matched with each other to permit Rule 1 to be fully utilized.

> DECISION RULE 7. MATCH THE $\frac{1}{4}$" SIZES WITH EACH OTHER OR THEMSELVES.

> DECISION RULE 8. THE SIZES WHICH ARE MOST STRINGENTLY CONTROLLED, INVENTORY-WISE, SHOULD BE GIVEN PREFERENCE AS FAR AS SHORT COIL LENGTHS ARE CONCERNED.

XIII. It is easier to balance out the coil widths if no one width requirement is enormously greater than the others.

> DECISION RULE 9. PREFERENCE SHOULD BE GIVEN TO THE COIL SIZES REQUIRED IN GREATEST QUANTITY FOR MATCHING FIRST. MULTIPLE CUTS OF THESE SIZES SHOULD BE MADE WHEREVER POSSIBLE.

XIV. It may be necessary to make a decision between purposely creating scrap, (i.e. in failing to meet the criterion of Decision Rule 1) or making a size for inventory. Management has made a decision that a maximum of one week's probablistic inventory of the strictly controlled sizes and six weeks' inventory of other sizes can be permitted. On these bases (the rationalism of which can be questioned) a decision rule may be formulated.

DECISION RULE 10. IN CASE IT IS NECESSARY TO CONSIDER CUTTING COILS IN A WAY NOT TO UTILIZE THE FULL USEFUL WIDTH OF THE MILL COILS, THE DECISION MAY BE MADE BY MEANS OF THE EXPRESSION:

$$Z = I - P + Q\,(W - S)$$

I = Inventory ceiling of the size, pounds

P = Present inventory of this size, pounds

Q = Weight of mill coil being slit, divided by its width

S = Size of coil in inch widths which will be created

W = Waste which would be created by not choosing a matching size. (i.e. adding up to useful width of mill coil inches

Z = Decision function: make waste if positive; make inventory if negative

This follows, since we are comparing the loss in pounds of material by not utilizing the full Mill Coil to the loss caused by obsolescense of inventory as defined by Management:

QW = pounds which would be scrapped as waste

$P + QS$ = pounds inventory after cutting size S

$(P + QS - I)$ = pounds which are waste by Management decision actually = $\not{f}\left(\frac{P + QS}{I}, I, P + QS\right)$

$$Z = QW - (P - QS - I)$$

$$Z = I - P + Q\,(W - S)$$

XV. It is advantageous to reduce the number of set ups to a minimum for three reasons:

A. Set up labor cost

B. Inefficient utilization of machinery which may require second or third shift operation

C. Idle, or poorly used, production labor during set up period.

DECISION RULE 11. WHENEVER POSSIBLE, CHOOSE MATCHING SETS WHICH WILL PERMIT MULTIPLE USE OF THE SAME MACHINE SET UP.

The cost of set ups at the present time is calculated at \$5.00 each. This is equivalent to the cost of 25 pounds of steel. Since this is a small item, it was not felt necessary to express this decision in what would be complex mathematical terminology.

XVI. When the sizes over 12" and the strictly controlled inventory sizes have been scheduled, it is advantageous to total the "lengths" of each size and determine the balance of sizes now required, as shown in Appendix K.

XVII. If it is not obvious how to best slit the remaining sizes, a simple matrix-like tool can be used. This tool may be expanded to permit a mathematical solution. It is not felt that this will normally be required. The process and the equations are shown in Appendix M.

> DECISION RULE 12. THE REMAINING SIZES MAY BE MATCHED BY MEANS OF A MATRIX IN WHICH THE ROWS ADD UP TO THE USEFUL MILL COIL WIDTH AND COLUMNS REPRESENT THE REMAINING SETS OF COILS TO BE MATCHED FOR SLITTING. ALL POSSIBLE COMBINATIONS OF THESE COILS, INCLUDING MULTIPLE USAGE OF INDIVIDUAL COIL SIZES SHOULD BE INDICATED. TOTAL THE NUMBER OF MARKS IN THE COLUMNS: FOR THIS PURPOSE A MULTIPLE MARK SHOULD BE COUNTED BUT ONCE. THE COIL SIZE TO BE CHOSEN FIRST SHOULD BE THE ONE WITH THE MINIMUM NUMBER OF AVAILABLE SLITTING POSSIBILITIES.

In the example there are only two ways of cutting the 9" coil, so it was chosen first. The matrix is a convenient method for systematically indicating combinations which are exhausted by the depletion of a coil size. In the example, (1) is placed over the 10" and the $10\frac{1}{2}$" columns, since these are consumed in completing the 9" requirements. The notation (1) is placed opposite the rows using the 10" and $10\frac{1}{2}$" sizes, as shown next to rows A, D, E, H, I, J, K, L and M. None of these rows may be utilized without increasing the inventory. Similarly, as the 9" coil is completed, a (2) is put on top of that row and possibility "F" is eliminated.

Tri-axial graph paper, one sheet for each useful Mill Coil width, could help in giving the additive information to complete the matrix. All the coil sizes used, and their multiples, would be marked on the lines of the graph. The intersections with the size being matched will represent one or two matching sets of coils meeting Decision Rule I.

XVIII. The remaining sizes may require a repetition of the matrix technique, choosing if needed, sizes for making matching sets which are in low inventory. By definition, the size being cut during the particular week have been at zero inventory. It is desirable to choose these sizes, not only from this viewpoint but because it will mean less handling of additional sizes in the warehouse, less record keeping, etc.

> DECISION RULE 13. CHOOSE MATCHING SETS FROM THE SIZES REQUIRED FOR THE WEEK'S SLITTING WHENEVER THIS WILL NOT INCREASE THE INVENTORY ABOVE THE LIMIT SET BY MANAGEMENT.

A purely mathematical solution to the problem might be obtained by generalizing the matrix technique, indicated under point XVII, expanding to include all of the combinations and the requirements of the original problem. The larger matrix required, and difficulties involved in stating boundary conditions result in an advantage for the procedure outlined previously.

Closing the Feed Back Loop

It must be recognized that some of the Decision Rules may well be arbitrary and must be checked against actual experience. The results must be compared and fed back so as to reassess these rules on a continuing basis. A convenient method of reassessment is the utilization of the Shewart Control Chart technique. Four charts should suffice, although a fifth chart might prove useful. The functions proposed in these charts are crude approximations to reality, but are capable of predicting trends which might prove disastrous if not watched.

Each week, these data should be plotted before slitting:

Chart I $\dfrac{\text{Pounds of excess material to strictly controlled inventory}}{\text{Total pounds cut}}$

Chart II $\dfrac{\text{Lbs. excess material to less strictly controlled inventory}}{\text{Total pounds cut}}$

Chart III $\dfrac{\text{Lbs. material to waste}}{\text{Total pounds cut}}$

Chart IV $\dfrac{\text{No. of set ups}}{\text{No. coil sizes required}}$

Chart V $\dfrac{\text{Time required to make calculations}}{\text{No. of coil sizes required}}$

It is probable that better criteria can be found. Neither the number of coil sizes nor the number of pounds to be cut is an entirely adequate normalizing factor. (Chart V, for example, is also a function of the number of Mill Coils in stock since they require calculation time.) The assumption that these are linear ratios must be checked by experience. The charts, however, should give warning signals and indicate general trends, or changes in environment and product mix, which require Rule modifications.

If any of the Charts I to IV are out of control for the week, the operator of this system should be instructed to report to her Supervisor before ordering the slitting operation. If out of control for two consecutive weeks, the Rules should be reexamined. In this way, no large changes in scrap or inventory can occur without Management being aware <u>before</u> it occurs.

The General Problem

The reader will recognize in much of our solution to this problem an approach which might have been developed by a Procedures Section. A procedure is static. Feedback helps to turn a partially static solution into a dynamic one: it in itself, however, cannot do the whole job. Isolated problems do not stay solved unless they are being restudied constantly and factored into the pattern of the whole business operation.

We offer a solution to the problem raised: but is it really the problem? This must be symptomatic of a whole series of related problems which in their addition are more involved than their simple arithmetic sum.

Forty sizes of laminated strip are required for the Power Transformer Product line. This raises some questions, though perhaps the wrong specific ones. Pure intuition, based on our past experience, and with limited knowledge of the transformer business structure, makes us concerned about this large variety of coil sizes.

We can visualize forty styles of winding forms, forty sets of tie rods, forty shapes of insulated cores, forty groups of insulated bolts, forty tank sizes and forty sets ad infinitum, all moving about in a manufacturing area, looking for their proper home: storage difficulties, inventory control problems, stock records and paper work forms, pile-upon-pile, wondering if they are in the optimum quantity and in the correct place at the right time. What does this variety cost in delivery time, in customer service, in inability to rearrange production schedules?

Why are these large variety of parts required? If it is economic to have forty lamination sizes, why not eighty? What could be saved by reducing them to twenty? to ten? Is the basic cause of the variety a marketing one, a somewhat arbitrary industry "standardization" or are engineers sub-optomizing theoretical engineering factors resulting in almost unmanageable manufacturing variety? Do we have the correct impedence match between the engineering design, available manufacturing methods, and the market? Have we logically structured our manufacturing, engineering and marketing activities into the larger business pattern?

What is the real function of the power transformer? What does the customer think he wants? Does he know or does he specify from habit? Can we teach him to specify rationally? What patterns of power usage will develop? What sizes will be required for use tomorrow? How can general patterns of these real needs be developed in the light of Design and manufacturing problems so as to optimize the whole Power Transformer Department operation rather than the efficiency of an engineering idea or a slitting machine? What are the underlying economic facts of this business?

It would appear that these problems, these questions, are the ones requiring a solution. They seem to be the fundamental ones where many times more returns are available in an area pregnant with possibilities.

These problems can be faced only by continued study and research into the operations and in day-to-day contact with the actuality of the business structure of the Power Transformer Department.

Appendix K

WEEK STARTING 2/28/55

Trancor Steel

Coil Size Wanted	4½	5½	5 3/4	6	6½	7½	8	8½	9	9½	10	10½	11½	12	13	14	16	Set Up No.	Total Cut Inches	Coil 28"	Coil: 30"	Waste Excluding ½" Edge	Notes
Pounds Needed	4800	1300	1200	4400	4400	8100	8600	7200	13050	7700	10500	10000	33900	11700	200	4100	1200						1
In Inventory	2400		500			1300																	
Pounds Required	2400	1300	700	4400	4400	6800	8600	7200	13050	7700	10500	10000	33900	11700	200	4100	1200	129					2
Pounds/Inches	533	237	122	735	675	906	1075	846	1450	810	1050	953	2950	975	16	253	75						
				169		169											169	1	29½		169	0	3
						170	170									170		2	29½		170	0	
						171	171									171		2	29½		171	0	
					169						169				169			3	29½		169	0	4
	160		160					160						160				4	29½		160	0	5
	191 x 2								191				191					5	29½		191	0	6
		240		240	240								240					6	29½		240	0	7
					266								266 x 2					7	29½		266	0	8
								227		227			227					8	29½		227	0	
								227		227			227					8	29½		227	0	
								232		232			232					8	29½		232	0	
Total Cut	533	240	160	409	675	510	341	846	191	686	169	0	1649	160	169	341	169						9
Balance Needed	0	- 3	-38	326	0	396	734	0	1259	124	881	953	1301	815	-153	-48	-89						10
									258		258	258						9	29½		258	0	11
									257		257	257						9	29½		257	0	
									225		225	225						9	29½		225	0	
									211		211	211						9	29½		211	0	
									182 x 2				182					10	29½		182	0	
				276									276	276				11	29½		276	0	12
				271									271	271				11	29½		271	0	
							268			268				268				12	29½		268	0	
Sub Total Cut				547			268		1317	268	953	953	730	815									
Balance Needed	0	-3	-38	-221	0	396	466	0	-58	-144	-72	0	671	0	-153	-48	-89						
							2 x 253						253					13	27½	253		0	13
						211					211		211					14	29½		211	0	
						207					207		207					14	29½		207	0	
Sub Total Cut						418	506				418		671										
Overage	0	3	38	221	0	22	40	0	58	144	490	0	0	0	153	48	89						
Weight of Overage	0	16	218	1326	0	165	320	0	422	1370	4900	0	0	0	1990	670	1330						14
Theoretical Min.Over.	X	X	X		X			X				X	X	X	X	~~X~~ ?	~~X~~ ?						15

22 reels cut

N O T E S

1. Sizes doubly underlined are to be kept to less than one week's inventory overage: the strictly controlled sizes.

2. Actual data showed for $7\frac{1}{2}$" size 7100# needed, 1300# in stock, 6800# required. 7100# should have been 8100#.

3. Start with large size as it is hardest to pair, but since overages are not too critical on this "wanted size", it is not minimized at expense of the 5 3/4" size which should use shortest mill Coil.

4. Strictly controlled sizes (i.e., the $6\frac{1}{2}$") are not chosen for pairing with the large sizes unless there is enough of this size remaining after the pairing to match with at least two full mill Coils.

5. The $\frac{1}{4}$" sizes can only be matched among themselves. They are matched next. The 160 mill Coil is the shortest in stock so no better one can be used - i.e., excess in the 5 3/4" size is at theoretical minimum.

6. The other $\frac{1}{4}$" size is disposed of, using the $11\frac{1}{2}$" as a match, as more of it is required than any other size.

7. 237 is needed of the strictly controlled $5\frac{1}{2}$" Coil. The nearest size mill Coil to cover it is 240. This is a theoretical best match.

8. The high demand $11\frac{1}{2}$" size is used whenever possible.

9. This completes the "large sizes" and the strictly controlled sizes. A "trial balance" indicates the additional Coil sizes and lengths required.

10. The negative signs show overages.

11. A "matrix" of the possible $29\frac{1}{2}$" sets is made of the remaining sizes. This is attached as Appendix M. There are only two possible 9" combinations, so this size is matched first.

12. The 12" size has the next fewer number of possibilities so it is completed.

13. Try combinations of $7\frac{1}{2}$", 8", $11\frac{1}{2}$", including the use of the 28" strip. Use any other needed size slit that week to match, if necessary. If no match can be found, use a matching size from the less strictly controlled sizes in low inventory. This approach is required as the matrix is now filled.

14. Only 234 pounds were generated in strictly controlled sizes. No scrap was made. Of the theoretically avoidable overages, only the $6\frac{1}{2}$", $9\frac{1}{2}$" and 10" are important. These total 7600 pounds. 14 resettings of the slitter were required -- 4 more than chosen by the present operator for the same week. This "costs" 4 x 5 = \$20.

15. The sizes "xed" have the theoretical best value under the conditions set up in the problem: no exhaustive solution could better them.

Appendix L

In Stock

TRANCOR STEEL

"Mill Coils"

Week Ending 3/8

28" Reels	Pounds		Pounds/in.	30" Reels	Pounds	Pounds/in	30" reels	Pounds	Pounds/in
	~~28"~~		~~28~~		~~30"~~	~~30~~		~~30"~~	~~30~~
+248	6940	248	253 X+	+157	4700	160 X + −	242	7260	246 + −
254	7100	254	258 +	+163	4950	169 X + −	243	7280	247 −
				+165	4960	169 X +	244	7320	248 −
				+171	5120	170 X + −	244	7320	248
				−173	5170	171 X +	244	7240	249
				178	5340	182 X	241	7360	250 −
				181	5440	185 + −	247	7400	252
				187	5620	191 X −	247	7400	252
				+191	5740	194 + −	248	7440	253 −
				+202	6050	205 +	249	7460	254
				−204	6100	207 X +	250	7500	255
				204	6130	208 + −	250	7500	255
				+206	6200	210 −	251	7540	256
				+207	6220	211 X	252	7560	257
				+207	6220	211	252	7560	257
				207	6220	211 X +	252	7560	257 X
				+211	6320	215 +	253	7600	258 X
				+214	6430	218 +	253	7600	258
				218	6520	222 −	253	7600	258
				221	6620	225 X + −	+254	7620	259
				222	6660	226 +	254	7620	259
				223	6700	227 X +	256	7700	261
				223	6700	227 X +	256	7700	261
				+224	6740	229 −	259	7780	264
				+228	6820	232 X −	260	7800	265
				+228	6850	232 −	260	7820	265
				+229	6880	233	261	7840	266 X
				+236	7060	240 X −	263	7900	268 X
				+238	7140	242 −	+265	7950	270 −
				238	7140	242 + −	+266	7980	271 X +
				240	7200	244 −	+271	8120	276 X − −
					[illegible]			4198.30	

"X"ed coils used in week's cutting

MATRIX OF REMAINING SIZES

Coil Sizes	6	7 1/2	(4) 8	(2) 9	9 1/2	(1) 10	(1) 10 1/2	11 1/2	(3) 12	Row Ident.	
		X				X			X	A	(1)
	XX	X				X				B	(1)
			X		X				X	C	(3)
	XX		X		X					D	(4)
			X			X		X		E	(1)
				XX				X		F	(2)
	X							X	X	G	(3)
			X			X		X		H	(1)
			X			X		X		I	(1)
				X		X	X			J	(1)
					X	XX				K	(1)
					XX		X			L	(1)
		X					X	X		M	(1)
	X	X	XX							N	(4)
Total Possibilities	4	4	6	2	4	7	3	6	3		

The numbers over the columns refer to order of cutting. The same numbers to the side of the rows indicate the possibilities which are eliminated with the depletion of the coil size.

The problem can now be expressed in the form of equations, which, however, do not lend themselves to a simple solution.

The columns are set equal to the remaining "lengths" of the column size required, with overages held to a minimum. X_i is this remainder function.

$$A + B + M + N = 665 + X_1$$
$$2B + 2D + G + N = 326 + X_2$$
$$C + D + E + I + 2N = 734 + X_3$$
$$2F + J = 1182 + X_4$$
$$C + D + K + 2L = 133 + X_5$$
$$A + B + E + H + I + J + 2K = 881 + X_6$$
$$J + L + M = 953 + X_7$$
$$E + F + G + H + I + M = 1063 + X_8$$
$$A + C + G = 815 + X_9$$

(1) $\sum_{i=1}^{i=9} X_i = \text{minimum}$

(2) $X_i \geqq 0$

(3) other unknowns, A to G > 200 or = 0

Condition (3) states that the lengths of the Mill Coils may not be used partially.

TABLE OF 30" COMBINATIONS

Comb. #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Max width	16		14					13						
16	1	1												
14			1	1	1	1	1							
13								1	1	1	1	1	1	1
12														
11½														
10½								1						
10			1						1					
9½				1										
9					1					1				
8½											1			
8		1				1					1	1		
7½	1					1				1				
6½					1				1				1	
6	1			1				1						
5-3/4							1						1	
5½		1	1				1							3
4¼							1					2	1	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0

12

	15	16	17	18	19	20	21	22	23	24	
16											16
14											14
13											13
12	1	1	1	1	1	1	1	1	1	2	12
11½	1										11½
10½											10½
10		1									10
9½			1								9½
9				1	1						9
8½				1							8½
8			1								8
7½		1				1					7½
6½							1				6½
6	1							1	2		6
5-3/4						1		2			5-3/4
5½							2		1	1	5½
4¼					2	1					4¼
	0	0	0	0	0	0	0	0	0	0	

11½

	25	26	27	28	29	30	31	32	33	
16										16
14										14
13										13
12										12
11½	1	1	1	1	1	1	1	1	2	11½
10½	1									10½
10		1								10
9½			1	1						9½
9					2					9
8½			1							8½
8		1				1				8
7½	1									7½
6½							1		1	6½
6								3		6
5-3/4						1	2			5-3/4
5½										5½
4¼				2		1				4¼
	0	0	0	0	0	0	0	0	0	

	34	35	35A	36	37	38	39	40	41	42	43	43A	44	45	45A	46	47
	10½									10							
16																	
14																	
13																	
12																	
11½																	
10½	1	1	1	1	1	1	1	2	2								
10	1									1	1	1	1	1	1	1	2
9½		2								1							1
9	1			1													
8½								1			1						
8					1							1					
7½						1	1						1		1		
6½			2											3	1		
6			1			1						1	2				
5-3/4				1			2			1							
5½					2	1					2	1			1	2	
4¼				1					2	1						2	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

	48	49	50	51	52	53	54	55	56	56A	57	58	58A	
	9½				9				8½					
16														16
14														14
13														13
12														12
11½														11½
10½														10½
10														10
9½	1	1	1	1										9½
9	1				1	1	1	1						9
8½		1			1				1	1	1	1	2	8½
8			1						1	1				8
7½						1	2			1		2		7½
6½						2			2				1	6½
6			2		2			2					1	6
5-3/4		2		2							1	1		5-3/4
5½	2						1			1	2			5½
4¼				2				2			1			4¼
	0	0	0	0	0	0	0	0	0	0	0	0		

	59	60	61	62	63	64	65	66	67	68	69	70	71	
	8						7½		6½			6		
16														16
14														14
13														13
12														12
11½														11½
10½														10½
10														10
9½														9½
9														9
8½														8½
8	1	1	1	1	2	3								8
7½	1	2			1		1	1						7½
6½		1	2						1	2	3			6½
6				1	1		2					3	4	6
5-3/4				1			1		4		1	2		5-3/4
5½	1			1		1		4		3			1	5½
4¼	2		2	1			1				1			4¼
	0	0	0	0	0	0	0	0	0	0	0	0	0	

BASIC ANALYSIS TABLE

width	lbs needed	In Inven.	net lbs req'd	#/in req'd	~~230#/in = 1 reel~~ equiv reels	reels to cut	variance from req'd	theor. #/in to cut	theor. #/in overage	actual #/in overage	actual # overage
16	1200		1200	75	1	1		230	155	88	1408
14	4100		4100	253	1+	1		230	(-23)	1	14
13	200		200	16	1	1		230	214	141	1833
12	11700		11700	975	5	5		1150	175	0	0
11 1/2	33900		33900	2950	13	13		2990	40	0	0
10 1/2	10 000		10 000	953	5	5		1150	197	159	1670
10	10 500		10 500	1050	5	5		1150	100	109	1090
9 1/2	7700		7700	810	4	4		920	110	28	266
9	13050		13050	1450	7	7		1610	160	22	198
8 1/2	7200		7200	846	4	4		920	74	138	1173
8	8600		8600	1075	5	6	+1	1380	305	290	2320
7 1/2	8100	1300	6800	906	4	4		920	14	0	0
6 1/2	4400		4400	675	3	3		690	15	1	6
6	4400		4400	735	4	5	+1	1150	415	338	2028
5 3/4	1200	500	700	122	1	1		230	108	35	202
5 1/2	1300		1300	237	1+	2	+1	460	223	124	682
4 1/4	4800	2400	2400	533	3	3		690	157	28	119
TOTALS	132350	4700	128150								13009

Net Analysis: 0 excess edge waste

13 set-ups

Pounds to cut (from Inventory) = 142 910

1/2 in Edge trim = 2382 lbs.

Net excess to Inventory = 12378 #

Reel Combination Selection Table

Comb. # →		1	5	13	15	24	29	25	26	41	35	56A	101	58A
Width	Reqts													
16	1	-67 1												
14	1+		+24 -1											
13	1			-73 1										
12	5				-45 3	-130 2								
11½	13				-45 3		-84 3	+97 2	+9 5					
10½	5							+97 2		-54 2	-69 1			
10	5								+9 5					
9½	4										-118 2		+36 2	
9	7		+24 1				-162 6							
8½	4											-24 1	+18 1	+70 2
8	5								+9 5			-24 1		
7½	4	-67 1						+97 2				-24 1		
6½	3		+24 1	73 1										+35 1
6	4	-67 1			-45 3									+35 1
5¾	1			-73 1										
5½	1+					-65 1						-24 ~~1~~		
4¼	3			-93 1						-86 2				
Reel Width		30	30	30	30	30	30	30	30	30	30	30	28	30
No. of reels		1	1	1	3	1	3	2	5	1	1	1	1	1
restrictions			≥253											
weight reels (#/IN) ↓		~~169~~	~~253~~	~~160~~	~~211~~	169	~~194~~	276	~~226~~	~~208~~	170	191	253	264
					~~211~~		~~205~~	~~271~~	~~229~~					
					~~215~~		~~207~~		~~232~~					
									~~233~~					
									240					
		163	254	157	207	165	191	271	228	202	171	206	248	265
					214		207	266	228					
					224		211		229					
									236					
									238					

May 6, 1955

Messrs: H. P. Dickie
D. C. Miller
B. Grad
T. F. Kavanagh
D. C. Dopp

Gentlemen:

For your general information, I am attaching an outline of a problem faced by the Power Transformer Department concerning slitting of lamination steel. We have been requested by Mr. F. McClintock, Manager--Materials, to assist in solving this material control problem.

Presently the problem has been fanned out to the following people who have indicated an interest, and who are individually attempting to arrive at a solution:

Mr. Stuart Dreyfus
AGT, Numerical Analysis

Dr. Melvin Salveson
Major Appliance Business Research

Mr. Rudolf Habermann, Jr.
Analytical Engineering, Apparatus Sales

Mr. Harlan D. Mills
Operation Research & Synthesis

Several other interested persons will be invited to tackle this problem also.

Within several weeks we plan to call everyone together here in New York to explore the several solutions in an effort to come up with the best approach for the Power Transformer Department.

I thought you might be generally interested in this problem and if you have any thoughts regarding a possible solution, I should be happy to receive them.

E. C. Thrasher

ECT

POWER TRANSFORMER DEPARTMENT

Problem of Slitting Lamination Steel

GENERAL ELECTRIC COMPANY

Manufacturing Services----------Production Control Services

January 1955

Problem of Slitting Lamination Steel

How many pounds of steel of specified sizes and grades should be slit from same thickness coils, received daily but which vary by coil weights, widths, and grades, so that given weekly production requirements can be filled in the most economical manner?

What is the procedure that should be used to answer the problem on a weekly basis, considering that input to inventory of mill coils and and next week's production requirements are static at the end of each week?

The circumstances which cause this problem together with a background information and statistical data are outlined in the following paragraphs:

I. General Background Information
II. Data, including some Operating Rules
III. Present approach to problem
IV. Problem solution—economic considerations

I. General Background Information. Steel slitting machinery capable of slitting 30 inches and wider coils each weighing a little under 5 tons, into 6 or less strips as may be required, was recently installed in Pittsfield, Mass. by the Power Transformer Department. Operational savings have already been realized by purchasing wide coils from the mills and performing the slitting operation per current practice, compared with previously having purchased numerous specific strip widths and weights direct from the mills. However, additional savings above that presently enjoyed, may be realized, if a definite procedure for determining the most economical coil cuts can be learned compared with present "seat of the pants" procedure.

II. Data, including some Operating Rules.

1. One thickness (.014) Silicon steel of two grades, Silectron and Trancor are purchased from two suppliers at a total weekly rate varying from 150 to 400 tons, with deliveries received daily.

2. Supplier "A" furnishes 30" wide coils with understanding that widths of 26" or 28" are acceptable up to a limit of 15% of total supplied. Weights of coils vary anywhere from 4000 to 9000 lbs. each.

3. Supplier "B" furnishes 25" wide coils with understanding that widths of 23", 23½", 24", and 24½" are acceptable. Weights of coils vary anywhere from 4000 to 9000 lbs. each.

4. However both suppliers are delivering coils which vary in widths from sizes given in (2) and (3) above actual experience shows the following coil widths are currently being received:---

Silectron	Trancor	
20"	24-3/4")	
21"	26")	15%
22"	28")	
23"	30"	85%*
$23\frac{1}{2}$"		
24"		
$24\frac{1}{2}$"		
25"		

* Shipments of Trancor steel always contain 85% of 30" Trancor steel.

4(a). No two coils are of the same weight -- all vary.

5. Weekly production requirements for both grades of steel are apecified at the end of each week, per exhibit A and B attached, giving the next week~~s~~ requirements.

5(a). Slit coil widths required may range from ~~2"~~ 1¼ to 22" usually in the incremental steps as follows:

~~2"~~ 1¼ to 6" in $\frac{1}{4}$" steps = ~~17~~ 20 sizes
from $6\frac{1}{2}$" to 12" in $\frac{1}{2}$" steps = 12 sizes
from 13" to 16" in 1" steps = 4 sizes
plus 18", $18\frac{1}{2}$", 20", 22" = 4 sizes
total = ~~37~~ 40 sizes

5(b). Slit coil poundage required may range from several hundred pounds to several tons in not less than 100 lbs. increments.

5(c). Sequence slitting for each day is another consideration which will be handled separately. Later investigation of this problem should also yield savings.

5(d). For the present generally one week's inventory of slit steel is permitted between the slitting operation and the next operation of punching. This permits ~~for~~ flexibility in slitting of coils without concern to punching sequence. (However examination of data discloses that rule is not fully exercised.--Further comment will be made later.)

5(e). To further complicate present situation it is required to keep steel separate after slitting by vendor indentification for given special jobs as designed by engineers.

6. At all times it is desired to slit a complete coil. Coils partially slit through are not wanted.

7. Slitting operation includes trimming of mill coil edge and it is desired that this waste be not more than $\frac{1}{2}$" on each side or not more than 1" waste per coil. This rule establishes minimum waste per coil but not applicable to any coil weight base for coil widths vary. Minimum waste relationship to mill coil width exists. See Exhibit "D". Also if subsequent slit coils are reslit, edge trim waste also results.

8. Typical week ending inventory status reports covering current four weekends are given in Exhibit "C".

9. Slit surplus of steel above actual requirements is to be minimized. (This rule to be further defined and clarified.)

10. Historical usage pattern of various sizes is given in Exhibit "G" and "G^1".

11. Reslitting of slit coils should be minimized for not only extra edge trim waste, results but extra machine set up and labor are incurred.

III. Present Approach to Problem: The present procedure for determining slitting instructions is carried out by a clerk (female) under the direction of a Production Supervisor. A Friden calculating machine is used by the clerk in calculating the arithemetic of the procedure. The steel is slit on a machine which can cut a maximum of six sizes from a coil at one time. Since two different kinds of steel silectron and trancor are used, weekly requirements must be calculated separately for each kind, but the mechanics are the same in both cases. Steel is received from the mill in various sizes of coils as previously listed in II Data.

1. The Production Supervisor is advised as to what jobs must be produced in a given week and can then determine how much steel is needed to produce these jobs. The clerk's first step is to combine jobs and arrive at the total requirements for the week for each kind of steel. See Exhibits A and B.

2. Deduct the amount that is in inventory (slit in previous weeks but not used), from the weekly requirements, (see red figures in Exhibits A and B). The balance is the amount and sizes to be slit.

3. Combine the sizes that are to be slit together from a coil. The clerk begins by selecting the largest size required, then fitting in smaller sizes. See Exhibit E. From Exhibit A the clerk knows the largest size of Trancor steel coil to cut from, but wants to avoid generating more than the ½" edge trim waste which must be trimmed from each coil. The clerk also wants to avoid slitting too many small size widths since there is little demand for the small widths. Keeping these facts in mind the clerk has selected a combination of 16" and 13" leaving a 1" band of waste. Several questions now come to mind. First, why didn't the clerk select a 28" coil and use a combination of 16" and 10"? Two inches of waste would have been generated, and of course this selection was hence avoided. The second question you may be asking is why we selected 13" when there is an excess of 775 pounds created? This is because the clerk knows that although the excess would be created, some will be used the following week on another production order,(?) and since 13" is a size with a high usage, the remainder will probably be used in the near future. It is in this area that our difficulties arise. Are the best combinations possible being selected?

4. The clerk then selects from among the coils on hand in the Pittsfield Warehouse, the coil weighing the closest to the desired weight. The actual weight is then recalculated against the desired weight to arrive at the actual pounds that will be slit from the coil. These actual figures are entered in the inventory. (Usually this presents no problem, since the weight desired per coil can usually be matched closely with the weight of an actual coil. The clerk receives notice of the weight of each coil of steel as it is received in Pittsfield by the Receiving Department. The material handler brings the coils which are desired from the warehouse to the slitting machine and the steel is slit in the widths desired.)

Exhibit A Trancor Steel required to meet production requirements for the

Week Starting 2/28/55

SIZES *

Production Order #	Weight Tons	4¼	5½	5 3/4	6	6½	7½	8	8½	9	9½	10	10½	11½	12	13	14	16
701340-1	6.8			1200				1300				2500			5000		3700	
703661-1	16.1	4800			4400		5500		4500	1300								
703X518-1	32.5					4400		7300		50	7700		10000	33900	100	200	400	1200
701424-2	10.6		1300				2600		2700			8000			6600			
Totals-Required To Meet Prod. Schedule	66.0	4800	1300	1200	4400	4400	7100	8600	7200	13050	7700	10500	10000	33900	11700	200	4100	1200
Deduct-Amounts Previously Slit and not used		2400		500			1300											
Balance-Amounts and sizes to be slit		2400	1300	700	4400	4400	6800	8600	7200	13050	7700	10500	10000	33900	11700	200	4100	1200

* sizes range from 2" to 22"

For simplicity, only those sizes are shown which are required for the week's output of 2/28/55

Exhibit A

Exhibit B
Silectron Steel Required to Meet Production Requirements
for Week Starting 2/28/55

Production Order #	Weight Tons	3	3¾	4¼	4¾	5½	6	7	7½	8	8½	9	9½	10	10½	11	12	14	15	16	18	20	22
703678-1	23.2			1400			2400		3100			1600					3600	4100		6700	23500		
703X051-1	27.0															2400			7400		6300	8200	2800
703877-1	16.1			2300			4300		5200		4100	16100											
701444-2	6.2		700					1500			2200			3900		4300							
701455-1	2.9	200				2800		800			1200		1400										
					400		1200			2900				3800	3700								
751921-1	6.																						
Totals R'qd. to meet prod Schedule	81.4	200	700	3700	400	2800	7900	2300	8300	2900	7500	17700	1400	7700	3700	6700	3600	4100	7400	6700	29800	8200	
Deductamt Previously Slit																							
Balance-Amts & Sizes to be Slit																							

* sizes range from "2" to 22"
For simplicity, only those sizes are shown which are required for the week's output of 2/28/55

Exhibit "C"

Inventory of Jumbo Reels
Week Ending 3/18
(in lbs.)

← Silectron →

← Widths →

23	23½	24	24
7146	6648	4004	5104
6906	7607	5462	5406
7058	5560	7214	6704
4564	5085	7474	
6284	4725	7304	
4900	5280	5660	
4426	5110	5285	
6424	5540	5605	
4774	7140	6050	
6454	6586	6665	
6461	6614	6675	
4940	5461	5475	
6305	5604	5495	
6180	5210	6696	
6440	6474	7644	
4320	5522	8226	
5745	5804	7654	
5824		5120	
7024		6086	
6626		6704	
5650		6664	
4930		6594	
4240		6704	
7144		6784	
6954		6294	
6564		5344	
6544		5216	
		6784	
		6774	
		6774	
		6754	
		4804	
		5084	
		6070	
		6714	
		5308	
		5244	
		5200	

← Trancor →

28	30	30
6940	5170	7500
7100	7280	7820
	7560	7260
	7400	7140
	5120	5740
	6220	6660
	7460	6740
	6620	6880
	7560	6220
	7700	4700
	7400	6700
	5620	4950
	4960	6320
	6200	7500
	7320	7560
	6130	7950
	6820	7600
	5340	7840
	7340	7780
	6220	7980
	7200	7440
	6430	7540
	6050	7800
	7900	7060
	5440	
	7600	
	6700	
	7140	
	6100	
	7320	
	6520	
	7360	
	8120	
	6850	
	7620	
	7700	
	7600	
	7620	

Exhibit "C"
(Cont.)

Inventory of Jumbo Reels
Week Ending 3/25
(in lbs.)

Silectron		Trancor		
← Widths →				
23	24	28	30	30
7146	5462	6940	5170	7800
6906	7214	7000	7280	7060
7058	7474	5920	7560	
4900	7304		7400	
6454	5285		5120	
4940	5605		6220	
5745	6665		7460	
5824	8675		6620	
4930	5475		7560	
6564	5495		7700	
6544	7644		7400	
4768	8225		5620	
6454			4960	
4940			6200	
			7320	
			6130	
			6820	
			5340	
			7340	
			6220	
			7200	
			6430	
			6050	
			7900	
			5440	
			7660	
			7140	
			7360	
			7260	
			7140	
			6660	
			6880	
			7560	
			7500	
			7560	
			7640	
			7440	
			7540	

Exhibit "C"
(Cont.)

Inventory of Jumbo Reels
Week Ending 4/1
(in lbs.(

Silectron				Trancor	
23	23½	24	24½	28	30
5810	7579	3368	7913	5160	7280
	6540	5541	6249	5540	6600
	5433	5905	5465		7880
	6760	5260	6121		7360
	5784	5924	6183		6120
	5184	7560	5865		7060
	5614	8099	4447		7420
	5053	7213	6309		6150
	4981	7746	6425		7050
	5850	7793	6286		6750
	6603	7971	6085		7850
	5430	8256	6357		7160
	7255		6317		6840
	5336		5760		7580
	6259		5533		7460
	7682		8703		7400
	7640				7320
	7378				7340
	7580				7200
	7412				7900
	7496				7700
					7600
					7620
					7500
					7260

Widths

Exhibit "C"
(Cont.)

Inventory of Jumbo Reels
Week Ending 4/8
(in lbs.)

← Selectron → ← Widths →

21	22	23	23½	24	24½
4748	5400	5764	6538	8291	4627
4377	5096	7110	8180	7890	7896
2390	4990	7109	8070	8419	7778
5290	5190	7420	7740	8563	6013
		6020	7823	8209	5307
		7440	8571	7787	7920
		7857	8450	6687	7980
		6090	8287	8621	8190
		7380	7496	6350	8440
		6440	7580	6828	6249
			6603	7870	6183
			5784	7760	6309
			6540	8400	6425
				7035	6357
				8320	6864
				8530	7980
				8157	8360
				6864	8110
				7577	7810
				6926	
				7830	
				7830	
				8287	
				8450	
				7850	
				7840	
				7980	
				8100	
				8360	
				8110	
				7810	
				5905	
				7746	
				7793	
				7971	

← Trancor →

28	30
5160	7280
5540	6600
6650	7880
	7360
	6120
	7060
	7420
	6150
	7050
	6750
	7850
	7160
	6840
	7580
	7600
	7700
	7620

Exhibit "C"

Inventory of Amounts Previously Slit and Not Used

WIDTH	Silectron 3/18	Silectron 3/25	Silectron 4/1	Silectron 4/8	Trancor 3/18	Trancor 3/25	Trancor 4/1	Trancor 4/8
1¼					1536#			
1½					1258			748#
1-3/4								2178
2¼				1371#				
2½	2369#	1669#	1699#	1669	558	558	558	558
2-3/4	1379	698	698	698	706	706	706	706
3	677	677	2708	2031	1917	2587	2587	2587
3¼	3276	2467	2467	2467	618	618	618	618
3½	3548	4879	4879	4879		1810	1810	1810
3-3/4					1479	1479	1479	1479
4	410	1977	6789	9037		1898	1898	1898
4¼	902	902	902	902	993	4384	993	6279
4½	1286	1286	1286	3436	4584	4584	4584	4584
4-3/4	1850	1988	1988	1988				
5	2039	2039	2039	2039	13082	13082	13082	13082
5¼	1501	1501	6996	6996	1946	1946	7100	7100
5½	29291	8280	8403	8425	3560	4936	4936	9208
5-3/4	2970			1299	1041	2937	7036	4310
6	1845	10407	8431	3777	5048	9236	13974	11196
6½	3062	1928	3579	6340	7636	5430	16108	
6-3/4		1511	1511	1511				
6-5/8	1511			2680				8195
7	4757	3051	3676	7015	5976	7735	14609	11950
7½	5682	3807	12824	10853	7114	10964	9039	8934
7-3/4	15692	10138	10138	10138				
8	5368	12452	4770	21053	3366	13610	9050	17579
8½	2630	2630		6148	1564			17115
9	3881	1891		7673	4470	14043	30927	30927
9½	1578		10973	15910	21563	16554	16554	7143
10	11649	7558	2870	8069		5027	23744	21197
10½		2647	427	19566	10248	13625	21110	6430
11	14250	14772	16136	16815		5690	2325	2325
11½	10692	10692	9398	11995	2577	8357	23169	2706

(Continued on next page

Exhibit "C"
Cont.

12	16480	8873	3216	6901	2400	2400	2400	4848
12½		2816	2816	25599				
13	9124	14621	28858	29244	806	806	806	7288
13½	5431	5431	5431	5431				
14	3545	54047	16056	36510	50	3569	3569	3569
14½							3006	3006
15	1173	7126	24610	28399	3000	3000	3410	10890
16	4888	24651	24465	17651			25551	
17			19886	9929				
18	85674	76683	12252	13825	4246	4246	4246	4246
20	26998	8104	4767	9672				
22					5374	5374	5374	5374

Exhibit D

Edge Trim Waste relationship to coil widths

	Width of coil (Inches)	Waste per coil (Inches)	% coil utilization desired
Silectrol	20	1	95.000
	21	1	95.238
	22	1	95.455
	23	1	95.652
	23½	1	95.745
	24	1	95.833
	24½	1	95.917
	25	1	96.000
Trancor	24-3/4	1	95.958
	26	1	96.154
	28	1	96.429
	30	1	96.667

Exhibit E

Trancor Steel Combinations - Week Ending 2/28/55

Coil Number	Width Combinations	Width of Coil	Desired Weight	Waste	Excess
1	16" - 1200#, 13" - 975#	30	2 250	75	13" - 775#
22	14" - 4102#,8" - 2344#, 7-½ - 2198#	30	8 790	146	0
3	12" - 11700", 9-½" - 9263", 8" - 7800#	30	29 250	487	8" - 1544 9-½ - 1563
4	11-½ (2 strips) - 16858# 6" - 4398#	30	21 990	734	0
5	11-½ (2 strips) - 15572", 6-½" - 4400#	30	20 310	338	0
6	11-½ - 1472#, 9" (2 strips) 2304#	30	3 840	64	0
7	10-½ (2 strips) - 9996#, 8-½" - 4046#	30	14 280	238	0
8	10" (2 strips) - 9" - 4725"	30	15 750	525	0
9	9" - 6021, 8-½" - 5682, 7-½" 5018 4-¾ - 2843#	30	20 070	502	4-¾ - 443 7-½ - 416# 8-½ - 2532 4-230#
10	5-3/4" (2 strips) - 920", 5-½" (3 strips) 1320#, 1-½" - 120#	30	2 400	40	5-3/4 - 220# 5-½ - 20# 1-½" - 120#

Exhibit "F"

Silectron Steel Combinations - Week Ending 2/28/55

Reel Number	Width Combination	Width of Reel	Desired Weight	Waste	Excess
1	18" - 9162 5½" - 2800#	24"	12 216	254	0
2	18" - 20639 6" - 6880	24½	28 092	573	
3	16" - 6700 7" - 2933#	23½	9 846	210	7" - 633
4	15" - 7396 8" - 3943	23½"	11 585	246	8" - 1 043
5	14" - 4103 9" - 2637	23½	6 886	146	0
6	12" (2 strips) 3600	24½	3 675	75	0
7	11" - 6700 (2 strips)	22½	6 852	152	0
8	10½" - 3696, 7½" - 2640, 6" - 2112	24½	8 624	176	6" - 1 092
9	10" (2 strips) - 7700 3" - 1155	23½	9 048	192	3" - 955
10	9½ - 1501, 8½ - 1343, 3-3/4 - 593	22½	3 555	118	9½ - 101
11	9" (2 strips) - 15320 4¼" - 3617	23	19 575	638	9" - 4907
12	8½" - 6337, 7½" - 5592, 4-3/4 - 3541	21½	16 029	559	4-3/4" - 3141 8½ - 480

Exhibit "G"

Historical Weekly Usage Pattern of Various Coil Widths
(Total for both Trancor and Silectron)

Width	1/1/53 - 6/30/53	10/1/53 - 3/30/54
1½"	90	465
1-3/4"	585	450
2"	1695	475
2¼"	730	910
2½"	440	310
2-3/4"	1660	1520
3"	1570	2730
3¼"	2095	1915
3½"	2065	1720
3-3/4"	1970	1715
4"	3460	4495
4¼"	2815	3155
4½"	5735	6690
4-3/4"	4450	3315
5"	6150	8665
5¼"	7225	6935
5½"	7820	7265
5-3/4"	2905	3995
6"	16330	15395
6½"	11395	5335
7"	17955	11965
7½"	15565	10955
8"	25485	21580
8½"	13605	7625
9"	23500	18700
9½"	16040	14995
10"	29550	22635
10½"	11555	12615
11"	27550	20760
11½"	18310	13190
12"	40605	46205
13"	30850	25830
14"	44150	38905
15"	30020	18870
16"	42120	34790
18"	49100	33810
18½"	35890	12855
20"	25635	17570
22"	19290	16755

Exhibit G[1]

Historical Weekly Usage Pattern of Various Coil Widths
in order of greatest usage

Width	1/1/53 - 6/30/53	Width	10/1/53 - 3/30/54
18"	49100	12"	46205
14"	44150	14"	38905
16"	42120	16"	34790
12"	40605	18"	33810
18½"	35890	13"	25830
13"	30850	10"	22635
15"	30020	8"	21580
10"	29550	11"	20760
11"	27550	15"	18870
20"	25635	9"	18700
8"	25485	20"	17570
9"	23500	22"	16755
22"	19290	6"	15395
11½"	18310	9½"	14995
7"	17955	11½"	13190
6"	16330	18½"	12855
9½"	16040	10½"	12615
7½"	15565	7"	11965
8½"	13605	7½"	10955
10½"	11555	5"	8665
6½"	11395	8½"	7625
5½"	7820	5½"	7265
5¼"	7225	5¼"	6935
5"	6150	4½"	6690
4½"	5735	6½"	5335
4-3/4"	4450	4"	4495
4"	3460	5-3/4"	3995
5-3/4"	2905	4-3/4"	3315
4¼"	2815	4¼"	3155
3¼"	2095	3"	2730
3½"	2065	3¼"	1915
3-3/4"	1970	3½"	1720
2"	1695	3-3/4"	1715
2-3/4"	1660	2-3/4"	1520
3"	1570	2¼"	910
2¼"	730	2"	475
1-3/4"	585	1½"	465
2½"	440	1-3/4"	450
1½"	90	2½"	310

MEMO: E. C. Throndsen

SUBJECT: Transformer Slitting Problem

After reviewing the data presented on the Transformer Slitting problem the following conclusions were reached:

1. The present manual approach is relatively inexpensive to operate and apparently inexpensive in terms of inventories and waste. It is not immediately evident as to why this should be so; however, it may be that the nature of the data is such as to lend itself to simple manual optimal-type solutions.

2. A Linear Programming or optimising approach to the whole problem can be postulated in terms similar to that used by M. E. Salveson in his "Line Balancing Problem". The complicating factor here is the definition of a basic unit, since the available reel sizes differ so greatly one from the other.

3. The size of a Linear Programming solution for the whole problem might well be prohibited, however, certain intuitive assumptions might be made which would reduce the magnitude of the variable portion of the problem to a handleable size.

4. It would not be a difficult chore to imitate the manual procedure on a Large-Scale Digital Computer (or medium sized one, for that matter), but a means would have to be discovered for producing comparatively random variates of the initial solution so that a series of non-redundant trials could be made. By evaluation of the results of each of these trials in terms of waste factor cost and inventory expense, a selection of the best solution could be made.

5. With adequate study on an actual model such as proposed above it would be a relatively simple matter to determine the distribution of costs for various solutions to the basic weekly problem. For instance, it might be evident that the inherant variation is of such a small magnitude that a simple manual method would be far superior in terms of total cost.

6. The manual method might well be improved by establishing more rigid combinatorial rules and less rigid inventory restrictions. This might well be explored through ABC analysis of historical requirements and study of actual inventory experience both week-by-week and accumulative since the new program was initiated.

In conclusion then, if the losses have been great enough over the past few months justification could be found for the approach suggested in steps 4 and 5. Then if this study shows adequate savings potential between the best and worst plans work on steps 2 and 3 would be of merit. If the present costs are low or the initial computer work indicates little variability in expense then attention should be directed to step 6 and improvement of the manual methods.

B. Grad
6/2/55

Stat analysis of
inventories
with usage + cumulative
ABC of historical reqts
compare cut (not used) to avg
usage
validate E.F.

POWER TRANSFORMER DEPARTMENT

Problem of Slitting Lamination Steel

GENERAL ELECTRIC COMPANY

Manufacturing Services-----------Production Control Services

January 1955

Exhibit A Trancor Steel required to meet production requirements for the

Week Starting 2/28/55

SIZES *

Production Order #	Weight Tons	$4\frac{1}{4}$	$5\frac{1}{2}$	5 3/4	6	$6\frac{1}{2}$	$7\frac{1}{2}$	8	$8\frac{1}{2}$	9	$9\frac{1}{2}$	10	$10\frac{1}{2}$	$11\frac{1}{2}$	12	13	14	16
701340-1	6.8			1200				1300				2500			5000		3700	
703661-1	16.1	4800			4400		5500		4500	1300								
703X518-1	32.5					4400		7300		50	7700		10000	33900	100	200	400	1200
701424-2	10.6		1300				2600		2700			8000			6600			
Totals-Required To Meet Prod. Schedule	66.0	4800	1300	1200	4400	4400	7100	8600	7200	13050	7700	10500	10000	33900	11700	200	4100	1200
Deduct-Amounts Previously Slit and not used		2400		500			1300											
Balance-Amounts and sizes to be slit		2400	1300	700	4400	4400	6800	8600	7200	13050	7700	10500	10000	33900	11700	200	4100	1200

* sizes range from 2" to 22"
For simplicity, only those sizes are shown which are required for the week's output of 2/28/55

Exhibit A

Exhibit B

Silectron Steel Required to Meet Production Requirements
for Week Starting 2/28/55

Production Order #	Weight Tons	3	3¾	4¼	4¾	5½	6	7	7½	8	8½	9	9½	10	10½	11	12	14	15	16	18	20	22
703678-1	23.2			1400			2400		3100			1600					3600	4100		6700	23500		
703X051-1	27.0															2400			7400		6300	8200	2800
703877-1	16.1			2300			4300		5200		4100	16100											
701444-2	6.2		700					1500			2200			3900		4300							
701455-1	2.9	200				2800		800			1200		1400										
					400		1200			2900				3800	3700								
751921-1	6.																						
Totals R'qd. to meet prod Schedule	81.4	200	700	3700	400	2800	7900	2300	8300	2900	7500	17700	1400	7700	3700	6700	3600	4100	7400	6700	28800	8200	
Deductamt Previously Slit																							
Balance-Amts & Sizes to be Slit																							

* sizes range from "2" to 22"
For simplicity, only those sizes are shown which are required for the week's output of 2/28/55

Exhibit "C"

Inventory of Jumbo Reels
Week Ending 3/18
(in lbs.)

Silectron				Trancor		
23	23½	24	24	28	30	30
7146	6648	4004	5104	6940	5170	7500
6906	7607	5462	5406	7100	7280	7820
7058	5560	7214	6704		7560	7260
4564	5085	7474			7400	7140
6284	4725	7304			5120	5740
4900	5280	5660			6220	6660
4426	5110	5285			7460	6740
6424	5540	5605			6620	6880
4774	7140	6050			7560	6220
6454	6586	6665			7700	4700
6461	6614	6675			7400	6700
4940	5461	5475			5620	4950
6305	5604	5495			4960	6320
6180	5210	6696			6200	7500
6440	6474	7644			7320	7560
4320	5522	8226			6130	7950
5745	5804	7654			6820	7600
5824		5120			5340	7840
7024		6086			7340	7780
6626		6704			6220	7980
5650		6664			7200	7440
4930		6594			6430	7540
4240		6704			6050	7800
7144		6784			7900	7060
6954		6294			5440	
6564		5344			7600	
6544		5216			6700	
		6784			7140	
		6774			6100	
		6774			7320	
		6754			6520	
		4804			7360	
		5084			8120	
		6070			6850	
		6714			7620	
		5308			7700	
		5244			7600	
		5200			7620	

Widths

259710 168680
38 reels + 24 = 62 reels
Total 428390
avg 6900#

Exhibit "C"
(Cont.)

Inventory of Jumbo Reels
Week Ending 3/25
(in lbs.)

← Silectron →		← Trancor →		
23	24	28	30	30
7146	5462	6940	5170	7800
6906	7214	7000	7280	7060
7058	7474	5920	7560	
4900	7304		7400	
6454	5285		5120	
4940	5605		6220	
5745	6665		7460	
5824	8675		6620	
4930	5475		7560	
6564	5495		7700	
6544	7644		7400	
4768	8225		5620	
6454			4960	
4940			6200	
			7320	
			6130	
			6820	
			5340	
			7340	
			6220	
			7200	
			6430	
			6050	
			7900	
			5440	
			7660	
			7140	
			7360	
			7260	
			7140	
			6660	
			6880	
			7560	
			7500	
			7560	
			7640	
			7440	
			7540	

Exhibit "C"
(Cont.)

Inventory of Jumbo Reels
Week Ending 4/1
(in lbs.(

← Silectron → ← Widths → ← Trancor →

Silectron			
23	23½	24	24½
5810	7579	3368	7913
	6540	5541	6249
	5433	5905	5465
	6760	5260	6121
	5784	5924	6183
	5184	7560	5865
	5614	8099	4447
	5053	7213	6309
	4981	7746	6425
	5850	7793	6286
	6603	7971	6085
	5430	8256	6357
	7255		6317
	5336		5760
	6259		5533
	7682		8703
	7640		
	7378		
	7580		
	7412		
	7496		

Trancor	
28	30
5160	7280
5540	6600
	7880
	7360
	6120
	7060
	7420
	6150
	7050
	6750
	7850
	7160
	6840
	7580
	7460
	7400
	7320
	7340
	7200
	7900
	7700
	7600
	7620
	7500
	7260

Exhibit "C"
(Cont.)

Inventory of Jumbo Reels
Week Ending 4/8
(in lbs.)

← Widths →

Selectron					
21	22	23	23½	24	24½
4748	5400	5764	6538	8291	4627
4377	5096	7110	8180	7890	7896
2390	4990	7109	8070	8419	7778
5290	5190	7420	7740	8563	6013
		6020	7823	8209	5307
		7440	8571	7787	7920
		7857	8450	6687	7980
		6090	8287	8621	8190
		7380	7496	6350	8440
		6440	7580	6828	6249
			6603	7870	6183
			5784	7760	6309
			6540	8400	6425
				7035	6357
				8320	6864
				8530	7980
				8157	8360
				6864	8110
				7577	7810
				6926	
				7830	
				7830	
				8287	
				8450	
				7850	
				7840	
				7980	
				8100	
				8360	
				8110	
				7810	
				5905	
				7746	
				7793	
				7971	

Trancor	
28	30
5160	7280
5540	6600
6650	7880
	7360
	6120
	7060
	7420
	6150
	7050
	6750
	7850
	7160
	6840
	7580
	7600
	7700
	7620

Exhibit "C"

Inventory of Amounts Previously Slit and Not Used

WIDTH	Silectron 3/18	Silectron 3/25	Silectron 4/1	Silectron 4/8	Trancor 3/18	Trancor 3/25	Trancor 4/1	Trancor 4/8
1¼					1536#			
1½					1258			748#
1-3/4								2178
2¼				1371#				
2½	2369#	1669#	1699#	1669	558	558	558	558
2-3/4	1379	698	698	698	706	706	706	706
3	677	677	2708	2031	1917	2587	2587	2587
3¼	3276	2467	2467	2467	618	618	618	618
3½	3548	4879	4879	4879		1810	1810	1810
3-3/4					1479	1479	1479	1479
4	410	1977	6789	9037		1898	1898	1898
4¼	902	902	902	902	993	4384	993	6279
4½	1286	1286	1286	3436	4584	4584	4584	4584
4-3/4	1850	1988	1988	1988				
5	2039	2039	2039	2039	13082	13082	13082	13082
5¼	1501	1501	6996	6996	1946	1946	7100	7100
5½	29291	8280	8403	8425	3560	4936	4936	9208
5-3/4	2970			1299	1041	2937	7036	4310
6	1845	10407	8431	3777	5048	9236	13974	11196
6½	3062	1928	3579	6340	7636	5430	16108	
6-3/4		1511	1511	1511				
6-5/8	1511			2680				8195
7	4757	3051	3676	7015	5976	7735	14609	11950
7½	5682	3807	12824	10853	7114	10964	9039	8934
7-3/4	15692	10138	10138	10138				
8	5368	12452	4770	21053	3366	13610	9050	17579
8½	2630	2630		6148	1564			17115
9	3881	1891		7673	4470	14043	30927	30927
9½	1578		10973	15910	21563	16554	16554	7143
10	11649	7558	2870	8069		5027	23744	21197
10½		2647	427	19566	10248	13625	21110	6430
11	14250	14772	16136	16815		5690	2325	2325
11½	10692	10692	9398	11995	2577	8357	23169	2706

(Continued on next page

12	16480	8873	3216	6901	2400	2400	2400	4848
12½		2816	2816	25599				
13	9124	14621	28858	29244	806	806	806	7288
13½	5431	5431	5431	5431				
14	3545	54047	16056	36510	50	3569	3569	3569
14½							3006	3006
15	1173	7126	24610	28399	3000	3000	3410	10890
16	4888	24651	24465	17651			25551	
17			19886	9929				
18	85674	76683	12252	13825	4246	4246	4246	4246
20	26998	8104	4767	9672				
22					5374	5374	5374	5374

Exhibit D

Edge Trim Waste relationship to coil widths

	Width of coil (Inches)	Waste per coil (Inches)	% coil utilization desired
Silectrol	20	1	95.000
	21	1	95.238
	22	1	95.455
	23	1	95.652
	23½	1	95.745
	24	1	95.833
	24½	1	95.917
	25	1	96.000
Trancor	24-3/4	1	95.958
	26	1	96.154
	28	1	96.429
	30	1	96.667

Exhibit E

Trancor Steel Combinations - Week Ending 2/28/55

Coil Number	Width Combinations	Width of Coil	Desired Weight	Waste	Excess
1	16" - 1200#, 13" - 975#	30	2 250	75	13" - 775#
2	14" - 4102#, 8" - 2344#, 7-½ - 2198#	30	8 790	146	0
3	12" - 11700", 9-½" - 9263", 8" - 7800#	30	29 250	487	8" - 1544 9-½ - 1563
4	11-½ (2 strips) - 16858# 6" - 4398#	30	21 990	734	0
5	11-½ (2 strips) - 15572", 6-½" - 4400#	30	20 310	338	0
6	11-½ - 1472#, 9" (2 strips) 2304#	30	3 840	64	0
7	10-½ (2 strips) - 9996#, 8-½" - 4046#	30	14 280	238	0
8	10" (2 strips) - 9" - 4725"	30	15 750	525	0
9	9" - 6021, 8-½" - 5682, 7-½" 5018 4-¼ - 2843#	30	20 070	502	4-¼ - 443 7-½ - 416# 8-½ - 2532 4-230#
10	5-3/4" (2 strips) - 920", 5-½" (3 strips) 1320#, 1-½" - 120#	30	2 400	40	5-3/4 - 220# 5-½ - 20# 1-½" - 120#

Exhibit "F"

Silectron Steel Combinations - Week Ending 2/28/55

Reel Number	Width Combination	Width of Reel	Desired Weight	Waste	Excess
1	18" - 9162 5½" - 2800#	24"	12 216	254	0
2	18" - 20639 6" - 6880	24½	28 092	573	
3	16" - 6700 7" - 2933#	23½	9 846	210	7" - 633
4	15" - 7396 8" - 3943	23½"	11 585	246	8" - 1 043
5	14" - 4103 9" - 2637	23½	6 886	146	0
6	12" (2 strips) 3600	24½	3 675	75	0
7	11" - 6700 (2 strips)	22½	6 852	152	0
8	10½" - 3696, 7½" - 2640, 6" - 2112	24½	8 624	176	6" - 1 092
9	10" (2 strips) - 7700 3" - 1155	23½	9 048	192	3" - 955
10	9½ - 1501, 8½ - 1343, 3-3/4 - 593	22½	3 555	118	9½ - 101
11	9" (2 strips) - 15320 4½" - 3617	23	19 575	638	9" - 4907
12	8½" - 6337, 7½" - 5592, 4-3/4 - 3541	21½	16 029	559	4-3/4" - 3141 8½ - 480

Exhibit "G"

Historical Weekly Usage Pattern of Various Coil Widths
(Total for both Trancor and Silectron)

Width	1/1/53 - 6/30/53	10/1/53 - 3/30/54
1½"	90	465
1-3/4"	585	450
2"	1695	475
2¼"	730	910
2½"	440	310
2-3/4"	1660	1520
3"	1570	2730
3¼"	2095	1915
3½"	2065	1720
3-3/4"	1970	1715
4"	3460	4495
4¼"	2815	3155
4½"	5735	6690
4-3/4"	4450	3315
5"	6150	8665
5¼"	7225	6935
5½"	7820	7265
5-3/4"	2905	3995
6"	16330	15395
6½"	11395	5335
7"	17955	11965
7½"	15565	10955
8"	25485	21580
8½"	13605	7625
9"	23500	18700
9½"	16040	14995
10"	29550	22635
10½"	11555	12615
11"	27550	20760
11½"	18310	13190
12"	40605	46205
13"	30850	25830
14"	44150	38905
15"	30020	18870
16"	42120	34790
18"	49100	33810
18½"	35890	12855
20"	25635	17570
22"	19290	16755

Exhibit G[1]

Historical Weekly Usage Pattern of Various Coil Widths
in order of greatest usage

Width	1/1/53 - 6/30/53	Width	10/1/53 - 3/30/54
18"	49100	12"	46205
14"	44150	14"	38905
16"	42120	16"	34790
12"	40605	18"	33810
18½"	35890	13"	25830
13"	30850	10"	22635
15"	30020	8"	21580
10"	29550	11"	20760
11"	27550	15"	18870
20"	25635	9"	18700
8"	25485	20"	17570
9"	23500	22"	16755
22"	19290	6"	15395
11½"	18310	9½"	14995
7"	17955	11½"	13190
6"	16330	18½"	12855
9½"	16040	10½"	12615
7½"	15565	7"	11965
8½"	13605	7½"	10955
10½"	11555	5"	8665
6½"	11395	8½"	7625
5½"	7820	5½"	7265
5¼"	7225	5¼"	6935
5"	6150	4½"	6690
4½"	5735	6½"	5335
4-3/4"	4450	4"	4495
4"	3460	5-3/4"	3995
5-3/4"	2905	4-3/4"	3315
4¼"	2815	4¼"	3155
3¼"	2095	3"	2730
3½"	2065	3¼"	1915
3-3/4"	1970	3½"	1720
2"	1695	3-3/4"	1715
2-3/4"	1660	2-3/4"	1520
3"	1570	2¼"	910
2¼"	730	2"	475
1-3/4"	585	1½"	465
2½"	440	1-3/4"	450
1½"	90	2½"	310