

AN APPROACH  
TO OPERATIONS  
STRUCTURE

II. Example: Armature Balancing

A. Time Study Source: West Lynn Studies

362355	367326	346816
352085	368005	368007
352090	368006	

B. Identification Chart

	55	85	90	26	05	06	16	07	Av. Time
AB		1-2	1	4	1-2	1			21.92 L/U - PL in Fix., 30.44-17.60-13.50-30.44-17.60 sec.
CAB	1-2						1-3	1-3	41.29 Cln - L/U - PL in Fix 20.60-51.54-51.54
DE				1					24.90 C/O (1) Adj Cwt - Asm (1) Adj Cwt 24.90
DEFGH		3	2		3	2			64.80 C/O (1) Adj Cwt - Asm (1) Adj Cwt - Asm (1) Cwt Col - Bal. - Rmv from Fix 49.40-80.20-49.40-80.20
DEFIHJ BG							4	4	106.40 C/O (1) Adj Cwt - Asm (1) Adj Cwt - Asm (1) Cwt Col - Asm (1) Comp Col - Rmv from Fix - Shellac Comp. Col - Pl in Fix - Bal 106.40-106.40
KL				2-3					21.95 C/O (2) Adj Cwt - Asm (2) Adj Cwt 21.95
DEFG	3								36.60 C/O (1) Adj Cwt - Asm (1) Adj Cwt - Asm (1) Cwt Collar - Bal 36.60
M		4			4				15.10 Sold (1) Cwt Coll. 15.10-15.10
MBN			3			3			82.00 Sold (1) Cwt Col - Pl in Fix - Rebal 82.00-82.00
KLG							5	5	62.30 C/O (2) Adj Cwt - Asm (2) Adj Cwt - Bal 62.30-62.30
MN	4								30.90 Sold (1) Cwt Coll - Rebal 30.90

Identification Chart (Cont'd)

	55	85	90	26	05	06	16	07	Av. Time
BDEG		5			5				78.70 Pl in Fix - L/O (1) Adj Cwt - Asm (1) Adj Cwt - Bal 78.70-78.70
KLBG			4			4			80.20 C/O (2) Adj Cwt - Asm (2) Adj Cwt - Bal 80.20-80.20
HCO			5		9	5 8	6-7	6-7 10	5.25 Rmv from Fix - Cln - Dispose 8.56-8.56-6.62-6.62-2.12-2.12-2.12
FGM				5					27.85 Asm (1) Cwt Coll - Bal - Sold (1) Cwt Coll 27.85
G				6 9					32.75 Bal 23.10-42.40
PQ				7-8	7	6		8	30.85 Asm (2) Cwt Coll - Sold (2) Cwt Coll 42.90-26.84-26.84-26.84
DEG HO	5								67.20 C/O (1) Adj Cwt - Asm (1) Adj Cwt - Bal - Rmv from Fix - Dispose 67.20
HO		6		10	6				5.45 Rmv from Fix - Dispose 6.42-3.52-6.42
BN					8	7		9	22.20 Pl in Fix - Rebal 22.20-22.20-22.20
	155.30	180.06	268.56	200.12	231.22	319.72	226.86	278.02	

III. Coding\*

- A = L/U
- B = Pl in Fix
- C = Cln Piv
- D = C/O (1) Adj Cwt
- E = Asm (1) Adj Cwt
- F = Asm (1) Cwt Coll.
- G = Bal
- H = Rmv from Fix
- I = Asm (1) Comp Coll
- J = Shellac (1) Comp Coll
- K = C/O (2) Adj Cwt
- L = Asm (2) Adj Cwt
- M = Sold (1) Cwt Coll
- N = Rebal
- O = Dispose
- P = Sold (2) Cwt Coll
- Q = Asm (2) Cwt Coll

\*Note: In short simple analyses where the number of steps is few, coding isn't necessary.

IV. Possible Balancing Configurations

T.S. Value

362355	155.30	O.S.
352085	180.06	
352090	<u>268.56</u>	
Avg.	<u>201.30</u>	<u>189.52</u>

T.S. Value

367326	200.12	O.S.
368005	231.22	
368006	<u>319.72</u>	
Avg.	<u>250.30</u>	<u>249.00</u>

T.S. Value

346816	<u>226.86</u>	O.S.
		<u>210.97</u>

T.S. Value

368007	<u>278.02</u>	O.S.
		<u>266.62</u>

Avg. Variation	201.30	189.52
	250.30	249.00
	226.86	210.97
	<u>278.02</u>	<u>266.62</u>
	956.48	916.11

$$\frac{40.37}{956.48} = 4.2\%$$

V. Relationships

A. Raw

362355    352085    352090    367326    368005    368006    346816    368007

C  
A  
B  
D  
E  
F  
G  
M  
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H  
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C  
O

Relationship Chart

B. Patterns

362355	352085	352090	367326	368005	368006	346816	368007
{ A B D E F G }	A B D E F G	A B D E F G	A B D E F G	A B D E F G	A B D E F G	A B D E F	{ A B D E F }
{ H }	H	H	H	H	H	I H J	{ I H J }
{ M B N }	M B N	M B N	M B N	M B N	M B N	M B	M B
{ D E }	D E	D E				G	{ G }
{ G }	G	G	K L G H P Q B N H C O	K L G H P Q B N H C O	K L G H P Q B N H C O	K L G	{ K L G H P Q B N H C O }
{ H C O }	H C O	H C O				H C O	{ H C O }

## VI. Time Values

Values result from average of a series of time studies, combination of more than one time element, derived values, etc. (See I K).

A / B	=	21.92
D / E	=	24.90
F	=	7.15
G	=	32.75
I	=	7.15
H	=	2.60
J	=	25.45
M	=	15.10
B	=	6.40
N	=	15.80
K / L	=	29.55
P / Q	=	30.85
H / C / O	=	5.25



VII. Source of Operation Structure Table Inputs

A. <u>Prod. Struct.</u> <u>Table</u>	<u>Description of Value</u>
2	Type of adj cwt on left crossarm
3	Type of adj cwt on pointer arm
4	Type of adj cwt on opposite arm
13	Number of compensating collars
14	Number of adj cwt on right crossarm
15	Number of cwt collars on crossarms
51	Cwt support length, opposite arm

VII. Source of Operation Structure Table Inputs

B. Engineering Information for Balancing

TS 55, 85, 90

- ② Adj Cwt Lft Crossarm (1)
- ⑤① ④ Adj Cwt Opp Arm (1) >7/64
- ①⑤ Cwt Collar Opp Arm (1)

TS 26, 05, 06

- ② Adj Cwt Lft Crossarm
- ⑤① ④ Adj Cwt Opp Arm >7/64
- ①④ Adj Cwt Rt Crossarm
- ①⑤ Cwt Collar LCA )
- ①⑤ Cwt Collar RCA ) 3
- ①⑤ Cwt Collar OA )

TS 16

- ② Adj Cwt LCA
- ①④ Adj Cwt RCA
- ⑤① ③ Adj Cwt Pt Arm <7/64
- ①⑤ Cwt Collar Pt Arm (1)
- ①③ Comp Collar Pt Arm (1)

TS 07

- ② Adj Cwt LCA
- ①④ Adj Cwt RCA
- ⑤① ③ Adj Cwt Pt A <7/64
- ①⑤ Cwt Collar LCA )
- ①⑤ Cwt Collar RCA ) 3
- ①⑤ Cwt Collar Pt A )
- ①③ Comp Collar Pt A (1)

VIII. Tables

AB and DB Armature Final Assembly  
Balancing  
Operation #8

Print Out

(A ≠ B) Lift up Armature and  
p1 in Fixture  
 $T_{F1} = 21.92$

(51)	>7/64	A/O
I <sub>1</sub>	(4)	(3)
I <sub>2</sub>	Opposite	Pntr

(D ≠ E) C/O (1) I<sub>1</sub> Adj Cwt &  
Asm to I<sub>2</sub> Supt. arm  
 $T_{F2} = 24.90$

(51)	>7/64	A/O
I <sub>3</sub>	Opposite	Pntr

(F) Asm. (1) Cwt collar to  
I<sub>2</sub> Supt.  
 $T_{F3} = 7.15$

(13)	0	1
P <sub>1</sub>	Bal	NE
I <sub>4</sub>	Asm	NE
T <sub>4</sub>	32.75	NE

(G) P<sub>1</sub> I<sub>4</sub>

(13)	0	1
P <sub>2</sub>	NE	Asm
I <sub>5</sub>	NE	1 Comp. Col
I <sub>6</sub>	NE	Pntr Arm
T <sub>5</sub>	NE	7.15

(I) P<sub>2</sub> I<sub>5</sub> to I<sub>6</sub>

(H) Remove Asm From Fixture  
 $T_{F6} = 2.60$

AB and DB Armature Final Assembly  
Balancing  
Operation #8

(13)	0	1
P3	NE	Shellac
P4	NE	Bake
I7	NE	(I5)
I8	NE	Iron
T7	NE	25.45

(J)  $\underline{P}_3$   $\underline{I}_7$  &  $\underline{P}_4$  w/ $\underline{I}_8$

(M) Solder Cwt Collar  
 $T_{F8} = 15.10$

(B) P1 Asm in Fixture  
 $T_{F9} = 6.40$

	(N)	(G)
P1	Bal	NE
P5	Rebal	Bal
T10	15.80	32.75

$\underline{P}_5$  Balance Assm.

(14)	(D/E)	(K/L)
I9	1	2
I10	(2)	(2)
I11	Left	Left
I12	NE	Right
T11	24.90	29.55

C/O  $\underline{I}_9$   $\underline{I}_{10}$  Adj. Cwts & Asm  
to  $\underline{I}_{11}$  &  $\underline{I}_{12}$  crossarm

(G) Bal. Asm  
 $T_{F12} = 32.75$

(15)	0	2
P6	NE	Rmv
I13	NE	Assm
I14	NE	Fixture
T13	NE	2.60

(H)  $\underline{P}_6$   $\underline{I}_{13}$  From  $\underline{I}_{14}$

PRODUCT AND OPERATION STRUCTURES

Philosophy

Techniques

Uses

Examples

D. W. Cameron  
September 1958

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## THE REGENERATIVE APPROACH

The ultimate aim of all automatic systems, be they data processing or material processing, is to be able to pour into the hopper a quantity of unrelated material, push a button, and get a finished result. To approach this ultimate aim in the data processing field, the Integrated Systems Project has developed what we call a "regenerative" system. Regeneration, in systems design, refers to the practice of recalculating or resolving problems at the particular moment the results are needed as contrasted with the more traditional file reference approach in which problem solutions are stored for future reference if the problem should arise again. Actually the regenerative approach is not something new. Without thinking of it as such, we regenerate information every day. Consider for example the science of mathematics where we can regenerate the product of any two numbers. To perform this regeneration of a product of two numbers it is only necessary for us to know the products of the combinations of numbers 1 through 9 and the summation of the combinations of the numbers 1 through 9. Then by following a set procedure, see Fig. 1, aided by our limited storage of relationships we are able to produce any product of any two numbers. The standard form for performing a multiplication is actually a shorthand version of Fig. 1. The value of a regenerative approach in mathematics is evident from this example.

In the manufacturing organization we also regenerate information every day. The engineer calls upon design formulas, standard parts, engineering policy, etc. when he designs a product. The manufacturing man applies similar methods and processes to similar jobs and computes the job price based on standard time elements. However, because this manual regenerative process is so time consuming and requires the efforts of highly technical men, it is usually reserved for new products and new processes. As a result, voluminous file systems have been established to preserve all of the information which has been generated by these people on past products.

In the past few years we have seen regenerative problems in the scientific area handled by computers where they became too laborious for manual effort. Would it not be possible for this same approach to be used in the fields of engineering and manufacturing planning? We think so and it was with this intention that the Integrated Systems Project was organized. Part of our objectives are to design computer programs which will be capable of performing the design function of engineering and the planning function of manufacturing. These programs are called Product Structure and Operation Structure respectively.

The purpose of Product Structure is not to design radically new products, but instead to provide a framework for continually re-designing old products and similar products which fall within the same boundaries or family as the old product as these products are ordered. Stored within this program will be all of the relationships that the engineers have previously determined between the customer specifications and the design requirements. However, these relationships will not be confined to single products, but will cover entire ranges or families of products. These relationships will be defined in explicit mathematical or logical terms so that by following a set procedure the computer will be able to manipulate the input data or customer specifications and obtain the design requirements or product characteristics of each part and assembly.

The Operation Structure will be similar to the Product Structure in nature. Here again the Operation Structure will not conjure up new processes, but from an established field of existing processes and methods the Operation Structure program will be able to select the correct method for manufacturing the part. In addition, it will be able to select the standard times which are related to the manufacture of the part and thus price the job.

These programs should provide a straightforward, logical approach to the design and planning of products, which will be cheaper, faster, and more accurate than presently possible.



Product

Structure

Principles

## REGENERATIVE SOLUTION

Input: a, b  
 Instruction: Multiply

Example: 239 x 57

Step 1                      (a<sub>1</sub> † a<sub>2</sub> † a<sub>3</sub>) (b<sub>1</sub> † b<sub>2</sub>)  
 Break down digits      (200 † 30 † 9) (50 † 7)  
 into units, tens,  
 hundreds, etc.

Step 2  
 Cross-multiply

a <sub>1</sub> x b <sub>1</sub>	1	0	0	0	0
a <sub>2</sub> x b <sub>1</sub>		1	5	0	0
a <sub>3</sub> x b <sub>1</sub>			4	5	0
a <sub>1</sub> x b <sub>2</sub>	1	4	0	0	
a <sub>2</sub> x b <sub>2</sub>		2	1	0	
a <sub>3</sub> x b <sub>2</sub>			6	3	

Step 3  
 Add Columns  
 (Carry Over)

	1	2	5	2	3
		1	1		

Step 4  
 Add Carry Over to Answer

	1	3	6	2	3
--	---	---	---	---	---

Fig. 1

PRODUCT STRUCTURE TABLES

Condition	Tests	
Result	Values	
Example:		
Rating	$\leq 5a$	$> 5a$
No. of Turns	$f(\text{Rating})$	Constant Value

If the rating  $\leq 5a$ , then  
 No. of Turns =  $f(\text{Rating})$

If the rating  $> 5a$ , then  
 No. of Turns = a constant value

Fig. 2

APPLICATION OF PRODUCT STRUCTURE  
PROGRAMMING TO A SPECIFIC EXAMPLE

The first step in a Product Structure analysis is to break down the product into generic parts. The following list is a partial breakdown for the switchboard instrument line:

- Armature
  - Coil
  - Shaft
  - Pointer
  
- Element Assembly
  - Frame
  - Magnet
  - Lamination Stacking
  
- Scale Plate
  
- Etc.

A single generic family is chosen from the breakdown. The scale plate (see Fig. 3) was chosen for this analysis as it represents considerable design complexity and extreme variation from model to model. The scale plate does not represent one single part but a group of parts each one of which is unique but which have the same common name.

The second step is to separate those characteristics which are fixed and common to all scale plates in the generic family from those which are variable. Some examples of fixed characteristics common to all scale plates are: scale plate material, (aluminum); scale plate shape, (circular); location of mounting holes; and the sub legends<sup>1</sup> "General (monogram) Electric" and "Made in U.S.A.". Examples of variable characteristics are the shape, size, color and location of such printed information as legends, digits, and calibration marks.

The third step is to determine and define the relationship between these variable design characteristics and the variable customer specifications. In Fig. 3 it can easily be seen how the legend A-C has a direct relationship to the customer specifications for current. Similarly, the legend, volts, the highest scale value, 150, and the lowest scale value, 0, are also direct customer specifications. However, the intermediate values, 60, 90, 120, are generally not directly customer specified although they can be related to customer specifications.

<sup>1</sup>Fixed on 99<sup>1</sup>/<sub>2</sub>% of scale plates

Consider a single customer specification such as the Right Scale Value (RSV). Fig. 4 is a sample of the variation of intermediate scale values with RSV. From this sample certain relationships can be observed:

1. The first digit always equals 0
2. The last digit always equals the RSV
3. The difference between any two digits on a single scale plate always equals a constant (i) except:

a. Where  $\frac{RSV}{i} = \text{whole integer}$ .

In this case, the second digit equals  $2i$ .

b. Where  $\frac{RSV}{i} = \text{whole integer} \neq 1/2$ .

In this case, the second digit equals  $3/2i$ .

c. Where  $\frac{RSV}{i} = \text{whole integer} \neq \text{some fraction} < 1/2$ .

In this case, the second digit =  $2i$  and the next to the last digit is dropped.

d. Where  $\frac{RSV}{i} = \text{whole integer} \neq \text{some fraction} > 1/2$ .

In this case, the second digit =  $2i$ .

These rules are valid where the Right Scale Value is any power of 10. The existence of the above relationships is logical when the function of the scale plate as a measuring reference is considered. It is desirable to have as many values as possible on the visual surface of the scale plate without having it look overcrowded, hence there are never less than four scale values nor more than seven. It is also desirable to divide the scale plate into equal increments, thus the constant difference between values. If the division  $\frac{RSV}{i}$  does not result in an integral number, it is preferable to include the "remainder" in the RSV.

The fourth step is to formulate these relationships into mathematical terms, which are general enough to cover the whole range of RSV's (.1 to 9.999). Fig. 5 shows a single tabular layout of the defined relationships. It is at this point in the analysis that the utility of a table solution is most evident.

To facilitate the computer programming a general "table solution" program (Tabsol) was devised. This general program requires a standard table form (see Fig. 2). The fifth step in a Product Structure analysis is to prepare the mathematical relations of Step 4 in this general form. Fig. 6 is the result of this step.

Start at Table 1. The function of Table 1 is to reduce the number of succeeding tables by determining the order of magnitude of the RSV in terms of powers of ten. When the RSV is divided by 10, the possible values of 6 are reduced to some number between 1.0 and 9.99, thereby reducing the size of Table 2 considerably. The term  $n$  is specified by Table 1. Simplification is possible because the incremental difference between values is the same, relatively for the ranges 1-10, 10-100, 100-1000, etc. The purpose of Table 2 is to specify this incremental difference. Table 3 specifies the whole integer and Table 4 determines the "remainder". Table 5 shows that the Left Scale Value (considered to be the first value) is always 0, and Table 6 calculates the second scale value based on  $R$ . At this point the answer is multiplied by the factor  $10^n$  as this factor has already served its purpose by simplifying Tables 2, 3, and 4.

Until now there has been no need to refer to the term "next address" as found in the tables because the tables have been solved sequentially. In the second column of Table 6, however, the "next address" is Table 8, while all other addresses are Table 7. This occurs because the remaining solutions differ for different values of  $R$ . The address system is a convenient way of selectively skipping through tables. The same technique is observed in Table 7.

Tables 7 and 8 both serve to generate the remaining values. Here another interesting application of the address system is observed. Where the same calculation is to be performed repeatedly until some condition is met, it is possible to "loop" back through the table.

Fig. 7 contains two examples which have been prepared to indicate table solution. The complete Product Structure for the scale plate with example is contained in Appendix 1.

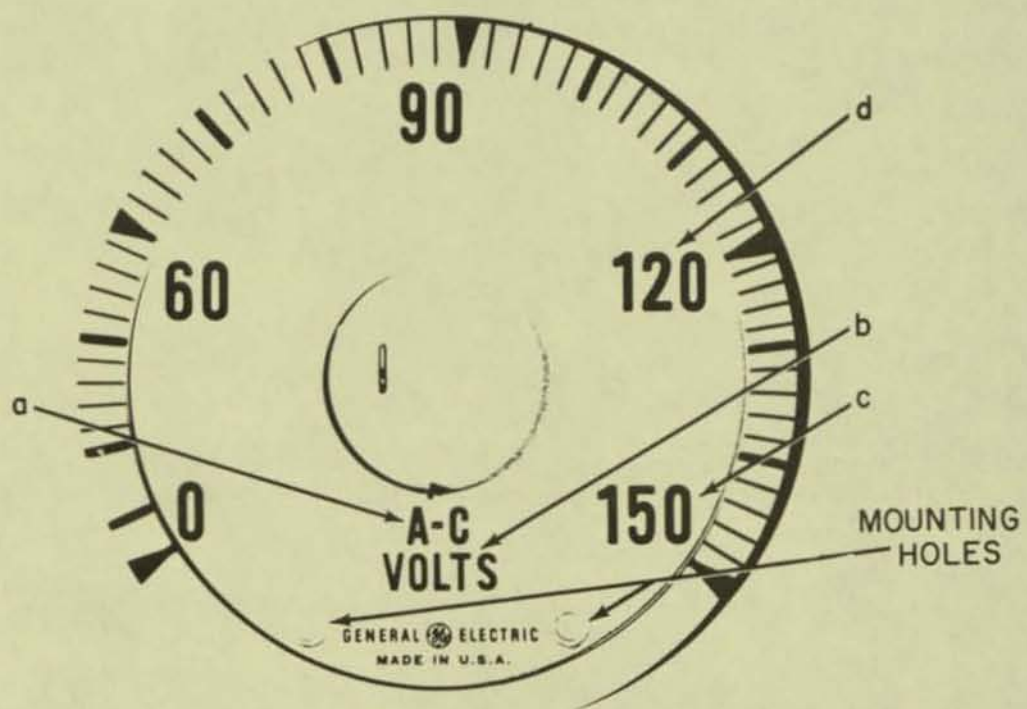


FIG 3

	Right Scale Values									
	10	12	15	17.5	24	25	30	35	40	45
1st Value	0	0	0	0	0	0	0	0	0	0
2nd Value	4	4	6	5	10	10	10	10	20	15
3rd Value	6	6	9	7.5	15	15	15	15	30	25
4th Value	8	8	12	10	20	20	20	20	40	35
5th Value	10	10	15	12.5		24	25	25		45
6th Value		12		15			30	30		
7th Value				17.5				35		

	Right Scale Values					
	50	54	70	75	80	90
1st Value	0	0	0	0	0	0
2nd Value	20	20	20	30	40	30
3rd Value	30	30	30	45	60	50
4th Value	40	40	40	60	80	70
5th Value	50	54	50	75		90
6th Value			60			
7th Value			70			

Fig. 4



I.  $\frac{RSV}{i} = (N \div R)$

where: RSV = Right Scale Value  
 i = Incremental difference between values  
 N = 1, 2, 3, .....  
 R > 0, R < 1

II.

	1 R = 0	2 R > 0 R < 1/2	3 R = 1/2	4 R > 1/2 R < 1
1st Value	0	0	0	0
2nd Value	2i	2i	3/2i	2i
3rd Value	3i	3i	5/2i	3i
'				
'				
'				
Last Value	RSV	(N-1)i RSV	RSV	RSV

III. Example: RSV = 54  
 i = 10

$\frac{RSV}{i} = (5 \div .4)$

From Column 2: 1st Digit = 0  
 2nd Digit = 20  
 3rd Digit = 30  
 4th Digit = 40  
 5th Digit = 54

Fig. 5

Table 1

RSV	$\geq .1$ $< 1.0$	$\geq 1.0$ $< 10$	$\geq 10$ $< 100$	$\geq 100$ $< 1000$	$\geq 1000$
n	-1	0	1	2	3
Next Address	Table 2				

Table 2

RSV/10 <sup>n</sup>	$\geq 1.0$ $< 1.5$	$\geq 1.5$ $< 1.6$	1.6	$> 1.6$ $< 1.75$	$\geq 1.75$ $< 1.8$
i	.2	.3	.4	.3	.25
Next Address	Table 3				

Table 2 (Cont.)

RSV/10 <sup>n</sup>	$\geq 1.8$ $< 4.0$	$\geq 4.0$ $< 7.5$	7.5	$> 7.5$ $< 8.0$	$\geq 8.0$
	.5	1.0	1.5	1.0	2.0
Next Address	Table 3				

Table 3

RSV/i10 <sup>n</sup>	$\geq 1.0$ $< 2.0$	$\geq 2.0$ $< 3.0$	$\geq 3.0$ $< 4.0$	$\geq 4.0$ $< 5.0$	$\geq 5.0$ $< 6.0$
N	1	2	3	4	5
Next Address	Table 4				

Table 3 (Cont.)

RSV/i10 <sup>n</sup>	$\geq 6.0$ $< 7.0$	$\geq 7.0$ $< 8.0$	$\geq 8.0$ $< 9.0$
N	6	7	8
Next Address	Table 4		

Fig. 6

Table 4

N	All Values
R	$RSV/i10^n - N$
Next Address	Table 5

Table 5

N	All Values
R	All Values
1st Value	0
Next Address	Table 6

Table 6

R	0	$>0$ $<1/2$	$1/2$	$>1/2$ $<1$
2nd Value	$2i10^n$	$2i10^n$	$3/2i10^n$	$2i10^n$
Next Address	Table 7	Table 8	Table 7	Table 7

Table 7

Previous Value	$\geq (N \neq R - 1) i10^n$	$< (N \neq R - 1) i10^n$
Next Value	RSV	Prev. Value $\neq i10^n$
Next Address	Table 9	Table 7

Table 8

Previous Value	$\geq (N \neq R - 2) i10^n$	$< (N \neq R - 2) i10^n$
Next Value	RSV	Prev. Value $\neq i10^n$
Next Address	Table 9	Table 8

Fig. 6 (Cont.)

Example I  
RSV = 900

<u>Step</u>	<u>Table</u>	RSV	$\geq 100$ $< 1000$
1	1	n	2
2	2	$RSV/10^n = 9$	
3	2	$\frac{RSV/10^n}{i}$	$\geq 8$ 2
4	3	$RSV/i10^n = 4.5$	
5	3	$\frac{RSV/i10^n}{N}$	$\geq 4.0$ $< 5.0$ 4
6	4	$RSV/i10^n - N = .5$	
7	5	1st Value = 0	
8	6	$\frac{R}{2nd\ Value}$	$\frac{1/2}{3/2i10^n}$
9	6	$3/2i10^n = 300$	
10	7	$\frac{Previous\ Value}{Next\ Value}$	$\frac{<(N \neq R - 1) i10^n}{Prev.\ Value \neq i10^n}$
11	7	Previous Value $\neq i10^n = 500$	
12	7	$\frac{Previous\ Value}{Next\ Value}$	$\frac{<(N \neq R - 1) i10^n}{Prev.\ Value \neq i10^n}$
13	7	Previous Value $\neq i10^n = 700$	
14	7	$\frac{Previous\ Value}{Next\ Value}$	$\frac{\geq(N \neq R - 1) i10^n}{RSV}$
15	7	RSV = 900	

Fig. 7

Example II

RSV = 54

<u>Step</u>	<u>Table</u>	RSV	$\geq 10$
1	1	n	$< 100$
2	2	RSV/10 <sup>n</sup> = 5.4	
3	2	RSV/10 <sup>n</sup>	$\geq 4.0$
		i	$< 7.5$
			1.0
4	3	RSV/i10 <sup>n</sup> = 5.4	
5	3	RSV/i10 <sup>n</sup>	$\geq 5.0$
		N	$< 6.0$
			5.0
6	4	RSV/i10 <sup>n</sup> - N = .4	
7	5	1st Value = 0	
8	6	R	$> 0$
		2nd Value	$< 1/2$
			2i10 <sup>n</sup>
9	6	2i10 <sup>n</sup> = 20	
10	8	Previous Value	$< (N \neq R - 2) i10^n$
		Next Value	Prev. Value $\neq i10^n$
11	8	Previous Value $\neq i10^n$ = 30	
12	8	Previous Value	$< (N \neq R - 2) i10^n$
		Next Value	Prev. Value $\neq i10^n$
13	8	Previous Value $\neq i10^n$ = 40	
14	8	Previous Value	$\geq (N \neq R - 2) i10^n$
		Next Value	RSV
15	8	RSV = 54	

Fig. 7 (Cont.)

## THE USE OF PRODUCT STRUCTURE TECHNIQUES IN EQUIPMENT DEVELOPMENT

Thus far Product Structure has been considered solely as a data processing tool. Product Structure information can also be of great value to the equipment designer. It provides a complete description of all the product specifications as well as the ranges of variation. This information is a necessary background for any equipment design. In addition, all of the relationships between product specifications are expressed, thus providing the equipment designer with a framework within which to modify product specifications for simplified equipment. The design of scale printing equipment is an example of the use of Product Structure.

The scale plate is the most variable part in the product line. There are over 700 standard designs and many times that number of special designs. To complicate the problem still further each scale plate is individually calibrated to record the accurate location of each calibration point. Because of the inherent variations in each instrument, even scale plates with identical designs vary with respect to the location of the calibration points. This extreme variety makes the scale plate a high unit cost item and thus a potential area for an automated printing process. The first step in planning an automated process is to obtain a complete understanding of all the product specifications the process will have to handle. It is in this area that Product Structure makes its contribution as a complete capsulated description of the part specifications and variety. Product Structure does more than just define what varies: it defines the boundaries and increments of variation. For example, it is obvious that the individual scale values will vary on different models as will their location, digit size, and digit color; but how much variation exists? Product Structure specifies:

1. The value is within the range from 0 to 9.999.
2. The color of the digits (black, white or other).
3. The sizes of digits are 14, 18, 30, 60 points.
4. The location of the digits within the boundaries of the scale plate is infinitely variable.

Considering just these variations, the above information leads to some tentative conclusions on equipment.

1. The wide range of value variation dictates the need for composing each value, digit by digit, as required rather than storing all possible values in the equipment. This approach reduces the storage from over 200 bits to 10, using digits 0 - 9, with the additional advantage of having infinite variety rather than a limited selection.

2. Printing or composing and printing values, digit by digit, is more time consuming than printing a single precomposed value. Therefore, to gain the advantage of flexibility new, faster printing techniques such as photo-printing must be evaluated.
3. The infinite variation in location requires rapid automatic positioning such as numerical positioning control.
4. The disparity on stored bits becomes even more gigantic because of digit size variation. Therefore, the technique must not only be faster but must reduce the amount of information required to be stored.

Further consideration of the variation in the legends, calibration points and special markings will validate or modify the previous conclusions, and point the way toward a specific equipment design.

Often, however, the optimum equipment design is prohibited by one (or many) restrictive part specifications. The elimination or modification of these restrictive specifications requires producibility engineering effort. Product Structure is a helpful analytical tool which enables the producibility engineer to test the effect of product design changes on the customer specifications and the related product specifications.

For example, there is infinite variety in the location of values on the scale plate. If all of the digits of these values are to be applied from the same printing location, then the part will have to be positioned for each digit of each value. The location of one digit with respect to another digit within a value can easily be determined. However, the location of each value with respect to the scale plate presents a different problem. The present specifications are illustrated in Fig. 20. The value must be radially located within 1/8" of the calibration markings, and angularly located so that a line passing through the calibration point and the center of the scale plate also passes through the center of the value. While these specifications are easily satisfied on a "cut and try" basis, it is difficult to arrive at positive dimensions for automatic positioning, since the one dial dimension is related to the "corners" of the value and the angular dimension is related to the center of the value. When these dimensions are translated to a common point (such as the center of the value) the host of new variables introduced are also effected by the dimensional size of digits, the number of digits per value and whether the scale plate is multi-value. Fig. 21

illustrates the mathematics involved in such a translation. The key variable in the solution for R is the angular location of the calibration point. The magnitude of  $\theta$  must be known before the value can be located. However,  $\theta$  is determined at instrument calibration. While it is perfectly feasible for the calibration station to measure  $\theta$ , and equally feasible for the printing station to use  $\theta$  for angularly positioning the scale plate, it is difficult to solve for the equation for R within the control network of either system. Such a solution might require an "on line" computer, an expensive and unnecessarily complex solution.

One obvious solution to the problem is to ignore the effects of  $\theta$  changes on R. Then R becomes a constant for every combination of a and b. A comparison between R (constant) and R (variable) was made for the extreme values of a and b. The results are illustrated in Fig. 22-25. The total difference between R (constant) and R (variable) never exceeded 15% of R and is negligible from a standpoint of appearance. Therefore, a minor design modification makes it possible for the Product Structure to determine the radial location of each value based on a and b, prior to calibration, eliminating the necessity of any "on line" computations.



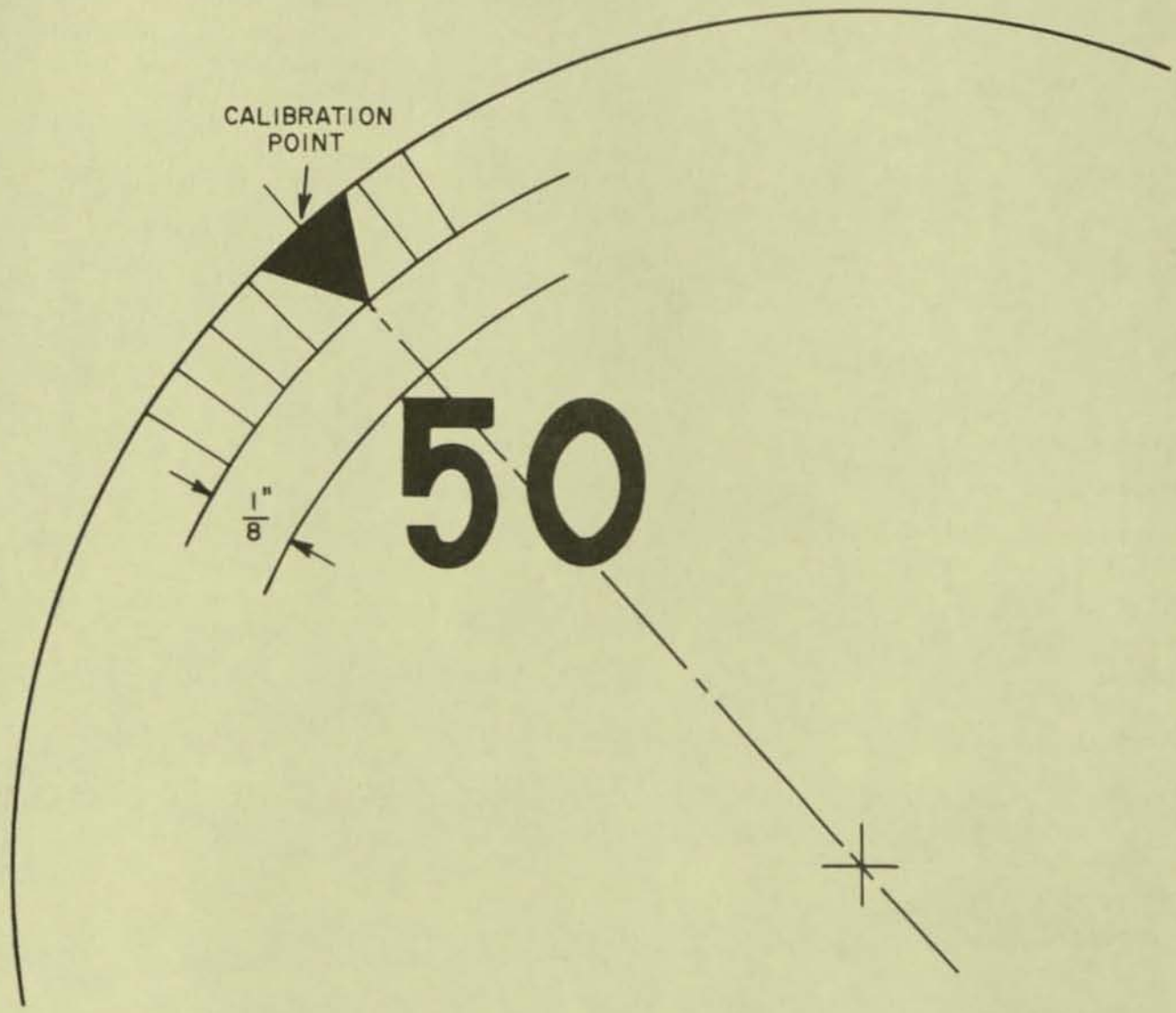
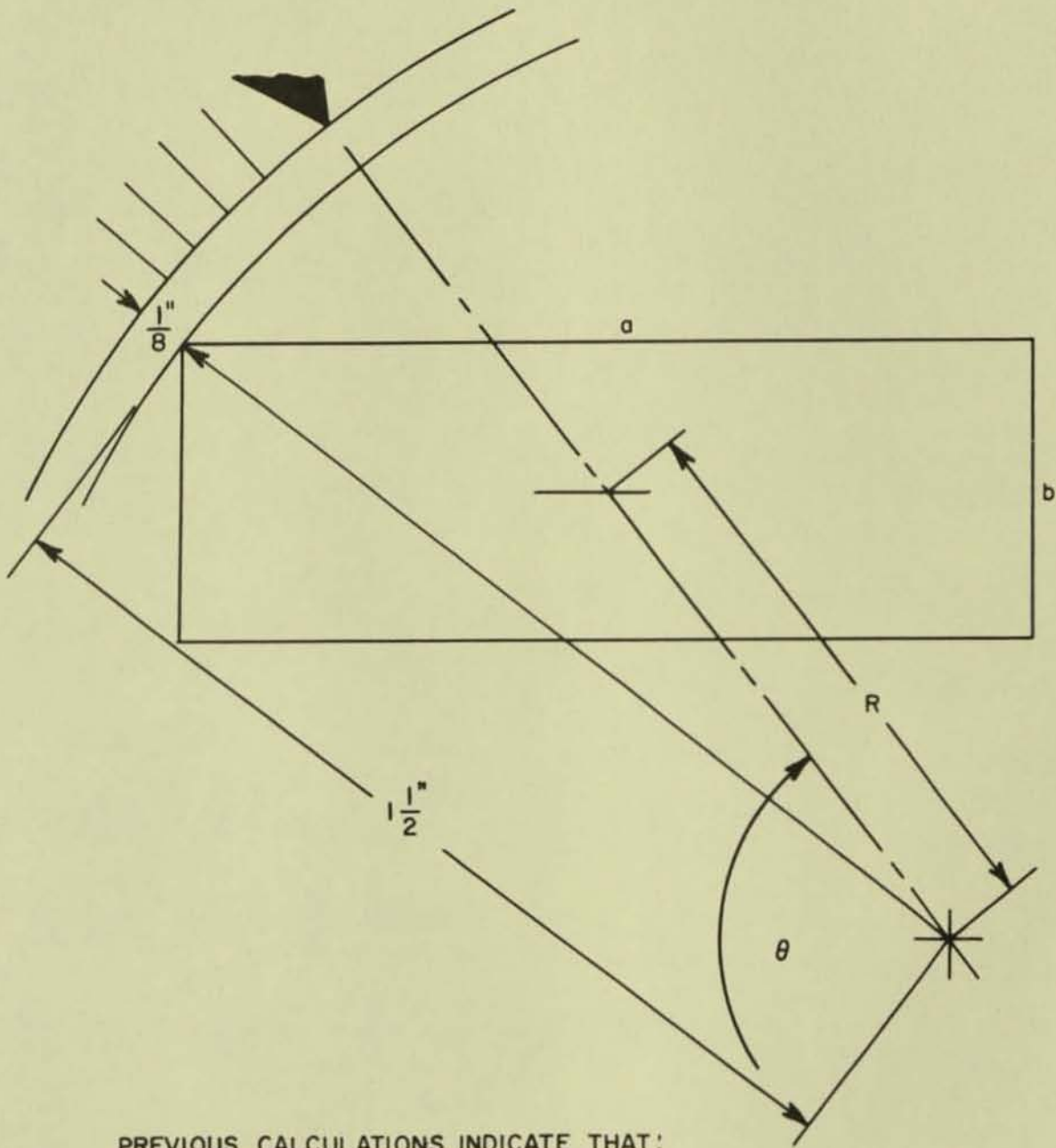


FIG. 20



PREVIOUS CALCULATIONS INDICATE THAT:

$$R = \sqrt{2.25 - (a^2 + b^2) \sin^2(\theta - b/a) - (a^2 + b^2) \cos(\theta - b/a)}$$

WHERE  $a$  &  $b = f$  (SIZE OF DIGITS, NUMBER OF DIGITS PER VALUE, NUMBER OF MULTIPLE VALUES)

FIG. 21

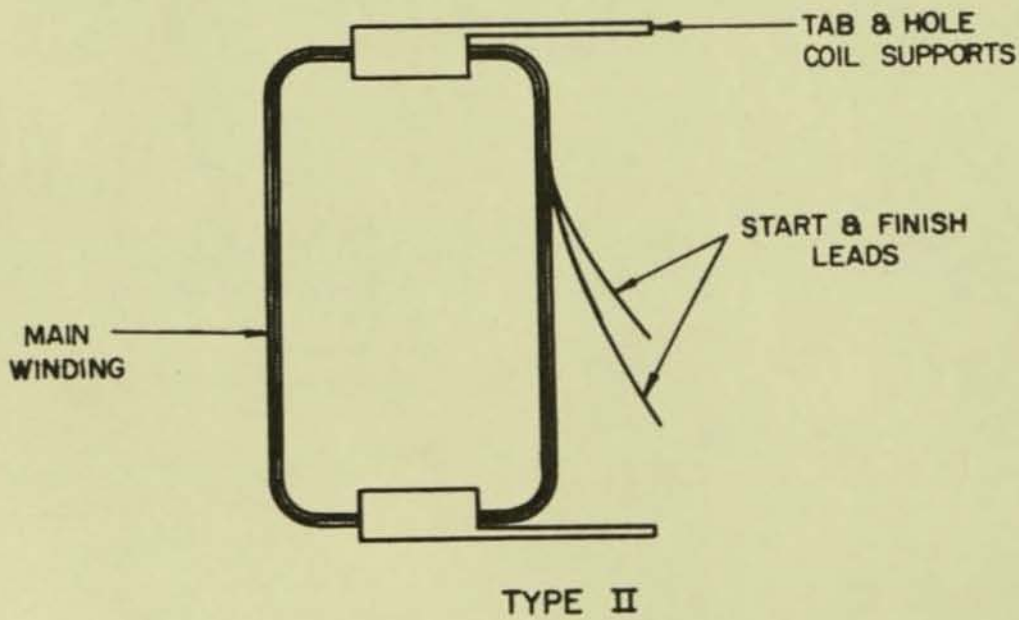
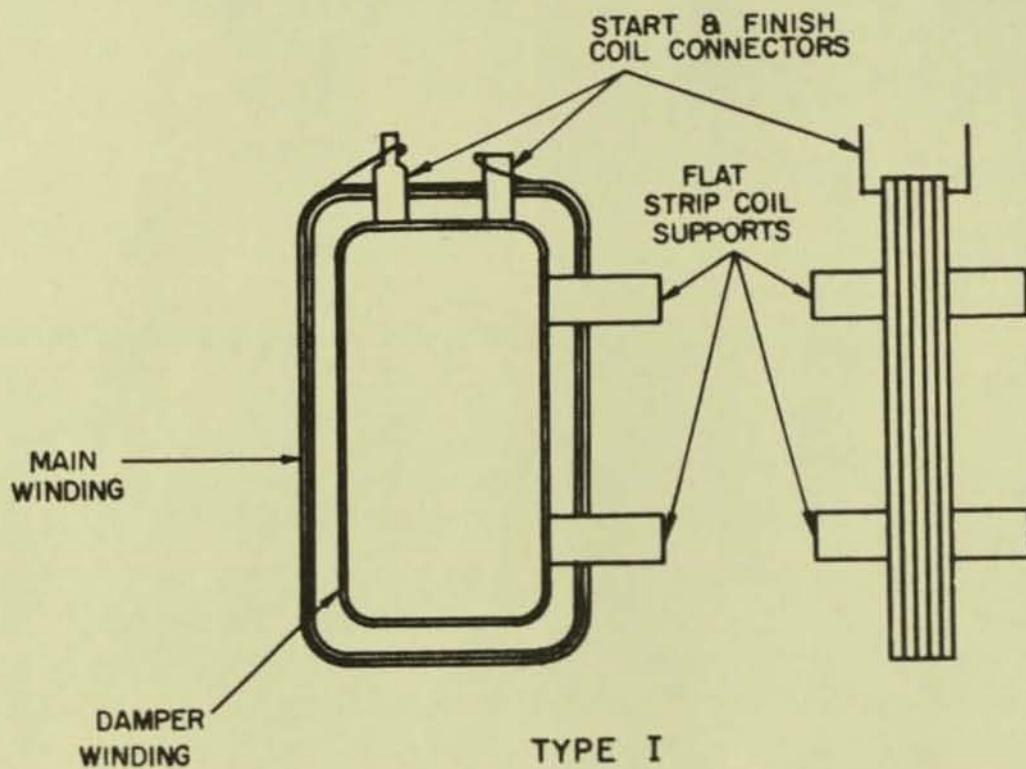
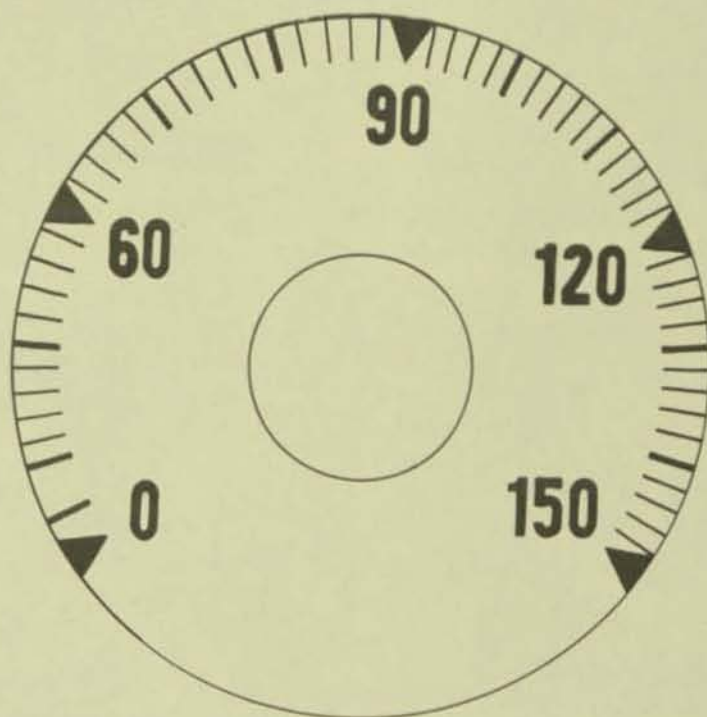
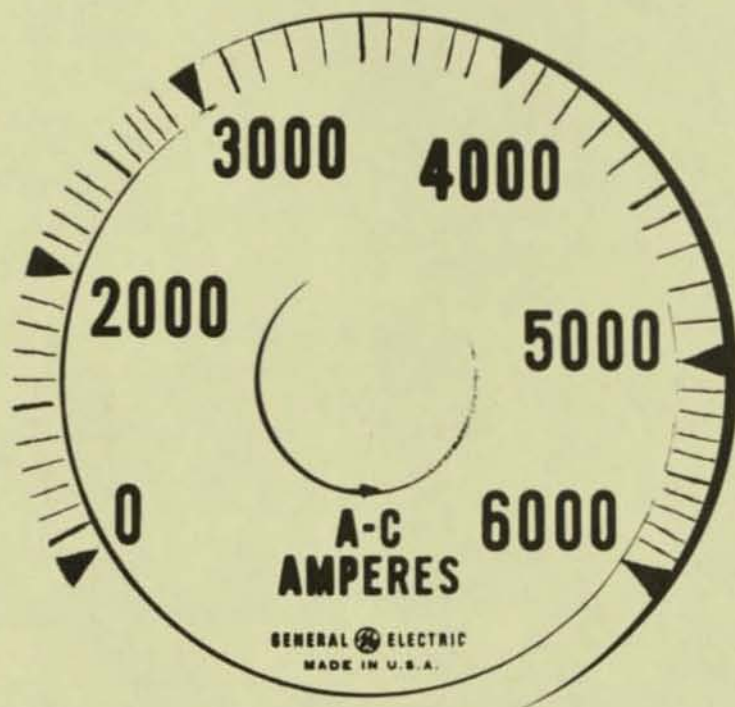


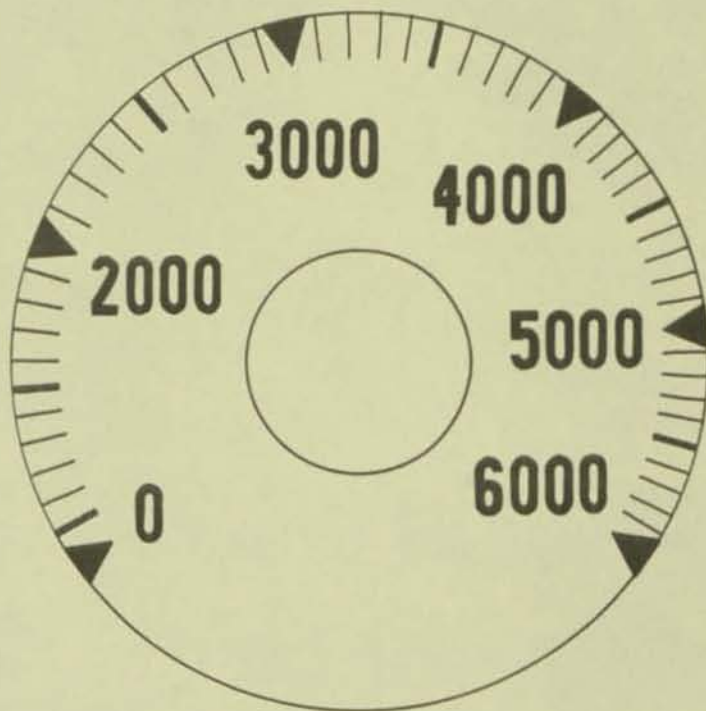
FIG. 9



"AFTER"  
FIG 23



"BEFORE"  
FIG 24



"AFTER"  
FIG 25

# PRODUCT STRUCTURE ANALYSIS FOR PRODUCT STANDARDIZATION

## Introduction

To achieve standardization where it really reduces costs, optimum design of the product line, better communications between marketing, engineering, manufacturing, finance and management, reduction in cycle time and many other benefits, an analysis is made of the product structure. Then the results of this analysis are used as a basis for a central information system and as a tool for engineers and manufacturing men.

The Product Structure analysis is setting forth the relations between what the customer wants and what the product is; i.e., between customer specifications and product characteristics. The fact that all parts dimensions, shapes, materials and other properties can be related to the specifications is rather surprising. Of course, there are many different ways of achieving these relations or, in other words, different designs of the same product. However, for a given design, all the decisions have been made so that the characteristics of the product which vary from model to model are determined by the customer's wishes.

The detailed analysis of the design of a product line reveals many interesting relations and makes possible:

1. Effective standardization
2. Optimum design of the complete product line
3. Easier introduction of design changes
4. A central information system for the product line
5. Improvement in planning, scheduling, inventory control and equipment selection
6. Reduction in cycle time and in mistakes in orders

## Procedure

The final result of this work is a set of relations, formulae or other logical statements relating specifications to characteristics. It has been found that a tabular form has been easy to use. Consequently, the results are known as Product Structure tables and the steps used to develop these are:

1. Customer Specification List - This list defines the product line and tells marketing people what the limits are. All possible models which can be ordered from the allowed values of these specifications are designed and planned. If the

customer does not specify a particular value, there is generally a standard chosen; e.g., unless otherwise specified, the color is always black.

2. Component Identification - The parts are listed by function as well as by similarity to make it easier to relate their properties to specifications. For example, resistors may have different functions, such as current limiting, element balancing, adjusting for full scale deflections, damping, bias, etc. By grouping the elements which produce a desired result the relations to specifications are more easily determined.
3. Fixed and Variable Characteristics - For each part or group of parts identified by the above procedure, there are certain fixed and variable characteristics. By examining drawings, parts lists and other such documents, the fixed and variable properties of each part is determined.
4. Product Structure Tables - How the variable characteristics are related to customer specifications is determined by studying the present design procedures. In most cases, simple logical statements are used, but sometimes a formula or equation is best. Where a range of values is possible the relation must be valid over the entire range.

### Examples

Examples taken from a study of the switchboard instrument line are given to illustrate these steps. Of course, different products may require different procedures to get the desired results. However, these steps appear to be universally useful at present.

#### 1. Customer Specification List

On this list are all the specifications which can be used by a customer. As the line is broadened by new designs, additional specifications may be added. By including many special requirements in the original list, much design engineering must be done, but once established, the system will handle a greater variety of customer requests; i.e., it will be more flexible.



TABLE I

<u>CS#</u>	<u>NAME</u>	<u>VALUES</u>
1	Kind of Service	D.C., A.C.
2	Type of Signal	Microamps, Milliamps, Amps, Millivolts, Volts, Watts, Vars
3	Current Rating	xx.xxxx e.g. 00.1000
4	Voltage Rating	xxxx.xxx e.g. 0400.000
5	Calibration Units	Volts, Amps, Watts
6	Values	xxxx.xxxx e.g. 0625.0000
7	Shock Rating	Normal, High
8	Size	4, 3/8, 8-3/4
9	Window Type	Clear, Antiglare
10	Cover Color	Black, Grey, Green xxxxxx e.g. xx Blue
11	Mounting Position degrees from vertical	xx e.g. 45
12	Accuracy	1%, 2%
13	Frequency or frequency range	25, 40, 50, 60, 400, 1000
14	Lead length in feet	xxx e.g. 500
15	Lead resistance in ohms	.xxx e.g. .063
16	Lead Compensation	No, Yes
17	Heavy Damping	No, Yes
18	# of Phases	1, 2, 3
19	Current Trans. Ratio	xxxx

<u>CS#</u>	<u>NAME</u>	<u>VALUES</u>
20	Potential Trans. Ratio	xxxx
21	# of wires	2, 3, 4
22	Temperature Compensated	No, Yes
23	Internal Illumination	No, Yes
24	Weatherproof	No, Yes
25	Nameplate	No, Yes
26	Military Number	xxxxxxxx
27	Legend, Line 1	AC, DC, Speed
28	Legend, Line 2	Volts Kilovolts Microamps Milliamp Amperes Kiloamperes Watts Kilowatts Megawatts Vars Kilovars Megavars RPM xxxxxxxx
29	Lowest Full Scale Value Right Hand	xxxx.x
30	Left Hand	xxxx.x
31	Higher Full Scale Value Right	xxxx.x
32	Left	xxxx.x
33	Highest F.S.V. Right	xxxx.x
34	Left	xxxx.x

<u>CS#</u>	<u>NAME</u>	<u>VALUES</u>
35	Main Scale Pattern	Linear A.C. Expanded Square Law
36	Special Mark No. 1 Color	Red, Blue, Green, Yellow, Orange, Black
37	Type	Arrow, Line, Wedge, Dot
38	Position (scale reading)	xxxx.x
39	Special Mark No. 2 Color	R, B, G, Y, O, Bl
40	Type	A, L, W, D
41	Position	xxxx.x
42	Special Mark No. 3 Color	R, B, G, Y, O, Bl
43	Type	A, L, W, D
44	Position	xxxx.x
45	Special Mark No. 4 Color	R, B, G, Y, O, Bl
46	Type	A, L, W, D
47	Position	xxxx.x
48	Special Band No. 1 Color	R, B, G, Y, O, Bl
49	Position Left End	xxxx.x
50	Position Right End	xxxx.x
51	Width	xx
52	Special Band No. 2 Color	R, B, G, Y, O, Bl

<u>CS#</u>	<u>NAME</u>	<u>VALUES</u>
53	Position Left End	xxxx.x
54	Position Right End	xxxx.x
55	Width	xx
56	Special Band No. 3 Color	R, B, G, Y, O, Bl
57	Position Left End	xxxx.x
58	Position Right End	xxxx.x
59	Width	xx
60	Government Packing	No, Yes
61	Zero Set Screw	No, Yes

As more "special" types of instruments are included in the line, the number of specifications increase. Some which could be added are fluorescent paint on scale and pointer, control initiation contacts mounted in instrument, etc.

## 2. Component Identification

A parts list giving the names of the parts yields considerable information, but if the parts have some functional identification, it is easier to relate them to specifications. For example, in Table II the resistors in the base assembly of the switchboard instrument are divided into groups according to their function.

TABLE II

### Types of Resistors

1. Full scale adjustment - variable
2. Element balance - variable
3. Current Limiting - fixed

### 3. Fixed and Variable Characteristics

For each group of components, the fixed dimensions, tolerances, finishes, coatings, etc., and the properties which vary with specifications are determined. For example, the pointers are always made of aluminum. The current limiting resistor used in wattmeters has fixed and variable characteristics as given in Table III.

TABLE III

#### Characteristics of Current Limiting Resistor-Wattmeters

<u>Fixed</u>		<u>Variable</u>	
Outside diameter	7/16"	Resistance value	6000 ohms
Diameter of body	5/16"		6400 ohms
Diameter of hole	3/16"		6700 ohms
Length	1-3/4		
Distance between outer terminals	1-3/8		
Distance between outer and middle terminals	11/16"		
O.D. plus terminal length	1-1/16"		
Wire	Nichrome		
Watt Rating	10		
Resistance tolerance	25%		

### 4. Product Structure Tables

A chart of Product Characteristics vs. Specifications is helpful as an intermediate step to see the overall picture but it is not necessary to get the final specific formulas. Table IV is a small example of such a chart.

TABLE IV

Partial Chart of  
Product Characteristics vs. Specifications

Specification	Control Spring Torque	Length of Pointer	No. of Turns Main Wdg.	Armature Shaft Material	Current Limiting Resistor
Kind of Service	X		X	X	X
Current Rating			X		
Voltage Rating			X		
Calibration Units	X		X		X
Calibration Values	X		X		X
Shock Rating				X	
Size	X	X			
Number of Phases	X				X
Scale Distribution	X		X		
Zero Location	X				

Table V illustrates one of several characteristics of parts which are dependent on the size of the scale plate. Others would be the size of bezel, size of letters on scale, distance between mounting studs, etc.

TABLE V

Length of Pointer

Conditions	Size of Instrument	Length of Pointer
	Large	3.370 $\pm$ .005
	Small	1.595 $\pm$ .005

Materials are determined in the same manner as shown in Table VI. One question which might arise from studying this table is, "What are the advantages and disadvantages to making all shafts out of bronze?" To answer this both engineering and manufacturing must study the problem.

TABLE VI

Armature Shaft Material

Conditions	Kind of Service	Shock Rating	Kind of Material
	DC	Normal	Aluminum 17ST
	DC	High	Phosphor Bronze B50W20
	AC	All	Phosphor Bronze B50W20

TABLE VII

Number of Turns - Main Winding of Armature Coil

Kind of Service	Calibration Units	Value	Scale Distribution	Number of Turns
DC	Volts	$\geq 1, < 300$	Regular	60
DC	Volts	$\geq 300$		120
DC	Millivolts	$\leq 150$		26
DC	Millivolts	$> 150$		13
DC	Amperes	$< .0135$		.300/cal. value
		$\geq .0135, < .018$		26
		$\geq .018, < .023$		15
		$\geq .023, \leq .033$		13
		$> .033, \leq 60$		26
AC	Volts	All		Expanded
AC	Volts	All	Regular	0
AC	Amps	All		0
AC	Watts	All		230

Examination of this table reveals quite a bit of the design philosophy used in this line. First, all electrodynamic type (wattmeters, varimeters and expanded scale voltmeters) instruments have a standard 230 turn winding. Therefore, to accommodate various ranges, different resistors, potential transformers, and current transformers are used. For low range D.C. ammeters, however, the range is determined by changing the number of turns. In the D.C. voltmeters and millivoltmeters, two standard coils are designed and the ranges obtained by changing resistors. The A.C. regular voltmeters and ammeters have an iron vane and thus have no armature coil. One question which might be asked is, "If the coil winding could easily accommodate any number of turns, would there be any advantage to making the number of turns the basic variable for all instruments?"

Table VIII indicates the scope of a rather complex set of specifications.

TABLE VIII

Control Spring Torque

Kind of Service	Calibration Units	Value	Zero Point Location	Size	No. of Phases	Scale Dist.	Torque		
AC	Watts	≥ 200, <250	Center	All	=1	Regular	.86		
					>1		1.70		
		≥ 250, <320	Center	All	=1	1.10			
					>1	2.20			
					≥ 320, <400	=1	1.45		
						Small	>1	2.60	
					≥ 400, <500	Center	All	=1	1.80
							Left	=1	.86
		Center	Small	>1	3.30				
		Left	Small	>1	1.50				



Kind of Service	Calibration Units	Zero Point Value	Location	Size	No. Of Phases	Scale Dist.	Torque	
AC	Watts	$\geq 500, < 600$	Center	All	=1	Regular	2.40	
			Left		=1		1.10	
	$\geq 500, < 575$	Center	Small	>1	4.00			
		Left	Small	>1	2.00			
		$\geq 575, < 626$	Center	Small	>1		4.80	
			Left	Small	>1		2.40	
	Amps.	All	Left	All	=1		1.40	
	Volts	All	Left	All	=1		1.20	
	Volts	All	Left	All	=1		Expanded	2.60
	DC	Volts	All	Center	All		>1	Regular
Amps.		$\geq 2.0002, < .035$	Center	All	>1		T=2.06NI-.15	
Amps.			Left	All	>1		T=3.97NI-.15	
Millivolts		All	Center	All			1.12	

Examination of the variation of control spring torque brings up questions such as, "Is it necessary to call for a different torque for large and small instruments?" The table shows that for some types there is a difference while in others there is none. "Is it easier to change from zero left to zero center by doubling the spring torque or by changing the resistors?" Here the engineers and manufacturing people must get together to see which standardization is best.

All of these tables were constructed by much detailed study of drawings, Master Lists, and other documents as well as discussion with design engineers. When completed, the tables give the design for the entire line, not just particular models.

By studying these tables, engineers can see how best to standardize the components, optimize the designs, introduce changes, and assist manufacturing people in reducing costs by selecting the proper manufacturing methods.

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## OPERATION STRUCTURE

There is very little that can be said about Operations Structure, which would not be a repeat of Product Structure. Where the Product Structure program defines the relationships between the Customer Specifications and the Product Design Characteristics, the Operation Structure program defines the relationships between the Product Design Characteristics and the Manufacturing Method and Time. The approaches which are used to establish each of these programs are identical.

There are two forms which the output from the Operation Structure can take. The first form is as a list of operator instructions or planning card (see Fig. 8), which can be issued in voucher form for manual operations. The second form is a punched digital tape which can be used to control automatic equipment. Examples of the Operation Structure programs that generate both of these outputs will be illustrated on the following pages.

### Operation Structure - Manual Operation (Product Oriented)

Fig. 9 illustrates the two major types of armature coils used on Switchboard instruments. There are many minor variations within each type, such as wire size, wire material and number of turns. However, there is enough similarity between all coils so that they may be classified as a generic family, the first step in creating an Operation Structure.

The second analytical step is to separate the fixed characteristics of the OPERATION from the variable. Examples of some fixed characteristics are: the machines on which the windings are made, the time and temperature for curing, the winding forms, and the gauging procedure. Some of the variable elements of the operation are: the materials to be selected, the location of the Flat Strip Coil Supports, the number of turns to be wound, and the operation time.

The third step is to relate the variable operations and times to the variable Product characteristics. Again as in Product Structure, some of these relationships are extremely simple. For instance, the materials to be selected by the Operations Structure are obviously identical to the materials specified by the Product Structure. However, the sequence in which the materials are assembled is not obvious. Consider, for example, the sequence in which the windings and coil supports are assembled. In Type II (See Fig. 9) the coil supports are assembled after the winding is completed; in Type I (See Fig. 9) the coil supports are interspersed between the windings.

Factory practice specifies that if the number of turns on the main winding is:

1.  $< 100$ , then wind 2 turns; assemble coil supports; wind remaining turns.
2.  $\geq 100$ , then wind  $1/3$  total turns; assemble coil supports; wind remaining turns.

The fourth step is to formulate these relationships into mathematical or logical expressions, but this step will be eliminated in this case because of its simplicity.

The fifth step is to prepare a tabular solution for the computer (see Fig. 10). In Table 1 the initial number of turns is specified with an address for the next instruction. It will be noticed that if the type of coil support is tab and hole, Tables 2 and 3 are skipped, because the winding is completed in the first table. In Table 4 it is not necessary to check the type of coil support again (hence the word "any"), because it is impossible to be in this table if the type of coil support is other than tab and hole. Similarly, if in Table 1 the type of coil support is flat strip, the next addresses are Table 2 for the assembly of the coil supports and Table 3 for the completion of the winding. Here Table 4 is skipped.

Fig. 11 shows the tables which would be used to compute the times for the elements in Fig. 10. In practice these sets of tables would be combined. The time values in Tables 2 and 4 are fixed, as it is apparent that each particular type of coil support has its own associated time for assembly. The winding time, however, is variable. This occurs because of winding acceleration and deceleration. As the number of continuous turns increases, the time per turn decreases. The formulas in Table 1a are empirical and are based on observation. The complete set of tables is in Appendix II.

In the opening description of the armature coil, it was observed that there were two major types and many variations within these types. It is apparent from a study of the illustrations in Fig. 9 and the tables in Fig. 10 and Fig. 11 that the Operation Structure is flexible enough to provide for infinite variation in total turns. Further tables would disclose equal flexibility in the selection of wire size and material as well as many other variations. The Operation Structure could not, however, plan the

method and time for a completely different type of coil, such as one that was wound. The existence or lack of flexibility depends entirely on the size of the sample observed. For instance, it was possible to develop winding equations, only because there was a large enough sample of coils with different numbers of turns, so that a trend or pattern could be discerned. However, the only shape of conductor, which was observed, was round wire. Without a pattern of conductor shapes, it is impossible to extrapolate the effects of a foil wound coil on the manufacturing method and time.

#### Operation Structure - (Equipment Oriented)

The principles upon which an equipment oriented Operation Structure is based are analogous to those employed in creating one that is product oriented. In review, the steps are:

1. Select an operation.
2. Separate the fixed portions of the operation from the variable portions.
3. Relate the variable portions of the operation to the variable design characteristics.
4. Express these relationships in mathematical or logical expressions.
5. Structure these mathematical or logical terms into a tabular solution.

An example of an equipment oriented structure is the machining cycle of the Spindlemaster on the base molding of the instrument. Fig. 12 is an illustration of the Spindlemaster, an automatic drilling, milling, tapping, etc. machine tool that has been conceived by the Manufacturing Laboratory. The equipment has a 36 tool reservoir from which any tool can be randomly selected. The 36 tool capacity should prove ample for any generic family of parts. The machine tool also includes a numerically controlled table capable of automatically positioning anywhere along its two axes and provides automatic selection of feed, speed, and depth. The base molding, see Fig. 13, which has been chosen for this example, is a plastic disc approximately 1/2" x 4", that serves as a back cover and mounting board for various components of the instrument. While the molding itself may be considered fixed, there is extreme variation in the types, sizes, and locations of the holes which are machined into the molding. In all there are over 300 standard hole configurations. It would seem desirable to machine these holes in a sequence that minimizes the total tool changing time and the total table positioning time.

However, because different tools and different locations occur for different bases, it is impossible to determine a single sequence which is optimum for each and every base. Therefore, the Operation Structure for the Spindlemaster machining of the base must specify not only the tools to be used and dimensions for positioning, but also the order in which the tools will be used and hole locations will be positioned. This changes the second step of the analysis, which is to separate the fixed characteristics (in this case the fixed holes) from the variable. While fixed operations may be performed in processing fixed design characteristics, the sequence of these fixed operations may be changed by the existence of variable operations. The only cases where this problem will not be encountered are those cases where all of the fixed operations are performed at one time, such as on a Zagar head.

At this point it is desirable for analysis to break the Operation Structure into two parts.

Part I: Determine for all of the operations the tools, locations, speeds, feeds and depths required.

Part II: Determine a sequence for the operations.

Part I presents little problem. Fig. 14 illustrates a possible table solution for the base illustrated in Fig. 13. Tables 1 and 2 give all of the necessary information to machine the fixed frame and terminal holes. Tables 3, 4 and 5 provide all the information concerning the machining operations on the variable holes. The test rows in Table 3 contain all of the possible combinations of hole sizes, tolerances, and threads. The columns under these rows specify the operations which must be performed, and the tool size, feed, and speed for each operation. As a single hole can only have one location, the X and Y coordinates are only specified once in Table 4. The values of these coordinates are obviously directly related to the drawing dimensions. Table 5 is an executive table which insures that every variable hole is processed through Table 3 before going on to the rest of the program.

When all of the operations have been identified by tool and hole location, the next problem is to sequence these operations to obtain a minimum machining time. It is at this point that it is difficult to separate the fixed and variable operations, as the fixed operations may change their sequence depending on the nature of the variable operations. Part II is to establish a sequence so that:

Total Time = Minimum (Tool Change Time / Table Position Time)

It is apparent that the minimum total time must consider the tool change time and table position time in combination. To minimize these times separately would lead to conflicting sequences. For example: the minimum tool change time occurs when each tool is changed but once, and all operations using that tool are performed in succession. Minimum positioning time occurs when each location is positioned but once and all operations at that location are performed in succession. In this situation minimizing one factor tends to maximize the other.

A further complication is introduced when one considers that if a position change and a tool change occur simultaneously, there is an overlap of times, see Fig. 15. Furthermore, the time is not fixed but varies with the distance between locations and the distance between tools.

There are two obvious approaches to this problem. First there is a strategic approach, which considers all of the possible permutations of operation sequence and selects the sequence with the shortest total time. Mathematically this is the only approach which will assure the optimum time, however, the number of separate time solutions required is  $1/2 (n^2 + n)$  and the number of sequences for which total times have to be computed and compared equals  $n!$ , where  $n$  = the number of operations.

The second obvious approach is a tactical solution which considers only the next best operation. The danger of the approach is the chance of "winning battles and losing wars". While the correct answer is not a mathematical certainty (or even a mathematical possibility where the number of operations is considerable) the degree of error is likely to be insignificant. The advantage of this approach is that while the number of separate time solutions is still  $1/2 (n^2 + n)$ , the number of possible sequences is reduced each time a next best operation is chosen. This method results in just one possible sequence and eliminates the necessity for any computation of total time and reduces the number of comparisons to the number of separate time solutions, i.e.  $1/2 (n^2 + n)$ . Fig. 16 and 17 are a comparison of these approaches when only one tool is used. Fig. 18 is an illustration of the danger of the tactical approach.

It is apparent that the millions of computations and comparisons required by the strategic approach on just a simple problem, requiring only ten locations and one tool, is prohibitive even on a computer. Thus the tactical approach is selected for practical purposes for location selection.

The tactical approach could also be used for tool selection; i.e. to select the next combination of tool and location, which has the smallest total time. The difficulty here is that a natural priority exists between tools used at the same location; i.e. mill before drill before tap, etc. At any point in the machining cycle there is apt to be some tool and location combinations that cannot be selected until prior operations have been performed. Once these prior operations have been performed, these combinations then become eligible for selection. The procedure of assigning priority numbers to tool and location combinations, and continually updating these priority numbers as preceding operations are performed is a considerable data processing task.

One solution to this problem is to eliminate the necessity of priorities by establishing a tool selection policy for all locations. For instance, first perform all end milling operations for all locations; second, all hollow milling operations for all locations; third, all drilling operations for all locations, etc. A second, and similar, policy would be to: first, perform all end milling operations at one location; second, perform all hollow milling operations at that same location; third, all drilling operations at that same location, etc. When all of the operations at one location have been performed, the tool selection cycle would repeat itself for the next location.

The choice of policy would depend on a comparison of the tool change time and the table position time. If the average time per tool change is  $>$  than the average time per position change, then the best policy is to hold each tool as long as possible. In this case the first policy (perform all milling operations at all locations, etc.) would be chosen. If the average time per position change is  $>$  than the average time per tool change, then the best policy is to hold the location as long as possible. Therefore, the second policy (perform all milling operations at one location, etc.) would be chosen.

Fig. 19 is a schematic illustration of the operation sequence solution based on the policies for tool selection, and the tactical approach for location selection.

It is obvious that this further simplification of the problem leads to a decreased optimization of the machining cycle. Additional investment is warranted to obtain the best balance of solution time and cycle time. Further investigation is also necessary to determine the average times per tool change and the average time per position change.



STRT	0150	CU	DW				
CUT WIRE							
WIND	0016	URNS					
PRSS	DW						
REV							
STRT	0060	CU	MW				
B/O	MW						
WIND	2	URNS					
INST	2	FS COIL SUPT &	FL STRT CONN &	FL FIN CONN &	INSL		
WIND	0058	URNS					
B/O	MW						
WIND	0060	URNS					
END OF OPERATION							
TOTAL TIME IS 16145							

FIG. 8

OPERATION STRUCTURE PRINTOUT  
FOR ARMATURE COIL WINDING

Table #1

Type of Coil Support No. of Turns in Main Winding	Tab & Hole ANY	Flat Strip	
		<100	≥100
Wind	Total <sup>1</sup> Turns	2 Turns	1/3 Total <sup>1</sup> Turns
Next Address	Table 4	Table 2	Table 2

Table #2

Type of Coil Support	ANY
Assemble	2 Flat Strip Coil Supports
Next Address	Table 3

Table #3

No. of Turns in Main Winding	< 100	≥ 100
	Wind	(Total <sup>1</sup> -2) Turns
Next Address	Table 5	

Table #4

Type of Coil Support	ANY
Assemble	2 Tab & Hole Coil Supports
Next Address	Table 5

<sup>1</sup>Total turns would be an output from Product Structure and thus would be a quantitative figure available in the computer for use in the solution of these tables.

Fig. 10

<u>Table #1a</u>						
<u>No. of Turns in Table #1</u>	< 15	≥ 15 < 100		≥ 100		
<u>Time (Sec.)</u>	1 Sec/Turn	125 (Wire Dia) 1	(No. of Turns) 2	1000 (Wire Dia) 1	No. of Turns 2	

<u>Table #2a</u>	
<u>Type of Coil Support</u>	ANY
<u>Time (Sec.)</u>	88.49

Table #3a (Same as Table #1a)

<u>Table #4a</u>	
<u>Type of Coil Support</u>	ANY
<u>Time (Sec.)</u>	104.69

<sup>1</sup>Wire diameter would be an output from the Product Structure

<sup>2</sup>No. of turns would be an output from Table #1

Fig. 11

# SPINDLEMASTER

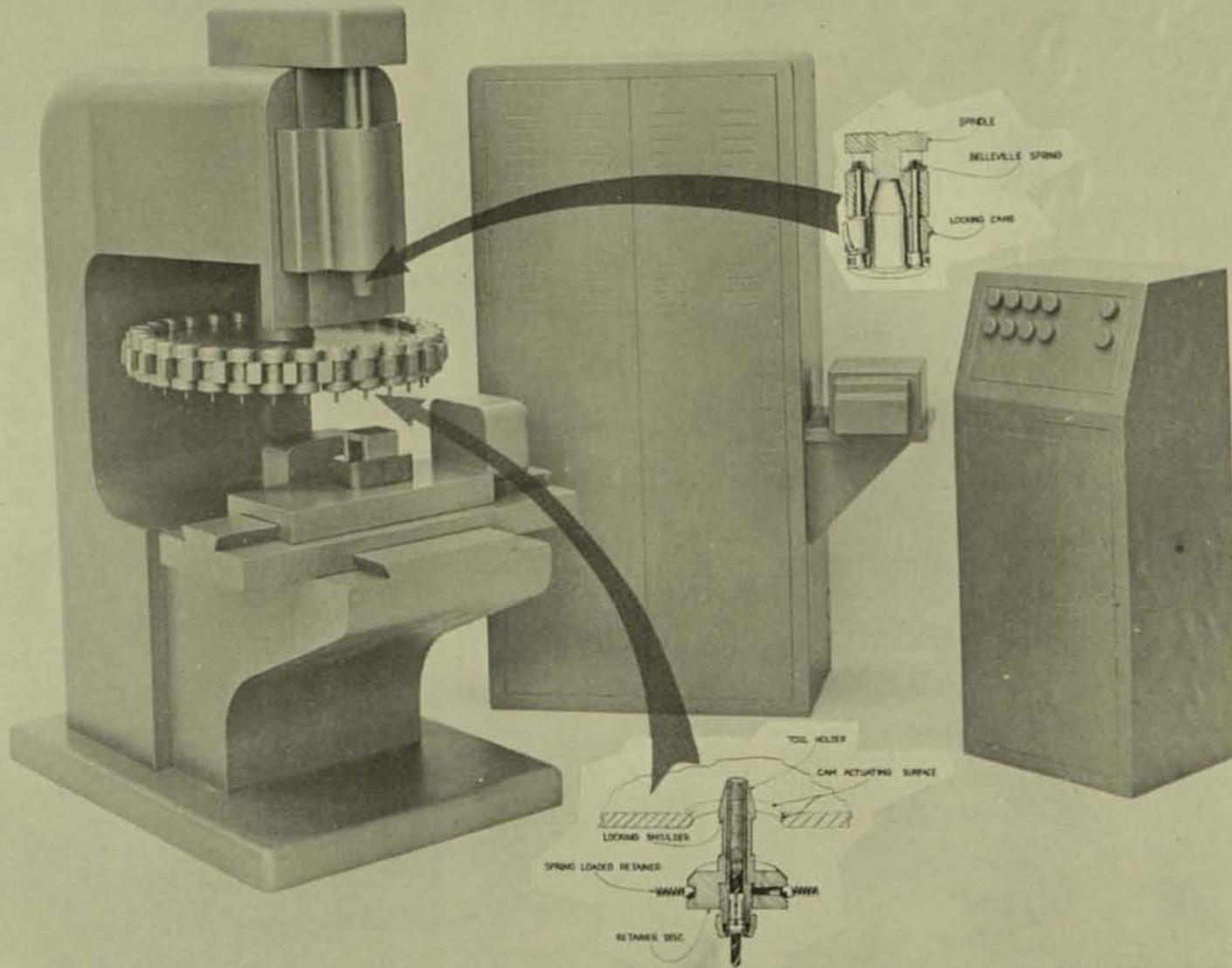


Fig. 12

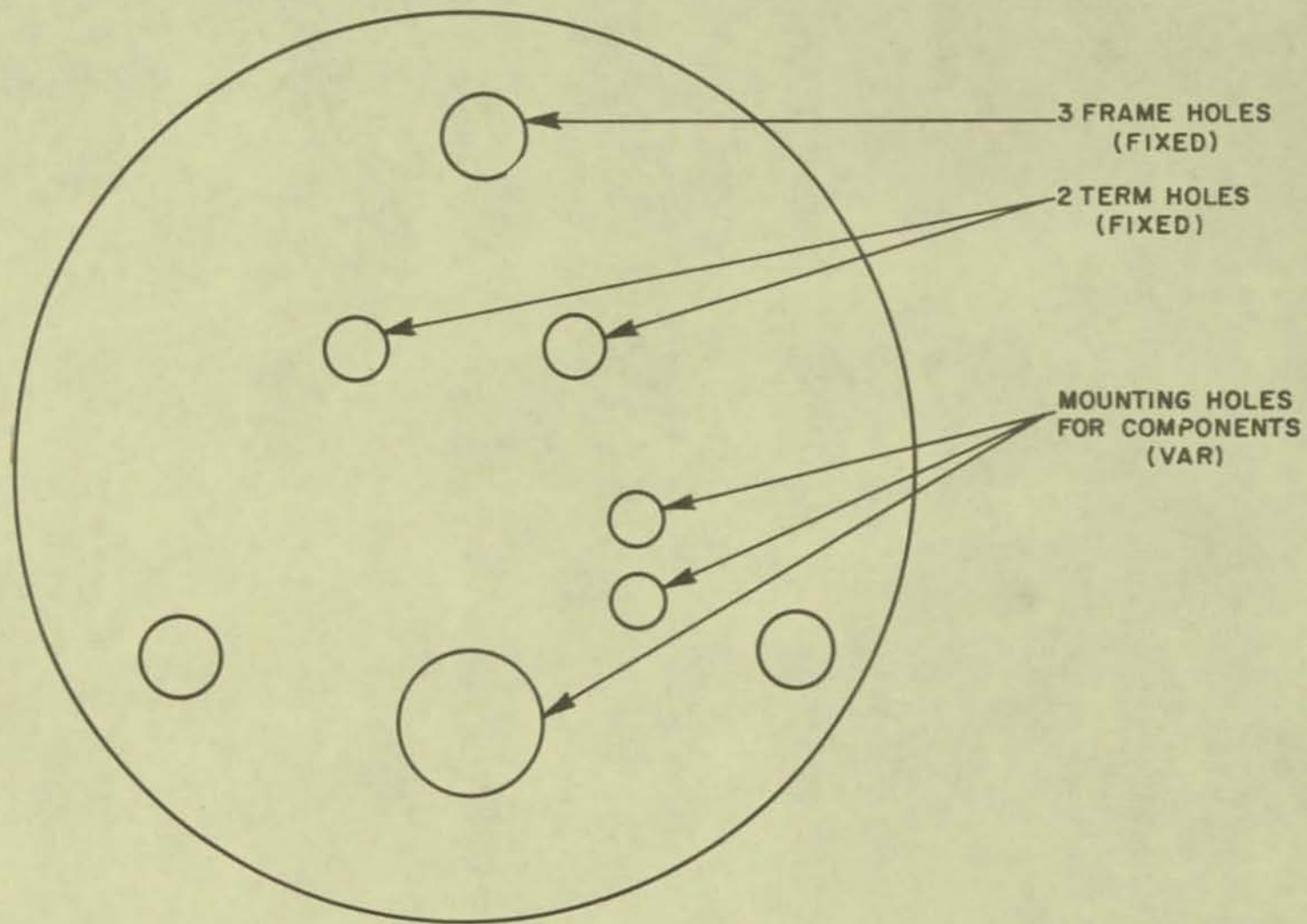


FIGURE 13  
INSTRUMENT BASE

Table #1

Frame Holes	ANY
Operation	Drill
Tool Size	#33
Tool Feed	.010"/Rev.
Tool Speed	600 rpm
Start Operation Z	Z.ZZZ
End Operation Z	Z.ZZZ
1st Hole Location X	X.XXX
Y	Y.YYY
2nd Hole Location X	X.XXX
Y	Y.YYY
3rd Hole Location X	X.XXX
Y	Y.YYY
Next Address	Table 2

Table #2

Term. Holes	ANY
Operation	Drill
Tool Size	#19
Tool Feed	---"/Rev.
Tool Speed	--- rpm
Start Operation Z	Z.ZZZ
End Operation Z	Z.ZZZ
1st Hole Location X	X.XXX
Y	Y.YYY
2nd Hole Location X	X.XXX
Y	Y.YYY
Next Address	Table 3

Table #3

	.250		#33	#6	
Next Hole Size	$\geq \pm .001$	$< \pm .001$	$\geq \pm .001$	$\geq \pm .001$	$\geq \pm .001$
Next Hole Tol	0	0	0	40	90
Next Thds/In	0	0	0	40	90
Next Operation	Drill	Drill	Drill	Drill	Drill
Tool Size	.250	.249	#33	#33	#33
Tool Speed	-	-	-	-	-
Tool Feed	-	-	-	-	-
Operation	NE	Ream	NE	Tap	Tap
Tool Size	NE	.250	NE	#6-40	#6-90
Tool Speed	NE	-	NE	-	-
Tool Feed	NE	-	NE	-	-
Next Address					

Table 4

Fig. 14

Table #4

Next Hole Location X	X Dimension /	Machine Reference	
Next Hole Location Y	Y	"	"
End of Rapid Trav.	Z <sub>1</sub>	"	"
Depth of Operation	Z <sub>2</sub>	"	"
Next Address			

Table 5

Table #5

Number of Times Table 3 has been used	= Number of Variable Holes	< Number of Variable Holes
Next Address	Table 6	Table 3

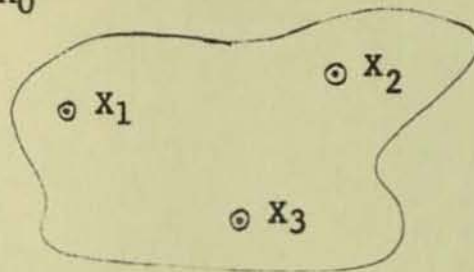
Fig.14 (Cont'd)

Position Tool	Change Same	Same Change	Change Change
Fixed Position Change Time	1.0	0	1.0
Var. Position Change Time	1.0/in	0	1.0/in
Fixed Tool Change Time	0	4.5	4.5
Var. Tool Change Time	0	.5/pos.	.5/pos.
Total Time	1.0 † 1.0/in	4.5 † .5/pos	4.5 † max (1.0/in or .5/pos)

Fig. 15



Start  
 ⊙ X<sub>0</sub>



In both solutions solve for:

$$t(0-1) = t(1-0), \quad t(0-3) = t(3-0), \quad t(1-3) = t(3-1)$$

$$t(0-2) = t(2-0), \quad t(1-2) = t(2-1), \quad t(2-3) = t(3-2)$$

I. Strategic Solution: Select Sequence associated with the smallest time summation

<u>Sequence</u>	<u>Times</u>
0 → 1 → 2 → 3	$t(0-1) + t(1-2) + t(2-3) = T_1$
0 → 1 → 3 → 2	$t(0-1) + t(1-3) + t(3-2) = T_2$
0 → 2 → 1 → 3	$t(0-2) + t(2-1) + t(1-3) = T_3$
0 → 2 → 3 → 1	$t(0-2) + t(2-3) + t(3-1) = T_4$
0 → 3 → 2 → 1	$t(0-3) + t(3-2) + t(2-1) = T_5$
0 → 3 → 1 → 2	$t(0-3) + t(3-1) + t(1-2) = T_6$

II. Tactical Solution:

Next Operation Time

0 → 1	t(0-1)	) Select Next Operation
0 → 2	t(0-2)	) Associated With The
0 → 3	t(0-3)	) Smallest Time Ex: 1
1 → 2	t(1-2)	) Select Next Operation
1 → 3	t(1-3)	) Associated With Smallest Time Ex: 3
3 → 2		) Only Choice Left

Fig. 16

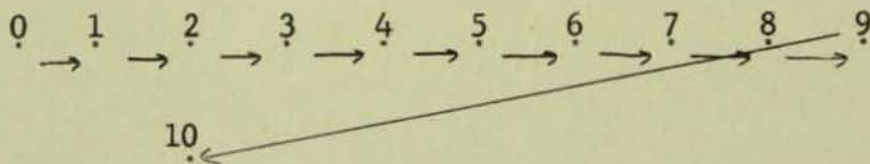
Comparison of Strategic and Tactical Approaches for 10 Operations Using One Tool

Number of Separate Time Solutions	Strat. $\frac{1}{2} (n^2 + n)$ 55	Tact. $\frac{1}{2} (n^2 + n)$ 55
Number of Total Time Solutions	$N!$ 3,628,800	0 0
Number of Comparisons of Total Times or Separate Times	$N!$ 3,628,800	$\frac{1}{2} (n^2 + n)$ 55

Fig. 17

Disadvantage of the Tactical Approach

Start



A better sequence is

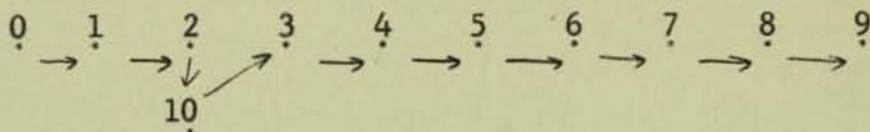


Fig. 18

H. W. Nidenberg

D. W. Cameron

9/11/58

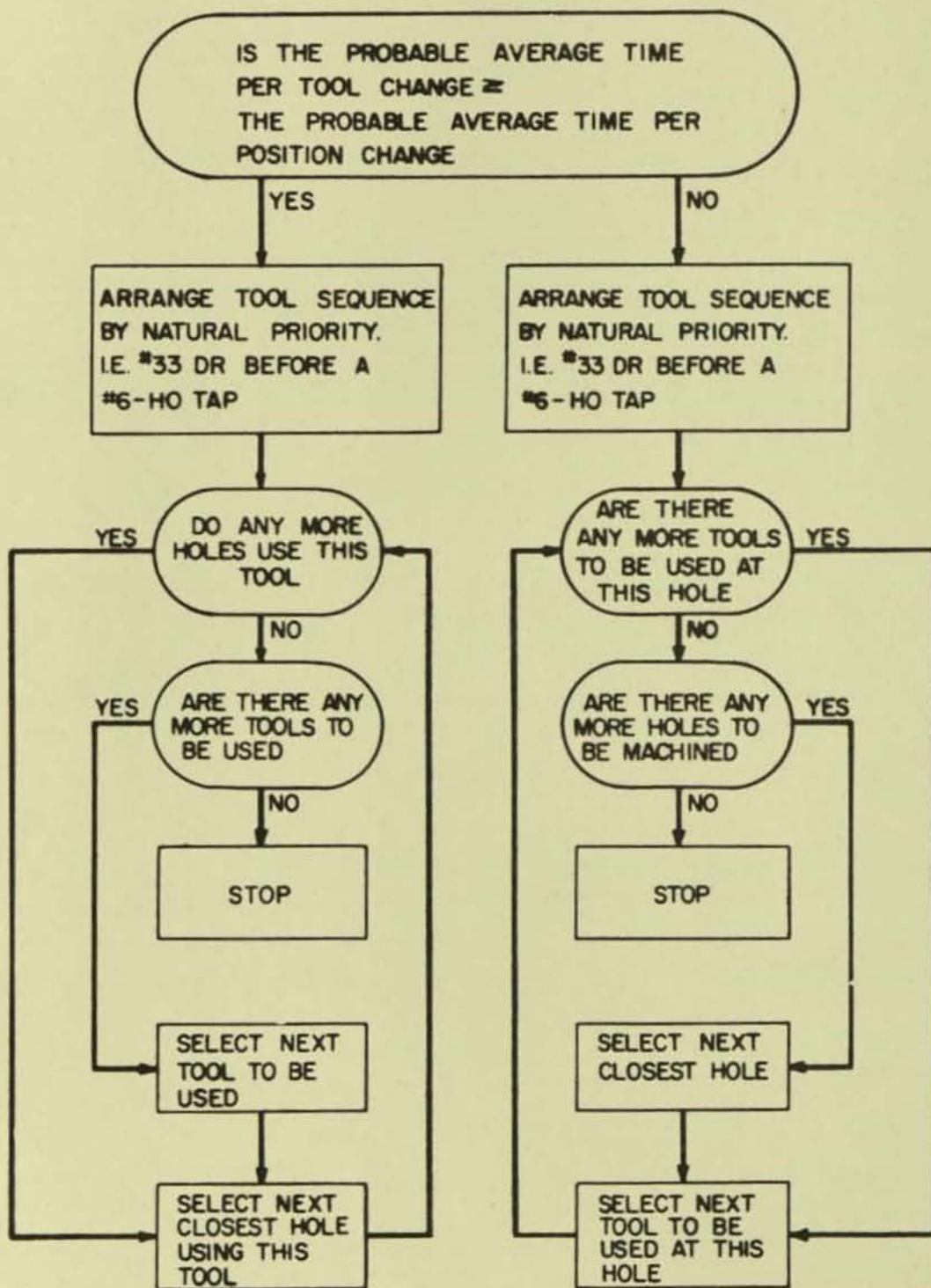


FIG. 19

Appendices I and II are available upon request. Both appendices contain a great deal of detail on the armature coil and scale plate structure tables.

SECTION IV

ALL INFORMATION CONTAINED  
HEREIN IS UNCLASSIFIED  
DATE 11/19/01 BY 60322 UCBAW

## TABFOR

B. Grad  
11/5/58

### TABSOL - For Formula Statements

1. It would be desirable for a structure table to have the ability to directly express simple formulas which could be solved by TABSOL rather than requiring explicit programming. Since the bulk of the equations used in Manufacturing Control Decision Rules are relatively simple this would allow the system designer to define the entire program without the necessity of any programming (even the relatively small amount now needed for pseudo-arithmetic.)
2. The economics of including a formula solver in TABSOL is not answered in this write-up, but only the technical feasibility of representing the arithmetic logic in a simple, usable form.
3. In general, it will be necessary to express the operations of: plus, minus, multiply, divide, square root and integer exponents (square, cube). These are called operators.
4. There are two types of operands required: literal, where the actual value itself is expressed; and non-literal where the name or location of the factor is denoted.
5. We must use and recognize two "delineators": open parenthesis  $\langle ( \rangle$  and close parenthesis  $\langle ) \rangle$ . This enables us to define related terms explicitly. Two additional symbols will be used to indicate the beginning  $\langle @ \rangle$  and end  $\langle \& \rangle$  of the formula.
6. Finally provision should be made for the incorporation of special formulas where required such as Sine functions, etc.
7. The balance of this paper will develop through examples a particular notation and logic which could be used to solve this problem. A technical summary of this approach is attached as exhibit A.
8. All formulas will be stated as a series of words (or blocks) in the result (or output) rows of a structure table. The first row will be the name or location of the result field. For example,  $R = a + b$  would be shown as:

R	@
-	a
-	+
-	b
-	¢

This would be a simple unconditional table stating that computed variable R equals the value of the expression (a + b).

9. To solve this simple expression the computer could use the logic expressed in the following tables combined with a reserved sequential storage area ( the Q line).

In the regular TABSOL routine the following test is made:

Is 1st Result Row

a computed variable	yes	no			
Go To TABLE	TABFOR (2)	normal TABSOL			
(2)					
type of present word	operand	operator	operand	@	¢
type of previous word in Q line	≠ operator	---	operator	---	---
store in Q line at Next Location (NL)	(present word)	(present word)	(present word)	(present word)	-
add to NL	+ 1	+ 1	+ 1	+ 1	-
add to present word location	+ 1	+ 1	+ 1	+ 1	+ 1
Go To TABLE	(2)	(2)	(3)	(2)	(7)

(3)

_____	_____
Inter Result	(NL - 1) operates per (NL - 2) on (NL - 3) note: NL - 2 is always an operator and the others operands.
Store at NL - 3 in Q line	Inter Result
Add to NL	- 2
Go To TABLE	(2)

(7)

_____	_____
Store at Result Location	1st Entry in Q line
Go To	TABSOL

10. Let's expand this to handle a more complicated problem:

$R = c(a + b)$       rewritten as  $R = c*(a + b)$   
where \* means times

_____	_____
R	@
-	c
-	*
-	(
-	a
-	+
-	b
-	)
-	ç



TABLE (2) would be expanded to handle this as follows:

type of present word	(	)
type of previous word in Q line	-	-
<hr/>		
store in Q line at Next Location (NL)	(present word)	-
add to NL	+ 1	-
add to present word location	+ 1	+ 1
Go To TABLE	(2)	(5)

(5)

<hr/>		<hr/>	
<hr/>		<hr/>	
store in Q line at location NL - 2		(Q line at location NL - 1)	
add to NL		- 1	
Go To TABLE		(6)	

(6)

NL	$\leq 3$	$\geq 4$	$\geq 4$
Type of word at NL - 2	-	operator	$\neq$ operator
Go To TABLE	(2)	(3)	(2)

Let us follow this through step by step.

-	-
R	@
-	c
-	*
-	(
-	a
-	+
-	b
-	)
-	ç

Present word location equals 1.

Step (1) (present word) = @

<u>Q Line</u>	<u>NL</u>	<u>Present Word Location</u>
	1	2

Step (2) (present word) = c

<u>Q Line</u>	<u>NL</u>	<u>Present Word Location</u>
c	2	3

Step (3)

<u>Q Line</u>	<u>NL</u>	<u>Present Word Location</u>
c	3	4
*		

Step (4)

<u>Q Line</u>	<u>NL</u>	<u>Present Word Location</u>
c	4	5
*		
(		

Step (5)

<u>Q Line</u>	<u>NL</u>	<u>Present Word Location</u>
c	5	6
*		
(		
a		

Step (6)	<u>Q Line</u> c * ( a +	<u>NL</u> 6	<u>Present Word Location</u> 7
----------	--	----------------	-----------------------------------

Step (7)	<u>Q Line</u> c * ( a +	<u>NL</u> 7	<u>Present Word Location</u> 8
Part (a)	b		

Part (b)	<u>Q Line</u> c * ( [a + b]	<u>NL</u> 5	<u>Present Word Location</u> 8
----------	---	----------------	-----------------------------------

Step (8)	<u>Q Line</u> c * [a + b]	<u>NL</u> 4	<u>Present Word Location</u> 9
Part (a)			

Part (b)	<u>Q Line</u> [c* [a + b]]	<u>NL</u> 2	<u>Present Word Location</u> 9
----------	-------------------------------	----------------	-----------------------------------

Step (9)

store at location R      [c\* [a + b]]

11. To test this for subtraction and division use - for subtract, use / for divided by:

$$R = \frac{abc}{(a - b)}$$

Rewritten as  $R = (a*(b*c))/(a - b)$

R	@
-	(
-	a
-	*
-	(
-	b
-	*
-	c
-	)
-	)
-	/
-	(
-	a
-	-
-	b
-	)
-	ç

This would work without modification. Try it to be sure.

12. The concept of square root and exponents has not yet been handled. Let us try a simple square root case:

$$R = \sqrt{b}$$

Rewritten as  $R = b^{*.5}$   
where \*\* means exponent.

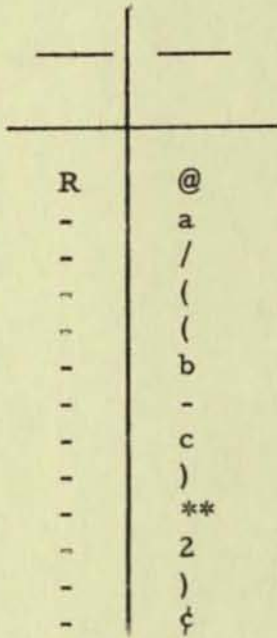
R	@
-	b
-	**
-	.5
-	ç

This will work satisfactorily without modifying any tables.

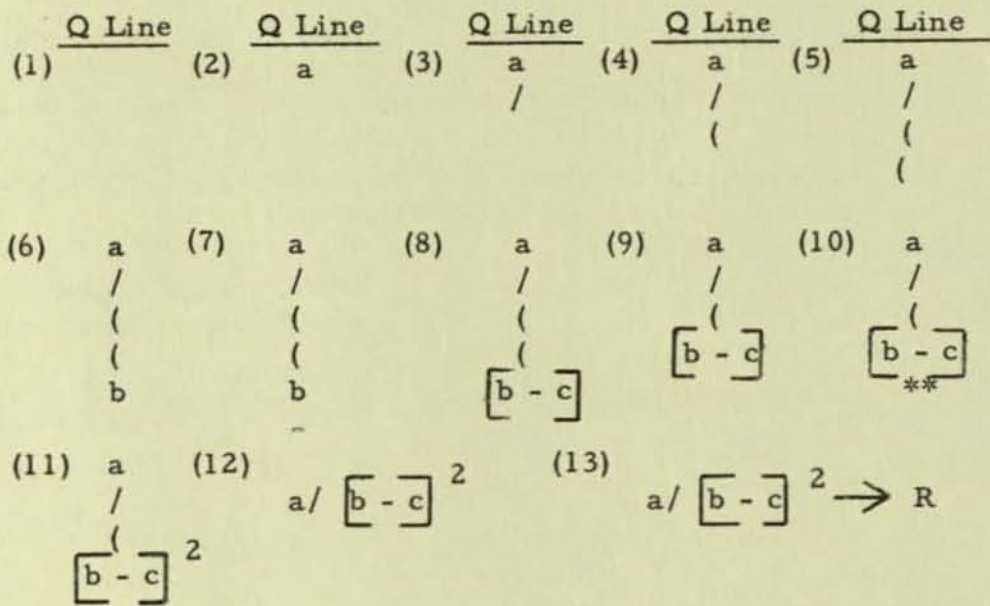
13. As a summary try the following example.

$$R = \frac{a}{(b - c)^2}$$

Rewritten as  $R = a / ((b - c) ** 2)$



The Q Line successively looks as follows:



TABFOR

Table Solution Of Formulas

B. Grad  
11/5/58

Definitions

$\sigma$	means operand
r	means operator
(	means front delineator
)	means close delineator
ç	means end of expression delineator
@	means beginning of expression delineator

All words in a result column will carry a tag. This tag will indicate the type of word that it is: operand, operator, front parenthesis, close parenthesis, beginning of expression or end of expression.

The content of an operand word in a result column will either be a literal value (fixed point noted by explicit inclusion or else assumed that the value is an integer) or a non literal which can be interpreted into an address.

The content of an operator word in a result column will designate the particular type of operator:

add or plus	by	+
subtract or minus	by	-
multiply	by	*
divided	by	/
exponent	by	**

The content of a delineator word in a result column will be blank.

T represents the tag of a result block.

$$T = \sigma, r, (, ), \text{ç}, @$$

PW indicates the  $kj^{\text{th}}$  block of a result matrix where k is the row and j the selected column; this is called the present word. The present word may have any of the following constructions:

σAAAA ≡ operand, non literal, relative address may be alphanumeric

σNNNN ≡ operand, literal, numeric only, one location may have a decimal point

rbbb+  
rbbb-  
rbbb\*  
rbbb/  
rbb\*\*

} five operators, add, minus, multiply, divided by, exponent

(bbbb  
)bbbb  
çbbbb  
@bbbb

} four delineators

↑ PW      PW  
contents of the present word

Q<sub>NL</sub> represents a queue line in which all information is stored prior to arithmetic manipulation. NL denotes the next location in the queue line.

L<sub>R</sub> represents the location where the result is to be stored.

R represents the value of the result.

Initially k is set and j is fixed at the proper column.

In the regular TABSOL routine the presence of the symbol @ will automatically transfer the program to the TABFOR subroutine.

The following are the TABFOR Tables:

(1) Go to (2)

$L_R$	Result variable kj location

(2)

$T_{PW}$	@	r	$\sigma$	(	$\sigma$	)	$\phi$
$T_{Q_{NL-1}}$	-	-	$\neq r$	-	=r	-	
$Q_{NL}$	-	$\overline{PW}$	$\overline{PW}$	$\overline{PW}$	$\overline{PW}$	-	-
NL	1	NL+1	NL+1	NL+1	NL+1	-	-
k	k+1	k+1	k+1	k+1	k+1	k+1	k+1
Go To	(2)	(2)	(2)	(2)	(3)	(5)	(7)

(3) Operate per  $Q_{NL} - 2$   
 Go to (4) on  $Q_{NL} - 1$   
 and  $Q_{NL} - 3$  } Inter result

(4) Go To (2)

$Q_{NL} - 3$	Inter result
NL	NL - 2

(5) Go To (6)

$Q_{NL} - 2$	$(Q_{NL} - 1)$
NL	NL - 1



(6)	NL	$\leq 3$	$\geq 4$	$\geq 4$
	$T_{Q_{NL-2}}$	-	r	$\neq r$
	Go To	(2)	(3)	(2)

(7)		
	R	$Q_1$

The simplest form is:

$$R = @ \sigma r \sigma \zeta$$

This would be written:

$L_R$	@
-	$\sigma$
-	r
-	$\sigma$
-	$\zeta$

Initial condition:  $k = 1$ ;  $L_R$  is set up.

<u>Step 1</u>	<u>Q Line</u>	<u>NL</u>	<u>k</u>	<u><math>L_R</math></u>
		1	2	
<u>Step 2</u>	<u>Q Line</u>	<u>NL</u>	<u>k</u>	<u><math>L_R</math></u>
	$\sigma$	2	3	

<u>Step 3</u>	<u>Q Line</u> $\sigma$ r	<u>NL</u> 3	$\frac{k}{4}$	<u>LR</u>
<u>Step 4(a)</u>	<u>Q Line</u> $\sigma$ r $\sigma$	<u>NL</u> 4	$\frac{k}{5}$	<u>LR</u>
(b)	<u>Q Line</u> $\boxed{\sigma r \sigma}$	<u>NL</u> 2	$\frac{k}{5}$	<u>LR</u>
<u>Step 5(a)</u>	<u>Q Line</u> $\boxed{\sigma r \sigma}$	<u>NL</u> 2	$\frac{k}{6}$	<u>LR</u>
(b)	<u>Q Line</u>	<u>NL</u>	$\frac{k}{6}$	<u>LR</u> $\boxed{\sigma r \sigma}$

We will now develop a wholly general form showing each possible kind of juxtaposition;

There are six symbols  $\sigma$ , r, (, ), @,  $\phi$

The possible permutations of six things taken two at a time (including permutations with itself) is 36: (x notes an invalid combination)

x $\sigma\sigma$	r $\sigma$	( $\sigma$	x) $\sigma$	@ $\sigma$	x $\phi\sigma$
$\sigma$ r	xrr	x(r	)r	x@r	x $\phi$ r
x $\sigma$ (	r(	((	x)(	@(	x $\phi$ (
$\sigma$ )	xr)	x()	)	x@)	x $\phi$ )
x $\sigma$ @	xr@	x(@	x)@	x@@	x $\phi$ @
$\sigma\phi$	xr $\phi$	x( $\phi$	) $\phi$	x@ $\phi$	x $\phi\phi$

1. Any permutation with @ last or  $\phi$  first can be eliminated.
2. Two operands or two operators cannot be adjacent.
3. An expression or a term cannot end in an operator.

4. An open parenthesis cannot be followed by a close parenthesis or a  $\phi$ .
5. An operand cannot directly precede an  $($ .
6. An operator cannot directly follow an  $($ .
7. A close parenthesis cannot be followed by an open parenthesis or an operand.
8. An  $@$  cannot be followed by a close parenthesis, a  $\phi$  or an  $r$ .

This leaves only twelve possible combinations of two symbols. The following three symbol combinations are possible using the above rules:

$\sigma r \sigma$	$x r \sigma$	$(\sigma r$	$)r-$	$@\sigma r$
$\sigma r ($	$r \sigma)$	$x(\sigma)$	$)r ($	$x@\sigma)$
$\sigma)r$	$r\sigma\phi$	$x(\sigma\phi$	$)r$	$x@\sigma\phi$
$\sigma))$	$r(\sigma$	$((\sigma$	$))$	$@(\sigma$
$\sigma)\phi$	$r(($	$(( ($	$))\phi$	$@(($

9. An operand cannot be both preceded and followed by an operator;
10. An operand cannot be both preceded by an open parenthesis or an  $@$  and followed by a close parenthesis or  $\phi$ .

The following four symbol combinations are possible using the above rules:

				$@\sigma r \sigma$
	$r\sigma)r$	$(\sigma r \sigma$	$)r\sigma)$	$@\sigma r ($
$\sigma r \sigma)$	$r\sigma))$	$(\sigma r ($	$)r\sigma\phi$	$@(\sigma r$
$\sigma r \sigma\phi$	$r\sigma)\phi$	$((\sigma r$	$)r(\sigma$	$@((\sigma$
$\sigma r(\sigma$	$r(\sigma r$	$((\sigma$	$)r(($	$@((($
$\sigma r(($	$r((\sigma$	$(( ($	$)r\sigma$	
$\sigma)r\sigma$	$r((($		$)r ($	
$\sigma)r ($			$))r$	
$\sigma))r$			$)))$	
$\sigma)))$			$)))\phi$	
$\sigma))\phi$				

The following five symbol combinations are possible using the above rules.

- x  $(\sigma r \sigma\phi$
- x  $@\sigma r \sigma)$

11. There must be a close parenthesis between an open parenthesis and a  $\zeta$ .
12. There must be an open parenthesis between a close parenthesis and a  $@$ .
13. There must be an equal number of open and close parentheses in an expression.
14. There must be only one  $@$  and one  $\zeta$  in an expression and they must respectively be in the first and last positions. No other symbol may be in either the first or last position.
15. A close parenthesis cannot occur in an expression unless an open parenthesis has previously occurred.
16. An open parenthesis cannot occur in an expression unless a close parenthesis subsequently occurs.

Under the above rules this complete expression is possible in five symbols:

$@ \sigma r \sigma \zeta$

The following nine symbol expressions are possible:

$@ \sigma r ( \sigma r \sigma ) \zeta$

$@ ( \sigma r \sigma ) r \sigma \zeta$

The following twelve symbol expression is possible: :

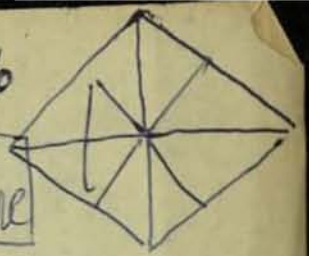
$@ ( \sigma r \sigma ) r ( \sigma r \sigma ) \zeta$

The following thirteen symbol expression is possible:

$@ ( \sigma r ( \sigma r \sigma ) ) r \sigma \zeta$

what key SF

726  
Mamaroneck Ave



Manpower Planning + Control for Eng Proj's

60-907-401

IBM OWEEO

GD Brode <sup>+</sup> X2325

61-560-4

Scan Converter Equipment  
"Auto Manu Sys Prog Report"

Erich Fugil

Erich Fiegla  
DSD

burden  
burden

porch



SECTION V

## REPORT ON WORK WITH INTEGRATED SYSTEMS PROJECT

We have recently been working with the Integrated Systems Project at the Instrument Department in West Lynn. The purpose of this report is to discuss the effect on Cost Accounting of the new Engineering-Manufacturing information system designed for possible use in the AB-DB Switchboard line.

The information system that the Integrated Systems Project is proposing eliminates model lists, material lists, planning cards, and the present drawing number system. It also changes the kind of data that is shown on the drawings or blueprints. This means that the documents that Cost has used for years to determine the direct material and direct labor content of products will no longer be available.

The Integrated Systems Project has not attempted to develop a total integrated information system that includes all functions, but rather an integration of certain portions of the Engineering and Manufacturing system. The new system directly affects those cost activities which develop cost information for the purpose of income determination. It does not directly affect the development of cost information for the purposes of cost control, decision making, and forecasting.

In our work with the Integrated System Project which began in September 1958 we have tried to answer the following questions:

1. Could Cost Accounting still determine the direct material and direct labor content of products from the new system?
2. Would the new Engineering-Manufacturing information system be more or less useful to Cost Accounting than the present one?

Up to this point, no attempt has been made to do the following:

1. Develop a complete cost system designed to meet the total needs of the business for cost information.
2. Determine the most economical method of costing for the AB-DB Switchboard line.

This report will be divided into the following sections:

1. Description of certain techniques that are used in the new Engineering-Manufacturing Information System and which may have a bearing on Cost Accounting.
2. Description of the Present Method of Developing Costs.
3. Description of New Method of Developing Costs.
4. Evaluation of the usefulness of the new information system to Cost Accounting.

## DESCRIPTION OF TECHNIQUES

### Regenerative Philosophy

The regenerative philosophy is based on the assumption that recomputing an answer may be more efficient than storing it. Therefore, the method of solving a problem is stored rather than the answer. For example, instead of calculating and storing the cost of a particular model, the method of calculating the cost of the model would be stored and the cost recalculated each time an order is received.

When analyzing the method of solving a problem, the variables are highlighted rather than the vast number of combinations of these variables. This results in a substantial reduction in the amount of information that is stored. Perhaps the following example will help illustrate this fundamental difference between working with the variables as contrasted with the combination of the variables. This example only involves regenerating the cost of the assembly rather than regenerating the cost of both the parts and the assembly.

The XYZ assembly is made up of a bolt, a washer and a nut. The material list for this assembly shows that there are 60 different group numbers for the assembly representing 60 different combinations of the parts. These 60 combinations result from the fact that there are three different sizes of bolts (1", 2", 3"), two different types of nuts (hex and square), and ten different diameters of washers. The allowed time is the same for assembling any of the 60 combinations.

One way of obtaining the cost of each group number or combination called for on the material list would be to do the following: (1) list each of the parts for each combination on a separate cost card, (2) write in the cost for each of the parts (3) add up the cost of the various parts to get the total cost of the assembly, and (4) write the total cost of the assembly on the cost cards.

Another way of obtaining the total cost of each group number or assembly would be to:

1. Make up tables similar to the one on the following page.
2. Using this tables and the material list, mentally add up the cost of the various parts going into the assembly.
3. Write down on each of the 60 cost cards only the total cost of the assembly instead of listing all of the parts and their respective costs on the cost cards.



Tables

<u>Size of Bolt</u>	1"	2"	3"
Cost per C	\$2.00	\$2.50	\$3.00
<u>Type of Nut</u>	Hex		Square
Cost per C	\$1.00		\$1.50

<u>Dia. of Washer</u>	1"	1½"	1¾"	1 3/4"	2"	2¼"	2½"	2 3/4"	3"	3½"
Cost per C	\$.25	\$.30	\$.35	\$.40	\$.45	\$.50	\$.55	\$.60	\$.65	\$.70

Assembly Labor \$1.50 per C.

The tables shows that if the material list calls for a 1" bolt and a square nut, and a 2¼" diameter washer then the cost per C of the assembly (parts plus assembly labor) is \$5.50. Now if the information that is on the tables were put into the computer, the computer could calculate the cost of each assembly and insert that cost on each memo of shipment provided it knew which size of bolt, which type of nut, and which diameter of washer was called for in the particular assembly that the customer ordered. Using the techniques which will be described in more detail in the following pages, the computer will be able to decide which bolt, nut, and washer are called for in the assembly on the basis of the customer specifications and then it will be able to put that cost on the memo of shipment.

The form and kind of information shown in the tables is about what Cost Accounting would have to furnish to Data Processing if the Regenerative Philosophy is used in costing. One of the most important things to understand about costing on a regenerative basis is that the cost input data would be in about the same form as it is in the tables used in the example, that is, the computer would be given the method of computing the cost of the assembly rather than the cost of the assembly after it has already been calculated. Although frequent references are made to the Regenerative Philosophy in this report not all of the information is regenerated. For example, it may be desirable to store the cost of a purchased part that is used in regenerating the cost of an assembly or model rather than trying to regenerate the cost of that part. Another way of saying the same thing is that this information system is designed to take advantage of the concept of regeneration wherever it appears practical.

Use of Structure Tables

Structure tables are used extensively with the new information system as a convenient method of describing certain reasons behind a decision. Any decision

process which can be explicitly defined can be fully represented by a structure table. For example, the following table describes the method of selecting the proper cost for the nut that is to be used in an assembly.

Type of nut	Hex	Hex	Square	Square
Kind of Material	Steel	Aluminum	Steel	Aluminum
Cost per C	\$1.00	\$1.25	\$1.50	\$1.90

The computer reads this table as follows:

If the type of nut required is hex and the kind of material is steel, then the cost per C is \$1.00. The second column can be read similarly. If the type of nut required is hex and the kind of material is aluminum, then the cost per C is \$1.25. The third column says if the type of nut required is square and the kind of material is steel, then the cost per C is \$1.50. Each structure table consists of two parts. The portion above the double line sets forth the particular set of conditions. The portion below the double line details the course of action that will be followed under the particular set of circumstances.

#### Product Structure

Product Structure makes it possible to determine the design of an instrument simply by using the Product Structure Tables. The Product Structure Tables set forth the relationship between the customer specifications and the parts characteristics. Examples of parts characteristics are the kind of material used in a coil, the size of the wire, the number of turns on the coil and the weight of the material. The customer specifications determine what the design or parts characteristics of the product will be.

The relationship between customer specifications and parts characteristics can be described by a structure table for the reason that the engineer follows a logical process in designing a product and therefore each part, dimension, shape, material, or other property can be related to the customer specifications. Normally there will be at least one Product Structure Table for each part. However, some parts may require more than one Product Structure Table. The following is an example of a portion of the Product Structure Table applicable to the damper winding. For the sake of brevity only one-half of the table has been shown. The items above the double line (kind of service, instrument rating units, etc.) are customers specifications or the input to the table. The information below the double line (number of turns, resistance, ohms, etc.) represent the parts characteristics (output from the table) that result from these customer specifications.

Kind of Service	DC	DC	DC	DC	DC	DC	AC
Instru. rating units	Amps	Amps	Amps	Volts	Volts	Millivolts	-
Ampere rating	$\geq 13.5$ ma $\leq 66$ amps	$\geq 220$ ma $< 450$ ma	$\geq 450$ ma $\leq 66$ amps	-	-	-	-
Instrument Size	Small	Large	Large	Small	Large	-	-
Number of turns	21	21	12	12	28	21	0
Resistance, ohms	3.46	3.46	0.45	0.45	1.33	3.46	-
Wire size, inches	.004	.004	.008	.008	.0071	.004	-
Number of layers	1	1	1	1	2	1	-

The above table shows that if the customer specifications are DC and amps and equal to or greater than 13.5 but less than 66 amps and small, then the damper winding has 21 turns and a wire size of .004 wire and 1 layer. The other columns are read similarly.

#### Operation Structure

Operation Structure makes it possible to determine the method of manufacture by going through the Operation Structure Tables. It also defines the time allowance for the required method of manufacture. The parts characteristics as determined by the customer specification determine the operation characteristics. The Operation Structure Tables set forth the relationship between the parts characteristics (output from the Product Structure Tables) and the operation characteristics. Operation Structure Tables provide the source of the various items of information including the time allowance that go on the labor voucher. There will be at least one operation structure table for each labor operation, and for most labor operations there will be several operation tables. Examples of operation characteristics are the machine on which a coil is wound, the winding form, the number of leads to be cut, the time allowance for performing the operation, etc.

The following is an example of an Operation Structure Table which determines the time allowance for winding the damper winding. The information above the double line (number of turns) is the part characteristic or input to the Operation Structure Table. The data below the double line (allowed time in seconds) represents the operation characteristic that result from the particular part characteristic.

Number of turns	Less than 15	Equal to or more than 15 but less than 100	Equal to or greater than 100
Allowed time in sec.	Number of turns	125 (Wire dia. x no. of turns)	1000 (Wire dia. x no. of turns)

The table on the preceding page shows that if number of turns on the damper winding are less than 15, then the allowed time in seconds for performing the winding operation is equal to the number of turns. The next column shows that if the number of turns is equal to or greater than 15, but less than 100, then the allowed time is equal to 125 times the wire diameter times the number of turns. The last column which includes the remaining possibility can be read in the same way.

## PRESENT METHOD OF DEVELOPING COSTS

The Instrument Department uses Component Costing with standard values to develop the labor and material cost of a model. Component Costing is a method of product costing wherein costs are first classified by component. These components are costed by calculating the cost using standard values of each operation to be performed and the materials required by the component specifications which are determined by engineering and manufacturing. At the present time, Cost utilizes the following procedure for developing the cost of a model in the Instrument Department.

### Step 1

The latest model lists, material lists, and drawings are obtained from Engineering. These documents show the drawing numbers for each part, sub-assembly, and model. Cost then makes up a separate cost card for each part, sub-assembly, assembly, and model. In addition, Cost manually extracts the following information from the model lists, parts lists, etc. and writes it on the cost cards:

1. Dimensions or weight of material
2. Kind of material
3. Quantity of parts
4. Name of part, sub-assembly or assembly

### Step 2

Planning cards for each part, sub-assembly, assembly and model are obtained from Manufacturing. These cards indicate whether a part is purchased or manufactured within the manufacturing sub-function. In addition, the following data is extracted from the planning cards and added to the cost cards:

1. Time value or estimated price of each labor operation
2. Job rate class
3. Sequence of operations

### Step 3

Cost obtains the standard material prices for the various kinds of raw material or purchased parts and the standard labor prices for the various job rate classes from its file of standard values that has been established. The standard material price (raw material or purchased part) is also added to the cost cards.

#### Step 4

The standard material value is calculated and inserted on the cost cards for each part. Also the standard labor value is calculated and inserted on the cost card for each labor operation on a fabricated part and also for each assembly labor operation.

#### Step 5

The total standard material and standard labor value is then calculated and inserted on the cost card for each part.

The above steps are repeated until the cost of each part, sub-assembly, assembly, and model is obtained. The result of the above procedure is a file of cost cards in which the answer is stored. In a number of departments, many of these steps are performed mechanically. Cost uses these detailed cost cards for obtaining the standard direct material and the standard applied direct labor values of a completed or partially completed part, sub-assembly, assembly, or model. This type of information is required in order to carry out the following cost activities:

1. Costing production
2. Costing shipments
3. Costing scrap tickets
4. Costing the physical inventory
5. Costing material transfers to other sections
6. Costing repair and returns (lot papers)

## NEW METHOD OF COSTING

With the new information system, much of the data that is now extracted from the material lists, planning cards, and drawings is included in the Operation and Product Structure Tables. One alternative is to continue the present routines except that information in the future would be taken from the various tables and the new identification system would be substituted for the present drawing numbers. This alternative was explored in sufficient depth to determine that it was possible to do this.

It was then decided to study a completely different alternative which was the feasibility of doing Regenerative Costing. This meant that Cost Structure Tables had to be developed. These tables would include the method of calculating the cost of a complete or partially completed product. For example, the method of calculating the cost of a DC ammeter would be stored in the computer, rather than the cost of the DC ammeter. Then the computer would recalculate the cost whenever it was needed and apply it to the proper document depending on whether it was a memo of shipment, inventory card or scrap ticket.

A Cost Structure Table represents the relationship between the parts characteristics and the standard direct material and standard applied direct labor value of these characteristics. The following example shows a Cost Structure Table. In this particular table the standard material and labor cost of a part is actually stored in the table. Later in this paper there will be examples of Cost Structure Tables in which the method of calculating the cost of a part is stored in the Table.

Quantity of coil support (Prod. Char.)	2	2	4
Kind of coil support (Prod. Char.)	8941928*	4137063*	4137063*
<hr/>			
Material cost per C	\$ .42	\$4.46	\$8.92
Labor cost per C	.14	-	-

\* These drawing numbers will be replaced by a new identification system which represents the parts characteristics.

The data above the double line are parts characteristics. The information below the double line indicates the cost value for the different set of parts characteristics. If the output from the product structure table calls for 2 coil supports which are currently designated as #8941928, then the standard direct material value is \$.42 per C and the standard applied direct labor value is \$.14 per C, thereby indicating that the part is fabricated within the department. If the output from Product Structure calls for 2 coil supports designated as #4137063, then the standard direct material cost is \$4.46 per C and there is no standard applied direct labor cost thereby indicating that the part is purchased from outside the department.

The computer would go through the following steps in regenerating the cost of a model.

#### Step 1

The customer specifications (input to the Product Structure Tables) determine the various parts characteristics (output from the Product Structure Tables) involved.

#### Step 2

The parts characteristics (from the Product Structure Tables) are the input to the Cost Structure Tables. Therefore, the parts characteristics determine the cost values that will be selected from the Cost Structure Tables for a particular assembly or model.

#### Step 3

After the computer selects the proper cost value for the specified parts characteristics from the Cost Structure Table, this cost value is temporarily stored in the computer until all of the Cost Structure Tables have been solved. A specific space in the computer will be reserved for the cost of a particular part, sub-assembly, etc.. After the cost is selected or calculated in the cost tables, the answer will always be put in the same place where it will be available at the time the computer starts building up the costs to obtain the model cost.

#### Step 4

A series of special structure tables which are designated as "Goes into" Tables makes it possible to build up a cost in the proper order. These tables determine the assembly relationship of the various parts, sub-assemblies, and assemblies. The "Goes into" Tables can be developed from a Parts Reference List. This Parts Reference List contains a list of the names of all the various parts that go into a particular sub-assembly, the names of the different parts and sub-assemblies that go into an assembly, etc.. These "Goes into" Tables are not the same thing as a "Where Used" file since they only show what parts go into a particular assembly rather than a list of all the assemblies in which a particular part is used. The following shows the portion of the Parts Reference List that is applicable to the Armature Coil Assembly.

#### Armature Coil Assembly

- Main Coil
- Connectors
- Insulation
- Damper Winding
- Connection Strip
- Coil Support



The various Cost Structure Tables that a computer would go through in calculating the standard direct material and standard applied direct labor value of a damper winding follow:

Cost Structure Tables for Direct Material

Table A

Kind of material	B50W70	B50W70	B50W70	B50W60
Wire size	.003	.004	.005	.008
Cost per C lbs.	\$159.68	\$112.31	\$93.02	\$88.59

Table B

-	-
Material weight per C	(Formula for determining weight of damper winding material)

Table C

-	-
Material cost per C	Cost per C lbs. x weight per C.

Using these Cost Structure Tables, the direct material cost would be determined as follows:

Table A

If Product Structure defines that the kind of material required is B50W70 and the wire size is .008, then the cost of the material is \$89.59 per C lbs.

Table B

The weight of the material required is calculated by including the number of turns (part characteristic determined from the Product Structure Table) into the formula included in this table.

Table C

The direct material cost of the damper winding is calculated by using the simple formula in Table C. This formula multiplies the standard cost per C that is selected from Table A times the weight of the damper winding which was calculated in Table B.

Cost Structure Tables for Direct Labor

Table D

Number of turns	Less than 15	Equal to or more than 15 but less than 100	Equal to or greater than 100
Allowed time in seconds	No. of turns	125 (wire dia. x no. of turns)	$\sqrt{1000}$ (wire dia. x no. of turns)

Table E

Labor cost per C	Time allowance x cost per second x 100
------------------	--

Using Cost Structure Tables D and E, the computer would calculate the direct labor cost of the damper winding as follows:

Table D

The Product Structure Table defines the required number of turns (parts characteristics). Depending on which of the three columns of the table the number of turns falls into, one of the three formulas will be used to calculate the allowed time.

Table E

The direct labor cost is calculated by using the simple formula in Table E which multiplies the allowed time determined in Table D by the cost per second of the operator doing the damper winding. The result is then multiplied by 100 to get the direct labor cost per C.

Relationship of Cost Structure Tables to the Identification Code System

In the preceding paragraphs, the method of getting from the customer specifications to the Cost Structure Tables via the Product Structure Tables has been discussed. However, there are many times that it will be necessary to determine the standard direct material and standard applied direct labor cost of a part, sub-assembly, assembly, or model when the customer specifications will not be available. Costing a physical inventory is one of the best examples of such a situation.

Under the present routines Cost would have already calculated the direct material and direct labor cost of each particular part or assembly represented by a drawing number and written it on a cost card where it could be obtained for costing the inventory. Under the new proposal, it is necessary to regenerate the cost for the particular part or assembly that is represented by the inventory card.

This part will be identified by a new identification code which includes the parts characteristics of the part. Special tables will then take the identification code and convert it into its parts characteristics for use as input into the Cost Structure Tables. Then the computer can go ahead and calculate the cost of the part and insert it on the inventory card. An example of the new identification code for an armature coil follows:

Coil Armature 3471926

Where the field means:

347 - Armature Coil

19 - Main winding wire diameter 8 mils, one wire in multiple.  
Dampener winding 12 turns of 8 mils diameter wire.

26 - Main winding turns is 26.

#### Refinement of Cost Structure Tables

The preceding paragraphs have illustrated examples of Cost Structure Tables that appear to be feasible and compatible with an Engineering-Manufacturing information system which utilizes the Regenerative Philosophy. However, additional work needs to be done in order to determine the optimum type of Cost Structure Tables from the standpoint of both the Cost Sub-Function and the economy of the Data Processing system. Factors that should be considered in this evaluation are:

1. What is the most efficient method of making changes in the Cost Structure Tables? The necessity for revising the tables results from changes in the Product and Operation Structure Tables caused by planning and/or design changes?
2. What is the most efficient method of making revisions in the standard material price and labor rate values that are included in the Cost Structure Tables?
3. Should weights or gross dimensions of material be included in the Product Structure Tables rather than the Cost Structure Tables? Cost needs this information for calculating direct material costs, but Manufacturing may also have use for such information.
4. What are the criteria for determining whether it is more economical to manually calculate the cost of a part and include it in the Cost Structure Table as contrasted to including the method of calculating the cost of the part in the table?

5. What type of coding of commodities for the purpose of making the LIFO calculations should be included in the tables?
6. Is it economical to use the computer for costing the portion of the work in process inventory that represents partially completed parts, sub-assemblies, and assemblies? It appears that inventory cards representing such items can be handled by this system. It would mean, however, a much larger number of Cost Tables since each operation on a particular part, sub-assembly, or assembly would have to have a separate Cost Table.

This problem should be studied to determine how extensive it is and what alternatives are possible. For example, in a product with a short manufacturing cycle for making a part, sub-assembly, assembly, and instrument, the total value of partially completed operations in a physical inventory may be relatively insignificant. Also, an analysis may show that this partially completed situation is most frequent on only a few parts, sub-assemblies, or assemblies and that a special table could be developed for use in manually costing these particular items.

#### Problems Still to be Resolved

In working with new techniques, it is not always possible to solve all the problems immediately or even foresee all the problems that may arise. Based on the work up to this point, certain things appear to be resolved such as the desirability of using standard cost values in the tables. Other problems need additional study before a final decision is made. The following paragraphs outline some of the problems which require a decision along with some of the alternative solutions that might be considered.

1. No changes have been contemplated to date in the form or type of information that is presently being furnished Cost on such documents as lot papers (repair and returns), material transfer cards, and scrap tickets. These documents involve activities that don't require too much time on the part of Cost Accounting, but they are dependent on the information that is presently in the files in the cost unit. However, it is certainly undesirable to maintain a complete set of cost files for such minor activities. One alternative would be to change the form the information is now in so that the computer could make the calculation and cost these items provided it is practical to use the computer for such low volume transactions. Another alternative might be to develop short cut methods of costing these items. Presumably the short-cut methods would not require the maintenance of elaborate files in the Cost Function.

2. There will still be some models that will fall outside the parameters of the Product Structure and Operation Structure Tables and therefore the Cost Structure Tables. This is a problem that could be critical if too many models are outside the tables. It is believed that the tables will take care of upwards of 95% of the different models and a much higher percentage of the total units produced.

It has not been determined as yet what kind of a routine will be set up in Manufacturing and Engineering for handling such models. However, it would appear that most of the parts, sub-assemblies and assemblies would be identical to those within the parameters of the tables and that the Cost Accountant could obtain whatever additional information is required from Manufacturing and Engineering and cost such models manually.

3. The method of determining the planning and design change variance must be resolved. One way would be to follow the same procedure as is now being used. Another alternative would be to change the Cost Structure Tables every time there is a significant planning and/or design change, but still continue to use prices based on the then current standard cost level. The Cost Accountant could then estimate the difference between the old and new planning and/or design for the items still in inventory and write off the difference. Then all orders received subsequent to the change in the tables would be costed at the latest planning and design.
4. Cost estimating is not much of a problem in the AB - DB Switchboard Line since there are very few requests for estimates of models. However, in departments where there are numerous requests, it will be possible to get a detailed parts and model list for all parts, sub-assembly, and assemblies that are within the Product Structure Tables. This could presumably be costed in order to obtain the standard direct material and standard applied direct labor value for this particular design. These standard figures could then be manually revised to take care of anticipated price changes.

#### Qualifications for Working with Cost Structure Tables

When new techniques are being considered, one of the questions that always arises is what special qualifications should a person have to handle these techniques?

The following comments may be helpful in answering the questions insofar as the techniques that have been discussed in this paper are concerned.

1. Most of our present cost analysts, cost estimators, or supervisors of cost accumulation should have the necessary qualifications to operate the system.
2. A knowledge of the product design and method of manufacture would be helpful.
3. An understanding of the Product and Operation Structure Tables is essential.
4. No particular mathematical background or training appears necessary in order to make up Cost Structure Tables and operate the system. Engineers can make up any necessary formula for physical dimensions if they aren't already available. However, the Cost Accountants should strive to understand these formula.
5. A knowledge of computers or how to program for a computer is not necessary although the more general understanding the Cost Accountant has in this area, the more effective he can be.

## USEFULNESS OF THE NEW INFORMATION SYSTEM TO COST ACCOUNTING

In the process of evaluating the feasibility of Regenerative Costing, Cost Structure Tables were developed for the entire Armature Coil Assembly. However, there was not enough time to incorporate these tables into the computer. In addition it was determined that it is possible to resolve such problems as building up the cost of a model in the proper order and costing the physical inventory. Therefore, although there is still much work to be done before the computer can be used to regenerate costs, it appears to be technically feasible in any business where the regenerative philosophy is followed in the Engineering-Manufacturing information system.

Now to the second question we were trying to answer in our work with the Project: Would the new information system be more or less useful to Cost Accounting than the present one? First, a word about the cost of doing Regenerative Costing. No attempt has been made up to this point to determine whether Regenerative Costing is the most economical method available. However, it does provide some savings over the present method in the Instrument Department. It also appears that the various techniques, used in conjunction with the Regenerative system, can be helpful to the Cost Accountant in ways which were not originally anticipated. The way in which Engineering, Manufacturing, and Cost information will be organized in the structure tables appears to be significant.

As a result of this new organization of data, the Cost Accountant should obtain a much clearer understanding of the product design and methods of manufacture. This improved understanding should result in:

1. More effective cost analysis
2. Better cost information for decision making
3. Simplified costing procedures

With the new organization of data in the Structure Tables the Cost Analyst should begin to visualize the product design in the same way the engineer looks at it rather than looking at the engineer's present output which is the material lists, model lists, and drawings with the maze of drawing numbers and group numbers tying the whole system together. However, these Material and Model Lists are normally not organized so that relatively similar combinations appear together. Instead each time a new combination is designed, it is simply given the next group number and added to the list. Similarly, the Cost Accountant should be able to analyze the various methods of performing an operation in the same way that the foreman views the problem. The foreman knows that although there are many different armature coils each with its individual drawing number he still follows one of three basic methods in winding the coil. This opportunity for more effective cost analysis should result in the Cost Accountant making a better evaluation of cost reductions, alternative designs and alternative methods of manufacture since he can more easily assemble and understand the facts.

Product and Operation Structure should also permit Cost to develop better information for decision making purposes since it should be easier to analyze labor, material, and scrap variances between the different methods of manufacture and the various designs. Insofar as the Instrument Department is concerned, another type of decision making cost that would be improved are the Cost Advices that are furnished to Marketing. These Cost Advices now include the same standard costs that are used for costing production and shipments. In some cases, these standards have not been revised for planning and design changes for three years except by application of a percentage planning and design factor that is applicable to the overall line. This means that there may be a number of inaccuracies between models that average out over the total line. It is difficult to evaluate how serious a problem this presents in the Instrument Department. Marketing only uses these Cost Advices for minor pricing decisions in which the unit values and quantities are low. However, because of the nature of the business, there are a large number of such decisions. The regenerative philosophy should facilitate more frequent revision of costs because of its ease in handling changes and thereby improve the accuracy of the Cost Advices.

The different form in which cost data will be organized in the Structure Tables may also be useful in simplifying the costing procedures. For example, the variations in the control spring among the various instruments are very great. However, the difference in cost between control springs is not too great. An analysis of the difference in costs between springs might lead to the conclusion that it would be advisable to have three or four different costs to cover the whole range of springs.

We might summarize our feelings about the new information by saying that it takes the skillful use of a great many different techniques to develop the kind of cost information that is needed in most businesses. Therefore, we in Cost Accounting are constantly looking for new methods and ideas that will improve the quality of our cost data. It is our opinion that the Product, Operation, and Cost Structure Tables and the new Identification System provide us with additional techniques that will be of considerable value.

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